CHAPTER 120—PAVEMENT DESIGN CONSIDERATIONS

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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.

Temperature

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. Dowelled JPCP slabs and CRCP are less susceptible to potential curling and warping distress due to steel reinforcement.

Figure 120–1: Slab curling and warping

Precipitation
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).
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>
<thead>
<tr>
<th>Subgrade Type</th>
<th>California R-value</th>
<th>Unified Soil Classification System (USCS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>R-value &gt; 40</td>
<td>SC, SP, SM, SW, GC, GP, GM, GW</td>
</tr>
<tr>
<td>II</td>
<td>10 ≤ R-value &lt; 40</td>
<td>CL, MH, ML, CH*</td>
</tr>
<tr>
<td>III</td>
<td>R-value &lt; 10</td>
<td>CH**</td>
</tr>
</tbody>
</table>

*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 PPCP 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>Moderate heat of hydration and sulfate resistance</td>
<td>IS (MS) Portland blast-furnace slag cement</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>High early strength (typically used only for RSC)</td>
<td>IP (MS) Portland-pozzolan cement</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>High sulfate resistance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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)

<table>
<thead>
<tr>
<th>SCM</th>
<th>AASHTO Test Method</th>
<th>Applications</th>
<th>Mix Properties</th>
<th>Concrete Properties</th>
</tr>
</thead>
</table>
| 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 (CaCl₂) 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**

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

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/](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.

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>
<thead>
<tr>
<th>Typical Curing Time (hours)</th>
<th>Concrete Mix Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2–4</td>
<td>Specialty or proprietary high early strength cement mixes under ASTM C219</td>
</tr>
<tr>
<td>4–6</td>
<td>Type III portland cement with non-chloride accelerators and high-range water-reducing admixtures</td>
</tr>
<tr>
<td>&lt; 24</td>
<td>Type II portland cement with non-chloride accelerators</td>
</tr>
<tr>
<td>≥ 24</td>
<td>Type II portland cement *</td>
</tr>
</tbody>
</table>

*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 to 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.

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).

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

Figure 120–5: Dowel bars

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:

- **Detour**: 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:

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](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](http://www.dot.ca.gov/hq/esc/oe/construction_standards.html).

REFERENCES
