State of California
Department of Transportation

CONCRETE PAVEMENT GUIDE




Caltrans

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January 2015

DISCLAIMER

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PREFACE

The Concrete Pavement Guide (CPG) provides a comprehensive overview of current new construction-reconstruction, preservation, and rehabilitation strategies used by the Department for concrete pavement. The information in this guide applies to all concrete pavement and composite pavement that was not previously cracked and seated. Some of these topics were previously addressed in the Maintenance Technical Advisory Guide (MTAG).

The CPG reflects updated Caltrans concrete pavement practices, including effectiveness and limitations; strategy and materials selection; design issues; and implementation of the revised 2010 construction contract standard plans, specifications, and bid items for individual pavement strategies. The CPG assists district design, maintenance, and materials personnel with concrete pavement project delivery by supplementing the information and design standards contained in Highway Design Manual (HDM) Chapters 600-670.

Some relevant concrete pavement construction information is included in the CPG, but the Construction Manual should be referenced for more comprehensive information about specific construction procedures.

The Concrete Pavement Guide is divided into 19 topical chapters organized into 4 parts: Part 1 provides general information and an overview of concrete pavement strategies and evaluation; Part 2 covers new concrete pavement and reconstruction strategies; Part 3 preservation strategies; and Part 4 rehabilitation strategies. Some chapters are reserved for future development.

CONCRETE PAVEMENT GUIDE

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CONCRETE PAVEMENT GUIDE

PART 1: GENERAL INFORMATION

CHAPTER 100 – PAVEMENT MANAGEMENT STRATEGIES

The Concrete Pavement Guide provides a comprehensive overview of current new concrete pavement construction/ reconstruction, preservation, and rehabilitation strategies used by the Department. The information in this guide applies to all concrete pavements and composite pavements (concrete overlayed with nonstructural hot mix asphalt) that were not previously cracked and seated. Included is a description of the effectiveness, limitations, material, design, and specification considerations for the individual strategies. Some limited information about construction is also included, but refer to the Construction Manual for more details about construction procedures.

The guide is divided into topical chapters organized into 4 parts: Part 1 provides general information and an overview of concrete pavement strategies and evaluation; Part 2 covers new concrete pavement and reconstruction strategies; Part 3 preservation strategies; and Part 4 rehabilitation strategies.

Chapter 100 introduces an overview of concrete pavement management strategies and concepts as well as a discussion of pavement strategy selection and funding programs.

100.1 PAVEMENT MANAGEMENT CONCEPTS

All pavement deteriorates over time. Effectively managing the roadway network requires optimizing new construction, preservation, maintenance, rehabilitation, and reconstruction pavement needs statewide with multiple constraints, including finite budget requirements, worker safety, user impacts, and regional issues. Preservation is the preferable network-level pavement management strategy: a long-term, proactive maintenance program intended to maintain pavements in good condition by applying cost effective project strategies at the optimal time to enhance pavement performance, extend pavement life, and conserve resources.

To be effective, a pavement preservation program must employ the right project-level engineering strategies before the onset of severe distress over an extensive area. The cumulative effect of a systematic, integrated preservation program is to postpone costly corrective maintenance, rehabilitation, or reconstruction projects (see Figure 100-1). Performing a series of successive pavement preservation strategies (HM or CAPM) during the life of a pavement is also less disruptive to uniform traffic flow than the longer closures normally required for rehabilitation (2R or RRR) and reconstruction projects. The frequency of application depends on the strategy selected (see Section 100.2), design life, performance over the anticipated service life (see Section 110.3), and future pavement management practices.

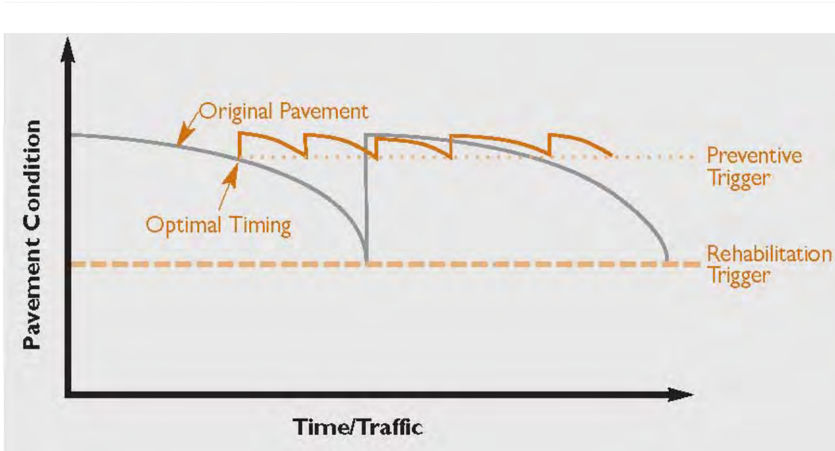

Figure 100–1: Pavement preservation concept (Galehouse et al, 2003)

100.1.1 Network-level Pavement Management

New construction, widening, and reconstruction are used for new alignments, to increase existing route capacity, or to replace obsolete roadway segments, respectively. Capacity improvement projects are typically funded by the State Transportation Improvement Program (STIP), local tax measure funds, bonds, or private developers. Current design standards require at least a 20-year design life for new construction and reconstruction. A minimum design life of 40 years is common for most concrete pavement given the cost effectiveness for higher traffic volumes typical on many routes (see HDM Topic 612).

Pavement Preservation includes preventive maintenance (HM) and CApital Preventive Maintenance (CAPM) pavement strategies (see Part 3) used to maintain or repair an existing pavement management segment that is still structurally sound overall. The District Maintenance Engineer typically initiates the projects and determines the preventive strategy, which can be funded as either preventive maintenance (HM) or CAPM projects depending on the existing pavement condition and budget constraints:

- Preventive Maintenance projects are typically done by the Department's Maintenance forces or through the Major Maintenance (HM) Program to preserve existing pavement in good condition. Preventive maintenance projects are not engineered for a minimum design life and typically do not include safety, geometric, or operational improvements.

- CAPM projects are funded through the State Highway Operation and Protection Program (SHOPP) but CAPM is considered a pavement preservation program because the strategies are more closely related to non-structural maintenance improvements than rehabilitation, which is designed to meet future long-term traffic loading.

  CAPM is intended to extend the pavement service life at least 5 years by making minor repairs to segments with limited distress, delaying further short-term deterioration that would require major roadway rehabilitation. Only cost-effective, easily implemented traffic safety and operational improvements such as signing and delineation are included in CAPM projects pending a review by District traffic personnel. More information about the CAPM program is in HDM Topics 603, 624, 644, and Design Information Bulletin 81 "Capital Preventive Maintenance Guidelines".

Roadway Rehabilitation is major engineered work intended to restore and extend the pavement service life when extensive structural distress occurs. Rehabilitation is funded through the SHOPP as a 2R or RRR project. A design life of at least 20 years is required and 40 years is likely for higher traffic volume projects pending life cycle cost analysis (LCCA). For more information, see HDM Topic 612 and the LCCA Procedures Manual. Upgrades to enhance safety, geometric design features, traffic operations, drainage, and structures are included in rehabilitation projects where needed. Additional discussion about roadway rehabilitation can be found in HDM Topics 603, 625, 645, and Design Information Bulletin 79 "Design Guidance and Standards for Roadway Rehabilitation Projects". CPG Section 100.2.3 and Part 4 have more information about rehabilitation strategies.

100.1.2 Optimal Project Timing

Optimizing selection of the best engineering strategies and the timing of project construction with the existing pavement condition is critical to long-term performance. The pavement management system (PaveM) uses models based on pavement structure, climate, and traffic loading to establish deterioration rates and predict future performance. By anticipating future distress conditions, preservation projects can be proactively initiated and developed through the design and construction process before deterioration progresses and more expensive repair is necessary. Eventually, pavement will age until preservation strategies are no longer effective and the pavement management system can help determine when more expensive rehabilitation or reconstruction is warranted.

Pavement management tools and engineering judgment are used to select specific strategies and optimum project timing, which are a function of many factors, including: overall pavement condition, distress types, deterioration rates, remaining service life, traffic, constructability, and economics. If pavement is not maintained effectively with timely, well-engineered strategies, it will prematurely deteriorate until reconstruction is required: the most expensive and least desirable resource management option. Figure 100-2 shows a generic pavement performance model with traffic and time. The optimal timing and relative cost of various pavement management strategies are superimposed.

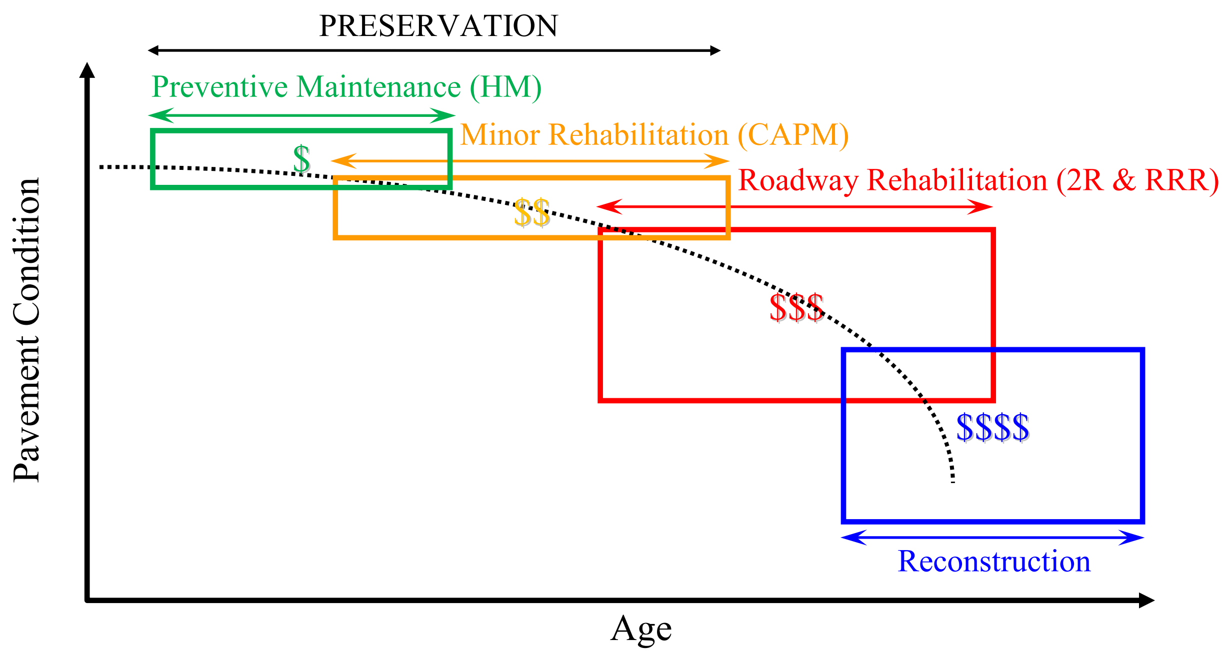

Figure 100–2: Typical pavement performance model and management strategies

100.2 PROJECT-LEVEL CONCRETE PAVEMENT STRATEGIES

Individual concrete pavement engineering strategies used by the Department are introduced below. Other strategies have been used nationally but are not currently used by the Department due to various reasons and limitations. Refer to the applicable Concrete Pavement Guide chapter of the individual strategy for more complete information. Chapter 110 contains more detailed discussion of the project-level pavement evaluation and selection process for engineering effective strategies.

100.2.1 New Design Strategies

Existing rigid pavement in California is generally non-doweled jointed plain concrete pavement (JPCP), although there are some limited areas of continuously reinforced concrete pavement (CRCP) and precast panel concrete pavement (PPCP). Although JPCP is more common, CRCP is currently favored by the Department for high traffic new construction, reconstruction, overlays, and some widening projects due to better long-term performance and reduced maintenance requirements. Pavement type selection for roadways should be determined by LCCA. More complete information about new concrete pavement design strategies currently used by the Department can be found in Part 2 of the Concrete Pavement Guide, introduced here:

- CRCP (Ch. 200) uses longitudinal joints and continuous reinforcement in the upper 1/3 of the concrete surface to control vertical and horizontal movement of transverse cracking in cast-in-place concrete. Tight cracks should occur randomly spaced in 3.5'– 8' intervals.

- JPCP (Ch.210) is unreinforced, cast-in-place concrete pavement designed with doweled transverse joints and tied longitudinal joints to control cracking as well as vertical and horizontal movement. Transverse and longitudinal joints are cut to a 1/8" width and not sealed except in desert and mountain climate regions.

- PPCP (Ch. 220) uses concrete panels that are precast off-site under controlled conditions and trucked to the project location. The panels must be placed on a smooth, finely leveled base and linked by dowel and tie bars. PPCP is an expensive nonstandard strategy that is currently used only on an experimental basis where extreme lane closure restrictions limit construction time.

100.2.2 Preservation Strategies

Many preservation strategies can be used individually or in combination with each other. Some can be funded as either preventive maintenance HM projects or CAPM projects. More comprehensive information about concrete pavement preservation strategies currently used by the Department can be found in Part 3 of this guide. Briefly summarized:

- Subsealing and Jacking (Ch. 300) slabs are preventive maintenance strategies used for isolated locations of settlement or loss of underlying support from base erosion. Subsealing can also be referred to as undersealing or slab stabilization. Slab candidates for subsealing or jacking should have signs of pumping or rocking but limited or no cracking. For jacking, some faulting should be evident.

- Spall Repair (Ch. 310) requires partial depth removal of deteriorated concrete pavement and patching with fast-setting, high-strength material. The rectangular limits of the damaged or defective areas should be determined by striking the pavement with a hammer or similar tool to detect hollow sounding concrete. The defective area is then marked beyond the outer limits of unsound concrete for removal by sawing and chipping with a jack hammer.

- Individual Slab Replacement (Ch. 320) is a preservation strategy used to replace individual failed slabs with rapid strength concrete (RSC) when much of the remaining pavement segment is still in good condition. Replaced slabs match the existing concrete pavement thickness and replacement of the underlying base may also be required. This strategy is typically cost effective when ≤ 20% of the slabs in a lane have severe cracking, but is most cost effective when 3 to 10% slabs require replacement.

- Dowel Bar Retrofit (DBR) [Ch. 330] is a preservation strategy used in combination with grinding to restore lost load transfer capability at transverse joints or cracks in existing, non-doweled JPCP with significant remaining structural service life. DBR candidate pavements should have few joints with spalling related to poor concrete durability or fatigue cracking. DBR can treat some low severity joint faulting ≤ ½" or loss of underlying support from base erosion.

- Grinding and Grooving (Ch. 340) can be used as individual preservation strategies (HM or CAPM) or in combination with other pavement strategies. Grinding enhances surface friction safety characteristics and removes faulting, roughness, rutting, and surface irregularities resulting from chains, snow removal activities, or other factors causing surface attrition. Gang-mounted diamond saw blades are used to shave a thin portion (0.06-0.75 inches) off the existing concrete surface layer. Grooving is used to address poor skid resistance and hydroplaning by using diamond blades to cut 1/8" to 1/4" deep longitudinal grooves spaced at ¾".

- Specialized Surface Treatments (Ch. 350) include high-molecular-weight methacrylate (HMWM), concrete surface hardener, and polyester concrete overlays.

  - HMWM is used to treat minor partial depth cracking in the upper concrete surface of relatively new pavements in very good condition.
  - Concrete surface hardener is a nonstandard preventive maintenance strategy used in snowy climates to reduce rutting and wear due to abrasion from tire chains, studded tires, and snow plows. The existing pavement surface is prepared by grinding or shot blasting and liquid lithium silicate is applied by spraying. The treatment penetrates and seals the concrete surface, increasing hardness and abrasion resistance to the treatment depth. Concrete hardener is being used on an experimental basis while its performance is evaluated for cost effectiveness, but a 3 to 5-year service life increase is anticipated.
  - Polyester concrete overlays are considered a nonstandard CAPM strategy for concrete pavement. Typically used for bridge decks, polyester concrete could be used to treat short areas of increased wear and deterioration, such as near chain areas or weigh stations.

- Joint and Crack Sealing (Ch. 360) inhibits water and incompressible materials from entering the pavement structure, thus slowing the rate of spalling and cracking deterioration. Joint faces must be in good condition with little to no spalling to seal effectively. Pavement that exhibits a slow rate of deterioration should have a high priority for crack sealing, which is currently a nonstandard strategy.

- Thin HMA Overlays (HMAOL) [Ch. 370] provide a wearing surface ≤ 0.25' thick that protects the existing concrete from deterioration and can improve aesthetics when traffic lanes are realigned. HMA overlays on concrete pavement are susceptible to reflective cracking and contribute to ongoing maintenance and rehabilitation expenses. Depending on the existing roughness, surface irregularities, and overlay thickness, a leveling course and reflective cracking control measures such as RHMA and a stress absorbing membrane interlayer (SAMI) should be considered.

- CRCP Full-Depth Repairs (Ch. 380) require full-depth removal of deteriorated concrete pavement, replacement of longitudinal steel reinforcement, and patching with RSC material. Punchouts occur between 2 closely spaced transverse cracks when high deflections at the pavement edge or longitudinal joint pump base material from beneath the slab, causing loss of support. Crack movement cycles reduce aggregate interlock and continued traffic loading creates cantilever action that eventually ruptures the longitudinal bars at the crack faces, punching the broken concrete segment into the base. The rectangular repair limits should be at least 6’ long, extend at least 6” beyond the damaged or defective areas, and be at least 18” away from adjacent, non-deteriorated cracks.

100.2.3 Rehabilitation Strategies

Roadway rehabilitation design information is given in HDM Topic 625. More complete information about rehabilitation strategies currently used by the Department can be found in CPG Part 4 and condensed here:

- Lane replacement (Ch. 400) is used to replace individual lanes on multilane highways when other lanes have significant remaining service life. Lane replacement is cost effective when more than 20% of the slabs in a lane have severe cracking, but can also be cost effective from 10 to 20% compared to CAPM individual slab replacement depending on LCCA. The pavement structure is designed as new concrete pavement to accommodate future traffic loading, so replacement of the underlying base layers may be required according to the design catalogs in HDM Index 623.1.

- Crack, Seat, and (HMA) Overlay (CSOL) [Ch. 410] is used where multiple JPCP concrete pavement lanes have extensive severe third stage cracking over 10% or combined structural cracking and spalling deterioration exceeding 15% of the management segment. Heavy drop hammer equipment breaks slabs into 4’ by 6’ segments. The closely spaced pieces reduce vertical and horizontal movement and maintain aggregate interlock through full-depth hairline cracks with little loss of structural capacity, creating a strong, stable base for the overlay that retards reflective cracking. Cracked concrete is then seated using heavy rollers to create a relatively uniform grade to support paving operations and re-establish adequate support between the base and the cracked slab. CSOL. After cracking and seating, an HMA leveling course is placed, followed by a stress absorbing membrane interlayer (SAMI) and final HMA lift (see HDM Index 625.1).

- HMA Overlays (HMAOL) [Ch. 370] are used where CSOL application is limited and vertical clearance issues can be addressed. HMA overlays provide a wearing surface to protect the existing concrete but are more susceptible to reflective cracking since the concrete surface is not cracked and seated. Reflective cracking control measures such as use of thicker HMA, RHMA, and a SAMI should be considered. A leveling course may be justified depending on the existing roughness, surface irregularities, and overlay thickness.

- Unbonded Concrete Overlay (UBCO) [Ch. 420] consists of new concrete typically placed over existing concrete pavement and a thin HMA bond breaker interlayer at least 0.10’ thick. The HMA interlayer reduces reflective cracking and provides flexibility for concrete pavement curling from temperature differentials between the top and bottom of the concrete surface.

100.3 CONCRETE PAVEMENT PROJECT IMPLEMENTATION

Once any type of pavement is constructed, it inevitably begins deteriorating over time due to traffic loading and environmental exposure to a variety of climatic conditions. Eventually, a maintenance strategy or pavement project will be required to delay more rapid deterioration or restore acceptable structural and functional condition. Successful project implementation requires a comprehensive, accurate pavement condition evaluation analyzed within a sound pavement management policy framework.

Collecting accurate data using repeatable methods are goals of the biannual automated pavement condition survey (APCS), accessible through iVision and summarized in PaveM. The APCS quantifies existing distress by type, severity, and extent. Distress accumulation from exposure to traffic loading and environmental conditions is monitored by the APCS over time for individual pavement management segments. When thresholds established by performance models and decision criteria in the pavement management system are reached, a project is initiated by district maintenance or advance planning offices and the development process begins.

Network-level policies and tools such as the APCS must be efficiently integrated with project-level support, analysis, and sound engineering judgment from the district project development team to engineer effective pavement strategies applied at the right time. The implementation process for concrete pavement project development is outlined by the flow chart in Figure 100-3. Ideally, as performance data accumulates, the process will evolve as individual elements are refined to maximize resources while collectively managing the entire 50,000 lane-mile roadway network statewide.

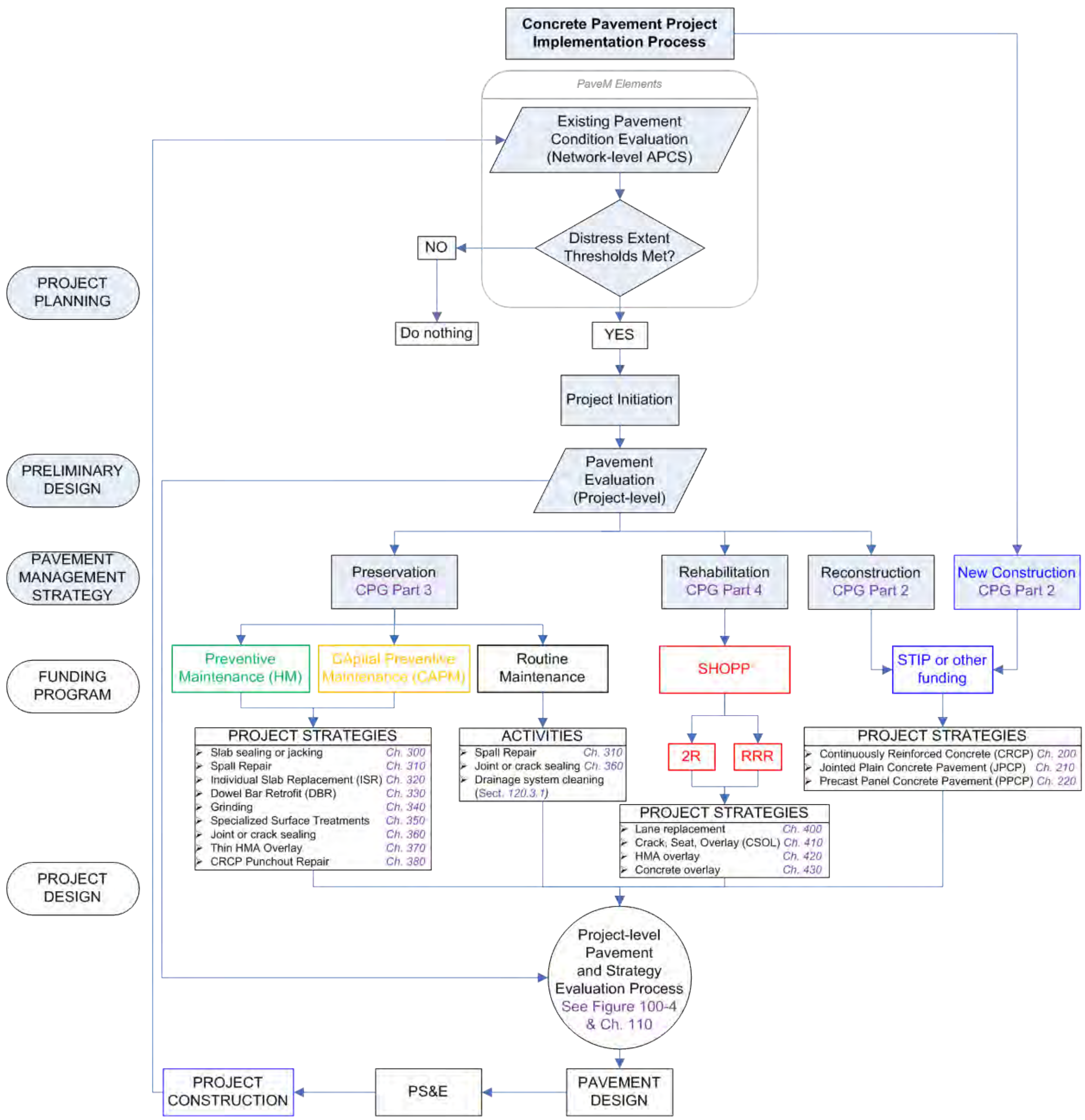

Figure 100–3: Concrete pavement management project development process

100.3.1 Pavement Strategy Recommendations

PaveM provides recommendations for project strategies to treat each individual distress. The strategies in Table 100-1 are network-level recommendations based on APCS structural and functional distress data and thresholds developed from pavement engineering principles and pavement management policy. Not all critical pavement distresses are quantified by the APCS, and failure mechanisms may not be readily identified from available images and data for the network. All project strategies and locations should be verified using engineering judgment after a scoping field review by the project team, consisting of the HQ program advisor or pavement reviewer and qualified District maintenance, materials, and design personnel (see Section 110.2). During the field review, areas where multiple distresses or failure mechanisms require additional repairs or pavement strategy combinations should be identified (see Section 100.3.2). After the pavement is evaluated by field review, the project development team should analyze the feasible alternatives and document the strategy recommendations in the appropriate project development report (PSR, PR, PSSR).

Chapter 110 contains more details about the project-level pavement and strategy evaluation processes, which are outlined below in Figure 100-4:

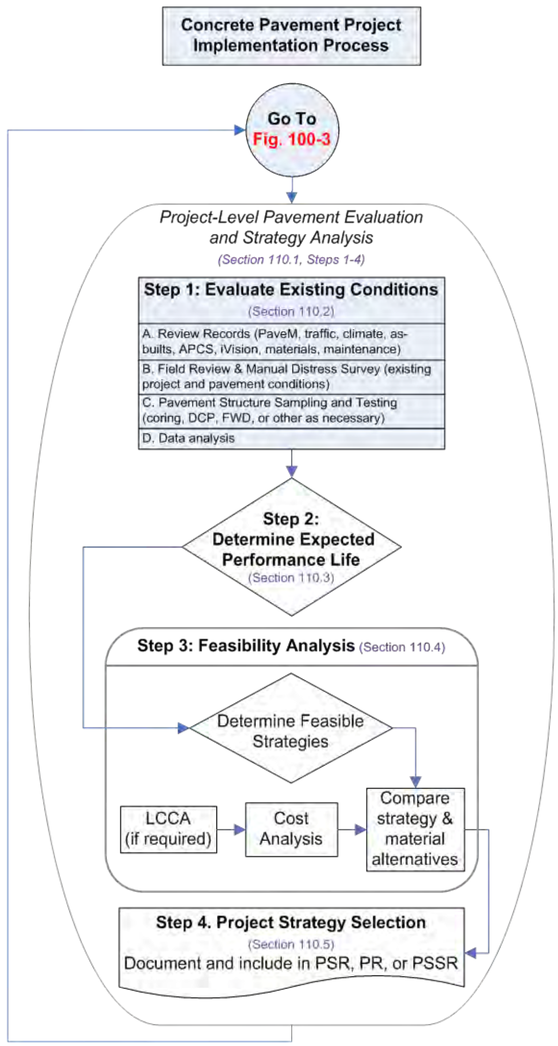

Figure 100–4: Concrete pavement strategy evaluation process

Table 100–1: Concrete Pavement Strategy Selection

Preventive Maintenance (HM)		CApital Preventive Maintenance (CAPM)		Rehabilitation (SHOPP)	
APCS Distress Type	**Severity**	**Quantity (per slab)**	**Management Segment Extent (%)**	**Recommended Primary Strategy***	**Reference**
Transverse, Longitudinal, or Corner Cracking (Count ≥ 1; Width: inches)	Low	< ¼”	100	None	APCS Manual
	Medium	¼ – ¾”	1–25	None	APCS Manual
			> 25	Crack sealing	Ch. 360
	High	> ¾”	1–15	▪ Individual slab replace ▪ HMAOL	▪ Ch. 320 ▪ Ch. 370
			> 15	▪ Lane replacement ▪ CSOL or HMAOL ▪ Unbonded concrete OL	▪ Ch. 400 ▪ Ch. 410 ▪ Ch. 420
3rd Stage Cracking (Width: inches)	Low	< ¼”	100	None	APCS Manual
	Medium	¼ – ¾”	1–20	None	APCS Manual
			> 20	Crack sealing	Ch. 360
	High	> ¾”	1–10	▪ Individual slab replace ▪ HMAOL	▪ Ch. 320 ▪ Ch. 370
			> 10	▪ Lane replacement ▪ CSOL or HMAOL ▪ Unbonded concrete OL	▪ Ch. 400 ▪ Ch. 410 ▪ Ch. 420
Spalling (ft^2)	Low	< 1	100	None	APCS Manual
	Medium	1–2	1–25	None	APCS Manual
			> 25	Spall repair	Ch. 310
	High	> 2	1–15	▪ Individual slab replace ▪ HMAOL	▪ Ch. 320 ▪ Ch. 370
			> 15	▪ Lane replacement ▪ CSOL ▪ Unbonded concrete OL	▪ Ch. 400 ▪ Ch. 410 ▪ Ch. 420
Roughness (IRI: inches/mile)	Low	< 95	100	None	APCS Manual
	Medium	95–170	100	None	APCS Manual
	High	> 170	1–50	None	APCS Manual
			> 50	Grinding	Ch. 340
Faulting (inches)	Low	< ¼”	100	None	APCS Manual
	Medium	¼ – 1”	1–50	None	APCS Manual
			> 50	▪ Grinding	▪ Ch. 340
				▪ DBR & Grinding	▪ Ch. 330 & 340
	High	> 1”	1–25	▪ Grinding	▪ Ch. 340
				▪ DBR & Grinding	▪ Ch. 330 & 340
			> 25	▪ Grinding, thin HMAOL	Ch. 340, 370
Rutting (inches)	Low	< ¼”	100	None	APCS Manual
	Medium	¼ – 1”	1–25	None	APCS Manual
			> 25	▪ Grinding, hardener	▪ Ch. 340 & 350
	High	> 1”	1–10	▪ Grinding, thin HMAOL	▪ Ch. 340 & 370
			> 10	▪ Grinding, thin HMAOL ▪ Unbonded concrete OL	▪ Ch. 340 & 370 ▪ Ch. 420
CRCP Punchouts (per mile)	Low	< 1		None	APCS Manual
	Medium	2–5		CRCP full-depth repair	Ch. 380
		6–9		CRCP full-depth repair, thin HMAOL	Ch. 380, 370
	High	> 10		▪ Lane replacement ▪ HMAOL ▪ Unbonded concrete OL	▪ Ch. 400 ▪ Ch. 370 ▪ Ch. 420

*The primary recommended strategy should be evaluated by a field review and pavement evaluation (see Ch. 110). Multiple distresses may require a combination of strategies for effective pavement performance.

100.3.2 Strategy Combinations and Preoverlay Repair

Performance of any pavement surface is dependent on uniform support from the underlying structure. Some distress combinations require multiple pavement strategies for effective repair or to address failure mechanisms. Medium and high severity spalling on slabs not identified for replacement should be repaired for all projects. If any type of overlay is recommended as the primary strategy, HDM Index 625.1 requires existing pavement distress to be repaired. Repair includes addressing the resulting distress and the mechanism causing the failure. Some repairs recommended for consideration are:

- Medium or high severity cracks should be sealed.
- JPCP slabs with severe 3rd stage cracking ≥ ½" may require replacement.
- JPCP slab medium severity settlement or faulting ≥ ½" may require base replacement.
- Medium severity roughness with an IRI from 95 to 170 inches/mile may require a leveling course or grinding prior to overlay.

Refer to the applicable Concrete Pavement Guide chapter of the recommended primary strategy for more information about identifying effective strategy combinations.

CONCRETE PAVEMENT GUIDE

PART 1: GENERAL INFORMATION

CHAPTER 110 – STRATEGY EVALUATION

Chapter 110 discusses key factors to be considered during the selection process for concrete pavement engineering strategies. This chapter describes the steps involved in the strategy selection process, including typical methods for evaluating existing pavement condition, determining expected performance life, analyzing feasible alternatives, and selecting a strategy.

110.1 STRATEGY EVALUATION PROCESS

Network-level pavement management uses several mechanisms, indicators, and tools to aid pavement evaluation, analysis, and eventual strategy selection, but ultimately optimization of the process relies on individual engineering judgment at the project-level.

The distress type, severity, extent, and deterioration rate are critical to identify, engineer, and select effective pavement strategies. Though consistent and expansive, the automated pavement condition survey (APCS) data accessible through iVision and summarized in PaveM has limitations for engineering pavement strategies. APCS data may not reflect actual project conditions since it focuses on certain readily quantifiable distresses and is scheduled for biannual collection. Not all critical pavement distresses are quantified by the APCS, and failure mechanisms generally cannot be identified from available images and data for the network.

The APCS data and field distress surveys are complimentary tools used to evaluate existing pavement condition. The APCS accurately measures some distress data for the entire roadway network statewide using repeatable automated or semi-automated methods, which reduces the subjectivity inherent in manually conducted distress surveys. Other distresses and current conditions must be quantified and investigated with a manual field distress survey by district personnel during preliminary project development. Depending on the selected strategies and duration of the development process, additional follow up field reviews may be necessary during pavement design or prior to PS&E for data verification and quantity estimation.

A four step evaluation process to analyze concrete pavement strategies is summarized below:

Step 1. Evaluate existing pavement and project conditions (Section 110.2):

A. Review available records
B. Field review and survey to identify project conditions, pavement distress types, and causes to verify and supplement APCS data.
C. Pavement structure sampling and testing as necessary.
D. Analyze data

Step 2. Determine expected performance life (Section 110.3). Consider the required design life and anticipated service life for the project strategy given wide-ranging, project-specific factors such as overall pavement condition, distress types, failure mechanisms, deterioration rate, remaining service life, traffic, constructability limitations, cost analysis, and budget restraints.

Step 3. Analyze feasibility (Section 110.4):

A. Determine the feasible strategies from the recommended primary strategies given in Chapter 100, Table 100-1, using data from the records review and pavement condition evaluation.

B. Analyze and compare the feasible alternatives identified in terms of cost, life expectancy, and extended pavement life predicted from the strategy. Evaluate cost effectiveness using LCCA or other cost analysis (see Section 110.4.1).

Step 4. Select strategy (Section 110.5). Document the analysis and recommendations in a report, which could include a summary and recommendations memo from the district maintenance or materials engineer or a complete materials report. Strategy recommendations should be discussed in the narrative of the appropriate project development report (PSR, PR, or PSSR) and attached for reference.

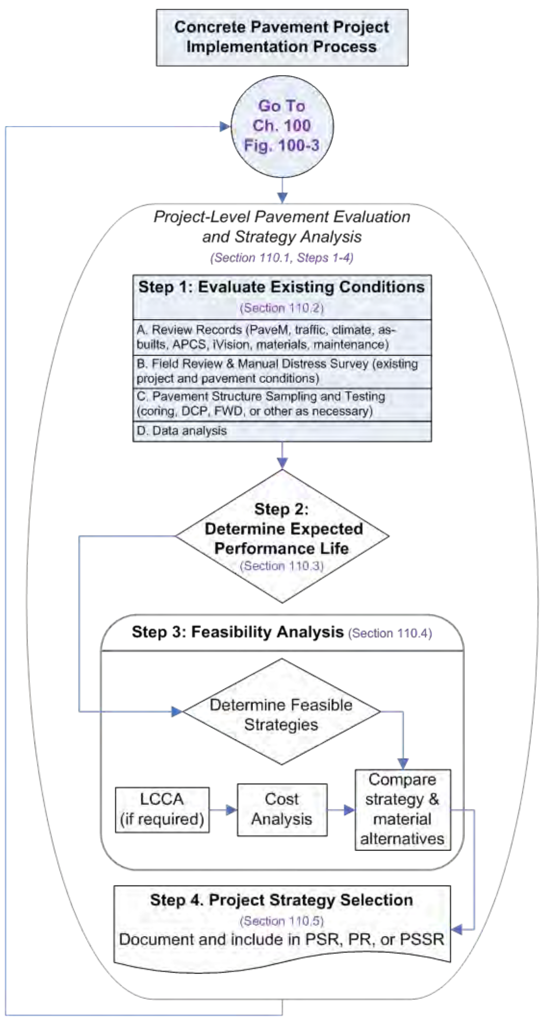

Figure 110-1: Concrete pavement strategy evaluation process

110.2 Step 1: Evaluate Existing Conditions

Conduct a comprehensive office and field review to evaluate the existing pavement and project conditions using the following process:

Step 1A. Review Records

Reviewing project information provides qualitative information to determine the causes of pavement deterioration and develop effective repair strategies, as well as the quantitative information needed to assess deterioration rates, identify potential pavement engineering strategies, analyze the timing of various strategies relative to the pavement life cycle, estimate pavement quantities, and develop inputs for cost analysis.

- Analyze historical records information about the project location, beginning with the PaveM database. Include traffic volumes, climate region, construction history (as-built plans), and recent APCS or pavement condition report (PCR) data from past surveys in the analysis.
- Consider other valuable information that may be available from district records including previous design reports, materials and subgrade properties from previous testing, maintenance and repair history, and specific weather data for the project location or climate region.
- Check for other projects in the area that may be planned, programmed, and under design or construction, including emergency storm damage and encroachment permit projects.
- Investigate existing pavement and project conditions using iVision images from the current APCS.

Step 1B. Project Field Review and Manual Distress Survey

A field review and manual distress survey is helpful in the pavement evaluation and strategy selection process to verify and supplement available project and pavement condition information. Depending on the size and nature of the project, a field distress survey can be conducted using observations from a windshield drive-through, median and outside shoulders, or a detailed distress mapping survey using lane closures. Additionally, other project-specific conditions such as those listed in Table 110-1 may be assessed during the field review.

- Participation should include the HQ program advisor or pavement reviewer and qualified District maintenance, materials, and design personnel.
- Collect data and information to analyze conditions including the distress type, severity, and extent; potential causes and failure mechanisms; and remaining pavement service life. For more information about distress identification and pavement rating, refer to the APCS Manual and FHWA's Distress Identification Guide.
- Identify project-specific local conditions such as surrounding terrain, existing drainage, and constructability limitations.

Condition analysis should include the identification of all pavement distress types and causes to verify and supplement APCS data with additional information about miscellaneous pavement conditions such as pumping, joint seal condition, surface texture, and shoulder separation or dropoff at the edge of traveled way. Additional project field conditions should also be evaluated. Indicators of subsurface distress or unusual conditions that could impact strategy selection should be considered. Table 110-1 lists some potential data needs:

Table 110–1: Potential Concrete Pavement Condition Data

APCS Data			Field Review Data[1]	
Condition	**Pavement Distress Type**	Miscellaneous Conditions	**Pavement Distress Type[2]**	**Project Considerations**
Structural Integrity (cracking or deterioration)	Corner cracking		Pumping or slab rocking	Terrain
	Longitudinal cracking		Joint seal condition	Subgrade
	Transverse cracking		Shoulder separation/ dropoff	Drainage
	3rd Stage cracking		Shrinkage cracks	Geometrics
	Spalling		Blowups	Vertical clearance
	Punchouts		Polishing	Right of way
Ride Quality (Roughness)	International Roughness Index (IRI)		Abrasion	Traffic control
			Popouts	Constructability
	Faulting		Scaling/ map cracking	
	Rutting		Freeze-thaw damage	

[1]The data listed are not comprehensive: specific local conditions and data needs will vary by project location.
[2]Refer to Section 110.4, Table 110-3 for recommended field distress severity and extent thresholds.

A specific distress may be caused by single or multiple mechanisms which should be analyzed as part of a comprehensive field review. An effective pavement strategy must not only mitigate the distress symptoms but also resolve the mechanism that caused the distress, which may be complex or affect multiple pavement structure layers. Distress mechanisms may require further evaluation or testing if they are not readily apparent from the pavement surface (see Step 1C).

Table 110-2 lists some potential causes and contributing factors to consider when analyzing distress mechanisms:

Table 110–2: Distress Mechanism Analysis

Distress Category	Potential Causes	Distress Type	Potential Factors					
			PRIMARY		CONTRIBUTING		NEGLIGIBLE	
			Design	Load	Water	Temp	Materials	Const
Cracking	Fatigue, joint spacing, shallow or late sawing, base or edge support, freeze-thaw, moisture related settlement/ heave, dowel bar lockup, curling, warping	*Transverse*						
		Longitudinal						
		3rd Stage						
		Corner						
Joint/ Crack Deterioration	Incompressible material, erosion, poor durability, dowel socketing or corrosion, high reinforcing steel	*Spalling*						
		Pumping						
		Joint Seal Damage						
Roughness	Poor load transfer, loss of support, pumping, settlement, freeze-thaw, moisture related settlement/ heave, curling, warping, poor construction practices	*Faulting*						
		Heave / swell						
		Settlement						
		Patch deterioration						
Surface Defects/ Durability	Over-finishing the surface, poor aggregate or mix quality, ASR, poor curing practices, freeze-thaw damage	*Map cracking/scaling*						
		Popouts						
		Shrinkage cracks						
	High traffic; tire chain abrasion; poor texture	*Polishing, abrasion, or Rutting*						
Miscellaneous	Incompressible material, support loss, less steel, slab thickness, close or wide cracks, corrosion, poor consolidation	*Blowups*						
		Shoulder drop-off						
		CRCP Punchouts						

Step 1C. <u>Pavement Structure Sampling and Testing</u>

Perform the sampling and testing necessary to evaluate existing pavement conditions, pavement structure, failure mechanisms, and design the pavement engineering strategy. Field testing may not be needed for most concrete pavement strategies, but could include coring, dynamic cone penetrometer (DCP), ground penetrating radar (GPR), or falling weight deflectometer (FWD) deflection testing to determine the transverse joint load transfer efficiency, structural capacity of individual pavement layers, or underlying voids due to base erosion (see Section 110.2.2). For more information about field testing, refer to the individual Concrete Pavement Guide chapter for the pavement strategy being evaluated.

Laboratory testing may be conducted to verify, confirm, or quantify field observations from distress surveys, analysis of distress failure mechanisms, or development of pavement engineering strategies. Examples of potential laboratory testing include:

- Subgrade characterization

- Concrete strength
- Resilient modulus of concrete or other materials

For more information on concrete pavement evaluation and testing, refer to Chapter 3 of the NHI Concrete Pavement Preservation Workshop for NHI Course No. 131126B.

Step 1D. Analyze data

Use engineering judgment and available references to consider all project-specific conditions, existing pavement conditions, available engineering strategies, and budget restraints for managing the pavement segment being analyzed. Some complex distress mechanisms may not have a cost effective long-term engineering solution, justifying increased future maintenance costs for isolated locations.

110.2.1 Faulting Mechanism Analysis

Faulting is one of the primary distresses of non-doweled JPCP. Understanding its mechanism is important to address this type of pavement deterioration. The conditions for slab faulting to occur are:

1. Slab curling, typically caused by thermal gradients
2. Erodible fine base material
3. Water in the pavement structure
4. Independent vertical slab movement: the up-stream slab must be able to rebound upward after the wheel load depresses the down-stream slab.

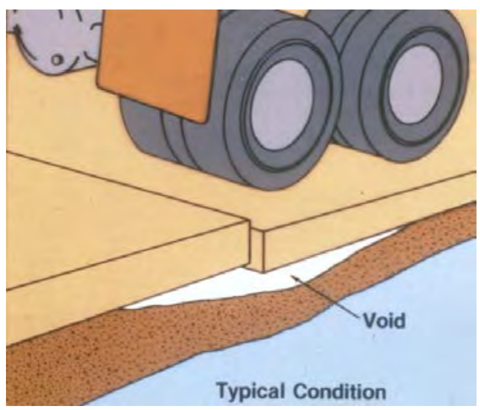

Figure 110-2: Slab faulting with eroded base[1]

When the faulting from the up-stream slab to the down-stream slab is greater than 0.06”, the shoulder begins to depress and cracks appear, mostly on the down-steam side of the joint. As faulting increases, so does shoulder deterioration, separation, and drop-off. Roughness and faulting continue to increase with time and traffic loading. Ride quality can be temporarily restored with grinding, but the pavement structure will continue to deteriorate until the failure mechanisms are addressed.

As faulting severity increases, support of the up-stream edge decreases. The slab functions analogous to a cantilevered beam with low tensile strength. Eventually, a short slab is formed when transverse cracks appear at the edge of underlying base support, usually within 3 to 6’ from the transverse joint. Longitudinal stresses are increased due to the decreased cross-sectional area of the smaller slab.

Dowel bar retrofit (DBR) of transverse joints and cracks may be a viable engineering strategy at this stage. If untreated, the transverse crack behaves as a joint and develops faulting. Further deterioration will ultimately result in 3rd stage cracking that requires slab and base replacement. As more slabs exhibit 3rd stage cracking, the pavement may need rehabilitation.

110.2.2 Evaluating Base Condition

Performance of any pavement surface is dependent on uniform support from the underlying structure. Assessing the underlying base condition is especially important for analyzing slab subsealing and jacking, overlay, and individual slab or lane replacement strategies. Underlying base layers in poor condition must be repaired or replaced to improve pavement structure performance, but determining replacement needs is challenging since the base layer is not visible until construction. The district materials engineer can conduct subsurface investigations to assess underlying base, subbase, and subgrade condition. GPR, FWD deflection testing, coring, and DCP testing can be used but they have limitations including time, expense, accuracy, and location. Determining where to conduct field testing and how much testing is warranted requires critical engineering judgment. It is difficult to characterize all field conditions with testing given the inherent variability along a project pavement segment.

Visual inspection of the pavement surface condition is typically the most efficient method for estimating base replacement within 25% of actual quantity during project design. If a visual survey is performed without additional testing or evaluation, assume base replacement is required if:

- The existing base is not LCB but is treated (CTB, ACB, or TPB) and JPCP slab settlement or faulting > ½”.
- Spalling is more than 2” wide extending over 75% of the crack length
- Rocking slabs move up and down relative to adjacent slabs
- The existing concrete pavement is approaching or beyond its design life and lane or individual slab replacement strategies are used. Base replacement provides cost effective extended strategy performance since existing concrete removal is an opportunity for simple access and existing base has deteriorated over time from loading and moisture intrusion.

It is important to provide flexibility in the PS&E package since pavement field conditions change over time and subsurface base evaluation is only an indicator of condition. Final determination will be made in the field during construction after concrete pavement is removed and base condition can be inspected. Including adequate estimates for all the required bid items to complete the work, supplemental funds in the contract estimate for additional slab or base replacement, and comprehensive notes in the resident engineer file will help ensure successful construction.

110.3 STEP 2: PERFORMANCE LIFE EXPECTANCY

Effective strategy selection must consider the design life and anticipated service life. The design life is the period of time a pavement structure is designed to meet a defined level of performance. HDM Index 612.1 defines this level of performance as the distress thresholds required to initiate a CAPM project. Whether a pavement design strategy performs adequately over the intended design life is dependent on the existing pavement condition, actual traffic loading, environmental conditions, design methodology, and construction practices. Accurate data and traffic forecasting is important to realistically determining the expected performance life.

Standards for design life of new, reconstructed, and rehabilitated concrete pavement are based on traffic volume as discussed in HDM Topic 612. A design life of at least 20 years is required but 40 years or more is typically used for concrete pavement strategies based on LCCA. CAPM projects have a design life between 5 and 10 years and do not require LCCA, although some analysis should be used to evaluate the cost effectiveness of material and strategy alternatives. Preventive maintenance projects are not engineered to meet a minimum structural design life, but actual service life can range from less than a few years to 15 years or more. Preservation strategies will not be effective for pavement with severe distress that requires rehabilitation or reconstruction.

Some pavement strategies will exceed their intended design life and remain in service longer than predicted, while others will not meet performance expectations and fail prematurely on an isolated or extensive basis. Good project-level engineering design and construction practices can contribute to success, but sometimes terrain, subgrade, drainage, budget limitations, excess traffic loads, or other challenging project conditions cannot be overcome and inhibit performance.

Table 110-3 indicates the anticipated ranges for service life of some individual pavement strategies. The information should only be used as a general indicator: more accurate performance data for individual strategies and specific pavement segments (deterioration rates, extended pavement life prediction) can be developed using district traffic forecasts and data in PaveM, or through local maintenance records.

110.4 STEP 3: FEASIBILITY ANALYSIS

Based on the recommended primary strategies in Chapter 100, Table 100-1, feasible pavement strategies for a project can be identified once the historical information has been analyzed, field review completed, pavement condition and structural capacity evaluated, test samples collected and analyzed, and expected performance life determined. Feasibility is not solely a function of affordability: the purpose is to determine what strategies best work for defined structural and functional conditions based on pavement engineering, using data from the records review and pavement evaluations. The most feasible alternative or recommended strategy may not have the lowest initial cost and must account for any identified project constraints.

Step 3A. Determine the feasible strategies

Determine feasibility by considering the ability of a strategy to address the existing functional and structural condition of the pavement while meeting future performance needs and budget constraints. A feasible alternative addresses all identified pavement distresses, cost effectively provides desired future performance over the anticipated service life of the strategy, and meets identified project constraints. Several concrete pavement strategies may be identified as feasible.

Step 3B. Analyze and compare the feasible strategies

Compare the feasible alternatives identified in terms of cost effectiveness, life expectancy, and extended pavement life predicted from the strategy. Analyze project specific engineering factors such as pavement condition, structural capacity, deterioration rate, remaining service life, traffic volume, and construction limitations (available time, closure requirements, geometrics, weather, etc.) when comparing different alternatives. Other considerations that can affect feasibility include:

- Regulatory restrictions
- Agency policies
- Pavement management practices
- Local government input
- Right-of-way restrictions
- Strategy performance history
- Climatic considerations
- Available project funding and scope
- Use of nonstandard experimental strategies or materials
- Constructability
- Safety of construction workers and traffic

- Traffic control requirements
- Available working days
- Available local contractor materials, equipment, and expertise

Strategies should be compared using a rational and systematic approach. A decision matrix can be used to summarize the selection criteria, assign weighting multipliers, rate each factor, and compare scores for individual strategy alternatives. If all the internal and external constraints are not identified or considered at this juncture of the evaluation, unnecessary work and project delays may be encountered later in the project development process.

Table 110-3 may be used in conjunction with Table 100-1 in Chapter 100 as a general guideline to indicate strategy feasibility based on the pavement engineering considerations shown. The information is not intended to be comprehensive or supplant engineering judgment. Table 110-3 does not address every possible distress type, strategy alternative, or project-specific consideration that should be analyzed. The costs in Table 110-3 are based on Maintenance data prior to 2008. These costs could be used for general planning purposes to compare strategies but should not be used for estimating.

Table 110–3: Strategy Feasibility Analysis

Strategy	Distress or Property (unit)	Field Measured Distress Threshold (severity; extent)	Anticipated Service Life (years)[1]	Estimated Cost ($)[2]
Crack sealing	Width (inch)	¼"< Width < ¾"; 25% extent	4 – 7	$28,000 – $42,000/ ln-mi
Joint sealing	Joint seal damage (joint)	> 25% extent	4 – 7	TBD
Grinding	Faulting (inch) IRI (inch/mile)	Faulting > ¼"; 50% extent IRI >170 inch/mile	10 – 18	$30,000 – $80,000/ ln-mi
Spall Repair	Spalling (ft^2)	> 2 ft^2/ slab	5 – 10	$135 – 270/ yd^3
Subsealing	Faulting (inch) Pumping/ Rocking (slab) Corner Deflection (mils)	≤ 1/8" < 5% extent See Concrete Pavement Preservation Workshop Ch.4	5 – 10	$2000/ ton
Individual Slab Replacement (ISR)	3rd stage cracking (width)	< ¾"	8 – 10	$4,000 – $8,000/ slab
Dowel Bar Retrofit (DBR)	Faulting (inch) 3rd stage cracking Pumping (slab) LTE (%)	< ½" < 5% extent Yes < 70%; 10%	8 – 15	$141,000 – $177,000/ ln-mi

[1]Based on Caltrans Maintenance Technical Advisory Guide (2008) and SHRP2 Report S2-R26-RR-2 (2011)
[2]Costs are for comparative planning purposes based on Maintenance data (2008). Do not use for estimating.

110.4.1 Cost Analysis

Well engineered projects use some type of comparative cost analysis to evaluate pavement alternatives, which can include variations in materials, designs, and individual strategies. The recommended strategy typically provides the greatest benefit for the lowest life cycle cost. Benefit can be measured in terms of pavement condition improvement, pavement life extension, or simply anticipated service life of the strategy.

Life-cycle cost analysis (LCCA) using a Caltrans modified version of FHWA's RealCost software is required for new pavement construction, rehabilitation, and reconstruction projects to evaluate potential costs over a long-term period. In LCCA, agency and user costs associated with a feasible pavement engineering strategy are compared economically based on the net present value (NPV) over a defined analysis period. LCCA consists of the following general components, described in more detail in the LCCA Procedures Manual:

- Establish initial strategy
- Determine analysis period
- Determine future maintenance and rehabilitation treatments
- Estimate agency and user costs using a defined discount rate
- Calculate total cost

For preservation strategies, including preventive maintenance, CAPM, and routine maintenance projects, comprehensive LCCA is not required but some LCCA principles should be applied to the cost analysis. Any cost analysis should consider initial strategy placement costs, performance life expectancy, future maintenance and rehabilitation needs, and remaining pavement service life to determine cost effectiveness. Initial costs can be estimated using historical contract cost data for all contracted bid items and other information available on the Division of Design cost estimating website at http://www.dot.ca.gov/hq/oppd/costest/costest.htm.

110.5 Step 4: Strategy Selection

Identifying a comprehensive concrete pavement strategy for a roadway segment is the culmination of the selection process. To successfully recommend effective strategies that compliment each other, all of the pavement engineering design elements must be collectively analyzed considering their interrelationship (shown schematically in Figure 110-3) and balanced with the identified project considerations and constraints (see Step 3, Section 110.4). For more specific concrete pavement design and materials information, refer to Chapter 120 and the applicable individual strategy chapters in Parts 2, 3, and 4 of the Concrete Pavement Guide.

Figure 110-3: Interrelationship of pavement design elements[2]

Document the analysis, assumptions, and pavement recommendations in a report, which could include a summary memo from the district maintenance or materials engineer or a complete materials report. Strategy recommendations should be attached to the project development report (PID, PSR, PR, or PSSR) and discussed in the narrative for future reference and documentation. If resource or time restrictions prevent full analysis, preliminary recommendations based on stated assumptions can be used during project planning for PID and PSR documents. Most pavement strategies are regarded as specialized engineering designs so recommendations are typically stamped by a professional civil engineer.

110.5.1 Documenting Pavement Recommendations (Typical Outline)

I. GENERAL

A. Project Description. Include a short project description with the location and background information helpful to understanding the materials report or pavement design recommendations. Include a scaled general project location or vicinity map showing post mile limits and stationing. Briefly address pertinent topics including:

1) Proposed project funding and scope of roadway improvements.
2) Climatic conditions. Indicate the climate region and include climate data used to prepare the report and comments on potential freeze-thaw conditions.
3) Terrain and Surface Drainage. A brief discussion of topography, surface drainage, land use, and other surface conditions affecting the highway. Include appropriate mapping.
4) Geology. Outline general geological formations, soil surveys, faults, or unstable areas.
5) Special conditions and assumptions.

B. Test summary. Summarize recent or past field investigations, cores, sampling, testing, and data evaluation. Reference locations relative to the existing or designed alignments. New core samples should be recorded in the iGPR-Core online database.

C. Other Reports and Investigations. Reference and identify relevant information and other reports such as geotechnical studies, boring logs, or coring records.

II. EXISTING ROADWAY

Describe the existing pavement structure in terms of material types, thicknesses, age, and current condition. Include deflection data if available. Describe critical distresses and probable mechanisms causing cracking, pumping, faulting, etc.

III. ROADWAY FOUNDATIONS

A. Description. Discuss the soil classification, foundation, and subsurface moisture conditions within the project limits. Address groundwater, natural springs, native material, unsuitable subgrade, and expansive soils.

B. Specific recommendations. Recommend foundation design features and treatments including subsurface drainage and soil stabilization design features as necessary.

IV. PAVEMENT STRUCTURE DESIGN RECOMMENDATIONS

Include the recommended pavement structure designs for the mainline roadway, shoulders, auxiliary lanes, ramps, local roads, etc. Include materials and thicknesses recommended for each TI submitted. Justify materials selection, exclusion, and any deviation from current design standards. Outline special materials requirements for project-specific conditions.

V. ATTACHMENTS

Attach copies of relevant information potentially including: APCS condition data, PaveM reports, consultant reports, special correspondence or memos, maps, typical cross-sections, pictures, etc.

REFERENCES

1. *PCC Pavement Preservation presentation,* Stahl, K. Pavement Preservation Task Group 2005 Forum.
2. *Concrete Pavement Preservation Workshop*. Reference Manual. Federal Highway Administration, Washington, DC.

CONCRETE PAVEMENT GUIDE

PART 1: GENERAL INFORMATION

CHAPTER 120 – PAVEMENT DESIGN AND MATERIALS

Chapter 120 discusses important factors that should be considered during concrete pavement design, including climate, traffic loading, pavement structure materials, layer thicknesses, and other engineering considerations. The information in this chapter compliments HDM Chapters 600 – 670, which should be referenced for required design standards and methodology. For more comprehensive information about concrete materials, refer to the DES Concrete Technology Manual available on the intranet.

120.1 PAVEMENT DESIGN

When properly designed, constructed, and maintained, concrete pavements can last for a long time. Standard design catalogs for new concrete pavement based on mechanistic-empirical analysis principles are in HDM Index 623.1 considering climatic effects, applied traffic loads, and subgrade quality. To select the best materials and determine layer thicknesses, successful pavement structure designs must consider these and other engineering factors such as traffic control and estimated costs.

For maintenance and rehabilitation strategies, accurate characterization of each pavement structure layer's condition and structural capacity is also critical to design and performance (see Ch. 110.2).

120.1.1 Climate

Pavement structures are exposed to variable environmental conditions daily and seasonally which affect their ability to support traffic loads. California has a wide variety of climates corresponding to geographic diversity including northern and southern coastal, valley, mountainous, and desert regions.

Average hourly temperature and precipitation data from weather stations throughout the state was used to model continuous climatic effects on pavement. Analysis of this data resulted in development of 9 pavement climate regions to account for California's general climate conditions in pavement structure design, combined with the design tables in HDM Index 623.1.

<u>Temperature</u>

Temperatures vary widely in California due to daily, seasonal, and climatic differences. Often the highest temperatures in the western hemisphere occur during summertime in the Mojave Desert, countered by extreme winter lows in the Sierra Nevada Mountains. Some mountain and valley areas also experience daily extremes with average temperature changes ranging between 30 and 40 °F.

Temperature variation causes concrete pavement surfaces to expand or contract, intensifying faulting, cracking, and spalling potential. As ambient air temperatures vary throughout the day and night, the pavement temperature also changes variably throughout the concrete depth. Temperature cycles cause a temperature difference between the top and bottom of the concrete, creating a temperature gradient (see Figure 120-1). As the concrete responds to temperature differences, internal stresses develop as it is resisted by its own weight, underlying layers, and restrained edge conditions. Since the underside is more insulated from temperature changes, the concrete surface expands and contracts at a different rate. During the daytime, the temperature towards the top of a JPCP slab is greater than at the bottom, causing surface expansion and downward curl. Cooler temperatures at night and during the early morning shrink the surface and curl the slab upward.

The temperature gradient can induce high curling stresses in the concrete that enhance or detract from traffic loading stresses, increasing faulting and cracking potential. Rare, sudden temperature increases can cause JPCP slabs with restricted movement to blowup or tent and require emergency replacement. Doweled JPCP slabs and CRCP are less susceptible to potential curling and warping distress due to steel reinforcement.

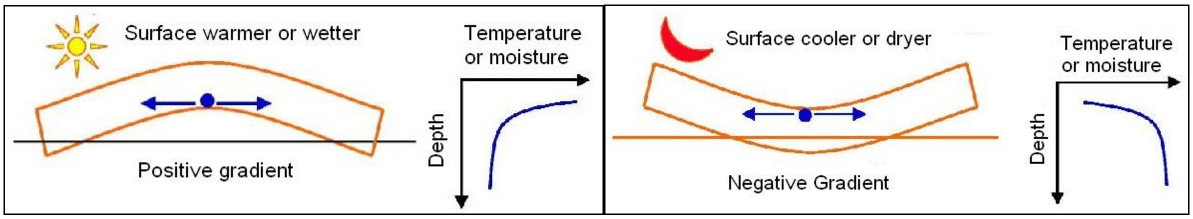

Figure 120–1: Slab curling and warping

<u>Precipitation</u>

Average annual precipitation in California ranges from around 3" in the southern Coachella Valley to in excess of 70" in northern mountainous terrain. Excessive moisture weakens underlying pavement structure material layers and provides a mechanism for deterioration, including pumping, erosion, voids, faulting, cracking, and freeze-thaw frost damage in cold climates. Identifying regions with higher precipitation can indicate project areas where additional drainage and pavement structure design features should be considered.

Moisture can infiltrate the pavement structure from precipitation on the surface or from subsurface sources due to extensive precipitation or high ground water, enabled by gravity flow and capillary action. Concrete pavement itself is considered virtually impervious to surface water except for access at joints and cracks, which can be sealed to limit infiltration. Depending on geometric grades, cut sections can be particularly susceptible to infiltration at the pavement edges, resulting in a bathtub effect. Edge drains, treated permeable base, geotextile fabrics, and waterproof membranes can be effective subsurface drainage components with proper design, construction, and maintenance. The pavement climate region can provide a general indicator, but potential drainage needs at a project location should be identified by field review and discussion with district maintenance and geotechnical services personnel. Refer to Section 120.3.1 for pavement drainage guidance.

Variations in moisture content from the top to the bottom of concrete pavement also result in warping stresses. When the upper portion of a JPCP slab is moist, downward warping occurs (see Figure 120-1). When the top of a JPCP slab is drier than the bottom, the pavement generally warps upward. As these movements are resisted by the concrete weight, underlying layer support, and end conditions, internal warping stresses develop from the moisture gradient, analogous to curling stresses from temperature gradients.

Freeze-Thaw Cycles

For pavements located in cold mountain climates, temperature and moisture effects can interact to create repetitive freeze-thaw cycles that increase internal pavement stresses. Over time, high tensile stress can rupture the cement paste and lead to concrete scaling and cracking deterioration. Air-entraining admixtures enhance long-term concrete durability performance in freeze-thaw conditions by creating a uniform matrix of air bubbles so water in the pavement can expand when frozen or contract when thawed.

120.1.2 Traffic Loading

Pavement structures are designed and constructed to withstand the stresses and strains from repeated wheel axle loads applied over the course of the design life. Accurately forecasting the future traffic axle loading on a roadway is important to maximizing the anticipated pavement service life for the design strategy.

The pavement design catalogs in HDM Index 623.1 quantify traffic loading using the traffic index (TI), which is calculated based on equivalent single axle loads (ESALs). ESALs represent the total accumulated number of 18,000 pound single axle loads for every heavy vehicle forecasted to travel the route segment over the design life. Heavy vehicles are classified by type according to the number of axles on the truck or bus: 2, 3, 4, and 5 or more axles. Truck traffic data from vehicle counts and over 100 weigh-in-motion (WIM) stations statewide is used to estimate current volumes. Combined with planning information for future development and traffic demand software models, future volumes are projected by district travel forecasting offices, converted to ESALs, and used to calculate the TI for the design years being analyzed. Multiple TI's can be generated for highways with 3 or more lanes in each direction, but constructability must be considered when designing pavement structure thicknesses.

As part of the continuing conversion to mechanistic-empirical analysis, pavement structure designs will use axle load spectra developed from WIM data to more realistically model traffic loading in the near future. Axle load spectra represent a normalized distribution of a range of axle loads for each axle type and truck classification, so no ESALs are used.

For more details on traffic analysis, refer to HDM Topic 613.

120.1.3 Concrete Pavement Structures

A concrete pavement structure is an integrated system that supports traffic by distributing load stresses through multiple material layers of varying thickness: typically a concrete pavement surface underlain by base, subbase, and subgrade (see Figure 120-2). The concrete pavement surface layer bears most of the traffic load and its strength limits deflection compared to a flexible HMA structure, but performance of any pavement surface is dependent on uniform support from the underlying structural layers.

For new concrete pavement structures, long-term performance is highly dependent on how the design accounts for existing subgrade quality and moisture conditions. For preventive maintenance and rehabilitation strategies, accurate characterization of each pavement structure layer's condition and structural capacity is critical to pavement design and performance (see Ch. 110.2).

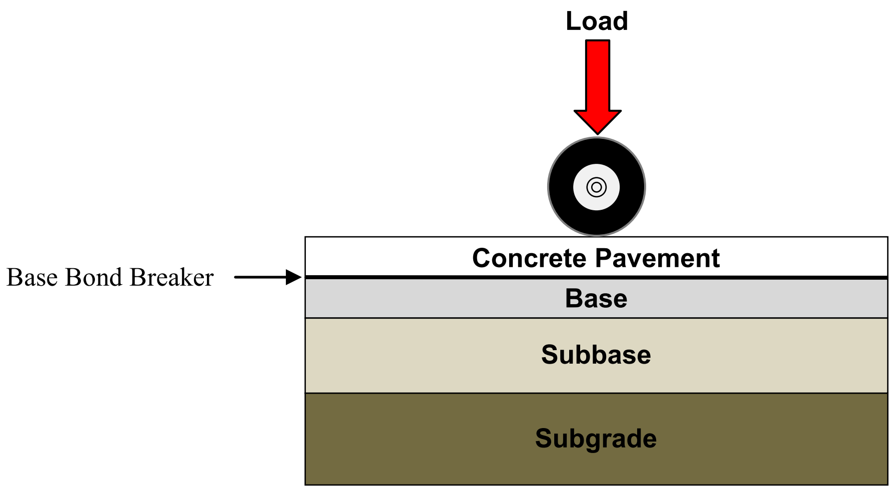

Figure 120–2: Typical concrete pavement structure

Subgrade

Subgrade is also referred to as basement soil, which is well-compacted, in-place native material or embankment used for fill sections. Subgrade depends on internal cohesive strength and friction to support loads. Since soil quality is dependent on geology and surrounding environmental conditions, it is highly variable throughout California and often throughout short distances in a project roadbed area. Generally, concrete pavement should be avoided through extensive areas of expansive soils with a plasticity index (PI) > 12 due to the potential for significant non-uniform differential settlement, lateral movement, and resulting costly maintenance repairs.

Alternatives are limited for routing and alignment of most new pavement construction due to surrounding land use issues, so there is limited control over existing subgrade quality and moisture conditions. Depending on characterization and project conditions, cost effective engineering solutions for expansive soils with a PI > 12 can include in-place stabilization using lime or cement treatment, reinforcement with geotextiles, increasing pavement structure thickness, over-excavation, or installing drainage systems to minimize surface and subsurface water infiltration. Consult the district materials engineer and geotechnical services for subgrade alternatives. More detailed information is also available in the Subgrade Stabilization and Subgrade Enhancement Geosynthetic guides.

HDM Index 623.1 classifies subgrade by type according to the most conservative R-value and USCS classification, shown in Table 120-1:

Table 120–1: Subgrade Classification (from HDM Index 623.1)

Subgrade Type	California R-value	Unified Soil Classification System (USCS)
I	R-value > 40	SC, SP, SM, SW, GC, GP, GM, GW
II	10 ≤ R-value ≤ 40	CL, MH, ML, CH*
III	R-value < 10	CH**

*PI < 12
**PI > 12

Subbase

Subbase is an optional layer between the base course and subgrade that can provide structural support, improved drainage, and mitigate pumping of subgrade fines. Subbase is not required for areas with high quality Type I subgrade. Subbase is generally constructed out of aggregate subbase (AS) on Type II subgrade, but can be lime or cement treated soil (LTS or CTS) with Type III subgrade.

Base

Base provides uniform support, additional load distribution, and contributes to drainage immediately beneath the concrete pavement surface. Base must resist erosion and have the strength and stability to support construction equipment. Treated base is required for higher volume heavy vehicle traffic loading (TI ≥ 11.5).

Cement treated base (CTB) was formerly the standard for concrete pavement structures and is common throughout the statewide highway network, though it is no longer recommended for new or reconstructed concrete pavement structures due to poor performance. Lean concrete base (LCB) has typically been used since 1980 to better reduce base erosion, voids, and subsequent concrete surface faulting and cracking. LCB is readily constructed using concrete plants and paving equipment but requires a base bond breaker for separation with the concrete pavement surface.

HMA is a treated base alternative that provides a smooth base layer, reduces friction, and provides a good bond breaker layer. HMA can outperform LCB in hotter environments such as the desert and southern inland valley climate regions because it provides more flexibility for concrete expansion and contraction with temperature fluctuations.

Base can also be aggregate base (AB), asphalt treated permeable base (ATPB), or cement treated permeable base (CTPB) depending on the designed traffic loading and drainage conditions. AB is only used for TI ≤ 11.0 or as a substitute for TPB in new pavement structure designs.

Due to performance issues, TPB layers are not recommended for new pavement structure designs unless required for continuity adjacent to existing layers. Although CTPB can erode, TPB designs should use CTPB instead of ATPB, which tends to strip and lose stability with prolonged moisture exposure. Refer to Section 120.3.1 and HDM Index 662.3 for more detailed information about pavement structure drainage and TPB.

Base Bond Breaker

Base bond breaker is a material used to reduce friction between concrete pavement and base material that can lead to cracking. SSP 36-2 allows the contractor to select various materials such as asphalt binder, curing compound, polyethylene film, curing paper, or geosynthetics depending on the type of base material. The bond breaker allows the pavement structure layers to move independently, reducing reflective cracking and providing flexibility for slab curling due to temperature differences between the top and bottom of the pavement surface.

Concrete Pavement

Concrete pavement surfaces support traffic loads and provide functional characteristics such as friction, smoothness, noise control, abrasion resistance, and drainage. Standard concrete pavement surface types include JPCP and CRCP, typically constructed from cast-in-place (CIP) portland cement concrete or rapid strength concrete (RSC) materials:

- CRCP (Ch. 200) uses steel reinforcement in the upper third of the concrete surface to control vertical and horizontal movement of transverse cracking, which should occur in randomly spaced 3.5 to 8’ intervals. Tied longitudinal joints are used to control horizontal movement of adjacent lanes.

- JPCP (Ch. 210) uses engineered transverse and longitudinal joints to control concrete cracking. JPCP is not reinforced pavement but uses smooth steel dowel bars as load transfer devices across transverse joints or cracks and tie bars along longitudinal joints to restrict lateral movement and hold abutting slab faces in contact.

Nonstandard surface types include precast panel concrete pavement (PPCP) and roller compacted concrete (RCC) for shoulders:

- PPCP (Ch. 220) uses concrete panels that are precast off-site under controlled conditions and trucked to the project location. The panels must be placed on a smooth, finely leveled base and linked by dowel and tie bars. PPCP is an expensive nonstandard strategy that can currently be used only on an experimental basis for lane and slab replacement strategies with unique project conditions such as high truck traffic, extreme lane closure restrictions, limited traffic control alternatives, and remaining service life of more than 20 years for the surrounding pavement. Despite higher material and engineering costs, PPCP offers the potential of improved quality control, material performance, and rapid construction using concrete fabricated in an offsite setting where casting and curing conditions can be controlled.
- RCC: refer to Section 120.2.2 for more information.

An approved nSSP, Construction Evaluated Work Plan (CEWP), and periodic reports are required to use PCCP or RCC on a project. Contact the Office of Concrete Pavement in the Headquarters Division of Maintenance Pavement Program or submit a non-standard special provision (nSSP) request to: nssp.submittals@dot.ca.gov.

120.2 MATERIALS

This is a brief introduction to materials used for concrete pavement, including concrete, concrete repair, and joint seal materials. Depending on pavement engineering needs and cost, some materials and properties are required by the specifications and bid items. Selection, proportioning, mix design, and use of some other materials within the specifications are the contractor's option.

120.2.1 Concrete Materials

Concrete consists of a combination of cementitious materials, coarse and fine-grained aggregate, water, and typically some property modifying admixtures. Concrete properties such as strength, durability, permeability, and abrasive wear resistance are materials dependent. An understanding of each component used in a concrete mix is vital to meeting project and pavement performance needs. Section 90 of the Standard Specifications defines the required chemical and physical concrete material properties for contractor developed mix designs, with some additional requirements for pavement in Section 40. For more comprehensive information about concrete materials, refer to the HQ-DES Concrete Technology Manual.

Cementitious Materials

Cementitious material is a blend of portland cement and supplementary cementitious materials (SCM). Portland cement consists of lime, iron, silica, and alumina. As part of the manufacturing process, the materials are broken down, blended in the proper proportions, and then heated in a furnace at a high temperature to form clinker. The clinker is cooled and ground to make portland cement. By varying the materials and fineness used in production, different types of cement are created with various properties. Standard Specification Section 90-1 allows portland and blended cement types with properties defined by ASTM C150/ 150M and AASHTO M 240 shown in Table 120-2:

Table 120–2: Standard Specification Section 90 Cements

ASTM C150/ 150M Specification for Portland Cement		AASHTO M 240 Blended Hydraulic Cement	
Type*	**Description**	**Type****	**Description**
II	Moderate heat of hydration and sulfate resistance	IS (MS)	Portland blast-furnace slag cement
III	High early strength (typically used only for RSC)	IP (MS)	Portland-pozzolan cement
V	High sulfate resistance		

*An "A" suffix indicates air entrainment
**MS indicates moderate sulfate resistance

SCMs are usually included in the contractor's mix to lower the demand for portland cement, which is typically more expensive, or improve concrete workability and durability properties. Generally, the rate of initial concrete strength gain is reduced, but long-term strength gain is increased through pozzolanic reactions. SCMs are not required for rapid strength concrete (RSC), which depends on a high amount of cement to achieve early strength for opening to traffic. Each SCM uniquely modifies multiple mix and concrete properties.

Some general SCM information is briefly summarized in Table 120-3:

Table 120–3: Standard Specification Section 90 Supplementary Cementitious Materials (SCMs)

SCM	AASHTO Test Method	Applications	Mix Properties	Concrete Properties
Fly ash or Ultra fine fly ash (UFFA)	M 295 Class F	• Freeze-thaw areas • Snowy mountain climates • High temperatures • Marine/ sulfate rich soil • Long life pavement	• Longer set time • Improved workability • Lower heat of hydration • Lower water demand • Reduced bleed water • Reduced segregation	• Reduced permeability, chloride & sulfate corrosion potential • Better abrasion resistance • Lower early strengths • Higher long-term strength • Increased ASR resistance
Natural pozzolans or Metakaolin	M 295 Class N	• Freeze-thaw areas • Low temperatures • Chemically aggressive environments • Marine/ sulfate rich soil • RSC or where early strength gain and high strength are required • If lighter color is desired	• Increased water demand • Significantly reduced workability • Decreased heat of hydration	• Increased early & long-term strength • Increased flexural strength • Reduced permeability, chloride & sulfate corrosion potential • Better abrasion resistance • Increased ASR resistance
Ground granulated blast furnace slag (GGBFS)	M 302 Grade 100 or 120	• Freeze-thaw areas • High temperatures • Marine or sulfate rich soil • Long life pavement	• Longer initial set time • Lower water demand • Improved workability • Lower heat of hydration	• Reduced permeability, chloride & sulfate corrosion potential • Lower early strength • Higher long-term strength • Increased ASR resistance
Silica fume	M 307	• Freeze-thaw areas • Snowy mountain climates • Chloride or sulfate rich environments • Long life pavement	• Significantly increased water demand • Significantly decreased workability • Less bleed water	• Significantly increased early & long-term strengths • Reduced permeability, chloride & sulfate corrosion potential • Significantly increased chloride resistance • Better sulfate resistance • Increased ASR resistance

For more information about SCMs approved for use in concrete, refer to the Cementitious Materials for use in Concrete list or prequalification program criteria on the METS authorized materials list website: http://www.dot.ca.gov/hq/esc/approved_products_list/.

Aggregate

Aggregates constitute most of the total concrete mix volume and have a significant effect on the durability, behavior, and ultimate concrete pavement performance. Concrete is made up of coarse aggregates retained by a No. 4 sieve with a maximum size of 1½ by ¾ inches and fine aggregates passing a No. 4 sieve. Aggregates include natural gravels, sands, and natural crushed rock. Gravel is typically considered more cost effective, but tends to have a high coefficient of thermal expansion which can decrease pavement performance. Aggregate affects the water-cement ratio and contributes to concrete strength.

Durability is a crucial property: the ability of aggregate to resist chemical and physical degradation from internal and external forces. Porous, fractured, and chemically active aggregates decrease concrete durability and can contribute to rutting, surface abrasion, and polishing. Durable aggregate is even more essential in snowy climates subject to freezing and thawing cycles, de-icing substances, tire chains, studded tires, and snow plows where the surface is particularly susceptible to these distresses. Standard Specification Section 90-1 requires innocuous aggregate from sources listed on the authorized material list and tests for durability including abrasion under California Test (CT) 211 (Los Angeles Rattler Test), soundness under CT 214, or durability index for fine aggregate under CT 229.

Water

Water that has no pronounced taste or odor is generally acceptable for concrete pavement mixes. Most water specification requirements are qualitative limits on oil, discoloration, and surface etching; but Standard Specification Section 90-1.02D also has quantitative restrictions for chlorides, sulfates, alkalis, and other impurities.

The water-cementitious ratio (W/C) is the ratio of the total water weight to the weight of cementitious materials in the concrete mix. W/C is an important mix design parameter contributing to the concrete strength and is monitored during construction using limits on water quantity and by testing for consistency and workability under CT 533 for penetration and under ASTM C143 for slump.

Admixtures

Admixtures are added to plastic concrete to obtain specific mixture characteristics. Some chemical admixtures such as accelerators, retarders, and water-reducing agents are used to obtain specific placement properties such as increasing workability or rate of strength gain. Other admixtures affect hardened concrete properties by increasing strength and durability. Air-entraining admixes enhance long-term concrete performance by creating a matrix of air bubbles so water in the pavement can expand when frozen or contract when thawed. Lithium nitrate admixtures react with silica in the aggregate to form a non-expansive gel which inhibits alkali-silica reactivity (ASR).

Chemical admixtures must comply with ASTM C494/494M; air-entraining admixes with ASTM C260; and lithium nitrate with the amounts in Standard Specification Section 90-1.02. Calcium chloride ($CaCl_2$) accelerators are not allowed since they produce excessive shrinkage and dowel bar corrosion which can cause cracking. Admixtures have limitations, side effects, and compatibility issues that must be anticipated to obtain desirable results and maximize performance when specifying materials to meet project conditions.

Table 120-4 briefly lists some admixture combinations, advantages, and disadvantages:

Table 120–4: Admixture Characteristics

ASTM C494 or C260		Advantages	Disadvantages
Type*	**Description**		
AE	Air Entrainment	• Reduces permeability • Improves durability and chemical resistance in freeze/ thaw climates • Improves mix workability, reduces bleeding and segregation	• Reduces strength depending on air and cementitious content, mix proportions • Effectiveness can be neutralized by other admixes
A	Water-reducing	• At constant water content: increases workability, reduces bleeding (lignosulphonic), facilitates consolidation • At constant penetration: reduces water content and permeability, increasing strength • Reduces need for air entraining admixes	• Hydroxylated types increase bleeding at constant water content • Low to moderate slump mixes may be sticky and difficult to finish • Combined with HRWR, accelerated slump loss and workability may occur
B	Set-retarding	• Delays initial set, extending available concrete placing and finishing time	• Increases bleeding • Delayed setting time may cause an excessive delay in hardening unless dosage is controlled
C	Accelerating	• Decreases time to initial set • Increases initial rate of strength gain	• Excessive dosage may severely reduce initial setting time or cause flash set • Increases drying shrinkage
F	High-Range Water-Reducer (HRWR): superplasticizer	• Reduces permeability, water, cementitious content required • Increases workability, early and long-term strength	• Additional admixture cost • Higher slump • Must coordinate with air entrainment • Varied response to different cements • Mild discoloration, blemishing, and air voids on exposed surfaces
S	Specific performance	• Variable properties such as shrinkage reduction, corrosion inhibition, hydration stabilization, ASR reduction	• Variable interactions with other admixtures

* ASTM C494/494M includes these combinations: Type D – Water-reducing and retarding; Type E – Water-reducing and accelerating; Type G – HRWR and retarding.

For more information about admixes approved for use in concrete, refer to the Chemical Admixtures for Use in Concrete list and prequalification criteria on the METS authorized materials list website: http://www.dot.ca.gov/hq/esc/approved_products_list/.

120.2.2 Roller Compacted Concrete (RCC)

Roller compacted concrete (RCC) is a nonstandard material that is primarily used for pavement shoulder surfaces or as a base material. RCC is made from the same components as conventional concrete, but in different proportions. Increased fine aggregates result in a dry, stiff mix that is extruded from a HMA paver, modified with a tamping screed, and compacted with vibratory steel drum and pneumatic-tired rollers for rapid construction and curing. RCC does not require joints, dowels, tie bars, reinforcement, forms, finishing, or saw cut joints, further reducing concrete materials costs and construction time.

RCC benefits include:

- RCC can be placed in lifts as thick as 10” depending on the mix and equipment used.

- RCC has less cement paste, reducing concrete shrinkage and related distress.
- High flexural, compressive, and shear strengths allow RCC to adequately support repetitive heavy loads.
- RCC has low permeability, increasing concrete durability and resistance to chemical attack and freeze-thaw cycles.

RCC limitations include:

- RCC surfaces tend to have a rough finish and show imperfections from handwork.
- Finished pavement surfaces must be ground to achieve adequate smoothness.
- RCC mixes are dry, increasing admixture demand and decreasing mixing and trucking capacity.
- RCC has low water content and is sensitive to water loss during construction.
- Cold joints can form rapidly if multiple paving passes are required.
- Pavement edges are more difficult to compact.

Figure 120–3: RCC pavement construction (NCPTC, 2010)

For more comprehensive information about RCC, refer to the National Concrete Pavement Technology Center (NCPTC) Guide for Roller-Compacted Concrete Pavements.

120.2.3 Concrete Repair Materials and Specifications

Materials typically used to repair or treat concrete pavements include cementitious repair materials (rapid strength concrete for slab replacements and fast-setting concrete for spall repairs), polymeric repair materials (polyester concrete and high-molecular-weight methacrylate treatment), and joint sealant (asphalt rubber, silicone, and preformed compression seals). Cementitious materials or other materials with high-early strength capabilities can meet virtually any opening time requirement, but rapid strength materials have higher costs, typically require special handling, are more difficult to construct, and are more likely to fail prematurely when not properly constructed. Other materials used for specialized applications include HMA for nonstandard temporary repairs and precast concrete panels for longer-term repairs of high truck traffic and remaining pavement service life segments. HMA tends to deteriorate so it is not suitable for long-term repairs.

- Rapid strength concrete (RSC) material specifications are in 2010 Standard Specification Section 90-3, Section 40-5 for lane replacement, and Section 41-9 for slab replacement.
- Spall repair material specifications are in 2010 Standard Specification Section 41-1. Section 41-4 requires polyester concrete for spall repair, but SSP 41-4 allows use of fast-setting

concrete (magnesium phosphate, modified high-alumina, or portland cement) for pre-overlay repairs or with district maintenance engineer approval.
- Narrow partial-depth surface cracks can be treated with high-molecular-weight methacrylate (HMWM) under 2010 Standard Specification Section 41-3.
- JPCP joints can be sealed with asphalt rubber, silicone, or preformed compression seals specified in 2010 Standard Specification Section 41-5.

Rapid Strength Concrete (RSC)

Rapid strength concrete (RSC) mixtures are selected and designed by the contractor based on a number of considerations, including strength, available mixing, placing, and curing time, prevailing climatic conditions, equipment requirements, cost, and the size and depth of repairs. In addition, material-specific properties, such as strength gain, modulus of elasticity, bond strength, scaling resistance, sulfate resistance, abrasion resistance, shrinkage characteristics, coefficient of thermal expansion, and freeze-thaw durability are also often considered in the selection process. Standard Specification Section 90-3 allows the contractor to select multiple concrete mix types for slab replacement, which typically depend on available curing time and cost:

Table 120–5: Typical Concrete Mix Types

Typical Curing Time (hours)	Concrete Mix Type
2–4	Specialty or proprietary high early strength cement mixes under ASTM C219
4–6	Type III portland cement with non-chloride accelerators and high-range water-reducing admixtures
< 24	Type II portland cement with non-chloride accelerators
≥ 24	Type II portland cement*

*Note: preferred for lower cost and superior performance when strength can be attained before traffic opening.

Although RSC materials can provide effective solutions for early opening to traffic, there are also associated performance concerns. Shrinkage is a crucial property consideration when using portland cement (especially Type III) for rapid construction due to increased cement content and multiple admixtures. High shrinkage values increase slab curl and can cause internal stresses that result in premature cracking. Cement shrinkage is limited by Standard Specification Section 90-1.02A to 0.050% under AASHTO T 160, but RSC mixes have complex interactions that exceed current testing capability. Increasing cement content does not necessarily increase concrete strength and may adversely affect RSC durability, so Standard Specification Section 41-9.01D also contains qualitative criteria limiting premature surface distress and cracking within 1 year of construction.

Polyester Concrete

Polyester concrete is used in concrete pavement applications for spall repair and dowel bar retrofit (DBR). It consists of an unsaturated isophthalic polyester-styrene copolymer resin binder and dry aggregate. A silane coupler is used to increase the resin bonding strength, and a high-molecular-weight methacrylate (HMWM) bonding agent is applied to penetrate microcracks in the substrate surface and increase shear strength at the bond interface.

Despite higher cost, polyester concrete is preferred for generally superior performance over a wider range of conditions when compared to fast-setting concrete materials. Polyester concrete cures rapidly, developing high compressive strength and good concrete adhesion for placement over a wide surface temperature range between 40 and 130 °F. The polyester resin gel time can be adjusted for field conditions.

Minimum polyester concrete material property requirements for viscosity, specific gravity, elongation, tensile strength, styrene content, silane coupler, saturated surface dry bond strength, and static volatile emissions are in 2010 Standard Specification Section 41-1.02C.

Fast-Setting Concrete

Fast-setting concrete is used for some spall repair applications and can be magnesium phosphate, modified high-alumina, or portland cement based concrete based on contractor preference. Selection criteria includes available curing time, climatic conditions, material costs, equipment requirements, working time for mixing and placing, and the size and depth of the repairs.

- *Magnesium phosphate cement* concrete mixtures are characterized by a high early strength, low permeability, and good bonding to clean dry surfaces. Use of epoxy bonding agent may be recommended by some manufacturers, and set time can be retarded to prevent reduced bonding strength. Workability is limited as significant strength reduction can occur from very small amounts of excess water.

- *Modified high-alumina cement* concrete mixtures produce rapid strength gain with good bonding properties to dry or damp surfaces and very low shrinkage. High-alumina cement is modified by adding calcium sulfate to reduce strength loss under high temperatures and moist conditions. Set retarders and accelerators are available from some manufacturers to adjust for variable field conditions.

- *Portland cement* type II or III is typically considered preferable for fast-setting concrete spall repairs. Since tight lane closure restrictions often limit construction and curing time, non-chloride accelerating admixtures that comply with 2010 Standard Specification Section 90-1.02E and ASTM C494/C494M can be used to achieve high early strength and reduce the time to open for traffic. Insufficient curing time, incompatible mixtures, or poor mix proportioning can cause premature deterioration and failure of the repair.

Minimum fast-setting concrete property requirements for compressive strength, flexural strength, bond strength, water absorption, abrasion resistance, drying shrinkage, water soluble sulfates and chlorides, and thermal stability are in 2010 Standard Specification Section 41-1.02B. Notably, a relatively high opening compressive strength of 3000 psi after 3 hours is required. In general, high early strength requirements result in higher cement content and more complex mixtures with greater failure potential. If the available traffic window allows a slower setting mixture, contact the Office of Concrete Pavement in the Headquarters Division of Maintenance Pavement Program or submit a non-standard special provision (nSSP) request to: nssp.submittals@dot.ca.gov.

Other Repair Material Types

There are other nonstandard but cost effective repair material alternatives available such as polyurethane and pozzolanic concrete materials that have performed well in various field maintenance applications. Others, such as gypsum, methacrylate, and epoxy concrete have been evaluated and are not used by the Department due to issues with performance or cost effectiveness. Additional materials, including some proprietary products that are not currently standardized for use on contract projects, could be included in a pre-qualified products list for concrete repair materials if one is developed for future specification updates.

Hot mix asphalt (HMA) materials are sometimes used for temporary partial or full-depth repairs on concrete pavements. HMA is not recommended for extended term repairs of concrete pavements because it can allow horizontal movement of adjacent slabs, provides no load transfer across transverse construction joints, and creates a patchwork of unsightly black and white surfaces. HMA repairs can deteriorate rapidly, so they should only be used:

- As an emergency surface repair for an unsafe functional condition
- As a responsive repair when deteriorated slabs need to be replaced before a project can be programmed or advertised (as determined by the district maintenance). If a project cannot be programmed and advertised within 5 years, concrete should be used to replace the slab, even for responsive repairs.
- When doing slab replacements as part of a project to overlay the concrete pavement.

If there is interest using a specific nonstandard concrete repair material on a project, contact the Office of Concrete Pavement in the Headquarters Division of Maintenance Pavement Program or submit a non-standard special provision (nSSP) request to: nssp.submittals@dot.ca.gov.

High-Molecular-Weight Methacrylate (HMWM) Treatment

Narrow partial-depth surface cracks can be treated with high-molecular-weight methacrylate (HMWM) under 2010 Standard Specification Section 41-3. HMWM consists of compatible resin, promoter, and initiator that penetrates partial depth shrinkage cracks and polymerizes to form a bonded seal, decreasing permeability and preventing moisture infiltration. HMWM is a preventive maintenance treatment suitable for relatively new pavements in very good structural condition.

120.2.4 Joint and Crack Seal Materials

Sealing joints and cracks prevents surface infiltration of water, incompressible materials, and de-icing chemicals that can result in pumping, erosion, faulting, cracking, spalling, and steel corrosion. Joint sealing requirements are in 2010 Standard Specification Section 41-5, but crack sealing is a nonstandard strategy. Joint seal materials can be liquid sealants (asphalt rubber or silicone) or preformed compression seals. Liquid sealants depend on lasting adhesion to the joint face while preformed compression seals need lateral rebound for good long-term performance.

Selecting sealant materials for long-term performance depends on the specific application (joint type, tied or doweled conditions) and climate, but generally joint seals tend to perform according to cost. Preformed compression seals are more expensive but typically longer lasting. They are best suited for sealing new pavement joints on projects with long design lives, but can also be used to replace existing seals if the joint width is consistent and spalls are repaired. Silicone and asphalt rubber liquid sealants can be used for new and replacement joint or crack seals. Asphalt rubber is less expensive but typically does not perform as well over time as silicone or preformed seals.

Refer to Chapter 360 for more detailed joint and crack seal material information.

120.3 OTHER CONSIDERATIONS

Pavement performance can be highly improved through proper design, construction, and maintenance. This section provides information about important pavement project design considerations such as drainage, load transfer, maintainability, constructability, and cost estimating.

120.3.1 Pavement Drainage

Designing, constructing, and maintaining effective surface and subsurface drainage is important to achieving good pavement performance. Saturated pavement structure layers are weaker and prone to damage from heavy vehicle loading. Drainage is highly dependent on project specific conditions including climate, terrain, geology, and surrounding land use. Inspect and consider problem areas associated with inadequate drainage, potentially including areas where:

- Surface water infiltrates the concrete pavement structure from cracks, joints, and side seepage. Depending on geometric grades, cut sections can be particularly susceptible to infiltration at the pavement edges, resulting in a bathtub effect.
- Subsurface water from high groundwater or natural springs saturates and weakens underlying layers.
- Agricultural plough furrows run perpendicular or towards the roadbed.

Edge drains, treated permeable base, geotextile fabrics, and waterproof membranes can be effective subsurface drainage components with proper design, construction, and maintenance.

Consider the condition of existing surface and visible subsurface drainage system components including drainage inlets, edge drains, side drains, and culverts. Drainage systems that are blocked by erosion, deicing, snow removal, or agricultural grading activity may require cleaning or repair. If side ditches and culverts are clogged or used for agricultural irrigation, or edge drains are malfunctioning, the pavement structure may be consistently saturated, weakening underlying layers. Cracks and joints should be sealed or resealed to prevent moisture infiltration.

If subsurface drainage is an issue, existing pavement sections can be retrofitted with edge drains near the edge of traveled way. Treated permeable base material for edge drains should be CTPB, which will require an nSSP for Section 68-4.02C of the 2010 Standard Specifications. For pavement structure widening adjacent to existing treated permeable base layers, new designs should use CTPB instead of ATPB, which tends to strip and lose stability, jeopardizing long-term pavement performance.

If CTPB is used in the design, coordinate with district maintenance make sure that edge drains and other drainage systems can be maintained by field crews. The estimated drainage maintenance costs should be included in the project development report separate from the construction cost estimate so district maintenance can pursue the resources and equipment needed to maintain pavement drainage systems. If drainage systems will not be maintained, an alternative to TPB should be found to prevent pavement structure damage.

Existing edge drains can conflict with outside slab and lane replacement strategies (see Ch. 400). When the existing JPCP slab is removed, the treated permeable base material and adjacent slotted edge drain pipe must also be removed. PVC pipe with no slots is spliced in to reconnect the edge drain system. During construction, care must be taken to prevent clogging existing edge drain systems.

Refer to HDM Chapter 650 for more information about pavement drainage and HDM Chapter 840 for subsurface drainage. Standard plans D99A-D contain pavement structure drainage system details.

120.3.2 Load Transfer

Load transfer is the ability of a joint or crack to transfer a portion of an applied traffic load from one side to the other. Ideally, load transfer is achieved by 3 mechanisms:

1. Mechanical load transfer devices such as dowel bars
2. Aggregate interlock across abutting edges of concrete
3. Friction between the concrete pavement surface and base

Dowel Bars

Dowels are smooth, round, steel bars that allow load transfer across transverse joints. Dowels restrict vertical slab movement while allowing horizontal expansion and contraction from thermal stresses (see Figure 120-4). Dowel bars decrease vertical deflection and improve ride quality by reducing pumping, faulting, excessive slab curling, and corner breaks.

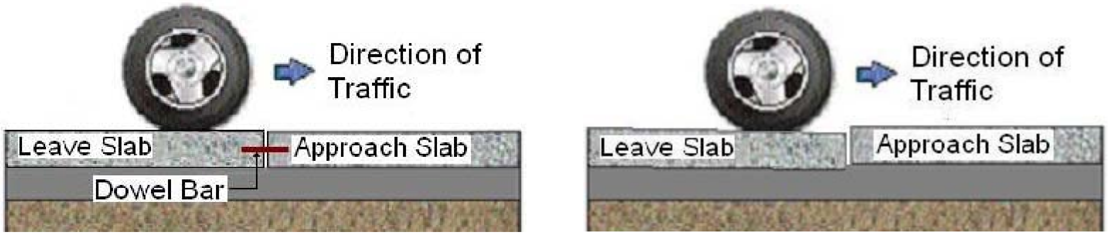

Figure 120–4: Vertical slab movement with and without dowel bars

Dowel bars are standard for most new JPCP lane designs and optional for slab replacements, but most existing concrete pavement was constructed without dowels. Dowel bar retrofit (see Ch. 330) is a CAPM preservation strategy that restores load transfer efficiency in existing transverse joints and cracks. Three dowel bars are placed in each wheel path. For individual slab replacement, 4 dowel bars are placed in each wheel path at construction joints (see Ch. 320 and Revised Standard Plan RSP P8). Dowel bars in new JPCP (see Ch. 210) are placed on center at 1' intervals along the transverse joint, with a 6" offset at longitudinal joints (see Figure 120-5 and Revised Standard Plan RSP P10).

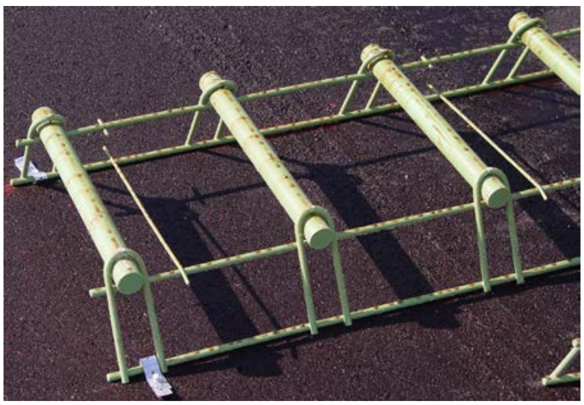

Figure 120–5: Dowel bars

Aggregate Interlock

Aggregate interlock is the connection between aggregate particles across opposing crack faces. In a JPCP joint, the interlocking crack occurs beneath the sawn joint reservoir (see Figure 120-6). For non-doweled JPCP, aggregate interlock provides most of the load transfer. As the pavement ages, interlocking faces can wear and load transfer efficiency drops.

Figure 120–6: Aggregate interlock at a transverse joint

120.3.3 Maintainability

Maintenance of roadway features is an important but often overlooked design consideration since it is outside the project delivery process. Providing safe worker access and the ability to maintain features like drainage systems ensures the opportunity for long lasting pavement performance. Engineering decisions such as choosing pavement strategies and materials can prominently affect future maintenance demand.

Minimizing initial project costs for immediate budget concerns can be a short-sighted philosophy that inefficiently increases the number and cost of future projects and maintenance activities. Section 2.7 of the LCCA Procedures Manual has some schedule information for predicting the sequence and timing of future activities that may be required to maintain and rehabilitate some pavement strategies. LCCA attempts to quantify some potential consequences with cost estimates, but it is not absolute. Many detailed project decisions are more nuanced than current evaluation procedures, so not all pavement engineering issues are included in LCCA. For example, not identifying all the necessary pavement structure repairs, choosing a thinner or narrower pavement structure, faster-setting concrete mixture, cheaper joint seal material, or flexible shoulder could jeopardize anticipated pavement performance with a shorter service life, require more frequent maintenance activity, or prematurely trigger a project.

Local maintenance personnel have valuable experience with problematic project areas, conditions, and potential engineering solutions. The district maintenance engineer and area maintenance superintendent should be involved early and throughout the project development process to make suggestions on the maintainability of project features and assist the project development team in identifying existing features for upgrading or rehabilitation.

120.3.4 Constructability

The project development team should review project plans and relevant field condition data at the 30%, 60%, and 95% design completion milestones. The review should focus on high priority constructability issues such as fatal flaws, determining the feasibility of constructing project features with minimal field revisions, and sharing experience and lessons learned among functional units. Additional constructability considerations essential for pavement performance including work sequencing, stage construction, and traffic handling should also be analyzed and discussed with district construction personnel.

Order of Work

The sequence of work is very important for the quality and workmanship of comprehensive projects using various combinations of pavement strategies. The project special provisions should specify the following order of work requirements for applicable operations:

1. Slab subsealing or jacking should be done initially to provide a stable construction platform and allow any accidental spalling to be readily repaired.
2. Spall repairs should be done before or concurrently with isolated slab replacement and dowel bar retrofit.
3. Mill or replace AC shoulders after isolated slab replacement.
4. Diamond grinding should follow subsealing, jacking, spall repair, isolated slab replacement, and dowel bar retrofit in a lane.
5. Prior to widening or lane replacement:
    a. Complete all repair work in the adjacent lane.
    b. Grind the entire adjacent lane width to establish a smooth profile for concrete paving equipment.
    c. Saw cut up to 2” of the existing adjacent slab width along the longitudinal joint to remove distress.

   d. Construct isolation joints between new and existing pavement.
6. Groove after diamond grinding
7. Joint sealing or joint seal replacement should be completed as needed following other work.

Stage Construction

Stage construction for new and reconstructed concrete pavement should be designed to maximize the paving area and construction time, minimize the number of stages required to construct the project, and provide at least 2' of trackline width for paving adjacent to vertical obstructions. Accommodating larger, heavier paving machines and limiting the number of equipment setups reduces the number of construction joints, increases production efficiency, and improves concrete surface quality. At a minimum, construction staging should ensure each lane is paved in a single pour to the full design width.

Most concrete pavement preservation and CAPM work is not constructed in stages but requires complex logistical coordination of multiple, labor intensive operations during short temporary traffic lane closures. Construction windows must be long enough to accommodate the number of work operations, time to construct a segment, and material curing time required to attain minimum material strength.

Traffic Handling and Safety

District traffic management personnel typically determine construction zone lane availability requirements for a route segment based on time of the year, day of the week, current hourly traffic volumes, type of construction work, and estimates of reduced work zone capacity. Coordinating with district traffic personnel to provide the maximum construction window is important to reduce the number of working days and construction cost while improving productivity, workmanship, concrete durability, quality, and pavement performance. Longer performing repairs reduce future maintenance and construction activities, increasing safety and life-cycle cost effectiveness.

Alternative construction closures and potential work zone traffic impacts can be analyzed using the CA4PRS software program, which was developed by the Department and FHWA to help districts select effective and economical pavement and traffic control strategies. The software uses alternative strategies for pavement designs, lane-closure tactics, and contractor logistics to estimate the total number of closures during project construction and quantify the impact to the traveling public in terms of user cost and queue time. CA4PRS is beneficial during project development to analyze alternatives for balancing production schedule, traffic delay, and budget affordability.

The CA4PRS software and more information are accessible through the Division of Research and Innovation website at http://www.dot.ca.gov/research/roadway/ca4prs/index.htm. Concrete pavement strategy production rates calculated from CA4PRS considering multiple variables are available in Table 3-6 of the LCCA Procedures Manual.

Considering the project location and scope of construction work, multiple traffic control alternatives are available for CA4PRS analysis and discussion with district traffic management personnel:

- Detours: If construction work includes roadway widening or reconstruction, consider designing the area to facilitate a traffic detour for construction staging. If alternative routes are available, maximum productivity, quality, and economy result when the roadway can be completely closed during the entire construction period.
- Continuous closure: Complete closure of single or multiple lanes for an extended time period is preferred for lengthy rehabilitation and reconstruction projects. Medians and temporarily

narrowed lanes can be used to minimize lane closures. Where medians are repaved, they should be designed to handle the construction period traffic. In addition, sufficient space has to be provided in the construction zone for clearance between the temporary concrete barrier and the trafficked lane (see *California MUTCD*, Part 6, Temporary Traffic Control). For JPCP, a minimum clearance of 2' should be provided between the temporary barrier and the lane to be replaced. For continuously reinforced concrete pavement (CRCP), a minimum clearance of 12' should be provided between the concrete barrier and the lane to be replaced to provide access for concrete material transfer.

- Weekend closure: Extended weekend closures up to 55 hours should be considered wherever possible to extend available construction working time and avoid peak demand during weekly commute hours. Even high-traffic volume roadways often have reduced weekend demand that can facilitate partial closures of inner or outer lanes. Full directional closures can be feasible if detours are available.
- Weekday closure: Extended weekday closures from Monday through Friday morning can be viable on rural routes with higher weekend traffic due to recreational demand.
- Day closure: In locations with directional commutes, it may be feasible to close a lane at the end of the commute period on one day until it begins the following day, providing up to an 18-hour construction window.
- Night closure: When none of the above options are possible, a temporary closure at night may be necessary for construction work, particularly on inner lanes where multiple lanes must be closed simultaneously. Although concrete work can be done in lane closure windows as small as 5 hours, longer windows of at least 8 to 12 hours will provide contractors more time to mobilize, work, and cure concrete, increasing performance and lowering bid costs. Night closures are the least desirable traffic handling alternative due to extended traffic impacts and adverse effects on construction quality, workmanship, and production rates.

Extended closures can have a greater potential impact on local businesses, so the project manager should coordinate with local agencies, commerce associations, and Department public affairs personnel during project design and construction to minimize impacts and inform the traveling public.

Adequate traffic control must be provided and maintained during field construction work for safety of the traveling public and construction personnel. Preservation and CAPM projects typically use temporary traffic control features such as changeable message signs, directional arrows, cones, drums, channelizers, portable delineators, and barricades. For construction on conventional highways, flagging or pilot cars are sometimes necessary to direct traffic flow. Major roadway rehabilitation or reconstruction projects typically require more working days and staged construction using extended temporary traffic control measures such as construction area signs, temporary realignment or detours, restriping, and K-rail or movable barriers to protect the work area. Standard Specification requirements for temporary traffic control are in Section 12 and more guidance is available from:

- Traffic Manual – http://www.dot.ca.gov/hq/traffops/engineering/control-devices/trafficmanual-current.htm
- California Manual on Uniform Traffic Control Devices (CAMUTCD) – http://www.dot.ca.gov/hq/traffops/engineering/mutcd/index.htm
- Code of Safe Practices – http://www.dot.ca.gov/hq/construc/flagging/2010_Code_of_Safe_Practices.pdf
- Temporary traffic control Standard Plans – http://dot.ca.gov/hq/esc/oe/project_plans/HTM/stdplns-US-customary-units-new10.htm#temporary

120.3.5 Cost Estimating

It is critical to make a reasonable estimate in the Project Report (PR) or Project Scope Summary Report (PSSR) when programming project funding for pavement work. Estimates should be based on identified locations and work boundaries but reasonably conservative to avoid underestimation. Estimates for some work such as pre-overlay repairs, spall repair, and individual slab and base replacement must anticipate invisible deterioration below the pavement surface and additional deterioration prior to construction.

For the engineer's estimate at PS&E, any previous quantity estimates should be updated to reflect existing distress levels. Quantities should be based on current pavement condition data from the pavement management system and verified with a field review as close to P&E as possible. The updated estimate should also account for future deterioration likely to occur prior to scheduled project construction, which can be predicted using deterioration rates established from historical pavement condition data or percentage rates based on engineering judgment and consultation with area maintenance personnel.

Initial costs can be estimated using historical contract cost data for all contracted bid items and other information available on the Division of Design cost estimating website at http://www.dot.ca.gov/hq/oppd/costest/costest.htm. If historical cost data for a material is limited or not reasonable for the project conditions, adjust the unit cost estimate for differences in available data.

When estimating costs for some pavement work such as new concrete pavement, spall repair, and individual slab replacement, bid items for associated work such as replacing base or sealing joints must also be included. Use the appropriate bid items for the specific type of work and materials. For more detailed information on joint sealing, refer to Chapter 360.

Accurate quantity estimates should be within 75 to 125% of the actual construction work performed. Some quantities for work such as spall repair and slab or base replacement will fluctuate during construction because field conditions change and the resident engineer determines the actual repair limits or locations.

Typical item codes and more detailed cost estimating information for concrete pavement work are provided in the individual chapters of this guide. Current contract standards including plans, specifications, and bid items are on the Division of Engineering Services Office Engineer website at http://www.dot.ca.gov/hq/esc/oe/construction_standards.html.

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CONCRETE PAVEMENT GUIDE

PART 2 NEW CONSTRUCTION

CHAPTER 200 – CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (CRCP)

Chapter 200 provides specific information about designing continuously reinforced concrete pavement (CRCP). Refer to Chapter 120 for general information about concrete pavement structure design and HDM Chapters 600 – 670 for pavement design methodology and standards.

200.1 PURPOSE AND DESCRIPTION

Continuously reinforced concrete pavement (CRCP) is concrete pavement with steel reinforcing bars with no transverse joints. CRCP is reinforced in the longitudinal direction with additional transverse bars used to support the longitudinal bars (see Figure 200-1). The longitudinal bars are lap spliced (see Section 200.2.2) to maintain continuity, ensuring continuous reinforcement.

CRCP develops transverse cracks that are spaced at random intervals due to:

1. Internal forces caused by the shrinkage of concrete
2. Expansion and contraction due to temperature changes
3. Concrete volume change resulting from moisture variation

Transverse cracks are restrained by continuous longitudinal bars that keep the transverse cracks tightly closed and minimize water penetration. Crack width can affect the corrosion rate of the reinforcing bars at the crack locations where water or deicing salts penetrate the cracks.

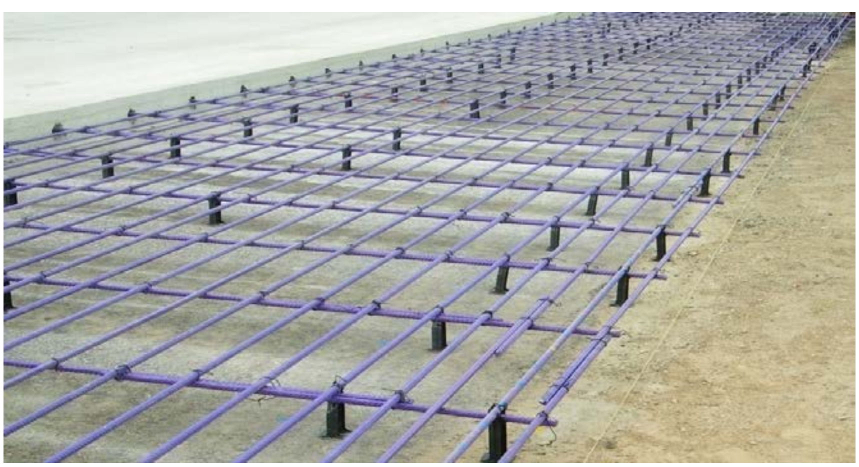


Figure 200–1: Epoxy coated CRCP reinforcement

The optimum amount of longitudinal bars, as detailed in the standard plans, is determined such that it satisfies all of the following three limiting criteria:

- Crack spacing: to minimize the potential of concrete punchouts and spalling, the spacing between consecutive cracks must be limited between 3' (to limit punchouts) and 7' (to limit spalling).
- Crack width: to minimize spalling, water infiltration, and load transfer the allowable crack width should not exceed 0.04".
- Steel stress: to prevent steel yielding and excessive permanent deformation, the tensile stress in steel is limited to ≤ 75% of its ultimate tensile strength.

200.1.1 Benefits

CRCP has a number of benefits, including:

- Minimal maintenance is required, reducing future maintenance costs, traffic closures, and worker safety risks compared to other pavement types.
- Tighter transverse cracks and fewer joints result in smoother pavement and reduce water penetration and potential base damage.
- Lower life cycle costs despite higher initial cost.
- Ability to handle heavier truck loading and volumes.

CRCP can provide a durable highway that can withstand high traffic and truck volumes for 40 years or more. Where cost effective, CRCP is the preferred type of concrete pavement. Life-cycle cost analysis (LCCA) is the most effective methodology to help make the determination. More information is available from the Division of Maintenance Pavement Program website at:
http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html.

200.1.2 Limitations

Situations where CRCP may not be desirable include:

- For conventional highways, local roads, and areas with underground utilities. Accessing utilities for maintenance can damage CRCP and result in costly repairs.
- For parking areas or where the traffic index (TI) ≤ 11.5. CRCP is expensive to build for lightly trafficked locations.

200.2 MATERIALS

200.2.1 Concrete

Concrete consists of a combination of cementitious materials, coarse and fine-graded aggregate, water, and typically some property modifying admixtures. Concrete properties such as strength, durability, permeability, and abrasive wear resistance are materials dependent. Concrete properties such as strength, durability, permeability, and abrasive wear resistance are materials dependent. CRCP should be designed using the highest quality concrete materials to maximize long-term durability. Use of rapid strength concrete (RSC) is not recommended.

Section 90 of the Standard Specifications defines the required chemical and physical concrete material properties for contractor developed mix designs, with some additional requirements for concrete pavement in Section 40. For more comprehensive information about concrete materials, refer to Chapter 120 and the Division of Engineering Services Concrete Technology Manual.

200.2.2 Bar Reinforcement

CRCP contains both longitudinal and transverse reinforcement bars. Steel reinforcing bar requirements are in Section 52 of the 2010 Standard Specifications. Because bar reinforcement is deformed, slippage is minimized and bonding with the concrete is increased. As a result, contraction and expansion movements are minimized. Epoxy coated bar reinforcement is required within half a mile of a salt water body and in high desert and all mountain climate regions to mitigate corrosion (see Figure 200-1). The climate map is available on the Headquarters Division of Maintenance Pavement Program website at: http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/Climate.html.

Longitudinal Bars

Longitudinal bars strengthen the pavement, provide the desired transverse crack spacing, and keep transverse cracks tightly closed. Narrow cracks maintain aggregate interlock, providing a high level of load transfer between the fractured concrete surfaces and reducing pavement flexural stress due to traffic loading. Tight cracks also reduce water infiltration and intrusion of incompressible material.

The cross-sectional area ratio of steel to concrete should between 0.55 to 0.70% for longitudinal bars. Longitudinal reinforcement used for CRCP consists of Grade 60, No. 6 steel bars spaced from 5.5 to 8.0" center-on-center. The first bar is placed 3 to 4" from the joint or edge of pavement. The longitudinal bar depth is 4" minimum clearance from the concrete surface to the top of the bars. For CRCP thicknesses > 0.95', 5" minimum cover is required so the transverse bars clear the sawcut at longitudinal joints (see Revised Standard Plan RSP P4).

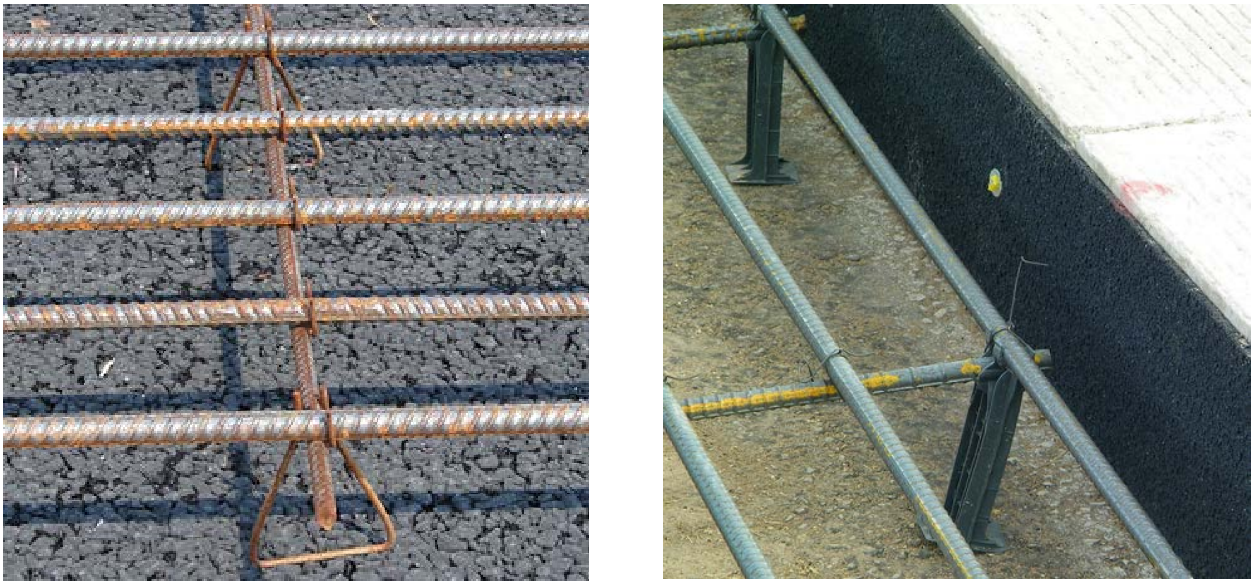
Maintaining steel continuity by overlap splicing each steel bar in the longitudinal direction ensures good CRCP performance. The staggered splice pattern shown schematically in Figure 200-2 is recommended for lap splicing longitudinal bars. Requirements for reinforcement splicing are in Standard Specification Section 52-6.03B. Additional longitudinal bars are placed at transverse construction joints to ensure sufficient reinforcement at points of discontinuity (see Section 200.3 and Revised Standard Plan RSP P31A for other types of CRCP joints).

Figure 200–2: Staggered lap splices

Transverse Bars

Transverse bars are used across the entire width of CRCP lanes primarily to support the longitudinal bars during construction and to hold random longitudinal cracks tightly closed to mitigate the potential risk of punch outs. Longitudinal cracks occur approximately parallel to the roadway centerline. Since transverse bars are used across the entire width of CRCP, intermediate transverse bars are also used to tie adjacent lanes together across longitudinal contraction joints (see below and Section 200.3.3).

Transverse bars are usually Grade 60, No. 6, deformed steel bars spaced at 48” center-on-center and placed on either steel or plastic support chairs (see Figure 200-3).



a) Steel chairs b) Plastic chairs

Figure 200–3: Reinforcement support chairs

<u>Tie Bars and Intermediate Transverse Bars</u>

Tie bars and intermediate transverse bars hold the faces of abutting concrete in contact and maintain adequate load transfer efficiency. Tie bars are deformed, 50” long, epoxy-coated, Grade 60, No. 6, steel bars placed in the same plane as transverse reinforcement, perpendicular to the longitudinal construction joint or between a lane and shoulder. Tie bar spacing is 24” where placed midway between or on adjacent transverse bars.

Tie bars are commonly placed with a mechanical splice coupler shown in Revised Standard Plan RSP P16 because bending and straightening tie bars after concrete placement is not allowed because of potential damage to the epoxy coating and the surrounding concrete.

Intermediate transverse bars tie the adjacent slabs together. They are deformed, 50” long, epoxy-coated, Grade 60, No. 6 steel bars placed at 48” spacing in the same plane as transverse reinforcement.

200.3 Joints

CRCP joints include transverse construction joints, longitudinal construction joints, longitudinal contraction joints, expansion joints, and terminal joints. Expansion and terminal joints are discussed with pavement transitions and end anchors in Section 200.4.

CRCP does not contain transverse contraction joints like JPCP and transverse cracks and construction joints should not be sealed. Longitudinal contraction and construction joints should not be sealed except in desert and mountain climate regions (see HDM Index 622.5).

200.3.1 Transverse Construction Joints

A transverse construction joint is placed to maintain longitudinal reinforcement continuity and avoid a cold joint when concrete is placed at different times, such as when paving is interrupted at the end of a work shift or for more than 30 minutes. Additional 50" long longitudinal reinforcement is placed in the transverse construction joint in the same plane at every other longitudinal bar to provide increased shear stress and load transfer at the joint. To eliminate extra joints, transverse construction joints should be planned to coincide with terminal joints wherever possible (see Section 200.4.1 for terminal joint information). Transverse construction joints are not sealed.

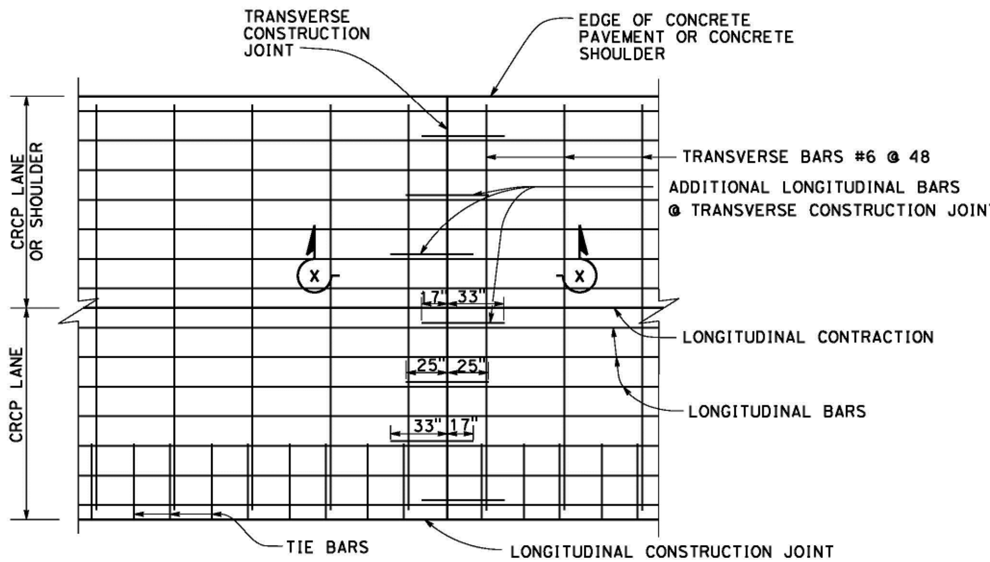


Figure 200–4: Transverse construction joint

200.3.2 Longitudinal Construction Joints

Longitudinal construction joints occur between separately placed adjoining lanes. Tie bars are used to hold the adjoining faces of concrete (see Figure 200-5 and Section 200.2.2). Longitudinal construction joints should not be sealed except in desert and mountain climate regions.

Figure 200–5: Longitudinal construction joint

200.3.3 Longitudinal Contraction Joints

Longitudinal contraction joints are necessary to control cracking in the longitudinal direction due to warping, expansion, and shrinkage stresses caused by temperature variations (Figure 200-6). Longitudinal joints are typically placed between 12' lanes or between the lane and shoulder (see Revised Standard Plan RSP P16). Where there are no lanes, longitudinal joints should be spaced at 12' intervals and no more than 14' apart. When widened lanes are used, longitudinal joints are omitted at the edge of traveled way. Longitudinal joints are held together by intermediate transverse bars and should be saw cut to a depth that would allow at least ½" clearance to any dowel bars, tie bars, or bar reinforcement (see Section 200.2.2). Longitudinal contraction joints should not be sealed except in desert and mountain climate regions.

Figure 200–6: Longitudinal contraction joints

200.4 TERMINAL JOINTS, PAVEMENT TRANSITIONS, & END ANCHORS

Where CRCP terminates at a different pavement type or structures approach slab, a pavement transition, terminal joint, or anchor must be provided at the end of the CRCP section to:

1. Isolate adjacent pavement of different types or structures approach slab.
2. Anchor CRCP so that excessive horizontal movement does not occur.
3. Accommodate horizontal movement that would otherwise damage CRCP and the adjacent pavement or structure approach slab.

Regardless of the CRCP length, the central portion of CRCP remains fully restrained by the underlying base so no movement or change in length will be experienced except for the last 200 to 300' at the end of pavement.

Terminal joints, expansion joints, wide flange beam terminal, and pavement end anchors are described in the following sections. Criteria for where to use the various types of transition joints are identified in Table 200-1:

Table 200–1: Transition Joint Applications

Transition Type	Location	Notes	CRCP Length (ft)		
			< 1,200	1,200 - 2,000	> 2,000
Terminal Joint	At each end of a CRCP segment		Yes	Yes	Yes
Type A	CRCP/ existing AC transitions	Used independently			
Type B	CRCP terminus/ future pavement	Used independently			
Type C	CRCP terminus/ temporary HMA	Used independently			
Type D	CRCP/ existing JPCP or approach slab transitions	Use with expansion joint, pavement end anchor, or wide flange beam terminal			
Type E	CRCP/ new JPCP or approach slab transitions	Use with expansion joint, pavement anchor or wide flange beam terminal			
Expansion Joint	CRCP to bridge, approach slab, or pavement transitions		Yes[1]	Yes	No
Pavement End Anchor (grade ≥ 3%)	CRCP/ concrete pavement or approach slab transitions	Use with expansion joint	No	Yes[2]	Yes[2]
Wide Flange Beam Terminal Joint (grade < 3%)	CRCP/ bridge, approach slab, or pavement transitions	Use with expansion joint	No	Yes[3]	Yes[3]

[1]When CRCP is ≤ 500’, provide only 1 side.
[2]Use pavement end anchor for profile grades > 3%. Provide 1 anchor lug per 1 % profile grade (5 maximum).
[3]Do not use wide flange beam terminal joints on profile grades > 3%.

200.4.1 Terminal Joints

Terminal joints are provided at transverse joints and at the beginning and end of CRCP segments. They are used to minimize deterioration where CRCP abuts flexible pavement and to minimize faulting where CRCP abuts another type of concrete pavement. The various terminal joint types are shown in Revised Standard Plan RSP P31A and briefly discussed below.

Terminal Joint Type (A)
Use Type A terminal joints where new CRCP transitions to existing AC pavement. Type A terminal joints consist of 2 contraction joints at 10 and 15’ from the CRCP terminus at the existing AC pavement. Dowel bars are not used.

Terminal Joint Type (B)
Use Type B terminal joints where newly constructed CRCP terminates and pavement will be constructed in the future. CRCP at the terminus will be supported by the reinforced concrete slab and backfilled with material that can be removed when the new pavement will be constructed.

Terminal Joint Type (C)
Use Type C terminal joints where newly constructed CRCP terminates and temporary HMA pavement will be constructed. CRCP at the terminus will be supported by the reinforced concrete slab. Type C terminal joints are mostly used in construction where temporary traffic for staging is required.

Terminal Joint Type (D)
Use Type D terminal joints where new CRCP is constructed next to existing JPCP or a structure approach slab. Type D terminal joints consist of a transverse construction joint with dowel bars drill and bonded to existing concrete.

Terminal Joint Type (E)
Use Type E terminal joints where new CRCP is constructed next to new JPCP or a structure approach slab. Type E terminal joints consist of a transverse construction joint with dowel bars placed at the joint of CRCP and the new concrete.

200.4.2 Expansion Joints

An expansion joint is provided to accommodate large expansion of pavement exceeding ½" in conjunction with wide flange beam terminal joints or pavement end anchors. Expansion joints are typically used where CRCP abuts up to bridges, structure approach slabs, or other types of concrete pavement (see Figure 200-6). Expansion joints are not used at pavement transitions between flexible and concrete pavement (see Section 200.4.5 and Revised Standard Plan RSP P30).

Where an expansion joint is used, a support slab beneath the joint is constructed to provide a bearing surface to support the free edges of abutting concrete pavement. Expanded polystyrene ¼ to ½" thick is placed over the support slab to prevent bonding and allow the pavement to easily expand and contract. The expansion joint should be doweled and sealed using a Type B seal with a movement rating ≤ 2" as shown on Standard Plan B6-21.

Figure 200–7: Expansion joint

200.4.3 Wide Flange Beam Terminal Joints

A wide flange beam terminal system is used to accommodate movement at the joint between the abutting end of a CRCP on one side and end of a bridge, approach slab, or another concrete pavement on the other side (see Figure 200-7). The wide flange beam size is dependent on pavement thickness. Within the limits of wide flange pavement terminal installation, the subgrade should be prepared and compacted in the same manner as the rest of the roadbed before additional pavement structure layers are placed on top of the subgrade. For expansive subgrade, reference HDM Index 614.4.

The wide flange beam is set partially into a 10' long, 12" thick support slab to provide end support for the CRCP on each side of the wide flange beam. In order to achieve long-term performance without significant repairs, wide flange beam designs should consider:

- Expansion joints at the bridge approach slabs or between the wide flange beam and pavement end transition to allow pavement end movements.
- Load transfer across the joint.
- Corrosion resistance. Wide flange beam terminal joints should not be used in high mountain or high desert climate regions due to corrosion from deicing salts. If wide flange beams are placed near salt water, galvanized and epoxy coated flange beams are corrosion resistant alternatives.
- Fatigue loading under heavy truck traffic. Using a thicker or wider flange can also provide for improved fatigue resistance.
- Rigid connection to bridge-side pavement. Wide flange beams can fail when the top flange separates from the beam web. Eight-inch long studs ¾" in diameter can be welded to the web and flange bottom, spaced alternately at 9" and anchored to the end of concrete pavement on the bridge side of the joint to maintain rigid connectivity and prevent failure. Maintaining the rigid connection can help maintain profile and cross slope at the joints over the service life.
- Future grinding. Wide flange beam terminal joints should not be used where a ½" or more of grinding is expected during the CRCP service life.

The project plans should show the wide flange terminal joint location by station on the layout and quantity sheets. In conjunction with wide flange beam terminal joints, an expansion joint is provided to accommodate large pavement expansion exceeding ½" (see Section 200.4.2). Refer to Revised Standard Plans [RSP P32A](), [RSP P32B](), and Figure 200-8.

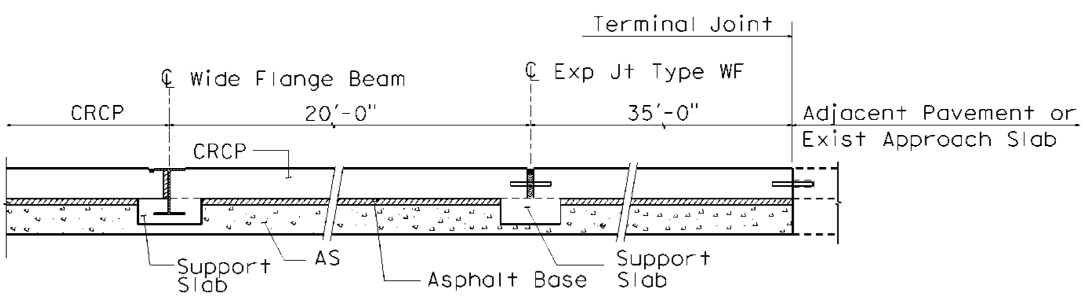


Figure 200–8: Wide flange beam terminal joint

200.4.4 Pavement End Anchors

Pavement end anchors restrain movement using a series of concrete lugs placed underneath the pavement that anchor to well-compacted subgrade (see Figure 200-9 and Revised Standard Plan RSP P31B). Pavement end anchors are used in combination with Type AN expansion joints to restrain CRCP movement at transitions with another type of concrete pavement or structure approach slab. Forms should not be used to construct the lugs.

Type III expansive subgrade with a plasticity index (PI) ≥ 12 or low stiffness may not be effective for end anchors, but a wide flange beam terminal joint may be considered as an alternative (see Section 200.4.3).

The project plans should show the pavement end anchor location by station on the layout and quantity sheets.

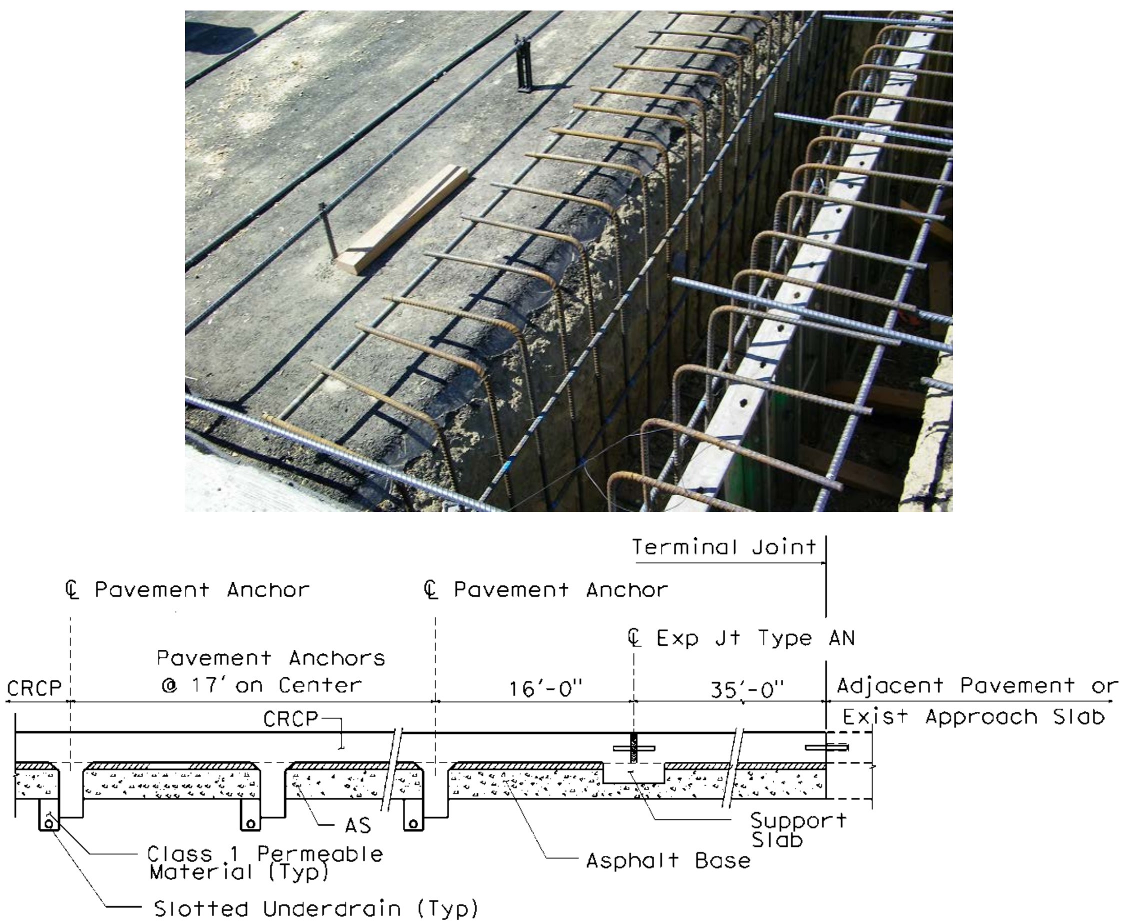


Figure 200–9: Pavement end anchor

200.4.5 Pavement End Transitions

Pavement end transitions are made up of different pavement materials constructed within the same lane. The pavement transitions can be CRCP abutting an approach slab or flexible pavement. For CRCP transitioning to existing AC or new HMA pavement, a doweled, reinforced concrete panel is recommended as an alternative to a Type A terminal joint at the transition to reduce damage from impact loading. An expansion joint is not required (see Revised Standard Plan RSP P30).

200.5 Design

200.5.1 Performance

CRCP should be engineered for a 40-year design life. HDM Topic 612 defines pavement design life as the optimum number of years that CRCP should be expected to perform before reaching its terminal serviceability or a condition that requires major rehabilitation.

CRCP is designed to have no more than 10 punchouts/ mile at the end of its design life (see Figure 200-10 and HDM Topic 622). This performance criterion differs from JPCP, which is primarily based on cracking and joint faulting.

Figure 200–10: Typical edge punchout

200.5.2 Pavement Structure Layers

The general engineering procedures for new CRCP construction, reconstruction, and widening are discussed in Chapter 120 and HDM Topic 623. Minimum design thicknesses for CRCP pavement structure layers are selected based on the subgrade type, climate region, and TI using HDM Tables 623.1B through M. CRCP is constructed using HMA Type A base, with Class 2 aggregate subbase added on Type II subgrade.

200.5.3 Shoulders

A tied CRCP shoulder or widened traffic lane with HMA or JPCP shoulders and no tie bars can be used adjacent to CRCP traffic lanes. Drainage inlets placed in the shoulder area should be called out by type and follow the applicable details shown on Revised Standard Plans RSP P45 and RSP P46.

Tied CRCP Shoulders

Tied CRCP shoulders are constructed monolithically with the CRCP mainline using no longitudinal construction joints. Longitudinal and transverse bars are extended through the shoulder area (see Revised Standard Plan RSP P4). The shoulder cross slope should match the lane cross slope and may require a design exception. The pavement structure design for the tied concrete shoulder should match the adjacent traffic lane.

Tied concrete shoulders are the most adaptable and preferred type when future widening is anticipated within the pavement design life, or when the shoulder will be used temporarily for stage construction or as a bus or truck lane. When tied concrete shoulders are expected to be converted into a future traffic lane, they should be built to the same geometrics and pavement structure standards as the CRCP traffic lane.

Widened Lanes
CRCP widened lanes are 14' wide with either JPCP panels or HMA shoulders (see Figure 200-11 and Revised Standard Plan RSP P5A). The edge of traveled way is striped for a 12' lane width, so the additional 2' width becomes part of the shoulder and keeps the wheel path away from the edge of pavement. This reduces critical edge stresses from heavy vehicle loading. During future maintenance or construction operations, the wider shoulders can be used to detour traffic.

HMA or JPCP shoulders may be placed adjacent to the widened lane. JPCP used in a shoulder application is constructed without tie bars. The design standards for lane and shoulder addition with widened lane are provided in Revised Standard Plan RSP P5B.

Figure 200–11: Widened CRCP lane with HMA shoulder

200.5.4 Temporary CRCP Gaps During Construction

Temporary CRCP gaps are sometimes necessary to allow for construction cross traffic so the contractor can move equipment from one side of the mainline to the other for paving. The gap is a planned opening in mainline paving located where cross traffic operation is anticipated. A minimum 1,000' opening is necessary to allow enough room for equipment maneuverability. If the mainline opening is paved, transverse construction joints are formed on both ends and longitudinal reinforcement continuity must be maintained for load transfer. Both sides of the construction joints must follow lap staggering and joint construction procedures. An expansion joint is necessary on one side of the construction joint to provide for expansion of the hardened concrete to prevent damaging the adjacent fresh concrete.

200.5.5 Standard Plans

Table 200-2 lists Standard Plans for use with CRCP available on the Caltrans internet website at http://www.dot.ca.gov/hq/esc/oe/project_plans/HTM/stdplns-US-customary-units-new10.htm#pavement. Contact the Headquarters Division of Maintenance Pavement Program, Office of Concrete Pavement and Pavement Foundations for more detailed information about these plans.

Table 200–2: CRCP Related Standard Plans

Plan Sheet	Title	Comments
P4	Continuously Reinforced Concrete Pavement	For new CRCP construction, reconstruction, widening, and lane replacement at standard lane width.
P5A	Continuously Reinforced Concrete Pavement (Widened Lane)	For 14’ wide concrete panels to reduce punchouts where edge loading is increased from high truck traffic volumes. Consider a rumble strip.
P5B	Continuously Reinforced Concrete Pavement (Widened Lane) –Lane and Shoulder Addition or Replacement	For widening an existing roadway using 14’ wide concrete panels to reduce punchouts where edge loading is increased from high truck traffic volumes. Consider a rumble strip.
P10	Concrete Pavement – Dowel Bar Details	Use where concrete pavement transition panel is placed between CRCP and existing HMA.
P13	Continuously Reinforced Concrete Pavement Single Piece Transverse Bar Assembly	Details for longitudinal bar support used for new construction, reconstruction, widening, and lane replacement in lieu of using plastic chairs for longitudinal bar support.
P14	Continuously Reinforced Concrete Pavement Transverse Construction Joint	Details for longitudinal bar continuity including additional longitudinal bar spacing and staggered placement.
P16	Continuously Reinforced Concrete Pavement Tie Bars and Joint Details	Use in conjunction with RSP P4 for new construction, reconstruction, widening, and lane replacement in curved lanes. Shows tie bar placement at construction joint, intermediate bar placement at contraction joint, and location of longitudinal joint saw cutting.
P18	Concrete Pavement-Lane Schematics and Isolation Joint Detail	Shows general cases for locating isolation joints. Use on all new construction widening and lane replacement.
P30	Concrete Pavement End Panel Pavement Transitions	Indicates where concrete panel pavement transitions are located. This plan is used where existing or new HMA abuts to approach, JPCP or CRCP at transverse joint.
P31A	Continuously Reinforced Concrete Pavement-Terminal Joint Details	Shows general cases where terminal joints are located. Used at existing asphalt concrete pavement, new HMA, temporary pavement, and at construction limits where future pavement is anticipated.
P31B	Continuously Reinforced Concrete Pavement Expansion Joint and Anchor Details	Use with Standard Plan B6-21 for pavement anchor terminals between the end of CRCP and bridges, approach slabs, or other pavement types.
P32A P32B	Continuously Reinforced Concrete Pavement Wide Flange Terminals	Use with Standard Plan B6-21 between the end of CRCP and bridges, approach slabs, or other pavement types.
P34	Continuously Reinforced Concrete Pavement-Lane Drop Paving Details	Use for new construction, reconstruction, widening, and lane replacements where CRCP lanes end.
P35	Concrete Pavement-Ramp Gore Area Paving Details	For new construction, reconstruction, and widening of exit and entrance ramp gore areas adjacent to CRCP lanes.
P45	Concrete Pavement – Drainage Inlet Detail No. 1	For drainage inlets without concrete apron. Isolation joint is used around the drainage inlet. Transverse CRCP reinforcement is terminated 2” from the longitudinal isolation joint edges.
P46	Concrete Pavement – Drainage Inlet Detail No. 2	For drainage inlets with a concrete apron. Isolation joint is used around the concrete apron. Transverse CRCP reinforcement is terminated 2” from the longitudinal isolation joint edges.
B6-21	Joint Seals (Maximum Movement Rating = 2”)	Use with Standard Plans RSP P31B, P32A, and P32B for sealing expansion joints at pavement anchor and wide flange beam terminals.

200.5.6 Standard Specifications

Table 200-3 lists some pavement CRCP related 2010 Standard Specifications that may be used by the pavement engineer on CRCP projects. The Division of Maintenance Pavement Program website at is also a good source of information for CRCP design.

Table 200–3: CRCP Related 2010 Standard Specifications

Section	Section Title	Comments
39-1	Hot Mix Asphalt	Use for CRCP with HMA shoulders or base.
40-1	Concrete Pavement	Use for general concrete pavement construction requirements.
40-2	Continuously Reinforced Concrete Pavement	For use with all CRCP.
40-3	Jointed Plain Concrete Pavement	Use for CRCP where adjoining JPCP is constructed.
41-5	Joint Seals	Use for sealing CRCP longitudinal joints as required in mountain and desert climate regions.

200.5.7 Cost Estimating

The quantity of CRCP is measured and paid for by the cubic yard based on the volume of concrete from the dimensions shown on the project plans. The unit price for bid item 400050 includes furnishing and placing longitudinal, transverse, and additional reinforcement; tie bars, epoxy coating, and terminal anchors such as wide flange beams, pavement end anchors, expansion joints, and terminal joints. Full compensation includes all steel beams, stiffener plates, end plates, drilled holes, welding, cutting, polystyrene sheet, joint filler, joint seals, concrete, reinforcement, and bond breaker materials; labor, equipment, tools, and incidentals necessary to complete terminal anchor construction work. HMA, AS, and other base materials are paid for separately (see Table 200-4).

Table 200–4: CRCP Related Bid Items (2010 and 2015 Standard Specifications)

Item Codes	Item Description	Unit	Section
400050	Continuously Reinforced Concrete Pavement	CY	40-2
390132	Hot Mix Asphalt	TON	39
250201	Class 2 Aggregate Subbase	CY	25
401083	Shoulder Rumble Strip (Concrete Pavement, Ground-In)	STA	40-1
Various	Joint Seal or Isolation Joint Seal	LF	41-5

Table 200-5 shows the approximate volume of concrete and bar reinforcement weight per lane-mile of CRCP for a standard 12’ lane width with various pavement thicknesses. Based on project bid data through 2013, CRCP costs range from \$150 to \$295 per yd^3.

Table 200–5: CRCP Bulk Quantities

Pavement Thickness (ft)	Concrete Volume (yd^3/ lane-mile)	Total Bar Reinforcement Weight[1] (pounds/ lane-mile)
0.75	1,760	152,663
0.80	1,877	160,594
0.85	1,995	168,524
0.90	2,112	176,455
0.95	2,229	184,386
1.00	2,347	192,316
1.05	2,464	200,247
1.10	2,581	208,177

[1]Includes transverse and longitudinal bars. Weight of reinforcement bars is shown for information only. Do not use for cost estimating: bar reinforcement is included in the CRCP unit price.

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CONCRETE PAVEMENT GUIDE

PART 2: NEW CONSTRUCTION

CHAPTER 210 – JOINTED PLAIN CONCRETE PAVEMENT (JPCP)

This Chapter discusses specific topics related to new JPCP design, including guidance for using related 2010 and 2015 Standard Plans and Standard Specifications. Refer to Part 4 for guidance on JPCP rehabilitation methods. General information about concrete pavement structure design and materials is contained in Chapter 120 and HDM Chapters 600 – 670. The Pavement Program website has additional technical pavement related information and links to other useful sites (http://www.dot.ca.gov/hq/maint/Pavement/Pavement_Program).

210.1 JPCP COMPONENTS

Jointed plain concrete pavement (JPCP) is unreinforced cast-in-place concrete pavement designed with doweled transverse joints and tied longitudinal joints to control cracking as well as vertical and horizontal movement. Transverse and longitudinal joints are cut to a 1/8" width and not sealed except in desert and mountain climate regions. JPCP is typically constructed with the components shown in Figure 210-1:

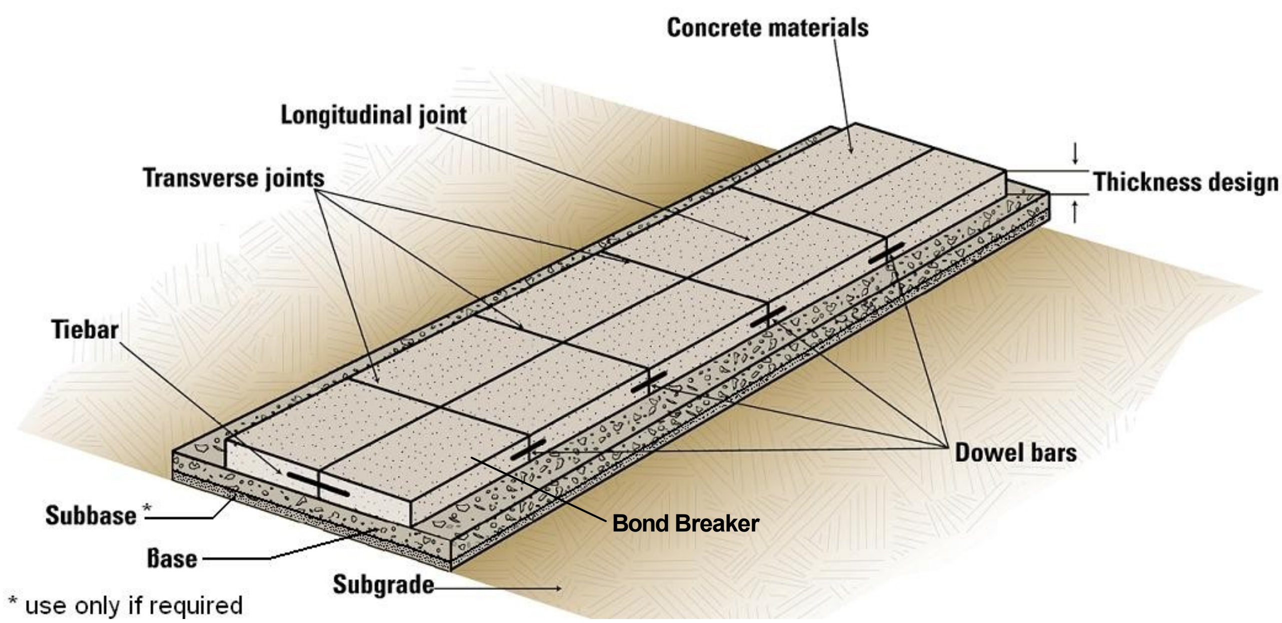


Figure 210–1: Typical JPCP components

Existing rigid pavement built in California prior to 2004 is generally non-doweled JPCP. Existing JPCP built prior to 1992 is typically untied.

This section contains a brief discussion of concrete, joints, tie bars, and dowel bars. Refer to Chapter 120 and HDM Chapters 600, 610, and 620 for more information about pavement structure design, materials, and other design considerations and requirements.

210.1.1 Concrete

Concrete consists of a combination of cementitious materials, coarse and fine-graded aggregate, water, and typically some property modifying admixtures. Concrete properties such as strength, durability, permeability, and abrasive wear resistance are materials dependent. Section 90 of the 2010 Standard Specifications defines the required chemical and physical concrete material properties for contractor developed mix designs, with some additional requirements for concrete pavements specified in Section 40. For more comprehensive information about concrete materials, refer to Chapter 120 and the Concrete Technology Manual.

Concrete pavement thickness is determined using standard design catalogs for new concrete pavement structures in HDM Index 623.1. The catalogs are based on mechanistic-empirical analysis principles considering climatic effects, applied traffic loads, and subgrade quality. To select the best materials and determine layer thicknesses, successful pavement structure designs must consider these and other engineering factors such as traffic control and estimated costs.

210.1.2 Joints

Concrete slabs will crack randomly from natural actions such as shrinkage or curling. Joints are vital JPCP design elements to control slab cracking and horizontal movement. Without joints, plain concrete pavements would be riddled with cracks within 1 or 2 years after placement. JPCP, if incorrectly placed or has poorly designed joints, will have premature cracking. JPCP joint types include longitudinal, transverse, construction, and intersection joints.

<u>Longitudinal Joints</u>

Longitudinal joints are necessary to control longitudinal cracking in JPCP. They are typically constructed at lane lines in multiples of 12’ (see Figure 210-2). Tie bars are typically placed at these joints to hold abutting slab faces in contact (see Section 210.1.4).

<u>Transverse Joints</u>

Transverse joints are constructed at right angles to longitudinal joints in new JPCP construction as seen in Figure 210-2. Historically, JPCP transverse joints were skewed and spaced at various intervals, including 15’ uniform spacing and staggered intervals of 18, 19, 12, and 13 feet or 12, 15, 13, and 14 feet. Beginning in 2013, 14’ uniform transverse joint spacing became standard.

Dowel bars handle the load transfer in new JPCP so skewed transverse joints are not necessary. Skewing also makes it difficult to place dowels along the transverse joint. Section 210.1.5 provides additional information on load transfer across transverse joints.

For lane/shoulder addition or reconstruction, the new transverse joints may not line up with the existing joint spacing in the adjacent lane. Revised Standard Plan RSP P18 shows 3 different cases of existing and new transverse joints alignment that may be encountered when reconstructing or adding concrete lane/shoulder adjacent to existing concrete pavement. To prevent crack migration from the existing transverse joints over to the new and weaker transverse joints, longitudinal isolation joints are needed.

Figure 210–2: Transverse and longitudinal joints

Isolation Joints

An isolation joint is a type of longitudinal joint that prevents existing transverse joints or cracks from migrating over to the newly placed JPCP. Isolation joints are generally used when matching the existing transverse joints is not practical. They are placed to separate dissimilar concrete pavement structure, and reduce compressive stresses that can cause uncontrolled cracking.

An isolation joint is required for:

1. Lane or shoulder addition and reconstruction where:
   a. New and existing transverse joints do not align
   b. New and existing transverse joints align and tie bars are not required.
2. Interior lane replacement where joints do not align between new and existing

When adding a new lane where an asphalt shoulder is removed, the abutting concrete slab edge should be saw cut to remove any surface roughness and protruding pockets of concrete at the isolation joint. Preformed bituminous expansion joint filler material is used to fill the isolation joint from the top of the base layer to the bottom of the reservoir. The joint is sealed at the surface with liquid sealant or preformed compression joint seal material to prevent infiltration of incompressible materials and moisture. The joint filler and seal material should be placed continuously from one edge of the slab to the other to the dimensions shown in Detail "A" on 2010 Revised Standard Plan RSP P18.

Construction Joints

A construction joint is either a:

1. Transverse joint that joins together consecutive slabs constructed at different times
2. Longitudinal joint constructed between lanes paved in 2 separate passes.

For longitudinal construction joints in non-doweled JPCP, tie bars usually connect adjacent slabs together. Transverse construction joints for doweled pavement should coincide with the standard 14' joint spacing.

Intersection Joints

Occasionally, state highways serve as local streets that require special joint layout considerations. Manholes, drainage inlets, curbs, gutters and other existing features need to be identified and considered for special construction details. Each intersection will require a custom joint layout that should be included as part of the construction details shown on the project plans. Joint design recommendations include:

- Maintaining perpendicular joints to simplify intersection construction. Skewed transverse or longitudinal joints should be minimized as much as possible in the intersection.
- Maintain lane widths and keep concrete panels as square as possible (1:1 to 1:1.25 ratio).

- Avoid triangular shaped panels and angles < 60°.
- Consider slab lengths as they approach the intersection if there is a transition from an alternating to constant transverse joint pattern.
- Design the joint layout considering traffic lane closure restrictions.

Field adjustments may be needed, but jointing plan details will provide clear guidance, help the contractor bid the project, and minimize disagreements or confusion during construction. Placement of new features such as traffic loop detectors that may affect daily production during construction should also be indicated.

210.1.3 Base Bond Breaker

Base bond breaker materials reduce friction between concrete pavement and rigid base material that can lead to cracking. For JPCP placed over LCB, SSP 36-2 allows the contractor to select asphalt binder, curing compound, or geosynthetic base bond breaker materials. The bond breaker allows the pavement structure layers to move independently, reducing reflective cracking and providing flexibility for slab curling due to temperature differences between the top and bottom of the pavement surface (see Section 120.1.1 for more information).

210.1.4 Tie Bars

Tie bars used in JPCP construction are 30" long deformed metal bars, placed at mid slab depth, perpendicular to the longitudinal construction and contraction joints. Tie bars are placed a minimum of 15" from a transverse joint and at 28" spacing thereafter (see Figure 210-3). Tie bars are typically used at longitudinal joints to hold abutting concrete faces in tight contact. Tie bars can also be used in transverse construction joints of non-doweled JPCP shoulders.

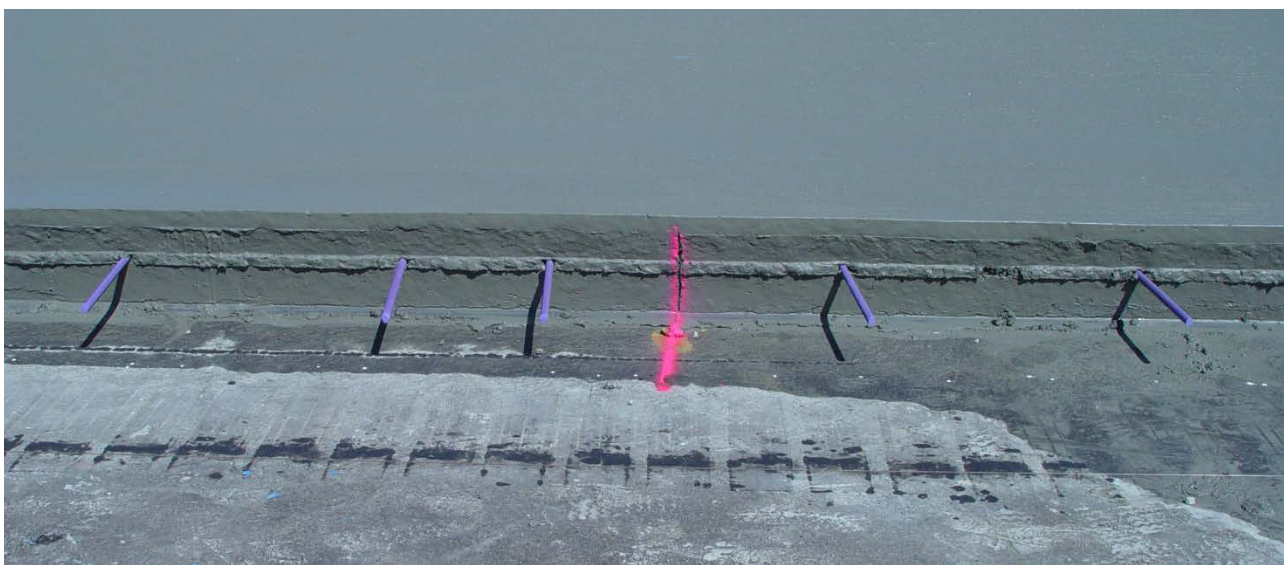


Figure 210–3: Tie bars

Tie bars are recommended at longitudinal construction joints for lane and shoulder additions or reconstruction, but are not recommended where isolation joints are required. Based on prior experience, tied JPCP lanes are limited to a 50' maximum width (see Revised Standard Plan RSP P18). When more lanes are tied together, concrete slabs tend to crack longitudinally. Tied slabs act collectively as one slab and friction between the base and the slabs is high enough to restrain movement and cause cracking. When more than 3 lanes and a shoulder or 4 lanes are being tied together, tie bars should be omitted at one of the longitudinal joints, preferably an inside lane without heavy vehicle traffic. Dowel bars are sometimes used for limited load transfer across untied longitudinal joints.

Revised Standard Plan RSP P18 provides lane schematics showing dowel and tie bar use at longitudinal joints and longitudinal isolation joint construction. The plan does not show all possible project conditions, so where project design scenarios differ, show the location of the untied longitudinal joint on a typical cross section or construction detail.

Where tie bars are installed at pavement transitions and the new concrete thickness is greater than the existing thickness, tie bars should be placed within the middle third of each slab (see Figure 210-4).

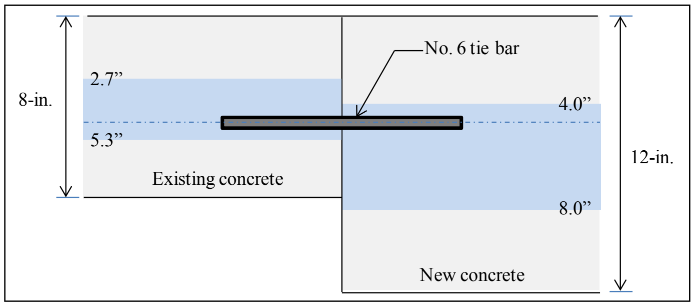


Figure 210–4: Example tie bar placement

Recommended tie bar placement depth ranges, measured in inches from the pavement surface, are shown in Table 210-1:

Table 210–1: Recommended Tie Bar Depth (inches)

Thickness (inches)		Existing Concrete (inches)				
		8	9	10	11	12
New Concrete (inches)	9	3.0 – 5.4	4.5			
	10	3.3 – 5.4	3.3 – 6.0	5.0		
	11	3.7 – 5.4	3.7 – 6.0	3.7 – 6.6	5.5	
	12	4.0 – 5.4	4.0 – 6.0	4.0 – 6.6	4.0 – 7.4	6.0
	13	4.3 – 5.4	4.3 – 6.0	4.3 – 6.6	4.3 – 7.4	4.3 – 8.0
	14	4.7 – 5.4	4.7 – 6.0	4.7 – 6.6	4.7 – 7.4	4.7 – 8.0

210.1.5 Load Transfer and Dowel Bars

Load transfer is the ability of a joint to transfer an applied traffic load from one side of the joint to the other. Dowel bars are smooth, round metal bars that allow load transfer across joints. Ideally, load transfer is achieved through 3 mechanisms:

1. Mechanical load transfer devices such as dowel bars
2. Aggregate interlock across abutting edges of concrete
3. Friction between the concrete pavement surface and base

In new JPCP pavement, dowels are placed on center at 1' intervals along the transverse joint, with a 6" offset at longitudinal joints (see Figure 210-5 and Revised Standard Plan RSP P10). Dowel bars are not required for concrete shoulders placed or reconstructed next to a widened slab (see Revised Standard Plan RSP P3B).

All dowel bars must be treated or epoxy coated, but Section 40 of the Standard Specifications allows the contractor to select the dowel bar materials with restrictions in more corrosive environments. Stainless steel bars are used in marine environments and in mountainous climates dowels are epoxy coated to prevent corrosion from exposure to deicing chlorides.

Refer to Section 120.3.2 for more information about load transfer and dowel bars.

Figure 210–5: Dowel Bars

210.2 Other JPCP Considerations

210.2.1 Widening

Longitudinal isolation joints are used when placing doweled pavement next to non-doweled pavement, or where the spacing pattern of transverse joints is different. Doweled rigid pavement will have a repeated interval spacing pattern, so matching the existing spacing is problematic. An isolation joint prevents cracks in the new lane or shoulder from adjacent existing transverse joints where joint spacing does not match.

2010 Revised Standard Plans RSP P3A and RSP P3B detail JPCP widening and indicate lane lines must be placed at longitudinal joints. For situations where the isolated longitudinal construction joint at the widening does not match the proposed lane lines, a small tied strip of variable width is used to line up the dimensions. If the width between the lane line and construction joint is > 3'-3", a longitudinal contraction joint is placed at the proposed lane line. For widths ≤ 3'-3", no longitudinal contraction joint is used.

When a lane addition occurs next to an existing lane, the existing adjacent lane should be ground smooth for the full width prior to new lane construction. Grinding the existing pavement will provide a level surface for the slip-form paving machine, resulting in construction of a smoother lane.

210.2.2 Widened Lanes with HMA Shoulders

2010 Revised Standard Plan RSP P3B shows a widened lane with HMA or JPCP shoulders. Widened lanes are not tied to rigid or flexible shoulders, but are striped to a 12’ traffic lane width to keep the wheel path away from slab edges where critical loading stress occurs. This reduces fatigue damage and improves JPCP performance. Studies have shown that the loading impact for a widened lane with HMA shoulders is comparable to a standard width slab with tied shoulders, although widened lanes with HMA shoulders are not preferred due to potential issues with curling and warping, as well as different material behavior from thermal movement (see Section 210.2.4).

210.2.3 Narrow Shoulders

A longitudinal joint should not be used if the shoulder is less than 4’ wide. The shoulder should be paved as part of the outside or inside panel and delineated by an edge stripe. If a rigid shoulder is added, tying the shoulder with tie bars is essential to hold the shoulder to the lane and provide edge support.

210.2.4 Pavement Transitions

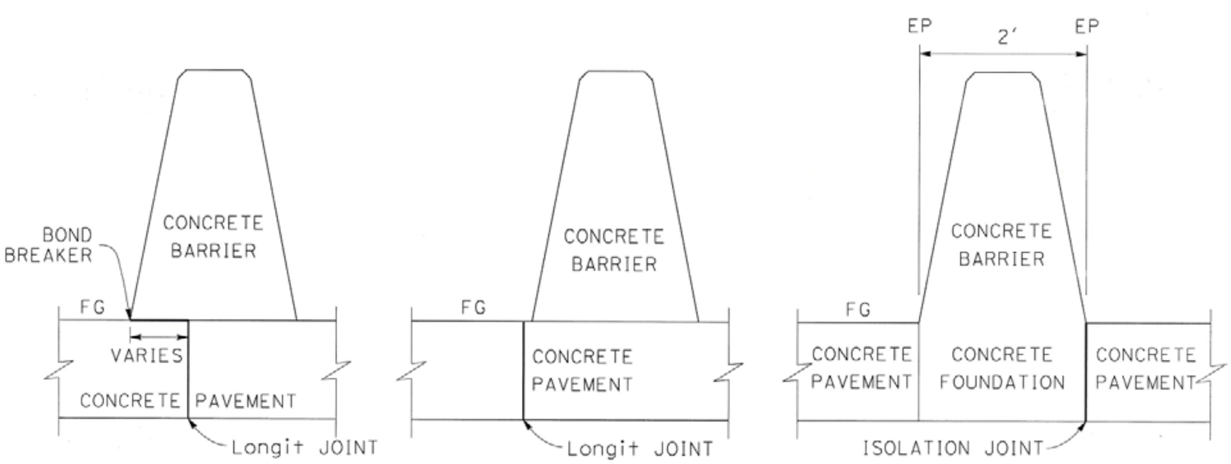
When end panel pavement transitions are to different pavement materials within the same lane (rigid to flexible or flexible to rigid), refer to 2010 Revised Standard Plan RSP P30. When the surface changes from flexible to rigid, special design consideration should be given to the impact loading at the transverse joint. An alternative to the reinforced concrete pavement transition is to thicken the concrete at the transition to existing AC, similar to what is shown on the pavement end anchor detail.

Placing flexible lane or shoulders next to concrete lanes is undesirable due to differential thermal movement. The softer AC tends to shove and deform. Occasionally, this produces a noticeable bump or joint separation at the interface.

Expansion joints are not used with JPCP. Using doweled JPCP and shorter panel lengths eliminates the need for pavement pressure relief, even with longer continuous runs of JPCP on steep grades. Often bridges, overpasses, approach slabs, and other roadway features break up the continuous runs and provide an expansion joint on approach or sleeper slab to account for thermal movement.

210.2.5 Concrete Barrier in Concrete Medians

Concrete barrier can be placed directly on concrete pavement, with a monolithic concrete foundation, or on compacted base material (see Standard Plan A76A). When concrete barrier is placed on concrete pavement, full contact friction develops at the surface interface as the concrete hardens. Friction limits the ability of the pavement slab to expand and contract with temperature changes, increasing longitudinal cracking potential if the barrier is placed over a longitudinal joint. Placing a bond breaker at the interface will allow JPCP slab movement (see Figure 210-6a). Another alternative is to align the concrete barrier so the entire width is placed on the same slab and no bond breaker is needed (see Figure 210-6b). For new alignments or concrete median widening where the finished grade of each roadbed is within 1.5”, the pavement can be placed narrower to accommodate the concrete barrier. The barrier can be placed together with a naturally formed monolithic concrete foundation in the gap, separated from the pavement by an isolation joint (see Figure 210-6c).



(a) Over longitudinal joint (b) Along longitudinal joint (c) Isolated concrete foundation

Figure 210–6: Concrete barrier placement alternatives

210.2.6 Concrete Pavement Over Culverts

Adequate cover provides support for traffic loads between the pavement surface and the culvert. Culverts and concrete pavement structures should be designed to withstand roadway traffic loading using the minimum cover for various pipe thicknesses and diameters shown in HDM Tables 856.3A through 856.3P. Standard Plan D88 has a table with minimum cover for construction loads on culverts. Figure 210-7 shows a rigid pavement constructed over an existing cross-drain culvert with inadequate cover:

Figure 210–7: Concrete pavement structure with inadequate cover

210.2.7 Stage Construction

There are various construction issues that influence the constructability of the concrete pavement and should be taken into consideration. Creating a means for consistent construction materials and methods will help create a smooth and long lasting pavement. Strategies include:

- Provide sufficient work area for required equipment and access for consistent product delivery and paver speed.
- Distance to batch plant should be taken into consideration. If one is not close to the project site, a staging area should be provided for contractor's use.
- Provide a minimum of 2.5' clearance width between pavement placement and barriers and hinge points to ensure good control of paving operation and smoothness.
- Minimize the number of stages and setups to provide consistent paving operations.

210.3 Plans, Specifications, and Estimating

The Standard Plans, Standard Specifications, and Standard Special Provisions (SSPs) are contractual documents that are components of the project design package. Standard Specification Section 40 contains concrete pavement specifications and Section 40-4 is for specific JPCP requirements, with various Standard Special Provisions (SSPs) used for associated work (see Section 210.3.2).

JPCP pavement structure limits for each type of concrete material should be accurately shown on the project typical sections, layouts, and construction details. Pavement on project plans and details must be identified as JPCP instead of previously used terms PCC or PCCP to match current standard plans, specifications, and bid items. JPCP is included as an abbreviation on Standard Plan A10A. If the pavement is non-doweled, it should be referred to on the plans and specifications as "JPCP (Non- Doweled)" and for sections where rapid strength concrete (RSC) is required, it should be referenced as JPCP (RSC). Non-standards pay items should be used to match the names shown on the plans.

The project engineer should assess all the individual features and determine if additional construction details, SSP edits, or nonstandard special provisions are needed to construct the project. Transitions to ramps, intersections, drainage features, and bridge approaches (clearance issues) are some elements that may require additional contract plan details. When unique or complicated pavement issues arise and a recommendation from Headquarters is desired, contact the Office of Concrete Pavement and Pavement Foundations in Headquarters Division of Maintenance for assistance.

210.3.1 Standard Plans

Table 210-2 lists 2010 Revised Standard Plans developed for use with JPCP as of July 2013 and available on the Office Engineer website at http://dot.ca.gov/hq/esc/oe/project_plans/HTM/stdplns-US-customary-units-new10.htm#pavement.

Table 210–2: 2010 Revised Standard Plans for JPCP

RSP Plan Sheet	Standard Plan Title	Description
P1	Jointed Plain Concrete Pavement – New Construction	Use for new construction with tied JPCP shoulder.
P2	Jointed Plain Concrete Pavement – Widened Lane New Construction	Use for new construction widened lane with flexible shoulder or untied JPCP.
P3A	Jointed Plain Concrete Pavement – Lane & Shoulder Addition / Replacement	Use for lane & shoulder addition.
P3B	Jointed Plain Concrete Pavement – Widen Lane & Shoulder Addition or Replacement	Use for widen lane & shoulder addition.
P10	Concrete Pavement – Dowel Bar Details	Shows orientation, tolerance and dowel bar layout. Use with P1, P2, P3A, & P3B.
P12	Concrete Pavement – Dowel Bar Basket Details	Baskets are always allowed with dowels. Use with P1, P2, P3A, & P3B.
P15	Concrete Pavement – Tie Bar Details	Shows orientation, tolerance and tie bar layout. Use with P1, P2, P3A, & P3B.
P17	Concrete Pavement – Tie Bar Basket Details	Baskets are always allowed with tie bars. Use with P1, P2, P3A, & P3B.
P18	Concrete Pavement – Lane Schematics and Isolation Joint Details	Shows general cases where isolation joints are to be located. Use standard plan for all concrete applications.
P20	Concrete Pavement – Joint Seals	Use joint seals for all locations where needed. Refer to Ch. 360.
P30	Concrete Pavement – End Panel Pavement Transitions	Use where concrete paving lane abuts to existing pavement at transverse joint. Use with P1, P2, P3A, & P3B.
P33	Concrete Pavement – Lane Drop Details No. 1	Use for projects when lane drops are included in jointed plain concrete pavement areas.
P34	Concrete Pavement – Lane Drop Details No. 2	Use for projects when lane drops are included in jointed plain areas.
P35	Concrete Pavement – Ramp Gore Area Details	Uses when ramps or gore areas are found in concrete pavement areas.
P45	Concrete Pavement – Drainage Inlet Details No. 1	Use for projects with shoulder drainage inlets with aprons. Isolation joint is constructed around drainage inlet.
P46	Concrete Pavement – Drainage Inlet Details No. 2	Use for projects with shoulder drainage inlets with aprons. Isolation joint is constructed around concrete apron of the inlet.

210.3.2 Standard Special Provisions (SSPs)

Table 210-3 lists some JPCP related SSPs for use with the 2010 Standard Specifications.

Table 210–3: JPCP Related Standard Special Provisions (SSPs)

SSP	Title	Comments
36-2	Bond Breaker	Use for base bond breaker between concrete pavement and concrete bases.
39-1.01	HMA (Type A)	Use for projects with HMA Type A, HMA Type B, HMA-O, RHMA-G, RHMA-O, or RHMA-O-HB.
40-1	Jointed Plain Concrete Pavement	Use for concrete pavement. Edit for stainless steel bars if tie or dowel bars are placed within 1,000 feet of marine environment or other salt water body.
41-5	Joint seal	Use if the climate region requires joint seal.
41-10	Drill and bond bars	Use if the method of tying the dowel and/or tie bars details is with drill and bond.

210.3.3 Cost Estimating

JPCP is paid by volume, calculated based on the width, thickness, and length shown on the project plans. The quantity of JPCP is measured and paid for by the cubic yard of concrete including furnishing and placing the dowel bars, dowel baskets, tie bars and saw cutting.

Unit cost estimates for JPCP volume are typically based on historical bid prices which can be found in the Contract Cost database accessible on the intranet at http://sv08data.dot.ca.gov/contractcost/. Contract cost data unit prices by year are also published online through the Office of Engineer website at http://www.dot.ca.gov/hq/esc/oe/awards/. Unit costs estimates should be adjusted based on project location, quantity of concrete, availability of materials used in the concrete mix, proximity of batch plants to construction site, and construction constraints such as lane closure windows and environmental restrictions.

Other items of work involved in the construction of concrete pavements may include base bond breaker, seal pavement joints, seal isolation joints, drill and bond bars, remove concrete and grinding existing concrete. These items of work are paid for separately and should be identified in the Project Initiation Document (PID) and Project Report (PR).

CONCRETE PAVEMENT GUIDE

PART 3: PRESERVATION STRATEGIES

CHAPTER 310 – SPALL REPAIR

This chapter provides an overview of spall repair, also known as partial depth repair. A description of the effectiveness and limitations of spall repair, as well as material and design considerations, are included. Some limited information about spall repair construction is also included. Refer to the Construction Manual for more details about construction procedures.

310.1 PURPOSE AND DESCRIPTION

Spalling is the loss of concrete, typically around joints or cracks. Spall repair is a corrective maintenance treatment that replaces deteriorated concrete with polyester or fast-setting concrete. Spall repair extends pavement service life and inhibits deterioration by:

- Restoring the structural integrity of the pavement
- Improving ride quality
- Restoring the joint seal reservoir

Depending on the existing pavement condition, spall repairs can be used as the primary pavement strategy or in combination with other corrective, preventive, or rehabilitation strategies. Common combinations include repair of additional spalled joints and cracks on individual slab replacement projects, as a pre-overlay repair to prepare a distressed pavement surface, or prior to grinding or joint sealing.

310.1.1 Spall Repair Applications and Limitations

Spall repair restores localized surface deterioration in joints, cracks, or miscellaneous areas within the upper 1/3 of the concrete slab depth. Spall repair is commonly used to repair isolated spalling between 6” and 6’ long caused by:

- Incompressible material in joints or cracks
- Localized areas of weak material from poor consolidation, curing, or finishing practices
- Joint inserts

More severe spalling distress is typically treated using partial or complete individual slab replacement with rapid strength concrete (see Chapter 320).

a) Transverse crack b) Slab corner

Figure 310–1: Spall repair candidates

Spall repair should be used as the principal strategy on a project if it is the primary distress and more than 25% of the slabs in a pavement segment length have medium severity spalling between 1-2 ft^2. Extensive severe spalling of greater than 2 ft^2 per slab over more than 15% of a pavement segment length may require a rehabilitation or reconstruction project strategy.

Table 310-1 illustrates the levels of spalling severity and extent where various strategies should be applied:

Table 310–1: Spall Repair Strategy Selection

Spalling Severity (per slab)	Area (ft^2)	Management Segment Extent (%)	Primary Pavement Strategy Recommendation	Reference
Low	< 1	100	None	Automated Pavement Condition Survey (APCS) Manual
Medium	**1–2**	1–25	None	APCS Manual
		> 25	**Spall repair**	**Chapter 310**
High	> 2	1–15	▪ Individual Slab Replacement (RSC)* ▪ HMAOL*	▪ Chapter 320 ▪ Chapter 370
		> 15	▪ Lane replacement ▪ CSOL* ▪ Concrete overlay*	▪ Chapter 400 ▪ Chapter 410 ▪ Chapter 420

*Some spall repair work may be appropriate on a project in combination with the primary strategy. See Chapter 100 and the applicable Concrete Pavement Guide chapter for more information.

Spalls caused by material problems such as alkali-silica reactivity (ASR) or vertical movement from shrinkage, fatigue, or failing dowel bars usually indicate deterioration beyond the upper 1/3 of the pavement thickness. If localized, these distress mechanisms should be treated using individual slab replacement instead of spall repair. More extensive distress should be treated by one of the rehabilitation or reconstruction strategies in Table 310-1.

310.2 Materials and Specifications

Spall repair material specifications are in 2010 Standard Specification Section 41-1. Section 41-4 requires polyester concrete for spall repair, but SSP 41-4 allows use of fast-setting concrete for pre-overlay repairs or with district maintenance engineer approval, typically for short-term repairs with an anticipated service life ≤ 5 years.

310.2.1 Polyester Concrete

Polyester concrete consists of an unsaturated isophthalic polyester-styrene copolymer resin binder and dry aggregate. A silane coupler is used to increase the resin bonding strength, and a high-molecular-weight methacrylate (HMWM) bonding agent is applied to penetrate microcracks in the substrate surface and increase shear strength at the bond interface.

Despite higher cost, polyester concrete is preferred when compared to fast-setting concrete materials for most applications due to generally superior performance over a wider range of conditions. Polyester concrete cures rapidly, developing high compressive strength and good concrete adhesion for placement over a wide surface temperature range between 40 and 130 °F. The polyester resin gel time can be adjusted for conditions anticipated in the field by adjusting the initiator percentage according to manufacturer recommendations.

Minimum polyester concrete material property requirements for viscosity, specific gravity, elongation, tensile strength, styrene content, silane coupler, saturated surface dry bond strength, and static volatile emissions are in 2010 Standard Specification Section 41-1.02C.

310.2.2 Fast-Setting Concrete

Fast-setting concrete can be magnesium phosphate, modified high-alumina, or portland cement based concrete. The type is selected by the contractor considering available curing time, climatic conditions, material costs, equipment requirements, working time for mixing and placing, and the size and depth of the repairs.

- Magnesium phosphate cement concrete mixtures are characterized by a high early strength, low permeability, and good bonding to clean dry surfaces. Use of epoxy bonding agent may be recommended by some manufacturers, and set time can be retarded to prevent reduced bonding strength. Workability is limited as significant strength reduction can occur from very small amounts of excess water.

- Modified high-alumina cement concrete mixtures produce rapid strength gain with good bonding properties to dry or damp surfaces and very low shrinkage. High-alumina cement is modified by adding calcium sulfate to reduce strength loss under high temperatures and moist conditions. Set retarders and accelerators are available from some manufacturers to adjust for variable field conditions.

- Portland cement type I, II, or III is typically considered preferable for spall repairs. Since tight lane closure restrictions often limit construction and curing time, non-chloride accelerating admixtures that comply with 2010 Standard Specification Section 90-1.02E and ASTM C494/C494M can be used to achieve high early strength and reduce the time to open for traffic. Calcium chloride ($CaCl_2$) accelerators are not allowed since they produce excessive shrinkage and dowel bar corrosion. Insufficient curing time, incompatible mixtures, or poor mix proportioning can cause premature deterioration and failure of the repair.

Minimum fast-setting concrete property requirements for compressive strength, flexural strength, bond strength, water absorption, abrasion resistance, drying shrinkage, water soluble sulfates and chlorides, and thermal stability are in 2010 Standard Specification Section 41-1.02B. Notably, a relatively high opening compressive strength of 3000 psi after 3 hours is required. In general, high early strength requirements result in higher cement content and more complex mixtures with greater failure potential. If the available traffic window allows a slower setting mixture, contact the Office of Concrete

Pavement in the Headquarters Division of Maintenance or submit a non-standard special provision (nSSP) request to: nssp.submittals@dot.ca.gov.

Table 310–2: Spall Repair Material Properties

Spall Repair Material		Approximate Working Time* (minutes)	Approximate Time To Traffic* (hours)	Repair Surface Temperature	Repair Surface Condition
Polyester concrete		20	2	40 - 130 °F	HMWM bonding agent
Fast-setting concrete	Magnesium phosphate cement	15	1	40 - 90 °F	dry
Fast-setting concrete	Modified high-alumina cement	15	1	> 40 °F	bonding agent or damp
Fast-setting concrete	Portland cement (with accelerator)	120	4	> 40 °F	bonding agent or damp

*At 72 °F. Refer to manufacturer's recommendations for more information.

310.2.3 Bonding Agents

A HMWM bonding agent is required with polyester concrete spall repairs to enhance the bond between the existing concrete and the repair material.

For fast-setting concrete, a bonding agent must be used if recommended by the concrete manufacturer. The bonding agent must comply with manufacturer recommendations, but epoxies have been widely used on these types of repairs.

If the fast-setting concrete manufacturer does not recommend a bonding agent, portland cement and modified high-alumina cement concrete can be placed on a damp surface that is not saturated. Magnesium phosphate cement concrete must be placed on a dry surface.

310.2.4 Other Repair Material Types

There are cost effective nonstandard repair material alternatives available such as polyurethane and pozzolanic materials that have performed well in various field maintenance applications. Others, such as gypsum, methacrylate, and epoxy have been evaluated and are not used by Caltrans due to issues with performance or cost effectiveness.

Additional materials, including some proprietary products that are not currently standardized for spall repair on contract projects, could be included in an authorized material list for concrete repair materials if one is developed for future specification updates. If there is interest using a specific nonstandard spall repair material on a project in the interim, contact the Office of Concrete Pavement in the Headquarters Division of Maintenance or submit an nSSP request to: nssp.submittals@dot.ca.gov.

310.3 DESIGN

Spall repair performance can be highly improved through proper design. This section provides important design considerations for spall repairs, such as concurrent work, repair locations and boundaries, and cost estimating.

310.3.1 Order of Work

The sequence of work is very important for spall repairs done as part of a comprehensive pavement project using various strategy combinations. The project special provisions should specify the following order of work requirements for applicable operations:

1. Slab subsealing or jacking should be done before spall repair so any accidental spalling that occurs can be readily repaired.
2. Spall repairs should be done before or concurrently with isolated slab replacement in case adjustments to locations or boundaries are necessary as construction proceeds.
3. Diamond grinding should follow spall repair, isolated slab replacement, and dowel bar retrofit.
4. Joint sealing or joint seal replacement should be completed as needed following other treatment strategies.

310.3.2 Repair Locations and Boundaries

Visual surveys are needed to identify spall locations and estimate spall repair area quantities during preliminary and final project design, and to mark repair boundaries during construction.

The pavement management system contains a visual record of every mainline concrete slab in the state, accessible online through the iVision software program at https://ivision.fugro.com/CaliforniaSH/#/Login. Visual and distress data are scheduled for collection biannually, so the available information can provide approximate pavement conditions but may not reflect the most current conditions, which should be verified with a field review to identify spall repair locations and estimate dimensions for quantities. Although lane closures may be difficult to obtain on high traffic volume routes, an effort should be made to estimate the depth of severely spalled areas. It may be possible to effectively survey the traveled way from median and outside shoulder areas during non-peak daytime hours. If existing spalls are deeper than 1/3 the slab thickness, individual slab replacement with rapid strength concrete should be used as the repair strategy.

A follow-up field evaluation should be performed by experienced construction personnel to define soundness limits as close as possible to the scheduled repair work so any additional spalling that developed since the design estimate is included. Engineering judgment, coring, and sounding techniques are used to identify the extent of the deterioration beneath the surface and determine accurate repair boundaries.

- The resident engineer will typically determine rectangular unsound concrete limits by sounding, which is listening for a dull, hollow sound after striking the concrete surface with a hammer, steel rod, or dragging chain.
- At least 2” beyond the unsound limits, the contractor will mark the saw cut lines for measurement and payment by the square yard.
- The actual spall repair area will also be marked by the contractor. The boundaries must extend at least 2” beyond the saw cut line, where concrete will be removed and tapered to form a rough surface sloped at 0.6:1 or flatter (between 30° and 60°) to finished grade. The additional tapered area beyond the saw cut is not paid for and should not be included in the spall repair area quantity estimate.
- Regardless of soundness limits, repair boundaries for spall repairs should extend at least 5” beyond the edge of the existing spalled surface.
- Spall repair areas closer than 2’ apart should be combined.
- If the spall repair area is less than 6” from a joint, the repair boundaries should be extended to the joint.

For more information about spall repair boundaries, refer to Figure 310-2 and 2010 Revised Standard Plan RSP P6.

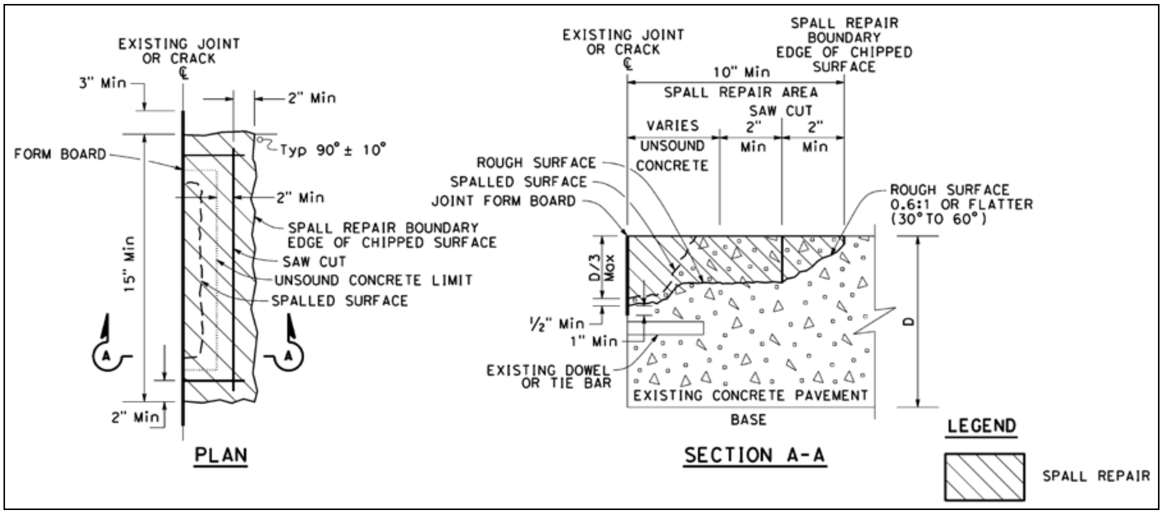


Figure 310–2: Typical spall repair at a joint or crack

Spall repair locations should be shown on the quantity plan sheets by post mile, station, or slab number. Spall repairs are measured by saw cut area, but the average length and width can be listed in the quantity table for additional information if designated as separate, nonpaid items. Given inherent variability, the plans should include a note that the Engineer will determine the exact spall repair locations and dimensions. For individual slabs with multiple spall repair locations, a typical construction detail or coded description and details can be used.

310.3.3 Cost Estimating

It is critical to make a reasonable estimate in the Project Report (PR) or Project Scope Summary Report (PSSR) when programming project funding for spall repair. Estimates should be based on identified locations and boundaries but reasonably conservative to avoid underestimation, account for invisible deterioration below the pavement surface, and anticipate additional deterioration prior to construction.

For the engineer's estimate at PS&E, any previous quantity estimates should be updated to reflect existing distress levels. Quantities should be based on the most recent pavement condition data from the pavement management system and verified with a field review as close to PS&E as possible (see Section 310.3.2). The updated estimate should also account for future deterioration likely to occur prior to scheduled project construction, which can be predicted using deterioration rates established from historical pavement condition data or percentage rates based on engineering judgment.

Table 310-3 provides the minimum dimensions for estimating spall repair area quantities, not the actual constructed spall repair area dimensions, which vary with concrete soundness.

Table 310–3: Estimating Spall Repair Quantities

Location of Spalling	Estimated Minimum Spall Repair Dimensions* (inches)		
	Depth	Length (Transverse)	Width (Longitudinal)
transverse joint or crack	2”	11” or spall length + 3”	8” or spall width + 3”
longitudinal joint, crack, or edge of concrete pavement	2”	8” or spall length + 3”	11” or spall width + 3”
miscellaneous repair area	2”	6” or spall length + 3”	6” or spall width + 3”

*Dimensions are relative to the traffic direction. Use the larger dimension to estimate repair area.

Accurate quantity estimates should be within 75 to 125% of the actual amount repaired during construction. The spall repair area quantity will fluctuate during construction because field conditions change and the resident engineer determines the actual limits of unsound concrete, which the contractor uses to determine the saw cut lines and repair boundaries. Accordingly, the unit price bid for spall repair is not adjusted for changes to the construction quantity.

Initial costs can be estimated using historical contract cost data for all contracted bid items and other information available on the Division of Design cost estimating website at http://www.dot.ca.gov/hq/oppd/costest/costest.htm. Typical bid items for spall repair work are shown in Table 310-4. As of 2013, the current standard bid items for spall repair are item 410120 Spall Repair (Polyester Concrete) and item 410121 Spall Repair (Fast-setting Concrete), but unit cost data may be limited. Previously item codes 413111, 413112, or 413113 were used for spalled joint repair. If historical spall repair cost data for a material is limited or not reasonable for the project conditions, adjust the unit cost estimate for differences in available data.

When estimating the cost to repair spalled joints, an estimate for replacing the entire joint seal length along the slab is also required. Replacing joint seals will reduce future spalls by preventing intrusion of incompressible materials and surface water. Use the bid item for the appropriate seal material. Both longitudinal and transverse repair joints must be resealed according to 2010 Standard Specification Section 41-5 using asphalt rubber, silicone, or preformed compression seal material. On projects bid prior to 2014, the joint seal replacement cost may have been included in the spall repair bid item or paid separately but limited to damage along the spall repair area. For more detailed information on joint sealing, refer to Chapter 360.

Table 310–4: Typical Spall Repair Work Bid Items

2010 and 2015 Standards			Prior Standards (for estimating unit costs only)	
Item Code	Description	Unit	Item Code	Description
410120	Spall Repair (Polyester Concrete)	SQYD	413113	Repair Spalled Joints (Polyester Grout)
410121	Spall Repair (Fast-setting Concrete)	SQYD	413112	Repair Spalled Joints (Fast-setting Grout)
---	---	---	413111	Repair Spalled Joints
414222 - 414224	Replace Joint Seal (Preformed Compression) - *3 size ranges*	LF	413114	Replace Joint Seal (Existing Concrete Pavement)
414221	Replace Joint Seal (Silicone)	LF	414119	Replace Concrete Pavement Joint (Silicone)
414220	Replace Joint Seal (Asphalt Rubber)	LF	414120	Replace Concrete Pavement Joint (Asphalt Rubber)

Current contract standards including plans, specifications, and bid items are on the Division of Engineering Services Office Engineer website at:
http://www.dot.ca.gov/hq/esc/oe/construction_standards.html.

310.4 CONSTRUCTION PROCESS

Some key information about spall repair construction is summarized in this section. Refer to the Construction Manual for more details about spall repair construction procedures.

310.4.1 Spall Repair Construction Sequence

The spall repair construction sequence is:

1. Engineer determines rectangular limits of unsound concrete (see Section 310.3.2). For projects with multiple, smaller spalled areas where sounding may not be efficient or safe for field conditions, the minimum dimensions in Table 310-3 can be used to establish the repair boundaries. The saw cut area used to measure pay quantities must be inset at least 2” in all directions from the outer repair boundary (see RSP P6).
2. Contractor marks the saw cut lines and spall repair area (see Section 310.3.2)
3. Saw cut and remove concrete pavement. Chip at least 2” beyond the saw cut to produce a rough surface angled from 30° to 60° (see Section 310.4.2). Leave a slight vertical face at the surface where the repair material conforms to the existing pavement to allow for aggregate thickness.
4. Clean the exposed concrete surfaces by sand or water blasting and blowing with compressed air (see Section 310.4.3)
5. Prepare the joint by placing a form board along the existing joint or crack alignment (see Section 310.4.4)
6. Place polyester concrete using a bonding agent or fast-setting concrete according to the manufacturer’s instructions
7. Finish and cure the concrete repair material according to the manufacturer’s instructions
8. Open to traffic (see Section 310.4.5)

310.4.2 Concrete Sawing and Removal

2010 Standard Specification Section 41-4 requires saw cutting with a diamond bladed saw at least 2” beyond the unsound concrete limit. The saw cut must be at least 1.5” deep for repairs using polyester concrete and 2” deep for fast-setting concrete. The spall repair depth should not extend more than 1/3 of the concrete slab thickness or 3.5” maximum, but must be at least a ½” below the existing spalled surface and deep enough to remove any deteriorated concrete.

No specific method is required for concrete removal, but typically 15 lb jackhammers are used to chip out the damaged concrete from the center of the repair area out towards the saw cut to the full cut depth:

- Concrete must be removed at least 2” beyond the saw cut toward the boundary edge and tapered at a rate of 0.6:1 or flatter (about 30° to 60°) to finished grade. The tapered edge results in a rough substrate surface that increases the surface area and bonding strength at the interface.
- At the repair boundary edge, a slight vertical face should be chipped out according to the repair material manufacturer recommendations to avoid a thin, feathered conform that could cause future spalling.

310.4.3 Cleaning

The repair surface must be thoroughly clean before the application of repair material to enhance bonding between the repair material and the existing concrete. Abrasive sandblasting or high-pressure water blasting, followed by compressed air blasting, are used to clean the exposed concrete substrate.

310.4.4 Joint and Crack Preparation

Adequate joint and crack preparation is essential to the performance of spall repairs. Repairs adjacent to joints and cracks require sufficient space to minimize the development of compression forces due to thermal expansion of the slabs. Also, a repair material that infiltrates the crack or joint can restrict slab movement and cause the development of compressive stresses at lower depths that will deteriorate the repair. This type of deterioration can also occur along longitudinal joints or at lane-shoulder joints.

Spall repair failures can be reduced by placing a compressible form board in the joint or crack between the repair material and the adjoining pavement. Once the repair material has cured, the form board must be removed before sealing the joint or crack.

310.4.5 Opening to Traffic

Regardless of the material used, spall repairs must cure for at least 2 hours from the time of final setting determined under ASTM C403/403M before opening to traffic. If the repair cannot be completed within the specified lane closure time, temporary pavement structure must be constructed according to the provisions in 2010 Standard Specification Section 41-1 and removed as a first order of work.

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CONCRETE PAVEMENT GUIDE

PART 3: PRESERVATION STRATEGIES

CHAPTER 320 – INDIVIDUAL SLAB REPLACEMENT

320.1 PURPOSE AND DESCRIPTION

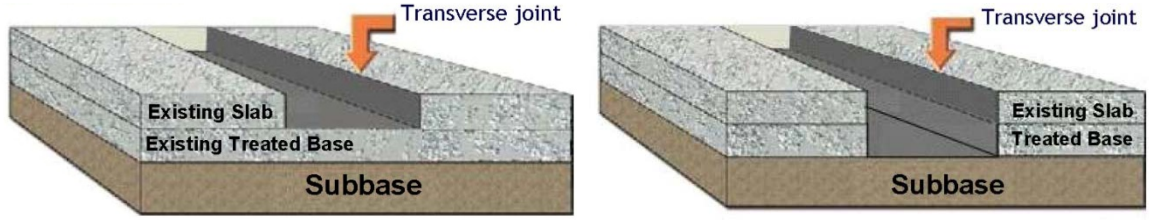
Individual slab replacement is a pavement preservation strategy for JPCP that improves the structural integrity and performance of existing concrete pavement. Slab replacement is not considered rehabilitation because it is not a new pavement structure designed for the long-term needs of the roadway.

Individual slab replacement is considered a limited-term fix with < 10 years of anticipated service life in truck traffic lanes. Even if a replaced slab lasts > 10 years, many surrounding slabs will likely continue to fail, indicating pavement rehabilitation strategies such as lane replacement should be considered. Performing successive slab replacement projects along the same route segment is inefficient pavement management that should be avoided.

Slab replacements patch isolated locations of failed pavement to minimize further deterioration and extend the life of the surrounding pavement. They are also effective for repairing distressed concrete pavement prior to an HMA or concrete overlay (see HDM Index 625.1).

Slab replacement involves the full-depth, full lane width removal of a severely deteriorated concrete slab and replacing it with an appropriate repair material that meets the design life and opening-time demands of the project.

Underlying base repair may also be required with slab replacement (see Figure 320-1). Slab and base replacement consists of removing the concrete pavement and underlying base and replacing both layers separately. New layers typically consist of portland cement concrete, rapid strength concrete, or HMA pavement and lean concrete base or concrete base, separated by a bond breaker.



Slab Replacement **Slab and Base Replacement**

Figure 320-1: Slab and base removal

320.1.1 Applications

Slab replacement should only be used to address severe deterioration of individual slabs in isolated areas when other strategies, including doing nothing, cannot extend the service life by at least 5 years or are not cost effective (refer to the Life-Cycle Cost Analysis Procedures Manual).

Slab replacement is appropriate when ≤ 10% slabs over the project or lane length meet the distress criteria in Table 320-3. When there is more extensive deterioration, the alternative with the lowest life cycle cost should be selected. Table 320-1 shows the slab replacement criteria used for concrete pavement strategy selection:

Table 320-1 Concrete Pavement Strategy Selection

Slab Replacement Extent (per lane)[1]	Primary Concrete Pavement Strategy
≤ 10%	Slab replacement[1]
10 – 20%	Slab or lane replacement[2] (use LCCA to determine)
> 20%	Lane replacement[2] or CSOL[3]

[1]Refer to Design Information Bulletin Number 81 "CAPM Guidelines"
[2]Refer to Ch. 400
[3]Refer to Ch. 410

The performance of slab replacements is dependent on appropriate application and the use of effective design and construction practices. The effectiveness of slab replacement depends on the timing of the repairs relative to the remaining pavement service life and identifying and repairing deterioration to the base (see Section 320.2.2).

Although not appropriate as a rehabilitation strategy by itself, slab replacement may be included as part of a rehabilitation project to address isolated locations within the project limits (see Table 320-2). These locations may include inside lanes where trucks are not legally permitted, ramps, shoulders, and truck lanes which are structurally adequate for at least 20 years and do not warrant rehabilitation.

Table 320-2 Slab Replacement Project Category

Slab Replacement Category[1]	Anticipated Service Life	Project Type	Notes
Responsive Repair	1 – 3 years	Maintenance (state forces) Purchase order	For critical failures prior to a follow up project
Short Term	≤ 5 years	HM CAPM 2R or RRR	Routine preventive maintenance Precursor to a follow up rehab project Pre-overlay repairs
Extended Term	5 – 10 years	CAPM 2R RRR	For pre-overlay or repairs in adjacent lanes without 2R and RRR work. Expect follow up replacement of additional slabs during the anticipated service life.

[1]Slab replacement category and anticipated service life vary based on existing distress type, severity, and extent (see Table 320-3), which should be used to choose the project type.

320.1.2 Limitations

It is important to recognize that slab replacement is not a suitable treatment for all pavements. Slab replacement does not address existing structural or material deficiencies, such as may be exhibited by pavement that is rapidly developing new cracking or is < 10 years old but with extensive cracking. These problems may be related to the concrete materials used or a lack of underlying support. Such problems require structural or functional enhancement, such as an overlay or lane replacement.

Similarly, slab replacement is not an effective strategy to combat other materials-related distress such as deterioration caused by alkali-silica reactivity (ASR), although it may be used as an interim measure until more extensive rehabilitation measures can be taken.

Slab replacement is not considered long-term pavement restoration and should not be used solely as a rehabilitation strategy. Slab replacement limitations include:

- Continued rapid deterioration of the remaining existing pavement.
- Limited service life. Slab replacements match the existing pavement thickness and are not designed for a 20-year life.
- Patches of different materials with construction joints that lower adjacent slab performance.

320.2 REPLACEMENT CRITERIA

320.2.1 Replacing Distressed Slabs

Not all cracks, spalls, or other distress in concrete pavement require slab replacement. Some cracked panels may provide acceptable performance for an extended period of time without any repair depending on the traffic volume, vehicle loading, climate, underlying base conditions, and distress type, severity, and extent. Those same variables affect the anticipated service life of slab replacements. Slab and base replacement criteria based on existing pavement condition and anticipated service life are summarized in Table 320-3:

Table 320-3: Slab Replacement Criteria

Distress (Type, Severity, Extent)	**Replace Base[1]**	**Anticipated Service Life**			**Reference Figure**
		Responsive Repair (1–3 years)	**Short-Term (≤ 5 years)**	**Extended-Term (5–10 years)**	
Corner cracks					
With settlement > ¼”	Y	N	Y	Y	320-6
≥ 2 regardless of settlement		N	N	Y	
Corner cracks ≥ ¾” width		N	N	Y	320-2
Transverse and Longitudinal Cracks					
Crack width ≥ ¾”		N	Y	Y	320-3
Settlement > ¼” relative to slab or adjacent slabs		N	Y	Y	
3rd stage cracking[1]		N	Y	Y	
Crack width ≥ ¼”		N	N	Y	
Crack width ≥ ¾”		N	Y	Y	
Crack width ≥ ¾” with spalling, rocking, or missing concrete		Low Priority[5]	Y	Y	320-4 320-5
Crack with settlement > ¼” relative to slab or adjacent slabs	Y	N	Y	Y	320-5 320-6 320-7
Spalling					
> 1 ft^2 and > 1/3 slab depth		N	Y	Y	
> 2 ft^2 or > 2” wide over 75% crack length Extent > 1-15% of pavement segment	Y	N	Y	Y	

Distress (Type, Severity, Extent)	Replace Base[1]	Anticipated Service Life			Reference Figure
		Responsive Repair (1–3 years)	Short-Term (≤ 5 years)	Extended-Term (5–10 years)	
Settlement[3]					
> ¼” with cracking	Y	N	Y	Y	
≥ ¾” relative to adjacent slabs regardless of cracking		N	N	Y	
Rocking slabs[4]	Y	Low Priority[5]	Y	Y	

Notes:
1. Since deteriorated base can extend beyond an individual slab into adjacent slabs, consider partial or complete replacement of adjacent slabs if distress includes: 3rd stage cracking with widths > ½”, corner cracks with widths > ¼”, or settlement. Refer to Section 320.2.2 for more information.
2. 3rd stage cracking is at least two interconnecting transverse, longitudinal, or corner cracks that divide a slab into ≥ 3 pieces.
3. Where the entire roadway or roadbed width has settled due to earth movement or hydraulic activity, consult with Geotechnical Services before implementing pavement strategies.
4. Rocking slabs move up and down relative to adjacent slabs when traversed by vehicles or trucks, a sign the slab is unstable and no longer supported by the base. Distress indicators of slab rocking include missing pieces, pumping fines, severe crack faulting or spalling, or slabs which have broken into > 6 pieces. If slab is intact, consider subsealing (see Ch. 300).
5. Low priority replacements can be included in projects with sufficient funding.

Rigid pavement distresses are described in more detail in the Automated Pavement Condition Survey Manual. Contact the Office of Pavement Management and Performance in the Division of Maintenance Pavement Program for more information.

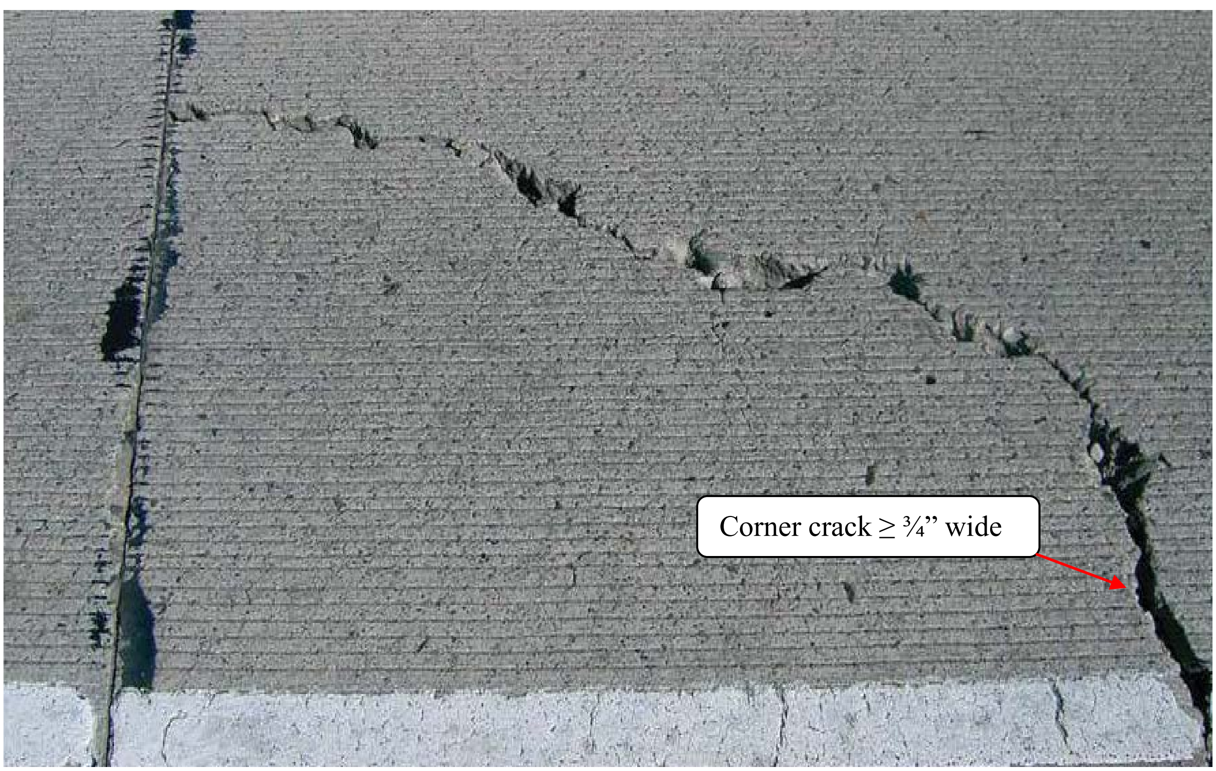


Figure 320-2: Replace slab – severe corner crack ≥ 3/4” wide

Figure 320-3: Replace slab – transverse crack ≥ ¾" wide with spalling

Figure 320-4: Replace slab – 3rd stage cracking ≥ ¾" wide with minor spalling

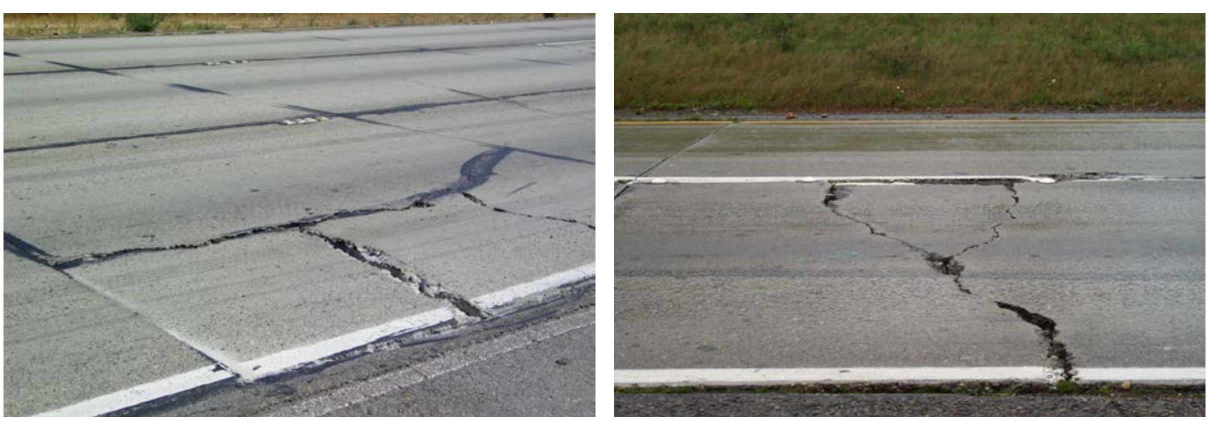


Figure 320-5: Replace slab and base – 3rd stage cracking ≥ ¾" wide, settlement ≥ ¼", spalling

320.2.2 Replacing Base

The most appropriate type of slab repair must be determined based on the condition of the entire pavement structure to be repaired, including the need to remove and replace the existing base. Performing only slab replacement when the underlying base is deteriorated will lead to early slab replacement failure, sometimes in < 1 year, resulting in additional repairs and increased cost. Conversely, replacing good base unnecessarily will increase the construction time and cost.

Determining when underlying base should be replaced is one of the more challenging aspects to engineering slab replacements since the base layer is not visible until construction. Coring and GPR can be used to investigate condition but have limitations including time, expense, and accuracy. The most efficient method for estimating base replacement during design is to use the surface distresses of the concrete slab to indicate base failure (see Table 320-3), considering that deteriorated base can extend beyond an individual slab into adjacent areas. Distress indicators include:

- Cracking with settlement > ¼”
- Rocking slabs (typically with pumping fines)
- Spalling > 2ft^2 total or > 2” wide over 75% of the crack length

Assuming base failure and replacement for all adjacent slabs is not practical, but adding 5% to the identified slab replacement quantity is a reasonable estimate without any other data. It should be possible to approximate the total estimate for base replacement within 25% of the final quantity, which will ultimately be determined during construction when slabs are removed and the base condition can be analyzed.

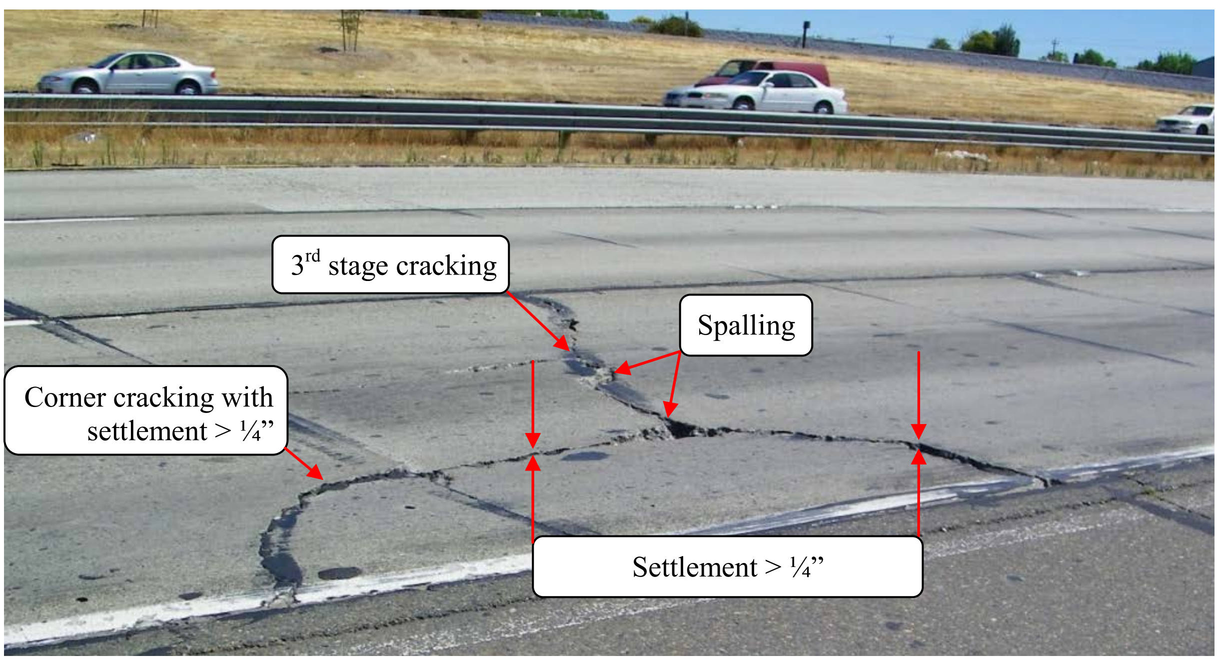


Figure 320-6: Replace slabs and base – corner and 3rd stage cracking with settlement > ¼”

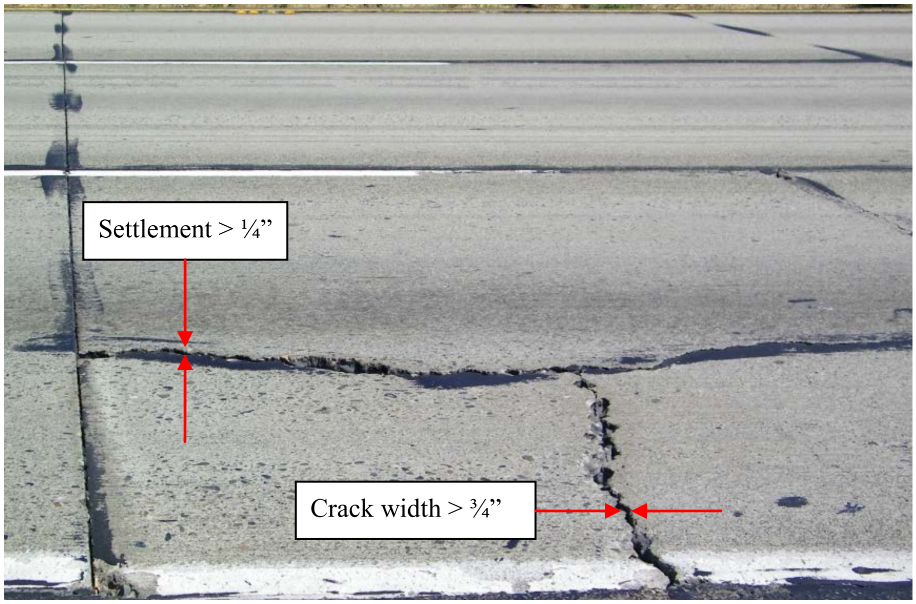


Figure 320-7: Replace slab and base – 3rd stage cracking and settlement

320.2.3 Other Repair Strategies

Cracks, spalls, and other distresses which do not meet the slab replacement criteria in Table 320-3 should be repaired using another strategy (see Table 100-1) or left in-place, except for situations when continuous removal is more cost effective (see Section 320.4.2). Some cracks do not affect the functional pavement serviceability for supporting traffic loads (see Figure 320-8) or result from construction defects in the original pavement (see Figure 320-9).

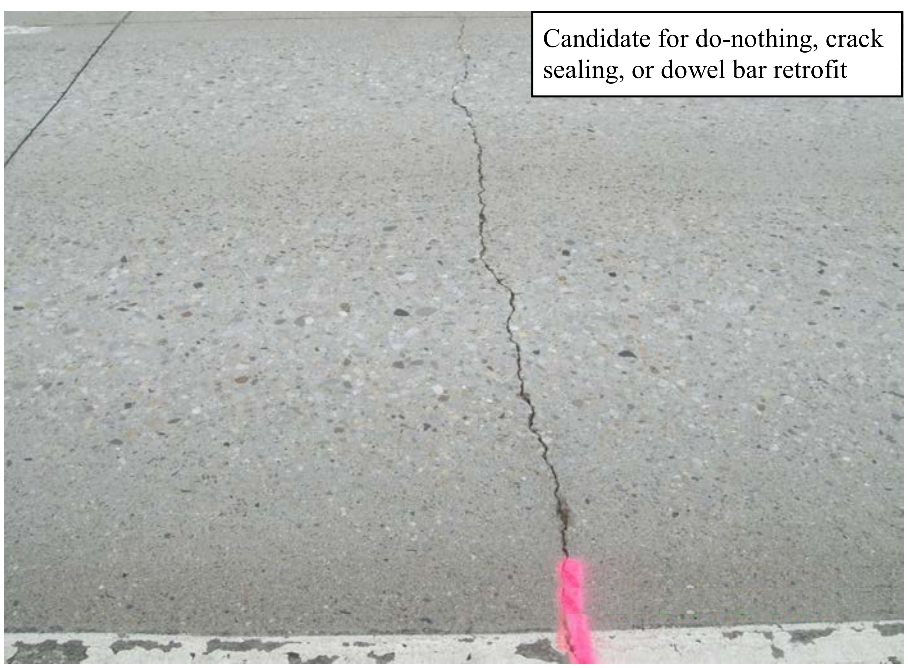


Figure 320-8: No replacement – narrow transverse crack < ¾” with no settlement

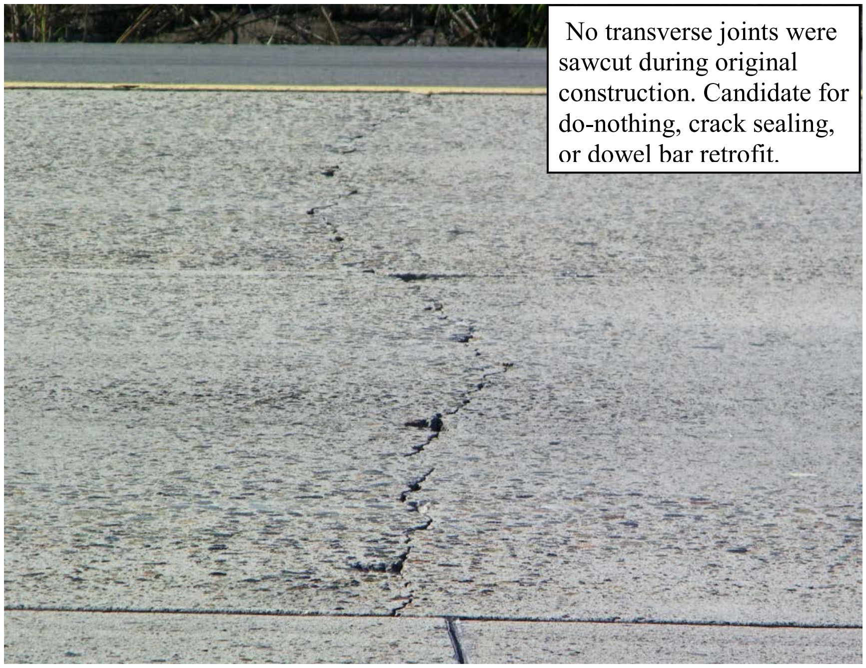


Figure 320-9: No replacement – voluntary transverse crack < ¾" with minor spalling < 2ft^2

320.3 MATERIALS

Slab replacement materials are selected based on a number of considerations, including strength, available curing time, prevailing climatic conditions, cost, equipment requirements, mixing and placing time, desired service life, and the size and depth of repairs. In addition, material-specific properties, such as strength gain, modulus of elasticity, bond strength, scaling resistance, sulfate resistance, abrasion resistance, shrinkage characteristics, coefficient of thermal expansion, and freeze-thaw durability can be considered in the selection process.

The district materials engineer should be consulted regarding desired material properties, unusual base and subgrade issues, and new potentially innovative technologies. The current state of practice in concrete pavement repair allows for virtually any opening time requirement using either conventional cementitious materials, rapid strength concrete (RSC), or precast concrete panels. However, RSC mixes and precast panels have higher costs, typically require special handling, are more difficult to construct, and are more likely to fail prematurely when not properly constructed. HMA is less expensive but is not recommended for extended-term slab replacements.

320.3.1 Base Replacement Materials

Rapid strength concrete base (RSCB) or lean concrete base rapid setting (LCBRS) is used to replace existing base under individual slab replacements. RSCB is RSC that complies with Section 90-3 of the Standard Specifications, although it must be placed separately from the RSC pavement surface using a bond breaker. Using RSCB instead of LCBRS can simplify the slab replacement construction operation and add strength to the pavement structure.

320.3.2 Base Bond Breaker

Base bond breaker is a material used to reduce friction between concrete pavement and base material that can lead to cracking. The bond breaker allows the pavement structure layers to move independently, reducing reflective cracking and providing flexibility for slab curling due to temperature differences between the top and bottom of the pavement surface.

320.3.3 Cast-in-Place Cementitious Materials

Cast-in-place cementitious RSC materials are most commonly used for slab replacement because of the need for high early strength before opening to traffic. Standard Specification Section 90-3 allows the contractor to design the concrete mix depending on available curing time. Generally, 4 types of concrete mixes are used for slab replacement:

Table 320-4: Concrete Mix Types

Typical Curing Time (hours)	Concrete Mix Type
2–4	Specialty high early strength cement mixes. The cement may be portland, non-portland, or blended.
4–6	In addition to specialty cements, Type III portland cement with non-chloride accelerators and high-range water-reducing admixture may be used if shrinking and early age cracking requirements are met.
< 24	Type II portland cement with non-chloride accelerators
≥ 24	Conventional Type II portland cement*

*Note: preferred for lower cost and superior performance when strength can be attained before traffic opening.

The use of calcium chloride ($CaCl_2$) accelerators to achieve rapid strength is not allowed since they can double the rate of steel corrosion and concrete shrinkage, resulting in excessive slab cracking.

Although RSC repair materials can provide effective solutions for early opening to traffic, there are also associated performance concerns. For example, NCHRP Report 540 about early-opening-to-traffic (EOT) RSC mixtures noted that many such mixtures contain higher cement contents and multiple admixtures, which can lead to increased shrinkage, altered microstructure, and unexpected interactions[(3)]. Furthermore, the study noted:

- Durable 6 to 8-hour and 20 to 24-hour EOT repairs can be constructed, but the 6 to 8-hour EOT rapid strength concrete materials are more prone to durability-related problems, heightening the risk of premature failure.
- Difficulty in achieving an adequate entrained air-void system was associated with EOT concrete, resulting in paste freeze-thaw deterioration and deicer scaling.
- Increasing cement contents do not necessarily increase concrete strength, and in fact may adversely affect the durability of the RSC mixture.
- Increased problems may result from interactions between the various mixture constituents. Extensive testing should be conducted on the actual job mixture during the mix design stage.

320.3.4 Precast Concrete

The use of precast concrete panels for slab replacement is currently under development. It offers the potential of rapid construction using conventional cementitious materials that are cast and cured away from the construction site, which could produce longer lasting slab replacements for a higher initial construction cost. In 2012, precast concrete pavement was about 30% to 100% more expensive than RSC according to contract cost data. Because of their high cost, precast concrete panels are best used where:

1. Traffic handling and detour options preclude the use of cast-in-place mixes that cure in 8 hours or more.
2. The existing pavement is expected to be structurally adequate or sound for at least the next 20 years, such as for ramps and inside, HOV, HOT, or other lanes where trucks are not permitted.

Precast concrete slab replacement is currently considered experimental, so use on a project must be approved by the HQ Division of Maintenance Pavement Program. Please refer to HDM Topic 621 and contact the Pavement Program for the most current information.

320.3.5 Hot Mix Asphalt

Using hot mix asphalt (HMA) materials for individual slab replacement is a nonstandard strategy that should only be considered in the following situations:

- As a responsive repair when deteriorated slabs need to be replaced before a project can be programmed or advertised (as determined by the district maintenance engineer or deputy district director of maintenance). If a project cannot be programmed and advertised within 5 years, concrete should be used to replace the slab, even for responsive repairs.
- As a short-term solution for a roadway that has a planned project to rehabilitate the lane within 10 years.
- When doing slab replacement repairs as part of an overlay project.

For better performing slab replacement with HMA, the best practice is to use a stiffer, more angular mix with a warm mix additive to aid compaction and cooling time. HMA is not recommended for extended-term repairs of concrete pavements because it can allow horizontal movement of adjacent slabs, provides no load transfer across transverse construction joints, and creates a patchwork of unsightly black and white surfaces.

Please consult with HQ Office of Concrete Pavement and Pavement Foundations regarding nonstandard special provision approval to use HMA for slab replacement.

320.4 DESIGN ISSUES

Design issues for slab replacement include dowel bar use, order of work, repair locations and boundaries, pavement smoothness, load transfer, design features, project plans and specifications, and cost estimating.

320.4.1 Order of Work

The sequence of work for slab replacement is very important for isolated repairs whether done independently or as part of a comprehensive pavement project. The following order of applicable work is recommended for pavement construction:

1. Slab subsealing or jacking should be done before spall repair so any accidental spalling that occurs can be readily repaired (see Ch. 300).
2. Spall repairs should be done before or concurrently with isolated slab replacement in case adjustments to locations or boundaries are necessary as construction proceeds (see Ch. 310).
3. Repair existing edge drains. Cap off any edge drains that are plugged and repair pipes and outlets where existing edge drains are still functioning.

4. Repair or reconstruct shoulders. Depending on the extent of distress, existing shoulders with minimal distress should be fog sealed, milled and filled when localized surface distress or minimal shoulder drop-off is present, or reconstructed when severe cracking or severe shoulder drop-off is present (see HMA Pavement Guide).
5. Diamond grinding should follow spall repair, isolated slab replacement, and dowel bar retrofit to restore pavement surface smoothness and avoid intermittent grinding that unnecessarily reduces the concrete thickness (see Ch. 340).
6. Joint sealing or joint seal replacement should be completed as needed following other repair strategies (see Ch. 360).

320.4.2 Repair Locations and Boundaries

Visual surveys are needed to identify individual slab replacement locations and estimate quantities during preliminary and final project design, and to verify locations and boundaries during construction. Identifying definitive repair boundaries is critical to completing a project quickly and ensuring good repair performance. Ensuring that all deterioration is included within the repair boundaries minimizes the need for additional, unplanned saw cutting and concrete removal work. Using the criteria in Section 320.2, project designers should also consult with the district maintenance engineer and area field personnel when selecting slabs for replacement. If existing spalls are deeper than 1/3 the slab thickness, slab replacement should be used as the repair strategy.

The pavement management system contains a visual record of every mainline concrete slab in the state, accessible online through the iVision software program at https://ivision.fugro.com/CaliforniaSH/#/Login. Visual and distress data are scheduled for collection biannually, so the available information can provide approximate pavement conditions but may not reflect the most current conditions, which should be verified with a field review to identify unrecorded or recent distress and potential failure mechanisms, such as issues with surrounding terrain or drainage conditions (see Section 110.2). It may be possible to effectively survey the traveled way from median and outside shoulder areas during non-peak daytime hours. Blank slab replacement field review forms are included in Appendix 320-1.

A follow-up field evaluation should be performed during PS&E or construction as close as possible to the scheduled repair work so any additional deterioration that developed since the latest estimate is repaired.

Engineering judgment, coring, and sounding techniques can be used to identify the extent of the deterioration beneath the surface and determine final repair boundaries. Refer to Standard Plan RSP P-8 and the criteria below regarding the sizing and layout of slab replacements:

- *Minimum length*: It is generally recommended that the entire panel length is replaced for 3rd stage cracking, settlement, or severely spalled cracks. Partial length slab replacement may be used on panels longer than 13’ when the damage (corner crack, joint spalls, etc.) is only on one side of the slab. A minimum repair length of 6.5’ is recommended to minimize rocking, pumping, and premature breakup of the slab.
- *Minimum width*: Always replace the full slab width between longitudinal joints because the boundaries are well defined and the repair is more stable.
- *Joints* (see Figure 320-10):

  - Match the spacing and skew of transverse joints in the existing pavement for cast-in-place and HMA replacements, except any slab replacement ≥ 15' long must have an intermediate transverse joint located at mid-panel to prevent uncontrolled cracking.
  - When the transverse joints in adjacent lanes do not match, the longitudinal joints must have an isolation joint to separate the new and existing pavement, preventing the intermediate slab replacement joint from causing cracks in the adjacent lanes.
- *Adjacent joints/cracks*: A slab replacement joint should be at least 6.5' from the nearest joint or crack to prevent the development of adjacent slab deterioration.
- *Adjacent base deterioration*: Deteriorated base can extend beyond an individual slab into adjacent slabs that will require partial or complete replacement to minimize additional failures. Consider replacing adjacent slabs outside the criteria given in Table 320-3 if distress includes 3rd stage cracking, crack widths > ½", corner cracks with widths > ¼", or settlement.

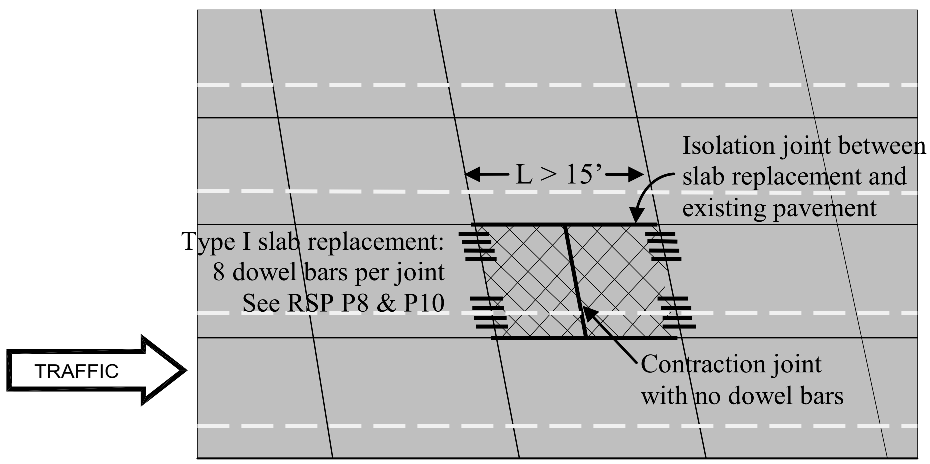


Figure 320-10: Example joint and dowel requirements

Because of the time and labor cost involved in preparing the transverse construction joints for slab replacement, it may be more cost effective to combine closely located replacement areas into one larger repair area, allowing a continuous concrete pour and potentially improving pavement performance. Figure 320-11 shows some examples of cost effective replacement area combinations.

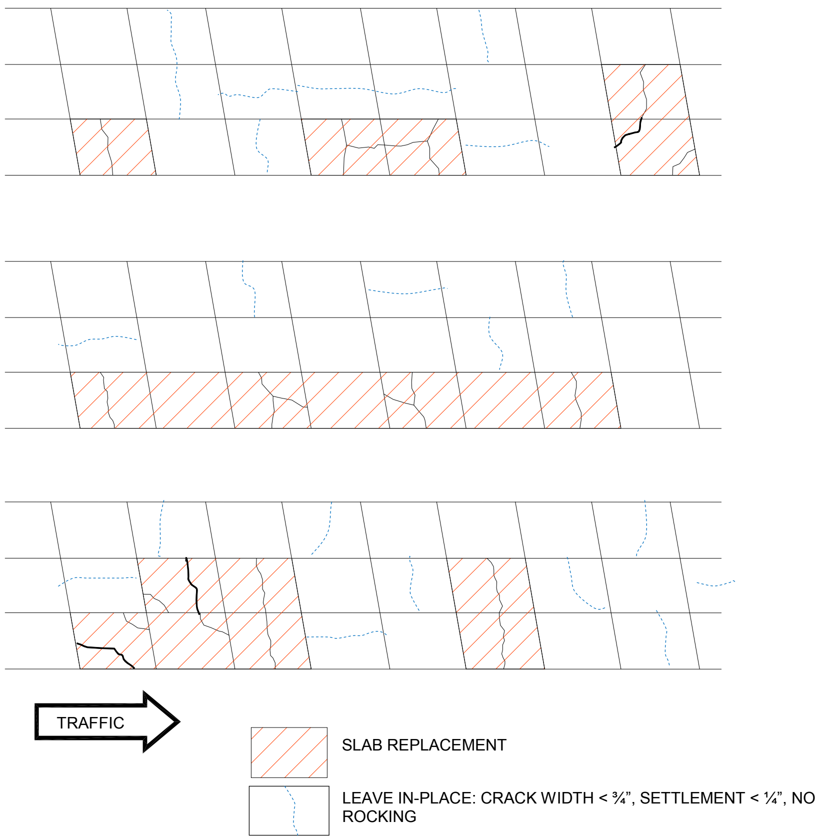


Figure 320-11: Example slab replacement repair areas

320.4.3 Dowel Bar Use

Load transfer is the ability of a joint or crack to transfer a portion of an applied traffic load from one side to the other (see Section 120.3.2). Since saw cutting around the slab replacement perimeter results in a smooth vertical surface with no aggregate interlock, dowel bars are recommended for extended term repairs ≥ 5 years to restore load transfer at transverse construction joints (refer to Type I in Revised Standard Plan RSP P-8). Restoring load transfer helps minimize differential vertical movement that can cause spalling, rocking, pumping, faulting, and premature failure of the replacement or adjacent slabs.

Dowel bars should be installed using the drill and bond method unless the construction window is too short to allow the operation (see 2010 Standard Specification Section 41-10). As an alternative, dowel bars may be installed from the pavement surface after slab replacement using the dowel bar retrofit method (see Ch. 330). Dowel bar retrofit is not preferred for slab replacements due to increased cost and failure potential.

Dowel bars are not necessary in transverse contraction joints saw cut between newly placed slabs because aggregate interlock is expected to provide adequate load transfer throughout the anticipated service life of the slab replacement. Recent data gathered statewide indicated dowels can potentially reduce 3rd stage cracking in replaced RSC slabs, but placing dowels in contraction joints of RSC with moderate shrinkage can cause excessive slab curling stresses.

320.4.4 Pavement Smoothness

Achieving a smooth surface is a challenge with slab replacement work. Consider including diamond grinding to correct smoothness issues associated with poor construction practice and workmanship if the existing pavement meets the criteria in Chapter 340 and HDM Topics 622 and 624.

320.5 PLANS, SPECIFICATIONS, AND ESTIMATING

320.5.1 Plans

A complete set of slab replacement plans requires these sheets:

1. Title sheet showing limits of project
2. Typical cross sections showing existing pavement widths and thicknesses
3. Quantity sheets specifying the type and amount of work.
    - Locations of slab replacement and other work should be tabulated in the quantity tables rather than shown on layout sheets, even if layout sheets are provided for other work. Include the following note: "Locations shown for individual slab replacement and replacing underlying base in quantity tables are approximate. Final locations will be determined by the Engineer."
4. Construction details for unique items of work not addressed on other plan sheets
5. Standard plans listed in Table 320-5:

Table 320-5: Standard Plans for Individual Slab Replacement

Design Feature	Plan	Comments
Individual Slab Replacement with Rapid Strength Concrete	P8	Details for 2 types of RSC slab replacements: • Type I uses drill and bond dowel bars at transverse construction joints for extended term repairs (5-10 years). • Type II without dowels for short term repairs (≤ 5 years) or for crack, seat, and overlay projects.
Joint Sealing	P20	Use when existing joint seals need to be replaced.
Dowel Bar Details	P10	Use for Type I slab replacements with dowel bars

320.5.2 Specifications

Standard Specifications, Standard Special Provisions (SSPs), and additional information on nSSP's for individual slab replacement work are listed in Table 320-6:

Table 320-6: Specifications for Individual Slab Replacement

Item Code	Description	2010 and 2015 Standards	Special Provisions	Comments
411105	Individual Slab Replacement (RSC)	41-9 90-3		For standard slab replacement work. Includes payment for base bond breaker.
Nonstandard	Individual Slab Replacement (precast concrete)		nSSP*	Use with approval for precast concrete. Include nonstandard construction details.
Nonstandard	Individual Slab Replacement (HMA)	39	nSSP*	Use with approval for HMA. Include nonstandard construction details.
Not used	Base Bond Breaker		36-2	Should be included for all individual slab replacement work. Specifies bond breaker materials and placement.

Item Code	Description	2010 and 2015 Standards	Special Provisions	Comments
280200	Replace Base		SSP 28-15	Should be included for all slab replacement work.
Nonstandard	Lean Concrete Base (3/8”)		nSSP*	Use for individual slab replacement with precast concrete.
410096	Drill and Bond (Dowel Bar)	41-10		Use for each bar at construction joints of Type I RSC slab replacements.
Various	Replace Joint Seal	41-5		Use when existing joint seals need to be replaced because of slab repair. Match the existing joint seal material.

*nSSPs must be approved by the HQ Division of Maintenance Pavement Program. Contact the Office of Concrete Pavement and Pavement Foundations.

Existing base removal specifications are in SSP 28-15 “Replace Base,” which also includes payment for the RSCB or LCBRS replacement material and placement. SSP 28-15 must be used together with the appropriate materials specifications in SSP 28-3 for RSCB or 28-4 for LCBRS.

Standard Specification Section 41-9 and SSP 36-2 allow the contractor to select various bond breaker materials such as polyethylene film, curing paper, or geosynthetics for RSCB or LCBRS. Payment for base bond breaker is included in bid item #411105 for individual slab replacement.

When individual slab replacement and other pavement repairs are included in a project, include order of work provisions when applicable (see Section 320.4.1 for recommendations).

The cost current standard specifications, special provisions, and plans are available through the Office Engineer Office of Construction Contract Standards website: http://oe.dot.ca.gov.OCCS.html.

320.5.3 Precast Concrete Pavement Issues

The use of precast concrete systems for slab replacement introduces some unique issues. Whereas cast-in-place systems typically require placing and curing new material in a hole created by the removal of broken slabs, precast systems are built off site using prebuilt forms. Since existing pavement thicknesses vary, establishing exact dimensions for each precast replacement slab during casting or at the site by saw cutting is very expensive and time consuming. To avoid unnecessary construction costs, use the following design features in precast panel system project plans:

1. The construction details developed for use statewide allow for adequate sizing so panels can be trimmed, either to re-establish the original longitudinal joint location between adjacent precast replacements or to customize installations adjacent to gutters. In general, the goal is to cut the hole to fit the precast slab rather than cutting or casting the precast slab to fit the hole.
2. Joints: use perpendicular transverse joints for new precast slabs rather than matching existing skewed joints.
3. Thickness: design the precast panels ½” thinner than the existing concrete thickness. To establish the existing pavement thickness, check ground penetrating radar data from the pavement management system, as-built plans, or consider coring.
4. Length: give Contractor flexibility to select the length of the panel to use for the slab replacement. Precast panel details should require a minimum 8’ length panel that extends at

least 0.10’ beyond the slab replacement limits. Any existing concrete slab left in place must be at least 6’ long.

5. Width: construct the precast slab 0.15’ wider on each side to address potential variability in the existing slab width.
6. Curves: for locations on curves, precast concrete panel plans must show the existing centerline radius information (from as-built data) for trapezoidal construction details.

Precast concrete pavement is an experimental product. Until standard plans, specifications, and guidance are adopted, contact the HQ Division of Maintenance Pavement Program for approval and assistance regarding precast concrete pavement use.

320.5.4 Cost Estimating

It is critical to make a reasonable estimate in the Project Report (PR) or Project Scope Summary Report (PSSR) when programming project funding for slab replacement. Estimates should be based on locations and boundaries identified from APCS, iVision, and field reviews, but reasonably conservative to avoid underestimation, account for invisible deterioration below the pavement surface, and anticipate additional deterioration prior to construction. The slab failure rate over several years at the project location can be used as an indicator of how many additional slabs may fail prior to construction completion. Approximately 15-20% additional slab replacement is typically reasonable. If better information is not available when preparing the cost estimate, assume 20% of the slab replacements will also require base replacement.

For the engineer’s estimate at PS&E, any previous quantity estimates should be updated to reflect existing distress levels. Quantities should be based on current pavement condition data from the pavement management system and verified with a field review as close to PS&E as possible, using the criteria in Section 320.2. The updated estimate should also account for future deterioration likely to occur prior to scheduled project construction, which can be predicted using deterioration rates established from historical pavement condition data or percentage rates based on engineering judgment. Generally, adding 5% to the slab replacement quantity to account for unforeseen locations and additional deterioration is reasonable. While estimates should be conservative to avoid underestimation, overestimating the final estimate for PS&E can lead to slabs that are in good condition being replaced with potentially poorer performing replacements in order to match the estimated quantity.

Accurate quantity estimates should be within 75 to 125% of the actual amount repaired during construction. Slab and base replacement quantities will fluctuate during construction because field conditions change and the actual base condition is unknown until the concrete surface is removed.

Unit Costs

Unit prices for slab replacement vary from project to project in different areas of the state. District construction personnel have unique knowledge and should be consulted about constructability issues that can affect cost such as: traffic handling and closure windows, equipment mobilization, haul routes, delivery times, and availability of rapid strength concrete plant production and scheduling.

Initial construction costs can be estimated using historical contract cost data for all contracted bid items and other information available on the Division of Design cost estimating website at http://www.dot.ca.gov/hq/oppd/costest/costest.htm. Currently, Item 411105 is used for Individual Slab Replacement (RSC), but cost data may be limited. Previously, Items 401000 or 401108 were used for slab replacement. If historical cost data for an item is limited or not reasonable for the project conditions, adjust the unit cost estimate for differences in available data. For approximate estimates of cast-in-place RSC or precast slab replacement, the multipliers in Table 320-7 for Item 401000 "Concrete Pavement" or Item 401050 "Jointed Plain Concrete Pavement" can be used:

Table 320-7: Slab Replacement Unit Cost Estimation

Construction Window (hours)	Cast-In-Place RSC Multiplier	Precast Multiplier
6 – 8	3 – 5x	5 - 8x
12 – 24	2x	3x
> 24	1x	1.5x

Additional Bid Items

A successful slab replacement project may also require additional pavement bid items for replacing base, spall repair, repairing asphalt concrete shoulders or ramps, sealing cracks, and replacing existing joint seals. Replacing the entire joint seal along the slab replacement and sealing cracks will reduce future slab failures by preventing intrusion of incompressible materials and surface water. For joint seals, use the bid item that matches the existing seal material. Reseal both longitudinal and transverse repair joints according to 2010 Standard Specification Section 41-5 using asphalt rubber, silicone, or preformed compression seal material. For more detailed information on joint sealing, refer to Chapter 360.

Bid items for typical slab replacement pavement work are shown in Table 320-8:

Table 320-8: Typical Individual Slab Replacement Pavement Work Bid Items

2010 and 2015 Standards			Prior Standards (for estimating unit costs only)	
Item Code	Description	Unit	Item Code	Description
280200	Replace Base	CY	---	Previously included in other bid items
410096	Drill and Bond (Dowel Bar)	EA	406050	Dowel Bar (Drill and Bond)
411105	Individual Slab Replacement (RSC)	CY	401108	Replace Concrete Pavement (RSC)
410120	Spall Repair (Polyester Concrete)	SQYD	413113	Repair Spalled Joints (Polyester Grout)
410121	Spall Repair (Fast-setting Concrete)	SQYD	413112	Repair Spalled Joints (Fast-setting Grout)
			413111	Repair Spalled Joints
414222 - 414224	Replace Joint Seal (Preformed Compression) - *3 size ranges*	LF	413114	Replace Joint Seal (Existing Concrete Pavement)
414221	Replace Joint Seal (Silicone)	LF	414119	Replace Concrete Pavement Joint (Silicone)
414220	Replace Joint Seal (Asphalt Rubber)	LF	414120	Replace Concrete Pavement Joint (Asphalt Rubber)
Nonstandard	Seal Cracks	LF	414105	Seal Random Cracks
			414111	Rout and Seal Random Cracks

320.5.5 Production Rates

Slab replacement production rates are dependent on lane closure restrictions, location, and the replacement materials used. Longer construction windows are more cost effective and yield greater production, as do replacements in outer lanes compared to center lanes. If slab replacement locations are more than a mile apart, re-mobilization may be required, greatly reducing production rates. If locations are in a confined area that does not accommodate large equipment, time-consuming maneuvering, hand-working, or special equipment may be required.

RSC is typically the most efficient material for slab replacement production. Precast concrete panels are hindered by a complicated installation process that may be unfamiliar to many contractors, while

HMA must be placed in multiple lifts that need to cool before overlaying. If the base needs replacing, production will be reduced by up to 20 minutes per slab.

When determining the number of working days, preproduction lead time also must be considered:

- For RSC, allow 20 working days for mix design verification and trial slab construction.
- Precast concrete pavement is fabricated at a plant, which requires at least 30 days lead time for forming, pouring, and curing. If the contractor proposes modifications to the precast plans, an additional 30 working days could be required to review shop drawings.
- For HMA, allow 25 days for job mix formula verification.

Table 320-9 contains an estimated range of production rates based on replacement material:

Table 320-9: Estimating Individual Slab Replacement Working Days

Replacement Material	Preproduction Lead Time (working days)	Estimated Production Range (slabs/ 8-hr shift)
RSC	20	20 – 32
Precast concrete panels	30 – 60	16 – 28
HMA (2" lifts)	25	15 – 25

320.6 OTHER CONSIDERATIONS

320.6.1 Traffic Control and Safety

Proper traffic control must be placed and maintained on all slab replacement projects for the safety of the traveling public and construction personnel. Providing the maximum construction window is important to reduce worker safety risk, decrease construction cost, and improve slab replacement performance. Longer performing repairs reduce the need for future maintenance and construction activities, increasing safety and life-cycle cost effectiveness.

Considering the project location, size, and scope of work, weekend closures should be used wherever possible, particularly for slab replacement in the far inside or outside lanes. Often, even roadways in high traffic volume areas do not require all lanes during the weekend.

Due to typical traffic demand, a temporary nighttime closure may be necessary to complete slab replacement work, particularly for inner lanes where slab replacement may require closure of multiple lanes at once. Although concrete work can be done in lane closure windows as small as 5 hours, longer windows of 8 to 12 hours provides contractors more time to mobilize, work, and cure concrete, increasing performance and lowering bid costs. Night closures are the least desirable traffic handling alternative due to extended traffic impacts and adverse effects on construction quality, workmanship, production rates, and performance.

Refer to Section 120.3.4 for more detailed information about traffic handling alternatives.

320.6.2 Resident Engineer File

Provide the resident engineer with the criteria and field notes used to select slabs and underlying base for replacement. See Appendix 320-2 for an example Resident Engineer Note.

For precast concrete slabs, include as-built plans showing the centerline curve radii. During construction, volumetric mixing trucks should be available as a contingency to provide material for failed base or removals that are considerably deeper than expected.

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APPENDIX 320-1: Individual Slab Replacement Forms

Distress Map

CO-RTE-PM: **Direction:** **Page:**

Panel No.: **Date:**

Lane

___

Lane

___

___ft ___ft ___ft ___ft ___ft ___ft ___ft

Comments:

Panel No.:

Lane

___

Lane

___

___ft ___ft ___ft ___ft ___ft ___ft ___ft

Comments:

APPENDIX 320-1: Individual Slab Replacement Forms

Field Data Summary Form

CO-RTE-PM: ______________________ **Date:** _______________

Direction: ______________

Lane	Panel No.	Cracking		Faulting	Pumping	Other	Photo no.	Comment
		Type	Severity	inch	(y/n)	Distress		

Cracking type:

TC = transverse; LC = longitudinal; CB = corner break
SS = Shattered Slab (3rd Stage with intersecting cracks)

Other distress type: ASR = Alkali-silica reactivity; R = Rutting

Transverse Cracking

Associated Distress	Severity		
	Low (L)	Medium (M)	High (H)
Crack width (in)	< ¼	¼ – ¾	> ¾
Faulting (in)	< ¼	¼ – 1	> 1
Spall area (ft^2)	< 1	1 – 2	> 2

Longitudinal and Corner Cracking

Associated Distress	Severity		
	Low (L)	Medium (M)	High (H)
Crack width (in)	< ¼	¼ – ¾	> ¾
Faulting (in)	< ¼	¼ – 1	> 1
Spall area (ft^2)	< 1	1 – 2	> 2

APPENDIX 320-1: Individual Slab Replacement Forms

Slab Replacement Summary Form

CO-RTE-PM: ____________________ **Date:** ____________________

Direction: ____________

Lane	Panel No.	Cracking		Faulting	Pumping	Material	Replace (y/n)		Repair size (ft)		Dowel	Jt. Seal	Grind	Photo	Comment
		Type	Severity	inch	(y/n)	Distress	Slab	Base	Width	Length	(y/n)	(y/n)	(y/n)	no.	

Cracking type:

TC= transverse; LC = longitudinal; CC = corner

SS = Shattered Slab (3rd Stage intersecting cracks)

Other distress types: ASR = Alkali-silica reactivity
R = Rutting

Associated Distress:

	Transverse Crack			Longitudinal & Corner Crack		
	Severity			Severity		
	Low (L)	Med (M)	High (H)	Low(L)	Med (M)	High (H)
Crack width	< ¼	¼ – ¾	> ¾	< ¼	¼ – ¾	> ¾
Faulting (in)	< ¼	¼ – 1	> 1	< ¼	¼ – 1	> 1
Spall area (ft^2)	< 1	1 – 2	> 2	< 1	1 – 2	> 2

APPENDIX 320-1: Individual Slab Replacement Forms

Slab Replacement Map

	Direction:								Direction:							CO-RTE-PM:___________
	Lane								Lane							
	S	4	3	2	1	H	S		S	H	1	2	3	4	S	Notes
								C								
								E								
								N								
								T								
								E								
								R								
								D								
								I								
								V								
								I								
								D								
								E								
								R								

S = Shoulder H = HOV Lane

CONCRETE PAVEMENT GUIDE

PART 3: PRESERVATION STRATEGIES

CHAPTER 330 – DOWEL BAR RETROFIT

330.1 PURPOSE AND DESCRIPTION

Dowel bar retrofit (DBR) is applied to JPCP originally constructed without dowels at transverse joints. DBR is a CAPM preservation strategy that can significantly prolong pavement service life from 10 to 15 years by improving load transfer efficiency (LTE) across joints and cracks. Dowel bars significantly decrease relative movement across joints and cracks under load, thus reducing faulting development and further deterioration of joints and cracks. DBR is combined with diamond grinding to provide a smooth-riding pavement surface.

The DBR process entails cutting parallel slots across the existing transverse joints and cracks, installing dowel bars in these slots, and backfilling the slots with polyester concrete (see Figure 330-1).

Figure 330-1: Completed dowel bar retrofit (single wheel path shown)

DBR to restores load transfer efficiency at JPCP joints or cracks. By restoring load transfer, the stresses in the slab and deflections at the joint can be reduced, extending the anticipated pavement service life.

330.2 DBR COMPONENTS

The DBR process contains the following components:

- Dowel bar slots cut into the existing concrete
- Caulk
- Dowel bars
- End caps
- Dowel support chairs
- Foam insert
- Polyester concrete backfill

A brief discussion of each of these components is presented below.

330.2.1 Dowel Bar Slots

Slots are cut in the concrete surface in order to place dowel bars into the existing pavement. The slots are 2.5” wide and parallel to each other and the longitudinal pavement joint. The slots are cut deep enough to allow space below the installed dowel bar for the backfill concrete to completely encase the bar.

330.2.2 Caulk

Latex caulk is used to prevent backfill concrete from entering the existing joint and crack. The caulk is placed into the joint and crack at the sides and bottom of the dowel bar slot. If the polyester concrete backfill material enters the space between adjacent pavement slabs, free movement at the joint could be inhibited, leading to joint damage.

330.2.3 Dowel Bars

Dowel bars are typically solid, smooth steel bars. The bars will either be epoxy coated or made of corrosion resistant steel and are coated with lubricant or release agent to allow longitudinal movement in the concrete backfill. The longitudinal movement allowance permits normal JPCP slab volume change with temperature cycling (see Section 120.1.1). In some special cases fiberglass bars may be used, but they are currently experimental and should only be used by nSSP under the direction of the Headquarters Division of Maintenance Pavement Program. Figure 330-2 shows the epoxy coated steel bars with end cap, support chair, and foam insert.

Figure 330-2: Dowels with end caps, support chairs, and foam inserts

330.2.4 End Caps

Using end caps on the dowel bars establishes a small gap between the dowel bar and the polyester concrete backfill at each end of the bar. As moisture content and temperature of the pavement changes, the concrete volume varies changing the joint width. The gap at the end of the dowel bar accommodates those changes.

330.2.5 Support Chairs

Support chairs hold the dowel bars in position inside the slots as the concrete backfill is placed, consolidated, and sets.

330.2.6 Foam Insert

A foam insert is used to form a joint in the polyester concrete backfill rather than saw cutting because the joint must extend through the entire backfill depth. The existing pavement may be at less than its maximum volume so shrinkage cannot be relied upon to create the joint.

330.2.7 Polyester Concrete Backfill

The polyester concrete backfill must perform the functions of holding the dowel bar in place and transferring load from the concrete pavement to the dowel bar, and from the dowel bar to the concrete pavement on the opposite side of the joint. Load is transferred between the pavement and the backfill through shear forces at the sides of the dowel bar slot. Load is transferred to and from the dowel bar through compressive forces at the top and bottom of the dowel bar.

330.3 PROJECT SELECTION

DBR is a preservation strategy that is suited to pavement that is structurally sound with relatively small amounts of slab cracking and low LTE < 70% at transverse joints and cracks. Generally, DBR can be effective for:

- An aging structurally sound pavement, with adequate thickness, exhibiting poor load transfer due to lack of dowels and poor aggregate interlock.
- A relatively young pavement in good condition but with the potential to develop faulting, working cracks, or corner breaks due to insufficient slab thickness, joint spacing greater than 15 feet (4.6 m), or inadequate joint load transfer.

330.3.1 Appropriate Use

Load Transfer – Perform a LTE survey of each lane in the pavement segment being considered for DBR. The survey should consist of at least 10 joints per ¼-mile. Pavements with LTE values < 70 percent are considered viable candidates for DBR.

3rd stage cracking – Perform a crack survey of the project. Count the slabs that have been replaced and slabs that have 3rd stage cracking. If the number of slabs with 3rd stage cracking plus those that have already been replaced is < 2% per lane in the pavement segment, DBR may be appropriate. If 3rd stage cracking plus replaced slabs is between 2 to 5%, and average accumulated faulting (current faulting plus previously ground faulting) is < 0.6", DBR may be appropriate.

330.3.2 Limitations

Do not perform DBR on pavement with any of the following conditions:

- Extensive 3rd Stage cracking – 3rd stage cracking plus slab replacement exceeding 5 percent is unsuitable for DBR. Pavement with 3rd stage cracking in excess of 5% is approaching the limit of its functional life; individual lab replacement for the short term and rehabilitation for the long term are more appropriate strategies.

- Concrete integrity – Concrete pavement with materials related distress such as alkali-silica reaction (ASR) or freeze thaw related deterioration is unsuitable for DBR.

- Structural condition of base – The base should be in good structural condition to support the slabs. If the base is exhibiting pumping or non-uniform support conditions, then DBR is not appropriate.

- Joint or crack spalling – DBR treatments require sound material near the transverse joint or crack to ensure adequate transfer of load from one slab to another. Transverse joints and cracks with extensive high-severity spalling > 2 ft^2 are not candidates for DBR.

If localized distress within the pavement segment limits continuous DBR application, consider using a combination of strategies (see Section 100.3.2) with DBR such as spall repair (Ch. 310) and slab replacement (Ch. 320) within the project limits.

330.3.3 Recommended Applications

Most transverse cracks should be retrofit with dowel bars. Figures 330-3 through 330-6 show recommended strategies based on existing slab condition, excluding severity (crack width). Slabs with cracks that are not retrofit should be replaced with longer design life Type I slab replacements (see Ch. 320).

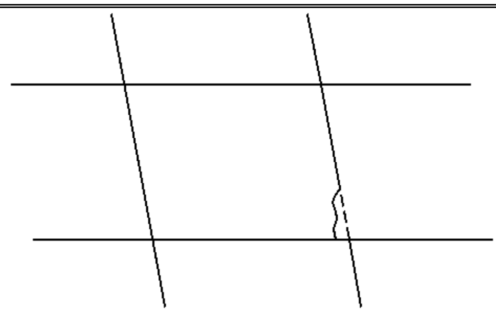
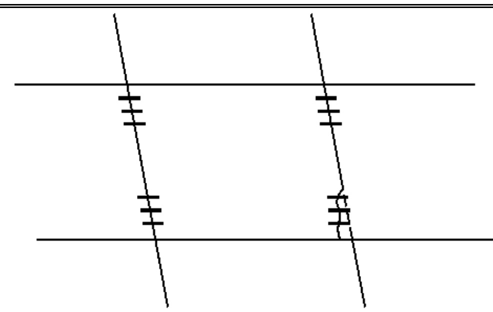
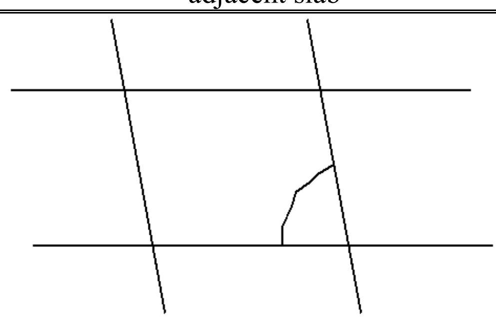
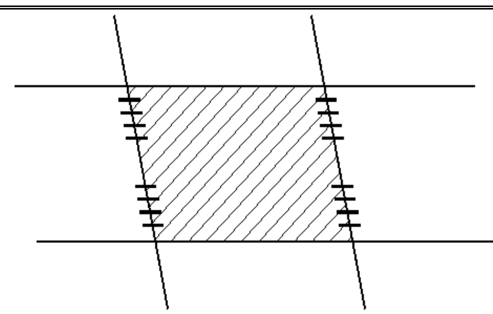
Existing Slab Condition	**Appropriate Strategy**
 Working corner crack: corner attached to adjacent slab	 DBR crack
 Corner crack: corner is an independent piece	 Replace slab using RSP P8

Figure 330-3: Corner cracking strategies

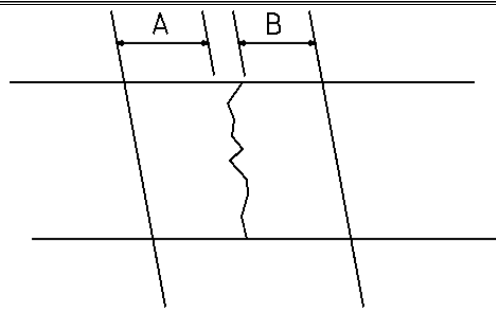
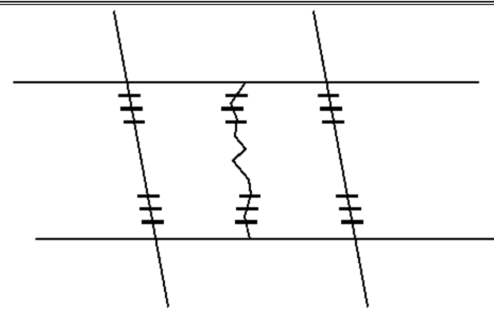
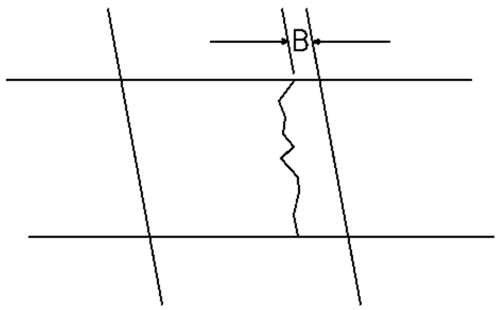
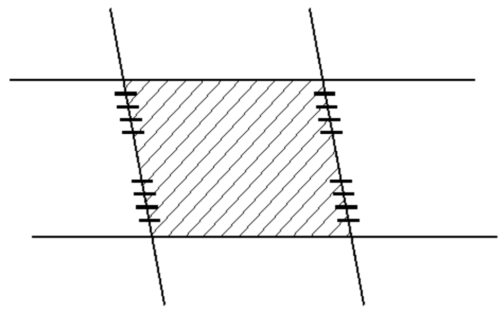
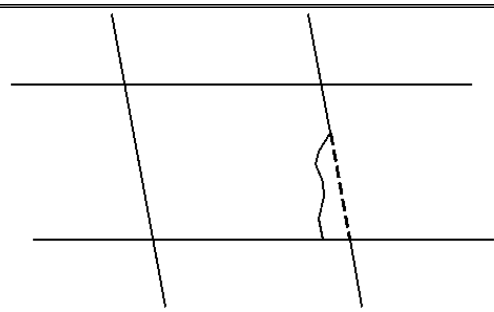
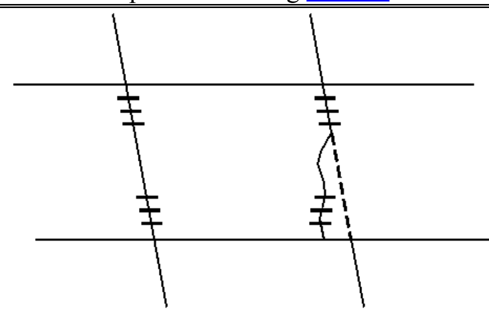
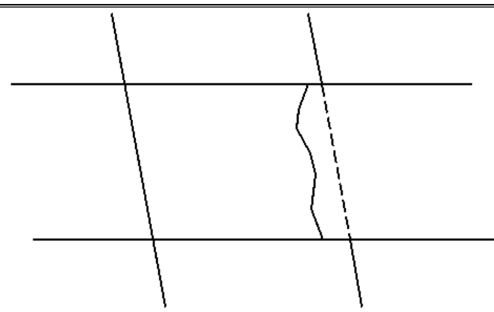
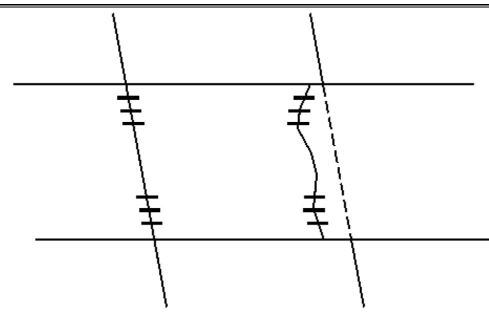
Existing Slab Condition	Appropriate Strategy
 Transverse crack: A and B greater than 3 ft	 DBR crack and joints
 Transverse crack: ‘B’ less than 3 ft	 Replace slab using [RSP P8]
 Transverse crack partially formed at saw cut	 DBR joints and active transverse crack
 Saw cut did not crack: transverse crack is active joint	 DBR transverse crack

Figure 330-4: Transverse cracking strategies

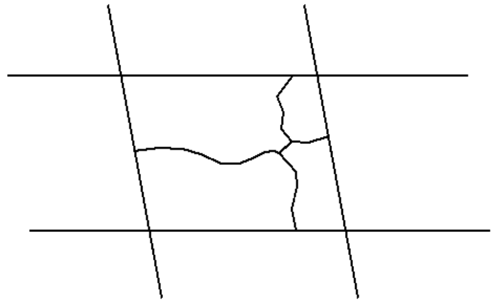
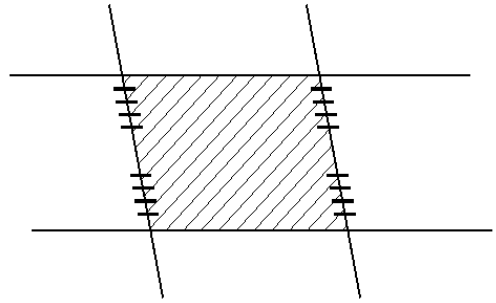
Existing Slab Condition	Appropriate Strategy
 3rd stage cracking: slab cracked into 3 or more pieces	 Replace slab using RSP P8

Figure 330-5: 3rd stage cracking strategy

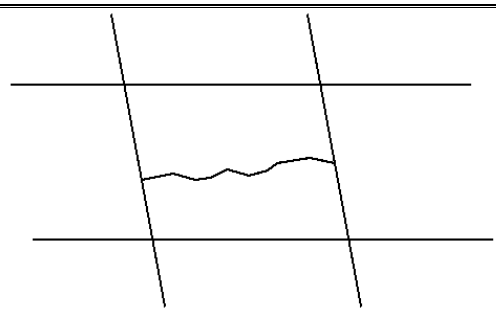
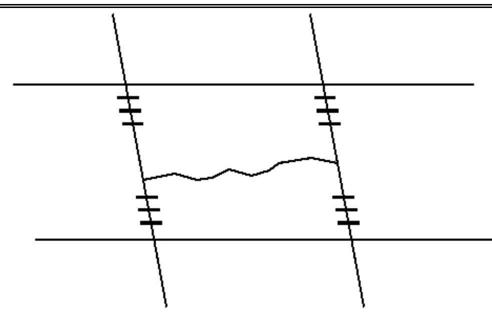
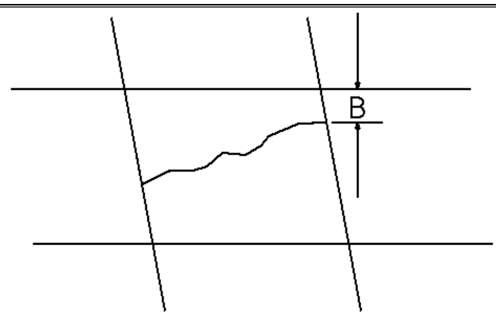
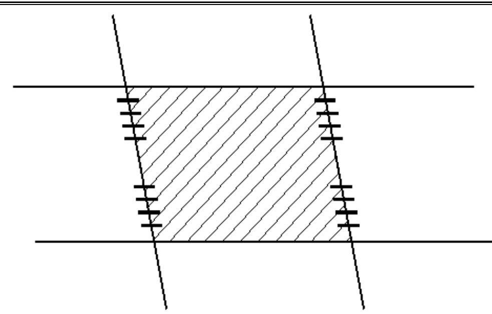
Existing Slab Condition	Appropriate Strategy
 Longitudinal crack mid panel	 DBR joints
 Longitudinal crack: B less than 4 ft	 Replace slab using RSP P8

Figure 330-6: Longitudinal cracking retrofit/replace strategies

330.4 PLANS, SPECIFICATIONS, AND ESTIMATING

330.4.1 Plans

Accurately indicate DBR and grinding limits on the project layout and typical cross section sheets. DBR details are shown on Revised Standard Plan RSP P7, available on the Office Engineer internet site: http://www.dot.ca.gov/hq/esc/oe/project_plans/highway_plans/stdplans_US-customary-units_10/viewable_pdf/rspp07.pdf.

Typically only the truck lanes are retrofitted, however, at locations where a JPCP auxiliary lane is adjacent to a lane being retrofitted, it should also be retrofitted regardless of its condition.

The entire limits of DBR work must be ground for smoothness using a separate pay item under Section 42 of the Standard Specifications.

330.4.2 Specifications

In the 2010 Standard Specifications, Section 41-8 is reserved for dowel bar retrofit using standard special provision (SSP) 41-8, which can be found on the Office Engineer website at http://www.dot.ca.gov/hq/esc/oe/construction_contract_standards/SSPs/2010-SSPs/division_5/41-8_A07-19-13.docx.

330.4.3 Estimating

The quantity sheets should indicate separate quantities for dowel bar retrofit (joint), dowel bar retrofit (crack), and grind existing concrete pavement. The construction effort to retrofit cracks is greater than to retrofit joints, so the cost will be a bit higher. In cases where DBR is performed on a joint that is formed partially along the saw cut and partially along a volunteer path, estimate the work as half DBR (joint) and half DBR (crack). Where a slab needs to be replaced, do not include the transverse joints at each end of or within the replacement area in the retrofit quantities since dowels will be installed as part of the slab replacement.

Dowel bar retrofit is paid for by each joint or each crack. The bid items are listed in Table 330-1:

Table 330-1: Dowel Bar Retrofit 2010 Bid Items

Item Code	Description	Unit	Standard Specification Sections
410091	DOWEL BAR RETROFIT (JOINT)	EA	41-1.01; 41-8
410092	DOWEL BAR RETROFIT (CRACK)	EA	41-1.01; 41-8
420201	GRIND EXISTING CONCRETE PAVEMENT	SQYD	42-3

After retrofitting joints and cracks with dowel bars, the entire surface width of the adjoining slabs must be ground. Grinding is paid separately from dowel bar retrofit, so include Item 420201 Grinding Existing Concrete Pavement in the work item estimate.

Typically, some slabs within the project limits will require replacement using the criteria given in Section 320.2 and in Section 330.3.3. Include item 411105 Individual Slab Replacement (RSC).

If spall repair is also needed within the project limits, it is measured by the square yard. Spall repair with polyester concrete (Item 410120) should be used since the repairs last longer and use polyester concrete materials similar to those used for DBR (see Ch. 310).

CONCRETE PAVEMENT GUIDE

PART 3: PRESERVATION STRATEGIES

CHAPTER 340 – GRINDING AND GROOVING

This chapter provides an overview for restoring functional surface characteristics using diamond grinding and grooving.

340.1 PURPOSE AND DESCRIPTION

Grinding is used as a preventive maintenance strategy to remove roughness from faulting or other sources, enhance concrete pavement surface friction characteristics, and improve safety. In snowy environments, grinding can remove rutting from surface attrition due to studded tires, tire chains, or other factors. Gang-mounted diamond saw blades (see Figure 340-1) are used to shave off 1/8" or more from the existing concrete surface, creating a level, quiet finished surface with longitudinal texture (see Figure 340-2).

Figure 340–1: Diamond saw blade

Figure 340–2: Diamond ground surface

The same technique and equipment is used for grooving, which is a separate preservation strategy from grinding used to reduce hydroplaning and traffic collisions. Grooving provides escape channels for surface water by cutting deep channels using power-driven, self-propelled machines with 0.10" wide diamond blades spaced at ¾" on centers to cut grooves from 0.12 to 0.30" deep in the longitudinal direction (see Figures 340-3 and 340-4).

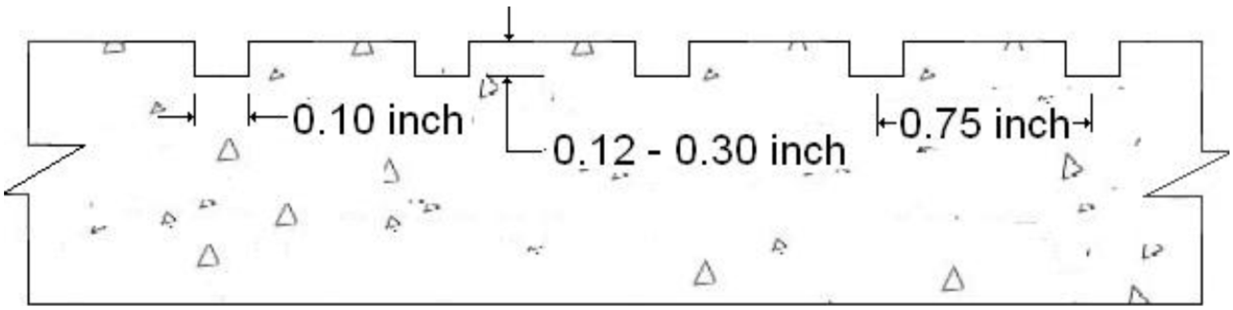


Figure 340–3: Grooved pavement detail

Figure 340–4: Grooved pavement surface

340.2 CRITERIA FOR USE

340.2.1 Grinding

<u>Applications</u>

Grinding improves pavement smoothness and ride quality. Roughness can develop from structural distresses such as cracking or spalling, or from faulting, which is a preliminary indicator of structural deficiencies (see Section 110.2.1). Pavement is considered to have poor ride quality when the international roughness index (IRI) is > 170 inches/mile. Grinding is more cost effective for treating faulting > ¼" over 50% of the pavement management segment.

For new JPCP or CRCP construction in lane replacement or widening projects, the entire adjacent lane width should be ground before widening if IRI ≥ 90 inches/mile to establish a smooth profile for concrete paving equipment.

In some situations, grinding should be used in combination with other preventive maintenance strategies such as spall repairs, dowel bar retrofit (Ch. 330) to treat poor load transfer < 70%, or individual slab replacement (Ch. 320) when cracking extent is < 10%. For rutting > ¼” due to concrete durability issues, grinding can be used in combination with specialized surface hardener treatments (see Ch. 350) or HMA overlays (Ch. 370).

Limitations

Grinding may not be the most effective strategy if cracking extends > 15% throughout the segment. Rehabilitation alternatives such as lane replacement (Ch. 400), crack, seat, and HMA overlay (Ch. 410), and unbonded concrete overlay (Ch. 420) should be considered. See Chapter 100 for more information about strategy selection.

Grinding can remove faulting and rutting to restore smoothness, but if the failure mechanism is not repaired the effects can be short-lived. If the pavement has structural or material deficiencies, such as slab cracking or rocking; inefficient load transfer; or reactive, soft, or polishing aggregates; grinding will not repair or improve these defects and repair strategy combinations should be considered and analyzed.

Grinding can maintain smoothness for up to 15 years of service life, but should be used with discretion when IRI ≤ 170 inches/mile because it reduces pavement thickness, which can affect long-term pavement performance. Depending on existing thickness, pavements may be ground up to 2 or 3 times without significantly affecting the structural capacity of the pavement structure. However, grinding is not advisable on concrete pavement thinner than 8” with heavy vehicle loading because reduced pavement thickness will lead to pavement rupture and cracking.

340.2.2 Grooving

A 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. Grooving longevity varies inversely with the traffic volume and gross weight of vehicles with tire chains. Concrete with better durability or abrasion resistance properties improves grooving effectiveness.

Similar to grinding, grooving should only be applied to pavements with sound structural and functional characteristics and where requested by district maintenance or traffic safety engineers.

340.3 OTHER CONSIDERATIONS

340.3.1 Order of Work

Diamond grinding is usually performed in conjunction with other repairs, and the order of work is important for pavement quality. Slab subsealing and jacking (Ch. 300), spall repairs (Ch. 310), individual slab replacement (Ch. 320), and dowel bar retrofit (Ch. 330) should be performed before diamond grinding to ensure uniform final smoothness and surface friction properties. Crack and joint sealing (Ch. 360) should be performed after grinding is completed to avoid residue accumulation.

Prior to widening or lane replacement, complete all repair work in the adjacent lane. If the adjacent lane has an IRI ≥ 90 inches per mile, grind the entire lane width before widening to establish a smooth profile for concrete paving equipment.

340.3.2 Concrete Pavement Grooving and Grinding Residues

Grinding and grooving generate concrete slurry residue from cooling water and ground concrete particles that must be removed and disposed of according to the guidance in Design Information

Bulletin 84. The large, motorized grinding and grooving machines have internal vacuums that collect the slurry, which must be removed and disposed of by the contractor according to the requirements in Section 13 of the Standard Specifications (see Figure 340-5).

Figure 340–5: Grinding residue collection

340.4 PLANS, SPECIFICATIONS, AND ESTIMATING

340.4.1 Plans

The location and limits of grooving or grinding that is paid separately should be shown on the project plans, including lanes adjacent to widening where IRI > 90 inches/mile. The typical cross sections should also indicate the grinding depth.

340.4.2 Specifications

Grooving specifications are in Section 42-2 of the Standard Specifications. Grinding specifications are in Section 42-3. Table 340-1 lists grinding and grooving related standard special provisions (SSPs) for the 2010 and 2015 Standard Specifications and some usage instructions.

Table 340-1: Grooving and Grinding 2010 and 2015 SSPs

SSP	Notes
42-1.03B	Use for concrete residue from grooving and grinding when onsite drying or disposal within the highway is allowed.
42-3.03A	Use if grinding locations are not specified in Section 42-3.03A or shown, such as at bridge decks or weigh-in-motion scales.

For new JPCP or CRCP construction under Standard Specification Section 40, including reconstruction, lane replacement, widening, and unbonded overlays, corrective grinding for localized IRI > 60 inches/ mile is included in the pavement work, so no additional grinding item is required for those surfaces.

Grinding is an optional combination strategy for spall repairs and individual slab replacement, but grinding is required for dowel bar retrofit work and paid separately.

340.4.3 Cost Estimating

Initial costs can be estimated using historical prices bid by Contractors and other information available on the Division of Design cost estimating website at http://www.dot.ca.gov/hq/oppd/costest/costest.htm. Available unit cost data should be adjusted based on project-specific factors such as location, quantity, contractor availability, and construction constraints such as lane availability and environmental issues.

The cost of grinding or grooving is paid by area at the contract unit price per square yard (see Table 340-2). Grinding and grooving is continuous along a traffic lane for the entire lane with, including lane lines. Due to the high mobilization costs associated with the large, specialized grinding equipment the unit cost will increase for projects with staged construction or if multiple setups are required to accommodate project conditions. Grinding cost does not include the water pollution control program, pavement marker or traffic striping removal, or joint seal replacement.

Grinding is not included in the pay item for spall repairs, individual slab replacement, or dowel bar retrofit and must be paid separately.

Table 340–2: Grinding and Grooving Item Codes

Item Code	Description	Unit
420102	Groove Existing Concrete Pavement	SY
420201	Grind Existing Concrete Pavement	SY

CONCRETE PAVEMENT GUIDE

PART 3: PRESERVATION STRATEGIES

CHAPTER 360 – JOINT AND CRACK SEALING

This chapter provides guidance on current practices for sealing or resealing transverse and longitudinal joints and cracks in JPCP, including procedures for selecting appropriate seal materials for specific applications, climatic, and traffic conditions. Some basic joint and crack preparation information is introduced, but refer to the Construction Manual or Maintenance Manual for more information.

360.1 INTRODUCTION

Transverse and longitudinal joints are designed and constructed in JPCP to allow slab expansion and contraction and prevent cracking. CRCP uses unsealed transverse cracks instead of transverse joints, and longitudinal joints which may be sealed depending on climate region. Joints are constructed by sawing to a partial depth shortly after concrete placement. Joints may be sealed using asphalt rubber, silicone, or preformed compression joint seal materials during initial construction (depending on climate region) and later resealed to improve pavement performance.

Sealing or resealing cracks requires a nonstandard special provision (nSSP) with approval from the Headquarters Division of Maintenance Pavement Program.

360.2 PURPOSE

The purpose of joint and crack sealing concrete is to reduce infiltration of moisture and incompressible materials into joints and cracks for improved pavement performance. Infiltration of water through unsealed joints and cracks is the main source of surface water into the pavement structure. Moisture in the pavement foundation can allow loss of slab support from base and subgrade erosion and pumping, which causes rigid pavement distress. Sealing also can prevent incompressible materials from entering joints or cracks. Incompressible materials lock joints or cracks open and create excessive stresses that may cause spalling, blowups, or shattering.

As concrete pavement ages, the slab is subjected to continued shrinkage, horizontal movement from expansion and contraction with temperature and moisture fluctuations, and the vertical impact of repeated traffic loads. Large tensile and compressive stresses can cause joint separation and cracking which may continue to widen with time.

360.3 APPROPRIATE USE

360.3.1 New Joints

According to HDM Index 622.5, the current policy is new JPCP and CRCP joints should **not** be sealed except for:

- Isolation joints
- Expansion joints
- Transverse JPCP joints in all desert and mountain climate regions

HDM Index 622.5 also recommends longitudinal construction joints be sealed in all desert and mountain climate regions, but this is currently considered unnecessary and unadvisable due to constructability issues.

Historically, standard policy has varied from not sealing any JPCP joints or cracks to sealing all joints and cracks. California has a varied climate that is typically temperate and arid and there is a long history of unsealed joints performing well in JPCP. The current joint seal policy is based on balancing the long-term benefits of sealing joints with pavement performance, installation and maintenance costs, and minimizing worker exposure to traffic.

360.3.2 Existing Joints and Cracks

Policies for existing joints have typically varied according to individual district maintenance practices. Typically, existing sealed and unsealed joints should be reviewed with the district maintenance engineer or materials engineer during planning and design of pavement preservation and rehabilitation activities to determine if joint sealing or replacement is warranted and if so, what material is recommended (see Section 360.5). Examples of good unsealed joint performance are shown in Figure 360-1.

a) Rte 99 Inland Valley built in 1960's

b) 08-SBd-10 – Built in 1949

Figure 360–1: Unsealed joint performance

There has been considerable national debate and research effort on the issues and cost effectiveness of joint and crack sealing and resealing, including need and timing (seal during initial pavement construction or as ongoing preservation and maintenance); materials, design, and application; and the relative effectiveness of such strategies. As annual automated pavement condition survey (APCS) data continues to be gathered and analyzed, it may be possible to better determine the cost effectiveness and optimal timing joint sealing for concrete pavement service life. Transverse and longitudinal joint condition is recorded for the APCS based on whether the joint is sealed or not sealed and spalled or not spalled. Joint separation is not currently reported for the APCS, but average and maximum crack width data are available in the pavement management system PaveM for individual slab data segments.

<u>Sealing Unsealed Joints and Cracks</u>

Joints should be sealed as pavement ages to extend the service life, typically about 20 years after initial construction but depending on variables including material type, climate, and pavement condition (see

Figure 360-1). Regardless of pavement age, existing joints and cracks should be sealed if joint separation or crack width ≥ 1/4" in the summer or 3/8" in the winter for > 50% length.

Replacing Existing Joint and Crack Seals

Joint and crack seals should be replaced when the existing material exhibits distress, but before the adjacent pavement is severely damaged (see Figure 360-2). Failure to replace seals on a regular basis can increase pavement damage. Joint resealing will typically be needed every 10 to 15 years depending on the material type, climate, and pavement conditions. It is often performed along with other pavement preservation work, including spall repair, individual slab replacement, and grinding.

a) Seals not maintained or replaced

b) Well maintained seals

Figure 360–2: Maintaining seals

360.4 Design

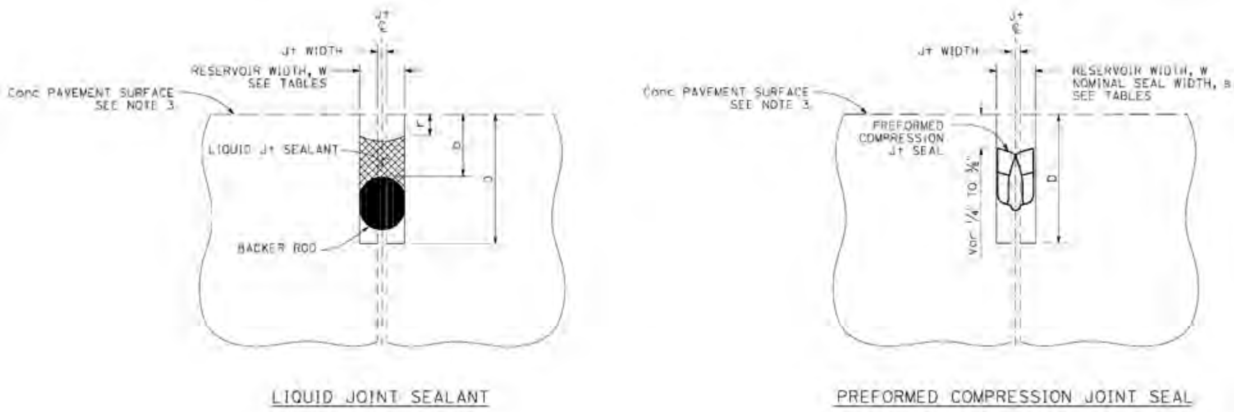
Joint seal dimensions for sealing new and existing joints are shown on Revised Standard Plan (RSP) P20. Appropriate joint sealing design and construction considerations can ensure extended joint seal performance and include:

- Material selection
- Reservoir dimensions
- Joint cleaning
- Material selection
- Seal material installation

360.4.1 Reservoir Dimensions

The joint reservoir width and depth are critical to seal performance. The joint seal reservoir width must be greater than the maximum joint movement that can occur during pavement service life.

To achieve the best seal performance, the dimensions for both liquid joint sealant and preformed compression seals should be designed and constructed according to RSP P20 (see Figure 360-3). The reservoir dimensions were determined using manufacturer recommendations based on typical relationships established between the maximum allowable seal strain and extension at the widest joint opening, considering various reservoir widths and depth-to-width ratios (shape factors).



RESERVOIR WIDTH W ±1/16"	LIQUID JOINT SEALANT DIMENSIONS					
	BACKER ROD NOMINAL Dia *	DEPTHS (ASPHALT RUBBER) **		DEPTHS (SILICONE)		
		RESERVOIR D ± 1/4"	BACKER ROD b ± 1/16"	RESERVOIR D ± 1/4"	BACKER ROD b ± 1/16"	RECESS r ± 1/16"
1/4"	3/8"	1 3/4"	7/8"	1 3/8"	1/2"	1/4"
3/8"	1/2"	1 7/8"	7/8"	1 1/2"	1/2"	1/4"
1/2"	3/4"	2"	7/8"	1 3/4"	9/16"	5/16"
5/8"	7/8"	2 1/4"	1"	2"	5/8"	5/16"
3/4"	1"	2 3/4"	1 1/8"	2 1/4"	3/4"	3/8"
7/8"	1 1/4"	3"	1 1/4"	2 1/2"	13/16"	3/8"
1"	1 1/2"	3 1/4"	1 3/8"	2 5/8"	7/8"	3/8"
1 1/8"	1 1/2"	3 1/2"	1 1/2"	2 13/16"	1"	1/2"

* Larger diameter backer rods may be substituted according to manufacturer recommendations if reservoir depth is increased equivalently.

** Asphalt rubber sealant recess depth "r" varies from 1/4" to 3/8"

RESERVOIR WIDTH W ±1/16"	PREFORMED COMPRESSION JOINT SEAL DIMENSIONS	
	NOMINAL SEAL WIDTH s	RESERVOIR DEPTH D ± 1/4"
1/4"	7/16"	1 1/4"
3/8"	9/16"	1 7/16"
1/2"	13/16"	1 9/16"
5/8"	1"	1 7/8"
3/4"	1 1/4"	2 1/8"
7/8"	1 5/8"	2 5/8"
1"	1 3/4"	2 5/8"
1 1/8"	2"	2 7/8"

Figure 360–3: Joint deal dimensions

360.5 Materials

Concrete pavement joints can be sealed using liquid sealants or preformed compression joint seal materials. Liquid sealants are either hot-applied asphalt rubber or cold-applied silicone materials used with backer rods. Preformed compression joint seals are elastomeric polychloroprene materials placed with lubricant adhesive.

Joint seal material requirements for liquid sealants and preformed compression joint seals are in Section 41-5.02 of the 2010 Revised Standard Specifications (RSS), summarized below in Table 360-1.

Table 360-1: Joint Seal Materials

Joint Seal Material*		Material Requirements	Description
Liquid sealants	Asphalt rubber (hot-applied)	ASTM D6690 Type II	Liquid sealant mixture of paving asphalt and min 10% rubber. Use Type 1 backer rods.
	Silicone (cold-applied)	Authorized Material List	Low modulus, 1-part liquid sealant formulation.
	Backer rods	ASTM D5249 (Type 1 or 3)	• Expanded, closed-cell polyethylene foam • Diameter > 25% of reservoir cut width
Preformed compression joint seals		ASTM D2628	• Polychloroprene elastomeric • 4 cells ≤ ½” wide • 5 or 6 cells > ½” wide
Lubricant adhesive		ASTM D2835	Polychloroprene based material

*Other types of joint seal materials are available but are not used by the Department due to various reasons.

360.5.1 Materials Selection

Material selection for joint and crack sealing or resealing requires an understanding of the basic properties and performance characteristics of available materials and relating those properties to the suitability of the seal for various joint types and environmental conditions on the project. Selecting an appropriate seal material for a specific project application is a challenge given all of the variables involved, including the application, performance requirements, anticipated project conditions, and other criteria. When selecting a seal material, consider severe project conditions that will require more durable sealants and more frequent replacement:

- Climate: preformed compression joint seals are recommended in mountain and high desert climate regions. Backer rods required with liquid sealants contribute to premature joint seal failure where chains are used during winter storms.
- Traffic characteristics: higher vehicle and truck volumes

No one material has the perfect properties suitable for all applications: key differences include physical properties, cost, and anticipated service life. The material with the longest service life suitable for the project conditions and intended use should be selected, but joint seals should not last longer than the pavement being sealed. Table 360-2 compares the anticipated service life of materials for joint sealing applications:

Table 360-2: Joint Seal Material Anticipated Service Life

Joint Seal Material*	Anticipated Service Life** (years)
Liquid sealants	---
Asphalt rubber (hot-applied)	5–10
Silicone (cold-applied)	7–12
Preformed compression joint seals	10–20

*Liquid sealants can be used for crack sealing applications, but expect reduced service life
**Modified from ACPA, 2001

Asphalt rubber sealants are initially cheaper than other seal materials but they generally have a shorter service life due to loss of elasticity and plasticity with age. Because of their low initial cost and wide range of applications, asphalt rubber sealants have been widely used in pavement joints.

In locations with temperature extremes and high truck traffic, silicone sealants or preformed compression joint seals may offer better long-term performance.

Tied joints generally move very little and the openings are relatively narrow, so materials used for longitudinal joints may not require as much extensibility as for transverse joints. Also, the same type of longitudinal joint seal material should be used on a project to maintain continuity.

<u>Replacing Existing Joint and Crack Seals</u>

Existing performance may indicate which type of replacement seal material should be used. If the existing joints are in good condition and the widths are consistent, preformed compression joint seals can be used for extended performance life replacements. If the existing joint or crack conditions vary, spall damage should be repaired and asphalt rubber or silicone liquid used to reseal joints and cracks. When considering the appropriate replacement material, consider these performance indicators:

- Missing or extruded seal material
- Adhesion loss: loss of bond with the joint face

- Cohesion loss: sealant tears
- Hardening/loss of flexibility
- Weed growth
- Embedded incompressible materials
- Joint spalling

360.5.2 Material Properties

Joint seal material properties critical to long-term performance include:

- *Durability*: allows the joint seal material to withstand the abrasion and damage of traffic and weather conditions, including temperature extremes, exposure to moisture, temperature and moisture fluctuations, ultraviolet light and ozone.
- *Extensibility/ Modulus*: the ability of the seal material to deform without rupturing. It is related to the strain component of elastic modulus. Low modulus (soft, low stress-strain ratio) seals are generally more extensible than higher modulus (stiffer) materials, but they are more vulnerable to intrusion by incompressible materials. Low modulus joint seal materials are desirable for achieving long-term performance in cold climate locations, but may be too soft where traffic is heavy or the climate is hot.
- *Elasticity/Resilience*: measures the amount of recoverable deformation that allows the seal material return to its original size and shape after being stretched or compressed. High values of elasticity and resilience are desirable and typically indicate good resistance to intrusion of incompressible materials. For some thermoplastic sealants, high resilience and resistance to intrusion may limit extensibility, so trade-offs may be necessary to balance the desired joint seal properties.
- *Adhesiveness*: the joint seal material's ability to adhere to joint faces is essential to liquid sealant performance. The condition and cleanliness of the joint or crack faces are critical to achieving adhesion for a successful application. Adhesiveness for preformed compression seal also depends on the lubricant adhesive.
- *Cohesiveness*: the ability of the seal material to hold together and resist internal rupture or tearing. Cohesive failures are more likely to occur in liquid sealants that have aged or stiffened.
- *Compatibility*: the ability of the seal to be compatible with other materials, such as backer rods, other sealants, and fuel or chemicals from spills.

360.5.3 Liquid Sealants

Section 41-5 of the 2010 Standard Specifications allows asphalt rubber and silicone liquid sealant materials, which are applied in liquid or semi-liquid form. Asphalt rubber is hot-applied and silicone is cold-applied. The sealants assume the shape of the reservoir and depend on long-term adhesion to the joint or crack faces for successful performance. Liquid sealants are usable over a wide range of extension and compression depending on climatic temperatures and material aging characteristics.

<u>Backer Rod</u>

Backer rod or joint filler material are needed to ensure long-term liquid sealant performance. Backer rods must be placed before installing liquid joint sealant except for isolation joints, which require joint filler material (see RSP P18). Backer rods are used with liquid sealants to:

- Limit the sealant depth, conserving material and defining the reservoir dimensions
- Facilitate tooling and shaping of the sealant material
- Limit sealant displacement from traffic and fluid pressure

- Provide a bond breaker, preventing the sealant from bonding to the bottom of the joint

Section 41-5 of the 2010 Revised Standard Specifications specifies that backer rods:

- Comply with ASTM D5249:
  - Type 1 for asphalt rubber joint sealant
  - Type 1 or Type 3 for silicone joint sealant
- Be expanded, closed-cell polyethylene foam
- Have a diameter > 25% of the saw cut reservoir width
- Be installed on a dry surface when the ambient air temperature is above 40°F and the dew point

Backer rods must be a flexible, non-absorptive material that is compatible with the liquid sealant material to be installed. It should compress within itself so sealant is not forced out as the joint closes, and it should recover as the joint opens. Care must be taken to use the correct backer rod diameter and installation depth so that the backer rod is compressed approximately 50%. Typically, the backer rod diameter should be about 25% larger than the joint width (see RSP P20 and Figure 360-3).

Asphalt Rubber

Asphalt rubber sealants are hot-applied liquid sealants that should be placed when the pavement surface temperature is at least 50°F. Section 41-5 of the 2010 RSS specifies that asphalt rubber sealant must:

- Consist of paving asphalt mixed with not less than 10% ground rubber by weight. Ground rubber is vulcanized or a combination of vulcanized and devulcanized materials passing a no. 8 sieve.
- Comply with ASTM D6690 for Type II.
- Be capable of melting at a temperature below 400 °F and applied to joints.

Asphalt rubber sealant should be uniformly installed by filling the joint reservoir from the bottom up without overfilling and by pulling the nozzle toward the installer to avoid trapping any air bubbles. RSP P20 shows the surface of the sealant should be recessed from 1/4” to 3/8” below the finished pavement surface to allow room for expansion during hot weather and avoid contact with traffic tires.

Properly installed asphalt rubber sealants are typically expected to have service life of 5 years, but field evaluations indicate they may achieve longer service life depending on climatic conditions and traffic loading.

Silicone

Silicone sealants are cold-applied liquid sealants. The Standard Specifications require the silicone joint sealant used be on the Authorized Material List, available on the METS internet site: http://www.dot.ca.gov/hq/esc/approved_products_list/pdf/silicone_joint_sealant.pdf.

Silicone sealants should be installed in the same manner as hot-applied asphalt rubber sealants, from the bottom to the top of the joint and pulling the nozzle toward the installer. Minimum placement depth is ¼” (see required dimensions on RSP P20). Properly installed silicone sealants are typically expected to have a service life of 7 to 12 years, but field evaluations indicate they may perform beyond 10 years depending on climatic conditions and traffic loading.

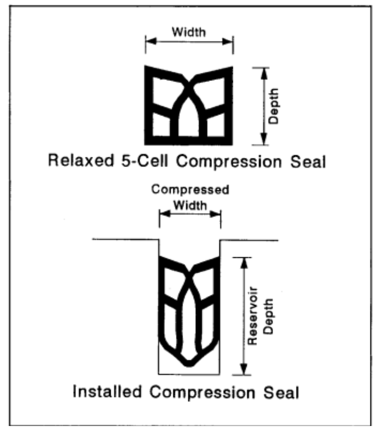
When installing both silicone and asphalt rubber sealants on a pavement section, the special provisions should specify silicone be installed first to reduce the potential for contamination of the transverse joint during the longitudinal joint sealing operations. The recommended practice is to install cold-applied sealants first, regardless of the joint orientation.

360.5.4 Preformed Compression Joint Seals

Preformed compression joint seals are comprised of compartmentalized cross-sectional cells extruded from elastomeric polychloroprene compounds. They consist of 4 to 6-cell configurations that exert lateral pressure against the joint faces and provide long-term compression recovery for successful sealing (see Figure 360-4).

To ensure effective sealing, sufficient contact pressure must be maintained at the joint face. The seal must always be in compression, which requires resistance to compression set. When joints expand, the seal should recover its original size and shape. Preformed compression joint seals perform well over a compression range of 20 to 50%.

a) Installation



b) Typical 5-cell cross section (ACPA, 1993)

Figure 360–4: Preformed compression joint seals

Preformed compression joint seals are effective over a wide range of temperatures in almost all applications. Seals may be used individually as shown in RSP P20, or as components for modular systems. The expected service life of preformed compression joint seals is approximately 10 to 20 years, but performance > 15 years may be achieved depending on the seals resistance to compression set, climatic conditions, and traffic loading. Failure is typically due to compression set or loss of elasticity so the seal no longer pushes against the joint faces. Compression > 50% may cause compression set if the cells stick together.

360.6 SPECIAL CONSIDERATIONS

360.6.1 Preformed Compression Seal Applications

Preformed compression seals can be used to seal both longitudinal and transverse joints for both new and replacement seals. When used to seal both longitudinal and transverse joints at the same location, the longitudinal seals must be installed before transverse seals. Longitudinal seals must be continuous, except splicing is allowed at intersections with transverse seals. Likewise, transverse seals must be continuous for the entire width of concrete pavement except splices are allowed for widening and staged construction. The longitudinal seal must relax enough to properly install the transverse seal, or be trimmed to form a tight seal between the joints.

Splicing of compression seals should be avoided whenever feasible, as this can create discontinuities. When splicing is authorized, it must comply with the manufacturer's instructions.

360.6.2 Replacing Joint Seals

- Project Timing: The optimum time of the year to replace joint seals is in the spring or the fall, when installation temperatures are moderate and cracks are likely to be near the middle of their expected range for expansion and contraction. This reduces the potential for the seal material to be extended or compressed too much when temperatures increase or decrease after installation.
- Isolation Joints: When replacing isolation joints, the seal material above the preformed expansion joint filler is removed. The filler should be left in place and tape placed as a bond breaker to separate the new seal from any existing sealant that may have been absorbed by the filler.
- Contraction Joints Near Isolation Joints: Contraction joints located within 100’ of existing isolation joints present some special issues. When the expansion joint closes, it allows neighboring contraction joints to open wider than similar joints located farther away. These wider contraction joints may require more extensible sealant, and it may be necessary to use wider backer rods or wider preformed compression joint seals to ensure adequate sealing.
- Existing Lane/Shoulder Joints: Up to 80% of surface water that enters the pavement structure infiltrates through the lane/shoulder joint, so proper sealing is critical to long-term pavement performance. When both the traffic lane and the shoulder are concrete, the joint between them is a typical longitudinal joint so sealing presents no special issues.

  Joints between concrete pavement lanes and AC shoulders can present major sealant performance problems. The differences between concrete and AC thermal and structural properties tend to cause differential vertical movement, which may manifest as settlement or shoulder heaving. Vertical movement may be larger than horizontal movement. Reservoir widths should be ≥ 1”, and the depth should be equal to the width. Asphalt rubber and specially formulated silicone sealants are highly extensible liquid sealants that can adhere well to both concrete and AC for this application. Cracks and other defects on the flexible shoulder should be repaired before placing sealant. Refer to Caltrans Maintenance Manual Section B.09 for additional information.

360.6.3 Crack Sealing or Resealing

Concrete pavement crack sealing or resealing requires an nSSP. The process follows the same basic steps as joint sealing: refacing, removal of old sealant, cleaning, backer rod installation, and sealant installation. The first step is to reface the crack to the desired width. However, the orientation of most cracks in concrete pavements makes it difficult to create a uniform sealant reservoir directly along the crack. Small diameter, diamond-bladed saws can be used to form reservoirs. The cutting blades for these saws are typically about 7 to 8 inches in diameter and ¼- to ½-inch wide. The width of the saw cut usually yields an appropriate shape factor for the expected crack movement. Smaller blade diameters and some lightweight two- or three-wheel unit designs allow crack saws to pivot and follow irregular crack profiles. Although the saws are not generally as maneuverable as routers, they reduce potential for spalling the crack faces.

After the reservoir is created, the crack faces should be cleaned by sandblasting, as with joints. Then the crack is blown with compressed air and the backer rod (if specified) and liquid sealant material are installed. Use of epoxy or glue in working cracks is not generally recommended, as it often contributes to subsequent adjacent cracking.

After installation, the sealant should be visually inspected to assure there are no gaps or obvious defects. Adhesion to the joint faces can be spot-checked with a simple knife test.

360.6.4 Seal Performance

The longevity of any joint seal is a function of:

- Joint design (location, material selection, reservoir dimensions, and spacing)
- Seal material properties and performance characteristics
- Construction quality (joint preparation, cleaning, and material installation)
- Climatic and traffic conditions

Joint or crack sealing and resealing are labor intensive operations, so contractor workmanship during construction is as critical to successful performance as selecting the correct material for the application. Quality control requirements are specified in Section 41-5 of the 2010 Revised Standard Specifications. The location and design of the joint itself may also cause seal problems. For instance, the shape of the joint reservoir and the type and amount of movement occurring at the joint will affect seal behavior.

Joint Seal Failures

Typical joint seal failures can be avoided with good construction practices:

- Sawing or forming the joint to the uniform dimensions required by RSP P20 at locations shown on the project plans.
- Aligning the joint with any connecting joints to avoid blockage to free movement.
- Correctly positioning and anchoring or supporting dowels.
- Removing any temporary material or filler used to form the sealant reservoir by raking out or cutting to the specified depth.
- Keeping curing compound from contaminating joint faces and reapply displaced compound

Effective removal of the existing seal material and backer rods and re-facing the joint reservoir provides clean surfaces for bonding. The contractor can select any of the following removal methods but cannot damage the joint reservoir:

- Sawing with diamond blades combines existing seal removal and joint re-facing into a single operation. Sawing is effective for removing older, hardened liquid sealants.
- Using rectangular joint plows.
- Cutting and removing the sealant using a knife blade.

Traffic should not be allowed over the newly sealed joints until liquid joint sealant is set, tack free, and firm enough to avoid tracking of the sealant or embedment of roadway debris in the sealant. This usually takes about 30 minutes to 1 hour after sealant placement depending on in-place curing conditions. Curing time for silicone sealants is usually about 1 hour but the manufacturer's instructions may provide additional information regarding opening to traffic.

360.7 PLANS, SPECIFICATIONS, AND ESTIMATING

360.7.1 Plans

The location of new and replacement concrete pavement joint seals should be listed in the roadway quantities shown on the project plans. For new concrete pavement, isolation joint seals should also be listed separately in the quantities where required by RSP P18.

Except for isolation joints, joint seal design details are shown in RSP P20. The joint seal dimensions in the revised standard plan are based on the joint width being sealed and the type of joint seal material indicated by the bid item and the quantity estimate. According RSP P15 (JPCP) and RSP P16 (CRCP), new contraction joints should be sawcut to 1/8" widths, so the minimum reservoir width is ¼". For replacing joint seals at existing concrete pavement joints, the widths will vary by location. Sealing longitudinal construction joints is no longer recommended in most climates due to constructability issues.

Isolation joints are constructed to ½" widths with no backer rod as shown on RSP P18. The joint filler material is placed during concrete pavement construction and is not included in the sealing work or pay items.

360.7.2 Specifications

Joint and crack sealing or resealing specifications are provided in Section 41-5 of the 2010 Revised Standard Specifications (RSS). Additional or special requirements may be included in the project special provisions, such as specifying all cracks and joints must be sealed prior to winterization. Nonstandard special provisions (nSSPs), such as for crack sealing, require approval of the HQ Division of Maintenance Pavement Program. For more information or to submit an approval request, contact the Office of Concrete Pavement at nSSP Submittals@DOT.

360.7.3 Estimating

Joint and crack sealing or resealing are measured in linear feet along the joints or cracks to be sealed, paid at the contract unit price, including full compensation for all aspects of sealing materials, labor, tools, equipment and incidentals required to complete the work. The pay items for Section 41-5 of the 2010 RSS are shown in Table 360-3 for new joint seals or replacing existing joint seals.

Table 360-3: Joint Seal Bid Items

2010 and 2015 Standards			
Item Code	**Description**	**Unit**	**Notes**
414200	Joint Seal (Asphalt Rubber)	LF	For sealing new pavement joints. Item includes reservoir cutting and cleaning; furnishing and installing the backer rod (if shown) and seal material. Initial sawcut included with concrete pavement item.
414201	Joint Seal (Silicone)	LF	
414202	Joint Seal (Preformed Compression)	LF	
414220	Replace Joint Seal (Asphalt Rubber)	LF	Includes removing existing sealant and backer rod; joint re-facing; cleaning the reservoir; furnishing and installing the backer rod (for liquid sealants) and seal material
414221	Replace Joint Seal (Silicone)	LF	
414222	Replace Joint Seal (Preformed Compression, 7/16" to 13/16")	LF	
414223	Replace Joint Seal (Preformed Compression, 1" to 1- ¼")	LF	
414224	Replace Joint Seal (Preformed Compression, 1-5/8" to 2")	LF	
414240	Isolation Joint Seal (Asphalt Rubber)	LF	Includes reservoir cutting and cleaning; furnishing and installing the seal material. Joint filler material included with concrete pavement item.
414241	Isolation Joint Seal (Silicone)	LF	
414242	Isolation Joint Seal (Preformed Compression)	LF	
Nonstandard*	Seal Cracks	LF	Requires use of an nSSP and nonstandard pay item. Contact the HQ Division of Maintenance Pavement Program

Initial costs can be estimated using historical contract cost data for all contracted bid items and other information available on the Division of Design cost estimating website at http://www.dot.ca.gov/hq/oppd/costest/costest.htm. Current standard bid items are based on the application and type of joint seal material, but unit cost data may be limited. Previous item codes are listed in Table

360-4. If historical cost data for a material is limited or not reasonable for the project conditions, adjust the unit cost estimate for differences in available data.

Table 360-4: Previous Joint Seal Bid Items

Prior Standards (for estimating unit costs only)			
Item Code	Description	Unit	Notes
413117	Seal Concrete Pavement Joint (Silicone)	LF	Previously, sealing new joints was included in the concrete pavement item
413118	Seal Pavement Joint (Asphalt Rubber)	LF	
414119	Replace Concrete Pavement Joint (Silicone)	LF	
414120	Replace Concrete Pavement Joint (Asphalt Rubber)	LF	

When including work for spall repair at damaged joints, a cost estimate for replacing the entire seal along the joint repair is also required. Replacing joint seals will reduce future spalls by preventing intrusion of incompressible materials and surface water. Both longitudinal and transverse repair joints must be resealed using asphalt rubber, silicone, or preformed compression seal material. Use the bid item for the appropriate seal material for the project location and application. On projects bid prior to 2014, the joint seal replacement cost may have been included in the spall repair bid item or paid separately but limited to damage along the spall repair area.

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CONCRETE PAVEMENT GUIDE

PART 3: PRESERVATION STRATEGIES

CHAPTER 380 – CONTINUOUSLY REINFORCED CONCRETE PAVEMENT FULL-DEPTH REPAIR

This chapter discusses the design and construction processes used in the full-depth repair (FDR) of CRCP, providing guidelines and criteria to replace localized areas of deteriorated pavement with reinforced concrete.

380.1 PURPOSE AND DESCRIPTION

Full-depth repair (FDR) of continuously reinforced concrete pavement (CRCP) is used to restore localized areas of damage when normal maintenance repairs can no longer be applied. FDR involves the full-depth, full-lane-width removal of a deteriorated CRCP area and replacement with RSC or conventional concrete that meets the durability and opening-time demands of the project. Underlying base repair may also be required with FDR, separated from the RSC pavement by a polyethylene bond breaker.

CRCP-FDR can extend pavement service life, delaying the need for costly overlays or total pavement reconstruction while addressing ride quality and safety issues. For FDR to be most effective, it must be engineered and constructed properly at the right time in the pavement life cycle. If the window of opportunity is missed, pavement distress will increase at an accelerated rate and FDR will be ineffective.

CRCP-FDR is currently a nonstandard strategy in the process of being standardized for the revised 2015 Standard Specifications. In the interim, a nonstandard special provision and construction details are available from the Office of Concrete Pavement in the Headquarters Division of Maintenance or by submitting a nonstandard special provision (nSSP) request to: nssp.submittals@dot.ca.gov.

Figure 380-1: Typical CRCP punchout distress (FHWA)

380.1.1 Background

CRCP is constructed with longitudinal and transverse reinforcing bars and no transverse joints. The reinforcement bars in the longitudinal direction keep the transverse cracks tight and additional transverse bars are used also in the transverse direction to hold the longitudinal steel in place. The longitudinal steel and aggregate interlock provide good load transfer at transverse cracks or construction joints.

CRCP is designed to crack in the transverse direction to relieve stress, so transverse cracks are not considered distress. The longitudinal bars in CRCP typically keep the transverse cracks tight from 0.02” to 0.04”. If transverse cracks widen, water will readily infiltrate the crack and erode underlying support. Associated high deflections under repetitive heavy traffic loads can cause the reinforcement bars to rupture, resulting in faulting and punchouts (see Figure 380-1).

CRCP is designed to have ≤ 10 punchouts per mile at the end of its design life. Punchouts can be caused by poor concrete consolidation around reinforcing steel that prevents adequate bonding, which can cause large crack spacing from 10’ to 14’ that sometimes leads to transverse crack widening and increased tensile stress in the reinforcement. If the reinforcement ruptures, the transverse crack will open and close freely, losing most load transfer, allowing water infiltration, and compromising CRCP performance. Typically, the steel reinforcement ruptures first in the outside lane, placing more stress on the inner bars as rupture progresses from the outside inward.

380.2 APPROPRIATE USE

FDR and base replacement should be considered to address CRCP distress caused by excessive wheel loading, pumping, and inadequate CRCP structural capacity from deficient concrete thickness or underlying support). CRCP distress such as longitudinal cracks, wide transverse cracks, and faulting are precursors to punchout failures. The punchout severity and extent should be evaluated using the criteria in Table 380-1 to identify FDR or other potential CRCP pavement strategies.

Table 380-1 CRCP Strategy Selection

APCS Distress Type	Severity	Extent (per lane-mile)	Recommended Primary Strategy*	Reference
CRCP Punchouts (Count ≥ 1)	Low	< 1	None	APCS Manual
	Medium	2–5	Full-depth repair	**Ch. 380**
		6–9	Full-depth repair, Thin HMAOL	**Ch. 380**, 370
	High	> 10	▪ Lane replacement ▪ HMAOL ▪ Unbonded concrete overlay	▪ Ch. 400 ▪ Ch. 370 ▪ Ch. 420

If CRCP distress is not repaired, increased deterioration will occur, further reducing ride quality.

Where to replace underlying base is determined based on the condition of the pavement structure being repaired. Pavement distress indicators of deteriorated underlying base include:

- Cracking with settlement > ¼”
- Pumping
- Spalling > 2ft^2 total or > 2” wide over 75% of the crack length

Removing and replacing the existing base affects the initial cost, duration, and ongoing maintenance demands of the project. Replacing underlying base in good condition will unnecessarily increase the construction time and material costs, while performing only concrete FDR when the treated base is deteriorated will lead to early repair failure and increased costs for additional repairs.

380.3 MATERIALS

FDR uses concrete bases, polyethylene bond breaker, bar reinforcement, and RSC materials to repair CRCP. HMA should only be considered for temporary CRCP repairs. Bituminous materials are not recommended for permanent repairs of concrete pavement because they allow excessive horizontal movement, provide no load transfer across transverse joints, and may lead to rapid deterioration.

380.3.1 Base Replacement Materials

Rapid strength concrete base (RSCB) or lean concrete base rapid setting (LCBRS) is used to replace existing base under CRCP-FDR. RSCB is RSC that complies with Section 90-3 of the Standard Specifications, although it must be placed separately from the RSC pavement surface using a polyethylene bond breaker. RSCB is the preferred material for any necessary repairs to the underlying base layer. Using RSCB instead of LCBRS can simplify the construction operation and add strength to the pavement structure.

380.3.2 Base Bond Breaker

Base bond breaker is a material used to reduce friction between concrete pavement and base material that can lead to cracking. The bond breaker allows the pavement structure layers to move independently, reducing reflective cracking and providing flexibility for concrete curling due to temperature differences between the top and bottom of the pavement surface.

For CRCP-FDR, a white, opaque polyethylene film that complies with the specifications for base bond breaker no. 3 under SSP 36-2 must be installed on top of the base layer before the RSC pavement surface is placed.

380.3.3 Reinforcement Bars

CRCP-FDR uses both longitudinal and transverse steel bars for reinforcement continuity at the construction joints. Deformed steel bars that meet the requirements in Section 52 of the 2010 Standard Specifications are used. The use of epoxy-coated reinforcement is not typically necessary for CRCP, except in areas where corrosion is known to be a problem because of the presence of salts. Epoxy coating should be used where the pavement is within 1/2 mile from a saltwater body or in high desert and mountain climate regions. The pavement climate regions map is available on the Pavement website at:
http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/Pavement_Climateregions_100505.pdf

380.3.4 Rapid Strength Concrete

RSC is typically used for FDR because of the need for high early strength before opening to traffic. Standard Specification Section 90-3 allows the contractor to design the concrete mix depending on available curing time. Generally, 4 types of concrete mixes are used for FDR (see Table 380-2).

Table 380-2: Concrete Mix Types

Typical Curing Time (hours)	Concrete Mix Type
2–4	Specialty high early strength cement mixes. The cement may be portland, non-portland, or blended.
4–6	In addition to specialty cements, Type III portland cement with non-chloride accelerators and high-range water-reducing admixture may be used if shrinking and early age cracking requirements are met.
< 24	Type II portland cement with non-chloride accelerators
≥ 24	Conventional*

*Note: Preferred for lower cost and superior performance when strength can be attained before traffic opening.

The use of calcium chloride ($CaCl_2$) accelerators to achieve rapid strength is not allowed since they can double the rate of steel corrosion and concrete shrinkage, resulting in excessive pavement cracking.

Although RSC repair materials can provide effective solutions for early opening to traffic, there are also associated performance concerns. For example, NCHRP Report 540 about early-opening-to-traffic (EOT) RSC mixtures noted that many such mixes contain higher cement contents and multiple admixtures, which can lead to increased shrinkage, altered microstructure, and unexpected interactions. Furthermore, the study noted:

- Durable 6 to 8-hour and 20 to 24-hour EOT repairs can be constructed, but the 6- to 8-hour EOT concrete materials are more prone to durability-related problems, heightening the risk of premature failure.
- Difficulty in achieving an adequate entrained air-void system was associated with EOT concrete, resulting in paste freeze-thaw deterioration and deicer scaling.
- Increasing cement content does not necessarily increase concrete strength, and may adversely affect the durability of the RSC mixture.
- Increased problems may result from interactions between the various mixture constituents. Extensive testing should be conducted on the actual job mixture during the mix design stage.

If the available traffic window allows a slower setting mixture, contact the Office of Concrete Pavement in the Headquarters Division of Maintenance or submit a non-standard special provision (nSSP) request to: nssp.submittals@dot.ca.gov.

380.4 Design

FDR performance can be improved with proper design, considering issues such as concurrent pavement work, repair locations and boundaries, and traffic control.

380.4.1 Order of Work

The order of CRCP work is important to mitigate any unintentional spalling or damage to adjacent pavement from FDR work. Isolated FDR should be done concurrently or before spall repairs of cracks or joints. Grinding and joint sealing should be the last CRCP work performed, if applicable.

380.4.2 Repair Locations and Boundaries

Visual surveys are needed to identify FDR locations and estimate quantities during preliminary and final project design, and to verify locations and boundaries during construction. Identifying definitive repair boundaries is critical to completing a project quickly and ensuring good repair performance. Ensuring that all deterioration is included within the repair boundaries minimizes the need for additional, unplanned saw cutting and concrete removal work. Using the criteria in Section 380.2, project designers should also consult with the district maintenance engineer and area field personnel when selecting CRCP areas for replacement. If existing spalls are deeper than 1/3 the pavement thickness, FDR should be used as the repair strategy.

The pavement management system contains a visual record of every mainline concrete slab in the state, accessible online through the iVision software program at https://ivision.fugro.com/CaliforniaSH/#/Login. Visual and distress data are scheduled for collection biannually, so the available information can provide approximate pavement conditions but may not reflect the most current conditions, which should be verified with a field review to identify unrecorded or recent distress and potential failure mechanisms, such as issues with surrounding terrain or drainage conditions (see Section 110.2). It may be possible to effectively survey the traveled way from median and outside shoulder areas during non-peak daytime hours. Blank slab replacement field review forms included in Appendix 320-1 can be adapted for CRCP-FDR use.

A follow-up field evaluation should be performed during PS&E or construction as close as possible to the scheduled repair work so any additional deterioration that developed since the latest estimate is repaired. The FDR area must be the full lane width between longitudinal joints and at least 6' long to minimize rocking, pumping, and pavement breakup.

The FDR boundary should not be too close to an existing transverse crack or construction joint to avoid adjacent distress. If the FDR boundary is within 1.5', extend the repair to the nearest transverse crack or construction joint.

380.4.3 Traffic Control

Various traffic control alternatives may be considered for CRCP-FDR depending on the project location, size, and amount of repair work:

- Continuous lane closure
- Weekend closure
- Nighttime closure

Exposure of full-depth saw cut repair areas to traffic is limited to ≤ 7 days between sawing and concrete removal operations to avoid adjacent pavement cracking. Traffic is not allowed on completed CRCP-FDR areas until RSC materials have cured and achieved a minimum flexural strength of 400 psi determined under CT 524.

380.5 CONSTRUCTION

Some key but limited information about FDR construction is summarized in this section. Refer to the Construction Manual for more details about FDR construction procedures.

FDR requires the following individual construction processes:

- Concrete sawing and removal (see Section 380.5.1)
- Cleaning
- Placing reinforcement bars (see Section 380.5.2)
- Placing no. 3 bond breaker and RSC
- Finishing and Curing (see Section 380.5.3)

380.5.1 Concrete Sawing and Removal

Concrete sawing for FDR can be accomplished by the following saw cutting procedures:

- Smooth-faced: the transverse joint is sawed to its full depth. No aggregate interlock is obtained with this procedure.

- Rough-faced: a diamond-bladed saw is used to outline the repair boundaries by making a partial-depth saw cut above the longitudinal bars. The pavement is removed by chipping or other methods below the partial saw cut. Chipping results in a rough face with aggregate interlock between the new repair and the existing pavement, analogous to a spall repair interface.

The repaired area must be at least 6' long and extend the full lane width between longitudinal joints (see Figure 380.2). Rough-faced, partial-depth saw cuts are made around the outer perimeter of the FDR area. Smooth-faced full-depth saw cuts are made 26" inside the outer perimeter of the existing CRCP that will typically be removed using the lift-out method to avoid damaging the pavement, base, and reinforcing bars remaining in-place (see Figure 380-3). Between the full and partial-depth saw cuts, existing concrete is chipped or otherwise removed to the full pavement depth, exposing the reinforcement bars so they can be lap spliced with replacement FDR bar reinforcement.

If the existing base is being replaced, a full-depth saw cut around the removal area is also required for any type of cement treated or concrete base material.

Exposure of full-depth saw cut repair areas to traffic is limited to ≤ 7 days between sawing and concrete removal operations to avoid adjacent pavement cracking.

380.5.2 Bar Reinforcement

Reinforcement bar continuity is critical to FDR performance. A short tied lap splice is used to join the existing longitudinal bars to the new longitudinal bars. A lap length of 26" is typically effective to re-establish longitudinal bar continuity for tensile strength. Tie bars are installed to provide adequate reinforcement across longitudinal construction joints. Refer to Figure 380-2 for placement details.

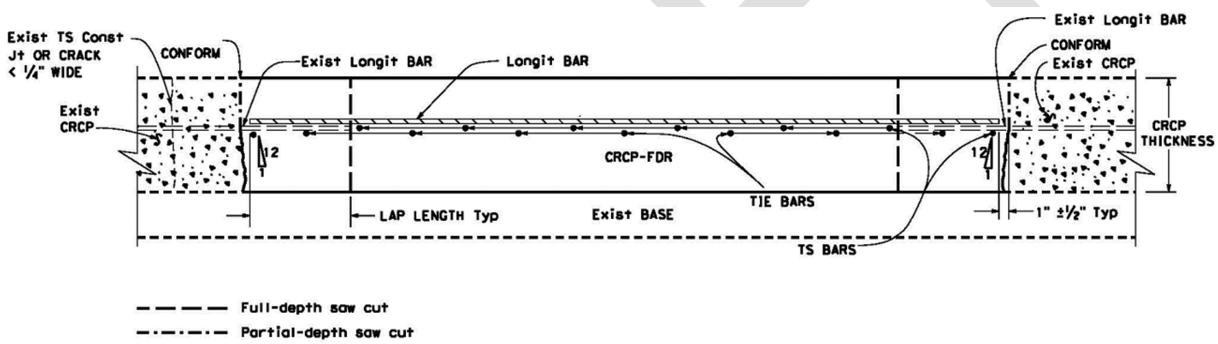


Figure 380-2: Partial and full-depth saw cuts in the repair area

Figure 380-3: Concrete removal using lift-out method

380.5.3 Finishing and Curing

Saw cuts are not required at longitudinal construction joints except where existing joint seals are being replaced in desert and mountain climate regions.

Traffic is not allowed on completed CRCP-FDR areas until RSC materials have cured and achieved a minimum flexural strength of 400 psi determined under CT 524.

380.6 PLANS, SPECIFICATIONS, AND ESTIMATING

CRCP-FDR is currently a nonstandard strategy in the process of being standardized for the 2015 Revised Standard Specifications. In the interim, the current construction detail plans and nonstandard special provisions (nSSP) for CRCP-FDR are available from the HQ Maintenance Pavement Program Office of Concrete Pavement and Pavement Foundations or by submitting a nonstandard special provision (nSSP) request to: nssp.submittals@dot.ca.gov.

380.6.1 Plans

A complete set of FDR plans requires these sheets:

1. Title sheet showing limits of project
2. Typical cross sections showing existing pavement widths and thicknesses
3. Quantity sheets specifying the type and amount of work.
   - Locations of FDR and other work should be tabulated in the quantity tables rather than shown on layout sheets, even if layout sheets are provided for other work. Include the following note: "Locations shown for full-depth repair and replacing underlying base in quantity tables are approximate. Final locations will be determined by the Engineer."
4. Construction details for unique items of work not addressed on other plan sheets
5. Standard plans listed in Table 320-5:

Table 380-3: Standard Plans for CRCP Full-Depth Repair Work

Design Feature	Plan	Comments
Tie Bar Details	P15	Use to show tie bar tolerances only. Tie bar placement details are included in the FDR construction detail.
Joint Sealing	P20	Use when existing longitudinal joint seals need to be replaced due to FDR work, typically in desert and mountain climate regions.

380.6.2 Specifications

The nSSP for CRCP-FDR includes requirements for removing existing concrete pavement, cleaning and preparing the excavation, placing base bond breaker, bar reinforcement, and RSC. When CRCP-FDR and other pavement repairs are included in a project, include order of work provisions when applicable (see Section 380.4.1 for recommendations).

Existing base removal specifications are in SSP 28-15 "Replace Base," which also includes payment for the RSCB or LCBRS replacement material and placement. SSP 28-15 must be used together with the appropriate materials specifications in SSP 28-3 for RSCB or 28-4 for LCBRS.

SSP 36-2 is used for polyethylene film base bond breaker no. 3 and payment is included in the nonstandard bid item for CRCP-FDR.

Table 380-4: Specifications for CRCP Full-Depth Repair Work

Item Code	Description	2010 and 2015 Standards	Special Provisions	Comments
Nonstandard	CRCP Full-Depth Repair (FDR) with RSC		nSSP*	For FDR work with RSC. Includes payment for no. 3 base bond breaker and bar reinforcement.
Nonstandard	CRCP Full-Depth Repair (FDR) with Concrete		nSSP*	For FDR work with adequate curing time for conventional cementitious materials.
Not used	Base Bond Breaker		36-2	Should be included for all FDR work. Specifies bond breaker materials and placement requirements.
280200	Replace Base		SSP 28-15	Should be included for most FDR work.
410097	Drill and Bond (Tie Bar)	41-10		Use for each tie bar at longitudinal construction joints for FDR.
Various	Seal Joint	41-5		Use when existing longitudinal joint seals need to be replaced because of FDR. Match the existing joint seal material.

*nSSPs must be approved by the HQ Division of Maintenance Pavement Program Office of Concrete Pavement/Foundations.

380.6.3 Cost Estimating

The quantity of CRCP full depth repair is measured and paid for by the square yard based on the authorized concrete repair area. CRCP-FDR payment includes removing existing concrete pavement, cleaning and preparing the excavation, placing no. 3 base bond breaker, bar reinforcement, and RSC. Replace base, drill and bond tie bars, and seal joint work is paid for separately using the standard individual bid items.

References

1. “Continuously Reinforced Concrete Pavement (CRCP), Chapter 2 – Publication Number HRT-05-081, October 2005, a publication of FHWA.

2. “Concrete Pavement Preservation Workshop Reference Manual, Federal Highway Administration Office of Pavement Technology, February 2008

3. “Texas DOT Specification - Full-Depth Repair of Concrete Pavement, 2004

4. Shatnawi, S., M. Stroup-Gardiner, and R. Stubstad. 2009. “California’s Perspective on Concrete Pavement Preservation.” *Proceedings*, National Conference on Preservation, Repair, and Rehabilitation of Concrete Pavements, St. Louis, MO.

5. Van Dam, T. J., K. R. Peterson, L. L. Sutter, A. Panguluri, J. Sytsma, N. Buch, R. Kowli, and P. Desaraju. 2005. *Guidelines for Early-Opening-to-Traffic Portland Cement Concrete Mixtures for Pavement Rehabilitation*. NCHRP Report 540. National Cooperative Highway Research Program, Washington, DC. Available online at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_540.pdf.

Disclaimer

The contents of this guide reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This guide does not constitute a standard, specification, or regulation.

CONCRETE PAVEMENT GUIDE

PART 4: REHABILITATION STRATEGIES

CHAPTER 400 LANE REPLACEMENT

400.1 PURPOSE AND DESCRIPTION

Lane replacement is a pavement rehabilitation or reconstruction strategy used for concrete pavement when preservation is no longer practical or cost effective. Lane replacement involves the full depth, full lane-width removal of consecutive concrete pavement slabs, potential removal or partial removal of underlying layers (including base, subbase, and subgrade), and replacement with a new concrete pavement structure (see Figure 400-1). Lane replacements are designed and constructed as new pavement sections with design lives of 20 or 40 years (see Highway Design Manual [HDM] Topic 612).

Figure 400-1: Lane replacement (1)

400.1.1 Application

Lane replacement is considered when more than 10% of the slabs in a pavement segment have 3rd stage cracking or were previously replaced. Lane replacement should also be considered when spalling combined with corner, longitudinal, and transverse cracking distresses exceed 15% over a pavement segment length. Recommendations for determining when to do lane replacement are summarized in Table 400-1.

Table 400-1: Lane Replacement Selection Criteria

<table>
<tr><th>Existing Condition</th><th>Extent</th><th>Action</th><th>Reference</th></tr>
<tr><td rowspan="3">3rd stage cracking

Previously replaced slabs</td><td>< 10%</td><td>Consider individual slab replacement with rapid strength concrete</td><td>Ch. 320 Individual Slab Replacement</td></tr>
<tr><td>10 – 20%</td><td>Use life cycle cost analysis to determine if individual slab replacement preservation or rehabilitation is more cost effective.</td><td>Life-Cycle Cost Analysis Procedures Manual</td></tr>
<tr><td>> 20%</td><td rowspan="2">Consider rehabilitation strategies: lane replacement, crack, seat, and overlay (CSOL), or unbonded concrete overlay</td><td rowspan="2">▪ Ch. 400 Lane Replacement
▪ Ch. 410 Crack, Seat, HMA Overlay
▪ Ch. 420 Unbonded Concrete Overlay</td></tr>
<tr><td>Corner, longitudinal, & transverse cracking

Spalling</td><td>> 15%</td></tr>
</table>

400.1.2 Limitations

Potential limitations associated with lane replacements may include:

- Traffic considerations: the existing traffic level can pose significant challenges during lane replacement construction. In these instances, traffic control requirements that use innovative techniques such as partial-lane closure, full-lane closure, continuous closures, weekend closures, or continuous dynamic lane configuration (e.g., using movable barriers) should be considered (see Section 120.3.4).
- Cost: lane replacement includes removing and replacing the existing pavement structure with significant construction costs and traffic control requirements.

Conducting a life-cycle cost analysis to compare lane replacement with CAPM slab replacement, or crack, seat, and HMA overlay will provide assistance in the selection of a cost-effective solution. In addition, the evaluation of highway construction time and traffic impacts can be further evaluated using the *Construction Analysis for Pavement Rehabilitation Strategies* (CA4PRS) software. Details and software download can be accessed from the Division of Research and Innovation webpage.

400.1.3 Concrete Pavement Type Selection

Lane replacements can use continuously reinforced concrete pavement (CRCP), jointed plane concrete pavement, or precast panel concrete pavement (PPCP). Some potential pavement type considerations are listed in Table 400-2:

Table 400-2: Concrete Pavement Type Selection

Pavement Type	Benefit	Limitations
CRCP	• Long life pavement	• Adds significant lane closure time for placement of bar reinforcement compare to JPCP or PPCP • Moderately increased cost compared to JPCP
JPCP	• Lower initial cost • Efficient construction	• Increased future maintenance potential compared to CRCP and PPCP
Precast panels (PPCP)	• No curing time for the panel, only for the grout. • Reduced user delay • Less susceptible to construction and material variability • Less testing during installation	• Requires accurate measurement and production of slab dimensions • Highest cost • Requires slab staging area • Requires use of a heavy mobile crane

400.2 MATERIALS SELECTION

400.2.1 Pavement Structure Materials

Pavement structure materials for a lane replacement project are selected based on strength, available curing time, prevailing climatic conditions, cost, equipment requirements, mixing and placing time, and desired service life. Table 400-3 provides a summary of the benefits and limitations of materials (both surfacing and base layers) used in lane replacement projects.

Table 400-3: Materials Selection

Pavement Structure Layer	Material	Benefits	Limitations
Surface	Concrete (conventional mix)	• Lowest cost • Known performance • Contractor experience	• Slower setting times (> 3 days)
	Rapid Strength Concrete (RSC)	• Faster setting times (< 3 days)	• Increased potential for shrinkage cracking • Complex mixes are more prone to durability problems and shorter life • High cost • Requires special handling
Base	Lean Concrete Base	• Minimal time constraints	• Requires placement of a bond breaker • More expensive than aggregate base
	Aggregate Base	• Low cost	• Slow production rate to allow for placement and compaction
	HMA Base	• Low cost • Known performance • Contractor experience	• Requires cooling to 120 °F prior to placement of concrete layer • More expensive than aggregate base
	Roller Compacted Concrete (RCC)[1]	• Concrete comparable strength • Simplified construction as compared to concrete • Low cost	• Use on shoulders and base layers only

[1]Contact Headquarters Maintenance Pavement Program – Office of Concrete Pavement and Pavement Foundations for details.

Although virtually any opening time requirement can be met using either conventional cementitious or rapid strength materials, conventional concrete materials should be utilized as much as possible (see Section 120.2.3).

400.2.2 Dowel Bars and Tie Bars

According to Standard Specification Section 40 Concrete Pavement, dowel and tie bars must be epoxy-coated carbon steel, stainless steel, or a low carbon, chromium steel bar depending on the project's climate region. Bar selection is ultimately up to the contractor and largely dependent on cost. Table 400-4 provides a summary of material selection criteria for tie bars and dowel bars based on Standard Specification Section 40-1.02C:

Table 400-4: Dowel and Tie Bar Characteristics

Material	Benefit	Limitation	Climate Region
Epoxy-coated carbon steel	Lower cost	Long-term corrosion potential	All
Stainless steel	Long-term performance	Higher cost	All
Low carbon, chromium steel	Long-term performance	Higher cost	Any except High Desert or mountainous

400.3 DESIGN

400.3.1 Replacement Locations and Boundaries

Lane replacement boundaries should extend the full transverse width between adjacent longitudinal joints. Limits will typically extend between natural breaks points such as pavement type changes or structures, and, lane replacement construction should begin and end at an existing transverse joint. Many individual slabs or segments may be in good condition within the lane replacement limits, but if more than 20% of slabs exhibit 3rd stage cracking, it is more cost effective to remove all slabs regardless of condition than to construct individual slab replacements.

Similarly, if the outside through lane of a multilane roadway needs replacement, the adjacent lane should also be considered for replacement regardless of the existing pavement condition using life-cycle cost analysis. Concrete pavers can be most productive when constructing multiple lanes simultaneously, and replacing both outer lanes where truck traffic is permitted is typically more cost effective pavement management than replacing lanes at separate times.

Existing Shoulders

Full-width shoulder replacement is not always required when the adjacent outside lane is replaced. Only a few situations such as existing shoulder widths ≤ 5’ require full-width shoulder replacement (see HDM Topic 613.5(2)). However, partial width removal of at least 2’ of the outside shoulder or 1’ of the inside shoulder is required for paving equipment access. Overcutting into the adjacent shoulder may also be required to allow for existing lane and edge drain removal.

The removal of an outside lane and replacement with a 14’ widened concrete slab will provide for improved performance by reducing slab stresses, deflections, and cracking and faulting potential. The traffic lane should be striped for a standard 12’ width, so if the resulting shoulder cross slope does not meet geometric or drainage requirements (see Design Information Bulletin 79-03), a design exception or grinding may be required (see HDM Index 302.2).

Replaced shoulders must be selected based on the standards in HDM Topic 626.2 and designed to meet the design life requirements in HDM Topic 612. See HDM Topic 613.5(2) for further information on pavement structure requirements for replaced shoulders and strategies for maintaining existing shoulders.

Longitudinal Construction Joint Locations

With lane replacement, a longitudinal construction joint will typically be required. When the longitudinal construction joint is between outside lanes where trucks are permitted and inside lanes where trucks are not permitted, remove 6” of the adjacent existing lane as part of the lane replacement. This provides both lateral support for the truck permitted lanes and a joint clean of existing spalls and undulations. For all other cases, remove 2” of the adjacent existing lane to provide a clean construction joint.

400.3.2 Pavement Structure Design

Lane replacement pavement structures are considered new designs. The materials and required pavement, base, and subbase layer thicknesses are designed based on pavement climate region, subgrade, and traffic index according to the tables in HDM Topic 623.

The pavement structure of the new lane will likely be thicker than the existing layers. Typically, removal and replacement of the existing base layers will be required either to accommodate the new, thicker pavement structure design or due to deterioration. Most existing concrete pavement was originally constructed from 8" to 9" thick over CTB. New concrete pavement layers are typically 10" to 14" because of higher traffic volumes and longer-life designs. Additionally, CTB and other treated bases are often deteriorated from traffic loading and erosion (see Section 110.2). If treated permeable base layers are removed for a lane replacement, continuous transverse drainage must be provided throughout the pavement substructure.

If preliminary pavement structure design thicknesses indicate existing base can remain in place, district materials personnel should conduct an assessment of underlying base condition (see Sections 110.2 and 320.2). Evaluation of the underlying base materials may include deflection testing using a falling weight deflectometer (FWD) and pavement coring. FWD testing may be helpful for indicating variability of underlying support, in-situ material properties, and the overall structural adequacy of the pavement. Although destructive to the existing pavement structure, coring can also be used as a more definitive means of assessing the underlying base layer condition through visual inspection and material sampling. Information from the iGPR website can also be utilized.

Lane replacement designs are intended to provide extended service life, and there are limited opportunities to access existing pavement substructure layers. Any underlying base that is cracked, in poor condition, and does not provide a uniform, compacted, and non-disturbed supporting layer should be removed and replaced with LCB or HMA Type A base. The thickness of the new base material may be adjusted depending on how much of the existing base or subbase material will remain in place.

Untreated aggregate base layers generally only need replacement if the remaining thickness of base or subbase is less than 0.40' or there has been deterioration due to pumping or other mechanisms. AB layers may also be removed if the existing subgrade is Type II or III and requires special engineering consideration to improve material properties (see Section 120.1.3). This could be indicated if more than 25% of existing slabs have settlement > ½".

Although not recommended for final design, the following general guidelines may be used for quantity and cost estimating purposes during project planning if a base investigation was not performed:

- Assume removal and replacement of the existing treated base with LCB, HMA Type A, or concrete base.
- Assume existing aggregate bases or subbases will remain in place unless one of the above conditions applies.

Whether or not a base investigation has been performed, designers should provide adequate information and flexibility in the RE file to ensure that the resident engineer understands the project expectations and has the tools to make adjustments in the field, particularly for identifying and replacing isolated locations of base and subbase.

400.3.3 Dowel Bars

Drill and bond dowel bars are required at all construction joints with existing concrete pavement or structure approach slabs, as shown in Standard Plan P10. For lane replacements with jointed plain concrete pavement (JPCP), dowel bars are required at all transverse contraction joints (see Standard Plan P1).

400.3.4 Tie Bars

Tie bars are typically required at JPCP longitudinal joints (see Standard Plan P1) unless an isolation joint is required. If the transverse joints in the new lane do not match the transverse joint orientation in the adjacent existing lane, an isolation joint should be used instead (see Figure 400-2 and Standard Plan P18). Note that the new transverse joint spacing patterns should match what is shown in Standard Plan P1.

Also, if the adjacent lane shows cracking, faulting, or spalling distress, tie bars should not be used across the JPCP longitudinal joint and an isolation joint should be used instead.

For CRCP, tie bars are placed perpendicular to the longitudinal construction joint or between an edge joint and shoulder.

Figure 400-2: Isolation joint

In instances where the new concrete pavement thickness is greater than the adjacent existing concrete pavement, tie bars should be placed within the middle third depth of each slab (see Figure 400-3).

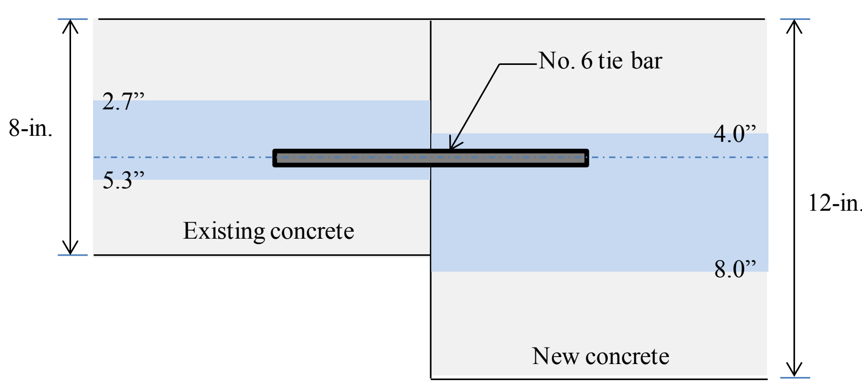


Figure 400-3: Example tie bar placement

Recommended depths for tie bar placement are shown in Table 400-5:

Table 400-5: Recommended Tie Bar Depth*

New Concrete Thickness (inches)	Existing Concrete Thickness (inches)				
	8	9	10	11	12
9	3.0 – 5.4	4.5			
10	3.3 – 5.4	3.3 – 6.0	5.0		
11	3.7 – 5.4	3.7 – 6.0	3.7 – 6.6	5.5	
12	4.0 – 5.4	4.0 – 6.0	4.0 – 6.6	4.0 – 7.4	6.0
13	4.3 – 5.4	4.3 – 6.0	4.3 – 6.6	4.3 – 7.4	4.3 – 8.0
14	4.7 – 5.4	4.7 – 6.0	4.7 – 6.6	4.7 – 7.4	4.7 – 8.0

*All dimensions measured in inches from existing pavement surface

400.4 Other Considerations

400.4.1 Combination Pavement Strategies

Existing lanes, shoulders, and interchange ramps remaining in place should also be considered for pavement work. The type of strategy and available funding will depend on the existing pavement condition. Pavement preservation, including preventive maintenance (HM program) and CAPM strategies, may be appropriate when the distress levels match the criteria for these funding programs. Possible strategies include:

- Replace distressed individual slabs and diamond grind adjacent lanes prior to lane replacement construction to provide a smooth paving platform for improved concrete surface smoothness. An International Roughness Index (IRI) of 60 inches/mile is the standard threshold for new construction.
- Existing asphalt shoulders can be fog or slurry sealed if no distress is observed. For minor cracking, shoulders should be considered for a mill and HMA overlay strategy. Consider more seriously distressed shoulders for reconstruction using hot mix asphalt (HMA), concrete, or RCC. Shoulders should be designed in accordance with HDM Topic 613.5.2a.
- Ramps and auxiliary lanes should be evaluated and preserved, rehabilitated, or reconstructed as needed. Mainline preservation, rehabilitation, or reconstruction requirements should be used for determining pavement strategies in these lanes.

400.4.2 Edge Drain Replacement

Existing edge drains can conflict with outside lane replacement strategies. When the existing JPCP slab is removed, the treated permeable base material and adjacent slotted edge drain pipe must also be removed. PVC pipe with no slots is spliced in to reconnect the edge drain system. During construction, care must be taken to prevent clogging existing edge drain systems.

If treated permeable base layers are removed for a lane replacement, continuous subsurface drainage must be provided transversely throughout the pavement structure. Refer to HDM Chapter 650 for more information about pavement drainage and HDM Chapter 840 for subsurface drainage.

400.4.3 Sequence of Work

The sequence of work is very important for project quality and workmanship, especially when using various pavement strategy combinations. The project special provisions should specify the order of work requirements for applicable operations. Any repair work in the adjacent lane should be completed first using the work sequence listed in Section 120.3.4. For lane replacement, the sequence of work depends on inside or outside lane position and existing project conditions.

<u>Inside Lane Replacement</u>

1. Demolish and remove the existing lane.
2. Repair or remove and replace base or subbase layers.
3. Construct new concrete pavement.
4. Cleanup roadway.
5. Replace traffic delineation.

<u>Outside Lane Replacement</u>

The sequence of work for outside lane replacement is based on 3 project conditions:

I. Existing edge drain removal and replacement
II. Existing asphalt concrete shoulder rehabilitation or reconstruction
III. Lane and shoulder replacement using:
   A. Widened 14’ concrete lane and 8’ concrete shoulder
   B. 12’ concrete lane width with 10’ tied concrete shoulder

I. Removal and replacement of existing edge drain
   1. Demolish and remove the existing lane and shoulder.
   2. Repair or remove and replace base and subbase layers.
   3. Remove existing edge drains.
   4. Place and finish (texturing, curing, sawing, sealing) new concrete pavement.
   5. Replace edge drains.
   6. Place HMA or treat asphalt concrete shoulder.
   7. Clean project site and place pavement delineation.

II. Rehabilitation or reconstruction of existing asphalt concrete shoulder
   1. Demolition and removal of existing lane(s) and shoulder.
   2. Removal and replacement of base and subbase layers as needed.
   3. Rehabilitation or reconstruction of asphalt concrete shoulder.
   4. Placement and finishing of new concrete pavement.
   5. Clean project site and place pavement delineation.

III. A-Lane replacement with widened 14’ concrete lane and concrete shoulder
   1. Demolish and remove existing lane and shoulder.
   2. Remove and replace base and subbase layers as needed.
   3. Place and finish new widened concrete pavement lane.
   4. Place and finish new concrete shoulder.
   5. Clean project site and place pavement delineation.

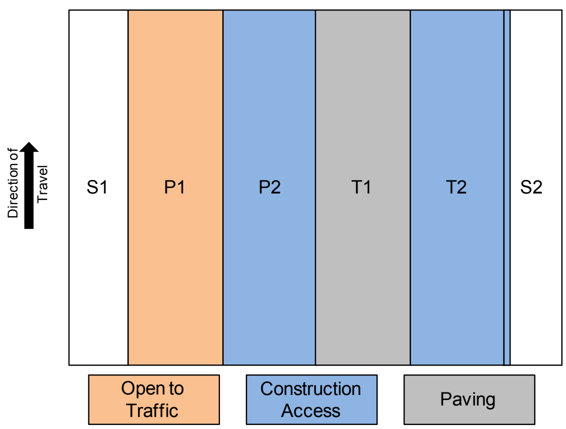
III. B-Lane replacement with 12' wide concrete lane and tied concrete shoulder
1. Demolish and remove existing lane and shoulder.
2. Remove and replace base and subbase layers as needed.
3. Place and finish new concrete pavement and tied concrete shoulder.
4. Clean project site and place pavement delineation.

400.4.4 Construction Staging

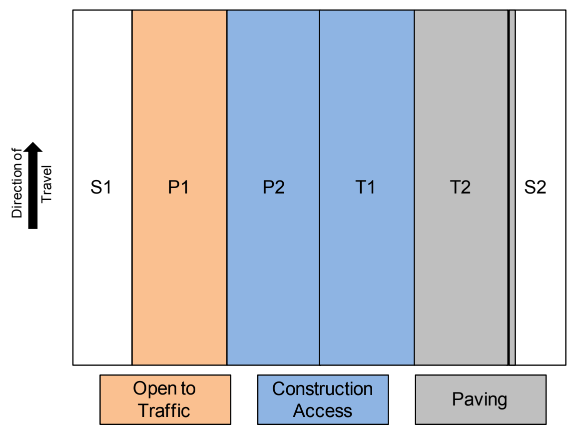
In general, construction staging includes 2 basic methods for conducting lane replacements: concurrent and sequential. Both methods can accommodate single or double lane replacements depending on traffic restrictions. The basic distinction is production, based on whether demolition and paving can proceed simultaneously (concurrent) or if the paving cannot begin until the demolition is complete (sequential).

<u>Concurrent Method</u>

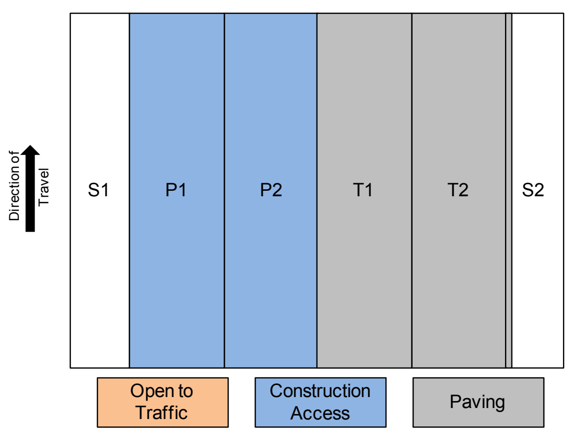
In the concurrent method, demolition and paving can be performed in parallel because each has its own construction access lanes (see Figure 400-4). Paving can also be delayed after demolition begins to minimize potential conflicts between the activities, such as when the paving operation catches up with the demolition operation.



a. Single inside lane replacement in T1 lane.



b. Single outside lane replacement in T2 lane.



c. Double lane replacement in the T1 and T2 lanes (directional traffic closure).

Figure 400-4: Concurrent working method example for 8-lane roadway [(4)]

Concurrent paving requires closing 3 lanes for single lane replacement on an 8-lane roadway (Figure 400-4a and 4b). One lane is rebuilt concurrently with the adjacent lanes or shoulder on either side providing access for demolition and paving.

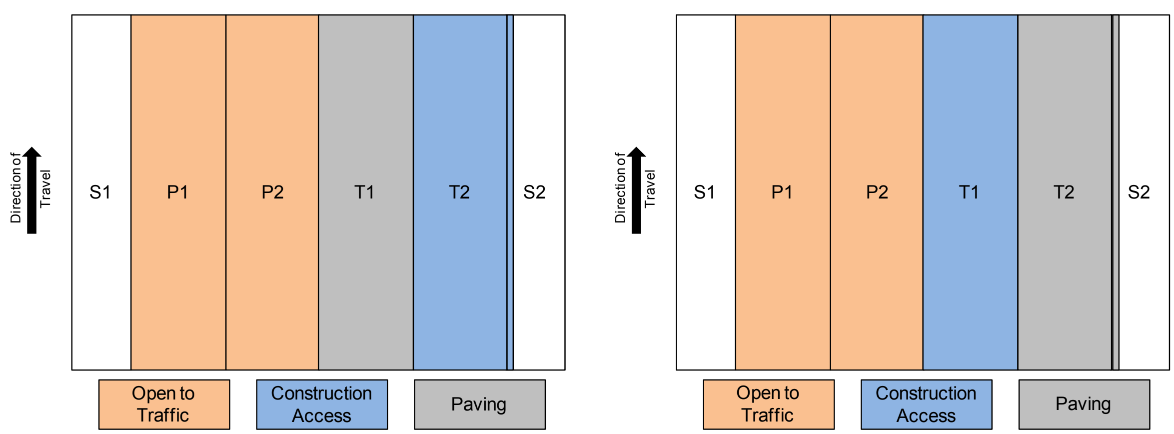
Another option is increasing production by rebuilding adjacent lanes together using concurrent double lane paving (see Figure 400-4c). This setup requires closing all 4 lanes to traffic, which results in one side of the roadway being closed. Advantages of concurrent double lane replacement paving include:

1. Higher paver production. If the paving machine speed is a major constraint limiting the production capability for single lane paving, double lane paving can achieve more production since the paver needs to run only half of the distance of a single lane operation to achieve an equivalent production length.
2. Simplified tie bar installation. The installation of tie bars between the longitudinal contraction joint can be done during the paving operation when 2 lanes are constructed simultaneously. With single lane paving, tie bars have to be drilled and grouted into the newly paved lane prior to reconstructing the adjacent lane.
3. Better longitudinal joint quality. The quality of the longitudinal contraction joint between the 2 lanes is likely to be much higher and the potential for damaging a newly constructed lane during demolition of the adjacent lane is avoided if they are constructed simultaneously. The risk of damaging the new lane by drilling and grouting tie bars is also avoided and a longitudinal contraction joint should perform better than a longitudinal construction joint due to the aggregate interlock between lanes.

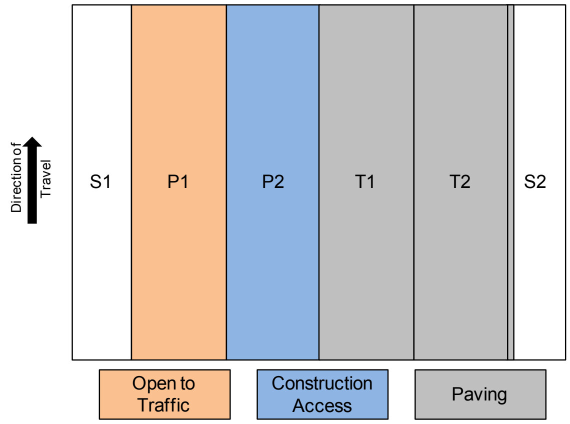
For roadways with 6 lanes or less, conducting concurrent double lane paving is more restrictive. A 12' access lane on either side of the replacement lane is required to aid the movement of construction vehicles in the work zone. The existing shoulder may be used as an access lane but may require strengthening or widening to at least 12' for construction traffic. Construction of a temporary lane or detour may also assist in movement of vehicles or construction equipment through the work zone.

<u>Sequential Method</u>

The sequential working method is used when interruptions to regular traffic must be avoided (see Figure 400-5). Demolition and paving cannot take place simultaneously because construction access is limited. Production with the sequential working method is hindered since paving can only start after demolition and base layer repair or construction is completed.



a. Single inside lane replacement in T1 lane. b. Single outside lane replacement in T2 lane



c. Double lane replacement in the T1 and T2 lanes.

Figure 400-5: Sequential working method example for 8-lane roadway [(4)]

400.4.5 Traffic Handling

District traffic management personnel typically determine construction zone lane availability requirements for a route segment based on time of the year, day of the week, current hourly traffic volumes, type of construction work, and estimates of reduced work zone capacity.

For lane replacement work, the project location, size, amount of concrete replacement work, lateral clearance, and availability of detours and alternate routes are also important considerations. For JPCP, a minimum lateral clearance of 2’ should be provided between the temporary barrier and the lane being replaced. For CRCP, 12’ minimum lateral clearance is needed to provide access for concrete material transfer.

Some typical traffic handling alternatives for lane replacement include:

- Complete Closures/ Detours: If construction work includes roadway widening or reconstruction, consider designing the area to facilitate a traffic detour for staging lane replacement operations. If alternative routes are available, maximum safety, productivity, quality, and economy result when the roadway can be completely closed during the entire construction period.
- Continuous Lane Closures: Since the outside truck lanes generally suffer the greatest pavement damage, lane replacement can sometimes be accomplished by complete closure of these lanes during construction. Medians and temporarily narrowed lanes can be used to minimize lane closures. Any temporary median paving should be designed to handle traffic loading during the construction period.

  When an inside lane is closed for use as a workspace, an adjacent lane should also be closed if possible for access. This procedure provides additional space for vehicles and materials and facilitates the movement of construction equipment within the workspace. On multilane undivided roads and streets where the left lane is closed, the additional space can be obtained by also closing the left lane in the opposing direction. Existing concrete barrier in the median may prohibit this option.
- Weekend Closures should be considered to increase production in high-volume traffic areas where lane closures may cause severe congestion, resulting in accidents and significant delays to motorists. RSC or precast concrete may be required during the final weekend shift to permit rapid reopening to Monday morning commute traffic.

- Weekday Closures are similar to weekend closures except that they occur from Monday until Friday morning. They are typically viable on rural routes that have higher traffic volumes on the weekends.
- Nighttime Closures are not recommended for lane replacement projects due to the extended traffic impacts, drastically reduced construction quality and productivity, and increased costs. Nighttime closures typically require the use of RSC or precast concrete.

Traffic Closure Case Study

Alternative construction closures and potential work zone traffic impacts can be analyzed using the CA4PRS software program, which was developed by the Department and FHWA to help districts select effective and economical pavement and traffic control strategies. The software uses alternative strategies for pavement designs, lane-closure tactics, and contractor logistics to estimate the total number of closures during project construction and quantify the impact to the traveling public in terms of user cost and queue time.

To illustrate the difference in traffic control methods on construction schedules, CA4PRS was used to evaluate the Devore project on Interstate 15. The project consisted of an outer truck lane replacement and individual slab replacements in the inner lane. Continuous closures, 72-hour weekday closures, 55-hour weekend closures, and 10-hour night-time closures were analyzed and the results are shown in Table 400-6:

Table 400-6: I-15 Devore Project Lane Closure Analysis

Closure Method	Total Closures	Total Closure Time (hours)	Cost (millions)			Maximum Delay (minutes)
			User Delay Cost	Agency Cost	Total Cost	
Continuous (24/7)	2	400	$5	$15	$20	80
72-hour weekday	8	512	$5	$16	$21	50
55-hour weekend	14	770	$14	$17	$31	80
10-hour nighttime	220	2200	$7	$21	$28	30

For the Devore project, continuous closures were selected because they resulted in the lowest number of closure hours and the lowest total cost. Ten-hour nighttime closures had the lowest maximum delay time, but also the most required closures, highest total closure time, and the lowest contractor production rate. For more information about traffic control alternatives and the CA4PRS software, refer to Section 120.3.4.

400.5 PLANS, SPECIFICATIONS, AND ESTIMATING

400.5.1 Plans

Lane replacements are usually shown in the same manner as widening and new construction on the typical cross section and layout sheets. Table 400-7 lists the Standard Plans typically used for lane replacement projects.

Table 400-7: Standard Plans Used for Lane Replacement Projects

Standard Plan	Sheet	Comments
JPCP-New Construction	P1	For lane replacements with dowel bars and tie bars.
JPCP-Widened Slab Details	P2	For widened slab and lane replacements in the adjacent shoulders.
JPCP Lane & Shoulder Addition or Replacement	P3A	For if you have shoulder addition or replacement
JPCP (Widened Lane) Lane & Shoulder Addition or Replacement	P3B	For if you have (widened lane) and shoulder addition or replacement
CRCP	P4	For lane replacements with reinforcing steel and no transverse joints.
CRCP (Widened Lane)	P5A	For lane replacements (widened lane) with reinforcing steel and no transverse joints.
CRCP (Widened Lane) Lane & Shoulder Addition or Replacement	P5B	For widened lane with reinforcing steel and shoulder addition or replacement.
Dowel Bar Details	P10	For all lane replacements using Standard Plan P1, P2, P3A, or P3B.
Dowel Bar Basket Details	P12	For all lane replacements using Standard Plan P1.
CRCP Transverse Construction Joint	P14	For all CRCP
Concrete Pavement Tie Bar Details	P15	For all JPCP
CRCP Tie Bars and Joint Details	P16	For 2 adjacent CRCP lanes
Tie Bar Basket Details	P17	For lane replacements where adjacent lanes or shoulders are being replaced.
Lane Schematics and Isolation Joints Detail	P18	• Use when transverse joints in replacement lanes are not aligned with existing adjacent slabs. • Use when an existing isolation joint needs to be replaced.
Concrete Pavement–Joint Details	P20	For lane replacements using Standard Plan P1, P2, P3A or P3B.
JPCP-End Panel Pavement Transition	P30	For when lane replacement abuts a hot mix asphalt pavement or approach or sleeper slab.
CRCP-Terminal Joint and Anchor Details	P31A & P31B	For constructing CRCP.
CRCP-Wide Flange Beam Terminals	P32A, & P32B	For constructing CRCP.
Safety Edge Treatments	P74, P75 & P76	For all pavement projects.
Drainage Inlets	P45 & P46	As needed when drainage inlets are placed within the limits of the concrete pavement.

400.5.2 Specifications

Standard Specifications, Standard Special Provisions (SSP), and Standard Plans used for lane replacement work are online at the Office Engineer intranet site for construction contract standards. For projects where nonstandard modifications may be required, contact the Division of Maintenance Pavement Program or refer to the website for information about developing and obtaining concurrence for nonstandard special provisions (nSSPs). Table 400-8 lists some applicable specifications for lane replacement work.

400.5.3 Cost Estimating

It is important to make a reasonable estimate in the Project Report (PR) or Project Scope Study Report (PSSR) to adequately fund lane replacement projects. Underfunded projects can delay development, resulting in shortened limits, revised work items, or requests for additional funding from the California Transportation Commission.

The unit cost of lane replacement work items will vary depending on the type of materials used, project location, and traffic handling methods. Concrete materials are selected based on the length of the construction window negotiated with district traffic management, with shorter construction windows generally leading to higher costs. Contractor production rates will increase if longer construction windows are provided. In many cases, an incentive/ disincentive clause should also be considered if construction work is highly dependent on traffic conditions.

Additional details and guidance for cost estimating can be found at the Division of Design Cost Estimating website.

Table 400-8: 2010 Standards Related to Lane Replacement

Section	Bid Item	Description	Unit	Comments
15-2	150847	Remove Concrete Pavement and Base	CY	Includes removal of concrete pavement structure layers, including underlying base and subgrade, to dimensions shown on the typical cross sections
15-2	150853 150854	Remove Concrete Pavement	SQYD CY	Includes removal of concrete pavement structure layers
19-2	190101	Roadway Excavation	CY	Use for removal of subgrade layers below the concrete pavement structure. Should not be used for removing concrete pavement
25	250201	Class 2 Aggregate Subbase (AS)	CY	Subbase is not required with Type I subgrade
26	260202 260203	Class 2 Aggregate Base (Ton) Class 2 Aggregate Base (CY)	Ton CY	Optional use for base layers with JPCP, Type I subgrade, and TI ≤ 11
28	280000	Lean Concrete Base (LCB)	CY	Typically used for base layers with JPCP.
SSP 28-4	280015	Lean Concrete Base Rapid Setting	CY	Typically used for base layers with JPCP constructed under short traffic closure windows.
29	290301	Cement Treated Permeable Base	CY	Use CTPB instead of ATPB regardless of adjacent material
39	390132	HMA (Type A)	Ton	Use for base with CRCP
40-2	400050	CRCP	CY	Use with general provisions in Section 40-1. Refer to Ch. 200 for usage guidance.
40-4	401050	JPCP	CY	Use with general provisions in Section 40-1. Refer to Ch. 210 for usage guidance.
SSP 40-5	401055	JPCP-RSC	CY	Use when constructing JPCP-RSC for short traffic closure windows
41-5	Various	Joint Seal	LF	Refer to Chapter 360 for usage guidance
41-10	Not Used	Drill and Bond Bar	Not Used	Section 41-10 specifies work requirements but payment is included in the JPCP or CRCP bid item
90	---	Concrete	---	Specifies concrete material requirements

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CONCRETE PAVEMENT GUIDE

PART 4: REHABILITATION STRATEGIES

CHAPTER 410– CRACK, SEAT, AND (HMA) OVERLAY

Chapter 410 provides guidelines and criteria for the pavement engineer to design cracked-and-seated JPCP pavement with a flexible pavement overlay to improve poor ride quality and reduce overlay cracking and related distress.

410.1 INTRODUCTION

When overlaying JPCP with flexible pavement, reflection cracking in the overlay is a common problem. Reflective cracking is induced by horizontal strains from thermal expansion and contraction and vertical strains from repeated heavy wheel loads above joints and other discontinuities in the underlying concrete. Cracking and seating the existing concrete reduces both horizontal and vertical JPCP movement, which reduces strain and cracking in the flexible overlay.

Crack, seat, and HMA overlay (CSOL) is a pavement rehabilitation strategy that consists of cracking existing JPCP slabs into segments from 3’ to 5’ long by 6’ wide (see Figure 410-1) and overlaying with a flexible pavement layer. Cracking the slabs is commonly performed using a heavy spring arm drop hammer machine (see Figure 410-2).

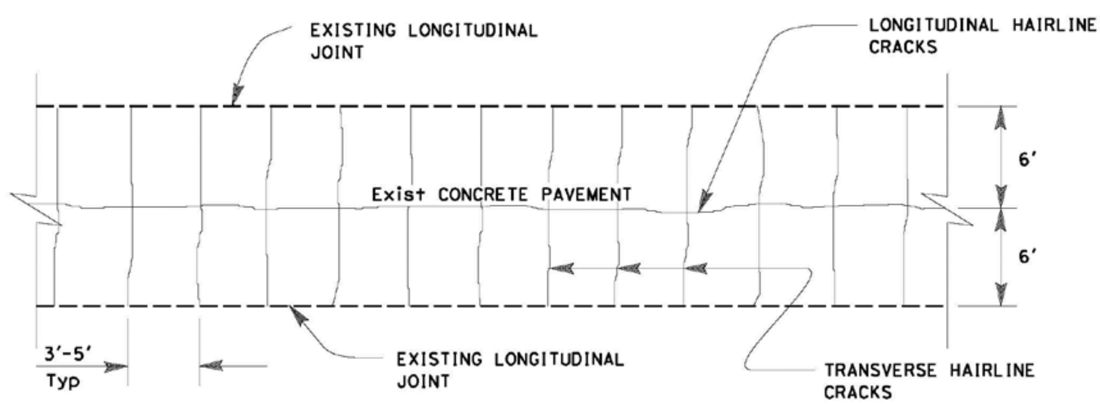

Figure 410-1: Typical cracking patterns and dimensions

The CSOL treatment produces concrete “mini-slabs” with reduced vertical and horizontal movement, while maintaining aggregate interlock and structural integrity between the cracked segments. Care must be taken in cracking the existing slab to ensure that the structural integrity of the interlocking slab sections remains high to provide the best foundation for the flexible overlay. If excessive force is exerted during the cracking process, aggregate interlock will be damaged and the effectiveness of the CSOL technique will diminish.

Figure 410-2: Spring arm drop hammer

After cracking, the cracked concrete segments are seated into the existing base layer using pneumatic-tired or pad-foot rollers to provide firm contact and limit vertical movement. Any joints, spalls, and cracks > ¾" are filled with a fine No. 4 graded HMA mix to provide a uniform support surface for the overlay.

Next, an overlay system comprised of an HMA leveling course, a geosynthetic pavement interlayer (GPI) or a stress absorbing membrane interlayer (SAMI), and additional flexible pavement layers are placed. Standard 20-year CSOL pavement structure designs are described in Section 410.4.2 and HDM Index 625.1.

410.2 PROJECT SELECTION

CSOL is typically used where multiple concrete pavement lanes have an unacceptable ride quality (ride score > 170 inches/mile), extensive 3rd stage cracking > 10% (see Figure 410-3), or stage construction alternatives do not allow for lane replacement strategies.

Since all lanes must receive CSOL, it may not be a cost effective strategy if there is sufficient remaining service life in multiple adjacent lanes. If the only an outside truck lane needs rehabilitation, lane replacement may be more cost effective than a multilane CSOL strategy (see Ch. 400). A life-cycle cost analysis (LCCA) should be completed to determine whether CSOL composite pavement is more cost effective over the long term than flexible or concrete lane replacement alternatives. The Headquarters Division of Maintenance Pavement Program website provides information on performing LCCA:
http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html.

Figure 410-3: 3rd stage JPCP cracking

Due to the increase of pavement profile resulting from CSOL, candidate projects should have few structures or other overhead obstacles. Vertical clearance requirements at overhead structures often dictate localized pavement reconstruction and require tapers to lower the mainline profile grade. Tapers of the overlay approaching existing bridge decks are also required. Refer to the pavement tapers and transitions guidance on the HQ Pavement Program website for more information.

By nature, CSOL operations generate an excessive amount of vibration that can cause damage to surrounding structures in close proximity to the roadway, especially shallow culverts and buildings with eligibility for the National Register of Historic Places. Depending on the structure type and age, various damage potential thresholds apply that could limit CSOL applicability for certain locations or projects. Special mitigation and vibration monitoring measures may be required. Refer to the Division of Environmental Analysis website and coordinate with district environmental personnel early in the project development process so the project area can be analyzed for compliance.

Other project selection considerations include:

- availability of special equipment and materials
- traffic impacts from repeated lane closures and limitations on longitudinal lane drop-off during overlay construction (see Section 410.4.3)

410.3 Materials

410.3.1 Flexible Pavement

CSOL flexible pavement materials may consist of HMA Type A, RHMA-G, or a combination of each. RHMA-G is recommended for the final surface layer because of its superior resistance to reflective cracking. For more information about flexible pavement materials, refer to the Asphalt Pavement Guide.

410.3.2 Interlayers

A pavement interlayer is included in all CSOL designs. GPI fabric and SAMI provide a continuous moisture barrier and additional resistance to reflection cracking in the pavement structure. Water intrusion can weaken underlying unbound layers and potentially unseat the cracked concrete. In drier climates where water intrusion is not a big concern, GPI paving grids may be preferable for superior reflective cracking resistance. Geocomposite strip membranes or "band-aids" are seldom used.

If RHMA-G is used as a flexible pavement surface layer, use a SAMI-R asphalt rubber binder seal coat or GPI paving mat in lieu of other GPI types, some of which can be susceptible to melting or loss of strength due to high RHMA-G placement temperatures.

GPI material requirements are in Section 88 of the Standard Specifications and placement provisions are in Section 39. SAMI requirements are in Section 37-2.06. Interlayer alternatives for crack, seat, and overlay strategies are summarized in Table 410-1.

Table 410-1: Interlayer Alternatives and Criteria for Application

Material	Description
GPI Paving Fabric	A geosynthetic used for paving fabric must be a lower stiffness (modulus), nonwoven material. It is used with a heavy asphalt tack coat and becomes saturated with asphalt cement prior to a flexible overlay or chip seal.
GPI Paving Mat	A geosynthetic used for paving mat must be a non-woven, higher stiffness (modulus) fiberglass or polyester hybrid material that is also used with a heavy tack coat and becomes saturated with asphalt. Placed prior to an asphalt overlay.
GPI Paving Grid	Geosynthetics used for paving grid must be a geopolymer material formed into a grid or open mesh with openings ≥ ½" to allow interlock with surrounding HMA materials. Applied with a self-adhesive or a lightweight scrim (nonwoven material <1.2 oz/yd^2 attached to the grid) and tack application before overlaying.
GPI Paving Geocomposite Grid	A paving grid laminated, bonded, or integrated with a paving fabric that is saturated with liquid asphalt binder before overlaying.
GPI Geocomposite Strip Membrane	12", 18", 24", or 36" width strips of rubberized or polymerized asphalt and geosynthetic materials. Applied with either a self-adhesive or asphalt tack before overlaying. Not recommended for CSOL.
SAMI-R	SAMI is an asphalt rubber binder seal coat under Section 37-2.05B. Heated asphalt rubber liquid binder is applied to the surface followed by precoated aggregate screenings. SAMI specifications are in Section 37-2.06.

410.4 DESIGN

410.4.1 Preliminary Repairs

Existing pavement distresses should be repaired before overlaying the existing pavement according to the advisory design standard in HDM Index 625.1. A visual field survey is needed during preliminary and final project design to identify and evaluate existing pavement distresses and estimate repair quantities. Potential repairs and preparations include:

- Sealing cracks from ¼ to ¾" wide (requires using nSSP with approval of HQ Division of Maintenance Pavement Program).
- Replace slabs with cracks ≥ ¾" wide, rocking under traffic loads, or missing pavement. Individual slab replacement may use concrete, RSC, or full-depth HMA material (see Ch. 320).
- Repair spalls and loose pavement. Cracking and seating under Section 41-6 of the 2010 Standard Specifications includes filling joints, cracks, and spalls > ¾" wide and 1" deep with HMA.
- Remove existing thermoplastic and painted traffic markings, striping, and pavement markers (refer to the HQ Division of Maintenance Pavement Program website http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/Pave-Over-Thermo-Paint.pdf).
- Remove previous AC overlays > 0.10' thick by milling before CSOL work begins.

Refer to Chapter 110 for more information about evaluating existing pavement conditions.

410.4.2 Pavement Structure Design

Crack, seat, and flexible overlay with a pavement interlayer is designed for a 20-year life without requiring significant pavement maintenance. The flexible pavement layer thickness and interlayer (GPI or SAMI) are critical design features of CSOL projects that delay reflective cracking. Following cracking, seating, and pre-overlay repair of the JPCP slabs, the flexible pavement overlay is placed, consisting of:

1. Tack coat
2. 0.10’ or 0.15’ HMA leveling course
3. SAMI-R or GPI pavement interlayer
4. Final HMA or RHMA-G flexible surface layers

Figure 410-4 shows 2 typical sections for crack-and-seat and flexible overlays. Section A is either HMA or RHMA-G above a pavement interlayer. Section B is a thicker combination of RHMA-G and HMA above the interlayer for Traffic Index (TI) ≥ 12.0.

The minimum standard thicknesses for a 20-year design life are found in Highway Design Manual (HDM) Index 625.1. The minimum layer thicknesses from Table 625.1 are given in Table 410-2.

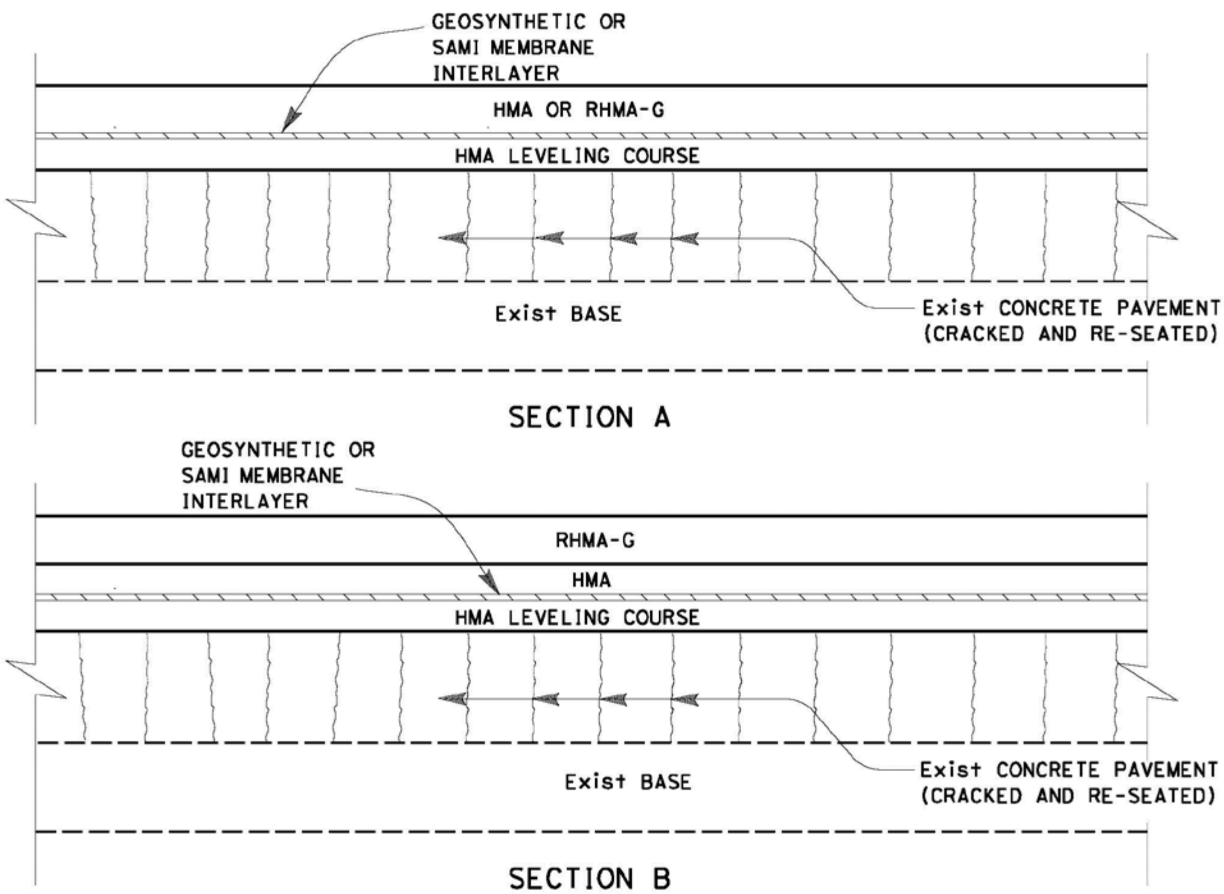

Figure 410-4: Typical crack, seat and HMA overlay sections

Table 410-2: Minimum Standard Pavement Structure Thicknesses (from HDM Table 625.1)

Traffic Index (TI)	Pavement Structure	Layer Thicknesses		
		Alternative 1	Alternative 2	Alternative 3
< 12	Surface Layer	0.35′ HMA	0.20′ RHMA-G	
	Interlayer	GPI or SAMI-R	SAMI-R	
	Leveling Course	0.10′ HMA	0.10′ HMA	
≥ 12	Surface Layer	0.40′ HMA	0.20′ RHMA-G	0.20′ RHMA-G 0.15′ HMA
	Interlayer	GPI or SAMI-R	SAMI-R	GPI or SAMI-R
	Leveling Course	0.15′ HMA	0.15′ HMA	0.10′ HMA

Where the slab deterioration is primarily limited to the outer lane for 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. The District Materials Engineer should be consulted about CSOL rehabilitation strategies.

410.4.3 Traffic Handling and Safety

Safety and traffic handling must be considered when developing crack, seat and overlay strategies to obtain the required quality of work with minimal increases in project costs.

Traffic control is an important consideration for CSOL project design. Consider the repeat lane closures required for the different phases of construction work, the 0.15’ restriction on longitudinal lane drop-off during paving, and the need to minimize traffic on the partially completed pavement.

Traffic is permitted to use cracked and seated JPCP within 24 hours of seating until the initial HMA lift is placed. Exposure of the partially completed overlay to public traffic and heavy trucks is limited to 15 days to avoid unseating of the JPCP and incremental cracking.

For more information about traffic handling alternatives, refer to Section 120.3.4 and coordinate with the district traffic operations, traffic management, construction, and public information office.

410.4.4 Other Design Considerations

Transverse Transition Tapers

The preferred method of conforming an HMA overlay to existing concrete pavement is to replace the pavement structure with a concrete pavement transition taper under Section 41-7 of the 2010 Standard Specifications. Transition tapers can prevent HMA raveling at the conform location and should be designed to meet pavement design life standards in HDM Topic 612. If the existing JPCP was built with an end anchor (see Revised Standard Plan RSP P30) and the overlay is ≥ 0.25’ with an interlayer, the existing concrete may be diamond ground until the remaining thickness is at least 0.65’.

410.5 CONSTRUCTION CONSIDERATIONS

Typical CSOL construction work includes:

- Replace distressed or unstable JPCP slabs
- Crack and seat existing concrete pavement
- Repair, patch, and sweep existing surface

- Place HMA leveling course
- Place GPI or SAMI interlayer
- Place additional HMA or RHMA-G flexible pavement layers

In addition to preliminary repairs and preparations described in Section 410.4.1, several other construction elements must be considered in the design phase to estimate work schedules, traffic controls, and working days, including:

- Sweeping and patching the pavement surface. Cracking the pavement can produce spalling, chipping, and surface deterioration. The contractor should fill joints, cracks, and spalls > ¾" wide and 1" deep with minor HMA according to requirements in Section 41-6 of the 2010 Standard Specifications. The surface also must be swept prior to public traffic use and HMA leveling course paving.

- Traffic closures. CSOL projects involve repeat closures of multiple lanes, creating significant traffic impacts. In many areas night work is required.

- Height differentials during construction. When planning project timelines and working day schedules, temporary vertical drop-offs from overlay lifts across multiple lanes must be considered together with safety issues for construction workers and motorists. The maximum temporary vertical drop-off is 0.15'.

- Traffic on cracked and seated pavement. Work sequencing for the project should reduce the exposure of cracked and seated pavement to truck traffic prior to full-depth overlay placement. Such exposure could cause unseating of the cracked pavement and expose traffic to loose gravel and debris.

  Section 41-6 of the 2010 Standard Specifications requires the initial overlay lift be placed within 24 hours of seating or the segment must be reseated. Similarly, intermediate overlay paving lifts should not be exposed to prolonged heavy truck traffic that could result in incremental cracking through each lift. The CSOL design should accommodate 24 hours of traffic between lift placements. Work should be scheduled so that the full overlay thickness will be in place quickly, or preferably before opening to traffic, to prevent incremental cracking of each lift. CSOL projects should not be considered candidates for stage construction.

For more details about CSOL construction, refer to the Construction Manual.

410.6 PLANS, SPECIFICATIONS, AND ESTIMATING

410.6.1 Plans

Crack, seat and flexible overlay details are usually shown in the following project plan sheets:

1. Title Sheet showing limits of project and pavement work.
2. Typical Section showing existing and proposed pavement widths and thicknesses.
3. Construction Details for unique items of work not addressed on the typical sections or standard plans.
4. Quantities Sheets specifying types and amounts of work. Locations and limits of CSOL should be tabulated in the quantity tables consistent to what is shown on the layout sheets.

410.6.2 Specifications

Crack and seat provisions are in Section 41-6 of the 2010 Standard Specifications. Flexible pavement overlay provisions for minor HMA, HMA, RHMA-G, and GPI are in Section 39. GPI material requirements are in Section 88 and SAMI-R provisions are in Section 37-2.06.

410.6.3 Cost Estimating

Crack, seat, and overlay related bid items for pavement work are shown in Table 410-3.

Table 410-3: Crack, Seat, and Overlay Related Bid Items

Item	Description	Unit	Notes
411105	Individual Slab Replacement (RSC)	CY	Replace slabs with cracks ≥ ¾" wide, rocking under traffic loads, or missing pavement (see Ch. 320)
413000	Crack and Seat	SQYD	Includes filling joints, cracks, and spalls > ¾" wide and 1" deep with HMA
390135	HMA (Leveling)	TON	Should be used for the initial paving lift to correct surface irregularities
390132	HMA (Type A)	TON	Includes GPI pavement fabric, paving mat, paving grid, paving geocomposite grid, or geocomposite strip membrane as shown
390137	RHMA (Gap Graded)	TON	Offers superior reflective cracking resistance
370120	Asphalt-Rubber Binder	TON	Use for SAMI-R
375035	Precoated Screenings	TON	Use for SAMI-R
Nonstandard	Crack Sealing (¼ to ¾")	LF	Use nSSP with approval of HQ Division of Maintenance Pavement Program

REFERENCES

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CONCRETE PAVEMENT GUIDE

PART 4: REHABILITATION STRATEGIES

CHAPTER 420 – UNBONDED CONCRETE OVERLAY (UBCO)

This chapter provides guidelines and design criteria for rehabilitation with an unbonded concrete overlay (UBCO) using an HMA interlayer and a new surface of either JPCP or CRCP. For more information about CRCP, refer to Chapter 200. For JPCP, see Chapter 210.

420.1 PURPOSE AND DESCRIPTION

An unbonded concrete overlay (UBCO) consists of a new JPCP or CRCP concrete layer over an HMA interlayer used as a bond breaker to separate the new concrete from the existing concrete (see Figure 420-1). The new concrete layer is at least 0.70’ thick, designed according to HDM Index 623.1, and the minimum HMA interlayer thickness is 0.10’.

UBCO overlays may be used over either existing JPCP or CRCP to increase the structural capacity of the pavement structure. Existing JPCP should be cracked and seated under Section 41-6 of the 2010 Standard Specifications to improve overlay performance and limit cracking potential.

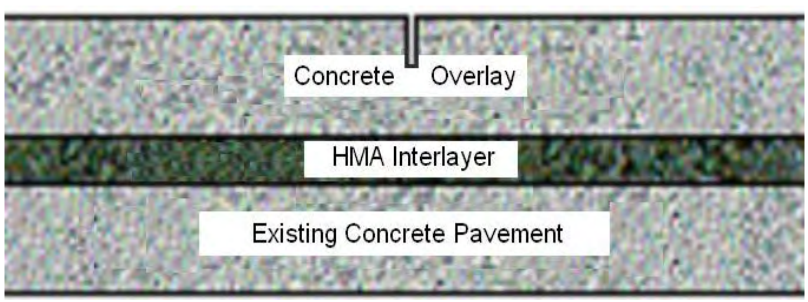

Figure 420-1: Unbonded concrete overlay layers

420.1.1 Appropriate Use

UBCO is used where the existing concrete pavement structure is in poor condition with severe distress extents including:

- 10-20 % 3rd stage cracking > ¾” wide pending LCCA results
- 20% 3rd stage cracking > ¾” wide
- 10% rutting > 1” deep
- 15% transverse, longitudinal, or corner cracking > ¾” wide
- 15% spalling > 2 ft^2

The existing pavement structure must have pavement distresses repaired prior to the UBCO placement (see Section 420.3.1). Existing poor subgrade material with moisture-related problems may benefit from UBCO since the pavement structural capacity in increased and drainage problems can be addressed as part of the design.

420.1.2 Cost Effectiveness

UBCO is most cost effective over severely distressed concrete pavement where existing traffic can be detoured away from the construction zone and in rural areas with high truck traffic volumes. Fewer overhead structures throughout the project increases cost effectiveness since limited vertical clearance for UBCO often requires tapers and pavement structure reconstruction for approaches. Compared to other rehabilitation strategies such as lane replacement, UBCO strategies increase the pavement's structural capacity and do not require extensive demolition and removal of existing pavement, saving construction costs and time. However, adjacent pavement around interchanges or intersections must be overlaid to match the UBCO profile grade. Future maintenance and rehabilitation demand is also reduced with a new UBCO surface compared to HMA alternatives such as CSOL.

Life-cycle cost analysis (LCCA) should be completed to determine whether UBCO is more cost effective over the analysis period compared to other rehabilitation alternatives. For 3rd stage cracking > ¾" between 10 and 20% extent, LCCA should be used consider the cost effectiveness of preservation using individual slab replacement. More information about LCCA is available from the Headquarters Division of Maintenance Pavement Program website at:
http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html.

420.2 MATERIALS

420.2.1 Interlayers

HMA Type A interlayers are typically designed 0.10' to 0.15' thick to provide a bond breaker between the existing concrete pavement and new CRCP or JPCP surface. The HMA interlayer improves smoothness, prevents bonding between the existing and new concrete layers, reduces reflective cracking, and provides flexibility for concrete pavement curling due to temperature differentials between the top and bottom of the concrete surface (see Figure 420-1).

Minimum HMA interlayer thickness should be increased to 0.15' or greater to improve performance and trigger compaction quality requirements in Section 39 of the Standard Specifications. Thicker interlayers account for existing pavement surface undulations and rough surfaces. Alternatively, a separate HMA leveling lift and bid item can be included in the project. The interlayer thickness can also be varied to cost effectively modify cross slopes.

Tack coat is applied to the existing concrete surface prior to HMA interlayer placement to improve HMA bonding to the existing concrete pavement. Some HMA interlayers may be designed with a geosynthetic pavement interlayer (GPI) to help retard reflective cracking in the UBCO.

420.2.2 Concrete

Concrete consists of a combination of cementitious materials, coarse and fine-graded aggregate, water, and typically some property modifying admixtures. Concrete properties such as strength, durability, permeability, and abrasive wear resistance are materials dependent. Section 90 of the 2010 Standard Specifications defines the required chemical and physical concrete material properties for contractor developed mix designs, with some additional requirements for JPCP or CRCP specified in Section 40.

For more comprehensive information about concrete materials, refer to Chapter 120 and the Concrete Technology Manual.

420.3 ENGINEERING CONSIDERATIONS

420.3.1 Pre-Overlay Repairs

Estimate repair quantities during preliminary and final project design. If the existing concrete pavement has distress such as cracking, spalling, or loss of underlying support, it should be repaired prior to interlayer placement according to HDM Index 625.1. Existing JPCP may require spall repair (see Ch. 310) or individual slab replacements (see Ch. 320).

Some repairs may require use of nonstandard special provisions. More cost effective JPCP repairs for well-supported slabs may be possible by filling joints, cracks, and spalls > ¾” wide and 1” deep with No. 4 graded minor HMA, analogous to the process detailed for crack, seat, and overlay (see Ch. 410 and Section 41-6 of the 2010 Standard Specifications). For CRCP, any punchouts or other severe failures should also be repaired (see Ch. 380).

Extensive faulting > ¼” or an IRI > 170 inches/mile should be repaired by grinding (see Ch. 340) and the cause should be evaluated and addressed (see Section 110.2.1). If the existing concrete has extensive surface irregularities, the HMA interlayer may require increased design thickness or an additional item for HMA leveling to fill in depressions. Severe localized faulting or rocking slabs should be replaced together with underlying base (see Section 320.2).

A visual field survey is needed to identify existing pavement distress and evaluate potential repair locations and strategies. Deflection testing with a falling weight deflectometer (FWD) may help assess the underlying support condition of the existing pavement structure where distress conditions indicate potential problems. Ground Penetrating Radar (GPR) or coring are other options for investigating the base, subbase, and subgrade conditions and thicknesses.

420.3.2 Design

JPCP or CRCP pavement thickness is determined for UBCO using the standard design catalogs for new concrete pavement structures in HDM Index 623.1. The catalogs are based on mechanistic-empirical analysis principles considering climate region, subgrade type, and applied traffic loads (traffic index). The minimum thickness for unbonded concrete overlays is 0.70’. Existing JPCP or CRCP is considered stabilized base, analogous to LCB in a new concrete pavement structure. Existing JPCP should be cracked and seated under Section 41-6 of the 2010 Standard Specifications to limit strain and reflective cracking potential in the overlay layers. The HMA interlayer is not accounted for in the design but does provide some structural benefit.
UBCO can be designed for a 20 or 40-year life according to HDM Topic 612. For more information about CRCP design, refer to Chapter 200. For JPCP design, see Chapter 210.

To select the best materials and determine layer thicknesses, successful pavement structure designs must consider these and other engineering factors such as traffic control and estimated costs.

Figure 420-2: Unbonded concrete overlay construction

420.3.3 Traffic Handling and Safety

Adequate attention must be given to traffic handling to ensure safe, quality work and accurate cost estimates. UBCO usually requires the use of construction staging, temporary ramps, or detours. During initial construction stages, traffic can use the adjacent lanes or shoulders if they are wide enough and structurally adequate for anticipated traffic loading. Inadequate shoulder conditions may require partial reconstruction.

For more information about traffic handling alternatives, refer to Section 120.3.4, Chapter 200 for CRCP, and Chapter 210 for JPCP. Consult with the district traffic operations, traffic management, construction and public information offices for guidance on traffic handling, safety, scheduling, and communication issues.

420.4 PLANS, SPECIFICATIONS, AND ESTIMATING

420.4.1 Plans

UBCO is shown in the same manner as new construction on the project typical sections and layout sheets. At a minimum, include:

1. Title Sheet showing limits of project and pavement work.
2. Typical Cross Sections showing existing and proposed pavement widths and thicknesses.
3. Profiles showing the design finished grade of the roadway.
4. Superelevation diagrams showing roadway design cross slopes and transitions.
5. Construction Details for unique items of work not addressed on the typical sections or Standard Plans.
6. Quantity Sheets specifying types and amounts of work. Locations and limits of UBCO should be tabulated in the roadway quantity tables consistent with what is shown on layout sheets.
7. Standard Plans and Revised Standard Plans for CRCP (see Ch. 200) or JPCP (see Ch. 210).

420.4.2 Specifications

Table 420-1 lists some related specifications that may be used for UBCO work.

Table 420-1: Unbonded Concrete Overlay Related 2010 Standard Specifications

Section	Description	Notes
39-1	HMA	Use for HMA interlayers, HMA leveling, and individual slab replacements with HMA (nSSP required)
40-2	CRCP	Use for CRCP overlay construction
40-4	JPCP	Use for JPCP overlay construction
41-4	Spall Repair	Pre-overlay repair of existing distress. May use SSP 41-4 for fast-setting concrete material.
41-6	Crack and Seat	Use for cracking and seating existing JPCP to improve UBCO performance
41-9	Individual Slab Replacement (RSC)	Pre-overlay repair of existing distress

420.4.3 Cost Estimating

Unit cost estimates are typically based on historical bid prices which can be found in the Contract Cost database accessible on the intranet at http://sv08data.dot.ca.gov/contractcost/. Contract cost data unit prices by year are also published online through the Office of Engineer website at http://www.dot.ca.gov/hq/esc/oe/awards/.

Unit costs estimates should be adjusted based on project location, quantity of concrete, availability of materials used in the concrete mix, proximity of batch plants to construction site, and construction constraints such as lane availability and environmental restrictions. Typically, shorter construction windows result in lower productivity and higher bid costs. Mobilization of equipment, staging, traffic handling, and equipment setup are associated costs that must be considered in UBCO estimates. A separate mobilization item may be needed for UBCO projects.

UBCO may include estimates for associated work using the items listed in Table 420-2. The primary UBCO costs are the HMA interlayer, paid by the tonnage placed; and the concrete overlay volume, calculated based on the dimensions shown on the project plans. If the existing concrete is rough with extensive surface irregularities or IRI > 170 inches/mile, grinding may be needed or the HMA interlayer may require increased thickness or an additional item for HMA leveling to fill in depressions. Isolated failures should be repaired before overlaying using JPCP individual slab replacement or CRCP full-depth repair. For a complete list of potential pavement bid items, refer to the Office Engineer website at: http://oe.dot.ca.gov/occs.html.

For assistance with UBCO questions or recommendations, contact the Office of Concrete Pavement and Pavement Foundations in the Headquarters Division of Maintenance Pavement Program. Concrete pavement design tools, standards, and guidance are available online at http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/index.html.

Table 420-2: Unbonded Concrete Overlay Related 2010 and 2015 Bid Items

UBCO Work	Item Code	Description	Unit	Notes
Pre-Overlay Repairs	410121	Spall Repair (Fast-Setting Concrete)	SQYD	Can be used with SSP 41-4 for pre-overlay repair of severe spalls.
	411105	Individual Slab Replacement (RSC)	CY	Use for severe 3rd stage cracking > ¾" wide
	420201	Grind Existing Concrete Pavement	SQYD	Use for extensive faulting > ¼"
	Nonstandard	CRCP Full-Depth Repair	SQYD	Repairs for existing CRCP. Contact HQ Division of Maintenance Pavement Program for nSSP use.
Interlayer	390135	HMA (Leveling)	TON	Use for rough surfaces with extensive irregularities and depressions
Interlayer	390102	HMA (TYPE A)	TON	0.10' minimum thickness
Concrete Pavement	400050	CRCP	CY	Design based on HDM Index 623.1
	401050	JPCP	CY	Design based on HDM Index 623.1
	Various	Joint Seal	LF	Use for sealing transverse joints in desert or mountain climate regions using individual material item code

APPENDIX A: Online References

ONLINE REFERENCES

CHAPTER 100 - PAVEMENT MANAGEMENT STRATEGIES

Topic	Internet Link	Page Number
Construction procedures	Construction Manual	100-1
Pavement Design Life (HDM Topic 612)	HDM Topic 612	100-2
CAPM program information	HDM Topic 603	100-2
	HDM Topic 624	100-2
	HDM Topic 644	100-2
	Design Information Bulletin 81	100-3
Life cycle cost analysis (LCCA)	HDM Topic 612	100-3
	LCCA Procedures Manual	100-3
Roadway rehabilitation	HDM Topic 603	100-3
	HDM Topic 625	100-3
	HDM Topic 645	100-3
	Design Information Bulletin 79	100-3
Pavement Management System (PaveM)	PaveM	100-3
Life cycle cost analysis (LCCA)	LCCA Procedures Manual	100-4
Pavement climate regions	pavement climate regions	100-4
Roadway rehabilitation	HDM Topic 625	100-6
Rigid concrete pavement design catalogs	HDM Index 623.1	100-6
Crack, seat, and (HMA) overlay pavement design	HDM Index 625.1	100-6
Pavement Management System (PaveM)	PaveM	100-7
	iVision	100-7
Preoverlay repair advisory design standard	HDM Index 625.1	100-11

CHAPTER 110 - STRATEGY EVALUATION

Topic	Internet Link	Page Number
Automated Pavement Condition Survey (APCS) Data	PaveM	110-1
	iVision	110-1
Review records information	PaveM	110-3
	traffic volumes	110-3
	pavement climate regions	110-3
	as-built plans	110-3
	pavement condition report (PCR)	110-3
	iVision	110-3

Topic	Internet Link	Page Number
SCM prequalification program	prequalification program	120-8
METS authorized materials lists (AML)	http://www.dot.ca.gov/hq/esc/approved_products_list/	120-8
Innocuous aggregate sources	authorized material list	120-8
Abrasion of coarse aggregate	California Test (CT) 211	120-8
Aggregate soundness	CT 214	120-8
Durability index	CT 229	120-8
Concrete penetration	CT 533	120-8
Concrete slump	ASTM C143	120-8
Chemical admixtures	ASTM C494/494M	120-8
Air-entraining admixtures	ASTM C260	120-8
Chemical admixtures	ASTM C494/494M	120-9
Chemical admixtures AML	Chemical Admixtures for Use in Concrete	120-9
Chemical admixtures AML prequalification criteria	http://www.dot.ca.gov/hq/esc/approved_products_list/	120-9
Roller-compacted concrete guidance	Guide for Roller-Compacted Concrete Pavements	120-10
Nonstandard special provision requests	nssp.submittals@dot.ca.gov	120-12
Pavement drainage	HDM Chapter 650	120-14
Subsurface drainage	HDM Chapter 840	120-14
Structural section drainage system details	Standard plans D99A-D	120-14
Dowel bars for individual slab replacement	Revised Standard Plan RSP P8	120-15
Dowel bars in new JPCP	Revised Standard Plan RSP P10	120-15
Future maintenance and rehabilitation timing (see Section 2.7)	LCCA Procedures Manual	120-16
CA4PRS traffic handling analysis software	http://www.dot.ca.gov/research/roadway/ca4prs/index.htm	120-17
Concrete pavement strategy production rates (see Table 3-6)	LCCA Procedures Manual	120-17
CAMUTCD temporary traffic control requirements	Part 6, Temporary Traffic Control	120-18
Traffic Manual	http://www.dot.ca.gov/hq/traffops/engineering/control-devices/trafficmanual-current.htm	120-18
California Manual on Uniform Traffic Control Devices (CAMUTCD)	http://www.dot.ca.gov/hq/traffops/engineering/mutcd/index.htm	120-18
Code of Safe Practices	http://www.dot.ca.gov/hq/construc/flagging/2010_Code_of_Safe_Practices.pdf	120-18
Temporary traffic control Standard Plans	http://dot.ca.gov/hq/esc/oe/project_plans/HTM/stdplns-US-customary-units-new10.htm#temporary	120-18
Cost estimating information	http://www.dot.ca.gov/hq/oppd/costest/costest.htm	120-19
Current contract standards	http://www.dot.ca.gov/hq/esc/oe/construction_standards.html	120-19

CHAPTER 200 - CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (CRCP)

Concrete pavement design standards and methodology	HDM Chapters 600 – 670	200-1
LCCA information	http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html	

Topic	Internet Link	Page Number
Concrete materials information	Concrete Technology Manual	200-2
Climate map	http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/Climate.html	200-3
CRCP terminal joint details	Revised Standard Plan RSP P31A	200-3
CRCP tie bars and joint details	Revised Standard Plan RSP P16	200-6
Concrete pavement end panel pavement transitions	Revised Standard Plan RSP P30	200-8
Expansion joint seal (Type B)	Standard Plan B6-21	200-8
CRCP wide flange beam terminals	RSP P32A	200-9
CRCP wide flange beam terminals	RSP P32B	200-9
CRCP expansion joint and anchor details	Revised Standard Plan RSP P31B	200-10
End panel pavement transitions	Revised Standard Plan RSP P30	200-11
Pavement Design Life (HDM Topic 612)	HDM Topic 612	200-11
General engineering procedures for CRCP	HDM Topic 623	200-12
Drainage inlet details	RSP P45	200-12
	RSP P46	200-12
Tied CRCP shoulders	Revised Standard Plan RSP P4	200-12
CRCP widened lane	RSP P5A	200-12
CRCP (widened lane) lane and shoulder addition or replacement	RSP P5B	200-13
CRCP related standard plans	http://www.dot.ca.gov/hq/esc/oe/project_plans/HTM/stdplns-US-customary-units-new10.htm#pavement	200-13
CRCP design information	Division of Maintenance Pavement Program website	200-15

CHAPTER 210 - JOINTED PLAIN CONCRETE PAVEMENT (JPCP)

Concrete pavement design standards and methodology	HDM Chapters 600 – 670	210-1
Division of Maintenance Pavement Program website	http://www.dot.ca.gov/hq/maint/Pavement/Pavement_Program	210-1
Pavement climate regions	pavement climate regions	210-1
Pavement structure design considerations and requirements	600	210-2
	610	210-2
	620	210-2
Concrete materials information	Concrete Technology Manual	210-2
Concrete pavement design catalogs	HDM Index 623.1	210-2
Transverse joint alignment for lane reconstruction or addition	Revised Standard Plan RSP P18	210-2
Base bond breaker standard special provisions	SSP 36-2	210-4
Width of tied JPCP lanes	Revised Standard Plan RSP P18	210-4
Dowel and tie bars at longitudinal joints	Revised Standard Plan RSP P18	210-4
Dowel bar placement	Revised Standard Plan RSP P10	210-5

Topic	Internet Link	Page Number
Shoulders adjacent to widened slabs	Revised Standard Plan RSP P3B	210-5
JPCP widening Revised Standard Plans	RSP P3A	210-6
	RSP P3B	210-6
Concrete pavement end panel pavement transitions	Revised Standard Plan RSP P30	210-7
Type 60 Concrete Barrier	Standard Plan A76A	210-7
Minimum cover for various pipe thicknesses and diameters	HDM Tables 856.3A through 856.3P	210-8
Minimum cover for construction loads on culverts	Standard Plan D88	210-8
JPCP standard plans	http://dot.ca.gov/hq/esc/oe/project_plans/HTM/stdplns-US-customary-units-new10.htm#pavement	210-9
Contract cost database	http://sv08data.dot.ca.gov/contractcost/	210-10
Contract cost data annual unit prices	http://www.dot.ca.gov/hq/esc/oe/awards/	210-10

CHAPTER 310 - SPALL REPAIR

Standard Specifications	Standard Specification Section 41-1	310-2
Standard Special Provision for fast-setting concrete	SSP 41-4	310-2
Nonstandard special provision requests	nssp.submittals@dot.ca.gov	310-4
iVision	https://ivision.fugro.com/CaliforniaSH/#/Login	310-5
Spall repair boundaries	Revised Standard Plan RSP P6	310-6
Cost estimating information	http://www.dot.ca.gov/hq/oppd/costest/costest.htm	310-7
Current contract standards	http://www.dot.ca.gov/hq/esc/oe/construction_standards.html	310-8
Spall repair dimensions	RSP P6	310-8

CHAPTER 320 - INDIVIDUAL SLAB REPLACEMENT

Repairing distressed concrete pavement prior to an overlay	HDM Index 625.1	320-1
Cost analysis information	Life-Cycle Cost Analysis Procedures Manual	320-2
Life cycle cost analysis information	LCCA	320-2
Type I individual slab replacement using dowel bars	RSP P-8	320-11
iVision	https://ivision.fugro.com/CaliforniaSH/#/Login	320-11
Type I individual slab replacement using dowel bars	RSP P-8	320-11
		320-13
Base bond breaker standard special provisions	SSP 36-2	320-15
Current contract standards	http://oe.dot.ca.gov/occs.html	320-15
Cost estimating information	http://www.dot.ca.gov/hq/oppd/costest/costest.htm	320-16
Concrete Pavement Preservation Workshop (FHWA)	http://www.cptechcenter.org/publications/preservation_reference_manual.pdf	320-18
Guidelines for Early-Opening-to-Traffic Portland Cement Concrete Mixtures for Pavement Rehabilitation	http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_540.pdf	320-18

Topic	Internet Link	Page Number
Rehabilitation of Concrete Pavements, Volume I — Repair Rehabilitation Techniques	http://isddc.dot.gov/OLPFiles/FHWA/013566.pdf	320-18
Full-Depth Repair of Portland Cement Concrete Pavement Checklist	http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=351	320-18

CHAPTER 330 - DOWEL BAR RETROFIT

Type I individual slab replacement using dowel bars	RSP P-8	330-4 330-5 330-6
Dowel Bar Retrofit Standard Plan	RSP P7	330-6
SSP 41-8	http://www.dot.ca.gov/hq/esc/oe/construction_contract_standards/SSPs/2010-SSPs/division_5/41-8_A07-19-13.docx	330-7

CHAPTER 340 - GRINDING AND GROOVING

Guidance for Projects Involving Portland Cement Concrete Pavement Grooving or Grinding	Design Information Bulletin 84	340-4
SSP for concrete residue from grooving and grinding when onsite drying or disposal within the highway is allowed	42-1.03B	340-4
SSP used if grinding locations are not specified in Section 42-3.03A or shown, such as at bridge decks or weigh-in-motion scales	42-3.03A	340-4
Cost estimating information	http://www.dot.ca.gov/hq/oppd/costest/costest.htm	340-5

CHAPTER 360 - JOINT AND CRACK SEALING

JPCP and CRCP joint sealing policy	HDM Index 622.5	360-1 360-2
Average and maximum crack width data	PaveM	360-2
Joint seal dimensions for sealing new and existing joints	Revised Standard Plan (RSP) P20	360-3
Isolation joint Standard Plan	RSP P18	360-6
Backer rod diameters and sealant recess depths	RSP P20	360-7
Silicone sealant authorized material list	Authorized Material List	360-7
Silicone sealant placement depth	RSP P20	360-7
Preformed compression joint seal details	RSP P20	360-8
Sealing existing lane-shoulder joints	Caltrans Maintenance Manual Section B.09	360-9
Joint seal construction dimensions	RSP P20	360-10
Isolation joint Standard Plan	RSP P18	360-10

Topic	Internet Link	Page Number
Joint seal design details	RSP P20	360-11
JPCP contraction joint Standard Plan	RSP P15	360-11
CRCP contraction joint Standard Plan	RSP P16	360-11
Isolation joint Standard Plan	RSP P18	360-11
Nonstandard special provision requests	nSSP Submittals@DOT	360-11
Cost estimating information	http://www.dot.ca.gov/hq/oppd/costest/costest.htm	360-12

CHAPTER 380 - CRCP FULL-DEPTH REPAIR

Nonstandard special provision requests	nssp.submittals@dot.ca.gov	380-1
Base bond breaker no. 3 standard special provisions	SSP 36-2	380-3
Pavement climate regions map	http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/Climate.html	380-3
Nonstandard special provision requests	nssp.submittals@dot.ca.gov	380-4
iVision	https://ivision.fugro.com/CaliforniaSH/#/Login	380-4
Nonstandard special provision requests	nssp.submittals@dot.ca.gov	380-7
Base bond breaker no. 3 standard special provisions	SSP 36-2	380-7
Guidelines for Early-Opening-to-Traffic Portland Cement Concrete Mixtures for Pavement Rehabilitation	http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_540.pdf	380-8

CHAPTER 400 - LANE REPLACEMENT

Design life	Highway Design Manual [HDM] Topic 612	400-1
Life-cycle cost analysis guidance	Life-Cycle Cost Analysis Procedures Manual	400-2
Evaluation of highway construction time and traffic impacts	Division of Research and Innovation webpage	400-2
CA4PRS software download	Construction Analysis for Pavement Rehabilitation Strategies	400-2
Existing shoulder replacement	HDM Topic 613.5(2)	400-4
Design Guidance and Standards for Roadway Rehabilitation Projects	Design Information Bulletin 79-03	400-4
Geometric cross slope requirements	HDM Index 302.2	400-4
Shoulder requirements	HDM Topic 626.2	400-4
Design life requirements	HDM Topic 612	400-4
Pavement structure requirements for replaced shoulders and strategies for maintaining existing shoulders	HDM Topic 613.5(2)	400-4
Pavement structure design	HDM Topic 623	400-5
Existing pavement structure and core data	iGPR	400-5
Dowel bar details	Standard Plan P10	400-6
JPCP dowel bars at transverse contraction joints	Standard Plan P1	400-6

Topic	Internet Link	Page Number
JPCP tie bars at transverse contraction joints	Standard Plan P1	400-6
Isolation joint details	Standard Plan P18	400-6
Spacing patterns for new transverse joints	Standard Plan P1	400-6
Shoulder design	HDM Topic 613.5.2a	400-7
Pavement drainage	HDM Chapter 650	400-7
Subsurface drainage	HDM Chapter 840	400-7
Division of Maintenance Pavement Program	website	400-13
Cost estimating information	Division of Design Cost Estimating website	400-14
Summary Report: Evaluation of Rigid Pavement Long-life Strategies	http://www.its.ucdavis.edu/research/publications/publication-detail/?pub_id=1171	400-15
Constructability and Productivity Analysis for Long Life Concrete Pavement Rehabilitation Strategies	http://www.ucprc.ucdavis.edu/PDF/Constructability%20Analysis.pdf	400-15
Full-Depth Repair of Portland Cement Concrete Pavements	http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=351	400-15
Rehabilitation of Concrete Pavements, Volume I — Repair Rehabilitation Techniques	http://isddc.dot.gov/OLPFiles/FHWA/013566.pdf	400-15
Concrete Pavement Preservation Workshop (FHWA)	http://www.cptechcenter.org/publications/preservation_reference_manual.pdf	400-15
Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual	http://www.cptechcenter.org/research/projects/detail.cfm?projectID=1982195539	400-15
Smoothness Specifications for Pavements	http://www.nap.edu/openbook.php?record_id=6337&page=R1	400-15
Achieving a High Level of Smoothness in Concrete Pavements without Sacrificing Long-Term Performance	http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/05069/05069.pdf	400-15

CHAPTER 410 - CRACK, SEAT AND (HMA) OVERLAY

Life-cycle cost analysis information	http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html	410-3
Pavement tapers and transitions guidance	pavement tapers and transitions guidance	410-3
Vibration mitigation and monitoring information	Division of Environmental Analysis website	410-3
Guidance for removing traffic markings, striping, and markers	http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/Pave-Over-Thermo-Paint.pdf	410-5
Design life requirements	HDM Topic 612	410-6
Construction procedures	Construction Manual	410-7

CHAPTER 420 - UNBONDED CONCRETE OVERLAY (UBCO)

Concrete pavement layer thicknesses	HDM Index 623.1	420-1
Life-cycle cost analysis information	http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html	420-2
Concrete materials information	Concrete Technology Manual	420-3

Topic	Internet Link	Page Number
Pre-overlay repair advisory design standard	HDM Index 625.1	420-3
Concrete pavement design catalogs	HDM Index 623.1	420-3
Design life requirements	HDM Topic 612	420-4
Contract cost database	http://sv08data.dot.ca.gov/contractcost/	420-5
Contract cost data annual unit prices	http://www.dot.ca.gov/hq/esc/oe/awards/	420-5
Pavement bid items	Office Engineer website	420-6
CRCP design	HDM Index 623.1	420-6
JPCP design	HDM Index 623.1	420-6
Division of Maintenance Pavement Program website	http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/index.html	420-6