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Site Investigation Guide for Mechanistic-Empirical Design of California Pavements

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16. ABSTRACT

This document provides guidance on conducting site investigations for new highway construction and widening, rehabilitation, and reconstruction of existing roads. Site investigation is an important part of the pavement design process. This guide has been developed as an integral part of the mechanistic-empirical pavement design procedures for new pavement and rehabilitation and reconstruction of existing pavement. An investigation requires four steps: (1) the preliminary site investigation and desktop data collection, (2) the detailed site investigation and data collection for design, (3) the site investigation data analysis, and (4) the project investigation report.

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PROJECT OBJECTIVES

The objective of this study is to prepare guidance on site investigations for new highway construction, reconstruction, rehabilitation, and widening projects. This site investigation guide is an integral part of the *CalME* mechanistic-empirical design procedures for flexible-surfaced alternatives, and *Pavement ME* procedures or use of the Caltrans catalog for rigid-surfaced pavement design.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AADTT	Average annual daily truck traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt concrete
APCS	Automated pavement condition survey
ASTM	American Society for Testing and Materials
ATPB	Asphalt-treated permeable base
Caltrans	California Department of Transportation
CAPM	Capital preventive maintenance
CBR	California bearing ratio
CC	Cement concrete
CCPR	Cold central plant recycling
COA	Concrete overlay on asphalt
COV	Coefficient of variance
CRCP	Continuously reinforced concrete pavement
CT	Caltrans test
CTB	Cement-treated base
CTPB	Cement-treated permeable base
DBR	Dowel bar retrofit
DCP	Dynamic cone penetrometer
DPI	Dynamic cone penetrometer penetration index
E	Elastic modulus
EI	Soil expansion index
FDR	Full-depth recycling
FWD	Falling weight deflectometer
GPR	Ground penetrating radar
HMA	Hot mix asphalt
HDM	Highway Design Manual
JPCP	Jointed plain concrete pavement
LCB	Lean concrete base
LCCA	Life cycle cost analysis
LTE	Load transfer efficiency
ME	Mechanistic-empirical
MEPDG	Mechanistic-Empirical Pavement Design Guide
METS	Materials and Engineering Testing Services
M_r	Resilient modulus
OGFC	Open-graded friction course

PA&ED	Project approval and environmental document
PCR	Pavement condition report
PDR	Partial-depth recycling
PI	Plasticity index
PIP	Project initiation proposal
PIR	Project initiation report
PPRC	Partnered Pavement Research Center
PS&E	Plans, specifications, and estimates
PSR	Project study report
PSSR	Project scope summary report
RAP	Reclaimed asphalt pavement
RHMA-G	Gap-graded rubberized hot mix asphalt
RHMA-O	Open-graded rubberized hot mix asphalt
SAMI	Stress absorbing membrane interlayer
TI	Traffic Index
UAS	Unmanned aerial system (drone)
UCPRC	University of California Pavement Research Center
UCS	Unconfined compressive strength
USCS	Unified soil classification system
USDA	United States Department of Agriculture
WIM	Weigh-in-motion

TEST METHODS CITED IN THE TEXT

Caltrans

CT 202 Sieve Analysis of Fine and Coarse Aggregates

CT 204 Method of test for liquid limit, plastic limit and plasticity index of soils

CT 354 Method of Test for Evaluating the Expansive Potential of Soils Underlying Portland Cement Concrete Pavements (Third Cycle Expansion Pressure Test)

CT 357 Method of Test for Obtaining Deflection Measurements and Layer Thickness Information for Rehabilitation Design of Pavements Using Mechanistic-Empirical Design and Analysis Procedures

AASHTO

M 145 Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

T 258 Standard Method of Test for Determining Expansive Soils

T 273 Standard Method of Test for Soil Suction

T 307 Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials

ASTM

D1196 Standard Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements

D2487 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D4546 Standard Test Methods for One-Dimensional Swell or Collapse of Soils

D4829 Standard Test Method for Expansion Index of Soils

D6951 Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications

CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
Length				
in.	inches	25.4	millimeters	mm
ft.	feet	0.305	meters	m
yd.	yards	0.914	meters	m
mi.	miles	1.61	kilometers	km
Area				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac.	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
Volume				
fl. oz.	fluid ounces	29.57	milliliters	mL
gal.	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
Mass				
oz.	ounces	28.35	grams	g
lb.	pounds	0.454	kilograms	kg
T	short tons (2,000 pounds)	0.907	metric ton	t
Temperature (exact degrees)				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C
Forces and Pressure or Stress				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
Length				
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft.
m	meters	1.09	yards	yd.
km	kilometers	0.621	miles	mi.
Area				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac.
km^2	square kilometers	0.386	square miles	mi^2
Volume				
mL	milliliters	0.034	fluid ounces	fl. oz.
L	liters	0.264	gallons	gal.
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
Mass				
g	grams	0.035	ounces	oz.
kg	kilograms	2.202	pounds	lb.
t	metric ton	1.103	short tons (2,000 pounds)	T
Temperature (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
Force and Pressure or Stress				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the abbreviation for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2021)

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1 INTRODUCTION

1.1 Purpose of This Document

The purpose of a site investigation is to allow pavement engineers to collect sufficient data to make informed and appropriate decisions throughout the project development and pavement design processes and to provide inputs for a chosen structural design method.

This document provides guidance to project engineers and material engineers for performing site investigations as a first critical step in confirming the recommended approach for capital maintenance (CAPM) projects, and in developing structural designs for projects that involve rehabilitation, widening, reconstruction, or new pavement. The guide's primary focus is on collecting the data required for mechanistic-empirical (ME) pavement design using the *CalME* software for flexible-surfaced pavement, and on using the *Pavement ME* software and the Caltrans rigid pavement design catalog for rigid-surfaced pavement. The guide also provides information specific to California conditions, providing details about site investigation procedures that can be used to supplement the current *Highway Design Manual* (*HDM*) and other available design guides.

Since it is part of the project development process, a site investigation should include collection of the following, with the level of detail dependent on the type of project and traffic:

- Layer information and materials properties
- The condition of the existing subgrade and pavement, including an assessment of distresses and their causes and origins
- The variability of the subgrade and pavement conditions within the project limits
  + Identification of localized areas that need repair or other actions that should be considered in determining appropriate treatment and design, such as localized pockets of weak subgrade, expansive soils, or localized drainage failures
  + Information to determine if a project should be divided into subsections that can be treated as uniform in terms of structure type selection and design of the pavement structure cross sections

1.2 Related Guidance

This guide supplements the project investigation requirements documented in the *Highway Design Manual*, Chapter 600–680 on Pavement Engineering *(1)*. Other Caltrans guides that contain site investigation information relevant to specific procedures include, but are not limited to, the following:

- Project Development Procedures Manual *(2)*
- Design Information Bulletin 79-04 *(3)*
- Design Information Bulletin 81-02 *(4)*
- Guide for Partial- and Full-Depth Recycling in California *(5)*
- Guidelines for the Stabilization of Subgrade Soils in California *(6)*
- Concrete Pavement Guide *(7)*
- Subgrade Enhancement Geosynthetic Design and Construction Guide *(8)*
- Aggregate Base Enhancement with Biaxial Geogrids for Flexible Pavements: Guidelines for Project Selection and Design *(9)*

1.3 Site Investigation in the Project Development Process

There are essentially nine stages in any Caltrans pavement project development process. Site investigations are an integral part of the process, but the level of detail and when they are completed will vary depending on the type of activity as follows:

- For maintenance projects, only limited site investigations are required to verify the pavement structural- and ride quality-related condition data and distresses obtained from the *PaveM* pavement management system. Detailed site investigations are only carried out if additional project-specific information is required (e.g., more detailed investigations on partial-depth recycling projects to determine optimum recycling depth and to ensure that thin, distressed layers do not remain beneath the recycled layer).
- For major roadway rehabilitation projects, the initial desktop study and preliminary site investigation are performed after the pavement sections that need rehabilitation have been identified. The nine stages in the project development process for major rehabilitation are shown in Figure 1.1. Site investigation occurs in stages 3 and 6 shown in the figure. There are five steps to the site investigation. The first two steps, the preliminary site investigation and the initial desktop study data collection (discussed in Chapter 2), are completed in Stage 3 and are included in the Project Scope Summary Report (PSSR). The last three steps—including the detailed site investigation, analysis of the data, and preparation of a site investigation report (discussed in Chapters 3, 4, and 5, respectively)—are completed in Stage 6.

- For new pavement on a new alignment and for widening projects, the preliminary site investigation and initial desktop study data collection (and/or geotechnical investigation) are done in the early planning stages of the project development process. The detailed site investigation is performed later to prepare alternative designs for life cycle cost analysis, which is part of the formal engineering studies after project initiation *(2)*.

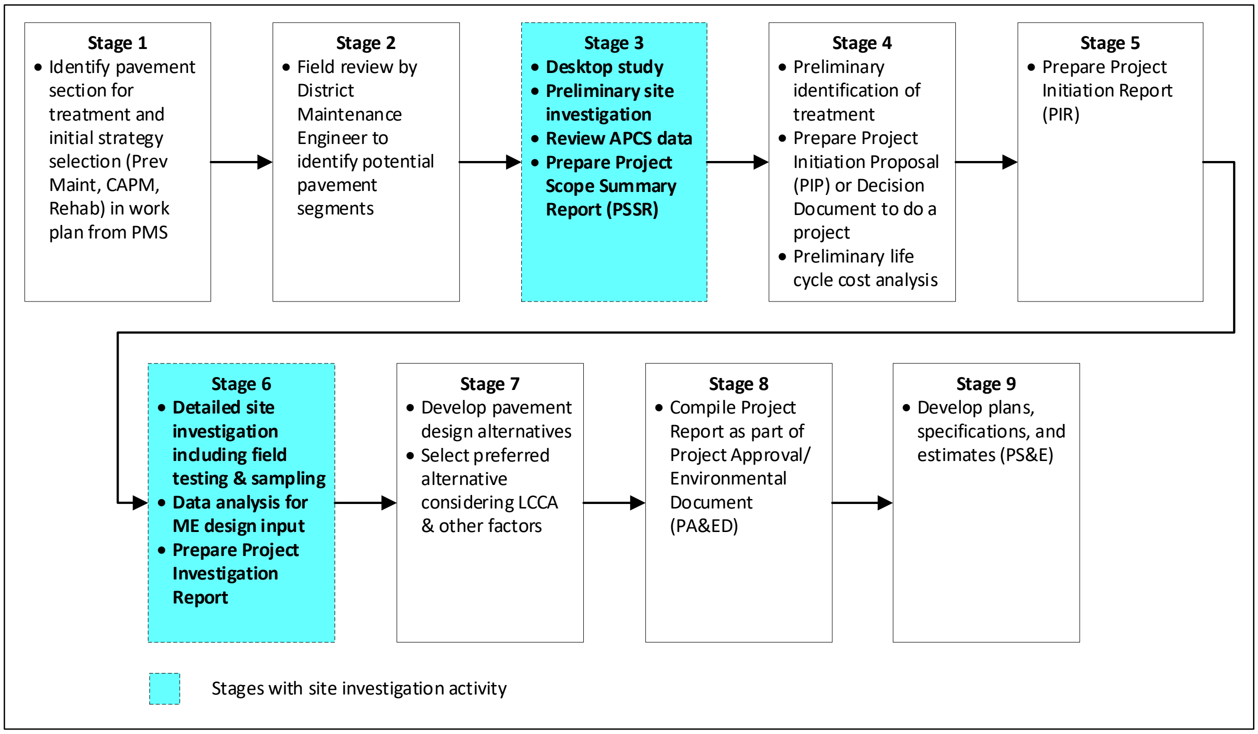

Figure 1.1: Stages in the project development process for major rehabilitation.

A detailed site investigation for an existing pavement is typically performed after a Project Initiation Report (PIR) has been approved and the project is programmed.

At each level of project development, all network-level condition data for proposed projects are verified and supplemented by field review and the use of images and tools available online through the *PaveM* website portal. Localized failures and their cause(s) should be identified, and their repair included in the scope of all projects. Additional project-level information, including testing data and materials analysis, may be necessary to make informed pavement management decisions and to develop designs *(3)*.

The results of the preliminary site investigation can be used with typical inputs for conceptual-level life cycle cost analysis (LCCA) of alternative pavement types and structures. It should be understood that the results of the LCCA may change once alternative pavement types and structures are further developed using the more precise information gathered during a detailed site investigation. The potential for a change in the LCCA results when the detailed site investigation is completed should be noted in the PSSR.

Detailed site investigations provide inputs for the mechanistic-empirical (ME) design of alternative pavement types and structural cross-sections. To select the final cross-sections, alternative pavement designs are evaluated using LCCA along with other information described in the *Life Cycle Cost Analysis Procedures Manual (10)*. It should also be understood that LCCA is one of several criteria considered when selecting the preferred alternative; consult the *LCCA Manual* for more details.

1.4 Structure of this Guide

The four steps in a project site investigation include the following and form the basis of the structure of this guide:

1. Preliminary investigation, which includes initial desktop study data collection and a preliminary site investigation (Chapter 2)
2. Detailed site investigation (Chapter 3)
3. Data analysis (Chapter 4)
4. Project investigation report (Chapter 5)

Additional supporting information is provided in three appendices.

2 STEP 1: PRELIMINARY INVESTIGATION

2.1 Introduction

A preliminary investigation is the first step taken in a project site investigation. This step includes an initial desktop data collection study to gather sufficient information to identify the project location, boundaries, and pavement information and the project goal and constraints. It also includes performing a preliminary site investigation to assess current condition and initial identification of causes of distress. The findings are used to develop a clearer understanding of the general condition of the pavement and site and to support decision-making about the most appropriate choice of strategy and design for a project, including confirming the recommended approach for capital maintenance (CAPM) projects, providing content for the project initiation report (PIR) required for major rehabilitation projects *(2)*, and providing content for the initial scoping in the engineering studies for new pavement on new alignment and widening projects *(3)*. On new construction, the preliminary site investigation may be done as part of a geotechnical investigation, which is not covered in this guide. For these projects, attach the geotechnical investigation report to the preliminary site investigation report.

The preliminary investigation should be carried out as early as possible to identify key issues that require more detailed investigation, to get an idea of project costs, and to maximize the time available for the analysis to determine the most appropriate design strategy. Although not always feasible, the preliminary site investigation should preferably be done during or at the end of the rainy season, when problems associated with subgrade moisture and drainage are most apparent.

Findings and observations from the preliminary investigation are documented in a Project Scope Summary Report (PSSR) with recommendations for proceeding with a more detailed site investigation if applicable.

2.2 Initial Desktop Study

The desktop study to collect initial project data requires finding resources, consulting key people involved in the project, and gathering all the information pertinent to the road for all types of rehabilitation, widening, reconstruction, and new pavement projects.[1] Information required for a desktop study will vary from project to project. It typically includes, but is not limited to, some or all of the following (summarize the findings on an Initial Desktop Study form [example Form 1 in Appendix A]):

- **Consultation** with the headquarters pavement advisor, district materials engineer, district maintenance engineer, maintenance superintendent, and project manager for input regarding the project must be done before any detailed analysis. Identify the goals of the project, including the funding program, expected design life, construction year, plans or expectations for future rehabilitation and/or widening, number of lanes, expected construction windows, and traffic characteristics such as speed and turning movements. Ask about any major issues that need special attention (e.g., drainage issues including those related to increased runoff from recent wildfire scars, climate change vulnerability, the prevalence of settlement, expansive soils, sulfate concerns for lime- or cement-stabilized materials and cement concrete, occasional flooding, etc.). The geotechnical report from the original construction can provide valuable information regarding underlying foundation layers.
- **Traffic data** are used to provide preliminary consideration of causes of pavement distress and construction work zone traffic handling.
  + Traffic index (TI) or average annual daily truck traffic (AADTT) provide an indication as to whether the pavement carries heavy truck traffic that will cause structural failures such as fatigue cracking and rutting on asphalt concrete (AC) surfaced pavement, and cracking and faulting on cement concrete (CC) pavement.
  + Collect information as needed when considering traffic handling during construction (including staged construction where traffic is allowed on partially completed lanes to facilitate construction operations)—including identification of alternative routes; the ability to construct temporary lanes; the ability to counter-flow traffic; other constraints on traffic handling such as bridges, underpasses, narrow shoulders, embankments and slopes; localized special road user constraints (e.g., hospitals, schools, businesses, events); and any other site conditions that might affect the safety of road users or construction workers.
- **Climate data** considerations include, but are not limited to, the potential for freeze-thaw of the subgrade at higher altitudes and excessive wetting of the subgrade, base, and subbase layers of the pavement due to localized rainfall variation. Consult local maintenance superintendents to determine if there are any specific climate-related anomalies for the

[1] Links to Caltrans online resources used in the desktop study can be found at https://dot.ca.gov/programs/engineering-services/.

area that need to be taken into consideration. Also refer to the District Climate Change Vulnerability Assessment Reports[2] for information that may affect the pavement's future performance.

- **Maps** help with understanding intersections, connecting routes, and traffic flows. Options include *Google Maps* and *Google Earth,* and Caltrans GIS maps.
- **Pavement management system (*PaveM*)** and pavement condition reports from the *PaveM* portal for existing pavements contain current and historical information on previous maintenance and rehabilitation projects (H-chart), pavement condition, and the history of previous maintenance and rehabilitation treatments. Caltrans employees can access *PaveM* automated pavement condition survey (APCS) distress and smoothness data by using the Pavement Condition Report (PCR) tool in the Pathway Services *PATHWEB* feature*.*
- **As-built plans** are available for many, but not all, past projects on the Caltrans intranet.[3] These provide historical information about existing pavement structures such as layer thickness, layer type, materials, drainage structures, design traffic, geometry, and lane reconfigurations. This information can provide an initial indication of the current pavement structure and may show where portions of previous structures are existing beneath the current structure. For projects where in-place recycling or on-site cold central plant recycling, or partial or complete removal of existing pavement layers is being considered, this information can be used to estimate the depth of recycling or removal.
- **Ground penetrating radar data** from the 2010/11 ground penetrating radar (GPR) survey of the state network, and verification cores from that survey, have been uploaded into the *iGPR* web-based tool[4] along with other coring that has been done since then as part of site investigations. This tool can be accessed for additional information regarding as-built structures. *iGPR* shows pavement cross sections, additional core data from later site investigations, and other coring on the state network. The plots of pavement cross sections from the GPR survey and the core data provide information about pavement layer types and thicknesses and variability along the project, as well as photographs of cores showing the condition of asphalt concrete, cement concrete, and stabilized layers at the time the core was taken.
- **Photographs** can be used to obtain a general overview of the proposed project site and an initial indication of the current condition of the road, problem areas and localized failures, drainage, and project surroundings. Caltrans employees can use the Pathway Services *PATHWEB* feature to access forward looking right-of-way photographs from the APCS. Plan views and the *Streetview* option in *Google Maps* can also be used to "drive" the road to

[2] https://dot.ca.gov/programs/transportation-planning/division-of-transportation-planning/air-quality-and-climate-change/2019-climate-change-vulnerability-assessments
[3] http://ppmoe.dot.ca.gov/des/oe/current-past-projects.php
[4] www.ucprc.ucdavis.edu/igpr

gather this information. Photographs, including the Google Maps Streetview features, should never be considered a substitute for a preliminary site investigation because the photographs cannot capture all aspects of the pavement or its context that can be seen in a site investigation and because photographs may be several years old and not reflect the current condition of the pavement or recent repairs.

- **Maintenance history**, obtained from the area maintenance superintendent, can be used to identify problem areas along the project that may require additional investigation and pre-treatment repairs such as patching and/or digouts, culvert washouts, localized areas of subsidence/settlement, and shoulder erosion.
- **Bridge height and subsurface utility information** are important for developing pavement design alternatives because they can constrain elevations of the road surface and the removal of pavement layers and other excavation. Information needed includes bridge heights and bridge height standards, and locations of shallow utilities such as water, gas, stormwater and sewage pipes, electrical or fiber optic conduit, internet, and other telecommunications cables, and utility access such as drainage inlets and manholes. Check these issues by connecting with online information and by contacting the district offices responsible for maintaining these structures, district maintenance engineers who are aware of these items in the right-of-way, and local government agencies where applicable.
- **Project notes**—including field notes, the draft treatment selection, and the master workplan cost estimate in the Project Report generated in the *PaveM* process—can provide information on the basis for early recommendations for a particular maintenance, rehabilitation, or widening strategy.

2.3 Site Visit and Visual Assessment

The preliminary site investigation includes a review and preliminary assessment of the project surroundings, drainage, pavement condition, alignment, and potential traffic accommodation and construction issues. In this step, the engineer visits the project site and evaluates the site condition in conjunction with the initial desktop study information already collected.

Record the results of the initial visual assessment on an appropriate form (either Form 2 [flexible pavements] or Form 3 [rigid pavement] in Appendix A). Completing a checklist of items/issues that may influence design decisions that will need to be discussed in the PSSR may also be useful (example Form 4 in Appendix A). The following assessment criteria apply primarily to CAPM, rehabilitation, widening, and reconstruction projects, but some aspects are also important for new construction projects:

- **Pavement management system (*PaveM Portal*) and pavement condition reports:** Verify the current pavement distresses.
- **As-built plans:** Verify the as-built plans such as pavement surface type, drainage structures, lane configurations, intersection configurations, shoulder widths, property access, construction constraints, and geometry.
- **Maintenance history and localized problems:** Check Highway Chart (H-Chart) in *PaveM* Portal to understand pavement maintenance history. Verify localized problem areas along the project and identify any likely failure mechanisms.
- **Surface distress assessment on existing pavement:** Verify any issues identified in the site investigation and information that were reviewed during the initial desktop data collection. Assess the pavement and adjacent areas and identify and/or estimate the following:
  + Extent of maintenance, especially patches and digouts, and their condition relative to the service life of other parts of the project to determine if they are localized and associated with poor drainage or with other problems requiring frequent maintenance (example in Figure 2.1).
  + Grade change limitations including, but not limited to, bridge heights and guardrails.
  + On rehabilitation projects, the road height above natural ground level and if an existing granular base layer is present (roads level with or below natural ground level, without curbs and drainage features, will usually have drainage problems [example in Figure 2.2]).

Figure 2.1: Example of early patch failure related to poor drainage.

Figure 2.2: Example of road below natural ground level.

  + On flexible pavements, the type, severity, and extent of cracking and the presence of fines from the subgrade, base, and/or subbase layers pumped through the cracks (and joints and/or cracks on rigid pavement). The presence of pumped fines on the surface (example in Figure 2.3), often occurring where there is extensive alligator cracking (example in Figure 2.4), usually indicates the presence of water in the base, subbase, and/or subgrade that is mobilized under traffic loading. Pumping can result in contamination of aggregate base and subbase layers with excess fines from the subgrade. Pumped fines may be plastic, which is particularly damaging to the properties of the base and subbase. The fines present on the surface may also come from moisture-damaged asphalt concrete layers (example in Figure 2.5). Extensive pumping is usually an indication that the road requires drainage improvements, rehabilitation, and/or structural improvement.

+ On flexible pavements, the rut depth, shape, and extent. Deep, wide ruts with fatigue cracking usually indicate base or subgrade problems (example in Figure 2.6).

Figure 2.3: Example of pumping.

Figure 2.4: Example of Alligator B cracking.

Figure 2.5: Example of fines pumped through alligator cracks from stripped asphalt layers.
(Core photo in insert)

Figure 2.6: Example of rutting associated with base/subgrade failure.

+ On jointed plain concrete pavement (JPCP), the presence of faulting and corner cracks, as well as pumped fines on the surface near joints and cracks, are indicators of pumping from the subgrade, subbase, and/or base layers (example in Figure 2.7, which also has a water table level in the pavement base layer due to poor drainage).
+ Identify the likely primary cause of pavement failure (e.g., age, inadequate structure for the traffic, poor drainage, poor compaction, or individual material failures such as asphalt concrete rutting, asphalt concrete moisture damage, or cement concrete

durability). Also note whether sufficient information has been collected in the preliminary site investigation to confirm the *PaveM* recommendation and what additional information, if any, needs to be collected in a detailed site investigation to complete the development of alternative designs. If the *PaveM* recommendation appears to be inappropriate, note the reasons for arriving at this decision, and list alternative, more suitable rehabilitation strategies, along with the testing and sampling needed to confirm these alternatives and complete the structural design.

Figure 2.7: Example of faulting and transverse and corner cracks on concrete pavement.

- **Efficiency of the drainage design**: Note the roadway geometry, side drains, and culverts, and whether they are carrying water off and away from the pavement (examples in Figure 2.8 and Figure 2.9). For new pavements on new alignments, identify surface and subsurface flow patterns and likely strategies for handling both in the design if these are not covered in a geotechnical investigation.

Figure 2.8: Example of blocked side drains and culvert.

Figure 2.9: Example of drainage problem in cut (note moisture in wheelpaths).

- **Surface water and land use immediately adjacent to the road:** Identify surface water bodies and land uses that may introduce water into the pavement that is not being handled by the drainage system, such as irrigation of agricultural lands and the use of side drains by landowners for irrigation purposes. These may lead to moisture-related problems (examples in Figure 2.10 and Figure 2.11).

Figure 2.10: Example of irrigated field draining into road.

Figure 2.11: Example of use of side drain to move irrigation water.

- **Utilities:** Identify any roadside signs and other indications of underground pipelines, cables, and other utilities (example in Figure 2.12), as well as manhole and other covers in the road. Identify locations of existing utilities in the area where new pavements on new alignments are to be constructed if this is not done during a geotechnical investigation.

Figure 2.12: Example of gas pipeline warning sign on side of road.

2.4 Sampling and Testing Plan for Detailed Site Investigation

If a project will require a structural design, sampling and testing will be critical parts of the detailed site investigation undertaken after the preliminary site investigation (discussed in Chapter 3). Preparing a comprehensive site sampling and testing plan for this part of the detailed site investigation is therefore an important part of the preliminary investigation and must be included in the PSSR. Detailed site investigations are typically not required for CAPM projects, but some items, such as coring to assess in situ materials and to choose an optimum milling or in-place/cold central plant recycling depth to prevent debonding of the new layers, are suggested (additional information on site investigations for in-place and cold central plant recycling is provided in Appendix B and the Caltrans pavement recycling guide *[5]*).

Table 2.1 lists sampling and testing plan types for rehabilitation, reconstruction of existing pavement, or widening where some or all the existing shoulder structure layers will be used in the widened lane. Table 2.2 lists sampling and testing plan types for new construction on new alignment or widening where none of the pavement structure layers in the existing outside or median shoulder will be used in the new structure.

Three levels of intensity of sampling, field testing, and subsequent laboratory testing are shown in the tables, with Level 1 representing the most intense level and Level 3 representing the least intensive. Select a plan primarily based on the design life and AADTT, but also considering the project type and the importance of the proposed project, project length in lane-miles, cost, and road classification. The plans shown in Table 2.1 and Table 2.2 may be modified based on the actual project conditions including traffic, safety during sampling and testing, and variability of subgrade soils, soil moisture, and layer thicknesses along the length of the project identified in the desktop study and preliminary site investigation.

Table 2.1: Detailed Site Investigation Sampling and Testing Plans for Existing Pavement

<table>
<tr><th>Test Plan Type</th><th>Application</th><th>Recommended Testing and Frequency</th></tr>
<tr><td>Existing1</td><td>Rehabilitation
or
Reconstruction
or
Widening where some of the existing paved shoulder or median pavement structure layers will be used in the new structure.

Use for:
Design life AADTT
20 years: ≥1,000
40 years: ≥400</td><td>• Perform deflection testing:
+ On flexible-surfaced pavement, perform deflection testing according to CT 357 (Level A) for backcalculating stiffnesses of all pavement layers and the subgrade (stiffnesses will be used in the design for those layers that will remain in the rehabilitated/reconstructed pavement).
+ On jointed plain concrete pavement (JPCP):
▪ Where the existing structure will be used substantially in the new structure (asphalt overlay or removal of concrete and use of underlying layers in pavement with new flexible surface), perform deflection testing according to CT 357 for backcalculating stiffnesses of all layers (stiffnesses will be considered in potential subsectioning based on condition of those layers that will remain in the rehabilitated/ reconstructed pavement).
▪ Where the existing layers below the concrete will be used in the new structure, deflection testing can be used to identify locations of poor condition in those underlying layers if they cannot be identified by other methods.
▪ Where the existing pavement layers will not be used in the new pavement, deflection testing is not warranted except where potential locations of poor subgrade support need to be investigated. If investigating for dowel bar retrofit, measure load transfer efficiency across the transverse joints and transverse cracks according to CT 357 (only applicable for rehabilitation or reconstruction of existing lane, not for widening).
+ On continuously reinforced concrete pavement (CRCP):
▪ Where the existing structure will substantially be used in the new structure (same cases as for JPCP), perform deflection testing according to CT 357 for backcalculating stiffnesses of all layers (stiffnesses will be considered in potential subsectioning based on condition of those layers that will remain in the rehabilitated/ reconstructed pavement).
▪ Where the existing pavement layers will not be used in the new pavement, deflection testing is not warranted except where potential locations of poor subgrade support need to be investigated.</td></tr>
</table>

Test Plan Type	Application	Recommended Testing and Frequency
Existing1 *continued*	Rehabilitation or Reconstruction or Widening where some of the existing paved shoulder or median pavement structure layers will be used in the new structure. Use for: Design life AADTT 20 years: ≥1,000 40 years: ≥400	• Take cores, conduct dynamic cone penetrometer (DCP) tests, and sample subgrade soils as follows: + On flexible-surfaced pavement, take at least 3 cores per lane-mile to measure bound layer (asphalt and/or concrete and/or stabilized base) thickness and visually assess condition and properties. More cores may be warranted in areas of observed distresses, patching, apparent changes in soil type and condition, and/or DCP results. + On flexible-surfaced pavement where there is surface cracking, take an additional 1 to 3 cores per lane-mile over cracks to determine if they are partial- or full-depth and if there are underlying problems (such as stripping in the asphalt). Where possible, core through any underlying concrete or cement- or lime-stabilized layers to determine if cracks have reflected up through the asphalt from those layers. + On JPCP, take at least 3 cores per lane-mile to measure underlying bound layer (asphalt concrete and/or cement concrete, stabilized base) thickness and to visually assess condition and properties. + Conduct DCP tests in each core hole to calculate a DCP penetration index (DPI) for determining unbound layer thicknesses and to estimate subgrade stiffness values. + Take soil samples from the core holes with an auger for soil classification (USCS[a] for flexible-surfaced pavement and AASHTO for rigid-surfaced pavement) and resilient modulus testing.[b] The number of samples taken will depend on DCP testing variability. • Determine layer thicknesses: + Option 1: Coring: ▪ Use the layer thicknesses determined during the coring and DCP investigation described above. + Option 2: Ground penetrating radar (GPR): ▪ Use cores and DCP results from the coring investigation (at least two per pavement structure type based on as-built information) for calibrating the GPR data analysis. ▪ Note that GPR can also identify subsurface features (utilities, etc.).

Test Plan Type	Application	Recommended Testing and Frequency
Existing1 *continued*	Rehabilitation or Reconstruction or Widening where some of the existing paved shoulder or median pavement structure layers will be used in the new structure. Use for: Design life AADTT 20 years: ≥1,000 40 years: ≥400	• If in-place or cold central plant recycling is a potential strategy, identify a representative location for a test pit, or if there are distinct pavement structures in the project, identify one test pit location per each pavement structure. From the test pit(s), sample enough asphalt and underlying materials from the layers that will be recycled for USCS and unconfined compressive strength (UCS) tests to select the most appropriate recycling agent/stabilizer.[c] Samples can also be collected using localized milling.
Existing2	Same application as Existing1 Use for: Design life AADTT 20 years: 100-1,000 40 years: 40-400	• Same as Existing1 except: + Perform deflection testing according to CT 357 (Level B). + On flexible pavements, reduce number of additional cores to 1 per lane-mile over surface cracks to determine depth of cracking, the possible presence of reflective cracks, and if there are underlying problems (such as stripping in the asphalt).
Existing3	Same application as Existing1 Use for: Design life AADTT 20 years: <100 40 years: <40	• Same as Existing1 except: + Perform deflection testing according to CT 357 (Level C). + On flexible pavements, reduce number of additional cores to 1 per lane-mile over surface cracks to determine depth of cracking, the possible presence of reflective cracks, and if there are underlying problems (such as stripping in the asphalt).

[a] USCS – Unified Soil Classification System per ASTM D2487; AASHTO Soil Classification System per AASHTO M 145.
[b] Resilient modulus testing per AASHTO T 307.
[c] Recycling agents are emulsified asphalt or foamed asphalt; stabilizers are portland cement, lime, or other chemical stabilizers.

Table 2.2: Detailed Site Investigation Sampling and Testing Plans for New Pavement

Test Plan Type	Application	Recommended Testing and Frequency
New1	New construction or Widening where none of the existing shoulder or median pavement structure layers will be left intact in the widened or new lane. Use for: Design life AADTT 20 years: ≥1,000 40 years: ≥400	• Take subgrade soil samples for soil classification (USCS for flexible-surfaced pavement, AASHTO for rigid-surfaced pavement[a]) and resilient modulus[b] testing. Frequency will depend on the observed variability of the subgrade soil, with samples taken from every 1,000 ft. (approx. 5/mi.) where there is high variability, to every mile (1/mi.) where there is low variability. • If not on identified cut or fill sections, perform dynamic cone penetrometer (DCP) testing every 500 ft. (approx. 10/mi.) or more intensively as warranted by observed changes in soil type, soil condition, and/or soil moisture. • If on identified cut sections, excavate soil to the depth of the cut and then take soil samples for soil classification and perform DCP tests next to the sampling locations. • If source(s) of fill for identified fill sections are known, take representative samples for soil classification and testing as described above. • Test one representative soil sample for resilient modulus for each soil classification found in the project. Also test one representative soil sample for resilient modulus in any areas with DCP results indicating significantly lower stiffness than other areas with the same soil classification.
New2	Same applications as New1 Use for: Design life AADTT 20 years: 100-1,000 40 years: 40-400	• Same as New1, but with no resilient modulus testing. • Perform soil classification at same intervals as New1. • Perform DCP testing at an interval between one and five per mile where applicable. • Supplement with other existing available data (e.g., R-value, California bearing ratio [CBR], or resilient modulus).
New3	Same applications as New1 Use for: Design life AADTT 20 years: <100 40 years: <40	• Same as New2 but with no DCP testing. • Perform soil classification at same intervals as New1. • Supplement with other existing available data (e.g., R-value, CBR, or resilient modulus).

[a] USCS – Unified Soil Classification System per ASTM D2487; AASHTO Soil Classification System per AASHTO M 145.
[b] Resilient modulus testing per AASHTO T 307.

2.5 Preliminary Scope Summary Report

Document the initial desktop data and the observations from the preliminary site investigation in the PSSR. Information presented includes, but is not necessarily limited to, the following:

- General project description, project identification, project goals, road description, program, and funding source.
- Current and expected future truck traffic, including limits of traffic subsections, and locations of any nontypical vehicle operations.
- Climate region and the limits of climate regions if project limits include more than one.
- Climate change vulnerability.
- For CAPM projects:
  + The existing as-built pavement structure as identified from available information, including layer thicknesses and materials. Note any gaps in the as-built pavement structure data in the existing information.
  + General description of the road condition.
  + Preliminary identification of typical failure mechanisms identified from the visual assessment, and imagery.
  + Potential problems identified and gaps in the available information that may need to be assessed in a more detailed site investigation and that could influence the choice of maintenance strategy.
- For rehabilitation and widening projects:
  + The existing as-built pavement structure as identified from available information, including layer thicknesses and materials. Note any gaps in the as-built pavement structure data in the existing information.
  + General description of the road condition.
  + Preliminary identification of typical failure mechanisms identified from initial site visit.
  + Potential problems identified and gaps in the available information that will need to be assessed as part of the detailed site investigation(s) and that could influence the choice of rehabilitation strategy.
- For rehabilitation projects, list specific factors that will typically affect consideration of specific strategies until further investigation is completed. These may include but are not limited to:
  + Known plans for future reconstruction or widening.
  + Known plans for treatments in adjacent lanes.
  + Known regular flooding and/or serious drainage-related problems such as saturated subgrade or base layers and/or drainage systems that are inadequate to divert water away from the pavement structure.
  + Known or suspected presence of a cement concrete layer or intact lean concrete or cement-treated base underlying thin asphalt concrete (i.e., asphalt concrete thickness ≤0.4 ft. [120 mm]).
  + Known or suspected presence of moisture damage in existing asphalt concrete layers.
  + Known or suspected deterioration of cement- or asphalt-treated layers.

    + Known or suspected presence of previous lane reconfigurations or widening that result in significantly different pavement structural sections within the project.
    + Known or suspected presence of shallow utilities within or close to the project (i.e., within the pavement structure or within the top 1 ft. [300 mm] of the subgrade).
    + Existing bridge heights and applicable bridge height standards.
    + Known or suspected presence of shallow bedrock or large boulders.
    + Known geological hazards (e.g., subsidence or slope instability, including areas affected by recent wildfires) that will require remedial action prior to rehabilitation.
    + Traffic volumes or constraints on the roadway's ability to handle traffic demand sufficient to produce construction work zone traffic delays exceeding 30 minutes.
    + Other project conditions that might affect road user or construction worker safety.
- The project-specific comprehensive sampling and testing plan for the detailed site investigation.
- Add suggestions for the correction of identified drainage problems to the scope of all projects because if not corrected, they will often lead to early failures that cannot be corrected through pavement design.

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3 STEP 2: DETAILED SITE INVESTIGATION AND DATA COLLECTION FOR DESIGN

3.1 Introduction

The detailed site investigation and desktop data collection for design are conducted to gather additional information on the pavement structure and materials for rehabilitation and widening projects, and if applicable, CAPM projects, and to gather additional site and subgrade information for new pavement projects. This information is primarily needed for mechanistic-empirical (ME) design of alternative cross-sections. Detailed data needed for design are collected, and any gaps in the preliminary investigation data gathering are addressed. During the detailed site investigation, the engineer conducts additional visual assessments and also supervises field testing, sampling for laboratory testing, and the laboratory testing done according to the plan developed during the preliminary site investigation (discussed in Chapter 2). The engineer may make necessary adjustments to the sampling and testing locations and intensity based on the visual assessment and on observations during sampling and field testing, and as required by the site conditions and to meet safety requirements.

Investigations can be undertaken any time of year but are best done during the wet season when construction activities are minimal and wet season problems, primarily those related to drainage, can be readily identified.

Detailed desktop data needed for design include:

- **Traffic data** are used as input to pavement design and construction work zone traffic handling.
  + Truck traffic inputs for mechanistic-empirical (ME) pavement design are the current truck traffic counts and axle load spectra group (also referred to as weigh-in-motion [WIM] group) in the design lane, and the expected rate at which future truck traffic will grow or decline. For flexible-surfaced pavement, truck traffic counts are automatically converted to annual axle load applications in the *CalME* software based on the inputs of traffic index (TI)[5] and WIM group. For rigid-surfaced pavement designs, truck traffic is characterized in terms of average annual daily truck traffic (AADTT) and WIM group. Get the TI or AADTT from the district Traffic Modeling and Forecasting office, who will include consideration of past traffic growth and any expected changes in land use that might

[5] Traffic Index will be replaced in *CalME* by Average Annual Daily Truck Traffic in the future.

change truck types and volumes. The WIM group is identified by project location in *CalME*, the rigid pavement online design catalog, or the traffic input calculator for *Pavement ME*.[6] Further information regarding traffic for ME design is presented in the *Highway Design Manual*. Identify locations with slow traffic speeds (i.e., less than 35 mph [≈55 km/h]) because truck speeds influence the stiffness of asphalt-bound materials and are therefore considered in *CalME*.

  + Inputs for construction work zone traffic handling for life cycle cost analysis are shown in the *Life Cycle Cost Analysis Procedures Manual (10)*.

- **Climate data** relevant to pavement design in California are identified by the pavement climate region.[7] Data for pavement temperatures are included in the *CalME* software based on the location of the project. Project limits may cross climate region boundaries and, when this occurs, use the different climate regions for the appropriate locations in the project.

A detailed site investigation should include the following:

- For rehabilitation, reconstruction, or widening where some of the existing paved shoulder or median pavement structure layers will be used in the new structure:
  + A detailed visual assessment (Section 3.2.1) that includes:
    - A distress assessment.
    - Notes on the causes and origins of distresses.
    - The condition of patches and digouts.
    - The presence, condition, and effectiveness of drainage systems.
    - Any roadside activity that may impact the project.
    - Utilities and overhead constraints that may impact the project during construction.
    - Locations for test pits, if needed to identify localized problems, or for sampling for in-place or cold central plant recycling.
  + Field testing and sampling following the selected Existing1, Existing2, or Existing3 plan from Table 2.1, which may include:
    - Deflection testing of the existing pavement with a falling weight deflectometer (FWD) following CT 357 (Section 3.2.2), including:
      - Testing for backcalculation of layer stiffnesses and subsection evaluation.
      - Testing for load transfer efficiency (LTE) on jointed plain concrete pavement transverse joints and cracks if dowel bar retrofit (DBR) is a potential treatment strategy.

[6] A Caltrans traffic input calculator software program is available for putting these data into the correct format if using *Pavement ME* for rigid pavement design and can be found at http://www.ucprc.ucdavis.edu/Media/Pavement%20ME%20Traffic%20Input%20Setup.msi.

[7] The Pavement Climate Region Map can be accessed at https://dot.ca.gov/programs/maintenance/pavement/concrete-pavement-and-pavement-foundations/%20climate.

        - Coring (Section 3.2.3) to:
            - Measure layer thicknesses and thickness variability.
            - Identify bound layer type and properties.
            - Determine the depth of cracking in asphalt concrete layers, whether reflective cracks over cement concrete or chemically stabilized (lime or cement) layers are present, and/or whether there are cracks originating from debonding between asphalt concrete layers.
            - Provide access for dynamic cone penetrometer (DCP) testing and soil sampling.
            - Identify the presence of stress absorbing membrane interlayers (SAMI), fabrics, geogrids, or other factors that might influence the strategy selection or affect construction activities.
        - Determining pavement layer thickness using:
            - Coring (Section 3.2.3) and DCP testing (Section 3.2.4, also used to estimate unbound layer stiffnesses); or
            - Ground penetrating radar (GPR, Section 3.2.5) together with limited coring and DCP testing.
        - Sampling subgrade soil and aggregate subbase and base (if subbase and/or base layers will be retained in the new structure) for laboratory soil classification and subgrade resilient modulus testing (Section 3.2.6).
        - On in-place or cold central plant recycling projects, identification of coring and/or test pit locations for contractor mix design sampling. These locations will need to be representative of the observed variability along the project.
- For new construction on new alignment and widening where none of the existing shoulder pavement structure will be used in the new structure:
    + Detailed visual assessment (Section 3.3.1, widening projects only, not for new construction on new alignment) including:
        - The condition of adjacent lanes.
        - The presence, condition, and effectiveness of drainage systems.
        - Any roadside activity that may impact the project.
        - Utilities and overhead constraints that may impact the project.
    + Field testing and sampling following the selected New1, New2, or New3 plan from Table 2.2, which may include:
        - DCP testing (Section 3.2.4).
        - Sampling of subgrade and/or fill materials for laboratory soil classification and subgrade resilient modulus testing (Section 3.3.3).
- Excavating forensic test pits (Section 3.4), if required for more detailed layer evaluations and/or for material sampling.

- Laboratory testing according to the test plan on samples collected in the field (Section 3.5), including:
  + Soil classification.
  + Resilient modulus.
  + If required, assessment of materials for stabilization following information in the *Guidelines for the Stabilization of Subgrade Soils in California (6).*
- Preparation of data for analysis.

3.2 Rehabilitation, Reconstruction, or Widening Using the Existing Shoulder Structure

A detailed site investigation for rehabilitation, reconstruction, or widening where some or all of the existing structure will be used includes several tasks whose sequence will depend on personal preference and the availability of staff and equipment. Options include:

- Combining all tasks into a single field visit (most efficient option).
- Doing the visual assessment first and using the findings to refine the structural assessment (FWD, coring, and DCP) and material sampling locations.
- Doing the structural assessments first and using the findings to plan where the visual assessment needs to be focused (this option is least desirable but can be selected if scheduling constraints are an issue).

3.2.1 Visual Assessment

The visual assessment conducted during a detailed site investigation builds on the information collected during the preliminary site investigation and desktop study.

The visual assessment is done to obtain an understanding of the condition of the existing pavement, to identify the general modes of failure, as well as any problem areas that may require specific remedial actions before the main project work is started. This will ensure that new designs will consider all relevant information from the project.

On widening projects where some or all of the shoulder structure will be used, the visual assessment is performed both on the current shoulder structure that will be included in the new structure and on the adjacent existing traveled lanes. This provides insight into potential contributions to pavement distress from existing drainage systems, or potential subgrade conditions that might also affect the new structure.

When in-place or cold central plant recycling is being considered, the visual assessment is also used to collect information to decide whether partial- or full-depth recycling is the most appropriate option, or to identify any specific reasons why in-place recycling may not be a suitable rehabilitation option.

For all cases, the visual assessment builds on the information collected during the preliminary site investigation. This more detailed visual assessment is best done by foot or bicycle, where safe, to allow a more thorough inspection that cannot be satisfactorily achieved from a moving vehicle. For long sections, a windshield or unmanned aerial system (UAS) survey can be done first, and then selected representative areas and areas of localized concern can be visited for a more comprehensive examination. Record results on the appropriate form (either example Form 5 or Form 6 in Appendix A for flexible-surfaced or rigid-surfaced pavements, respectively).

Complete the following tasks during the visual assessment of the existing lanes and, where applicable, the shoulder:

- For flexible-surfaced pavement, assess the modes of distress (see the *Automated Pavement Condition Survey Manual* for more details of distress descriptions). For the purposes of the proposed flexible pavement design, the distresses of most interest are primarily cracking and rutting.
  + **Fatigue cracking.** Typically, this type of cracking initiates at the bottom of the asphalt concrete and propagates upward (Figure 3.1) but, in some instances, it can begin at the top and propagate downward or begin at poorly bonded interfaces between asphalt concrete layers and propagate in either or both directions. Fatigue cracking only appears in the wheelpaths and occurs when the traffic loading has exceeded the structural capacity of the pavement (Figure 3.2). Potholes occur when fatigue cracking has progressed to the point that traffic dislodges cracked pieces from the surface. Water will infiltrate through the cracks, weakening the underlying unbound layers and possibly leading to pumping of subgrade fine materials upward and onto the surface (Figure 3.3).
  + **Low-temperature cracking.** This type of cracking appears only in locations that have extensive periods of temperatures below freezing (e.g., higher altitudes in California). Low-temperature cracks initiate at the top of the pavement and propagate downward. These cracks are transverse across the roadway and are generally spaced 20 to 50 ft. (6 to 15 m) apart, with close to uniform spacing (Figure 3.4).

Figure 3.1: Initial fatigue cracking in wheelpath.

Figure 3.2: Severe fatigue cracking.

Figure 3.3: Cracking, pumping, & potholes from moisture damage in asphalt concrete layers.
(a core from the section is shown on the inset photo)

Figure 3.4: Low- temperature cracking.

- **Oxidative-aging cracking.** This type of cracking initiates at the top of the pavement and propagates downward. It is caused by oxidation of the asphalt concrete over time, and usually appears when the pavement has not had a preservation or maintenance treatment for 10 years or more. Cracks are usually transverse, with spacing equal to or less than the width of the roadway. They develop into block cracks when subsequent longitudinal cracking connects perpendicularly across the transverse cracks (Figure 3.5). Oxidative-aging cracking appears sooner in hot, sunny environments and where the asphalt concrete is poorly compacted (Figure 3.6).
- **Reflective cracking.** This type of cracking is caused by the propagation of existing cracks or joints in the underlying layers upward through asphalt concrete layers or seal coats that have been placed on top of them (Figure 3.7 and Figure 3.8). The rate of reflection is influenced by the number of heavy vehicles and/or day/night or seasonal temperature fluctuations. Reflective cracks can be identified by coring over surface cracks to see if they extend downward into the underlying layers from which they propagated.

Figure 3.5: Oxidative-aging cracking in block pattern.

Figure 3.6: Oxidative-aging cracking in random pattern.

Figure 3.7: Reflected cracking from underlying jointed plain concrete slabs.

Figure 3.8: Sealed transverse oxidative-aging cracks (reflection confirmed with core).

+ **Asphalt concrete surface rutting.** This appears as narrow ruts with displaced material (“humps”) at their sides (Figure 3.9). This rutting only occurs in the wheelpaths of heavy vehicles, particularly where they have been moving slowly, within the top 2 to 4 in. (50 to 100 mm) of the asphalt concrete layer(s). This may be caused by poor mix design for the conditions where they are located and/or poor compaction.
+ **Unbound layers rutting.** This distress appears as deep, wide ruts on the pavement surface without displaced material at the sides (Figure 3.10). It occurs in the aggregate base, subbase, and/or subgrade layers (i.e., deeper distress), and it is mirrored on the surface by the asphalt concrete layer. Rutting of these unbound aggregate or soil layers may be due to poor compaction of those layers, a pavement structure that is insufficient for the level of truck traffic, drainage problems, and/or a pavement that has cracked and where water has entered and weakened the underlying layers.
+ **Pumping.** This is seen in the presence of fine soils particles on the surface of the pavement that have been pumped from cracks or joints during rain or when underlying materials are wet (Figure 3.11). Pumping often indicates poor subsurface drainage and/or the high permeability of poorly compacted asphalt concrete, which both

contribute to excess water in the base, subbase, and/or subgrade layers. Moisture-damaged asphalt concrete and deteriorated cement-stabilized or asphalt-treated layers (lean concrete base [LCB], cement-treated base [CTB], asphalt-treated permeable base [ATPB], cement-treated permeable abase [CTPB], full-depth recycling [FDR], or partial-depth recycling [PDR]) with excess water in them may also pump fines to the surface.

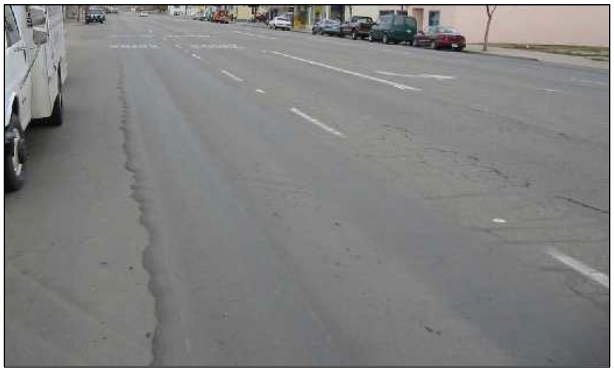

Figure 3.9: Asphalt concrete rutting (top 2 to 4 in., with hump at side of wheelpath).

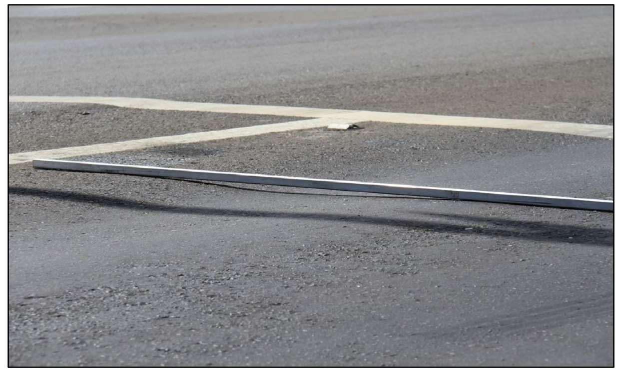

Figure 3.10: Rutting in unbound layers (no humps).

Figure 3.11: Pumping of fines from underlying unbound layers through fatigue cracks.

- For rigid-surfaced pavement and flexible-surfaced pavement with rigid pavement beneath it (identified by as-builts and/or coring or GPR) that will be rehabilitated with a crack, seat, and asphalt concrete overlay, assess the modes of distress (see the *Automated Pavement Condition Survey Manual* for more details of distress descriptions). For the purposes of the new pavement flexible surfacing design, the distresses of most interest are corner cracking that has settled, pumping problems, and shattered slabs.
  + **Corner cracking.** These cracks appear at the corners of cement concrete slabs (Figure 3.12) and may also reflect up into previous asphalt concrete overlays. Corner cracks may have pumping that causes them to settle, which affects traffic the same way a pothole does on a flexible surface. Corner cracks wider than 3/4 in. (≈20 mm) will not have aggregate interlock with the rest of the slab (Figure 3.13), and the broken corner will likely settle under an overlay.

+ **Shattered slabs.** Shattered slabs are those with two or more wide transverse or longitudinal cracks extending from one side of the slab to the other, or with cracks that divide the slab into three or more pieces (Figure 3.14 and Figure 3.15). Shattered slabs will likely need to be replaced prior to overlay.

Figure 3.12: Corner cracks on jointed plain concrete pavement.

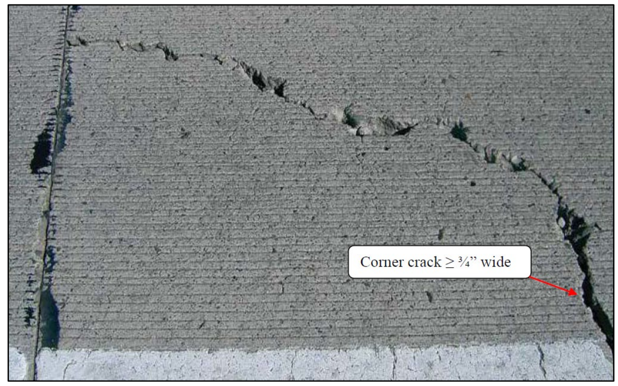

Figure 3.13: Wide corner crack causing loss of aggregate interlock *(7)*.

Figure 3.14: Jointed plain concrete truck lane with shattered slabs.

Figure 3.15: Jointed plain concrete slab with wide and spalled third-stage cracking *(7)*.

+ **Pumping.** This distress looks the same on cement concrete pavement and overlaid cement concrete pavement as it does on asphalt concrete pavement, with pumped fines appearing on the surface around cracks and joints.
+ **Other cracking and faulting on cement concrete pavements.** These are not of concern for asphalt concrete overlays with crack and seat or cement concrete pavement lane replacements.

- For cement concrete pavement projects that involve slab replacements, identify first- and third-stage cracked and shattered slabs. First-stage cracking is defined as slabs with either one transverse (Figure 3.16) or one longitudinal crack (Figure 3.17).
- For dowel bar retrofit projects on cement concrete pavement, quantify the faulting (Figure 3.18) and note the presence of spalling on joints and transverse cracks (Figure 3.19).

- Note any rutting and loss of fines on cement concrete surfaces due to chain wear (Figure 3.20).
- Note the loss of surface texture from polishing by traffic, which can cause skid resistance problems on cement concrete pavements (Figure 3.21).

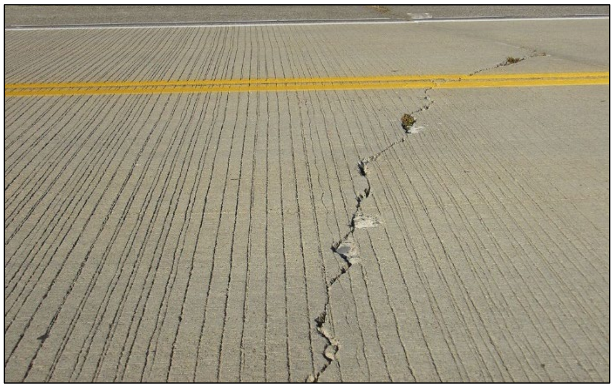

Figure 3.16: Transverse crack with spalling on jointed plain concrete slabs.

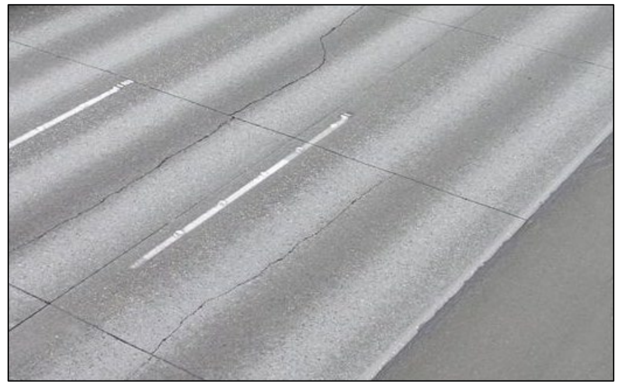

Figure 3.17: Longitudinal cracks on jointed plain concrete slabs.

Figure 3.18: Faulting on jointed plain concrete slabs.

Figure 3.19: Spalled transverse joint between jointed plain concrete slabs.

Figure 3.20: Wheelpath rutting from chain wear on jointed plain concrete pavement.

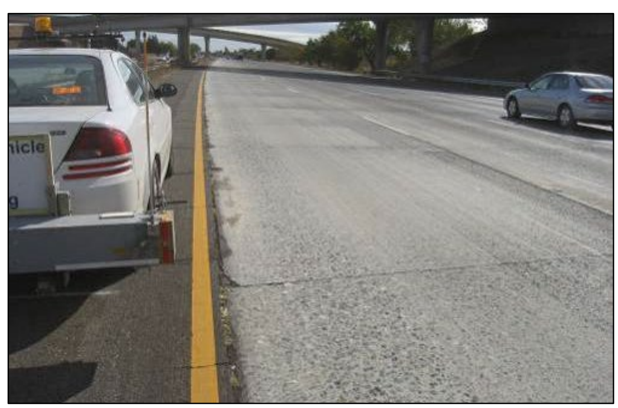

Figure 3.21: Polished surface and loss of texture on jointed plain concrete pavement.

- Assess the extent and condition of existing patches, slab replacements, and digouts, giving special attention to areas that are failing again at regular intervals (Figure 3.22 through Figure 3.24). Identify and document the causes of failure in these areas (e.g., drainage problems, change in subgrade materials, agricultural irrigation, etc.). Problems in these areas may require specific actions in the design, including, but not limited to, the following:
  + If the visual assessment is done first, identify areas with potential structural problems for additional FWD testing.
  + If FWD testing was completed prior to the visual assessment, inspect all areas with low backcalculated FWD subgrade stiffnesses, poor DCP penetration index (DPI) results, and/or issues identified from cores. Identify likely reasons for low stiffnesses such as drainage problems, weak subgrade materials, or poor compaction (Figure 3.25).

Figure 3.22: Early failure in patch (drainage problem).

Figure 3.23: Early failure in patch (note water pumping in joint).

Figure 3.24: Early failure in wheelpath digout repairs.

Figure 3.25: Example of area with low deflection modulus (note pumped fines on surface).

- Building on observations during the preliminary investigation, assess the condition of drainage systems including internal drainage paths, side drains, and culverts as well as problem areas associated with inadequate drainage and/or known seasonal flooding that might influence pavement performance after rehabilitation, including, but not limited to, areas where:
  + Side drains do not exist (Figure 3.26).

+ Side drains and culverts have been blocked by roadside activity (Figure 3.27).
+ Side drains are used for moving irrigation water (Figure 3.28).
+ Plow furrows run perpendicular or at an angle to the road rather than parallel to the road (Figure 3.29).
+ Irrigation water contacts the road (Figure 3.30).
+ Water ponds next to the road, flows into the roadway from access roads and driveways (Figure 3.31), or flows down adjacent slopes with no or inadequate cutoff drains (Figure 3.32 and Figure 3.33).

Figure 3.26: Poor drainage associated with absence of paved shoulders and side drains.

Figure 3.27: Blocked side drain and culvert.

Figure 3.28: Side drain used for irrigation water.

Figure 3.29: Plow/irrigation furrows perpendicular to road.

Figure 3.30: Irrigation water sprays onto the road.

Figure 3.31: Access road drainage problems (note patch).

Figure 3.32: Cut slope with no side drain.

Figure 3.33: Water flowing downslope into the road.

- If required for identifying subsurface problem areas and/or if in-place or cold central plant recycling is being considered, identify test pit (if called for in the test plan) and/or additional core and DCP locations to investigate underlying layers or moisture conditions or to sample materials from specific layers.
- For potential in-place or cold central plant recycling projects:
  + Note the presence of large areas of loose asphalt concrete blocks in areas of severe alligator cracking (Figure 3.34). These may influence the consistency of the recycled material (i.e., some recyclers may not crush/break down the old asphalt concrete layers to a satisfactory gradation; although Caltrans does not specify equipment, using a multi-unit recycler with built in crusher or milling, crushing, and then recycling through a cold central plant are options for these conditions).
  + Note any bleeding in patches, which usually indicates high binder contents that may influence in-place or cold central plant mix designs (Figure 3.35).

Figure 3.34: Loose blocks in severe alligator cracking.

Figure 3.35: Bleeding in digout repairs.

  + Identify any other factors that may influence a decision to choose in-place or cold central plant recycling as a rehabilitation strategy, including but not limited to:
    - Overhead power lines that cannot be moved and overhanging trees or trees near the road that cannot be trimmed or removed and may interfere with the recycling train.

- The presence of drainage systems within or close to the anticipated recycling depth.
- The need to connect to existing drainage features.
- The presence of known utilities/services (e.g., pipelines, cables, manholes, etc.) within or close to the anticipated recycling depth.
- Height clearance of final constructed elevation below bridge structures.
- The presence of bedrock, hardpan, culverts, or cement concrete at shallow elevations within the depths that will be recycled.

3.2.2 Structural Assessment: Deflections from Falling Weight Deflectometer

The primary purpose of FWD (Figure 3.36) testing is to:

- Evaluate the pavement structure in general.
- Evaluate the stiffness of pavement materials, especially the layers that will not be removed, recycled, or replaced.
- Identify sections of uniformity for pavement design.
- Identify weak areas that require special investigation and potential remediation treatment before construction of the project.

Figure 3.36: Falling weight deflectometer (FWD).

Follow the procedures described in CT 357. Consider the following suggestions when planning FWD testing:

- If possible, test well into or at the end of the rainy season, when subgrade moisture is likely to be highest.
- For rehabilitation and reconstruction on flexible-surfaced pavement:
  + Test the lane with the worst existing condition unless each lane is to be designed separately, in which case test all lanes.
  + Test in the right wheelpath, unless there is:
    - Severe wheelpath cracking in the right wheelpath only, in which case test in the left wheelpath provided that it is safe. Note which wheelpath was tested. Core and do

DCP testing in the right and left wheelpaths to identify why there is a large difference in cracking.

  - Severe wheelpath cracking in both wheelpaths or, if testing is for a section that will be recycled: test between the wheelpaths to minimize the effects of severe wheelpath cracking on the seating of the FWD load and sensors. The asphalt concrete layers will be removed or recycled and therefore knowing the stiffness in the wheelpaths is not important.

- For lane reconstruction with rigid-surfaced pavement, deflection testing is generally not warranted because the primary input to rigid pavement design is the subgrade AASHTO soil classification and not the measured stiffness of the underlying layers. Deflection testing may be used for identification of areas with weak support where the existing pavement layers will be substantially reused as a bound base layer (usually the existing asphalt concrete layers in the new pavement).
- For dowel bar retrofit of jointed plain concrete pavement, test at night or in the early morning, when possible, to obtain results when the joints or cracks will have the widest opening. Test in the wheelpaths at the joints and transverse cracks following CT 357 procedures for placement of the sensors over the joint or crack.

3.2.3 Structural Assessment: Observations from Cores

Coring is typically conducted in coordination with deflection testing, DCP testing, and soil sampling during the same traffic closure. Use the following procedure for coring and core assessment:

- Check that core locations are not over a drainage structure or pipe.
- Remove a 4 in. or 6 in. (≈100 mm or 150 mm) diameter core from the outer wheelpath following the selected testing plan to check asphalt concrete, cement concrete, and stabilized base layer thicknesses. Alternate core locations between lanes (example in Figure 3.37). On two-lane roads, take a set of three cores across the full road width (outer wheelpaths and centerline) to check for transverse thickness variation at least once every mile (1.6 km) and 50 ft. (≈15 m) in from the start and end of the project. Follow a similar coring pattern on multilane highways except only take the full set of transverse cores at the beginning and end of the section and where there are questions about consistency of thickness between and within lanes (example in Figure 3.38), such as where there may be different underlying structures transversely within the lane because of partial realignments, conversion of shoulders into travel lanes, and other reasons. Only take cores in the inner lanes where safe to do so. Use of highway-speed GPR is recommended where there are more than two lanes in one direction to provide safe collection of data on all lanes, with a reduced amount of coring needed in the outside lane to verify and calibrate the GPR results.

Priority of coring on multilane highways is the outside lanes followed by the inside lanes. Log the core locations on an appropriate form (example Form 7 in Appendix A).

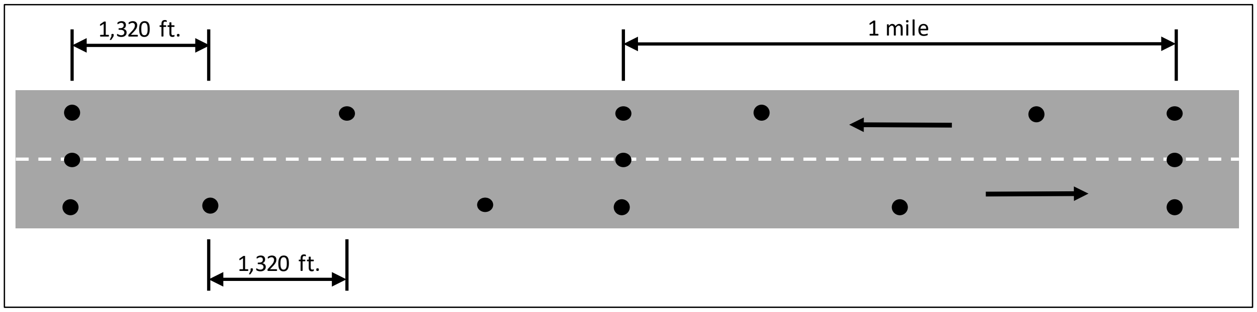

Figure 3.37: Suggested coring layout (example for 2 mi. section of a two-lane road).

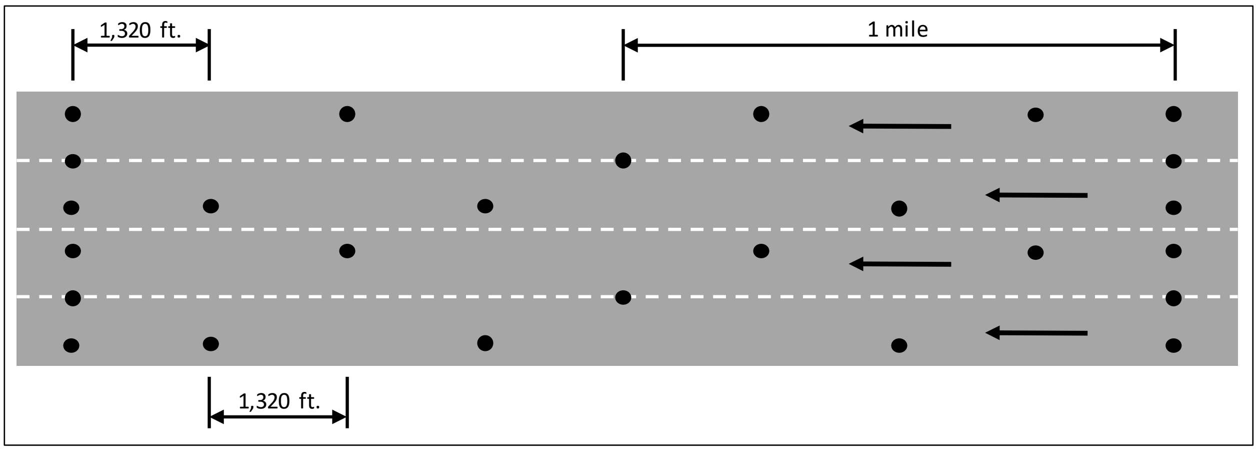

Figure 3.38: Suggested coring layout (example for 2 mi. section of a multilane highway).
(Note: GPR recommended for more than two lanes in one direction; priority of coring is outside lanes followed by inside lanes).

- Take additional cores in areas with more severe distress, with large patches and digouts, where variability or differences in pavement design or construction are apparent and, if applicable, in problem areas identified during the FWD assessment. This should include cores over cracks in asphalt concrete surface layers to identify whether cracks extend all the way through the surface layer, whether cracks are reflective, and whether there is debonding between asphalt concrete layers.
- Perform a DCP test after the core has been removed (see Section 3.2.4). Record the testing location and results on an appropriate form (example Form 8 in Appendix A).
- If called for in the testing plan, sample underlying materials as described in Section 3.2.6 for the tests listed in Section 3.5 at the first location and again each time the DCP tests indicate an apparent change in the underlying materials (thickness, properties, or moisture content).
- Fill the core holes with backfill materials, grout, or broken up cores after they have been logged and photographed (and if they are not needed for laboratory testing) and top off the

surface layer with a suitable ready mix or cold patch material or as required by the local maintenance superintendent.

- Measure each core and record the thickness of the asphalt concrete and bound and intact underlying layers (e.g., cement-treated base) (Figure 3.39 through Figure 3.42) or the thickness of the cement concrete and underlying base thickness (Figure 3.43). An example core log is provided in Appendix A (Form 7). Photographs of cores with a location reference are typically inserted in the core log form.

Figure 3.39: Core measurement of core with only asphalt concrete layers.

Figure 3.40: Core with asphalt concrete surface over cement concrete (layers are bonded).

Figure 3.41: Core with asphalt concrete surface on cement-treated base.
(Note visible debonding and debonded moisture-damaged layer, held together by tape).

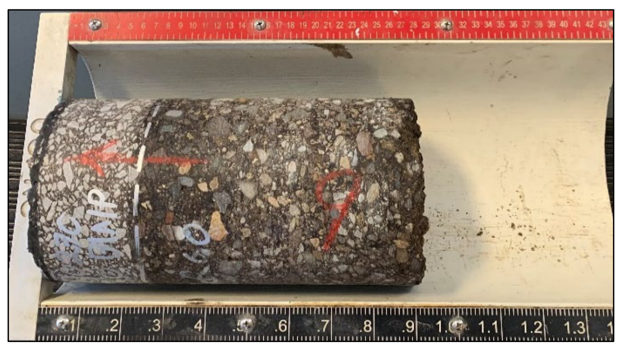

Figure 3.42: Core with asphalt concrete surface on full-depth recycled (foamed asphalt) base.

Figure 3.43: Core of concrete with asphalt base (core is upside down in photograph).

- Coring data from all site investigations and construction as-built coring should be submitted for inclusion in *iGPR* (check with Pavement Program (HQ) for procedures for doing this). Submittal of core data for inclusion in *iGPR* keeps the data in this tool up to date for use in future site investigations.
- Record the depth of cracking (i.e., top-down partial-depth [Figure 3.44] or full-depth [Figure 3.45]) as well as any specific characteristics that could influence the choice of maintenance strategies such as asphalt concrete overlay, mill and asphalt concrete overlay, cement concrete overlay on asphalt (COA), reconstruction, or in-place recycling strategy decisions (whether in-place recycling is feasible, recycling depth, and/or choice of recycling agent [emulsified asphalt or foamed asphalt] or choice of stabilizer [cement or lime]). In particular:
    + Identify the depth of surface cracks. Surface cracks that do not extend all the way through the asphalt concrete surface layers can be considered to have originated at the top and are termed "partial-depth." Cracks that extend all the way through the asphalt concrete may have started at the top or bottom, and they are termed "full-depth." Cracks are considered reflective when the cracks on the surface are connected to cracks in the underlying asphalt concrete layers (Figure 3.45 showing reflective cracking between asphalt concrete layers), cement concrete, and/or stabilized base layers.

Figure 3.44: Partial-depth top-down crack (caused by low temperatures).

Figure 3.45: Debonded asphalt concrete with full-depth reflective crack.

    + Look for debonding between bound layers (Figure 3.41 and Figure 3.45 to Figure 3.47) and between bound and unbound layers. Bound layers are those bound with asphalt or cement, including asphalt concrete, cement concrete, cement-treated bases, and bases recycled with asphalt recycling agents. Debonding can influence both the backcalculation of asphalt concrete stiffnesses and the future performance of overlays and recycled layers, especially if thin debonded layers are left below milled and overlaid or partial-depth recycled layers (Figure 3.47).

Figure 3.46: Layer debonding and moisture damage at debonded interface.

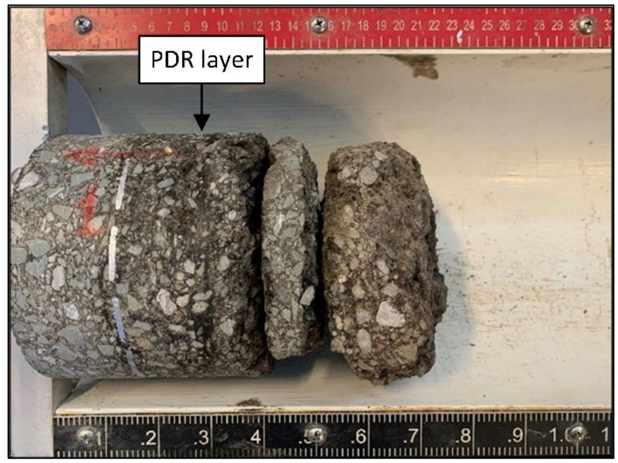

Figure 3.47: Thin debonded layers below partial-depth recycled layer.

+ Check for the presence of an open-graded asphalt concrete layer (OGFC or RHMA-O) or a chip seal between asphalt concrete layers. Check whether these layers have moisture damage caused by trapped water in the voids. Check for treated permeable base layers (asphalt-treated [ATPB] or cement-treated [CTPB]) below the asphalt concrete or cement concrete and their condition.
    - Note that the presence of open-graded layers on the surface will not have an important impact on backcalculated stiffnesses. Debonding between asphalt concrete layers, whether caused by lack of a tack coat in previous multiple lift asphalt construction or by stripping, and/or the presence of an open-graded layer between dense-graded layers will result in a lower backcalculated stiffness for the combined asphalt concrete layers. Open-graded layers, on the surface or in between dense-graded asphalt concrete layers, are too thin to be considered separate layers in backcalculation.
+ Check for the presence of fabrics or geogrids to help determine if they may cause problems with milling or in-place recycling of asphalt concrete. Correctly installed fabric can usually be milled/recycled effectively. However, poorly installed fabric (i.e., not saturated by the tack coat) and plastic or polypropylene geogrids will usually tear out of the pavement during milling/recycling and either wrap around the milling drum or be deposited as large compressible lumps in the recycled material.
+ See the Caltrans in-place recycling guidance *(5)* for additional considerations when examining cores on potential recycling projects.

3.2.4 Structural Assessment: Layer Thicknesses and Soil Resistance from DCP

The purpose of the DCP assessment (Figure 3.48) in investigations for rehabilitation, reconstruction, or widening projects where some or all of the existing structure will be used to obtain a measurement of unbound aggregate base and subbase layer (if present) thicknesses and to further evaluate the in situ stiffness of these layers and the subgrade. As with deflection testing, the results are affected by the moisture condition of the soils at the time of the DCP testing, and it is therefore best if testing is done at the time of wettest condition (during the winter or spring in California). This information can be used to identify drainage problems, for potential subsectioning, and to identify weak areas that require special treatment before construction. An introduction to DCP testing is provided in Appendix C.

Figure 3.48: DCP testing (manual DCP).

Conduct DCP testing according to ASTM D6951, taking the following into consideration:

- Note that the water used to cool the core bit can soften the upper layer of unbound material under the asphalt concrete or cement concrete surfacing, giving an unrealistically low shear strength for that upper layer. These effects can be minimized by keeping the water flow at the minimum required to cool the core barrel and by vacuuming water from the hole both during coring and as soon as the core has been removed from the hole.
- Use either an automated or manual DCP. Measure penetration after every five blows up to the maximum depth that the length of the DCP permits (typically 800 to 1,000 mm [31.5 to 39.4 in.]) or to refusal (i.e., penetration depth does not change after 10 blows), whichever occurs first, with depth of penetration of the unbound layers dependent on the thickness of the asphalt- or cement-bound layers removed in the core. Record DCP measurements on an appropriate form (example Form 8 in Appendix A). If a manual DCP is used, it is often

faster, easier, and safer (because of less time in the closure) to record DCP measurement locations and depths on lath and then take them back to the office for recording on the form. Note that measurements in whole millimeters are recommended as it is easier and quicker to read these off the measuring scale and to record and analyze whole numbers rather than decimals of centimeters, fractions of inches, or decimals of feet.

- DCP testing may not be possible where there are large aggregates in the unbound material (larger than 1.5 in. [38 mm]).

3.2.5 Structural Assessment: Layer Thicknesses and Material Types using GPR

If justified and available, ground penetrating radar (GPR, Figure 3.49) can be used to supplement the core and DCP data already collected and the data available in *iGPR* to obtain a reliable indication of pavement layer type, thickness, and thickness variability within a project. GPR can also be used to identify the location and depth of underground utilities, drainage systems, and bedrock, and it will provide a continuous evaluation of pavement layer thickness along the section. If a GPR survey is undertaken, use thicknesses from select cores to calibrate the GPR data.

Figure 3.49: Ground penetrating radar systems.

Arrange GPR surveys and analysis through the Caltrans Field and Forensic Services Branch in the Division of Materials Engineering and Testing Services (METS). GPR testing and interpretation procedures are not discussed in this guideline.

3.2.6 Material Sampling for Laboratory Testing

Take samples from the existing pavement, following the requirements in the test plan (see Table 2.1), as follows:

- Take material samples from core holes using a soil auger, ensuring that mixing of materials from different layers does not occur. Use the DCP-determined layer thicknesses to identify when to stop and remove each sample. The following samples sizes are recommended:

+ For soil classification tests, collect approximately 22 lb. (10 kg) of material at each location to ensure that sufficient fines are available for the Atterberg Limit tests. Sample size can be reduced on fine soils.
+ For resilient modulus tests, collect approximately 110 lb. (50 kg) at each location in the sampling plan. This allows for production of three 6 × 12 in. (150 × 300 mm) specimens (i.e., three replicate tests) per location. Reduce the sample size accordingly if smaller specimen sizes are tested or fewer replicates are required.
+ On rehabilitation projects where existing pavement will potentially be recycled in-place:
  - Take representative samples (22 lb. [10 kg]) from each unbound layer, including the subgrade for soil classification.
  - Keep the cores and sample additional materials (110 lb. [50 kg]) to the expected recycling depth. This will allow preparation of combined material samples that are representative of those in the combined likely recycling depth. Test results from this combination of materials will be used to identify the most appropriate recycling strategy and recycling agent (emulsified asphalt or foamed asphalt) or stabilizer (cement or lime, or a combination of the two).
  - Note that in-place and cold central plant recycling mix designs are usually undertaken by the contractor after the project is awarded. If the agency intends to do an in-house mix design, representative material samples should be collected from test pits.
+ Note that augering is best done through a 6-in. (150-mm) diameter or larger core hole, especially if large samples are required and/or where layers contain large aggregates (larger than 1.5 in. [38 mm]). Alternatively, consider excavating small test pits for collecting larger samples (see Section 3.4).

- Separate materials from different layers and place each sample in a plastic bag, cylinder, or bucket with an appropriate identifier. Clearly label all sample containers. Include the sample location and layer description on the label and in the sample log (example Form 9 in Appendix A).

3.3 New Construction or Widening Where Existing Structure is Not Used

3.3.1 Visual Assessment

For new construction on new alignments, the goal of the visual assessment is to assess the existing subgrade, potential cut and fill areas, imported fill (if known), drainage conditions with respect to drainage design plans, and any other constraints that may affect decision-making and design. Complete the following tasks during the visual assessment:

- Identify and document cut and fill areas, existing soils, soils in areas of cut and fill, soils in proposed borrow pits, and the presence of marshy areas that may have very soft and potentially organic soils. Problems in these areas may require specific actions in the design.
- Building on observations during the preliminary investigation, assess the natural drainage of the site with respect to proposed drainage design (i.e., internal drainage path, side drains, and culverts) and its potential to influence pavement distress development. Problems in these areas may require specific actions in the design and/or construction processes. Consider:
  + The potential for side drains and culverts to be blocked by agricultural activity, cut slope soil and rock debris, and/or vegetation and tree debris.
  + Irrigation water, whether from rural agricultural or urban median vegetation irrigation.
  + Presence of known utilities/services (e.g., pipelines, cables, overhead power lines, etc.).
- Identify any other potential issues to consider that might affect constructability when selecting material types and their transportation, placement, and compaction; other required construction activities; and worker safety.

For widening where the existing pavement structure will not be used in the widened or added lane, the visual assessment is undertaken to identify the modes of failure of the adjacent existing pavement in the existing traveled way and to determine where the distresses originated. Follow the guidance in Section 3.2.1. These observations are used to determine whether those distresses or other aspects of the existing structure will affect the new pavement and if there are drainage conditions affecting the existing pavement that may also affect the new pavement.

3.3.2 Structural Assessment: Layer Thicknesses and Soil Resistance from DCP

The purpose of the DCP assessment in investigations on new alignments and on widening projects where none of the existing structure will be used is to obtain an indication of in situ subgrade stiffnesses. The results will be influenced by the moisture condition of the soils at the time of testing, and it is therefore best if testing is done at the time of wettest condition. This information can be used to identify problem areas requiring specific design considerations including, but not limited to, those with high plasticity and potential drainage issues. An introduction to DCP testing is provided in Appendix C.

For new construction on new alignment, conduct DCP testing according to ASTM D6951 as follows:

- Test along the proposed centerline of the lanes at the intervals recommended in Table 2.2. If the project is a divided highway, then test along the centerlines of each direction. If the visual investigation indicates substantial transverse variability on divided highways, then stagger the DCP locations across the transverse width of each direction.
  + Do not do DCP testing on identified cut or fill sections that will be constructed in the future because the existing subgrade will not necessarily have the same properties as the soil at the top of the cut or in the fill. A geotechnical investigation can find properties of the soil at the future level of the subgrade in cut sections.
- Measure penetration after every five blows up to the maximum depth that the length of the DCP permits (typical length of 800 mm [31.5 in.] to 1 m [39.4 in.).
  + Note that measurements in whole millimeters are recommended as it is quicker and easier to read these off the measuring scale and to record and analyze whole numbers rather than decimals of centimeters, fractions of inches, or decimals of feet.
  + DCP testing may not be possible if there are numerous large aggregates in the unbound material (i.e., larger than 1.5 in. [38 mm]).
- Record the data on a form (example Form 8 in Appendix A).

For widening where the existing pavement structure will not be used in the widened or added lane, conduct DCP testing according to ASTM D6951 as follows:

- If coring is part of the investigation, do the DCP tests through the core holes as discussed in Section 3.2.4. If a soil sample is to be taken from the core hole, do the DCP testing before taking the soil sample. At locations where DCP testing is to be done and a core is not taken, drill a minimum 1 in. (25 mm) diameter hole through the existing bound layers that will be removed and do the DCP test through the drill hole.
- Measure penetration after every five blows up to the maximum depth that the length of the DCP permits. Depth of penetration of the unbound layers will be dependent on the thickness of the asphalt or cement-bound layers.

3.3.3 Material Sampling for Laboratory Testing

For new construction on new alignment, collect sufficient subgrade soil and/or fill material samples for soil classification and, if required in the test plan (Table 2.2), for resilient modulus testing. Sample as follows:

- Using an auger
  + On native ground, on previously constructed fill, or on cut, take a sample of material between 1.5 and 3 ft. (0.5 and 0.9 m) below the proposed final subgrade surface level. If observation from DCP tests or augering of soils from different depths indicates

differences in soil type within 3 ft. of the proposed final subgrade surface level, take a representative sample of the layers. If the subgrade is not all clay take a separate sample of any clay layers that may be expansive or considered weak for separate classification and testing. This is particularly important where expansive materials may be present in lenses that could cause subgrade soil expansion problems, but when mixed with non-expansive materials from other depths during sampling are not sufficient in quantity to result in a USCS soil classification of CH or MH or an AASHTO soil classification of A-7-6 or A5/A-7-5. Use caution when using an auger to collect soil samples as the auger will tend to mix soils from different depths. Bulk sampling on native ground may be better done by digging rather than using an auger. If soil sampling or DCP testing indicates softer layers deeper than 3 to 4 ft. (0.9 to 1.2 m), additional deeper sampling to 5 to 10 ft. (1.5 to 3.0 m) may be warranted.

- Using test pits
  + Take a sample from each distinct layer in the top 4 ft. (1.2 m) of the proposed final subgrade surface level, collecting sufficient material to perform all required tests in the test plan. Look out for lenses of expansive soils and if these exist, note their extent, and take sufficient samples from them for separate soil classification and other required testing in test plan.
- For fill locations where the fill has not yet been constructed, take representative soil samples from the identified source for fill material.
- The following sample sizes are recommended:
  + For soil classification tests, collect approximately 22 lb. (10 kg) of material at each location to ensure that sufficient fines are available for the Atterberg Limit tests. Sample size can be reduced on fine soils.
  + For resilient modulus tests, collect approximately 110 lb. (50 kg) at each location in the sampling plan. This allows for production of three 6 × 12 in. (150 × 300 mm) specimens (i.e., three replicate tests) per location. Reduce the sample size accordingly if smaller specimen sizes are tested or fewer replicates are required.

On widening projects where none of the existing paved shoulder or median pavement structure layers will be used in the widening:

- Take representative samples (22 lb. [10 kg]) from the subgrade and/or fill material for soil classification using sampling procedures similar to those for new construction. Do not sample from the layers that will be removed.
- If required in the testing plan, take additional samples of the subgrade and/or fill material (110 lb. [50 kg]) for resilient modulus testing. Do not sample from the layers that will be removed.

Separate materials from different layers and place each sample in a plastic bag, cylinder, or bucket with an appropriate identifier. Clearly label all sample containers. Include the sample location and layer description on the label and in the sample log (example Form 9 in Appendix A).

3.4 Pavement Layer Assessment from Test Pits or Trenches

Test pits (Figure 3.50) or trenches (full lane width) are used if sufficient information about localized areas of the pavement that may present high risk of early failure cannot be gathered from the procedures described above. Test pits and trenches serve several purposes—they show a cross section of the pavement layers and subgrade where the origins of distresses and contributions to surface rutting of asphalt concrete layers, base, subbase, and subgrade layers can be seen; they allow inspection of subgrade moisture conditions; and they provide a source of material for laboratory testing.

If test pits or trenches are considered appropriate, excavate them in locations that were identified as requiring additional investigation during the visual and/or structural assessments. Note that test pits or trenches are rarely excavated for site investigation on rigid pavements, particularly continuously reinforced concrete pavement, unless a major forensic investigation is required.

Figure 3.50: Test pit.

Excavate test pits across the outer wheelpath and trenches across the full lane width. Dimensions of test pits are approximately 3.5 × 3.5 × 3.5 ft. (approximately 1.0 × 1.0 × 1.0 m), which is large enough to afford adequate space for an investigation and provide sufficient material for testing. If material sampling is the primary purpose, excavate with care to ensure that materials from different layers are not mixed during collection.

The assessment and analysis of the test pit or trench will depend on the reason it was excavated. Once the test pit or trench has been excavated, clean the pit face and delineate the individual layers with string (as shown in Figure 3.50). Carefully inspect the pit face and document the observations (example Form 10 in Appendix A). Examples of items to inspect include, but are not limited to, the following:

- **Layer thickness.** Measure each layer thickness across the test pit face and calculate an average thickness. Note any major differences in layer thickness from one side of the pit to the other.
- **Layer moisture contents.** Remove a sample of material from each of the underlying layers and place it in a sealed container immediately after excavation for later moisture content determination. This can be used to refine the DCP analyses, to determine resilient modulus test compaction water content (if resilient modulus is required), and to establish a mixing moisture content range for in-place recycling operations.
- **Asphalt concrete assessment.** Inspect each asphalt concrete layer to identify the extent and origin of distresses, debonding, stripping, and the presence of rubber, interlayers, fabrics, geogrids, or other materials that may influence the rehabilitation strategy selection.
- **Base and subbase assessment.** Inspect the base and subbase to assess:
    + Material type, gradation, presence of cobbles and other oversize aggregates, and plasticity range, and to identify signs of contamination from the subgrade (pumping) and/or evidence of severe moisture fluctuations (e.g., mottling in the form of spotted or streaked areas of different color). Moisture problems will typically be associated with high subgrade deflection modulus values and high DCP penetration rates.
    + On cement-stabilized bases, check for shrinkage cracks and for carbonation (loose uncemented material at the top of the layer). The presence of carbonation can also be checked by spraying phenolphthalein on a strip covering the full thickness of the layer. Uncarbonated intact areas will appear bright red, while carbonated areas will not show any color.
    + On asphalt-treated permeable bases, check for stripping.
    + On cement-treated permeable bases, check for crumbling/disintegration.
- **Subgrade assessment.** Inspect the subgrade to identify moisture condition, signs of fluctuating moisture conditions (mottling[8]), signs of shearing (e.g., slickensides, which are areas with smooth faces with linear grooves, generally caused by expansion and relative

[8] Soil mottling means a soil color pattern consisting of patches of different color or shades of color interspersed with the dominant soil color. The secondary soil colors are not associated with compositional properties. Redoximorphic features are a type of mottle associated with wetness. Lithochromic mottles are a type of mottling associated with variations of color due to weathering of parent materials.
https://www.lawinsider.com/dictionary/soil-mottling;
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052523.pdf

lateral movement of adjoining clay peds on wetting [example in Figure 3.51]), presence of organic materials, inadequate support for the overlying layer (punching of aggregate), and any other problems that may require attention in the design or during construction.

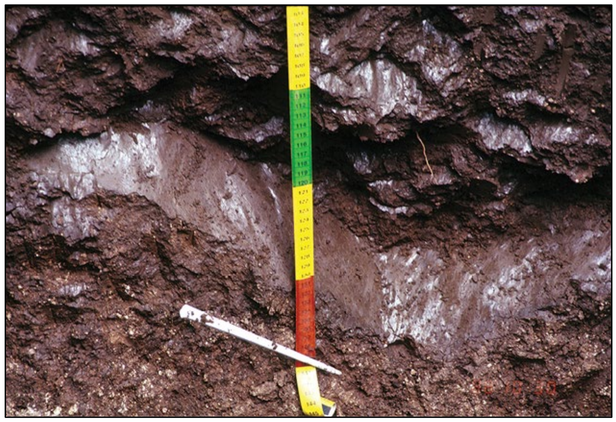

Figure 3.51: Slickenside in subgrade soil (USDA Natural Resources Conservation Service)**.**

3.5 Laboratory Testing of Sampled Materials

Conduct laboratory testing, as needed, on samples collected during the site investigation. The types of testing will depend on the complexity of the project and are based on the testing plans in Table 2.1 and Table 2.2. Tests include the following:

- Soil classification
  - Unified soil classification system (ASTM D2487) for flexible pavement design or AASHTO soil classification (AASHTO M 145) for rigid pavement design, which require the following tests:
    - Sieve analysis (CT 202) and Atterberg Limits (CT 204 [liquid limit, plastic limit, and plasticity index [PI]).
- Resilient modulus, following AASHTO T 307.
- Subgrade Expansion Index. Consult with the district materials engineer to determine if this is required. A subgrade soil is generally considered at high risk for clay expansion based on the soil expansion index (EI) determined following ASTM D4829 or AASHTO T 258. ASTM D4546 can also be used to identify expansive soils and soils that are susceptible to swell or collapse of soils.
- If full-depth recycling is being considered, either because it was recommended from the *PaveM* decision trees or the preliminary site investigation indicated that it should be considered, conduct additional tests (pH and unconfined compressive strength) to determine whether an asphalt recycling agent (emulsified asphalt or foamed asphalt) or portland cement should be used (see the Caltrans in-place recycling guidance *[5]* for additional information and testing procedures).

4 STEP 3: ANALYSIS OF DETAILED INVESTIGATION DATA

4.1 Introduction

The initial data analysis discussed in this guide involves summarizing the data collected from field investigations and laboratory tests, estimating the resilient modulus of unbound materials (aggregate base, subbase, and subgrade) from DCP and soil classification data, estimating stiffnesses for bound materials and resilient modulus of unbound soils by backcalculating deflection data, and examining data for potential subsectioning for mechanistic-empirical design.

Initial data analysis consists of the following:

- For rehabilitation, reconstruction, and widening where some or all of the existing structure will be used:
  - + Estimate stiffnesses from DCP tests (Section 4.2) and soil classification data (Section 4.3) to use with backcalculated moduli and laboratory resilient modulus test results to develop design moduli.
  - + Identify pavement layer thicknesses for backcalculation from cores, DCP, and GPR data from the site investigation, and historical core and GPR data in *iGPR* (Section 4.4).
  - + Determine subsections with approximately uniform pavement cross sections for backcalculation (Section 4.5). Backcalculation of stiffnesses requires an approximately uniform structure for each subsection defined as same pavement layer material types and similar thicknesses for each layer.
  - + Backcalculate layer stiffnesses using deflection data for each subsection of the project (Section 4.5). Guidance on backcalculation of stiffnesses from deflection data input for mechanistic-empirical design is covered in the *CalBack* user manual.
  - + Plot estimated resilient moduli versus project location from each of the frequently sampled data sources (backcalculation, DCP, soil classification) along with the less frequent laboratory-measured resilient moduli, to determine the moduli to be used for design and to check if subsectioning is needed (Section 4.6).
- For new construction and widening where an existing structure will not be used:
  - + Estimate stiffnesses from DCP tests (Section 4.2) and soil classification data (Section 4.3) to use with laboratory resilient modulus test results to develop design moduli.
  - + Plot estimated resilient moduli versus project location from each of the frequently sampled data sources (DCP, soil classification) along with the less frequently sampled laboratory-measured resilient moduli, to determine the moduli to be used for design, and to check if subsectioning is needed (Section 4.6).

- On in-place and cold central plant recycling projects, identify mix design sampling locations for contractor mix designs (Section 4.7).
- On projects requiring lime- or cement-stabilized soil, identify sampling locations for determining lime or cement application rates.

4.2 Analysis of DCP Data to Determine Unbound Layer Thicknesses and Stiffnesses

Use the following procedure to analyze DCP data:

- Calculate the DCP Penetration Index (DPI [penetration depth divided by number of blows]). A single DPI for the full depth of penetration and/or a DPI for each layer can be calculated.
- Plot DPI against depth and identify depths at which any distinct changes occur. The depths at which there is a consistent change in DPI indicate changes in material characteristics and/or moisture content and provide a useful indication of layer boundaries. An example of a distinct change in the rate of DCP penetration (boundary between base and subgrade) can be seen in Figure 4.1.

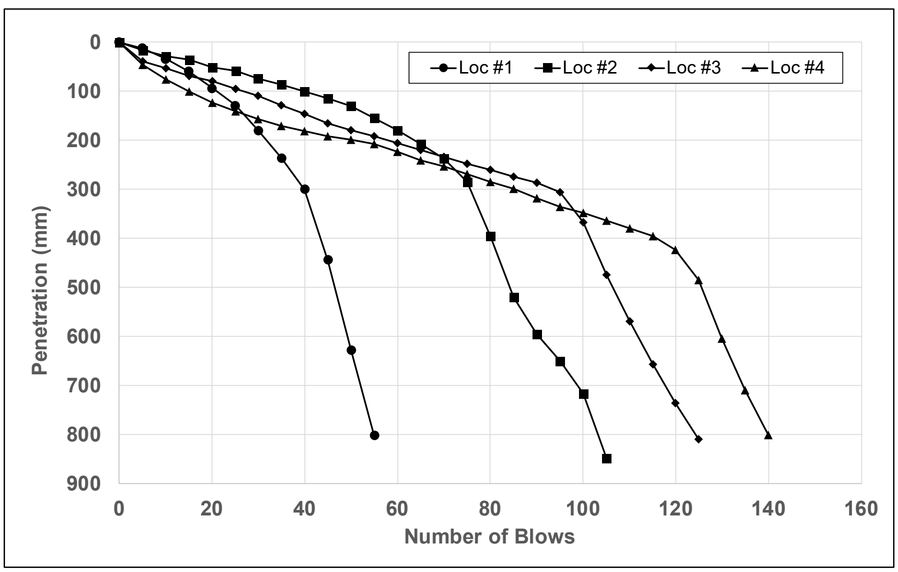

Figure 4.1: Example of use of DCP penetration rate to identify two unbound materials layers.
(Layer type change at 300 to 400 mm [12 to 16 in.] depth).

- Estimate stiffness ("stiffness [*E*]" is often used for "resilient modulus" when the results do not come from a laboratory resilient modulus test) of each layer for each station based on the average DPI for each identified layer using Equation 4.1 (US Standard [ksi] and metric [MPa] units versions shown).

$$\log_{10}\left(M_r \; or \; E\right) \; in \; ksi = 1.884 - 0.730\log_{10}\left(DPI\right) \; in \; mm/blow \qquad \textbf{4.1}$$

$$\log_{10}\left(M_r \; or \; E \; in \; MPa\right) = 2.722 - 0.730\log_{10}\left(DPI\right) \; in \; mm/blow \qquad \textbf{4.1}$$

Information about the development of this equation for estimating soil stiffness from DPI is included in Appendix C.

4.3 Analysis of Soil Classification Data to Determine Subgrade Stiffnesses

Use the soil classifications for the subgrade samples taken during the site investigation to determine estimated subgrade stiffnesses using Table 4.1 (USCS) or Table 4.2 (AASHTO). The recommended values in Table 4.1 are the default values used in *CalME*. Information about the development of the equation for estimating soil stiffness from soil classification is included in Appendix C.

Table 4.1: Estimating Resilient Modulus (Stiffness) from Unified Soil Classification System

USCS Classification	Resilient Modulus (M_r) (ksi)			Resilient Modulus (M_r) (MPa)		
	Min.	Max.	Default for *CalME*	Min.	Max.	Default for *CalME*
GW	26	42	38	179	290	262
GP	18	35	29	127	241	200
GM	16	42	30	108	290	207
GC	13	26	20	87	179	138
GW-GM	24	40	To be determined	167	275	To be determined
GP-GM	19	37		132	259	
GW-GC	16	37		113	259	
GP-GC	16	35		113	240	
SW	16	31	21	108	211	145
SP	9	26	17	65	179	117
SM	9	26	21	65	179	145
SC	6	16	14	39	108	97
SW-SM	13	27	To be determined	92	186	To be determined
SP-SM	13	27		92	186	
SW-SC	11	25		74	170	
SP-SC	11	25		74	170	
ML	6	13	11	39	92	76
CL	6	13	9	39	87	62
OL	5	6	To be determined	33	39	To be determined
MH	3	9	6	22	65	41
CH	3	13	4	17	87	28
OH	4	4	To be determined	27	31	To be determined

Table 4.2: Estimating Resilient Modulus (Stiffness) from AASHTO Soil Classification System

AASHTO Classification	Resilient Modulus (M_r) (ksi)			Resilient Modulus (M_r) (MPa)		
	Min.	Max.	Default for *Pavement ME*	Min.	Max.	Default for *Pavement ME*
A-1-a	30	42	40	207	290	276
A-1-b	24	35	38	163	241	262
A-2-4	16	26	32	108	179	221
A-2-5	13	27	28	92	186	193
A-2-6	9	18	26	65	127	179
A-2-7	11	16	24	74	108	165
A-3	13	24	29	87	163	200
A-4	9	16	24	65	108	165
A-5	8	13	20	55	92	138
A-6	6	13	17	39	87	117
A-7-5	3	8	12	21	55	83
A-7-6	3	6	8	17	39	55

4.4 Determination of Material Types and Layer Thicknesses for Backcalculation

Identify material types and layer thicknesses for backcalculation of stiffnesses for rehabilitation, reconstruction, and use of existing layers for widening as follows:

- Identify layer thicknesses for each bound material type (asphalt concrete, cement concrete, cemented bases and subbases, and recycled layers) from cores or GPR data and for each unbound material type (aggregate bases and subbases) from DCP results (see Section 4.2), or from soil boring and soil classification testing and historical data.
- Identify approximate uniform pavement cross-section subsections based on the following:
  + Plot layer material types and thicknesses from the site investigation cores for bound layers and the DCP results for unbound layers. Where appropriate, supplement this data with that identified from cores, as-builts, and GPR data in *iGPR* (both the historical cores and the 2011 GPR plots), as well as from historical information that is still applicable in as-builts. A spreadsheet or software plotting tool can be used to prepare this plot, or it can be done by hand.
  + Identify boundaries of approximately uniform cross-section subsections that have:
    - The same material layers.
    - Approximately the same thicknesses for those layers, based on identification of distinct changes in thicknesses of layers (more than about 20% and/or more than 2 in. [50 mm] different).
    - Minimum lengths of 0.5 mi. (0.8 km). If shorter, or a valid explanation for their existence was noted in the visual assessment, list them as requiring specific attention before the main construction starts.

4.5 Backcalculation of Stiffnesses with Deflection Data

Backcalculate stiffnesses from deflection data for rehabilitation, reconstruction, and use of existing layers for widening by analyzing the data according to CT 357 using the *CalBack* software. This involves the following steps:

- Import the FWD data into *CalBack*.
- Manually divide the FWD data into preliminary subsections following the preliminary subsection scheme developed from the analysis of layer thickness data discussed in Section 4.2.
- Set up a pavement structure for each subsection following the preliminary subsection scheme and the *CalBack* user manual instructions. Adjacent layers that have similar stiffnesses and layers thinner than about 0.25 ft. (3 in. [75 mm]) will need to be combined in *CalBack* to improve consistency of the backcalculation. Guidance on doing this is provided in the *CalBack* user manual.
- Perform the backcalculation:
  + For flexible-surfaced pavement, backcalculate the stiffnesses of all layers for input to *CalME*. Layers with similar properties (e.g., all the asphalt concrete layers, all cemented layers, all unbound layers, including the subgrade) are usually grouped together for backcalculation.
  + For existing rigid-surfaced pavement where the concrete is to be cracked, seated, and overlaid with asphalt concrete, backcalculate the stiffnesses of all layers for input to *CalME*. Underlying unbound layers and subgrade are usually grouped together for this.
  + For existing rigid-surfaced pavement being considered for dowel bar retrofit, calculate the load transfer efficiency (LTE).
  + For existing rigid-surfaced pavement to be reconstructed with a new rigid surface where the existing pavement layers will be substantially reused as a bound base layer (usually the existing asphalt concrete layers in the new pavement) and deflections were taken to identify areas of weak base, subbase, and/or subgrade support, backcalculate the layer stiffness of all layers below the concrete as one layer for identification of weak areas. Do not use backcalculated stiffnesses with *Pavement ME*, only use soil classification.
- Export the results from *CalBack* directly into *CalME* for use in flexible-surfaced pavement designs.

4.6 Comparison and Verification of Stiffnesses and Subsectioning Adjustment

For rehabilitation, reconstruction, and widening where some or all of the existing structure will be used and where each of the subsections with approximately uniform layer material types and thicknesses will be used for backcalculation:

- Plot the subgrade stiffnesses estimated from backcalculation and/or soil classification, and/or DCP, and/or resilient modulus testing, as applicable, against project stationing. Include soil classifications against stationing in the plot. The first and last sensor deflections can also be plotted, with the first sensor providing an indication of the overall bearing capacity of the pavement and subgrade acting together, and the last sensor providing an indication of subgrade stiffness only.
- Verify that stiffnesses from all data sources are reasonably consistent with each other. Identify potential explanations where they are not reasonably consistent and whether any further investigation is needed. Consider the following:
  + First and last sensor plots can help with checking reasonableness of backcalculation results and each deflection location.
  + Possible reasons for large differences between backcalculated stiffnesses from deflection testing and laboratory resilient modulus test results and other stiffness estimates (from DCP, soil classification, or other test methods) or estimates at other stations from other methods can be attributed to:
    - Layering in the backcalculation that does not produce reasonable results. See the *CalBack* user manual for information about layering and grouping of layers for backcalculation.
    - Areas of localized moisture damage or debonding in asphalt-bound materials.
    - Localized damage, shrinkage cracking, or debonding in cement-stabilized layers.
    - Localized areas of high moisture in unbound aggregate and soil layers.
- Identify whether additional subsectioning is needed beyond the subsectioning for backcalculation. This may be needed because of areas with consistently different soil classifications and stiffnesses within the areas with approximately uniform pavement cross sections. The minimum length for subsections should be approximately 0.5 mi. (0.8 km). The variability of the stiffness across the project area can be considered in terms of the coefficient of variation (COV), which is calculated as the standard deviation of the backcalculated stiffnesses divided by the mean stiffness. This can be done in a spreadsheet. In general, if there is limited variability (i.e., if the COV is <2), use the average stiffness, and the reliability calculation in the ME design method will account for within-project variability. If there is high variability (i.e., if the COV is ≥2) through the subsection, select the soil stiffness used for design from the lower range of stiffnesses within the subsection.
- Identify short sections (not more than 0.1 mi. [0.16 km]) within each subsection that have lower stiffnesses and need to be addressed. Options to improve stiffness include use of geosynthetic, chemical stabilization, removal and replacement, and other remedies.
- Select layer stiffnesses for each final subsection for ME design as follows:
  + For flexible-surfaced pavement design, load the verified backcalculation results from *CalBack* into *CalME.*

- For rigid-surfaced pavement lane replacement design using the design catalog, use the AASHTO soil classifications to select the pavement design from the design catalog. Use the soil classification found within the project limits that produces the thickest pavement structure. Where there is variability of soil classifications between distinct areas within the project limits, consider remedying weak support conditions in short sections (maximum length 0.1 mi. [0.16 km]) using one of the approaches identified above for flexible-surfaced pavements or subsectioning (minimum length 0.5 mi. [0.8 km]). Where the existing base and subbase layers are going to be used in the lane replacement structure and deflections were taken for identification of weak support from those layers, the backcalculated stiffnesses of the combined layers (base, subbase, and subgrade) beneath the concrete can be used to identify potential subsections following the same COV criteria (≥2) used for flexible-surfaced pavements. However, they are not used as *Pavement ME* inputs (use the AASHTO soil classifications).
- For rigid-surfaced pavement lane replacement design using *Pavement ME*, use the AASHTO soil classifications, not backcalculated stiffnesses, as input for subgrade characterization. This recommendation is made because the calibration of *Pavement ME* includes conversions of AASHTO soil classifications to *k*-values using specific relationships that did not include use of backcalculated values. The assumed *k*-values for each soil classification are included in the *Pavement ME* software and its documentation.

For new construction and widening where an existing structure will not be used:

- Plot subgrade stiffnesses estimated from soil classification and/or DCP and/or resilient modulus testing, as applicable, against project stationing. Include soil classifications against stationing in the plot.
- Verify that stiffnesses from all data sources are reasonably consistent with each other. Identify potential explanations where they are not reasonably consistent, and whether any further investigation is needed.
- Identify whether there is a need for subsectioning of areas with consistently different soil classifications and stiffnesses within the project. The minimum length for subsections should be approximately 0.5 mi. (0.8 km).
- Identify any short sections (not more than 0.1 mi. [0.16 km]) within each subsection that have lower stiffnesses that need to be addressed. Options for increasing stiffness include, but are not limited to, geosynthetics, subgrade soil improvement, or removal and replacement.
- For flexible-surfaced pavement design, determine the typical subgrade stiffness (resilient modulus) for the project or for each subsection within the project for *CalME* design.
- For rigid-surfaced pavement design using the design catalog, use the AASHTO soil classification to select the pavement design from the design catalog. For rigid-surfaced

pavement design using *Pavement ME*, use the AASHTO soil classifications for subgrade characterization as input rather than the estimated stiffnesses from DCP or laboratory resilient modulus testing. This recommendation is made because the calibration of *Pavement ME* includes conversions of AASHTO soil classifications to *k*-value using specific relationships developed for the calibration. Use of static plate testing using ASTM D1196 or other tests to measure *k*-value is not recommended.

4.7 Identification of Mix Design Sampling Locations on In-Place Recycling Projects

On in-place or cold central plant recycling projects, the contractor is required to take samples from designated sampling locations and perform mix designs for the recycled layer. The project specifications will identify the minimum number of mix design locations and these need to be identified during the site investigation.

Identify suitable sampling locations for mix designs on in-place and cold central plant recycling projects using the subsectioning information. This will ensure that the mix design(s) will be representative of the project.

5 STEP 4: PROJECT INVESTIGATION REPORT

The project investigation report (PIR) is an update to the preliminary investigation report and is prepared upon completion of the detailed investigation and data analysis as part of the Project Study Report (PSR). The contents of the project investigation report serve the following purposes:

- Identifies type, origin, and extent of distresses for selecting the most appropriate design strategy.
- Provides stiffnesses and other information for ME design.
- Provides subsections for design based on uniform cross sections from information gathered during the site investigation, and information for additional subsectioning if needed.
- Identifies localized issues that need additional attention.
- On in-place and cold central plant recycling projects, identifies locations for the contractor to take samples for mix designs.
- On projects requiring soil stabilization, identifies locations to take samples for determining lime or cement application rates.

Use a checklist to ensure that all of the above items are covered in the report (example Form 11 in Appendix A). Include field investigation and laboratory test results as appendices to the report.

5.1 Inputs for Structure Type or Rehabilitation/Reconstruction Strategy Selection

Select a structure type after reviewing all the options available for the chosen rehabilitation, reconstruction, or widening strategies, where some of the existing structure can potentially be used. Note that a treated permeable layer—although not recommended for new construction, rehabilitation, or reconstruction—may be required on widening projects to match the existing pavement structure and to maintain a path for drainage.

A number of factors are used to decide on the most appropriate rehabilitation strategies to consider in a mechanistic-empirical design; these factors are discussed in the *Highway Design Manual*, Chapter 600 and other guidance. The information collected during the investigation that informs these decisions is listed below and should be documented in the report to support the decision.

- Project objective:
  + Is structural improvement required?
  + Are there any grade restrictions?

- Type and depth of distress to be addressed:
  - For existing flexible pavement:
    - Are the distresses present on the surface confined to the top 0.2 ft. of the asphalt concrete layers?
    - Are the distresses top-down and confined to the asphalt concrete layers, but deeper than 0.2 ft.?
    - Are the distresses primarily bottom-up but confined to the asphalt concrete layers?
    - Are there distresses occurring in layers below the asphalt concrete or cement concrete layers, such as debonding, permanent deformation, cracking, or other damage?
    - Are there enough areas needing localized attention to justify cost-effectively addressing them as part of the strategy selection rather than through localized repairs?
  - For existing rigid pavement to be rehabilitated with a flexible surface:
    - Are there enough areas needing localized attention to make it more cost-effective to address them as part of the strategy selection rather than through localized repairs?
  - For existing rigid pavement to be rehabilitated with a rigid surface:
    - Are there enough areas needing localized attention to make it more cost-effective to address them as part of the strategy selection rather than through localized repairs?
- Are the distresses drainage related?
  - If yes, how can solutions to drainage problems be incorporated into the structural alternatives?
- Structure of existing pavement:
  - What layers, if any, in an existing pavement can be left in place in the new structure?
  - What layers, if any, can be recycled in place?
  - What layers, if any, can be recycled within the site or off-site?

5.2 Inputs for *CalME* Design of Flexible-Surfaced Pavement

For rehabilitation or reconstruction with flexible surface of existing pavements or widening where some layers of the existing structure will be used, the *CalME* design software requires the following input for each of the subsections:

- Project location: district, county, route, direction, post miles (start and end).
- Stiffness values:
  - If available, *CalBack* backcalculation output files. Note the following:
    - Output files include thicknesses, stiffnesses of existing pavement layers, and variability of stiffnesses of existing layers from backcalculation of deflection data.
    - Remove any layers that will not be used in the new structure.

        - Any layers that will be recompacted or otherwise changed may not have the same stiffness. Decide whether to use the backcalculated stiffness if significant changes are unlikely, or an adjusted stiffness if it is expected to change.
    - If backcalculated subgrade stiffnesses are not available, use DCP-determined stiffnesses or default stiffnesses derived from USCS values.
- Standard materials layer types for new layers and initial trial thicknesses for different alternatives.
- Where the existing surface is asphalt concrete, the extent of existing pavement cracking as a percentage of the wheelpath with Alligator A plus Alligator B cracking.

For new pavements with flexible surface or widening where none of the existing structure will be used, the *CalME* design software requires the following input for each of the subsections:

- Project location: district, county, route, direction, post miles (start and end).
- Subgrade soil classification (USCS) and subgrade resilient modulus.
- Standard materials layer types, initial trial thicknesses for different alternatives, and their resilient moduli (soils layers) or stiffnesses (asphalt- or cement-bound layers).

5.3 Inputs for Design for Rigid-Surfaced Pavement

For design using the design catalog for reconstruction or rehabilitation of existing pavement and widening where layers in the existing structure will be used in the new structure, the following input is required:

- Project location: district, county, route, direction, post miles (start and end) to determine climate region and obtain traffic data.
- Subgrade soil AASHTO classification.
- Layer type and thicknesses for existing layers that will be used in the structural alternatives.
    - Contact the Caltrans Office of Concrete Pavement for more information about consideration of existing layers in the rigid pavement design catalog.

For design using the design catalog for new pavement and widening where none of the existing structure will be used in the new structure, the following input is required:

- Project location: district, county, route, direction, post miles (start and end) to determine climate region and obtain traffic data.
- Subgrade soil AASHTO classification.

For new or reconstruction using the *Pavement ME* design software, contact the Caltrans Office of Concrete Pavement for guidance on how to proceed.

5.4 Considerations and Inputs for Subsectioning

Cost savings may be found by subsectioning long-length projects with distinct areas of different subgrade conditions that will influence design decisions (i.e., designing the entire project based on the weakest section can result in expensive and unnecessary over-design for the remainder of the project). Short sections with isolated problems can usually be corrected separately without them impacting the project design. However, potential cost savings need to be weighed against the potential risks of having different cross sections along the project.

Propose a subsectioning plan using the combined analysis discussed in Section 4.6. Additional factors to consider in a subsectioning recommendation include boundaries for the following:

- Grade constraints:
  + Bridges and tunnels
  + Underground utilities
  + Slopes
  + Transitions from cut to fill
  + Intersections
  + Roadside features that may influence structural design choices such as barriers, rails, sound walls, signs, signals, and curb and gutter
- Changes in traffic.
- Existing structure or layers that will remain on rehabilitation (including in-place and cold central plant recycling) and reconstruction projects.
- Causes of failure, failure origin, and extent of distresses on rehabilitation (including in-place and cold central plant recycling), and reconstruction projects.

After completing initial *CalME* or rigid pavement designs, review the subsectioning scheme. Consider consolidating similar designs to simplify construction and potentially reduce cost. Base these decisions on trade-offs between cost-effectiveness and construction efficiency.

5.5 Considerations and Inputs for Localized Issues

Compile a list of localized issues that need to be addressed before the main construction based on a review of the localized problems identified during the investigation and analysis steps. Examples of localized issues include, but are not limited to, the following:

- Significantly weaker subgrade compared to most of the project.
- Poor drainage and/or high groundwater table and/or are prone to localized flooding.

- Heavy localized distress, debonding, moisture damage, patching, and/or digouts.
- Culverts and shallow utilities.
- Bedrock or large cobbles (this is a problem only if it will interfere with construction that involves excavation or in-place recycling at or below the depth of the rock).
- Underlying previous pavement structure that is not on the same alignment and therefore not uniform across the current structure. This includes longitudinal joints in previous construction that are now immediately below the wheelpaths of new layers.
- Existing interlayers or materials that may cause problems for construction activities, such as milling and in-place recycling.

Where appropriate, provide preliminary recommendations for addressing these localized issues. Guidance on solutions can be found in other Caltrans guides, including the *Highway Design Manual (1)*, *In-Place Recycling Guide (5)*, *Subgrade Stabilization Guide (6)*, *Concrete Pavement Guide (7)*, and the *Construction Manual (11)*.

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APPENDIX A: EXAMPLE FORMS AND CHECKLISTS

The following example forms are provided in this appendix:

1. Desktop Study Report
2. Initial Visual Assessment (Flexible)
3. Initial Visual Assessment (Rigid)
4. Project Investigation Preliminary Report
5. Visual Assessment-Detailed Site Investigation (Flexible)
6. Visual Assessment-Detailed Site Investigation (Rigid)
7. Core Log
8. DCP Assessment
9. Sample Log
10. Test Pit Assessment (Flexible-Surfaced Pavement Only)
11. Project Investigation Analysis

1 Desktop Study Report

Project No.:			**Project Description:**				
Route No.:		**Post Mile:**	to	**Date:**		**Assessor:**	

Study Description:								
Climate Region:		**Traffic:**		**Lanes:**		**Shoulders:**	Y	N
***PaveM* Recommendation**								

Pavement Information from As-Built Data and Maintenance Records

Layer	Thickness	Description	Material
1			
2			
3			
4			
5			
6			

General Condition:	
Maintenance History	
Potential Problems:	1
	2
	3
	4
	5
	6
	7
	8
	9
	10
Critical Issues:	

Potential recycling candidate?	Yes		No		
Continue with preliminary investigation?	Yes		No		

2 Initial Visual Assessment (Flexible)

Project No.:		**Project Description:**							
Route No.:		**Post Mile:**	**to**	**Date:**			**Assessor:**		
Observation									**Comments**
1. Distress origin	Top-down		Bottom-up		Subgrade		Drainage		
2. Crack type and extent	Alligator		Transverse/thermal		Longitudinal		Extent	%	
	Block						Extent	%	
3. Pumping	From cracks		From other				Extent	%	
4. Rut depth and extent	Depth		Surface		Structural		Extent	%	
5. Maintenance	Patches/Digouts		Slab replacement				Extent	%	
6. Cause of failures	Age		Traffic		Structural		Drainage		
7. Gravel base	Yes	No	Cemented base	Yes	No				
8. Height above natural ground			Sufficient for drainage	Yes	No				
9. Drainage	Adequate		Functioning		From slope/cut		Irrigation		
10.									
11.									
12.									
13.									
14.									
15.									
Samples taken?	Yes	No	Purpose						
Critical issues?	Yes	No	Reason						
***PaveM* recommendation appropriate?**	Yes	No	Reason						

3 Initial Visual Assessment (Rigid)

Project No.:			**Project Description:**						
Route No.:		**Post Mile:**	**to**		**Date:**			**Assessor:**	

Observation									**Comments**
1. Distress origin	Top-down		Bottom-up		Subgrade		Drainage		
2. Crack type and extent	Transverse		Longitudinal		Corner		Extent	%	
	1st Stage		3rd Stage		Shattered		Width		
3. Pumping	From cracks		From joints		From other		Extent	%	
4. Maintenance	Slab replacement		Joint seal		Grind		Extent	%	
	Dowel bar retrofit		Chain wear repair						
5. Cause of failures	Age		Traffic		Structural		Drainage		
6. Drainage	Adequate		Functioning		From slope/cut		Irrigation		
7.									
8.									
9.									
10.									
11.									
12.									
13.									
14.									

Samples taken?	Yes		No		Purpose	
Critical issues?	Yes		No		Reason	
***PaveM* recommendation appropriate?**	Yes		No		Reason	

4 Project Investigation Preliminary Report

Project No.:			**Project Description:**				
Route No.:		**Post Mile:**	**to**	**Date:**		**Assessor:**	

Observation					**Comments**
Are distresses top-down only?	Yes		No		
Are distresses primarily bottom-up?	Yes		No		
Are distresses indicative of subgrade failure?	Yes		No		
Are patch/digout/slab replacement repairs failing rapidly (flexible only)?	Yes		No		
Are there any issues that preclude in-place recycling on flexible pavements?	Yes		No		
Is existing drainage adequate and functioning?	Yes		No		
Can drainage problems be easily corrected?	Yes		No		
Does adjacent land-use/slope-stability influence performance?	Yes		No		
Can land-use/slope-stability problems be easily addressed?	Yes		No		
Are shallow underground utilities evident?	Yes		No		
	Yes		No		
	Yes		No		
	Yes		No		
	Yes		No		
	Yes		No		
	Yes		No		
	Yes		No		
	Yes		No		
	Yes		No		

Other notes:

***PaveM* recommendation appropriate?**	Yes		No		Reason	
Continue with detailed investigation?	Yes		No		Reason	

5	Visual Assessment-Detailed Site Investigation (Flexible)

Project No.:				**Project Description:**																				
Route No.:			**Post Mile:**		to			**Date:**				**Assessor:**												
FWD	Y	N	**Coring**	Y	N	**DCP**	Y	N	**GPR**	Y	N	**Samples**	Y	N	**Test Pits**	Y	N							

Surfacing Assessment

Surfacing type:	HMA		HMA-O		RHMA-G		RHMA-O		Chip Seal		Other	

	Degree						Extent					Length	Width	Location
	Slight					Severe	<5				>80			
Surface ruts	0	1	2	3	4	5	1	2	3	4	5			
Thermal/aging cracks	0	1	2	3	4	5	1	2	3	4	5			
Bleeding/flushing	0	1	2	3	4	5	1	2	3	4	5			
Raveling	0	1	2	3	4	5	1	2	3	4	5			
Edgebreak/shoulder drop	0	1	2	3	4	5	1	2	3	4	5			

Structural Assessment

	Degree						Extent					Narrow (% area)	Wide (% area)	Position	Location
	Slight					Severe	<5				>80				
Cracks - Alligator A	0	1	2	3	4	5	1	2	3	4	5				
Cracks - Alligator B	0	1	2	3	4	5	1	2	3	4	5				
Cracks - transverse	0	1	2	3	4	5	1	2	3	4	5				
Cracks - longitudinal	0	1	2	3	4	5	1	2	3	4	5				
Block	0	1	2	3	4	5	1	2	3	4	5				
Pumping	0	1	2	3	4	5	1	2	3	4	5				
Rutting - structural	0	1	2	3	4	5	1	2	3	4	5				
Undulation/settlement	0	1	2	3	4	5	1	2	3	4	5	Number	Diameter		
Potholes	0	1	2	3	4	5	1	2	3	4	5				
Delamination	0	1	2	3	4	5	1	2	3	4	5				
												Small	Medium	Large	Location
Patching/digouts	0	1	2	3	4	5	1	2	3	4	5				

Ride Quality and Drainage Assessment

	Degree					Influencing Factors							
	Good				Poor	Potholes		Patches		Digouts		Cracks	
Riding quality	1	2	3	4	5	Raveling		Undulation		Utilities		Other	
Surface drainage	1	2	3	4	5								

Drainage	Side drains	1	2	3	4	5	Water from slopes/cuts	1	2	3	4	5
	Culverts	1	2	3	4	5	Seepage/spray from irrigation	1	2	3	4	5

Additional Assessment Factors

Cause of failure requiring patches/digouts:	
Cause of low stiffness areas in FWD/DCP survey:	
Cause of rutting (asphalt or unbound layers):	
% Area surface/top-down distresses:	
% Area deep/bottom-up distresses:	
% Area drainage problems:	
% Area recycling constraints:	

Notes	Photographs
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6 Visual Assessment-Detailed Site Investigation (Rigid)

Project No.:				**Project Description:**									
Route No.:		**Post Mile:**		to		**Date:**			**Assessor:**				
FWD	Y	N	**Coring**	Y	N	**DCP**	Y	N	**GPR**	Y	N	**Samples**	Y	N

Assessment											
Surfacing type:	JPCP		JCPC with DB		JCPC with DBR		CRCP				

	Degree						Extent					Details/location
	Slight					Severe	<5				>80	
Faulting	0	1	2	3	4	5	1	2	3	4	5	
Cracks - transverse	0	1	2	3	4	5	1	2	3	4	5	
Cracks - longitudinal	0	1	2	3	4	5	1	2	3	4	5	
Cracks - corner	0	1	2	3	4	5	1	2	3	4	5	
Cracks - random	0	1	2	3	4	5	1	2	3	4	5	
Shattered slabs	0	1	2	3	4	5	1	2	3	4	5	
Pumping from cracks	0	1	2	3	4	5	1	2	3	4	5	
Pumping from joints	0	1	2	3	4	5	1	2	3	4	5	
Spalling on cracks	0	1	2	3	4	5	1	2	3	4	5	
Spalling on joints	0	1	2	3	4	5	1	2	3	4	5	
Sinking corners	0	1	2	3	4	5	1	2	3	4	5	
Shoulder damage	0	1	2	3	4	5	1	2	3	4	5	
Potholes	0	1	2	3	4	5	1	2	3	4	5	
Undulation/settlement	0	1	2	3	4	5	1	2	3	4	5	
Ruts from chain wear	0	1	2	3	4	5	1	2	3	4	5	
Patching	0	1	2	3	4	5	1	2	3	4	5	
Slabs replaced with CC	Yes		No									
	0	1	2	3	4	5	1	2	3	4	5	
Slabs replaced with AC	Yes		No									
	0	1	2	3	4	5	1	2	3	4	5	

Ride Quality and Drainage Assessment

	Degree					Influencing Factors									
	Good				Poor										
Riding quality	1	2	3	4	5	Faulting		Patching/Digouts		Cracking		Spalling		Undulation	
						Potholes		Chain wear		Utilities					
Surface drainage	1	2	3	4	5										

Drainage	Side drains	1	2	3	4	5	Water from slopes/cuts	1	2	3	4	5
	Culverts	1	2	3	4	5		1	2	3	4	5

Additional Assessment Factors

Cause of faulting:	Doweled?	Y		N		
Cause of failure requiring patches/digouts:						
Cause of low stiffness areas in FWD/DCP survey:						
% Area drainage problems:						

Notes	Photographs
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7	Core Log							
Project No:		**Project Description:**						
Route No.:		**Post Mile:**	to	**Date:**			**Assessor:**	

Core No./ Photo No.	PM/Lane/ Position	Layer Description and Thickness						Observations: (Crack type, crack origin, crack reflection, debonding, fabric, geotextile, SAMI, etc.)
		1	2	3	4	5	6	

Notes:

8 DCP Assessment

Project No:		**Project Description:**								
Route No.:		**Post Mile:**	to	**Date:**		**Assessor:**				
Test No.:		**Post Mile:**			**Test No:**		**Post Mile:**			
Location:	OWP	BWP	IWP	**Lane/Direction:**		**Location:**	OWP	BWP	IWP	**Lane/Direction:**

Reading on surface:		**Reading on surface:**	
Reading on top of layer:		**Reading on top of layer:**	
Reading after seating blow:		**Reading after seating blow:**	

Record penetration in mm after every 5 blows

5	130	255	380	5	130	255	380
10	135	260	385	10	135	260	385
15	140	265	390	15	140	265	390
20	145	270	395	20	145	270	395
25	150	275	400	25	150	275	400
30	155	280	405	30	155	280	405
35	160	285	410	35	160	285	410
40	165	290	415	40	165	290	415
45	170	295	420	45	170	295	420
50	175	300	425	50	175	300	425
55	180	305	430	55	180	305	430
60	185	310	435	60	185	310	435
65	190	315	440	65	190	315	440
70	195	320	445	70	195	320	445
75	200	325	450	75	200	325	450
80	205	330	455	80	205	330	455
85	210	335	460	85	210	335	460
90	215	340	465	90	215	340	465
95	220	345	470	95	220	345	470
100	225	350	475	100	225	350	475
105	230	355	480	105	230	355	480
110	235	360	485	110	235	360	485
115	240	365	490	115	240	365	490
120	245	370	495	120	245	370	495
125	250	375	500	125	250	375	500

Notes

9 Sample Log

Project No:			**Project Description:**				
Route No.:		**Post Mile:**	to		**Date:**		**Assessor:**

Sample No./ Core hole	PM/Lane/ Position	Layer/ Material Type	Sample Type	Sample Depth	Sample Size	Sample Condition	Program of Work

Notes:

10 Test Pit/Trench Assessment (Flexible-Surfaced Pavement Only)

Project No:			**Project Description:**				
Route No.:		**Post Mile:**	to	**Date:**		**Assessor:**	
Pit Number:		**Post Mile:**		**Lane/Direction:**		**Position:**	

Total Layer Thickness

Layers	Present	Type	Average	Thickest	Thinnest	Comments
Asphalt concrete						
Base						
Subbase 1						
Subbase 2						
Other						
Other						

Asphalt Concrete Layers

Observations	Debond?		Fabric?		Geogrid?		Other?	
Notes								

Unbound, Recycled, or Cemented Granular Layers

Problems	Grading?		Oversize?		Plasticity?		Rutting?	
	Moisture?		Pumping?		Mottling?		Other?	
Notes								

Subgrade

Problems	Punching?		Plasticity?		Silt?		Rutting?	
	S/slides?		Moisture?		Mottling?		Other?	
Notes								

Samples

Moisture	AC		Base		Subbase		Subgrade	
Material	AC		Base		Subbase		Subgrade	

Notes	**Photographs**
	1
	2
	3

11 Project Investigation Analysis

Project No:		**Project Description:**					
Route No.:		**Post Mile**	to	**Date:**		**Assessor:**	

Investigation Component		**Observation**					
Design notes	How much change in final surface elevation is allowable up or down (ft.)?						
	Are there critical issues that preclude in-place/on-site recycling?	Yes		No		N/A	
	Is central plant recycling logistically feasible?	Yes		No		N/A	
FWD & DCP	Is subgrade stiffness <M_r = 6,500 psi on more than 10% of the project?	Yes		No		N/A	
	If >10% of project, can weak areas be strengthened as part of project?	Yes		No		N/A	
	Are drainage issues causing subgrade strength issues & can they be corrected?	Yes		No		N/A	
Layer thickness & core inspection	Are distresses top-down only?	Yes		No		N/A	
	Are distresses primarily bottom-up?	Yes		No		N/A	
	Are debonded layers present?	Yes		No		N/A	
	Can design strategies be adjusted to remove debond?	Yes		No		N/A	
	Are distresses confined to the top 0.2 ft. of the asphalt concrete layers?	Yes		No		N/A	
	Are layer thicknesses sufficient for the intended design choice?	Yes		No		N/A	
	Will presence of geosynthetic reinforcing layers or rubber affect design choice?	Yes		No		N/A	
Visual Assessment	Are distresses indicative of subgrade failure (subgrade rutting, pumping, etc.)?	Yes		No		N/A	
	Are patch/digout repairs failing within 12 months (i.e., after wet season)?	Yes		No		N/A	
	Does adjacent l&-use/slope-stability influence performance?	Yes		No		N/A	
	Can l&-use/slope-stability problems be easily corrected?	Yes		No		N/A	
	Are shallow underground utilities evident that might be affected by recycling?	Yes		No		N/A	
	Can utilities be managed, moved, or lowered if needed?	Yes		No		N/A	
Drainage	Is existing drainage adequate & functioning?	Yes		No		N/A	
	Can drainage problems be easily corrected?	Yes		No		N/A	
	Do drainage or material issues preclude any design strategies?	Yes		No		N/A	
FDR	If asphalt concrete thickness >0.85 ft., can it be premilled as part of project?	Yes		No		N/A	
	Does combined material have USCS of GW or GP?	Yes		No		N/A	
	Does combined material have USCS of SC, OL, MH, or CH?	Yes		No		N/A	
	Is unconfined compressive strength (UCS) at ICS + 1% cement >450 psi?	Yes		No		N/A	
Other				Yes		No	

Other notes:

PaveM recommendation appropriate?	Yes		No		Reason	
Project is suited to in-place recycling?	Yes		No		Reason	

APPENDIX B: ADDITIONAL INFORMATION FOR IN-PLACE RECYCLING

B.1 Introduction

This appendix covers the choice of recycling strategy and recycling agent (emulsified asphalt or foamed asphalt) or stabilizer using the information collected during the project investigation. Detailed information on this topic is provided in the Caltrans *Guide for Partial- and Full-Depth Pavement Recycling in California (5)*.

Choosing the correct recycling strategy is important for ensuring good long-term performance of a maintained/rehabilitated pavement. The selection of one recycling strategy or another is based on where the distresses originated and whether increased structural capacity is required as part of the rehabilitation design. A decision about which recycling agent/stabilizer to use is based on the properties of the materials that will be recycled.

Note that cold central plant recycling can be considered on rehabilitation projects that require vertical and/or horizontal alignment changes, given that grade changes can be readily made during milling and repaving phases of the work.

B.2 Selecting a Recycling Strategy

As noted, the decision whether to use a partial- or full-depth recycling strategy is primarily based on the origin of the distresses, and on whether the goal of CAPM/rehabilitation is simply to restore structural capacity or the goal includes making required structural improvements and/or alignment changes. Follow these steps to make an initial decision on which strategy to use:

1. Confirm that drainage problems can be corrected. If they cannot be corrected, accept that reduced performance may result. Note that poor drainage will impact the performance and life of any type of pavement regardless of how it is built, maintained, or rehabilitated, and that recycled pavements are no different. Note that recycled pavements do not require different or "better" drainage than other CAPM/rehabilitation approaches.
2. If structural improvements are not required and distresses are top-down and confined to the asphalt concrete layers only (i.e., there are no deep ruts, no pumping of fines through the cracks, no full-depth patches or digouts, etc.), then partial-depth recycling is an appropriate recycling strategy.
3. If structural improvements are required and/or the distresses are bottom-up and affect the full depth of the asphalt concrete layers and possibly the underlying unbound layers (i.e., deep ruts,

fatigue cracking, pumping of fines through cracks, presence of full-depth patches and digouts, etc.), then either full-depth recycling or a combination of lower-layer/subgrade stabilization and cold central plant recycling of the upper layers will usually be the most appropriate strategy. A combination of partial- or full-depth recycling and thicker asphalt concrete surfacing may also be an option for some projects if grade changes can be accommodated.

4. If the pavement requires horizontal and/or vertical alignment improvements that cannot be accommodated as part of premilling and partial- or full-depth recycling operations, then cold central plant recycling will usually be the most appropriate strategy, with those improvements made during the milling and paving parts of the operation.

If partial-depth recycling (in-place or using material processed in a cold central plant) is selected, follow the steps listed in Section B.2.1.

If full-depth recycling (in-place, using material processed in a cold central plant, or a combination of in-place stabilization and central plant) is selected, follow the steps in Section B.2.2.

B.2.1 Partial-Depth Recycling Considerations

A number of considerations should be addressed before deciding that partial-depth recycling is the most appropriate choice. These are based on the findings of the project investigation and include the following:

- If the top-down distresses are limited to the top 0.2 ft. (60 mm), then a mill-and-overlay or thin-overlay-only strategy may be more cost-effective than in-place recycling and should also be considered.
- If the distresses are top-down and limited to the top 0.4 ft. (125 mm), then partial-depth recycling is appropriate provided that:
  + Any geosynthetic materials (fabric and geogrids) in the asphalt concrete layers will recycle effectively or can be removed during the recycling process before spreading and compaction.
  + RHMA-G and RHMA-O thicknesses do not exceed 25% of the recycle depth (gradation and compaction problems may be experienced with high recycled gap- or open-graded RHMA contents). Actions to reduce the percentage of RHMA in the recycled material (e.g., milling off the RHMA-O layer) or increase the recycle depth to reduce the percentage of RHMA can be taken if required. A decision to include higher percentages of RHMA materials in partial-depth recycled layers can usually only be made after mix design testing has been completed by the contractor.
  + No extended areas of large, loose blocks of distressed asphalt concrete are present (this is not a common problem in California). If they are present, cold central plant recycling can be considered because the milled material can be crushed in an impact crusher prior to mixing. An alternative is to premill the problem layer and then complete the partial-depth recycling

on the remaining material. A multi-unit recycling train with onboard screen and crusher will also be appropriate for this scenario; however, this would be a contractor decision as Caltrans does not specify the type of recycling train that must be used on an in-place recycling project.

  + The remaining asphalt concrete layers below the planned recycle depth are intact with no distresses. It is critical to ensure that thin, distressed, and/or debonded asphalt concrete layers are not left below the recycled layer as this will reduce structural capacity and lead to early distresses in the rehabilitated pavement. Options to address this concern that still use PDR include increasing the recycling depth (maximum of 0.5 ft. [150 mm]) so that all of the old in-place asphalt concrete is recycled, or premilling the top asphalt concrete layer(s) to allow increasing the recycling depth. Alternatively, FDR or cold central plant recycling (CCPR) strategies can be considered.
  + The material below the planned recycle depth can support the recycling train. Intact asphalt concrete thicker than 0.2 ft. (60 mm) or intact, dry Class 2 aggregate base layers thicker than 0.5 ft. (150 mm) will typically have sufficient structural integrity to provide this support. Note that trucks carrying asphalt recycling agent, water, and active filler travel in front of the recycling train on the existing pavement and do not need to be factored into this consideration.
- If the distress depth exceeds 0.4 ft. (125 mm), then options include premilling the top layer(s) and either using the material elsewhere on the project or trucking it off-site, and then completing the partial-depth recycling on the remaining layers. Alternatively, a full-depth or cold central plant recycling strategy can be considered.
- If one or more concerns cannot be cost-effectively addressed, then consider an alternative CAPM or rehabilitation strategy.
- Consideration can be given to changing to a full-depth or cold central plant recycling strategy, where appropriate, to address relevant concerns.

If partial-depth recycling is considered to be an appropriate recycling strategy, confirm the recycling depth, ensuring that it is not in close proximity to an existing debond and that no thin, distressed layers will remain under the recycled layer. Recycling agents for partial-depth recycling include emulsified asphalt and foamed asphalt.

B.2.2 Full-Depth Recycling Considerations

As with partial-depth recycling, a number of considerations will need to be addressed using the findings from the project investigation. These include the following:

- If any geosynthetic materials (fabric and grids) are present, then a determination will need to be made about whether they can be recycled effectively or need to be removed either by premilling or during the recycling process before compaction. If these materials cannot be effectively managed, then an alternative rehabilitation approach may need to be considered.

- If no structural and/or alignment improvements are required and there are no grade-height restrictions, then full-depth recycling (in-place or cold central plant) is appropriate provided that:
  + There is sufficient material to recycle effectively (i.e., 0.65 to 1 ft. [≈200 to 300 mm]) to meet the design requirements. Include a minimum of 0.1 ft. (30 mm) of unbound material in the selected recycle depth to ensure that there are sufficient fines for an optimal gradation and for cooling the recycler milling teeth.
  + There are no large areas of loose asphalt concrete blocks present in one or more of the layers. As noted, this is not a common problem in California; but, if loose blocks are present, the problem layer can be premilled and full-depth recycling can be completed on the remaining material. Alternatively, cold central plant recycling can be used because the milled material can be crushed prior to mixing.
- If no structural and/or alignment improvements are required and there are no grade-height restrictions, but the thickness/structural design requirements cannot be met with the existing materials, then one of the following full-depth recycling (in-place, cold central plant recycling, or a combination of the two) options can be considered:
  + Import, spread, shape, and compact a new layer of material (processed reclaimed asphalt pavement [RAP], Class 2 aggregate base, or a mix of the two) on top of the existing road surface and then recycle the new layers and a portion of the existing layers to the required depth. In this case, the remaining existing base will now be a subbase.
  + Recycle/stabilize the existing materials in-place with a suitable recycling agent/stabilizer to a depth of between 0.8 and 1 ft., and then pave a new layer of aggregate base or cold central plant recycled material with a suitable recycling agent on top of this first recycled layer. The thickness of the single new layer should not exceed 0.5 ft. (150 mm). More than one layer can, however, be considered.
- If structural and/or alignment improvements are required and grade-height restrictions exist, then full-depth recycling using a combination of lower-layer/subgrade stabilization and cold central plant recycling can be considered. In this option, the existing asphalt concrete and underlying quality base materials will be milled off and stockpiled at the nearby cold central plant operation. The remaining roadbed is then stabilized in-place up to a depth of 1 ft. (300 mm) with a suitable additive (e.g., portland cement, lime, or a combination of the two depending on material properties), shaped, and compacted. The milled materials are crushed in an impact crusher while the in-place stabilization is being completed and then processed through the cold central plant with a suitable recycling agent (emulsified or foamed asphalt) before being laid with a paver. Individual lift thicknesses of the cold central plant material should not exceed 0.5 ft. (150 mm).

- If extensive vertical and/or horizontal alignment improvements are required and these cannot be accommodated as part of in-place recycling procedures, then cold central plant recycling can be considered. In this option, alignment changes can be done as part of the milling and paving operations. Individual lift thicknesses of the cold central plant material should not exceed 0.5 ft. (150 mm).

If full-depth recycling is considered to be an appropriate recycling strategy, confirm the process or processes that will be used and the depth(s) that will be processed. Then, choose a recycling agent/stabilizer (foamed asphalt or portland cement [emulsified asphalt is currently not specified by Caltrans for FDR]) following the steps below:

1. If the recycled materials are asphalt concrete and aggregate base (well-graded gravel [GW] or poorly graded gravel [GP], and in some instances silty gravel [GM] in the Unified Soil Classification System [USCS]), then use foamed asphalt (or emulsified asphalt if a specification is available) with an active filler (typically portland cement in California).
2. If the recycled materials comprise a relatively thin asphalt concrete layer over marginal materials (i.e., the combined materials do not classify as well-graded, poorly graded, or silty gravel), then consider using cement stabilization.
3. If portland cement treatment is being considered, review the following using the plasticity index, pH, and UCS test results from the project investigation:
   + If the combined materials have a plasticity index >20 and classify as clayey sand (SC), lean clay (CL), elastic silt (MH), or fat clay (CH), consider using a combination of lower-layer stabilization with cement, lime, or a combination of the two, followed by paving with cold central plant asphalt-treated materials in the upper layer(s).
   + If the UCS determined with the cement content required to achieve a constant pH in the initial consumption of stabilizer test, plus 1%, does not exceed the specified strength limit (the suggested limit is 450 psi [3.1 MPa]), then use portland cement.
   + If the UCS determined with the cement content required to achieve a constant pH in the initial consumption of stabilizer test, plus 1%, exceeds the specified strength limit, then review the full-depth recycling strategy. Options include the following:
     - Adding supplemental materials to improve the properties so that an asphalt recycling agent can be used.
     - Using a combination of lower-layer stabilization with cement, lime, or a combination of the two, followed by paving with cold central plant materials treated with foamed asphalt (or emulsified asphalt if a specification is available) in the upper layer(s).
     - Note that this guide does not recommend increasing the recycling depth to incorporate more marginal-quality subgrade materials into the mix to meet pH and UCS requirements for portland cement stabilization.

- If any supplemental materials include crushed recycled concrete, then consider foamed asphalt (or emulsified asphalt if a specification is available) with an active filler. Note that crushed cement concrete can contain considerable amounts of unhydrated or partially hydrated cement that can rehydrate during watering and compaction, resulting in a recycled layer that could exceed UCS limits and behave as a semi-rigid pavement rather than a flexible pavement.

Table B.1 summarizes the likely choices of full-depth recycling agent/stabilizer in terms of the ASTM Unified Soil Classification System (ASTM D2487) and the AASHTO Soils and Soil-Aggregate Mixture Classification System (AASHTO M 145).

Table B.1: Example Full-Depth Recycling Agent/Stabilizer Choice for Different Materials

Parent Material Type to be included in Full-depth Recycling Layer	Material Description	Classification		Foamed Asphalt P_{200} = 5 – 15[2] PI < 6[3]	Emulsified[a] Asphalt P_{200} = 5 – 15 PI < 6	Portland Cement P_{200} >20 PI < 20 SO_4 < 3,000 ppm[4]	Lime[b] P_{200} >25 PI > 20 SO_4 < 3,000 ppm
		USCS[1]	AASHTO				
AC plus Good Base	Well-Graded Gravel	GW	A-1-a	■■■	■■■	■	
	Poorly Graded Gravel	GP	A-1-a	■■■	■■■	■	
AC plus Marginal Base	Silty Gravel	GM	A-1-b	■■■	■■■	■■■	
	Clayey Gravel	GC	A-1-b A-2-6	■	■	■■■	
Subgrade	Well-Graded Sand	SW	A-1-b	■	■	■■■	
	Poorly Graded Sand	SP	A-3 or A-1-b	■	■	■■■	
	Silty Sand	SM	A-2-4 or A-2-5	■	■	■■■	
	Clayey Sand	SC	A-2-6 or A-2-7			■■■	■■■
	Silt or Silt with Sand	ML	A-4 or A-5			■■■	
	Lean Clay	CL	A-6			■■■	■■■
	Organic Silt/ Organic Lean Clay	OL	A-4				
	Elastic Silt	MH	A-5 or A-7-5				■■■
	Fat Clay, Fat Clay With Sand	CH	A-7-6				■■■

[1] USCS = Unified Soil Classification System [2] P_{200} = Percent passing #200 sieve [3] PI = Plasticity Index [4] SO_4 = Sulfate

[a] Emulsified asphalt is currently not specified by Caltrans for FDR projects.

[b] Lime is currently not specified by Caltrans for FDR projects. Note that FDR on high plasticity materials (PI>20) is not recommended. Cold central plant recycling in combination with lower-layer stabilization can be considered as an alternative.

■■■	Appropriate if meets specifications or guidance-recommended minimum and maximum limits.
■	Usually not appropriate due to not meeting specifications or guidance-recommended minimum and maximum limits.
	Generally not appropriate and unlikely to meet specifications or guidance recommendations, or will not be economical.

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APPENDIX C: ESTIMATION OF SUBGRADE STIFFNESS

C.1 Introduction

Soil classification and dynamic cone penetrometer (DCP) data can be used to estimate the stiffnesses of unbound soils layers using correlations from the literature. The stiffnesses in Table 4.1 are based on a recent comprehensive review of the literature relating soil classification, DCP, and empirical soils tests (California Bearing Ratio [CBR] and R-value) to resilient modulus (M_r) laboratory testing and field-determined stiffnesses for unbound subgrade soils.

CalME relies on having representative modulus values for the foundation layers in the pavement structure. In an existing pavement, these can be determined from deflection testing; but in new construction, or on projects where deflection testing is not carried out, they need to be estimated. Caltrans has traditionally used R-value to characterize subgrade materials, but this and other tests such as CBR and triaxial resilient modulus require field sampling at multiple locations and laboratory testing to determine sections with uniform subgrade properties. This sampling and testing make the exercise expensive and time consuming.

C.2 Estimation of Unbound Layers Stiffness Using DCP Data

The DCP has been used worldwide since the 1950s as a tool for determining the strength of the top ≈3 ft. (≈1 m) of the unbound granular layers in pavements, and it was introduced in California in 2000. The DCP (Figure C.1) consists of a hammer with a known weight and drop height to drive a cone through the soil, while measuring the depth of penetration after each blow.

The penetration rate can be used to determine a strength profile with depth and is well correlated with the CBR, resilient modulus, unconfined compressive strength, and shear strength of the materials. In the United States, the most common parameter used from DCP tests is the DCP Penetration Index (DPI), which is usually reported in mm/blow.

Because R-value is not used extensively outside California and the DCP has not been widely used within California, there are no correlation studies between R-value and DPI. However, several studies have correlated R-value to modulus, and modulus is a required parameter used in *CalME.*

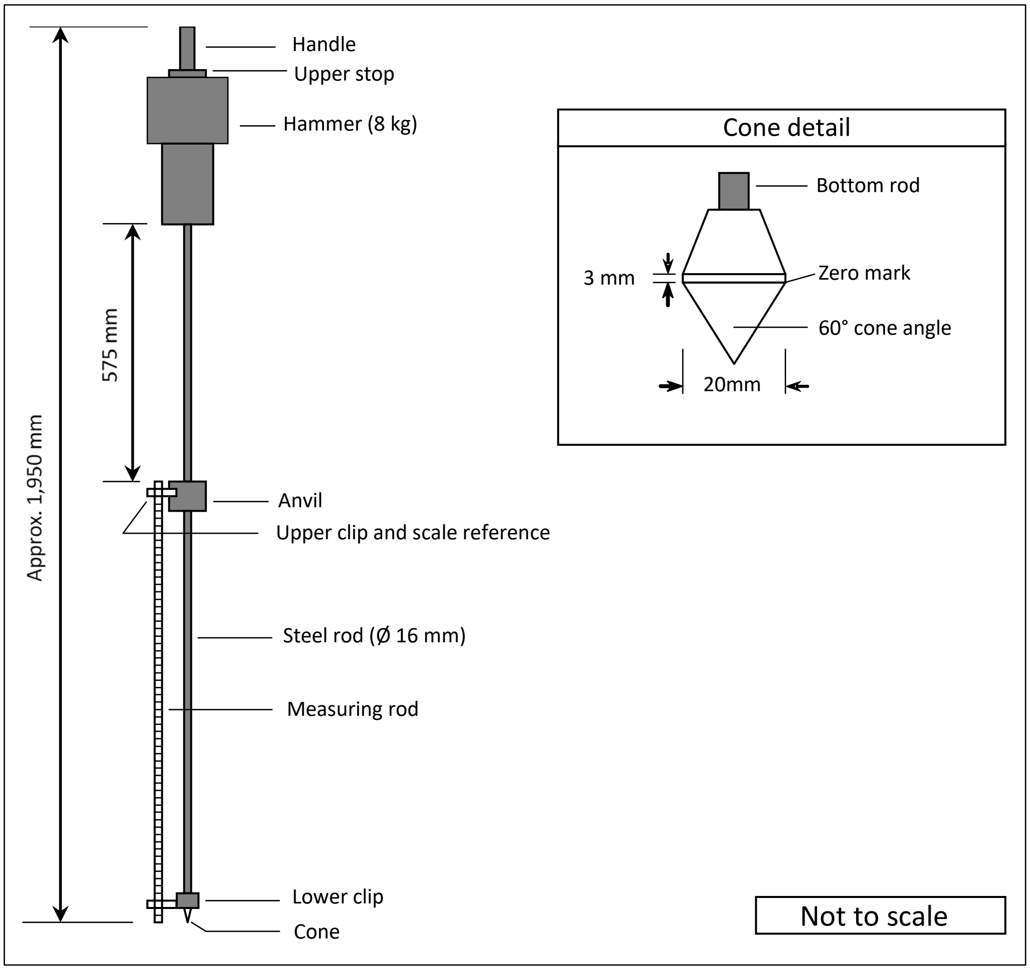

Figure C.1: Dynamic cone penetrometer (DCP) schematic.

Published correlations between various measured properties (e.g., DPI, resilient modulus, unsoaked and soaked CBR, and R-value) can be used to establish estimated subgrade modulus values for use in *CalME*. However, there are many such published correlations from materials all over the world, including the example of separate equations for high and low plasticity clay from the Army Corps of Engineers shown in ASTM D6951. However, it is not clear which is the most appropriate for California. As a result, a meta-analysis of these correlations was undertaken by the UCPRC in 2020. In a meta-analysis, the equations (which represent the median result for each study) are used as if they represent data to obtain a best fit from all the published relationships. In addition, because there are five different properties that are commonly correlated (DPI, resilient modulus, unsoaked and soaked CBR, and R-value) the meta-analysis can simultaneously fit all published pairs of correlations, which is more robust than chaining conversions (e.g., from DPI to CBR and then to resilient modulus). The following equation relates resilient modulus (M_r, soil stiffness measured using a triaxial testing device with a repeated load), often more generically referred to as stiffness (*E*), to DPI based on the meta-analysis. The meta-analysis results relating resilient modulus to unsaturated CBR (CBR_u), saturated CBR (CBR_s), and R-value (*R*) are shown in Equation C.1, Equation C.2, and Equation C.3, respectively. The metadata for these three equations are applicable to nearly all soil types (i.e., CBR values >2 and R-values >6). Since resilient modulus is the desired variable, use Equation C.4 to convert DPI to resilient modulus or stiffness.

Resilient modulus or stiffness in ksi:

$$\log_{10}\left(M_r \; or \; E \; in \; ksi\right) = 0.266 + 0.726\log_{10}\left(CBR_u\right) \quad \textbf{C.1}$$

$$\log_{10}\left(M_r \; or \; E \; in \; ksi\right) = 0.242 + 0.861\log_{10}\left(CBR_s\right) \quad \textbf{C.2}$$

$$M_r \; or \; E \; in \; ksi = 1.12 + 0.55R \quad \textbf{C.3}$$

$$\log_{10}\left(M_r \; or \; E \; in \; ksi\right) = 1.884 - 0.730\log_{10}\left(DPI \; in \; mm\right) \quad \textbf{C.4}$$

Resilient modulus or stiffness in MPa:

$$\log_{10}\left(M_r \; or \; E \; in \; MPa\right) = 1.105 + 0.726\log_{10}\left(CBR_u\right) \quad \textbf{C.1}$$

$$\log_{10}\left(M_r \; or \; E \; in \; MPa\right) = 1.081 + 0.861\log_{10}\left(CBR_s\right) \quad \textbf{C.2}$$

$$M_r \; or \; E \; in \; MPa = 7.7 + 3.8R \quad \textbf{C.3}$$

$$\log_{10}\left(M_r \; or \; E \; in \; MPa\right) = 2.722 - 0.730\log_{10}\left(DPI \; in \; mm\right) \quad \textbf{C.4}$$

Equation C.4 is applicable to all unbound soils layers—including aggregate bases, subbases, and subgrades—provided that the maximum stone sizes are not so large that they bias the DCP results (maximum size approximately 1.5 in. [38 mm]).

The review of the literature to develop an updated equation for predicting resilient modulus from DCP data also included the literature relating Unified Soil Classification System (USCS) results to resilient modulus of subgrade soils. The results of the literature review were used in Table 4.1. A graphical summary of the relationships between subgrade soils resilient modulus or stiffness (elastic modulus [*E*]) and soil classifications and empirical soils tests (CBR, DPI, and R-value) is shown in Figure C.2. The USCS and AASHTO soil classification to resilient modulus estimations were sourced from the Mechanistic-Empirical Pavement Design Guide (MEPDG) report from NCHRP Project 1-37A (2004) (http://onlinepubs.trb.org/onlinepubs/archive/mepdg/guide.htm).

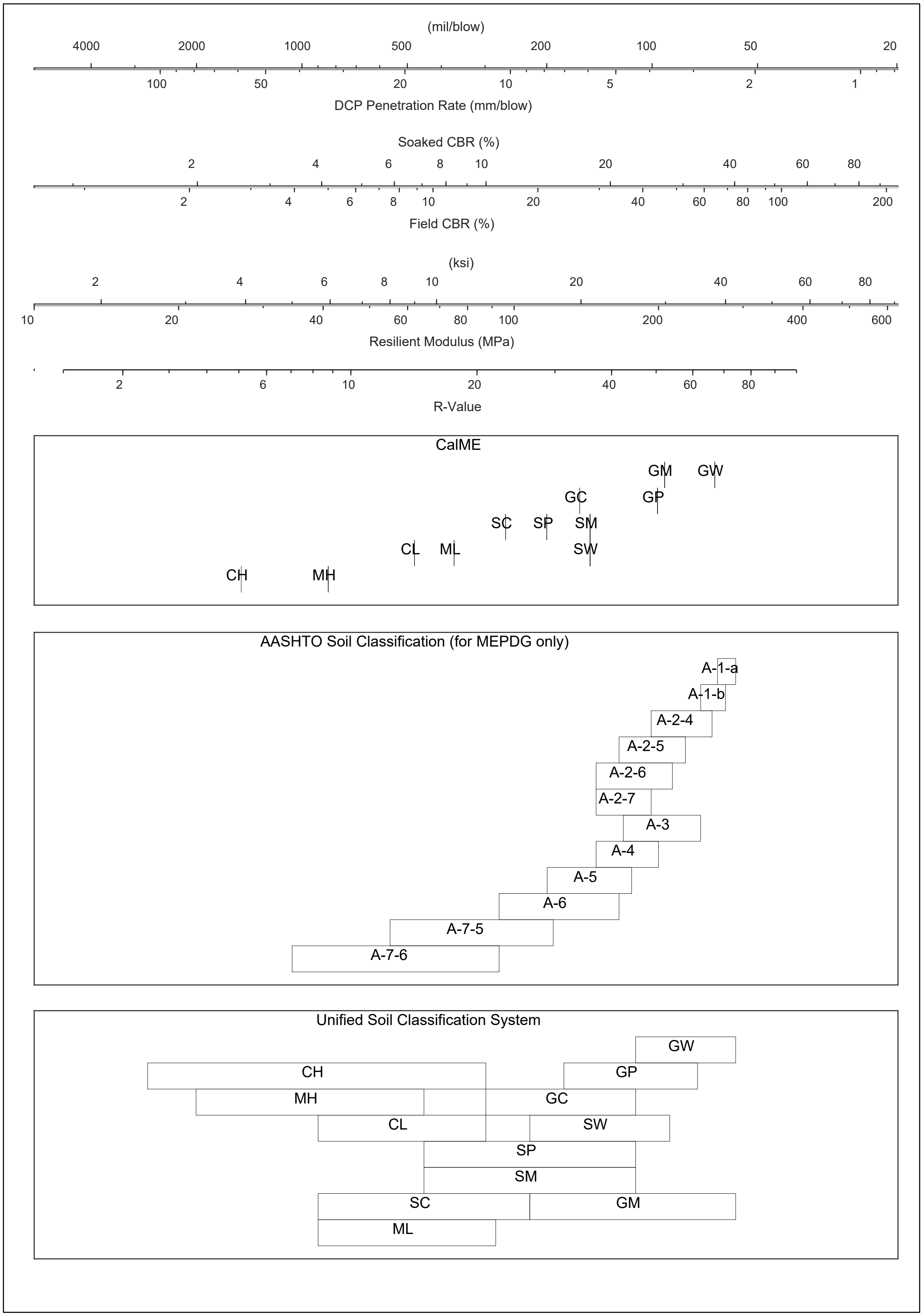

Figure C.2: Plot of relationships between subgrade resilient modulus and other test results.

(Note: the width of the box on the bottom of the nomograph indicates the range of stiffnesses when projected up to the resilient modulus values).