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.

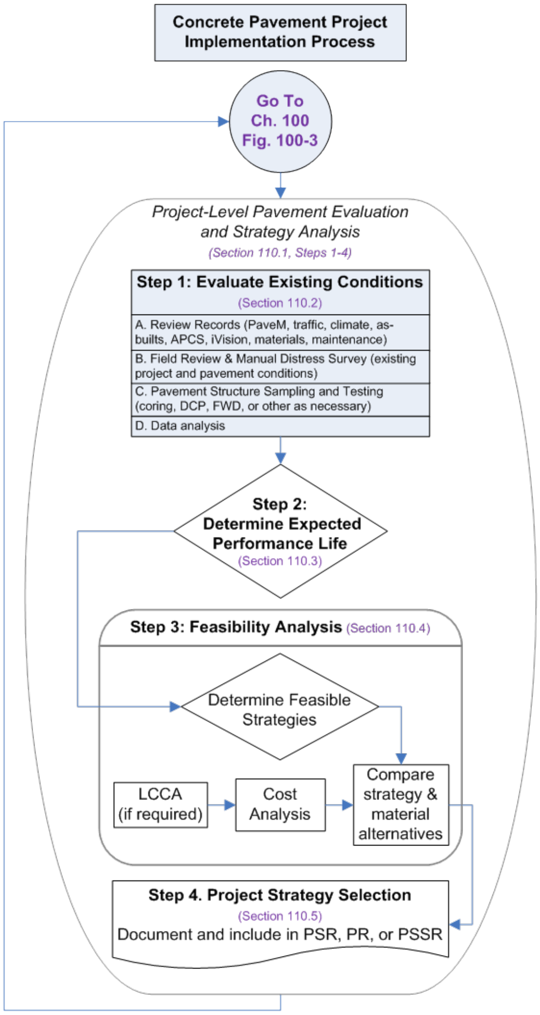

Figure 110-1: Concrete pavement strategy evaluation process

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.

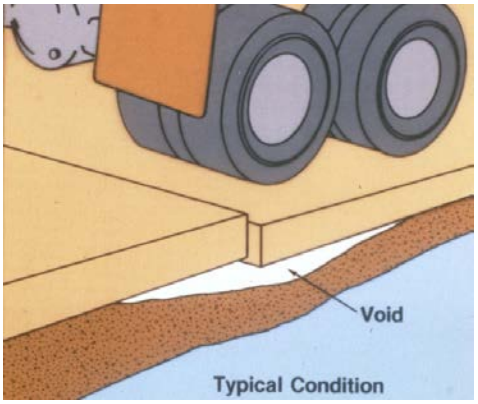

Figure 110-2: Slab faulting with eroded base[1]

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.