Evaluation of the SHRP2 Pavement Renewal Solutions (R-23) Scoping Tool *rePave* and Implementation Recommendations

Round 3 SHRP 2 Implementation Assistance Program

Imad Basheer, Ph.D., P.E.
Pavement Program, Division of Maintenance
Caltrans

April 3, 2017

Caltrans
U.S. Department of Transportation
Federal Highway Administration
SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

Evaluation of the SHRP2 Pavement Renewal Solutions (R-23) Scoping Tool *rePave* and Implementation Recommendations

Imad Basheer, Ph.D., P.E.
Pavement Program
Caltrans

ACKNOWLEDGMENT

This work was sponsored by the Federal Highway Administration (FHWA) in cooperation with the American Association of State Highway and Transportation Officials (AASHTO). It was conducted in the second Strategic Highway Research Program (SHRP 2), which is administered by the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine. The funding received by the Pavement Program of the California Department of Transportation (Caltrans) from the FHWA for evaluating the Pavement Renewal Solutions and investigating implementation potential is greatly appreciated. The engineering evaluation was conducted and report written by Imad Basheer, Ph.D., PE of the Pavement Program at Caltrans.

The author would also like to thank Newton Jackson, Principal Engineer at Nichols Consulting Engineers (NCE) and one of the *rePave* Development Team members for providing technical assistance and valuable suggestions on the use of *rePave*. Also, the continued support of FHWA engineers Stephen Cooper, Ken Jacoby, Tom Deddens, and Steve Healow during the study is acknowledged and greatly appreciated.

TABLE OF CONTENTS

Evaluation of the SHRP2 Pavement Renewal Solutions (R-23) Scoping Tool *rePave* and Implementation Recommendations

Imad Basheer, Ph.D., P.E.
Pavement Program
Division of Maintenance
Caltrans

1 INTRODUCTION

1.1 INTRODUCTION

This report documents the results of Caltrans' evaluation of one key product of the second Strategic Highway Research Program (SHRP 2) Pavement Renewal Solutions (R23) named *rePave*[1]. The *rePave* tool is used for scoping of pavement rehabilitation designs intended to provide long life performance. It is a web-based user-friendly interactive tool that intuitively guides the users through decision matrices and provides easy and organized access to all of the resource documentation. The SHRP 2 "Pavement Renewal Solutions R 23"[2] task emphasizes using existing pavement in-place and achieving long life. In order to achieve this goal, the R23 investigated and developed ways to shorten project delivery, minimize disruption to the traveling public, and reduce project costs while focusing on utilizing the existing pavement in-place. Upon completing the evaluation of *rePave*, Caltrans will decide whether to adopt and this tool for use throughout the State to help Caltrans engineers expand their suite of pavement rehabilitation scoping tools and guidelines as well as rehabilitation strategies to meet the demands of maintaining a sustainable transportation network.

The California Department of Transportation (Caltrans) was one of nine agencies which received funding through the SHRP 2 Implementation Assistance Program (IAP)[3], Round 3[4], to utilize in the evaluation and possibly incorporation of R23 Pavement Renewal Solutions Technology into the long life pavement rehabilitation process and the suite of scoping tools and guidance available for use by engineers at the early phases of the projects. The SHRP 2 IAP is administered by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO). The primary objective of the implementation plan developed by the FHWA and AASHTO is to support state adoption and use of the Pavement Renewal Solutions product. For the individual state transportation agencies, this support is provided in the form of outreach, technical assistance, and training. The nine agencies that received implementation assistance funding are Arizona, California, Kentucky, Minnesota, Louisiana, North Dakota, New Jersey, New York, and Utah. Four of these agencies (Arizona, California, Kentucky and Minnesota) received funding for "Lead Adopter", and the remaining five states as "User Incentive" agencies.

In this report, and as part of the evaluation plan, a number of design examples (case studies) for actual long-life (30+ years) pavement design projects in four geographical areas of the state of California (north, south coastal, south desert, and central) will be analyzed and compared with

---

[1] http://www.pavementrenewal.org/

[2] http://www.fhwa.dot.gov/goshrp2/Solutions/Renewal/R23/Pavement_Renewal_Solutions

[3] http://www.fhwa.dot.gov/goshrp2/implementationassistance

[4] http://www.fhwa.dot.gov/goshrp2/implementationassistance#round3

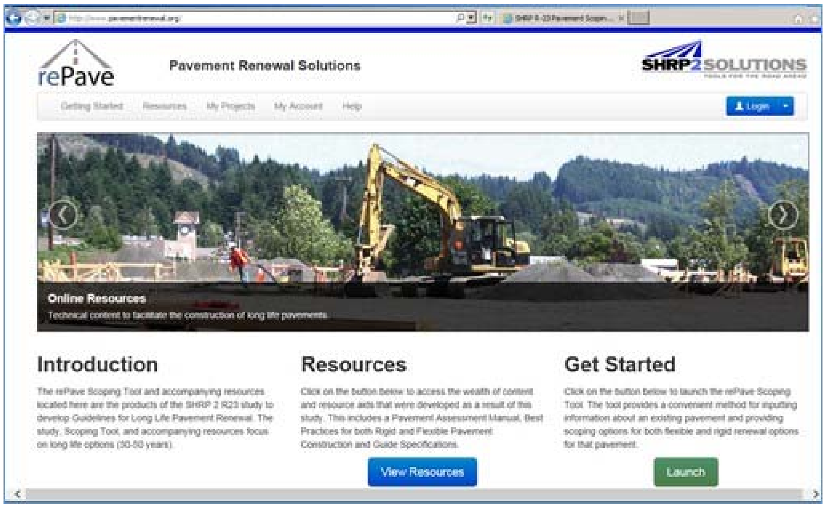
both final designs and preliminary scoping designs that would have been produced at early stage of these projects using the current California Department of Transportation scoping tools. In total there are 5 projects studied. Out of these five, four were constructed and the fifth is currently being constructed as of this month (March 2017). The general location of the projects are as follow: two in Northern California, one in Central California, one in Southern California (coastal climate), and one in Southern California (desert climate). The evaluation also included conducting numerous runs with the current Caltrans scoping tools and available pavement design software. The results of the evaluations were compared with results obtained from the *rePave* scoping tool.

Before presenting the detailed information on the evaluation efforts conducted for these case studies, as well as discussion of the obtained results, a brief discussion of the *rePave* tool is provided in the next sections.

1.2 PREVIEW OF REPAVE

The web-based *rePave* tool was developed to assist pavement designers and project engineers in selecting long-life pavement rehabilitation strategies for scoping of long-life projects based on the project existing distress conditions and other related project constraints and design information. The *rePave* scoping tool provides strategies for existing flexible, rigid, and composite pavement structures. The *rePave* tool was calibrated to provide rehabilitation strategies that have service lives in the range of 30 to 50 years. The main focus of the rehabilitation strategies proposed by the *rePave* tool is on using the pavement in-place.

The opening webpage of the interactive web-based long-life pavement design scoping tool *rePave* is shown in Figure 1-1. The *rePave* scoping tool can be found on the internet at http://www.pavementrenewal.org/. The *rePave* tool is available at this site along with a number of important resources that are beneficial for the design and project engineers. These resources include specifications, pavement assessment manual, life cycle costs, scoping methodologies, and other published reports that were used in the development of this tool.



Online Resources

Technical content to facilitate the construction of long life pavements.

Introduction

The rePave Scoping Tool and accompanying resources located here are the products of the SHRP 2 R23 study to develop Guidelines for Long Life Pavement Renewal. The study, Scoping Tool, and accompanying resources focus on long life options (30-50 years).

Resources

Click on the button below to access the wealth of content and resource aids that were developed as a result of this study. This includes a Pavement Assessment Manual, Best Practices for both Rigid and Flexible Pavement Construction and Guide Specifications.

Get Started

Click on the button below to launch the rePave Scoping Tool. The tool provides a convenient method for inputting information about an existing pavement and providing scoping options for both flexible and rigid renewal options for that pavement.

Figure 1-1. The *rePave* web-based scoping program.

The development of the renewal solution tool *rePave* was driven by the highway agencies' need of guidance as to when (i.e., under what conditions) and where (i.e., which project) it is "beneficial" to use the existing pavement as part of roadway renewal project to accelerate rehabilitation project delivery while reducing total initial and reoccurring costs based on providing long-life treatment strategies. The rehabilitation strategies offered by the scoping tool include use of traditional materials such as hot mix asphalt (HMA) and Portland cement concrete (PCC), in addition to other non-traditional innovative materials. Numerous benefits can be realized with long-life rehabilitation when using the pavement in-place. These include:

1. Decreased use of new pavement materials; thus reducing the environmental footprint,
2. Reduced cost due to eliminating the need for hauling new materials into the project site and transporting away and dumping removed material,
3. Shorter construction time which enhances safety by reducing exposure to work zone hazards of both motorists and construction workers, and
4. Better return on investment (cost effectiveness) due to longer pavement service life.

It is to be noted that while it is possible that using the existing pavement in rehabilitation is not always a viable solution, guidance is always necessary to assist pavement and project engineers analyze their projects or identify candidate projects where this technique can be beneficial.

The *rePave* scoping tool was developed from a huge database that was assembled based on extensive survey of a large number of in-service pavement performance records and hundreds of mechanistic-empirical pavement design simulations. The performance records were gathered by review of the literature of in-service pavements within the US and other countries around the world. The FHWA long term pavement performance (LTPP) database was also analyzed for treatment strategies and performance. Where the LTTP data was not available for specific conditions, numerous simulations using the NCHRP 1-37A Mechanistic-Empirical Pavement Design Guide (MEPDG)[5] software were performed to estimate pavement service life for a range of LTTP sites. Finally, extensive analysis and queries of the developed database resulted in the creation of 20 decision tables (matrices) representing nearly every possible condition of an existing pavement. Also, an additional set of 5 tables were developed to set the order in which these matrices must be used. There are also 12 separate rules that connect the decision tables to the design tables. A sample of decision tables is shown in Figure 1-2.

In order to facilitate the navigation through the large amount of information offered by the decision matrices, an interactive web-based and user-friendly program *rePave* was developed (shown previously in Figure 1-1).

---

[5] http://onlinepubs.trb.org/onlinepubs/archive/mepdg/home.htm

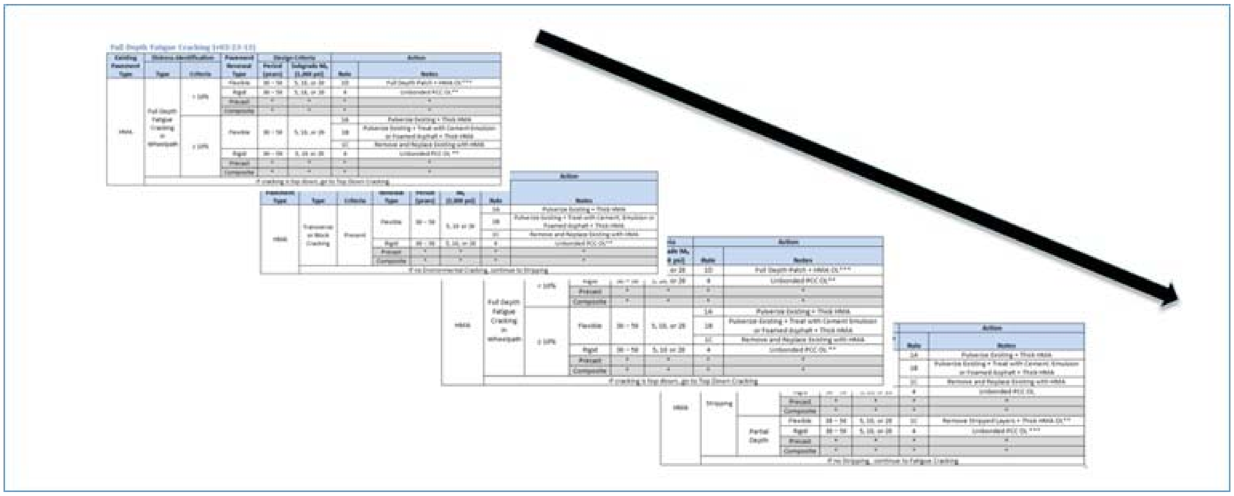


Figure 1-2. An example of successive use of decision tables.

The long-life rehabilitation strategies that were found to be <u>effective</u> for 30-50 years of service were as follows:

1. Unbonded PCC overlays of flexible pavements,
2. Unbonded PCC overlays of rigid pavements,
3. Bonded continuously reinforced concrete pavement (CRCP) overlay of CRCP,
4. HMA overlays of rigid pavements which includes the following options:
    a. with rubblization of PCC pavement,
    b. with crack and seat of JPCP, and
    c. with saw crack and seating of JPCP, and finally
5. HMA overlays of flexible pavements (provided that all stripping, fatigue cracking, and thermal cracking have been addressed).

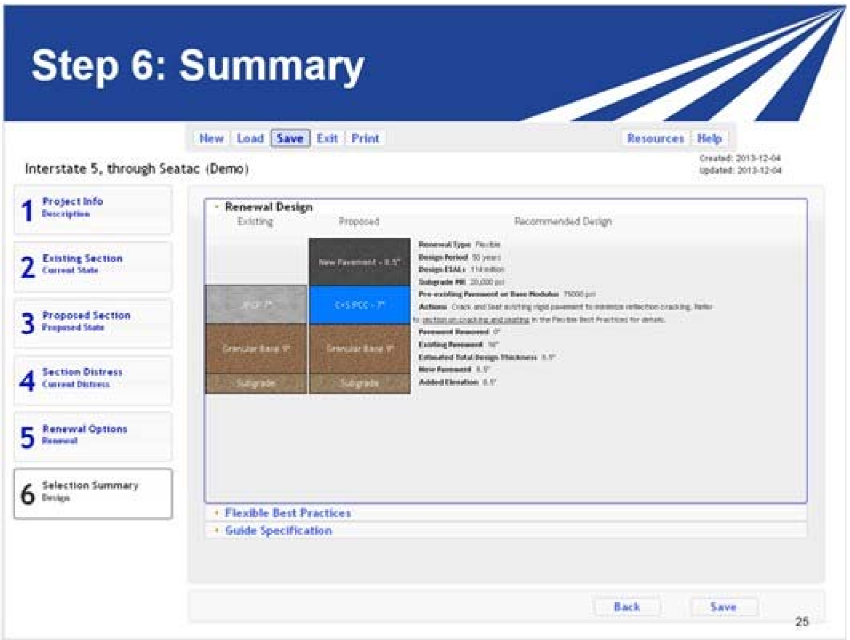
1.3 REPAVE DESIGN STEPS

The web-based *rePave* scoping tool is efficiently designed to walk the user through the decision making process in a series of six steps:

- **Step 1**: Project information such as project name, route number and location, and project description.
- **Step 2**: Existing section which lists the structure information (material types and thicknesses) of the existing pavement.
- **Step 3**: Future section which requires inputs such as design period of the intended rehabilitation, subgrade resilient modulus, projected ESALs for the design period, traffic growth rate, current AADT, number of through lanes, and final grade restrictions.
- **Step 4**: Existing distress in which the all surface distresses of the existing pavement must be entered.

- **Step 5**: Renewal options which allows the user to review all the options that are available based on entered project data and information.
- **Step 6**: Summary, which shows a schematic of the existing section and the selected option that was selected by the user from the list of renewal options provided in Step 5.

Figure 1-3 shows the summary page of a given example.



Renewal Type: Flexible
Design Period: 50 years
Design ESALs: 114 million
Subgrade MR: 20,000 psi
Pre-existing Pavement or Base Modulus: 75000 psi
Actions: Crack and Seat existing rigid pavement to minimize reflection cracking. Refer to section on cracking and seating in the Flexible Best Practices for details.
Pavement Removed: 0"
Existing Pavement: 16"
Estimated Total Design Thickness: 8.5"
New Pavement: 8.5"
Added Elevation: 8.5"

Figure 1-3. Step 6 of the design process encoded in *rePave*.

It is emphasized that the *rePave* tool was exclusively developed for project scoping (programming) purposes and not for developing final designs for the project. In such cases, an alternative project-specific tool capable of producing final long-life designs must be adopted and used. The Caltrans' pavement design and analysis software suite includes some advanced long-life pavement design tools that can be used for developing final designs. These tools will be presented in a later section of this report.

Besides preliminary design for scoping purposes, the pavement renewal system developed under SHRP 2 also offers additional helpful resources aimed at providing guidance to project engineers necessary for the successful completion of their long life projects. These include four detailed manuals and guides; namely:

1. Project Assessment Manual,
2. Guide Specifications,
3. Best Practice-Rigid, and
4. Best Practice-Flexible.

These manuals and guides are available at http://www.pavementrenewal.org/.

2 CALTRANS SCOPING TOOLS

2.1 CURRENT CALTRANS SCOPING TOOLS AND GUIDES

A number of Caltrans design documents and tools offer the Engineer means and guidance for the early programming (scoping) of their pavement projects. These resources include the Caltrans' Highway Design Manual (HDM)[6], technical guides, Design Information Bulletin (DIB)[7], and relevant computer pavement design programs[8]. Whereas the majority of these resources offer the project engineers only conventional design lives (i.e., up to 20 years), some of these resources can be used to scope pavement projects for longer design lives (e.g., 30 and 40 years). Since the emphasis of this evaluation is on pavement life exceeding 30 years, this chapter will discuss available tools that can enable pavement engineers to scope their long-life projects. In the following sections, the tools that are currently available to Caltrans engineers for scoping their long life projects are presented and discussed in some detail. In California, long life design is defined as any design life providing at least 30 years of acceptable service; but typically long life projects have been designed for a design life of either 30 or 40 years. In recent Caltrans long-life projects (to be discussed in later chapters of this report), the design life was selected to be 40 years.

The discussion of the Caltrans scoping tools is divided based on existing pavement surface type; namely flexible and rigid. The Caltrans HDM defines a composite pavement as one with asphalt concrete structural layer placed over Portland cement concrete structural layer. One example of this pavement type results from the placement of HMA overlay over cracked and seated jointed plain concrete pavement (JPCP). Additionally, because the emphasis of SHRP2/R23 project is on using the pavement in-place, all scoping concerned in this report is for rehabilitation of existing pavements, not for constructing a new pavement (e.g., for a new alignment or a new lane addition). Note that sometimes the severe distress condition for an existing pavement may warrant reconstruction as the only practical method for pavement improvement. In such case, scoping for a "new construction" design using applicable standard tools will be needed. This will be outside the scope of this study as SHRP 2 emphasizes on using the pavement in place to achieve longer life. In practice, it may be unlikely for interstate and highway pavements (or only in rare circumstances) to be left to deteriorate to condition requiring complete reconstruction from the subgrade up, including base replacement.

2.2 LONG-LIFE PROJECTS

In California, roadway new construction and reconstruction projects must be designed for a either 20 years or 40 years (Table 612.2 HDM). Similarly, roadway rehabilitation projects must be designed for a minimum of 20 years (Topic 612.5 HDM). Roadways with existing rigid pavements

---

[6] http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm

[7] http://www.dot.ca.gov/hq/oppd/dib/dibprg.htm

[8] http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/Software.html

or with current annual average daily traffic (AADT) of at least 15,000 vehicles, the design life must be selected as either 20 or 40 years depending on which life produces the lowest life-cycle costs (Topic 612.5 HDM). Even with AADT less than 15,000 and at discretion of the District a 40-year pavement design life may be selected (Topic 612.5 Roadway Rehabilitation, HDM)[9]. Note that the initial cost of a long-life asphalt pavement (30-40 years) may be 10-25% higher than a conventional (20 years) pavement; depending on specific design aspects of the project. Whereas the initial cost is higher, the life-cycle cost of the long-life asphalt pavement usually tends to be significantly lower. For this reason, many states are investing in constructing long-life asphalt pavements[10] on their state highway and interstate system including Arkansas, California, Colorado, Delaware, Illinois, Kentucky, Michigan, Minnesota, Mississippi, Ohio, Oregon, Texas, Washington State, and Wisconsin.[11]

2.3 SCOPING REHABILITATION FOR ASPHALT-SURFACED PAVEMENTS

Caltrans manages a total of ~50,000 lane miles of state highway system; of which ~37,000 lane miles (~74%) are asphalt concrete-surfaced pavement and the remaining ~13,000 lane miles (26%) Portland cement concrete-surfaced pavements[12].

For a project involving existing asphalt-surfaced pavements, there is a variety of distress conditions and planned improvements that are applicable. Project scoping with currently available Caltrans tools may be performed using a variety of ways. The selection of one scoping method over another is often dictated by the distress conditions; but it can be for other reasons including surface type of adjacent lanes, district preferences and experience, future plans for the project site, final surface type desired, etc. When more than one treatment is applicable (example asphalt surfacing versus concrete surfacing of an existing asphalt pavement), and no other restrictions that hold the engineer from using one particular treatment for their project over the others, then life-cycle cost analysis (LCCA)[13] must be performed to decide on the treatment type that must be pursued by the district.

For a given <u>asphalt-surfaced pavement</u> project, the following scenarios may be applicable:

1. If existing surface distress condition is "acceptable" and distresses are believed to be confined to the surface course, then a "basic" overlay is reasonable. This overlay can be designed as either:
    a. 40-year Portland cement concrete (PCC) overlay, or

---

[9] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0610.pdf

[10] Called perpetual asphalt pavement in other states.

[11] Advanced High-Performance Materials for Highway Applications: a Report on the State of Technology. https://www.fhwa.dot.gov/pavement/materials/pubs/hif10002/hif10002.pdf)

[12] http://www.dot.ca.gov/hq/maint/Pavement/Pavement_Program/PDF/2013_SOP_FINAL-Dec_2013-1-24-13.pdf

[13] http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html

   b. 40-year HMA overlay.
2. If existing surface distress is "unacceptable" and indicative of insufficient structural support of one or more underlayers (including subgrade), then the following is normally considered:
   a. Existing surface layer and possibly base and/or subbase layers are removed and replaced with base and subbase layers and topped with a PCC layer (including addressing subgrade condition if necessary), or
   b. Existing surface layer and possibly base and/or subbase layers are removed and replaced with base and subbase layers and topped with HMA layer (including addressing the subgrade if needed). The base layer can also be replaced with an HMA layer.

The base layer is selected and its thickness designed based on HDM guidelines. The base types available include HMA base (HMAB), lean concrete base (LCB), cement treated base (CTB), asphalt treated base (ATB), cement treated permeable base (CTPB), asphalt treated permeable base (ATPB), granular base (AB)[14]. The subbase types include aggregate subbase (AS), lime stabilized soil (LSS), and cement stabilized soil (CSS).

According to HDM[15], composite pavements are either "asphalt over concrete composite pavements" or "concrete over asphalt composite pavements". Therefore, the first type of California composite pavements belong to the "asphalt-surfaced pavements" category. For these composite pavements, if the surface distress condition is extremely severe, the asphalt concrete overlay and possibly the PCC layer may need to be removed and replaced with either asphalt layer or concrete layer, or combination of HMA base and a PCC surface layer. The PCC layer could be either a JPCP or CRCP.

Scoping design of the various possibilities is currently performed in California as discussed in the following two sub-sections (applied to both flexible and composite pavements).

2.3.1 Scoping a 40-year Portland Cement Concrete Overlay

For this treatment option, the existing asphalt pavement layer is treated as an asphalt (HMA) base+ of a new 40-year rigid pavement (commonly JPCP). Table 623.1 (B to M)[16] of the Caltrans Highway Design Manual (HDM) can be used to determine the thickness of the required concrete overlay (also called whitetopping or unbonded concrete overlay) by considering a concrete pavement structure with a flexible HMA base. Figure 2-1 shows a sample of the available 12

---

[14] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0660.pdf

[15] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0640.pdf

[16] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0620.pdf

design tables that vary by climate region[17] and soil type[18]. The design section (JPCP or CRCP) is selected based on climate, traffic index (TI) for the 40-year design life[19], soil type, and lateral support[20]. For example, one of the sections that has an asphalt base may be used as the design thickness of the concrete overlay (JPCP or CRCP type). Because the existing pavement may or may not have an aggregate base or subbase layers, the engineer must select from the HDM design Catalog (Table 623.1) one or more structurally adequate sections that are suitable for the existing pavement structure. The minimum thickness of the unbonded concrete overlay (JPCP or CRCP types) is 0.70 ft and the minimum thickness of the HMA bond breaker is 0.1 ft. Note that all the JPCP structures given in Table 623.1 are doweled. Considerations to distress condition of existing asphalt layer and structural capacity and condition of existing sub-layers must be kept in mind in selecting the most appropriate concrete overlay thickness. The distress condition of the existing asphalt concrete layer must be such that it will be suitable to receive a PCC layer. Also, it is often difficult to evaluate the structural equivalency between distressed asphalt concrete layer of a given thickness and the design thickness of a new HMA as given in the catalog. Therefore, caution must be taken when using the catalog tables for estimating the required thickness of the concrete overlay.

In the case where the existing HMA surface structural layer and base must be removed, then the choices for the engineer are either a flexible pavement or a rigid pavement structure. In the case of rigid pavement structure, the HDM catalog is used to select the layers thicknesses (based on climate, soil type, lateral support condition, traffic index, and the type and strength of existing subbase if present). A different base material than the one that was removed may also be selected depending on the choices available in the HDM concrete catalog. It is possible that the existing profile grade elevation will be altered due to using different materials and thicknesses, therefore, adjustments to the structural section will be necessary if the existing profile grade must be maintained. Finally, when a flexible pavement structure has been selected, the scoping method for flexible pavement design is discussed in the next paragraphs. When both flexible and rigid pavements can be used on the project, life-cycle cost analysis (LCCA) must be performed (per HDM recommendations) to select the most cost-effective renewal solution for the project.

---

[17] There are nine distinguished climates in California: North Coast, Central Coat, South Coast, Inland Valley, Desert, Low-Mountain, South Mountain, High Mountain, and High Desert.

[18] Three types of soils are used in the catalog: Type I (SC, SP, SM, SW, GC, GP, GM, GW), Type II (CH with PI < 12, CL, MH, ML), and Type III (CH with PI >12) where OI is the Plasticity Index of the subgrade soil.

[19] Traffic Index (TI) is calculated from the formula$TI = 9.0 \times \left(\frac{ESAL \times LDF}{1{,}000{,}000}\right)^{0.119}$, where ESAL is total number of cumulative 18-kip equivalent single axle load repetitions during the entire design life and LDF is the lane distribution factor.

[20] The pavement is considered laterally supported if it is tied to an adjacent lane, has tied rigid shoulders, or has a widened slab.

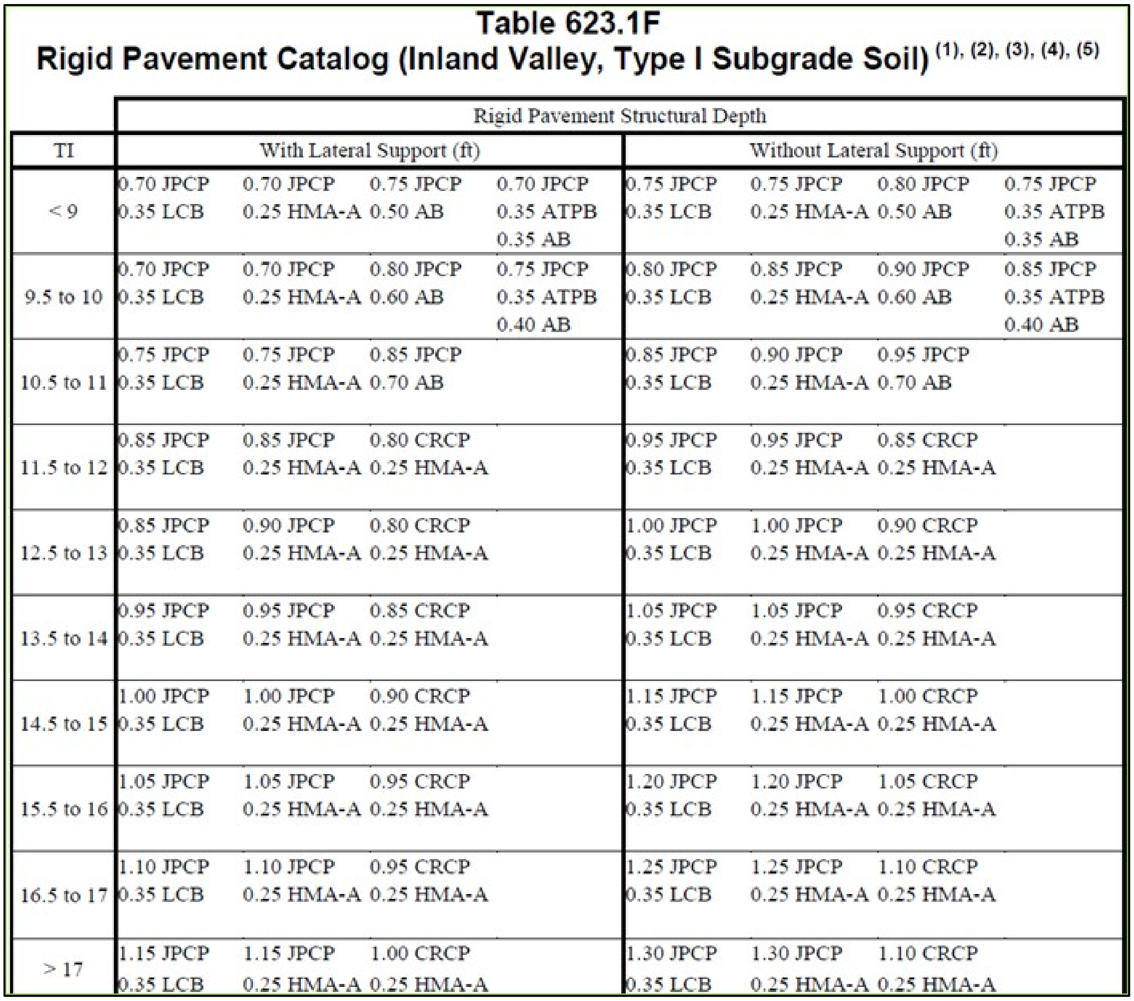


Table 623.1F
Rigid Pavement Catalog (Inland Valley, Type I Subgrade Soil) (1), (2), (3), (4), (5)

	Rigid Pavement Structural Depth							
TI	With Lateral Support (ft)				Without Lateral Support (ft)			
< 9	0.70 JPCP 0.35 LCB	0.70 JPCP 0.25 HMA-A	0.75 JPCP 0.50 AB	0.70 JPCP 0.35 ATPB 0.35 AB	0.75 JPCP 0.35 LCB	0.75 JPCP 0.25 HMA-A	0.80 JPCP 0.50 AB	0.75 JPCP 0.35 ATPB 0.35 AB
9.5 to 10	0.70 JPCP 0.35 LCB	0.70 JPCP 0.25 HMA-A	0.80 JPCP 0.60 AB	0.75 JPCP 0.35 ATPB 0.40 AB	0.80 JPCP 0.35 LCB	0.85 JPCP 0.25 HMA-A	0.90 JPCP 0.60 AB	0.85 JPCP 0.35 ATPB 0.40 AB
10.5 to 11	0.75 JPCP 0.35 LCB	0.75 JPCP 0.25 HMA-A	0.85 JPCP 0.70 AB		0.85 JPCP 0.35 LCB	0.90 JPCP 0.25 HMA-A	0.95 JPCP 0.70 AB	
11.5 to 12	0.85 JPCP 0.35 LCB	0.85 JPCP 0.25 HMA-A	0.80 CRCP 0.25 HMA-A		0.95 JPCP 0.35 LCB	0.95 JPCP 0.25 HMA-A	0.85 CRCP 0.25 HMA-A	
12.5 to 13	0.85 JPCP 0.35 LCB	0.90 JPCP 0.25 HMA-A	0.80 CRCP 0.25 HMA-A		1.00 JPCP 0.35 LCB	1.00 JPCP 0.25 HMA-A	0.90 CRCP 0.25 HMA-A	
13.5 to 14	0.95 JPCP 0.35 LCB	0.95 JPCP 0.25 HMA-A	0.85 CRCP 0.25 HMA-A		1.05 JPCP 0.35 LCB	1.05 JPCP 0.25 HMA-A	0.95 CRCP 0.25 HMA-A	
14.5 to 15	1.00 JPCP 0.35 LCB	1.00 JPCP 0.25 HMA-A	0.90 CRCP 0.25 HMA-A		1.15 JPCP 0.35 LCB	1.15 JPCP 0.25 HMA-A	1.00 CRCP 0.25 HMA-A	
15.5 to 16	1.05 JPCP 0.35 LCB	1.05 JPCP 0.25 HMA-A	0.95 CRCP 0.25 HMA-A		1.20 JPCP 0.35 LCB	1.20 JPCP 0.25 HMA-A	1.05 CRCP 0.25 HMA-A	
16.5 to 17	1.10 JPCP 0.35 LCB	1.10 JPCP 0.25 HMA-A	0.95 CRCP 0.25 HMA-A		1.25 JPCP 0.35 LCB	1.25 JPCP 0.25 HMA-A	1.10 CRCP 0.25 HMA-A	
> 17	1.15 JPCP 0.35 LCB	1.15 JPCP 0.25 HMA-A	1.00 CRCP 0.25 HMA-A		1.30 JPCP 0.35 LCB	1.30 JPCP 0.25 HMA-A	1.10 CRCP 0.25 HMA-A	

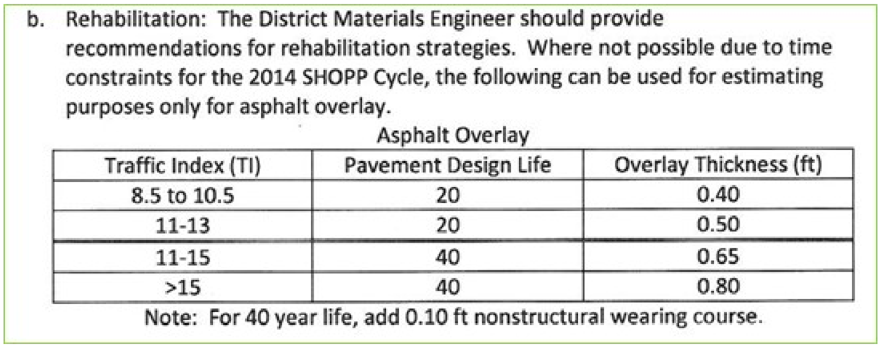
Figure 2-1. An example from the Caltrans HDM catalog of rigid pavements for inland valley climate and soil type I.

2.3.2 Scoping a 40-year Hot Mix Asphalt (HMA) Overlay

This section describes the methods currently available to Caltrans pavement engineers for estimating (scoping) the rehabilitation needs utilizing asphalt concrete (or hot mix asphalt HMA) for an existing asphalt-surfaced pavement. Depending on the extent and severity of distresses present on the existing pavement, several possibilities exist ranging from the design of basic HMA overlay to layers replacement to complete reconstruction.

Determining the required HMA thickness for scoping of a project consisting of an existing asphalt pavement can be performed in several ways; the most “direct” of which are discussed in the following:

a. Using the CAPM guidelines given in the Caltrans' "*Quick Reference Guide for 2014/2016 Pavement SHOPP PIDs*" available at the Caltrans intranet[21]. Figure 2-2 shows a partial screenshot of the CAPM guidelines for the estimated minimum HMA overlay thickness for long-life rehabilitation (40 years).



b. Rehabilitation: The District Materials Engineer should provide recommendations for rehabilitation strategies. Where not possible due to time constraints for the 2014 SHOPP Cycle, the following can be used for estimating purposes only for asphalt overlay.

Asphalt Overlay

Traffic Index (TI)	Pavement Design Life	Overlay Thickness (ft)
8.5 to 10.5	20	0.40
11-13	20	0.50
11-15	40	0.65
>15	40	0.80

Note: For 40 year life, add 0.10 ft nonstructural wearing course.

Figure 2-2. Recommended minimum HMA overlay thickness (with 80% reliability) for scoping purposes taken from Caltrans' CAPM guidelines.

According to these guidelines, these thicknesses must be used only for project programming and cost estimation purposes, and not as final design thicknesses. As shown in Figure 2-2, for 40-year traffic index (TI) of 11.0-15.0, project scoping is based on an HMA overlay thickness of no less than 0.65 ft, and for TI>15.0 based on a minimum HMA 0.80 ft thick. An additional 0.10 ft nonstructural wearing course (such as open graded friction course rubberized) must also be scoped along with the 40-year HMA overlay. This nonstructural wearing course; which improves skid resistance and protects the structural HMA from oxidation and weather aging, must be replaced periodically. The recommended minimum HMA thickness shown in Figure 2-2 are derived based on a study that was performed by the author of this report analyzing actual HMA overlays designed for 5-, 10-, and 20-year service lives using the Caltrans empirical overlay design method and deflection data collected from over 2000 pavement sections spanning the entire California highway system[22]. Probabilistic analysis was performed to estimate the overlay thickness requirement at various reliability levels. The overlay thicknesses shown in Figure 2-2 above ensure a minimum design reliability of 80%. Since the original designs did not include 40-year data, extrapolation was performed to estimate the overlay thickness at various reliabilities for the longer design life.

b. The second method that can be used for scoping long-life rehabilitation needs for an existing asphalt-surfaced pavement is based on using the California asphalt design

---

[21] Only accessible to Caltrans staff at (http://onramp.dot.ca.gov/hq/maint/pavement/PMC_docs/PMC_Mtg_7-11-12_Handout_23_Quick_Reference_Guide_PIDS.pdf

[22] Basheer I. (2006). Alternative Procedure to Estimate Flexible Pavement Rehabilitation Requirements for Project Scoping. Pavement Tech Note, November 1, 2006. This document can be found at http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/Flex_Pav_Rehab_Final_071101.pdf

software CalME. The CalME (Figure 2-3) is the California mechanistic-empirical (ME) design and analysis program that allows the user to design new pavements or rehabilitation existing ones by utilizing project specific data such as traffic and climate data pertinent to the project site and distress data and materials properties relevant to the pavement under study. This scoping method is more elaborate than the "Quick Reference Guide, QRG" (shown in Figure 2-2 above) but it is believed to be more reasonable since it utilizes some available project specific data.

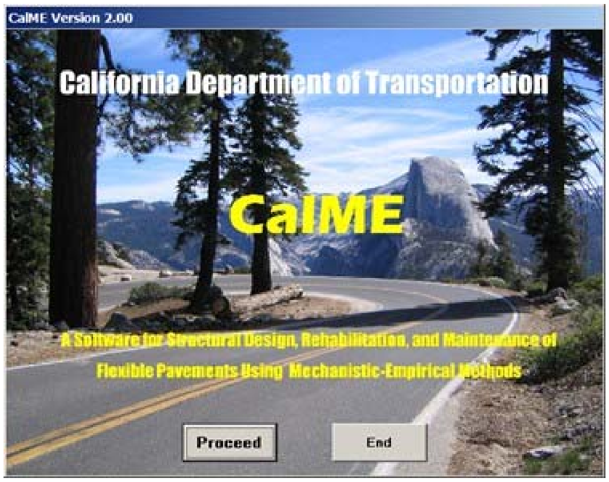


Figure 2-3. Opening screen of the Caltrans' mechanistic-empirical software CalME.

Whereas this advanced tool is capable of performing detailed final designs, it can be used for scoping (estimating) rehabilitation needs based on limited information available to the design engineer at the early phase of the project. In this case, the engineer may use CalME <u>default values for the materials</u> in the pavement section and the overlay. Some adjustment to the strengths of the materials of the existing layers may be made by the engineer to account for the structural condition of the existing layers. CalME requires detailed traffic and climate data, which can be uploaded from the database solely based on project location (district, highway #, and post mile limits). A high level of design reliability; e.g., 90-95% may be sought by the engineer when scoping for a given project to account for the fact that the rehabilitation design is based on default and estimated materials values and conditions rather than actual conditions. The downside of using this design tool is that unlike using the QRG, it requires some knowledge of the CalME software by the engineers responsible for scoping of rehabilitation needs of their projects. Caltrans district materials engineers are familiar with CalME and therefore can assist project engineers in scoping of their long-life rehabilitation projects. On the positive side, using CalME in scoping offers a wider variety of rehabilitation options such as mill/fill, CIR, FDR, and reconstruction compared to the QRG which is limited to basic HMA overlay. Additionally, unlike QRG, CalME offers the engineer with the ability to include multiple types of asphalt concrete materials typically needed for long-life (perpetual) design and with their choice of asphalt binder grade suitable for the climate prevailing at the project site. At the present time, there are no guidelines available for performing this type of scoping using CalME; but an engineer familiar with the software can successfully use it with the limited amount of information available about the project.

In CalME, it is possible to use “New Construction” or “Rehabilitation” modes for long-life rehabilitation design. The former may be used when the entire existing HMA is to be milled off. To use the latter approach, the “Old HMA” material must be selected from the default library to represent the strength and condition of the existing asphalt concrete layer. The resilient moduli of existing layers must be obtained from a deflection test (using falling weight deflectometer, FWD) and backcalculation; or assumed if such data is not available. Again, it is important that these rehabilitation needs estimates not be taken as substitute to final designs where actual material properties and existing layers conditions must be obtained through detailed field and laboratory testing and used in the determination of actual rehabilitation needs.

c. The third method that can be used for scoping of long-life rehabilitation is by simply using the “full depth structure” recommended by the HDM; page 630-7[23]. This structure represents a “new construction” rather than a rehabilitation; therefore it can only be selected for scoping if it was decided that the existing pavement structure must be completely removed and replaced (i.e., reconstructed). The HDM requires that the long-life structural section be designed using the Caltrans empirical procedure for flexible pavements[24] (i.e., the R-value method) along with the corresponding 40-year traffic index (TI_{40}). In this case, a “full depth hot mix asphalt” structure is designed and the minimum thickness of HMA is determined. Because the Caltrans empirical method for flexible pavements is not applicable for design lives greater than 20 years, some enhancements must be incorporated in the design to provide for a long-life design as described below:
    - Place a minimum 0.50 ft of Class 2 aggregate base (AB-Class 2) beneath the HMA structural layer designed above. This aggregate base layer is not considered part of the pavement structural design and cannot be used to reduce the thickness of the full depth hot mix asphalt layer.
    - Use a non-structural wearing course (such as open graded friction course, OGFC) above the surface layer (minimum 0.10 ft thick). See Index 602.1(5) of the HDM for further details[25].
    - Use rubberized hot mix asphalt (maximum 0.20 ft) or a polymer modified asphalt binder (minimum 0.20 ft) for the top of the surface layer.
    - In addition, the following enhancements must also be incorporated:

---

[23] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0630.pdf

[24] Caltrans offers a free software for the standard empirical flexible pavement design method called CalFP available at http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/Software.html

[25] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0600.pdf

i. Use higher asphalt binder content[26] for the bottom of the surface layer (rich-bottom concept) and using higher stiffness asphalt binder.
ii. Utilize subgrade enhancement geotextile on the subgrade when the California R-values of subgrade is less than 40.
iii. Use stress absorption membrane interlayer, SAMI (e.g., geosynthetic interlayer or rubberized chip seal) within the surface asphaltic layer.
iv. Use a separation fabric (geotextile) above the granular base layers. The geotextile must be carefully selected such that it is able to resist construction loads; otherwise construction equipment must be kept off of the geotextile. Caltrans Standard specifications book (Section 96: Geosynthetics) provides minimum properties requirements of such geotextiles (Caltrans Specs 2015)[27].

This procedure will commonly produce a very conservative (high cost) structure compared with the other methods. The method is often used for final design of long-life new asphalt pavements when the district chooses (for any reason) not to use the CalME method which requires advanced testing of the asphalt mixes.

Again, when the pavement distress conditions require complete reconstruction, the CalME procedure may be alternatively used for reconstruction design based on project specific data pertaining to soil, climate, traffic and materials. In this case, default material parameters may be selected for scoping purposes in addition to traffic and climate data selected based on project location.

2.4 SCOPING REHABILITATION FOR CONCRETE-SURFACED PAVEMENT

In California, rigid pavements are either the jointed plain concrete pavements (JPCP) or the continuously reinforced concrete pavement (CRCP) type; with JPCPs being the majority of these pavements. The Caltrans HDM[28] offers a limited resource for engineers to scope rehabilitation of an existing Portland cement concrete (PCC) surfaced pavement at early phase of the project. Currently, Caltrans project engineers may scope their rigid pavement rehabilitation projects using the few resources discussed below. The discussion below can also provide guidance to project and materials engineers on how to use these available resources in scoping of their long-life rigid pavement rehabilitation projects.

1. The new rigid pavement (JPCP and CRCP) design catalog given in the Caltrans HDM Table 623.1 (B through M)[29] offers 40-year final design sections for new pavement structures. These sections are selected based on climate, traffic index (TI), subgrade type and

---

[26] Usually 0.5% higher than the actual binder content determined for the mix.
[27] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0600.pdf
[28] http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm
[29] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0620.pdf

strength, and lateral support condition, as discussed previously. Whereas the catalog is designed to be used for designing new pavement structures, it can also be used as a scoping tool for rehabilitation of existing concrete pavements. Depending on the severity and quantity of surface distresses (in addition to other constraints such as existing grade elevations), the engineer may consider either lane replacement or an unbonded concrete overlay. The catalog may be used to either design an entire structure if the pavement is to be completely reconstructed or to only determine the required PCC layer thickness depending on the existing configuration of the existing structure (base and subbase types and thicknesses). The engineer may compare the existing pavement structure in terms of its existing layers types and thicknesses against one or more sections available in the catalog. Because the catalog provides sections for new rigid pavements, the engineer may adjust available thicknesses to account for the "estimated" deterioration by applying some reduction factors to the measured thicknesses. The equivalent thickness method based on the rigidity principle can be used to determine the equivalent (reduced) thickness of the existing thickness to reflect the new material strength. The rigidity[30] is defined as:

$$R = \frac{Eh^3}{12(1-\mu)}$$

Therefore, an existing layer of resilient modulus of E_e and thickness h_e must have the same rigidity as a "new" or virgin layer of modulus E_n and thickness h_n. Hence, the equivalent "new" thickness of a deteriorated material may be calculated as:

$$h_n = \left(\frac{E_e}{E_n}\right) \times {h_e}^3$$

The new thickness would be less than the existing thickness if the layer has lost strength and more if it has gained strength. This simplistic approach assumes that the strength (in terms of resilient modulus) of the existing layer is available. The strength of the new layer must also be available or reasonably assumed. The PCC thickness found to be required for the existing pavement may be used as the scoping thickness; although it also represents the final design thickness since the catalog is often used for final design. While the resilient modulus of existing layers can be estimated with backcalculation following FWD testing of the existing pavement, it is not expected that such deflection testing is performed at the early phase of project. Therefore, the engineer may resort to established moduli values of virgin materials and apply appropriate reduction factors to account for the estimated deterioration of the in-place materials.

When long-life rehabilitation is determined to be lane replacement of one or more lanes of the existing rigid pavement, then either a flexible or rigid structure can be constructed; the final choice depends on project specifics and life-cycle cost analysis[31]. Scoping of this type of long-life rehabilitation follows the methods described earlier. In all cases,

---

[30] Huang Y. H. (1993). Pavement Analysis and Design. Prentice Hall, Englewood Cliffs, NJ.

[31] http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html

attention should be given to maintaining existing drainage patterns underneath the surface layer.

2. The Catalog can also be used to designing unbonded JPCP overlay over existing rigid pavement by first placing an HMA layer over existing concrete surfacing. The HMA layer will act as a bond breaker between the existing PCC and the new PCC overlay. The engineer may use the Catalog to determine the required thickness of both the HMA layer and the concrete overlay based on project specifics (TI, climate, soil type, concrete surfacing type: JPCP or CRCP, etc.). Using the Catalog suggested sections will ensure that the unbonded overlay will provide the desired 40-year service life. Note that Caltrans has used this technique (i.e., using the Catalog) to design the unbonded PCC overlay placed on the mainline travelled way of I-80 from the Donner lake undercrossing to West Truckee.

3. The Caltrans rigid pavement catalog was developed using hundreds of simulations run with the mechanistic-empirical pavement design guide; MEPDG (version 0.80)[32]. The research grade MEPDG has been lately replaced with the enhanced commercial AASHTO version "AASHTOWare ME Pavement Design" software[33]. Therefore, this software can also be used to scope long-life projects involving concrete pavements[34]. In this case, default "Level 3" inputs must be used. The limitation of this approach is that the engineer has to decide on the methods of rehabilitation and then use the software to perform the design and analysis. In the software, the engineer may perform the analysis as either a rehabilitation design problem or as a new pavement design problem with some selected default values for the pavement structure layers' strength (including the subgrade soil). All truck traffic distribution factors may be assumed to be at the national-level values in terms of axle load spectrum and truck class distributions. The annual average daily truck traffic (AADTT) is selected based on project location; which is normally available at early stages of the project or from truck traffic report available from the Caltrans Traffic Census Program[35]. The AASHTO ME software allows the user to enter distress values of the surface layer. The software requires a good level of familiarity by the engineer in order to perform design and analysis; which is another limitation of its use as a long-life scoping tool for rigid pavement rehabilitation.

4. If the engineer determines that a valid strategy for rehabilitating an existing jointed plain concrete pavement (JPCP) is the "crack, seat, and HMA-overlay", then there is no such tool or guidance available at the present to determine the thickness of the long life (40

---

[32] Currently, the table is being revised using the AASHTOWare program Pavement Design.

[33] http://www.aashtoware.org/Pavement/Pages/default.aspx

[34] Caltrans' IT installs the software to interested Caltrans pavement engineers upon request.

[35] http://www.dot.ca.gov/trafficops/census/

years) asphalt concrete overlay. Currently, the Caltrans HDM (Table 625.1)[36] is limited to crack, seat and overlay rehabilitation strategies (i.e., in terms of required HMA and RHMA-G thicknesses) with 20-year designs. Table 2-1 shows the 20-year minimum crack, seat and overlay design thicknesses obtained from the Caltrans HDM.

Table 2-1. The HDM's minimum standard thicknesses for crack, seat and overlay for 20-year design. Note: SAMI-F & R is stress absorption membrane interlayer fabric & rubberized chip seal. LC is level course, GPI is geosynthetic pavement interlayer (e.g. fabric).

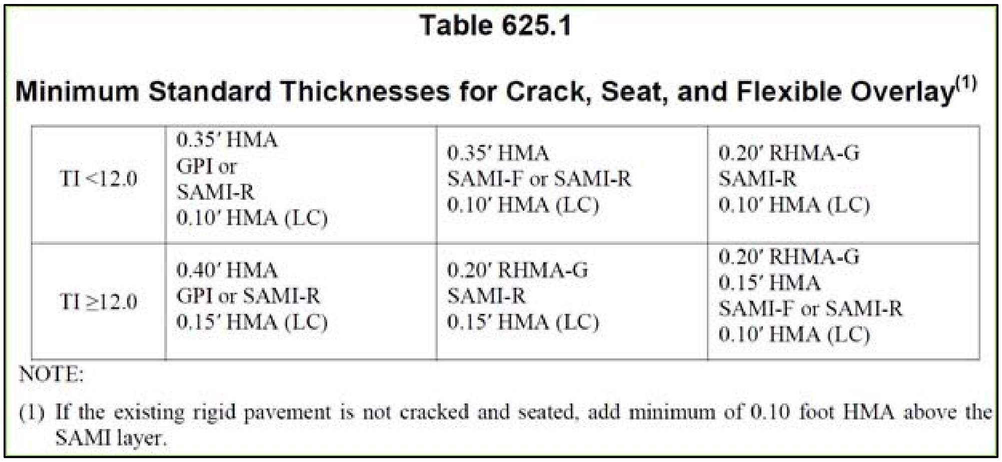


Table 625.1

Minimum Standard Thicknesses for Crack, Seat, and Flexible Overlay(1)

TI <12.0	0.35′ HMA GPI or SAMI-R 0.10′ HMA (LC)	0.35′ HMA SAMI-F or SAMI-R 0.10′ HMA (LC)	0.20′ RHMA-G SAMI-R 0.10′ HMA (LC)
TI ≥12.0	0.40′ HMA GPI or SAMI-R 0.15′ HMA (LC)	0.20′ RHMA-G SAMI-R 0.15′ HMA (LC)	0.20′ RHMA-G 0.15′ HMA SAMI-F or SAMI-R 0.10′ HMA (LC)

NOTE:

(1) If the existing rigid pavement is not cracked and seated, add minimum of 0.10 foot HMA above the SAMI layer.

Because there is currently no standard crack, seat, and asphalt overlay design for JPCP design life greater than 20 years, the Caltrans HDM proposes some other rehabilitation alternatives. These includes lane replacement and unbonded concrete overlays. Lane replacement is engineered using the catalog in Table 623.1 but attention should be given to maintaining existing drainage patterns underneath the surface layer. The unbonded concrete layer thickness is designed also using the catalog Table 623.1 in the same way it is done for new pavement. It is important to provide a flexible asphalt concrete interlayer (0.1 ft minimum) between the existing pavement and rigid overlay to act as a bond breaker. While the designs are assumed to be final in the HDM, the engineer can also use them for scoping purposes since they do not require any more information above what is normally known at the early phase of the project.

In recent long-life projects in California, the CalME software was used to develop final 40-year crack-seat and overlay design of JPCPs (e.g., Weed and Solano projects[37]). For scoping, CalME can also be used to estimate required asphaltic overlay thickness (possibly with multiple types of HMA layers) using default input values for the existing layers strength (including subgrade), and traffic and climate inputs that are automatically uploaded in the software based on project location. The engineer must select HMA types (based on the binder grade and other mix parameters) from the asphalt mixes default materials. Because there are many asphaltic materials in the CalME library and no testing is normally done at this phase of the project, the engineer must consider evaluating as

---

[36] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0620.pdf

[37] These projects will be discussed later in this report.

many mixes as possible from the CalME library and select a conservative HMA thickness (or thicknesses when multiple HMAs are analyzed) for scoping of their project. At a later phase of their project, it is important that materials testing be performed and the final design be evaluated using the actual materials inputs.

2.5 SCOPING FOR COMPOSITE PAVEMENTS

Caltrans defines two configurations of composite pavements:[38]

1. Asphalt over concrete composite pavements in which an asphalt concrete layer is placed over a concrete surface layer (typically JPCP or CRCP) where the asphalt layer is used to protect or enhance the performance characteristics of the concrete pavement. Excluded from this definition is the pavement in which an asphalt layer is constructed over lean concrete base (LCB) or cement treated base (CTB); in which cases the pavement is still considered to be flexible pavements. Asphalt over concrete composites are typically concrete pavements that have been rehabilitated with asphalt concrete overlay. Examples of this type of rehabilitation include JPCPs that have been overlaid with asphalt concrete whether they were cracked and seated or not prior to overlaying. In California, no new composite pavement have ever been constructed with asphalt concrete layer over Portland cement concrete layer (JPCP or CRCP).

2. Concrete over asphalt composite pavements in which a Portland cement concrete layer is placed on top of a flexible pavement to improve the overall structural capacity of the pavement as well as its other functional qualities.

The rehabilitation design of these two types of composite structures follows the same procedures discussed earlier depending on the existing surfacing type (i.e., asphalt concrete or Portland cement concrete). As an example, if an “asphalt over concrete composite pavement” such as a previously cracked, seated and HMA overlaid JPCP needs to be rehabilitated, some of the viable options can be an HMA overlay or an unbonded concrete overlay. The design of HMA overlay over cracked and seated JPCPs was discussed previously. Similarly, if a “concrete over asphalt composite pavement” is to be rehabilitated, then some of the viable options can be an unbonded concrete overlay or and asphalt concrete overlay (with or without crack and seating). Thus, the distinction in pavement type adopted in this evaluation report was based on the material type of the existing structural surface layer.

---

[38] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0640.pdf

3 LIMITATIONS OF CALTRANS SCOPING TOOLS

In Chapter 2, the methods currently available to Caltrans engineers for scoping their long-life (40-year design life) rehabilitation projects were presented and discussed. Two sets of methods were presented based on the type of final surface being either asphalt concrete (flexible pavement) or Portland cement concrete (rigid pavement) including composite pavement structures that were previously rehabilitated with either flexible or rigid pavement. It was observed that the guidelines available to specifically scope rehabilitation of existing pavements, except for estimating asphalt overlay thickness for 10, 20, and 40 year designs, were somewhat limited. It was also discussed in Chapter 2 how some final design methods (employing software) could be used as tools to scope long-life rehabilitation of both asphalt-surfaced and concrete-surfaced existing pavement structures.

3.1 LIMITATIONS

The following are the limitations of existing tools or guidance available in HDM or in any other sources regarding scoping of long-life pavement rehabilitation projects:

1. Available tools that could be used for scoping are generally final-design tools that result in either greatly overestimating or underestimating rehabilitation needs; thus increasing risk of either over-budgeting or under-budgeting of rehabilitation projects,

2. Some of the final design tools require a good knowledge in the design software even though it could be run with default materials inputs. Examples of these software are CalME[39] and AASHTOWare ME Pavement Design[40].

3. Available guidelines for scoping may be limited in the type of rehabilitation to be considered for the project. For example, 40-year asphalt overlay thicknesses based on traffic index are only available to project engineer for scoping their project without consideration as to whether this is a viable rehabilitation option. Such guidelines do not require any distress condition, for example, to scope the project. It is very possible that the overlay is not the best rehabilitation strategy for the project because of the severe surface distress condition. Therefore, scoping should also include a few more inputs that are either available at early phase of the project or can be obtained fairly easily to improve on the estimation of rehabilitation needs which can result in a more efficient project programming. Scoping for long-life rehabilitation can include reconstruction, overlay with either concrete or asphalt, full depth reclamation, mill-and-fill, etc. Unless additional

---

[39] P. Ullidtz, J. Harvey, I. Basheer, Jones D., Wu R., Lea J., and Lu Q. (2010). *CalME*: A New Mechanistic-Empirical Design Program for Flexible pavement Rehabilitation. Transportation Research Record, No. 2153, pp. 143-152.

[40] http://www.aashtoware.org/Pavement/Pages/ME%20Design.aspx?PID=1

commonly available inputs are used in the scoping process various rehabilitation methods can be overlooked. It is possible that future final design may result in finding one of these overlooked methods to be most viable; which can result in excessively deviating from allocated budget. Alternatively, there is a risk that the scoped method of rehabilitation will drive the final rehabilitation method adopted for the project.

4. Available “new construction” catalog[41] for rigid pavement for scoping an existing flexible pavement (i.e., considering unbonded concrete overlay) can be used but it greatly underestimates the structural contribution of the existing pavement and thus can result in excessively over-conservative rehabilitation needs. Whereas such catalog provides 40-year designs, there no such directly available method (e.g., catalog) for scoping a 40-year asphalt overlay over rigid pavement. In order to scope such rehabilitation treatment, the engineer is forced to consider lane replacement with rigid structure. An alternative approach would be to use CalME (at software default inputs) to design or analyze a planned long-life rehabilitation strategy; which requires a good amount of knowledge of the software by the engineer.

5. Whereas the existing knowledge available in the HDM and other related sources can be used to more effectively scope long-life projects, they require great amount of engineering judgment on the project engineer’s part. A more systematic scoping system can help streamline the process which can result in consistent statewide scoping of projects. This system will equally appeal to all engineers regardless of their level of expertise and proficiency in pavement design.

To summarize, long-life scoping guidelines are either completely missing from Caltrans HDM or other related documents, or are very limited in the type of rehabilitation methods available to the engineer. It is to be noted that long-life rehabilitation or new construction is only a relatively new concept that has not been around for many years. Therefore, it is not surprising that scoping guidelines for long life rehabilitation be limited or not available. There is a need to develop a simple stand-alone system for long-life scoping consisting of a software and guidance that can be used by project engineers at early project stage. It is also desirable that minimal amount of information that are normally available at initial phases of project be sufficient for running the scoping system. In other words, it is not expected that significant materials laboratory testing or field testing would be needed to obtain information for use in the scoping process.

3.2 NEW TOOL

The Pavement Renewal Solutions’ tool *rePave* offers a great advantage to Caltrans to supplement the suite of scoping tools available to project engineers to consider on their project at scoping phase. While *rePave* requires only a few additional data than what is routinely obtained at the scoping phase, it can help the engineer evaluate a wider variety of possibly viable long-life rehabilitation options, resulting in a better understanding of rehabilitation needs and more accurate cost allocation for the project. It is believed that either minimal or no additional cost

---

[41] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0620.pdf

would be incurred by Caltrans engineers when using *rePave* since nearly all needed inputs are routinely collected for any project. The various input data and information needed for the project that will enable the engineer run *rePave* include:

1. **Current surface distress condition**: This information can be obtained from multiple Caltrans sources including the Caltrans automated pavement condition surveys (APCS) Pathweb (2015 data)[42].
2. **Existing pavement structure information**: This includes material types and thicknesses and can be obtained from available as-built plans for the subject pavement, or cores (via iGPR[43], and iGPR-Core[44]) taken from the project or its vicinity, as well as from the PaveM database[45].
3. **Traffic data and other general information:** These include the current AADT, total ESALs[46], ESALs per year[47], and growth rate which can be obtained from available traffic documents published by the Caltrans Traffic Operations' Traffic Census Program[48] as well as other sources such as PaveM. Some analysis of the traffic data may be needed to obtain representative growth rate. The design life is also required to run rePave and it is normally available for any project (for long-life design the design life is commonly considered to be 40 years). Finally, the number of lanes in one direction as well as any final grade restrictions are also required for running rePave.
4. **Resilient modulus of subgrade**: This strength parameter is not routinely measured on Caltrans projects because Caltrans uses R-value for subgrade soil strength characterization. However, the future Caltrans Highway Design Manual edition discussing

---

[42] http://pathweb.pathwayservices.com/ca/

[43] http://www.ucprc.ucdavis.edu/iGPR/

[44] http://www.ucprc.ucdavis.edu/iGPR-Core/

[45] Accessible to Caltrans staff at http://onramp.dot.ca.gov/hq/maint/pavement/PaveM.shtml

[46] The total ESALs can be determined from the Caltrans Traffic Index (TI) equation for the desired design life. Consult the HDM for the range of total ESALs for the proposed TI and use the upper limit for conservative estimate of ESALs. See sample calculation of total ESALs in the Case Studies chapter.

[47] The parameter ESALs per year required by rePave is calculated not by simply dividing the total ESALs by the design life in years. Instead assume that the known total ESALs has grown from an initial (first year) ESALs count using a geometric growth equation and the assumed growth rate. Starting with a "guessed" initial ESALs count (i.e., by trial and error), and using an Excel spreadsheet the ESALs are accumulated year after year and the computed total ESALs is compared with the actual total ESALs. See sample calculations in the Case Studies chapter.

[48] http://www.dot.ca.gov/trafficops/census/

ME for asphalt pavements will provide a list of reasonable resilient moduli values of subgrade soils based on their USCS[49] classification (Table 614.2 of HDM[50]); which is routinely tested or is easily obtained from historical project records.

Since all of these information and inputs required by *rePave* are either already available or can be easily obtained at no additional cost, there is a great benefit in adopting this relatively more comprehensive scoping tool. This tool can supplement current tools and guidance for scoping of future long-life rehabilitation projects.

When using *rePave*, there is a great potential of cost saving that may be realized for certain projects because of the variety of long-life rehabilitation strategies that are made available to the engineer when scoping their projects to compare and select from based on their feasibility and initial cost. While it is not and should not be used as a final design tool, it is useful in alerting the pavement engineer to the various rehabilitation options available. At the final design stage, the pavement engineer can consider all of these possible options and then determine the most cost-effective option for their project. The engineer can focus on both the materials cost and user delay costs associated with the construction of various alternatives before a final decision on the optimal rehabilitation strategy can be made. Recently, Washington State DOT estimated in one project 30% materials cost saving and 50% reduction in user delay cost using guidance in *rePave* compared to removing the existing pavement and constructing a new pavement[51].

The next five chapters discuss several case studies (representing actual Caltrans long-life pavement designs and construction projects) that were used to compare *rePave* scoping designs against the available Caltrans scoping tools and final designs performed with the Caltrans ME methods.

---

[49] Unified Soil Classification System.

[50] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0610.pdf

[51] In a presentation by rePave lead developer Mr. Newt Jackson.

4 EVALUATION WITH CASE STUDIES

In the next four chapters, we present comparisons between *rePave* prediction and predictions made by the Caltrans scoping tools and final designs for five recent actual Caltrans long-life projects (case studies). The case studies involved four projects which have been actually constructed, and another which is still in a preliminary phase. Description of these 5 projects is given below:

1. I-5 near the City of Red Bluff in Northern California. This project consisted of an asphalt concrete pavement. The project lies in Tehama County from Antelope Boulevard Crossing to Gas Point Road. It extends from PM 37.5 to PM 41.5. It is a four-lane divided highway which experienced extensive fatigue cracking and reflection cracking, as well as stripping and delamination at various depth within the asphalt layer as evidenced from a number of cores extracted from the pavement at various locations. This is a long life project that was designed for a service life of 40 years with the Caltrans ME method (using Caltrans' CalBack and CalME software[52]). The 40-year traffic index (TI_{40}) for the mainline lanes was 16.0. The site was actually rehabilitated in 2013. A map of the location of this projects is shown in Figure 4-1.

2. I-5 near the City of Weed in Northern California. This project consisted of an asphalt concrete pavement placed over a JPCP (i.e., composite pavement structure). The project lies in Siskiyou County starting from Route 97 intersection to 0.3 miles south of the Weed Roadside Rest Area and extends from PM 19.0 to PM 25.2. The project has two segments: one is a four-lane divided highway and the other is a two-lane undivided highway. Both segments experienced extensive reflection fatigue cracking (transverse and longitudinal) from the broken concrete slabs beneath the asphalt concrete, as well as occasional rutting and stripping. Cores retrieved from the pavement at various locations showed delamination at various depths within the asphalt layer. This is a long life project that was designed for a service life of 40 years with the Caltrans ME design and analysis system (CalME/CalBack). The 40-year traffic index (TI_{40}) for the mainline traffic lanes was 15.0. The site was actually rehabilitated in 2013. The approximate location of this projects is shown in Figure 4-1.

3. I-80 between the City of Dixon and the City of Vacaville in Northern California. This project consisted of a JPCP structure. The project lies in Solano County and extends from 0.6 miles east of Leisure Town Road Overcrossing to 1.0 mile west of Pedrick Road overcrossing. The project is located between PM 30.55 and PM 38.7. It is a six-lane divided highway

---

[52] CalME is the Caltrans mechanistic-Empirical (ME) design and analysis software used for flexible pavement design and rehabilitation. CalBack is also a Caltrans' software used for backcalculation of in-situ resilient moduli of structural layers of both flexible and rigid pavements from falling weight deflectometer (FWD) deflection data. CalBack backcalculated resilient moduli are uploaded into CalME for designing rehabilitation strategies for an existing asphalt-surfaced pavement.

with three lanes in each direction. The pavement exhibited 1st and 3rd stage cracking[53] as well as extensive corner breaks and faulting at both the transverse joints and major cracks. The ride quality was extremely poor. This is a long life project that was designed for a service life of 40 years with the Caltrans ME method. The 40-year traffic index (TI_{40}) for the mainline lanes was 15.0. The site was rehabilitated in 2014. A map showing the approximate location of this projects is shown in Figure 4-1.

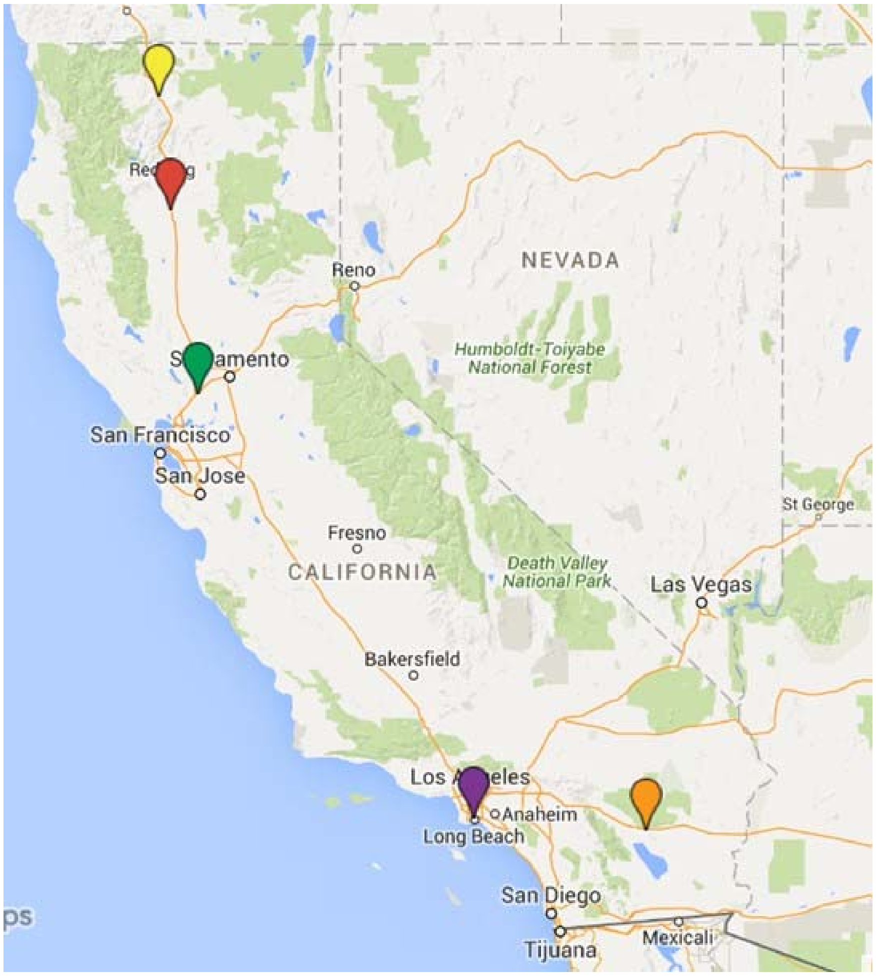


Figure 4-1. The approximate location of the 5 long-life rehabilitation projects on California highway system used as case studies for scoping design comparison between *rePave* and Caltrans scoping and final design tools (Yellow=Weed, Red=Red Bluff, Green=Solano, Purple=LA-710, and Orange=Riverside).

---

[53] Caltrans defines 1st stage cracks as those that non-intersecting transverse, longitudinal, or diagonal cracks in a concrete slab that divide the slab into two or three large pieces (not including corner breaks). 3rd stage cracks divide the slab into three or more pieces with interconnected cracks developing between cracks or joints.

4. I-710 freeway near the City of Long Beach in Southern California between the Pacific Coast Highway (Route 1) and I-405 and extending between PM 6.8 to PM 9.7. The project is a six-lane divided highway with three lanes in each direction. The pavement exhibited 1st and 3rd stage cracking as well as extensive corner breaks, faulting, and ride quality issues. This is a long-life project that was designed for a service life of 30 years with the Caltrans ME method. The 30-year traffic index (TI_{30}) for the mainline lanes was 17.0. The site was rehabilitated in 2004, and is considered the first long-life project in California. A map of the location of this projects is shown in Figure 4-1.

5. I-10 freeway in Riverside County in Southern California desert. The project extends from 1.9 miles east of Cactus City Rest Area at PM R 74.0 to 0.4 miles east of Desert Center Rice Road at PM R 105.0. The project is a four-lane divided highway with two lanes in each direction. The project has not been constructed as of today and pavement rehabilitation designs based on FWD deflection testing and cores were developed. No advanced material laboratory testing has not yet been conducted. The asphalt pavement surface distress condition was conducted in January 2015 by the District Materials Office and found to have bleeding, pumping, rutting and low to moderate fatigue cracking. Some lane-shoulder drop offs were also observed. This is a long-life project that was designed for a service life of 40 years with the Caltrans ME method (CalME/CalBack). The 40-year traffic index (TI_{40}) for the mainline truck lanes was 17.5. The construction of this project is expected to be in 2019. The approximate location of this projects is shown in Figure 4-1.

A more detailed discussion of each of these projects along with scoping design with *rePave* and Caltrans tools are presented in the next four chapters of this report.

5 CASE STUDY 1 (I-5 RED BLUFF)

5.1 PROJECT DESCRIPTION

The Interstate 5 long -life project just north of the City of Red Bluff in Tehama County in Northern California was constructed in 2012 and has been in service for over 4 years. An aerial map of the project location with approximate beginning and end limits of the project is shown in Figure 5-1. This facility is a four-lane divided highway and the project limits extended from PM 37.5 to 41.5 in both directions. The project is located between the Antelope Boulevard crossing to Gas Point Road.

Figure 5-1. Aerial map showing the location limits of the Red Bluff project.

Prior to rehabilitation, the asphalt pavement within the project limits exhibited extensive fatigue and reflection cracking as well as occasional stripping. Additionally, cores obtained from the pavement at various locations exhibited delamination within the asphalt concrete at various depths. Figure 5-2 shows a photo taken from the northbound direction at PM 38.57 and showing the surface condition of the pavement at that location in year 2009 as obtained from the Caltrans Roadview Explorer[54].

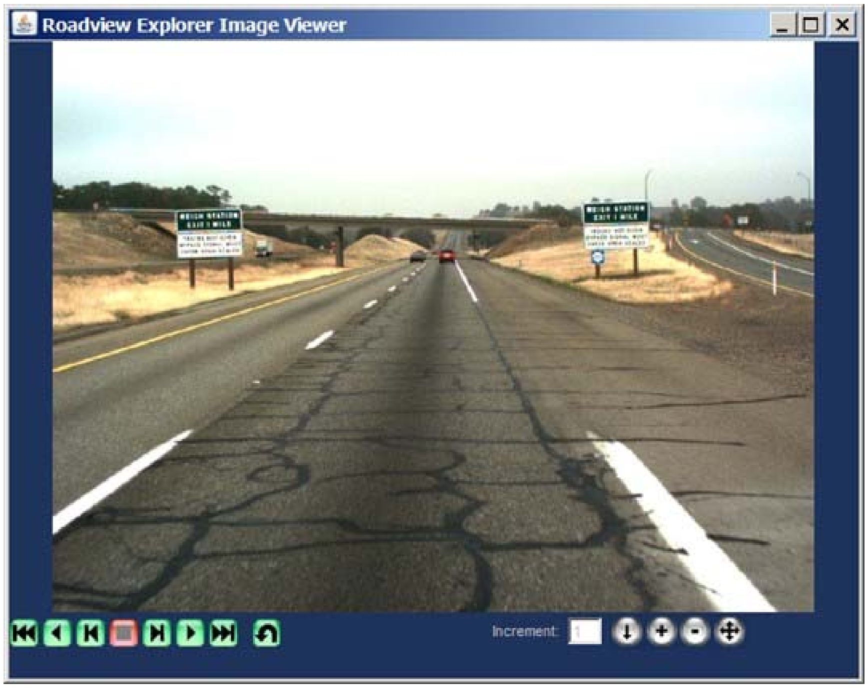


Figure 5-2. Pavement surface condition at PM 38.57 NB (2009 condition survey cycle) of the I-5 Red Bluff long-life project prior to rehabilitation.

5.2 TRAFFIC

The project traffic report indicated a 40-year ADT (average daily traffic) of 102,000 vehicles based on a 2009 traffic survey. The percentage of trucks based on this survey was found to be 17.0%. The 40-year ESAL count (18-kip equivalent single axle load) was determined to be equal to 140,930,000 based on traffic forecasting study and the project traffic report. The 5-year ADT was also given as 54,000 vehicles and the corresponding 5-year ESAL count as 11,590,000.

The Caltrans' empirical design method requires the traffic index (TI) as an input which is calculated as follows:

$$TI = 9.0 \times \left(\frac{ESALs}{1{,}000{,}000}\right)^{0.119} \qquad \textbf{(Equation 1)}$$

where ESALs is the total number of 18,000 lb ESALs expected during the design life. The 5-year and 40-year TI's are calculated as TI_5=12.0 and TI_{40}=16.0 (rounded up).

The growth rate (GR) is a required parameter in the SHRP 2 scoping tool *rePave*. This traffic parameter was determined from available traffic data provided in the District's traffic report for this project. The 5-year ESALs and 40-year ESALs provided above were used to determine the

---

[54] Available to Caltrans engineers on Intranet at http://onramp.dot.ca.gov/photolog/roadview/roadview.php

growth rate. The traffic growth is considered to be of a compound type (geometric) and therefore the growth rate was calculated from the following equation:

$$ESALs_t = ESALs_0 \times (1 + GR)^t \qquad \textbf{(Equation 2)}$$

In this equation, $ESALs_t$ and $ESALs_0$ are, respectively, the total ESALs at time t (e.g., end of design life) and time zero (i.e., when the pavement is re-opened to traffic after construction). Equation 2 can be re-written in terms of GR as follows:

$$GR = \left(\frac{ESALs_t}{ESALs_0}\right)^{\frac{1}{t}} - 1.0 \qquad \textbf{(Equation 3)}$$

Since both the 5-year and 40-year ESALs are available, the $ESALs_t$ is equal to 140,930,000 and $ESALs_0$ is equal to 11,590,000. In this case, the exponent “t” in Equation 3 is equal to 35 (which is the time span in years between the two available ESALs estimates). Using Equation 3, the geometric growth rate (GR) is calculated as:

$$GR = \left(\frac{149{,}930{,}000}{11{,}590{,}000}\right)^{\frac{1}{35}} - 1.0 = 0.074 = 7.4\% \qquad \textbf{(Equation 4)}$$

Since the *rePave* scoping tool does not allow GR above 5%, a growth rate of 5% was used in the analysis for this project, as will be shown later in this chapter.

It is important to note that Equation 2 gives the number of ESALs expected for each year. In order to calculate the total ESALs that the pavement will receive during the entire design life all the estimated annual ESALs must be summed up. Therefore, the total design ESALs is calculated from:

$$Design\ ESALs = \sum_{t=0}^{t=N} ESALs_t \qquad \textbf{(Equation 5)}$$

where $ESALs_t$ is calculated from Equation 2 for each year during the design life, and N is the length of design life in years. It is important to mention that the *rePave* tool does not allow for more than 200 million ESALs (mESALs) over the design life and will warn the user if a greater total ESALs has been entered in the program. For the Red Bluff project, the total ESALs is 126 mESALs; which is below the *rePave* recommended total of 200 mESALs.

5.3 “ESALS PER YEAR” CALCULATIONS

“ESALs per year” is another traffic input in the *rePave* scoping tool. This is considered to be the initial value of ESALs that will grow over the entire design life using the calculated (or assumed) growth rate to result in the total number of ESALs used as the basis for designing the rehabilitation strategy. A Microsoft Excel spreadsheet was developed using the ESAL growth equations (Equations 2 and 5). Knowing the total ESALs during the design life (say 40 years), the spreadsheet will allow the user to enter an initial number of ESALs along with the growth rate (GR). The accumulated ESALs over the design life is then calculated by the spreadsheet and compared to the total ESALs the pavement would be designed for. If the calculated accumulated

ESALs is close to the total ESALs for the design life then the initial ESALs is selected as the "ESALs per year" and used as an input in *rePave*. Otherwise, a new value of initial ESALs is entered and the same trial-and-error procedure performed. The new value to be entered in the spreadsheet is either higher or lower than the value previously entered and the selection depends on how far off the calculated total ESALs appears to be from the known total design ESALs. Note that if the actual growth rate was found to be greater than 5%, then a 5% growth rate was used in the spreadsheet to estimate initial ESALs.

For the Red Bluff project, the total design ESALs for 40 years life is 126 mESALs. The actual growth rate was found to be 7.4%, but then assumed to be equal to 5%. Using the spreadsheet, the initial ESALs was found to be equal to 1.1 mESALs. In other words, starting with 1.1mESALs at time zero and a compound growth rate of 5% over 40 years, the pavement would receive a total of 126 mESALs by the end of the 40th year of trafficking.

5.4 DISTRESS CONDITION

The surface distress types and quantities are also inputs to the *rePave* scoping program. The Caltrans Pavement Condition Report (PCR) of 2008; which provides a collection of surface distress data, was used to obtain quantities of existing distresses at the time of pavement condition survey. Alligator cracking types A and B (based on the Caltrans distress characterization system) varied from 0 to 67% for alligator A and from 0 to 14% for Type B. According to Caltrans distress identification system, Alligator A cracking is longitudinal cracking in wheel path, Alligator B is multiple interconnected cracking in wheel path, and Alligator C cracking is multiple interconnected cracking across entire lane.

The 2008 PCR data was the only data available prior to construction in 2013. Therefore, the distresses where increased to account for the additional pavement deterioration prior to rehabilitation. The average distresses quantities were finally assumed to be as follows:

- Alligator A=20%
- Alligator B=20%
- IRI=100 in/mile (all lanes)

5.5 EXISTING PAVEMENT STRUCTURE

The existing structure layer information; both layer material types and thicknesses are also needed for running the *rePave* scoping tool. The average structure within the project limits was assumed to be as shown in Figure 5-3 below. The cement treated base (CTB) was constructed in 1963 (based on an available Materials Report written in 1976), and the aggregate subbase (AS) was constructed in 1946 based on the same report. As seen in Figure 5-3 the average structure had 0.85 ft (10 in.) HMA over 0.5 ft (6 in.) CTB over 1.0 ft (12 in.) AB over subgrade.

The subgrade basement soil has an R-value of 20 based on the 1976 Materials report. The resilient modulus (M_r) of the soil is needed for running the *rePave* program. The M_r (in psi) can be determined from the R-value using the equation:

$$M_r = 1155 + 555 \times R\_value \qquad \textbf{(Equation 6)}$$

Hence, the subgrade soil M_r is determined as 12,255 psi.

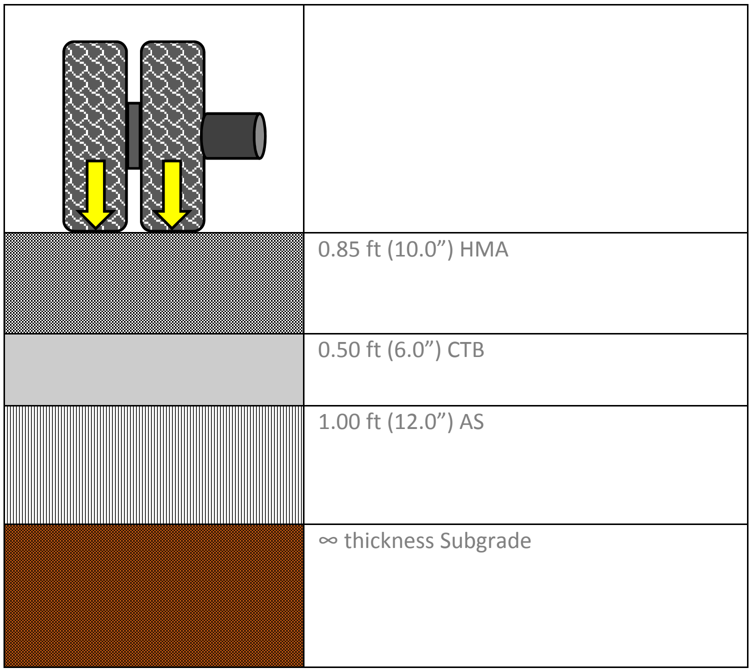
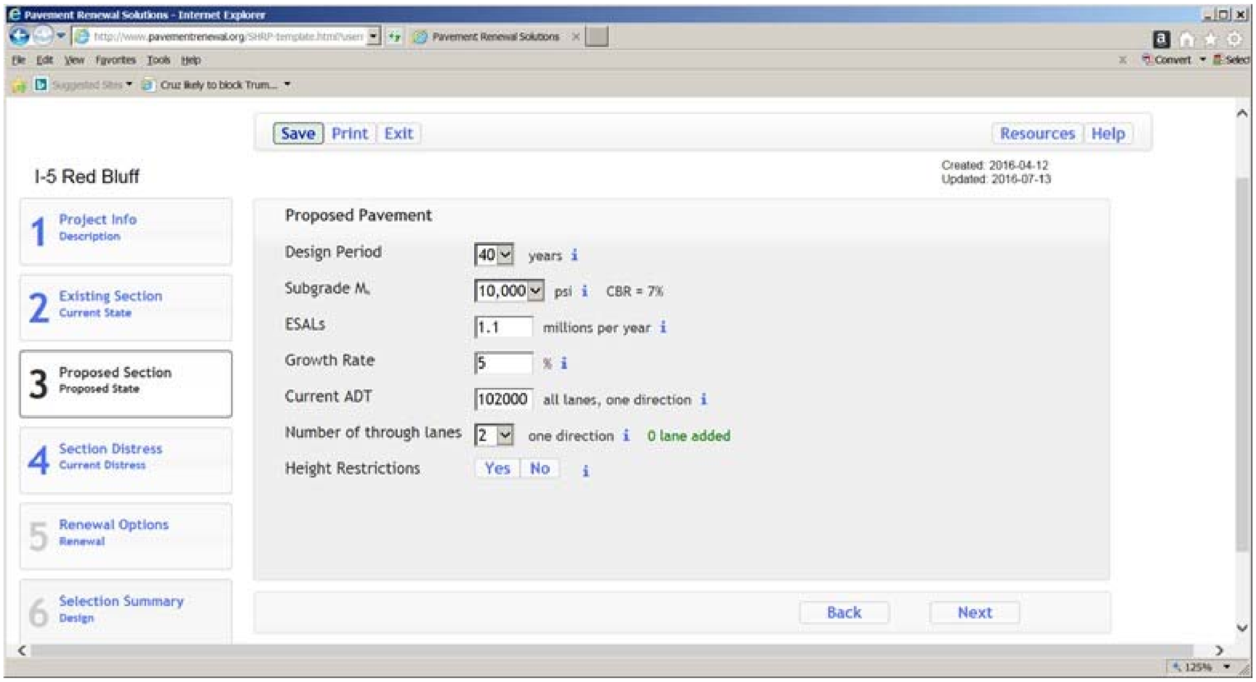


Figure 5-3. Existing pavement structure for Red Bluff project.

At the time of rehabilitation design in 2012-2013, falling weight deflectometer (FWD) testing was conducted on the pavement and resilient modulus backcalculation of all structural layers was performed using the Caltrans software CalBack. The subgrade was found to have an average resilient modulus (M_r) of about 25000 psi. This value represents the in-situ strength of the soil and therefore must be used in the analysis with *rePave*. Since *rePave* allows only three levels of M_r (namely 5000, 10000, 20000 psi corresponding to CBR of 3, 7, and 13, respectively), the M_r value to be used in *rePave* was selected to be 20,000 psi.

5.6 REPAVE SCOPING DESIGN

In this section, the inputs to the *rePave* scoping design tool are discussed. Figure 5-4 shows screenshot of the first set of inputs for the Red Bluff project. It includes design life, subgrade modulus, ESALs per year calculated using the Excel spreadsheet, growth rate, and current ADT.



I-5 Red Bluff

Created: 2016-04-12
Updated: 2016-07-13

Proposed Pavement

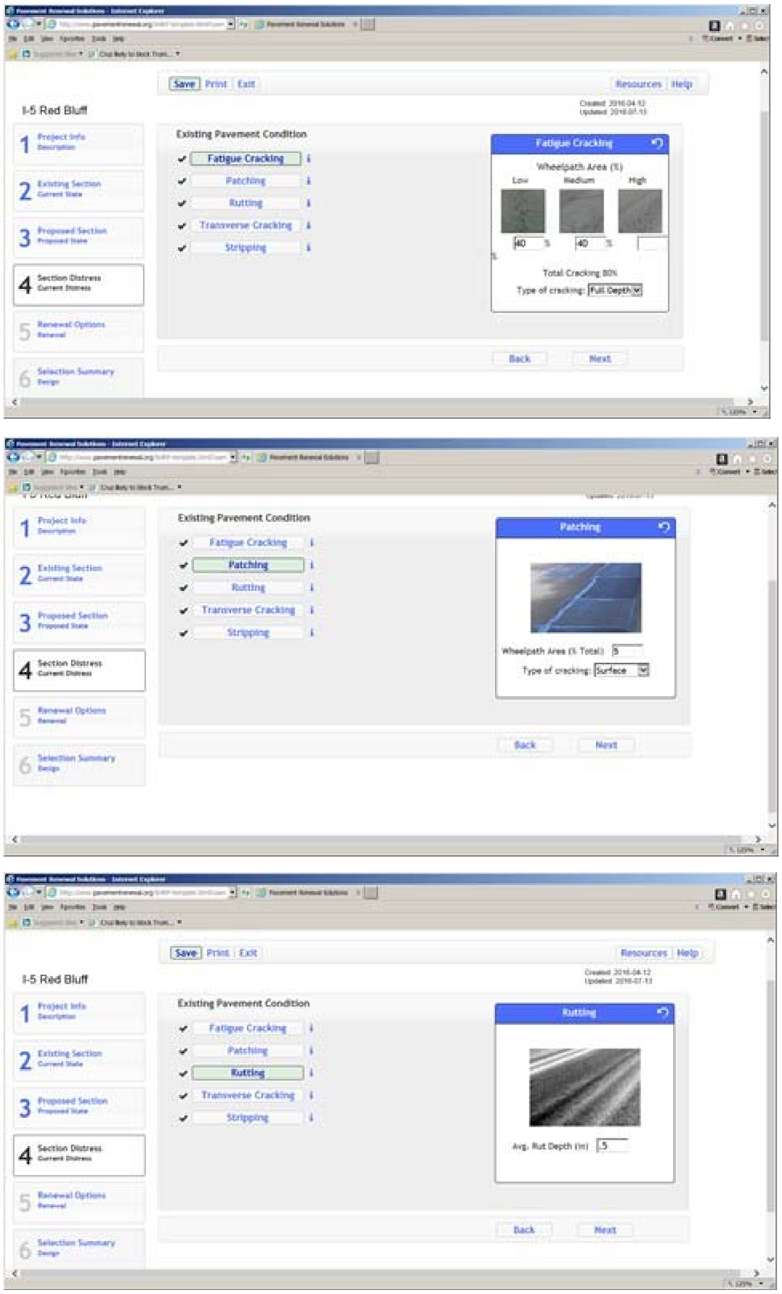
Design Period: 40 years
Subgrade M_r: 10,000 psi CBR = 7%
ESALs: 1.1 millions per year
Growth Rate: 5 %
Current ADT: 102000 all lanes, one direction
Number of through lanes: 2 one direction 0 lane added
Height Restrictions: Yes No

Figure 5-4. Some general inputs for the Red Bluff project.

Next, the following types and quantities of distresses were entered in *rePave* as follows:

- Fatigue cracking=40% low severity and 40% medium severity,
- Patching=5%,
- Rutting=0.5 inch,
- Transverse cracking=5 per 100 ft, and
- Stripping in the HMA layer.

Figure 5-5 (a, b) shows the entered values in *rePave*.



I-5 Red Bluff

Created: 2016-04-12
Updated: 2016-07-13

Fatigue Cracking

Wheelpath Area (%)

Low	Medium	High
40 %	40 %	

Total Cracking 80%

Type of cracking: Full Depth

Patching

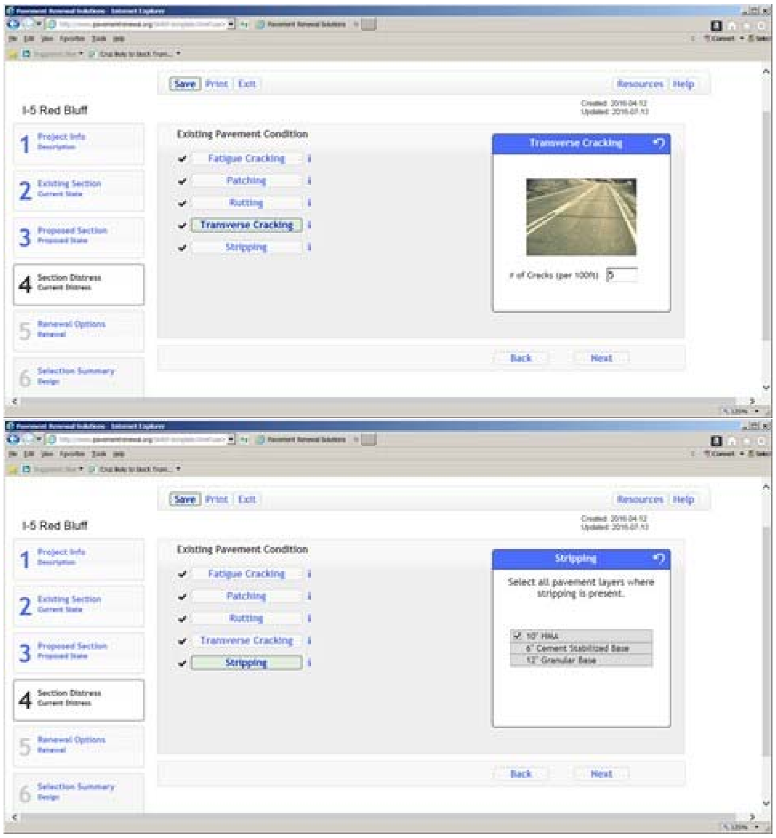
Wheelpath Area (% Total): 5

Type of cracking: Surface

Rutting

Avg. Rut Depth (in): .5

Figure 5-5 (a). Current distress levels for the Red Bluff project entered in *rePave*.



Transverse Cracking

# of Cracks (per 100ft) 5

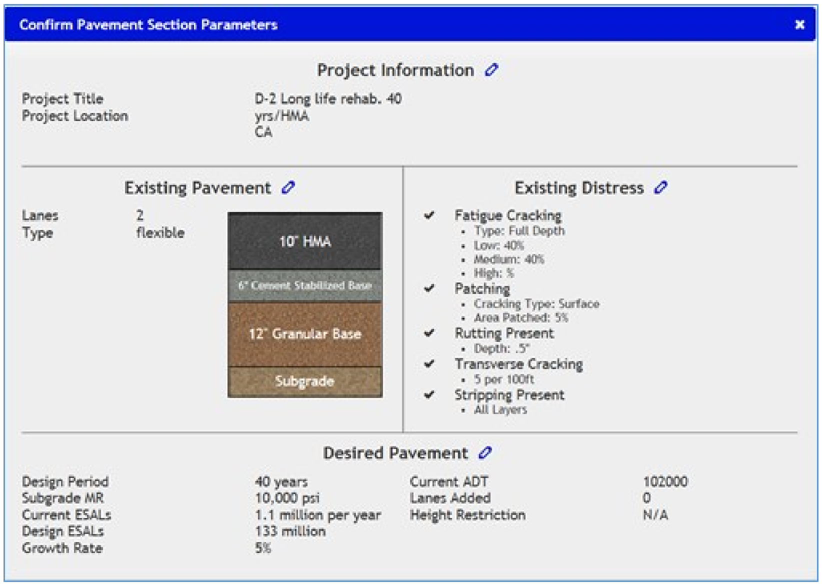
Stripping

Select all pavement layers where stripping is present.

☑ 10" HMA
☐ 6" Cement Stabilized Base
☐ 12" Granular Base

Figure 5-5(b). Current distress levels for the Red Bluff project entered in rePave.

A summary of the entered project information as displayed by *rePave* is shown in Figure 5-6.



Confirm Pavement Section Parameters

Project Information

Project Title	D-2 Long life rehab. 40 yrs/HMA
Project Location	CA

Existing Pavement

Lanes	2
Type	flexible

Existing Distress

- ✓ Fatigue Cracking
  - Type: Full Depth
  - Low: 40%
  - Medium: 40%
  - High: %
- ✓ Patching
  - Cracking Type: Surface
  - Area Patched: 5%
- ✓ Rutting Present
  - Depth: .5"
- ✓ Transverse Cracking
  - 5 per 100ft
- ✓ Stripping Present
  - All Layers

Desired Pavement

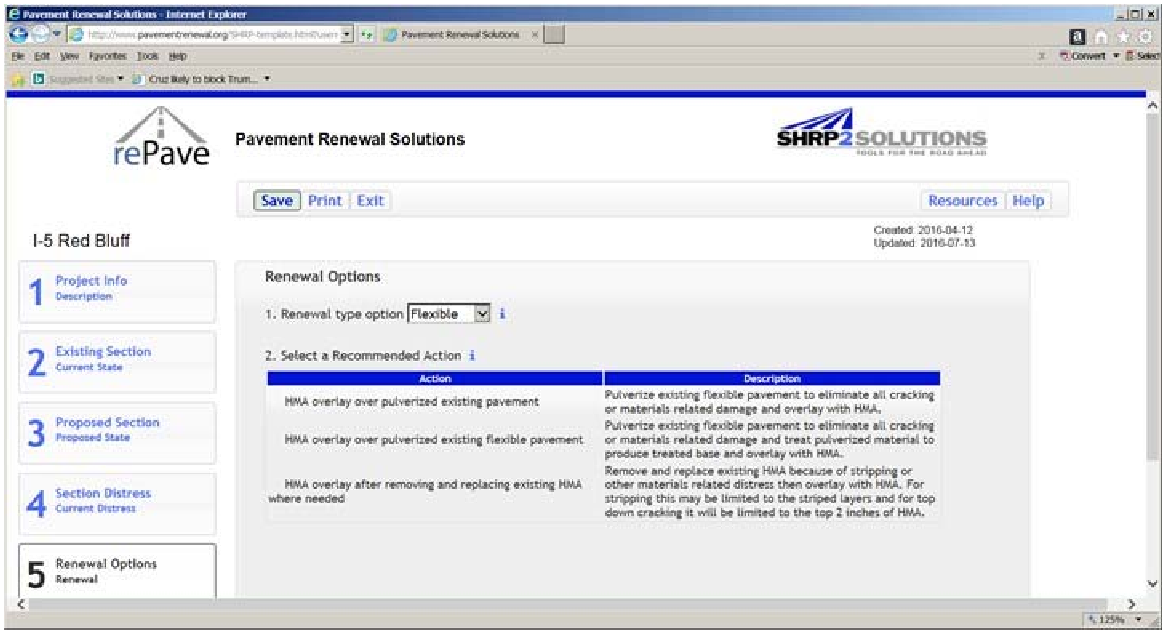
Design Period	40 years	Current ADT	102000
Subgrade MR	10,000 psi	Lanes Added	0
Current ESALs	1.1 million per year	Height Restriction	N/A
Design ESALs	133 million		
Growth Rate	5%		

Figure 5-6. Summary of entered data for the Red Bluff project.

There are two viable options that can be considered in scoping of this project. The first is using asphalt concrete and the other using Portland cement concrete (PCC). The first option was adopted as the final strategy to be used on the Red Bluff project, and will be discussed first in the next section. The other option involving PCC is concerned with the placement of an unbonded concrete overlay (whitetopping) over the existing asphalt concrete. This option will also be discussed.

5.6.1 Rehabilitation with Asphalt Concrete

The *rePave* scoping tool proposes several renewal options as shown in Figure 5-7 for this project. Because the actual rehabilitation design was performed and consisted of removing all existing HMA on top of the CTB and placing a new HMA, a similar renewal option was selected from the shown list (the bottom selection in Figure 5-7).



I-5 Red Bluff

Created: 2016-04-12
Updated: 2016-07-13

Renewal Options

1. Renewal type option Flexible

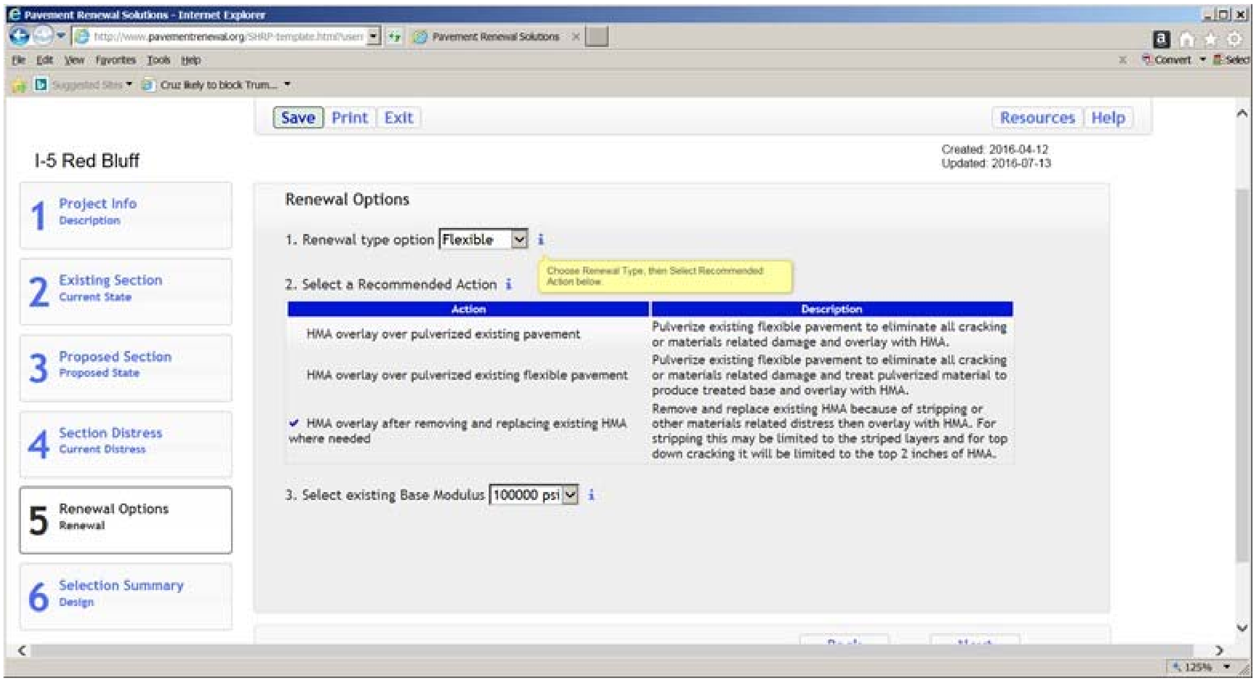
2. Select a Recommended Action

Action	Description
HMA overlay over pulverized existing pavement	Pulverize existing flexible pavement to eliminate all cracking or materials related damage and overlay with HMA.
HMA overlay over pulverized existing flexible pavement	Pulverize existing flexible pavement to eliminate all cracking or materials related damage and treat pulverized material to produce treated base and overlay with HMA.
HMA overlay after removing and replacing existing HMA where needed	Remove and replace existing HMA because of stripping or other materials related distress then overlay with HMA. For stripping this may be limited to the striped layers and for top down cracking it will be limited to the top 2 inches of HMA.

Figure 5-7. Renewal options proposed by *rePave* for the Red Bluff project.

For this renewal option, the “base” modulus must be entered in *rePave* as shown in Figure 5-8. For this renewal option, the *rePave* tool offers three levels of base resilient modulus depending on the type of base produced in the renewal process:

- For basic pulverized asphalt concrete, the suggested modulus is 50000 psi,
- For a pulverized asphalt concrete treated with a stabilizing agent to improve the strength of the produced base, the suggested resilient modulus value is 100000 psi, and
- For an existing aggregate base layer beneath an existing asphalt concrete the modulus of the base is assumed to be 30000 psi.



I-5 Red Bluff

Created: 2016-04-12
Updated: 2016-07-13

Renewal Options

1. Renewal type option Flexible

2. Select a Recommended Action

Choose Renewal Type, then Select Recommended Action below.

Action	Description
HMA overlay over pulverized existing pavement	Pulverize existing flexible pavement to eliminate all cracking or materials related damage and overlay with HMA.
HMA overlay over pulverized existing flexible pavement	Pulverize existing flexible pavement to eliminate all cracking or materials related damage and treat pulverized material to produce treated base and overlay with HMA.
✓ HMA overlay after removing and replacing existing HMA where needed	Remove and replace existing HMA because of stripping or other materials related distress then overlay with HMA. For stripping this may be limited to the striped layers and for top down cracking it will be limited to the top 2 inches of HMA.

3. Select existing Base Modulus 100000 psi

Figure 5-8. The existing base modulus that must be selected.

The rules for renewal utilizing these options are given in the document (page 31) provided at http://www.pavementrenewal.org/docs/ScopingMethodology.pdf. The *rePave* tool allows the user to change these suggested values depending on the quality of the base; therefore, 4 modulus levels are available: 30000, 50000, 75000, and 100000 psi.[55] According to an email from Newt Jackson received after initial review of this report, the rePave program suggests a base modulus of 75000 psi for crack-seat-and-overlay design to account for reflection cracking to be more in line with the Transport Research Laboratory (TRL)'s guidance on this method of rehabilitation. A higher modulus value of 100000 psi would only result in slightly thinner asphalt concrete overlay.[56]

---

[55] In a communication with Mr. Newt Jackson (lead developer of *rePave*), it was clarified that the development of rePave was based on the assumption that a minimum thickness of HMA must be 7 inches over any cement stabilized base or CSOL to address reflection cracking potential issue. The TRL's guidelines suggests using a minimum of 6 inches thickness to minimize reflective cracking. The rePave increased this minimum to 7 inches. To obtain a minimum of 7 inches thick HMA, rePave pre-sets the base modulus to 75000 psi if CTB or cracked-and-seated JPCP is the underlying layer beneath the new HMA. It also pre-sets base modulus to 100000 psi when there is no reflection cracking or when HMA is to be placed over CRCP.

[56] As general guidance, an email from Newt Jackson recommended that the base modulus be assigned a value of 75000 psi for general asphalt concrete and a value of 100000 psi when the asphalt mix consists of a special binder or when the layer is a rich bottom layer type.

If more than one base layer exists, this report proposes to obtain modulus of a "composite base". The composite base modulus is a modulus representing all the available base and subbase layers between the asphalt concrete layer and the subgrade. For the Red Bluff project, there are two layers of bases: a 6-inch cement treated base (CTB) and a 12-inch aggregate subbase (AS). In order to obtain the modulus of the "composite" base (i.e., a base with the combined effect of the CTB and AS layers), the structural rigidity principle[57] discussed in Chapter 2 was used. In this regard, the composite layer (CTB+AS) is related to the individual layers moduli (E's) and layers thicknesses (h's) using the following expression (presented in general form earlier in Chapter 2):

$$h_{CTB+AS} \times \sqrt[3]{E_{CTB+AS}} = h_{CTB} \times \sqrt[3]{E_{CTB}} + h_{AS} \times \sqrt[3]{E_{AS}} \qquad \textbf{(Equation 7)}$$

If the modulus (E) and thickness (h) of the CTB and AS layers are known, then the composite base modulus can be determined from the following equation:

$$E_{CTB+AS} = \left(\frac{h_{CTB}\times\sqrt[3]{E_{CTB}}+h_{AS}\times\sqrt[3]{E_{AS}}}{h_{CTB}+h_{AS}}\right)^3 \qquad \textbf{(Equation 8)}$$

At the time when actual rehabilitation design was sought for this long life project, FWD testing was conducted in both the southbound and northbound lanes for about 1.3 miles in each direction. The deflection basin data along with the structural section layers thicknesses obtained from cores, as-built plans, and ground penetrating radar (GPR) survey were used to determine the in-situ resilient moduli of the existing CTB, AS, and the subgrade using backcalculation analysis. The Caltrans backcalculation software CalBack was used for such analysis. The backcalculation indicated that the existing CTB layer is still in a relatively fair-to-good condition with an average resilient modulus of ~425000 psi. Similarly, the AS layer was found to have an average modulus of ~31000 psi, and the subgrade an average modulus of ~25000 psi. Cores, as-built plans, and GPR data revealed that the thickness of the CTB and AS layer averaged about 6 inches and 12 inches, respectively. Therefore, the composite base modulus was determined from Equation 8 as follows:

$$E_{CTB+AS} = \left[\frac{6"\times\sqrt[3]{425000}+12"\times\sqrt[3]{31000}}{6"+12"}\right]^3 \approx 90{,}000\ psi \qquad \textbf{(Equation 9)}$$

If an Engineer is scoping this project, no FWD data would typically be available. Therefore, the composite base modulus must be determined using average typical modulus values of CTB and AS. Care must be taken in selecting CTB modulus value because it is highly dependent on the structural integrity of the CTB layer as observed from the taken cores[58]. Future Caltrans HDM

---

[57] Huang Y.H. (1993). Pavement Analysis and Design. Prentice Hall, Englewood Cliffs, NJ (Equation 3.29, p. 139).

[58] In absence of any guidelines, the Engineer may consider the following values of resilient modulus of the CTB in scoping of their project depending on the base overall condition: Poor 250,000 psi, Fair 500,000 psi, and Good 1,000,000 psi.

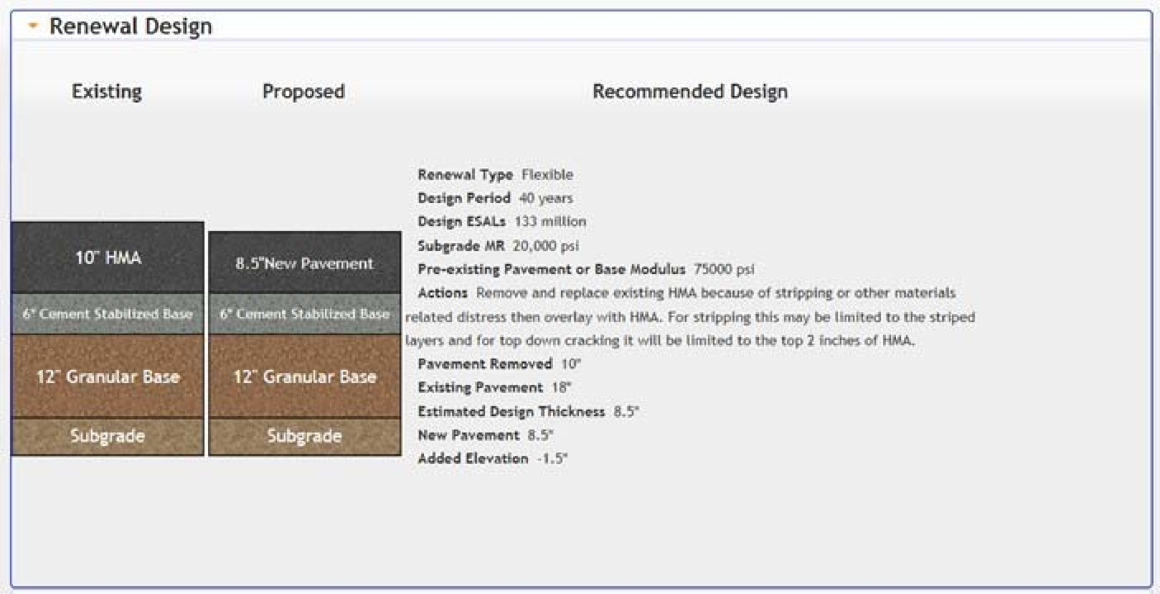
updates will provide typical values of resilient modulus of pavement materials for various condition levels.

For the Red Bluff project, the estimated composite modulus of 90000 psi lies between the *rePave* suggested values of 75000 psi and 100000 psi. Therefore, two renewal designs are available based on the assumed modulus:

1. Based on the lower end of this range (i.e., 75000 psi), the renewal recommendation proposed by the *rePave* tool is 8.5 inches of HMA overlay placed over the CTB layer.
2. Based on the upper end of this modulus range (i.e., 100000 psi), the renewal recommendation is 7.0 inch HMA overlay over the CTB layer.

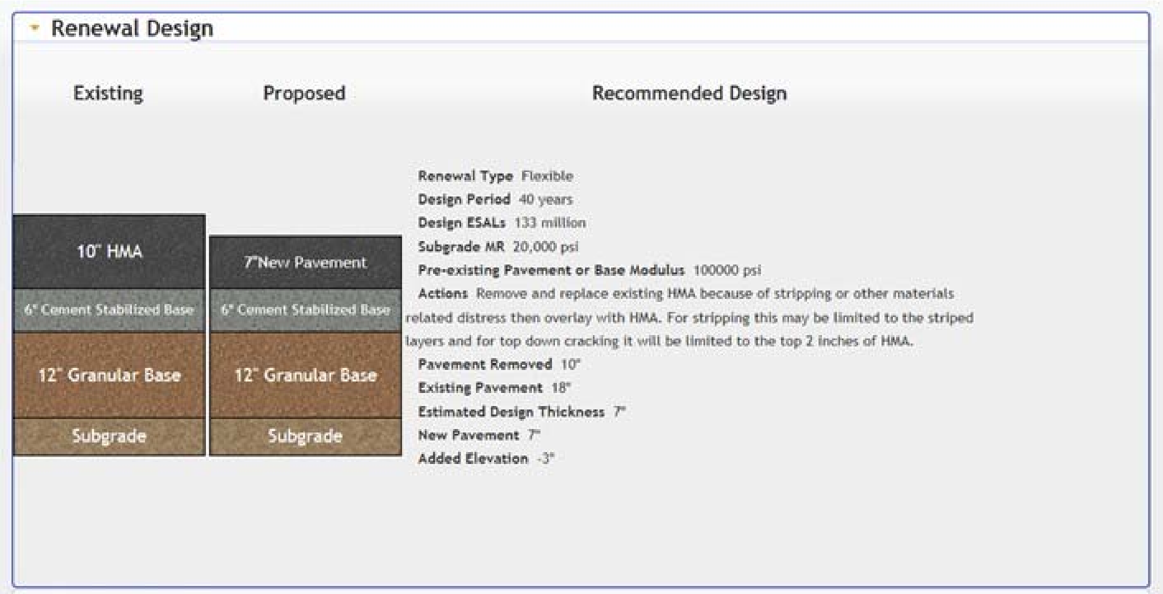
These two strategies are shown in Figure 5-9 below.

In a later section of this chapter, the *rePave* scoping designs will be compared against the final design obtained using the Caltrans mechanistic-empirical design program (CalME).



Renewal Type Flexible
Design Period 40 years
Design ESALs 133 million
Subgrade MR 20,000 psi
Pre-existing Pavement or Base Modulus 75000 psi
Actions Remove and replace existing HMA because of stripping or other materials related distress then overlay with HMA. For stripping this may be limited to the striped layers and for top down cracking it will be limited to the top 2 inches of HMA.
Pavement Removed 10"
Existing Pavement 18"
Estimated Design Thickness 8.5"
New Pavement 8.5"
Added Elevation -1.5"

(a) Using composite base modulus of 75000 psi



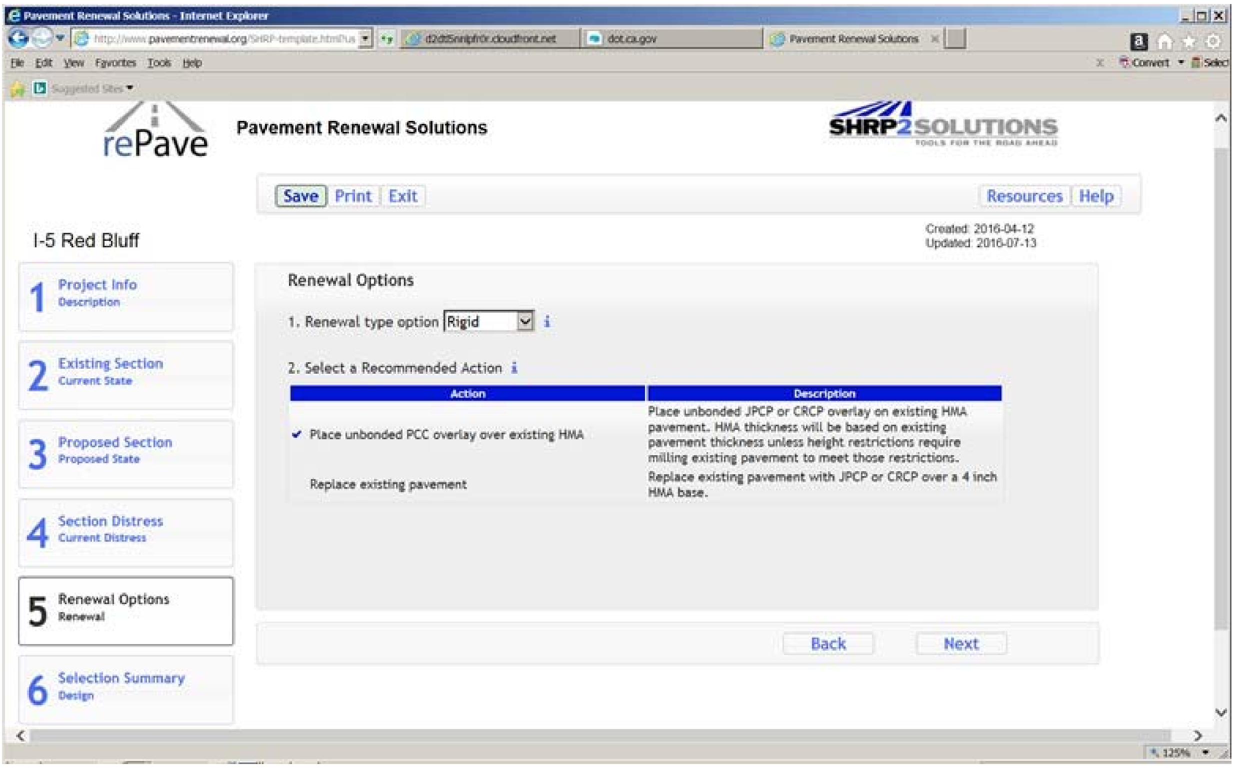
Renewal Type Flexible
Design Period 40 years
Design ESALs 133 million
Subgrade MR 20,000 psi
Pre-existing Pavement or Base Modulus 100000 psi
Actions Remove and replace existing HMA because of stripping or other materials related distress then overlay with HMA. For stripping this may be limited to the striped layers and for top down cracking it will be limited to the top 2 inches of HMA.
Pavement Removed 10"
Existing Pavement 18"
Estimated Design Thickness 7"
New Pavement 7"
Added Elevation -3"

(b) Using composite base modulus of 100000 psi

Figure 5-9. Renewal design recommendation for the *rePave* tool based on a composite base modulus of (a) 75000 psi and (b) 100,000 psi.

5.6.2 Rehabilitation with Unbonded PCC Overlay (Whitetopping)

Whitetopping is an unbonded jointed plain Portland cement concrete layer (PCC overlay) placed over the existing asphalt concrete. Although the final design included milling off the existing asphalt concrete and replacing with a new overlay designed using CalME, whitetopping could have been considered as another viable option for scoping of the project. The pavement scoping tool *rePave* can be used to determine the PCC overlay thickness for the project. In this case, the renewal type option is selected as “Rigid” as shown in Figure 5-10. By selecting the unbonded concrete overlay action, the PCC overlay thickness was determined to be 11.5 inches as shown in Figure 5-11.



I-5 Red Bluff

Created: 2016-04-12
Updated: 2016-07-13

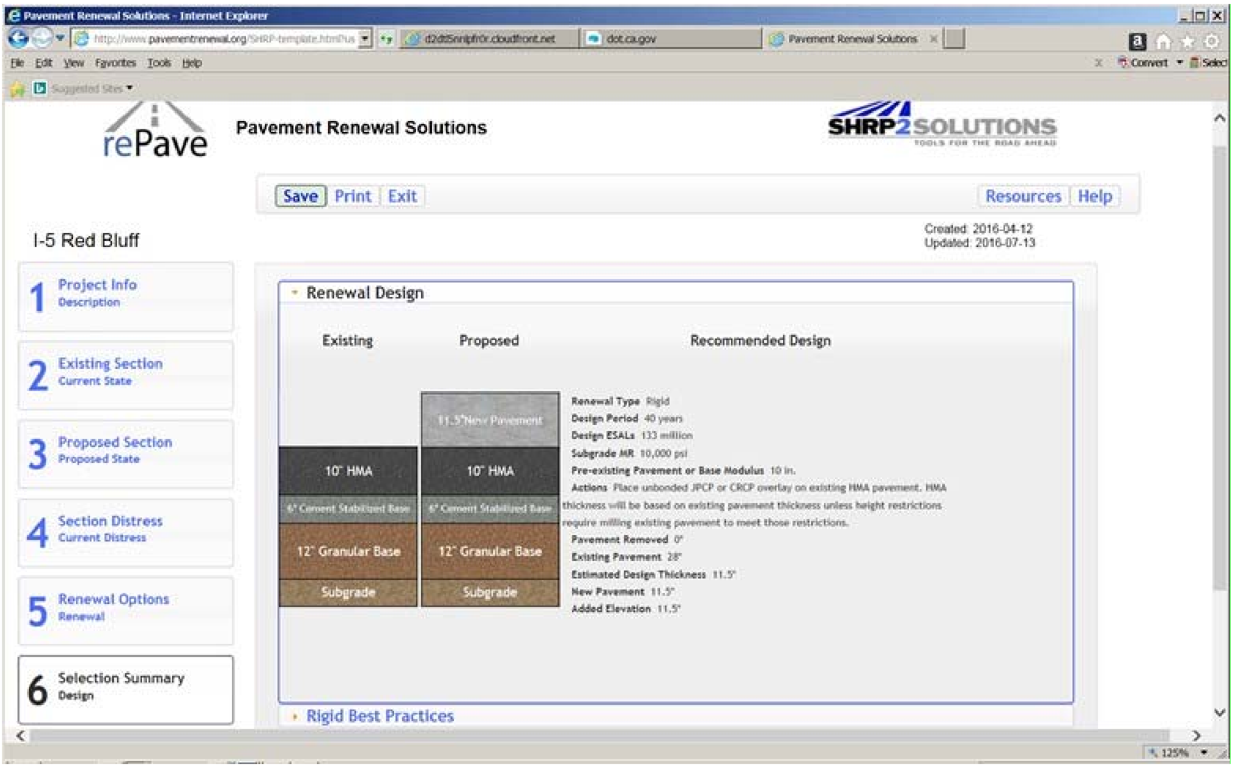
Renewal Options

1. Renewal type option Rigid

2. Select a Recommended Action

Action	Description
✓ Place unbonded PCC overlay over existing HMA	Place unbonded JPCP or CRCP overlay on existing HMA pavement. HMA thickness will be based on existing pavement thickness unless height restrictions require milling existing pavement to meet those restrictions.
Replace existing pavement	Replace existing pavement with JPCP or CRCP over a 4 inch HMA base.

Figure 5-10. Unbonded PCC overlay selection in *rePave* for Red Bluff project.



Renewal Type Rigid
Design Period 40 years
Design ESALs 133 million
Subgrade MR 10,000 psi
Pre-existing Pavement or Base Modulus 10 in.
Actions Place unbonded JPCP or CRCP overlay on existing HMA pavement. HMA thickness will be based on existing pavement thickness unless height restrictions require milling existing pavement to meet those restrictions.
Pavement Removed 0"
Existing Pavement 28"
Estimated Design Thickness 11.5"
New Pavement 11.5"
Added Elevation 11.5"

Figure 5-11. The required unbonded PCC overlay thickness determined with *rePave* for Red Bluff project.

5.7 FINAL DESIGN

5.7.1 Asphalt Overlay Design Using CalME

CalME is the advanced Caltrans' mechanistic-empirical (ME) software used for reliability-based designing and analysis flexible pavements (both new construction and rehabilitation)[59]. The Caltrans ME method utilizes a vast number of design inputs pertaining to materials engineering properties, climatic factors, and detailed traffic loading based on weigh-in-motion (WIM) data and loading spectra to determine a set of pavement performances (cracking, rutting, IRI, etc.) expected during the design life. The 40-year rehabilitation strategy of this project was designed using CalME. Detailed hot mix asphalt (HMA) inputs for characterizing the fatigue cracking and rutting performances as well as flexural stiffness of the HMA materials are needed for such analysis and were all obtained from advanced HMA testing employing the standard test methods AASHTO T 320 (repetitive shear deformation for asphalt concrete rutting characterization)[60] and

---

[59] P. Ullidtz, J. Harvey, **I.** Basheer, Jones D., Wu R., Lea J., and Lu Q. (2010). CalME: A New Mechanistic-Empirical Design Program for Flexible pavement Rehabilitation. Transportation Research Record, No. 2153, pp. 143-152).

[60] Method of Test for Determining the Permanent Shear Strain and Stiffness of Asphalt Mixtures Using the Superpave Shear Tester (SST)

AASHTO T 321 (repetitive 4-point beam bending for asphalt fatigue characterization)[61]. It is outside the scope of this evaluation report to discuss the details of the design parameters used or the design process employed, but the following step-by-step final rehabilitation recommendations were developed:

1. Mill off existing HMA 0.85 ft (10”),
2. Place 0.20 ft (2.4”) HMA PG 64-10 Rich Bottom (no Reclaimed Asphalt Pavement RAP),
3. Place 0.20 ft (2.4”) HMA PG 64-10 with 25% RAP,
4. Place 0.30 ft (3.6”) HMA PG 64-28 PM (with up to 15% RAP allowed), and finally
5. Place 0.10 ft (1.2”) rubberized open graded friction course (OGFC).

Figure 5-12 shows schematic of the rehabilitated pavement structure. This design was obtained for a reliability level of 90%.

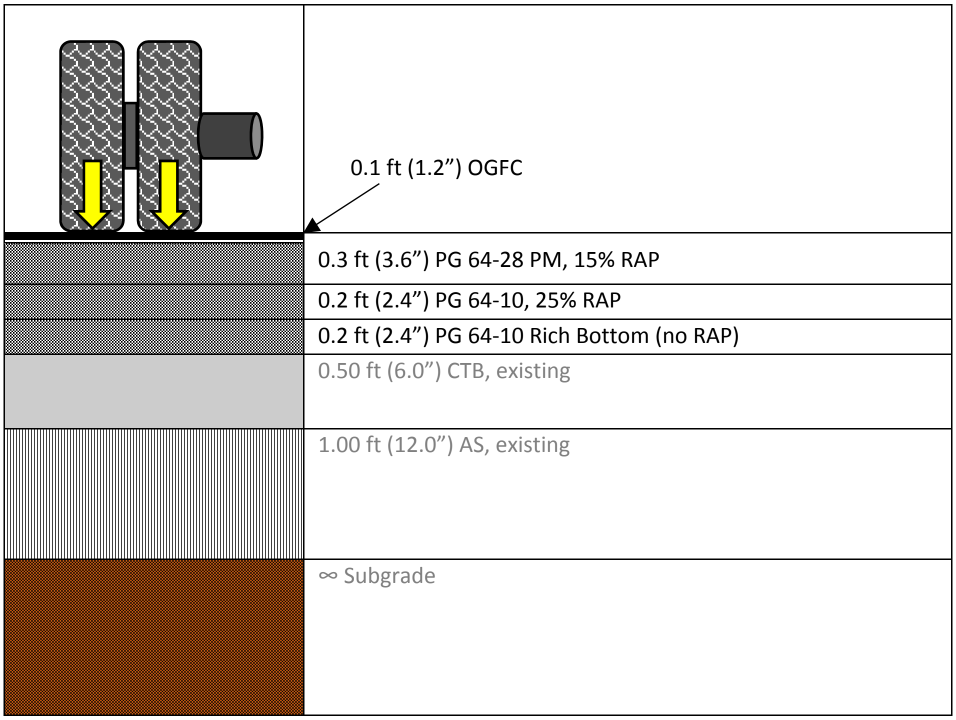


Figure 5-12. Rehabilitation design for Red Bluff project using the CalME process.

As noticed in the rehabilitation recommendations and Figure 5-12, the mill and replace strategy included milling off all the existing HMA and the placement of a three-HMA type overlay structure to provide for a perpetual (long life) pavement performance. In this structure, the first layer of HMA consists of a rich bottom layer which has 0.5% additional binder content over what is normally designed for. This will provide for a more fatigue resistant HMA at the bottom of the overlay to prevent bottom up cracking at the underside of the overlay. The middle layer is a rutting resistant layer that has 25% reclaimed asphalt pavement (RAP), and the top layer has

---

[61] Standard Method of Test for Determining the Fatigue Life of Compacted Asphalt Mixtures Subjected to Repeated Flexural Bending

fatigue and rutting resistant layer made with a polymer modified binder. The rich bottom layer was not allowed to have any RAP, whereas the top polymer-modified (PM) layer has 15% RAP. A non-structural wearing course composed of open graded friction course (OGFC) was also recommended to improve the final surface skid resistance and to provide for additional protection for the structural HMA layer against hardening and oxidation. This wearing course will have to be replaced regularly (every 5-7 years) to maintain the integrity of the structural HMA layer. As seen in Figure 5-12, the total HMA thickness above the CTB layer is 0.70 ft (8.4 inches).

6.7.2 Whitetopping Design with Caltrans HDM Concrete Catalog

The Caltrans HDM allows the design (actually final design) of an unbonded concrete overlay (whitetopping) as if it were a new jointed plain concrete pavement (JPCP) placed over an asphalt concrete base. The existing asphalt concrete is considered the asphalt concrete base and it also serves as the bond breaker. In order to determine the required thickness of the PCC overlay, the Caltrans HDM catalog (Table 623.1) is used. The following four basic project-related inputs are required for determining the PCC overlay thickness:

1. Climate: The climate prevailing at the project site is determined with the aid of the climate map given in Figure 615.1 of the Caltrans HDM[62]. For this project, the climate was determined using the CalME’s climate database in terms of the project location data (county, route No., and post mile limits). For this location, the climate is found to be “Inland Valley”.

2. 40-year Traffic Index (TI_{40})=16.0,

3. Lateral support: It is assumed that the concrete slabs will have no lateral support. According to the HDM, lateral support condition exists if concrete shoulders are available or when widened concrete slabs are constructed, and

4. Subgrade type: The subgrade is assumed to be a Type II (based on R-value and soil classification, see HDM F 623.1A[63]).

Given the climate and subgrade type, Table 623.1 G of the Caltrans HDM concrete catalog is selected. Based on TI and lateral support condition, the unbonded PCC overlay thickness was found to be 1.20 ft (14.5 inch). This thickness is part of the new concrete pavement structure consisting of 1.20 ft JPCP over 0.25 ft HMA base over 0.70 ft AS over subgrade (see Table 623.1 G of the HDM). Note that all JPCP sections in the Catalog are steel-dowelled (see HDM Chapter 620, Table 622.1 for dowel dimensions). Additionally, all catalog designs provide a 90% reliability and are based on performance thresholds provided in Table 622.1 of the Caltrans HDM. A schematic of the final rehabilitated structure using this renewal option is given in Figure 5-13.

---

[62] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0610.pdf

[63] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0620.pdf

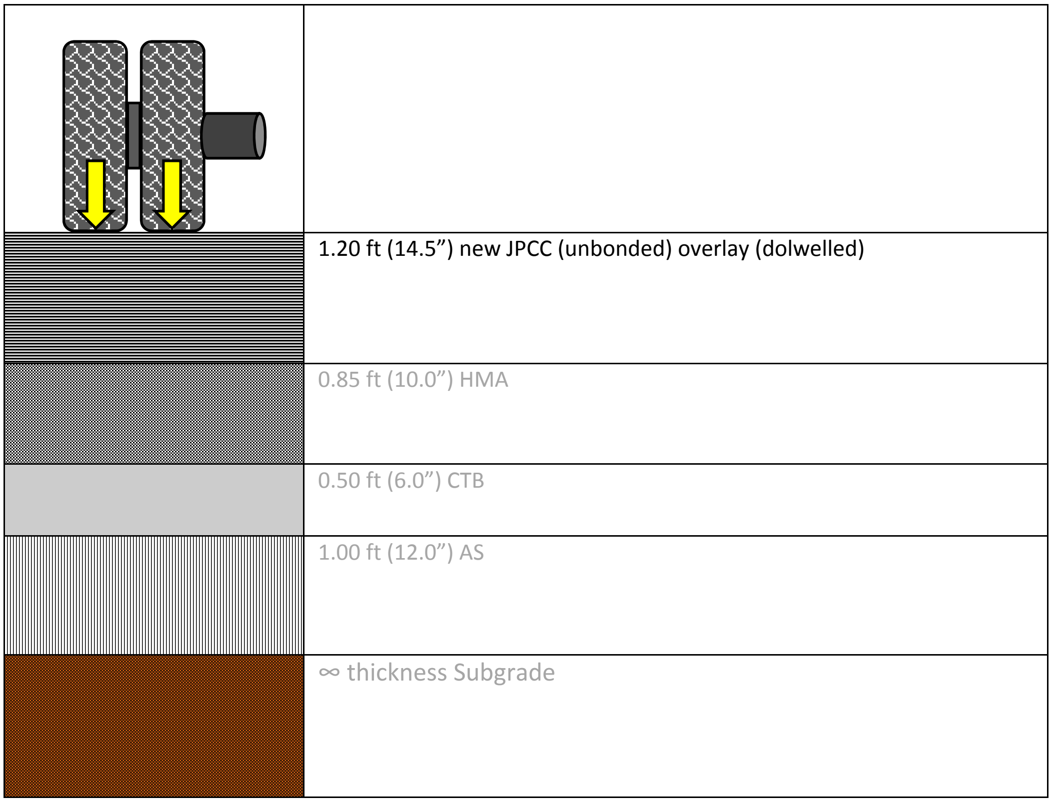


Figure 5-13. Unbonded PCC overlay placed over the pavement for the Red Bluff project.

5.8 COMPARISON

Regarding the “flexible” renewal option, the scoping tool *rePave* showed that a total of 7.0 inches HMA would be needed over the 100000 psi CTB, or 8.5 inches of HMA when the CTB modulus is assumed to be 75000 psi. These two values must be compared with the actual design thickness determined with CalME which was found to be 0.70 ft (8.4 inches) of HMA. For a composite modulus of 90000 psi the ME-based design thickness is between these two *rePave* estimated values. In fact, the proposed HMA thickness based on a 75000 psi base modulus is almost identical to the ME-based final design (8.4 inch final design vs. 8.5 inch from *rePave*). This finding indicates that the *rePave* estimation of the rehabilitation needs based on limited amount of project data and no laboratory or field testing (although some backcalculated base modulus values were used) is quite reasonable for scoping purposes[64]. It is to be noted that the *rePave* Development Team used 90% reliability in developing the scoping designs assuming that the designs would be largely on Interstate or similar highways[65]. Similarly, the CalME design given

---

[64] Despite this finding, it is important that *rePave* use be restricted to scoping purposes and not for developing final designs. Instead, a final design tool must be used and comprehensive materials laboratory and field testing must be performed to determine the actual rehabilitation needs (e.g., using CalME).

[65] Email from Mr. Newt Jackson dated 8/12/2016

above was also based on 90% reliability. This provides for a valid comparison since the thickness is highly dependent on the reliability sought for the design.

Regarding the "rigid" option, the *rePave* scoping design was 11.5 inches of unbonded concrete overlay, whereas the Caltrans HDM catalog design indicated a total of 14.5 inches of concrete would be needed. The Caltrans HDM catalog provides for a more conservative design since it is actually developed for new JPCP pavements rather than concrete overlays. The "new construction" design per the catalog has 1.2 ft JPCP over 0.25 ft HMA base over 0.70 ft AS. Using the PCC overlay thickness given in the catalog without giving any consideration to the actual existing structure obviously contributed to the 3.0 inches difference in the thicknesses between the two methods (with the Catalog's design being overconservative):

1. the existing HMA is much thicker than what would be needed per the catalog design,
2. the CTB in the existing section has been disregarded.

Note that the HDM's rigid Catalog designs offer 90% reliability.

It is important that the effect of traffic inputs be taken into consideration when comparing the two scoping systems. The scoping tool *rePave* uses traffic loading based on load spectra representative of rural interstate[65], but CalME uses load spectra reflective of the actual traffic at the project site measured using weigh-in-motion data. On the other hand, the California HDM catalog was developed based on using statewide representative "Urban" and "Rural" axle load spectra[66]. The effect of the possible variation in load spectra on the design thicknesses between the three design systems is outside the scope of this evaluation study and was not investigated any further.

---

[66] See report http://www.ucprc.ucdavis.edu/PDF/MPEDG%20Stg%205%20Final%20UCPRC-TM-2006-04%20with%20FHWA.pdf

6 CASE STUDY 2 (I-5 WEED)

6.1 PROJECT DESCRIPTION

The I-5 long-life project near the City of Weed in Northern California was constructed in 2012 and has been in service for 4 years. The project location is shown in the "Google Earth" aerial map given in Figure 6-1. The project limits extend from PM 37.5 to 41.5 in both directions. The project is located in Siskiyou County between Antelope Blvd crossing to Gas Point Road. The facility within the project limits is primarily a four-lane divided highway with two lanes in each direction. In the remainder of this report, this project will be referred to as the Weed Project.

Figure 6-1. Aerial map of showing the location limits of the Weed project.

Before rehabilitation, the pavement within the said project limits exhibited extensive reflection cracking in the asphalt concrete and occasional stripping. The existing asphalt concrete was placed over an originally constructed jointed plain concrete pavement (JPCP), that is believed to have been cracked and seated prior to placement of the asphalt concrete. Cores obtained from the asphalt layer at various locations exhibited delamination at various depths. Figure 6-2 shows a photo of an example pavement surface condition taken from the northbound direction at PM 24.6 (based on a 2009 survey available in the Caltrans Roadview Explorer). Notice in Figure 6-2 the transverse and longitudinal reflection cracking that existed in 2009. In 2013; right before construction, the distress condition was noticed to have deteriorated further.

Figure 6-2. A photo of the asphalt concrete overlaid JPCP taken at PM 24.6 NB of the Weed project.

6.2 TRAFFIC

The traffic report prepared for the Weed project indicated a 40-year ADT (average daily traffic) of 30,500 vehicles based on the 2009 traffic survey. The percentage of trucks based on 2009 survey was found to be 24.0%. The 40-year ESALs (18-kip equivalent single axle load) is given as 65,740,000. The 5-year ADT was estimated as 18,850 and the corresponding 5-year ESALs 6,790,000 based on the project traffic report. The 5-year and 40-year TI's are calculated (and rounded up) as follows:

- 5-year TI (TI_5)=11.5
- 40-year TI (TI_{40})=15.0

The growth factor (rate) is a required parameter in *rePave* and it was calculated in the same way as was done previously for the Red Bluff project. Using the above 5-year and 40-year ESAL estimates, the geometric growth rate (GR) is calculated as:

$$GR = \left(\frac{65740000}{6790000}\right)^{\frac{1}{35}} - 1 = 0.067 = 6.7\%$$

The upper limits of the 5-year and 35-year ESALs based on the provided TI values are 7,850,000 and 82,490,000, respectively (according to Caltrans HDM). With these ESALs, the GR was also calculated using the same equation shown above and found to be equal to 7.0%. Since the *rePave* scoping tool does not allow GR above 5%, a growth rate of 5% was used in the analysis.

6.3 "ESALS PER YEAR" CALCULATIONS

ESALs per year is another input in *rePave* and was calculated in the same way as it was calculated for the Red Bluff project. For the Weed project, the total design 40-year ESALs is 65,740,000 ESALs

(~66 mESALs). The actual growth rate was found to be 7.0%, but then assumed to be equal to 5%. Using the ESAL accumulation spreadsheet, the initial ESALs was found to be equal to 0.7 mESALs. This means that starting with 0.7 mESALs and at a compound annual growth rate of 5% over 40-year period (the project design life) the pavement is expected to receive a total of 66 mESALs by the end of the 40th year of trafficking.

6.4 DISTRESS CONDITION

The 2008 Caltrans Pavement Condition Report (PCR) was used to obtain the type and quantities of existing distresses needed to run *rePave*. The following average distress quantities were finally assumed:

- Alligator A (longitudinal)=15%
- Alligator B (fatigue)=30%
- IRI=130 in/mile (all lanes)

These values where increased from the 2008 PCR data to account for the additional deterioration that occurred to the pavement until year 2013 when construction started.

6.5 EXISTING PAVEMENT STRUCTURE

The existing structural layer information in terms of layer material types and thicknesses is also needed for the *rePave* scoping tool. The average structure representing the Weed project is shown in Figure 6-3. The average structure consisted of 0.45 ft (5.5 in.) HMA over 0.65 ft (8.0 in.) old PCC over 0.45 ft (5.5 in.) CTB over 0.5 ft (6.0 in.) AS over subgrade. Based on the 1976 Materials Report, the existing asphalt concrete was constructed in 2000, the PCC pavement in 1990, the cement treated base (CTB) in 1963, and the aggregate subbase (AS) in 1946. The existing HMA overlay was almost 13 years old when the latest rehabilitation was performed as the initial crack-seat-and overlay was completed in 2000 (the original crack-seat and overlay design was the standard 10-year design).

The subgrade basement soil has an R-value of 20 based on the 1976 Materials Report. The resilient modulus (M_r) of the soil was determined from the known R-value using the following relationship: $M_r(psi) = 1155 + 555 \times R\_value$, and found to be equal to 12,255 psi. At the time of rehabilitation design in May 2011, a deflection study was conducted on the pavement (using FWD) and backcalculation using the Caltrans software CalBack was also performed. The in-situ average resilient modulus of the subgrade was found to be 16,500 psi. Since *rePave* allows only three levels of resilient modulus (5000, 10000, 20000 psi), the subgrade M_r used in *rePave* was 10,000 psi.

Backcalculation of the CTB layer indicated an average resilient modulus value of ~400,000 psi. The PCC elastic modulus was assumed to be 2,500,000 psi. The AS layer indicated a resilient modulus of about 33000 psi.

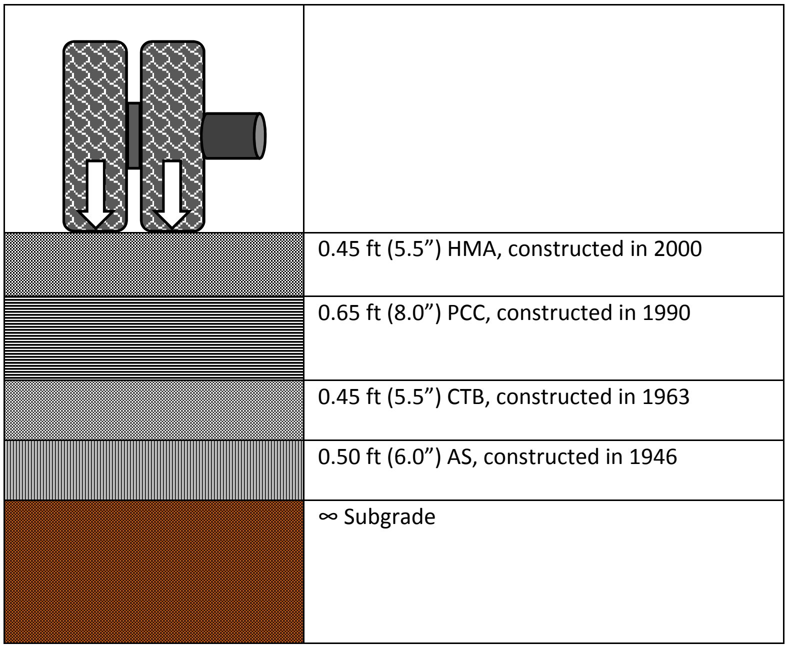
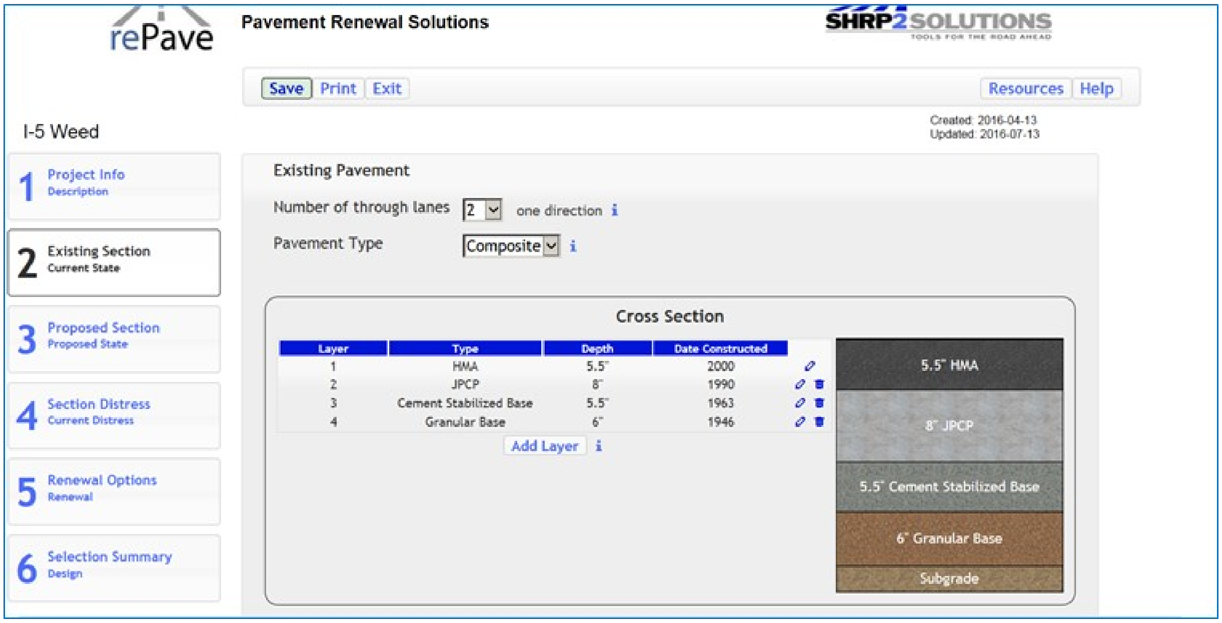


Figure 6-3. Existing pavement structure for Weed project.

6.6 REPAVE SCOPING DESIGN

The existing structure for the Weed project was entered in *rePave* scoping tool as shown in Figure 6-4.



I-5 Weed

Created: 2016-04-13
Updated: 2016-07-13

Existing Pavement

Number of through lanes: 2 one direction

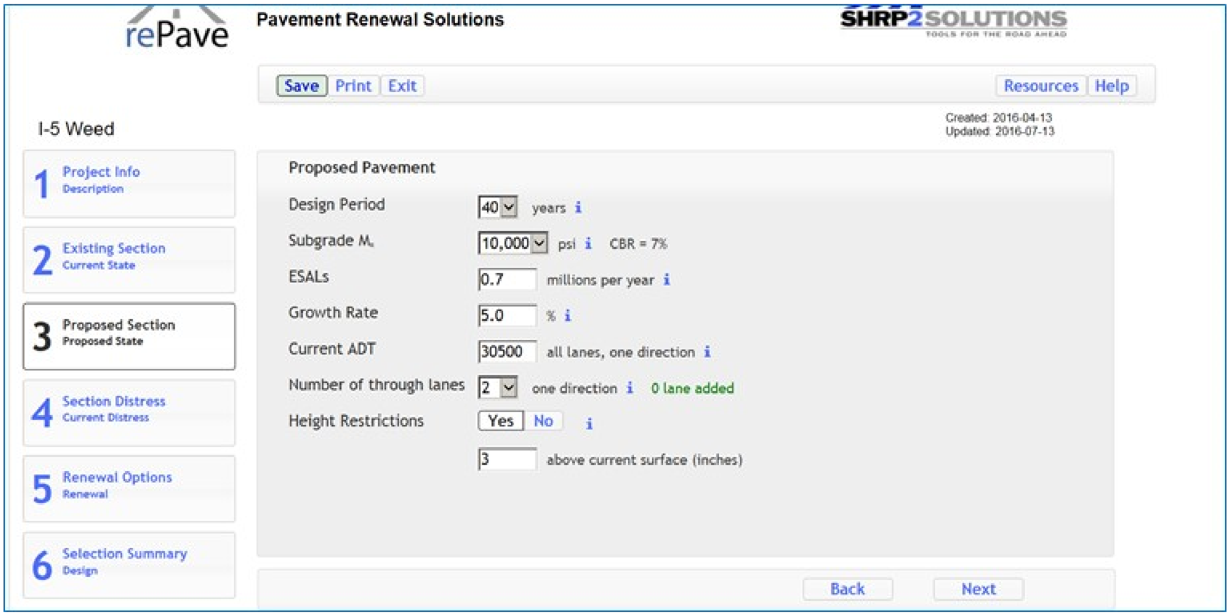
Pavement Type: Composite

Cross Section

Layer	Type	Depth	Date Constructed
1	HMA	5.5"	2000
2	JPCP	8"	1990
3	Cement Stabilized Base	5.5"	1963
4	Granular Base	6"	1946

Figure 6-4. The existing structure of the Weed project as entered in *rePave*.

The general design inputs as entered in *rePave* for the Weed project are as shown in Figure 6-5.



I-5 Weed

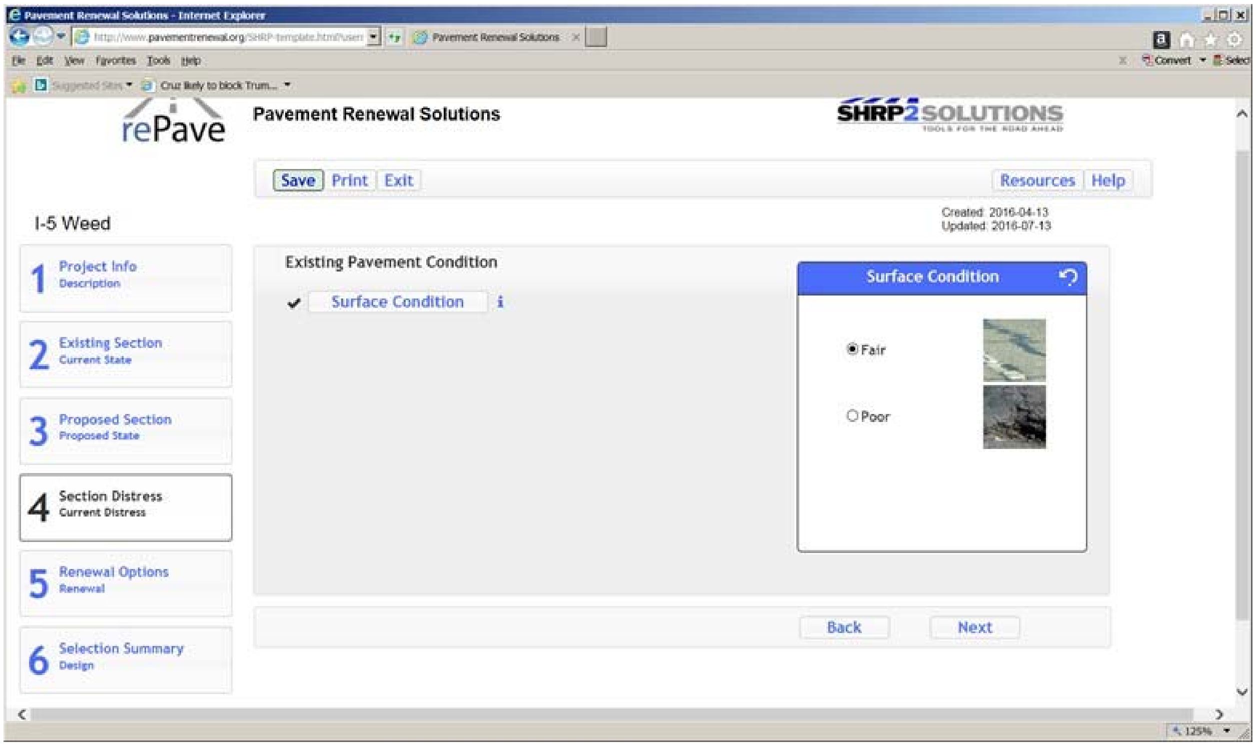
Created: 2016-04-13
Updated: 2016-07-13

Proposed Pavement

Design Period: 40 years
Subgrade M_r: 10,000 psi CBR = 7%
ESALs: 0.7 millions per year
Growth Rate: 5.0 %
Current ADT: 30500 all lanes, one direction
Number of through lanes: 2 one direction 0 lane added
Height Restrictions: Yes No
3 above current surface (inches)

Figure 6-5. General design inputs for Weed project.

The only distress that was required by *rePave* for this type of structure is the general condition of the pavement surface as shown in Figure 6-6. The general condition was assumed to be fair.



I-5 Weed

Created: 2016-04-13
Updated: 2016-07-13

Existing Pavement Condition

✓ Surface Condition

Surface Condition

● Fair
○ Poor

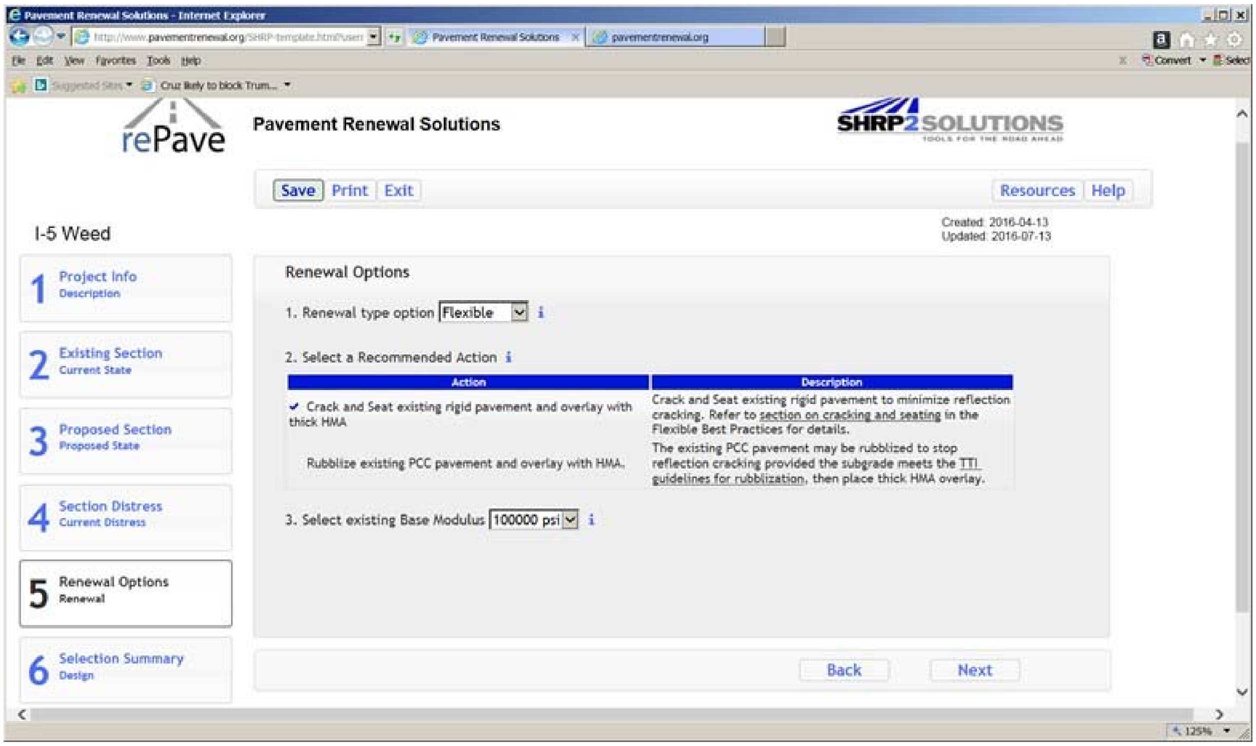
Figure 6-6. General condition of the pavement.

The *rePave* tool proposes several renewal options; namely flexible, rigid, precast and composite. In addition, there are several rehabilitation actions recommended under each option. Both flexible and rigid options were considered for this project. In the flexible option, an asphalt concrete overlay was selected. In the rigid option, an unbonded PCC overlay (whitetopping) was selected. These two options are discussed below.

6.6.1 Rehabilitation with Asphalt Concrete Overlay

Since the rehabilitation for this project consisted of milling off the entire existing cracked asphalt concrete layer down to the top of the JPCP slabs and overlaying with HMA, the “flexible” option was selected in *rePave*. In this “flexible” category, the available renewal actions are as shown in Figure 6-7 and are as follows: (1) crack, seat and overlay with HMA, and (2) rubblize and overlay with HMA. Note that *rePave* does not have the option of finding an option for a JPCP that was originally cracked and seated and overlaid. Therefore, the options provided by the tool do not entail milling off existing asphalt concrete (the top layer shown in Figure 6-4), but instead *rePave* treats the existing pavement as if it were a JPCP; as it is evident in Figure 6-7.

The base modulus is also required; which is the composite base modulus of the materials beneath the new HMA overlay; i.e., the cracked and seated PCC, CTB, and AS. In *rePave*, the four levels of base modulus available are 30000, 50000, 75000, and 100000 psi. For this composite base, the modulus is expected to be greater than 100000 psi. Because the highest modulus available is 100,000 psi, it was selected for this renewal option. This is also shown in Figure 6-7.



I-5 Weed

Created: 2016-04-13
Updated: 2016-07-13

Renewal Options

1. Renewal type option Flexible

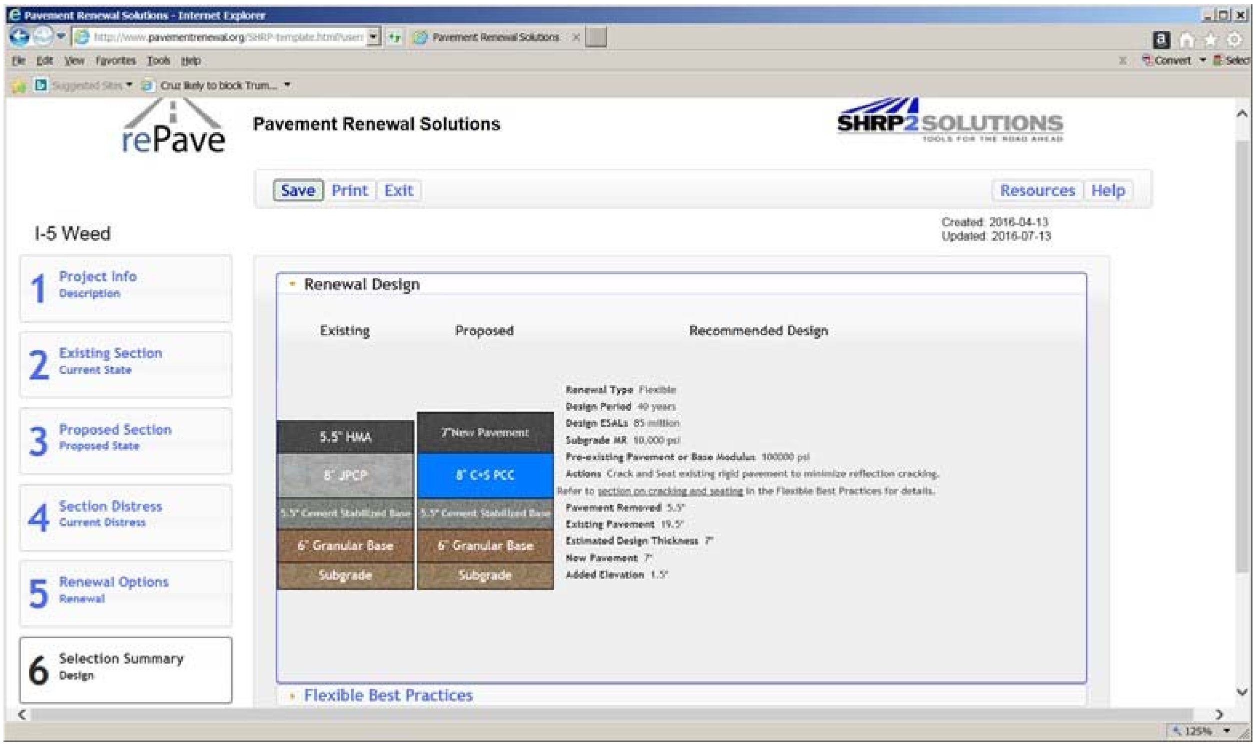
2. Select a Recommended Action

Action	Description
✓ Crack and Seat existing rigid pavement and overlay with thick HMA	Crack and Seat existing rigid pavement to minimize reflection cracking. Refer to section on cracking and seating in the Flexible Best Practices for details.
Rubblize existing PCC pavement and overlay with HMA.	The existing PCC pavement may be rubblized to stop reflection cracking provided the subgrade meets the TTI guidelines for rubblization, then place thick HMA overlay.

3. Select existing Base Modulus 100000 psi

Figure 6-7. Recommended actions for the “flexible” renewal option for Weed project.

Based on the input values given, a total of 7.0 inches of HMA was found to be needed over the cracked and seated existing JPCP slabs. This is shown in Figure 6-8. [67]Most of California composite pavements consist of an asphalt concrete overlay placed over JPCP slabs that were cracked and seated. Therefore, when the existing asphalt concrete layer is milled off to expose the PCC slabs only re-seating would be required. Note that in recent years Caltrans HDM started to allow asphalt concrete overlaying over JPCPs without cracking and seating; and thus requiring an increase in the asphalt concrete thickness[68].



Created: 2016-04-13
Updated: 2016-07-13

Renewal Type Flexible
Design Period 40 years
Design ESALs 85 million
Subgrade MR 10,000 psi
Pre-existing Pavement or Base Modulus 100000 psi
Actions Crack and Seat existing rigid pavement to minimize reflection cracking. Refer to section on cracking and seating in the Flexible Best Practices for details.
Pavement Removed 5.5"
Existing Pavement 19.5"
Estimated Design Thickness 7"
New Pavement 7"
Added Elevation 1.5"

Figure 6-8. *rePave* design for the Weed project.

According to the *rePave* Development Team[69], the crack-seat-and overlay strategy was designed such that the required HMA overlay thickness after crack and seating would be in line with the general guidelines of the Transport Research Laboratory (TRL) regarding overlay thickness. Therefore, in order to force a thicker overlay that would be needed to mitigate reflection cracking, a lower modulus of 75000 psi was adopted in rePave as the default value. When using this recommended base modulus value, the HMA overlay thickness would be 8.5 inches. This is an increase in thickness by 1.5 inches over that is required with a base modulus of 100000 psi.

---

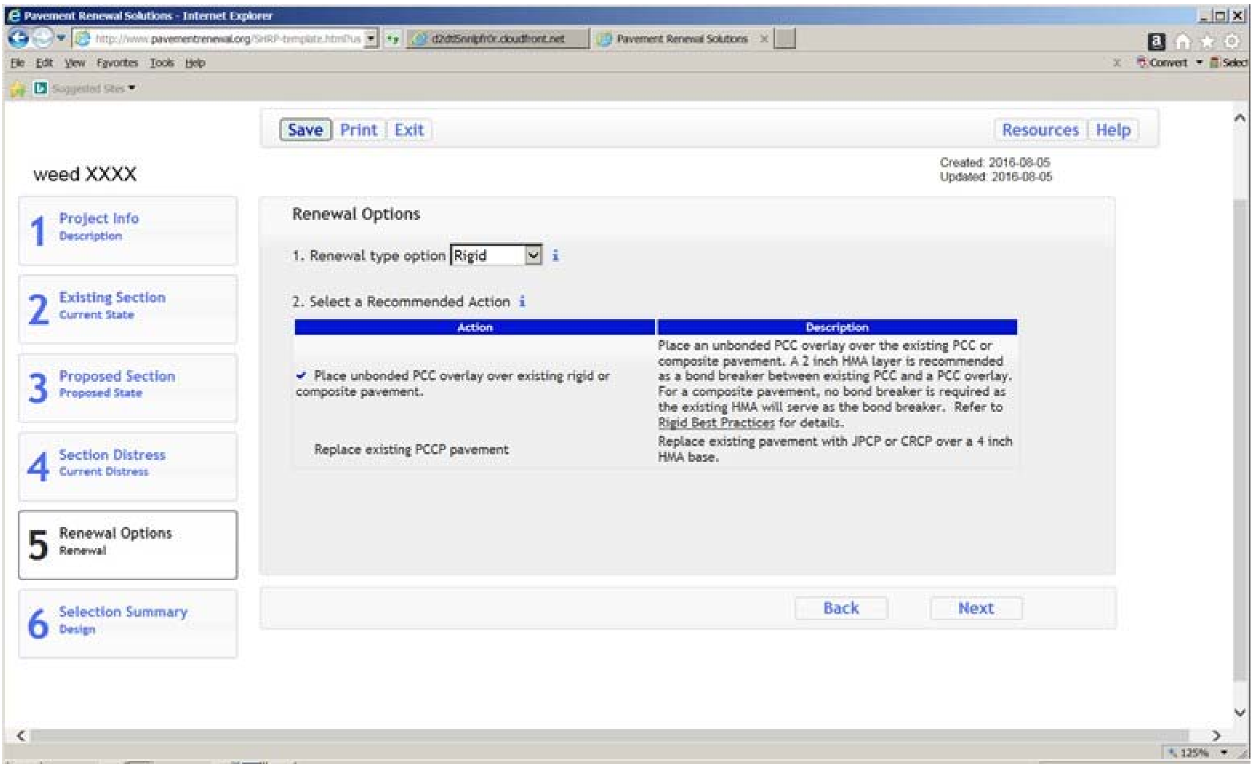
[67] While the *rePave* schematic of the pavement section does not show the "existing" HMA layer over the PCC, it logically assumes it be removed by milling to enable cracking and seating the existing JPCP slabs.

[68] See Table 625.1 of the Caltrans HDM at http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0620.pdf

[69] According to Mr. Newt Jackson.

6.6.2 Rehabilitation with Unbonded PCC Overlay (Whitetopping)

Whitetopping is an unbonded jointed plain concrete pavement (JPCP) placed over the existing asphalt concrete. This option could also be considered as another viable option. The pavement scoping tool *rePave* can also be used to determine the Portland cement concrete (PCC) overlay thickness for the project. In this case, the renewal type option is selected as "Rigid" as shown in Figure 6-9. By selecting the unbonded concrete overlay action, the PCC thickness was determined to be 10.0 inches as shown in Figure 6-10.



Created: 2016-08-05
Updated: 2016-08-05

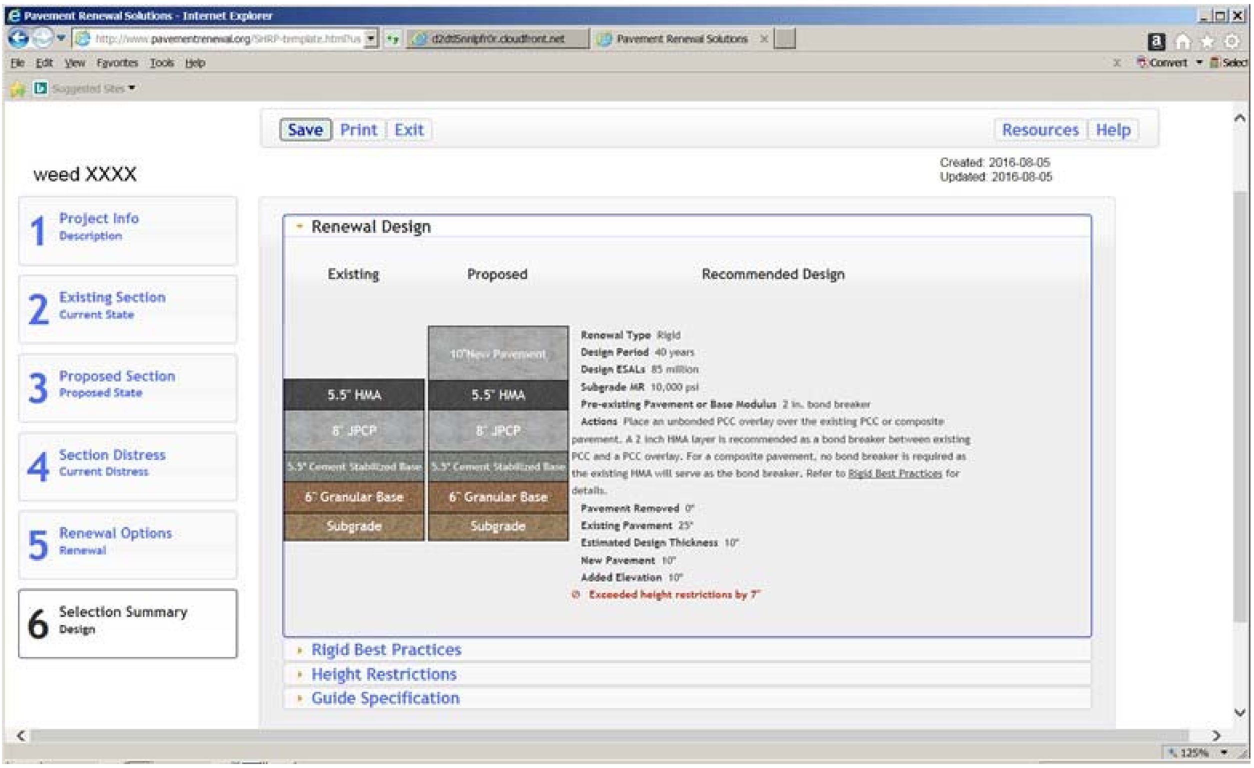
Renewal Options

1. Renewal type option Rigid

2. Select a Recommended Action

Action	Description
✓ Place unbonded PCC overlay over existing rigid or composite pavement.	Place an unbonded PCC overlay over the existing PCC or composite pavement. A 2 inch HMA layer is recommended as a bond breaker between existing PCC and a PCC overlay. For a composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to Rigid Best Practices for details.
Replace existing PCCP pavement	Replace existing pavement with JPCP or CRCP over a 4 inch HMA base.

Figure 6-9. Unbonded PCC overlay selection in *rePave* for the Weed project.



Renewal Type Rigid
Design Period 40 years
Design ESALs 85 million
Subgrade MR 10,000 psi
Pre-existing Pavement or Base Modulus 2 in. bond breaker
Actions Place an unbonded PCC overlay over the existing PCC or composite pavement. A 2 inch HMA layer is recommended as a bond breaker between existing PCC and a PCC overlay. For a composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to Rigid Best Practices for details.
Pavement Removed 0"
Existing Pavement 25"
Estimated Design Thickness 10"
New Pavement 10"
Added Elevation 10"
Exceeded height restrictions by 7"

Figure 6-10. The required unbonded PCC overlay thickness determined with *rePave* for the Weed project.

6.7 FINAL DESIGN

6.7.1 Asphalt Overlay Design with CalME

The Caltrans mechanistic-empirical (ME) based method encoded into the CalME software was used for the final 40-year design of this project. As mentioned previously in the Red Bluff project (Chapter 5), advanced HMA materials testing was conducted and laboratory data was used in deriving empirical performance model constants which were used in design. The final rehabilitation recommendations for a 90% reliability level were as follows:

1. Mill off existing HMA 0.45 ft (5.5”) to expose JPCP slabs. Reclaim the milling to use as RAP,
2. Re-seat the JPCP slabs (no cracking is needed since JPCP slabs were originally cracked and seated),
3. Place 0.15 ft (1.8”) HMA PG 64-16 with 25% RAP as leveling course,
4. Place stress absorption membrane interlayer-rubberized (SAMI-R, also called rubberized chip seal),
5. Place 0.25 ft (3.0”) HMA PG 64-16 with 25% RAP,
6. Place 0.35 ft (4.2”) HMA PG 64-28 PM (with up to 15% RAP allowed), and finally
7. Place 0.10 ft (1.2”) open graded friction course (OGFC).

Figure 6-11 is a schematic of the rehabilitated pavement structure.

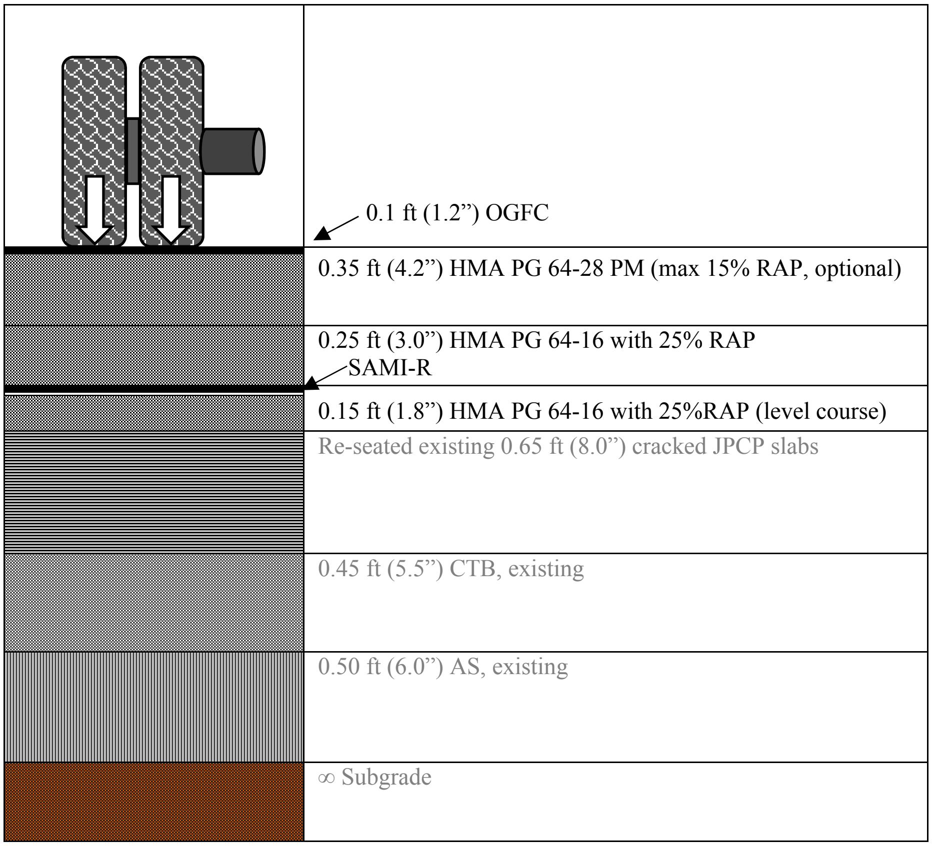


Figure 6-11. Final structure section for the Weed project.

The leveling course provides an even platform for the SAMI-R to be placed on. It is normally considered as non-structural material as it normally cracks rapidly after opening the pavement to traffic. Therefore, the total structural HMA is equal to 0.6 ft (7.2 inches). The SAMI-R is considered to be equivalent to 0.1 ft (1.2 inch) of HMA when placed on treated material such as PCC to minimize reflective cracking in the structural HMA overlay on top[70]. The wearing course composed of open graded friction course (OGFC) is also a non-structural material and is typically used to improve skid resistance and wet weather conditions, and to provide for additional protection against hardening and oxidation of the HMA structural layers. Typically, this wearing course is regularly replaced every 5-7 years.

6.7.2 Whitetopping Design with HDM Concrete Catalog

The Caltrans HDM allows the design of an unbonded concrete overlay (whitetopping) as if it were a new jointed plain concrete pavement (JPCP) placed over an asphalt concrete base. The existing asphalt concrete is considered the asphalt concrete base and it also serves as the bond breaker (between PCC and CTB in this structure). In order to determine the required thickness of the PCC overlay, the HDM catalog (Table 623.1) is used, and the following inputs related to the project are needed:

---

[70] See Caltrans HDM, page 630-15, http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0630.pdf

- Climate: The climate prevailing at the project site can be determined with the aid of the climate map given in Figure 615.1 of the Caltrans HDM[71]. Alternatively, the climate was determined for the project site using the climate database available in CalME based on the project location inputs; namely county, route No., and post mile limits. For this location the climate is classified as “High Mountain/High Desert”.
- 40-year traffic index (TI_{40})=15.0.
- Lateral support: no lateral support is assumed (note that lateral support is provided only with concrete shoulders and widened concrete slabs).
- Subgrade type: Type II (based on R-value and soil classification, see HDM Table 623.1A)[72].

Given the climate and subgrade type, Table 623.1 M is selected. Finally, based on TI and lateral support condition, the unbonded PCC overlay thickness was found to be 1.25 ft (15.0 inch). All Catalog JPCP sections are dowelled (HDM Chapter 620)[72]72 above. This design also provides a 90% reliability as mentioned in Table 622.1 of the Caltrans HDM[72]. A schematic of the final rehabilitated structure using this renewal option is given in Figure 6-12.

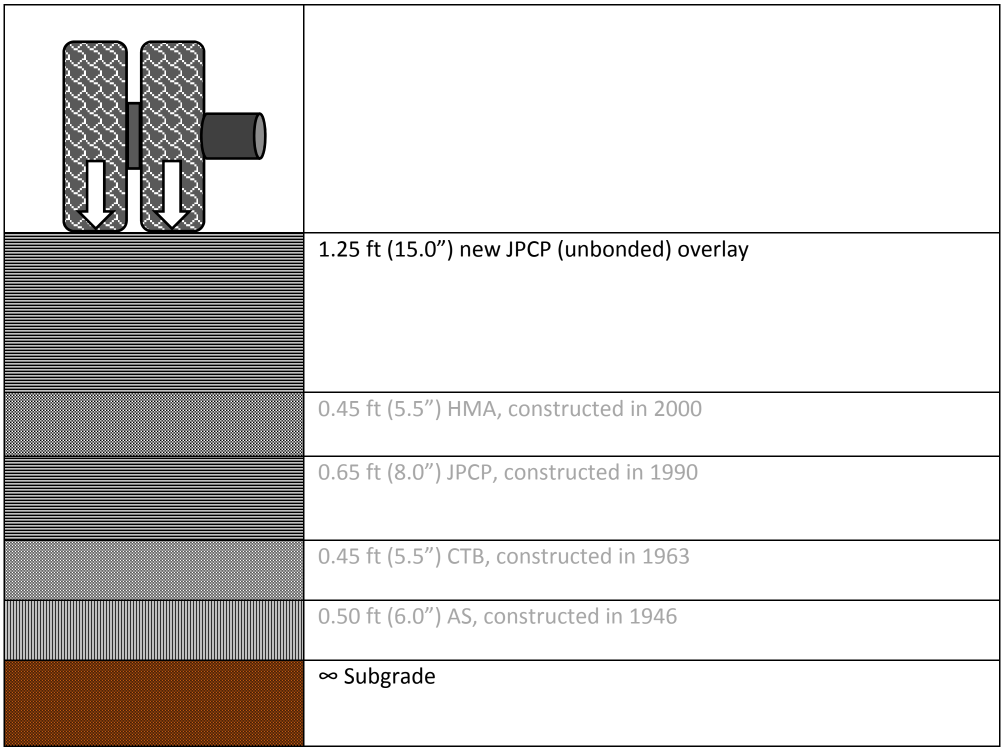


Figure 6-12. Unbonded PCC overlay placed over the pavement for the Weed project.

---

[71] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0610.pdf

[72] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0620.pdf

6.8 COMPARISON

The scoping tool *rePave* showed that a total of 7.0 inches HMA would be needed over the cracked and seated JPCP slabs, when a base modulus of 100000 psi was used. According to *rePave* Development Team recommendation, a base modulus of 75000 psi should always be used for crack-seat-and-overlay design. In this case, an 8.5 inch thick overlay was obtained with *rePave*. In comparison, the structural HMA thickness based on CalME was found to be equal to 0.6 ft (7.2 inch) and an equivalent of 0.1 ft (1.2 inch) HMA provided by the SAMI-R. Therefore, the total HMA is 0.7 ft (8.4 inch). Using the recommended 8.5 inch design by *rePave*, both the CalME final design and *rePave* scoping design were almost identical in terms of the HMA overlay thickness. The scoping tool *rePave* does not use a SAMI-R or geosynthetic fabric but the designer may always substitute a 0.1 ft HMA of the *rePave* scoping thickness with any of these two materials intended for reflective cracking mitigation. A leveling course is always recommended over cracked and seated JPCP slabs before placement a SAMI-R or a fabric.

Regarding the “rigid” renewal option, the unbonded PCC overlay was found to be 10 inches thick using the scoping tool *rePave*. This is to be compared with the HDM catalog design of 15 inches. The overconservative design based on the HDM Catalog is mainly due to the fact that the existing structure layered system has been disregarded to provide additional structural support. The Catalog design was originally developed to provide a JPCP structure for a new pavement structure comprised of 1.25 ft JPCP over 0.25 ft HMA over 0.70 ft AS over subgrade. By simply assuming that this structure provides the same structural capacity as the structure shown in Figure 6-12 is in itself an overconservative assumption by the Catalog design when only the PCC thickness is used as the unbonded overlay.

As mentioned previously in Chapter 5, the traffic load spectra used in the three design systems (*rePave*, CalME, and HDM rigid catalog) are not identical and may have impacted the design results. The effect of load spectra was not studied in this report.

7 CASE STUDY 3 (I-80 SOLANO)

7.1 PROJECT DESCRIPTION

The I-80 long life project between the cities of Dixon and Vacaville in northern California was constructed in 2013 and has been in service for nearly 4 years. A "Google Earth" aerial map of the project location is shown in Figure 7-1. This facility is mainly a six-lane divided highway with three lanes in each direction. The project limits extend from PM 30.55 to PM 38.70 in both the east and west directions. The project is located within the Solano County limits. This project has both asphalt and jointed plain concrete pavement (JPCP) sections; with the asphalt lanes being the fast lane (No. 1 lane) in both directions. The analysis provided in this chapter will only focus on the rehabilitation of the concrete sections.

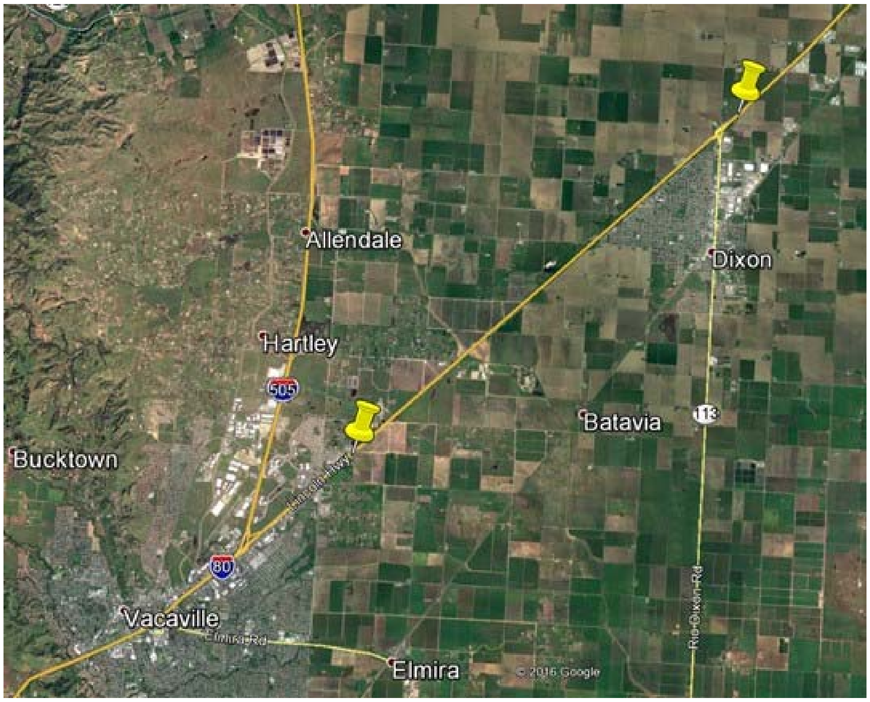


Figure 7-1. An aerial map showing the limits of the Solano I-80 project.

Before rehabilitation, the pavement within the project limits exhibited extensive cracking of the JPCP slabs (both 1st and 3rd stage cracking)[73], pumping, and faulting. Figure 7-2 shows a photo of an example pavement surface condition taken from the eastbound direction at PM 32.55 and showing condition of the pavement at that location in year 2009 (from the Caltrans Roadview

---

[73] Caltrans defines 1st stage cracks as non-intersecting transverse, longitudinal, or diagonal cracks that divide the slab into 2 or 3 large pieces (not including corner breaks). 3rd stage cracks divide the slab into 3 or more pieces with interconnected cracks developing between cracks or joints.

Explorer). Notice in Figure 7-2 the extensive amount of transverse and longitudinal cracks that have been sealed with hot pour asphalt.

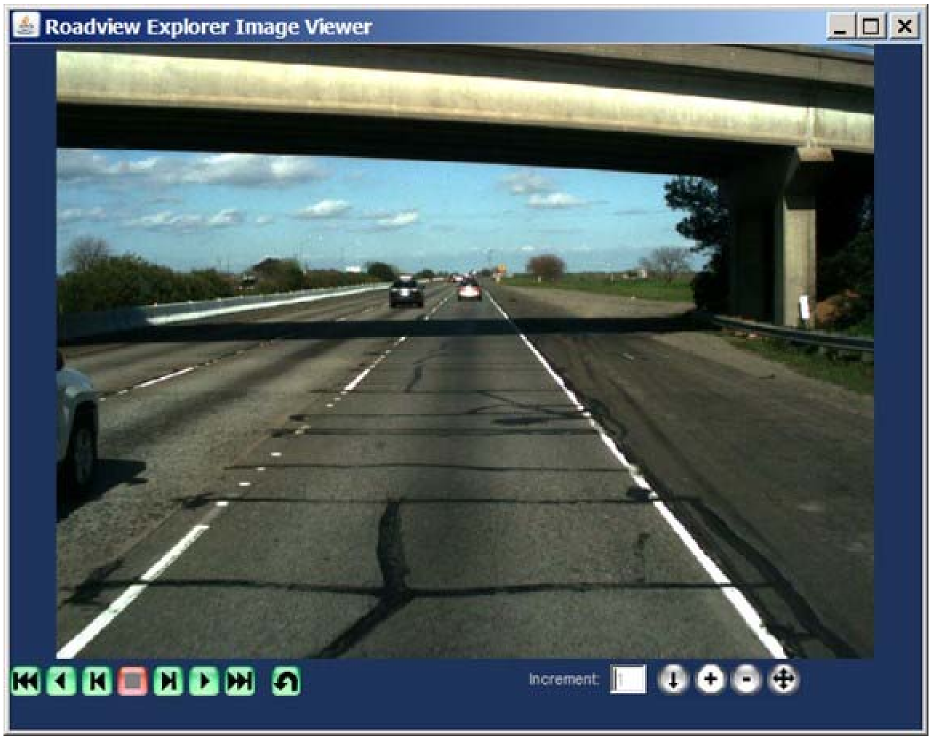


Figure 7-2 A photo of a JPCP truck lane taken at PM 32.55 EB of the Solano project.

7.2 TRAFFIC

The traffic report prepared for the Solano project indicated that the current (year 2010) two-way average daily traffic (ADT) to be equal to 120,100, and the estimated 40-year two-way ADT of 193,000. The percentage of trucks from the total traffic was reported to be 6.72%.

The estimated 40-year Traffic Index (TI_{40}) for mainline lanes was estimated to be equal to 15.0. Similarly, the 5-year traffic index (TI_5) was found to be 11.5. Using the HDM equation relating TI to ESALs, the corresponding ESALs for these two TI values are 73.2 mESALs and 7.8 mESALs, respectively.

The growth factor is a required parameter in *rePave* and it was calculated in the same as was discussed previously. Using the available above 5-year and 40-year ESALs, the geometric growth rate (GR) was calculated as:

$$GR = \left(\frac{73{,}200{,}000}{7{,}800{,}000}\right)^{\frac{1}{35}} - 1.0 = 0.066 = 6.6\%$$

Since the *rePave* scoping tool does not allow GR above 5%, a growth rate of 5% was used in the analysis.

7.3 “ESALS PER YEAR” CALCULATIONS

ESALs per year is another input in *rePave* and was calculated in the same way as discussed for the Red Bluff and Weed projects (Chapters 5 and 6). For the Solano project, the total 40-year design ESALs is 73,200,000 ESALs (~73.2 mESALs). The actual growth rate was found to be 6.6%, but then assumed to be equal to 5%. Using the ESAL accumulation spreadsheet developed for this study, the initial ESALs was found (by trial and error) to be equal to 0.61 mESALs. Therefore, starting with 0.61 mESALs and a compound growth rate of 5% over 40-year period, the pavement is estimated to receive a total of 74 mESALs by the end of the 40th year of trafficking (corresponding to a TI_{40} of 15.0).

7.4 DISTRESS CONDITION

For the existing pavement distress types and quantities needed to run *rePave*, the 2008 Caltrans Pavement Condition Report (PCR) was used to obtain the types and quantities of the most prevailing distresses. The following average distress quantities were finally assumed:

- 1st stage cracking=40%,
- 3rd stage cracking=30%,
- Corner breaks=30%,
- Faulting=1/4” (average), and
- IRI (average for all lanes)=130 in/mile (all lanes).

Note that the above values where increased from the available 2008 data to account for the additional deterioration that took place until the construction year of 2013.

7.5 EXISTING PAVEMENT STRUCTURE

The “average” structure representing the JPCP lanes of the Solano project is shown in Figure 7-3. The structure had 0.67 ft (8.0 inches) JPCP over 0.33 ft (4.0 inches) cement treated base (CTB) over 0.92 ft (11.0 inches) aggregate subbase (AS) over subgrade. Available records indicated that the existing PCC may have been constructed in 1990, the CTB layer in 1999, and the AS layer in 1965, based on available Materials Report.

The subgrade basement soil was assumed to have an R-value of 15; which is reasonable for the project site. The resilient modulus (M_r) of the soil was determined as 9480 psi (using the resilient modulus vs. R value relationship). Therefore, the M_r used in *rePave* was assumed to be 10,000 psi. No falling weight deflectometer (FWD) evaluation was done for the project. The AS modulus was obtained from a study by UCPRC[74] (conducted on a test track) and found to be ~25000 psi. The CTB layer was assumed to have an elastic modulus of 400000 psi (assumed to be similar to the CTB modulus of the Red Bluff project).

---

[74] University of California Pavement Research Center, http://www.ucprc.ucdavis.edu/PublicationsPage.aspx

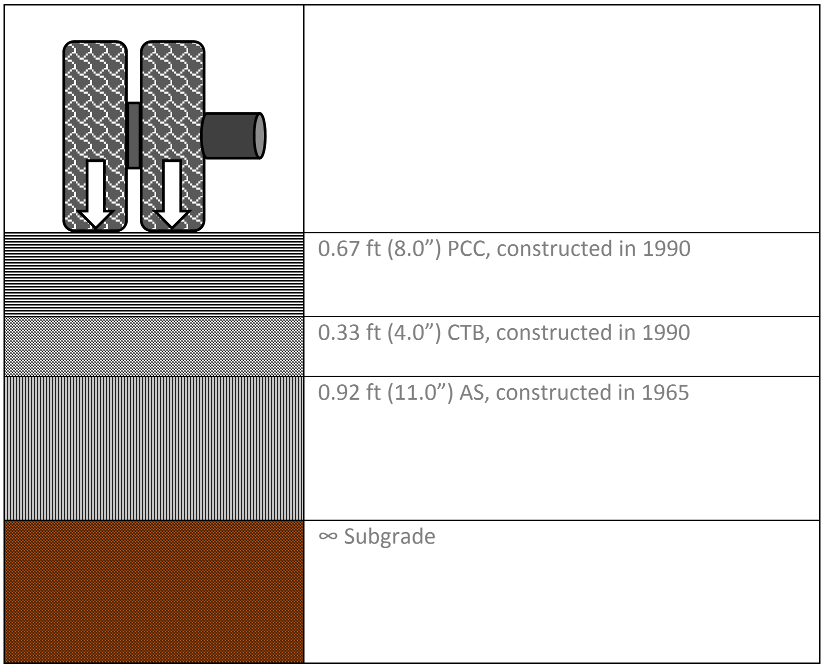
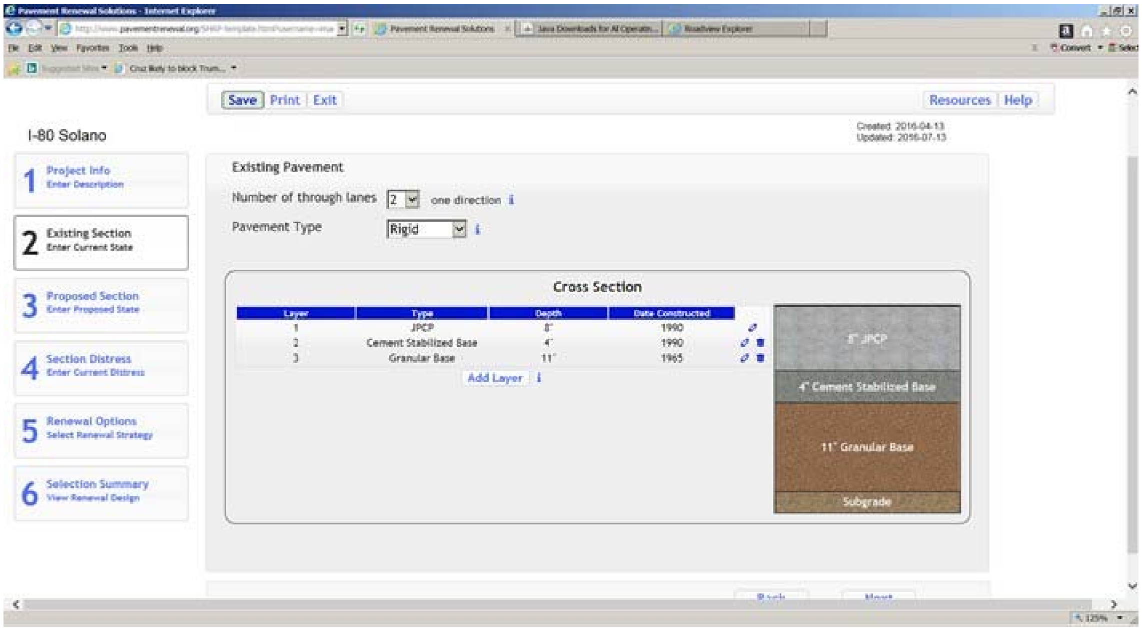


Figure 7-3. Existing pavement structure for the Solano project JPCP prior to rehabilitation.

7.6 SCOPING DESIGN WITH REPAVE

The existing structure configuration in terms of layers thicknesses and types for the Solano project concrete lanes are shown in the *rePave* screenshot displayed in Figure 7-4.



I-80 Solano

Created: 2016-04-13
Updated: 2016-07-13

Existing Pavement

Number of through lanes: 2 one direction

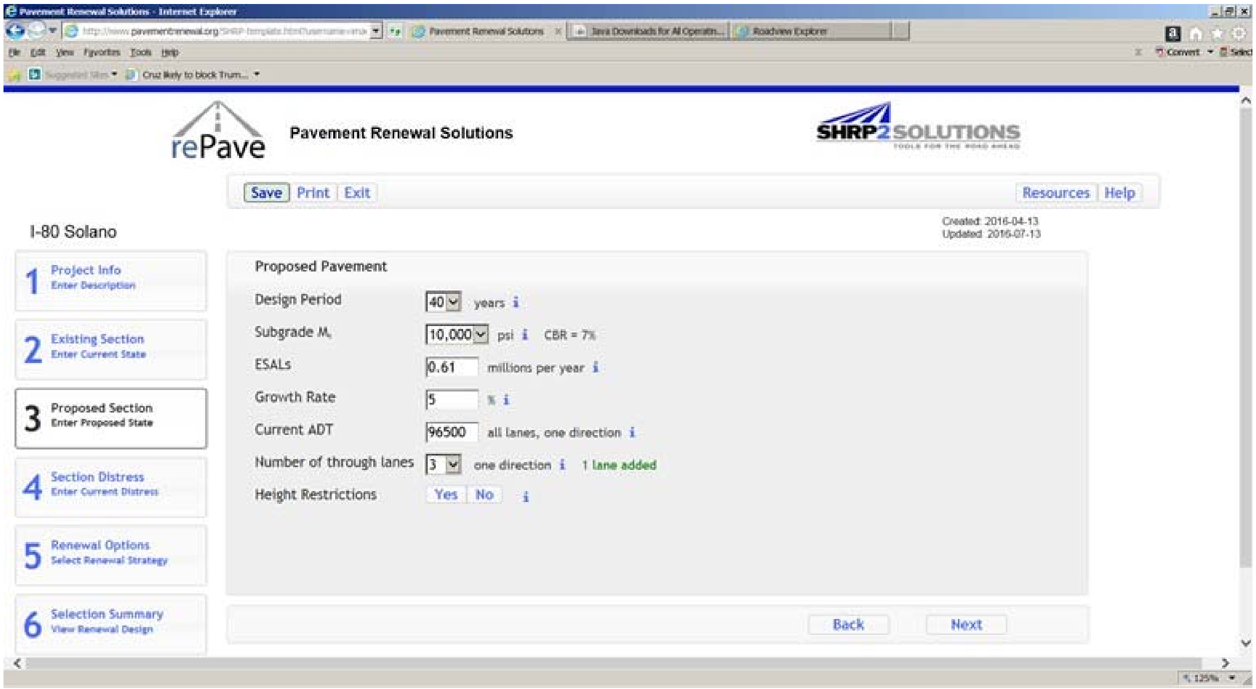
Pavement Type: Rigid

Cross Section

Layer	Type	Depth	Date Constructed
1	JPCP	8"	1990
2	Cement Stabilized Base	4"	1990
3	Granular Base	11"	1965

Figure 7-4. Solano pavement structure entered in *rePave*.

The general inputs pertaining to design life, traffic and subgrade modulus are also shown in Figure 7-5.



I-80 Solano

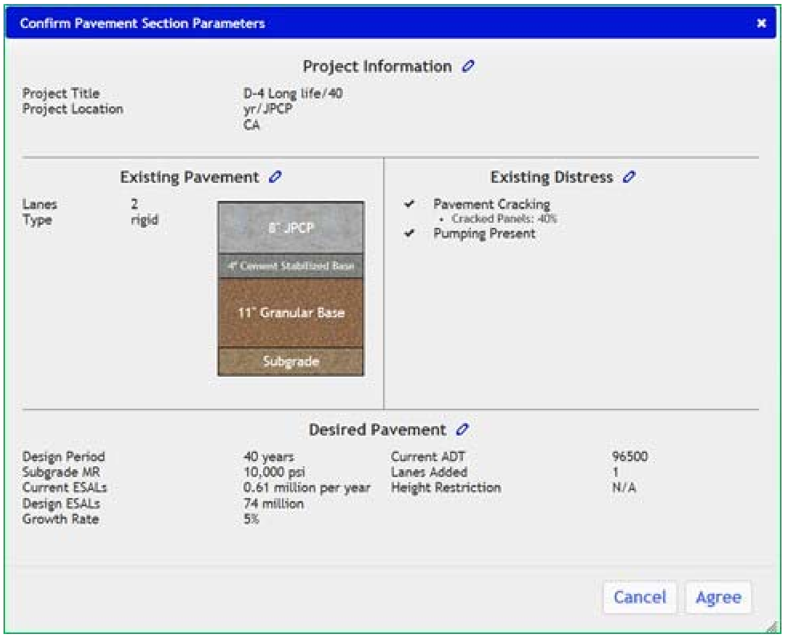
Created: 2016-04-13
Updated: 2016-07-13

Proposed Pavement

Design Period	40	years
Subgrade M	10,000	psi CBR = 7%
ESALs	0.61	millions per year
Growth Rate	5	%
Current ADT	96500	all lanes, one direction
Number of through lanes	3	one direction 1 lane added
Height Restrictions	Yes No	

Figure 7-5. General inputs for the Solano project.

The distress types and quantities as given above were also entered in *rePave*. A summary of most *rePave* inputs for this project are given in the screenshot shown in Figure 7-6.



Project Information

Project Title D-4 Long life/40 yr/JPCP
Project Location CA

Existing Pavement

Lanes 2
Type rigid

Existing Distress

- ✓ Pavement Cracking
  - Cracked Panels: 40%
- ✓ Pumping Present

Desired Pavement

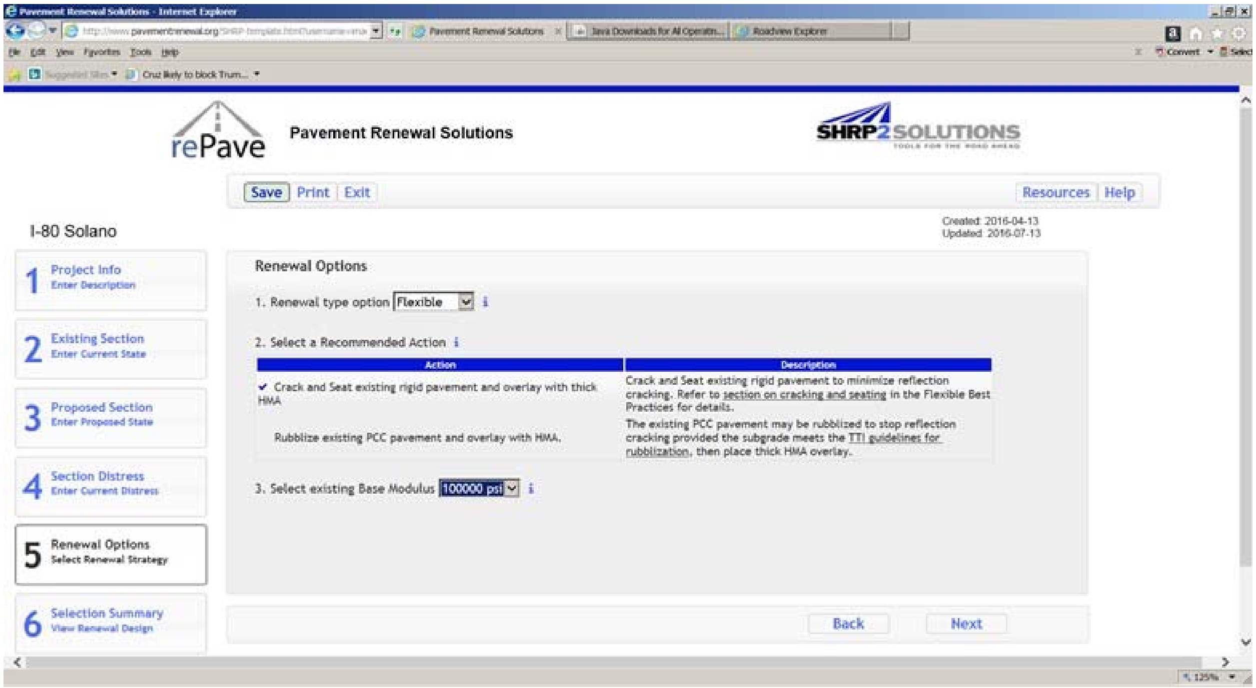
Design Period	40 years	Current ADT	96500
Subgrade MR	10,000 psi	Lanes Added	1
Current ESALs	0.61 million per year	Height Restriction	N/A
Design ESALs	74 million		
Growth Rate	5%		

Figure 7-6. Summary of Solano general project inputs.

RePave offers two types of renewal methods. The "flexible" renewal considered includes crack, seat and overlay with asphalt concrete. The "rigid" renewal option available in *rePave* provides either reconstruction of the concrete pavement or an unbonded concrete overlay. The three strategies will be discussed below. Note that it was decided during project design phase to crack, seat and overlay the existing pavement (i.e., using a flexible option).

7.6.1 Crack, Seat, and HMA Overlay

The "flexible" option in *rePave* for this project includes: (i) crack and seat existing PCC and overlay with HMA, and (ii) rubblize existing and overlay with HMA, as shown in Figure 7-7. The base modulus is also required; which is the composite base modulus of the materials beneath the new HMA overlay; i.e., the cracked and seated PCC, CTB, and AS. In *rePave*, the four levels of base modulus available are 30000, 50000, 75000, and 100000 psi. For this composite base, the modulus is expected to be greater than 100000 psi. Because of the highest modulus available in *rePave* is 100,000 psi, it was selected for this renewal option, as shown in Figure 7-7.



Created: 2016-04-13
Updated: 2016-07-13

Renewal Options

1. Renewal type option Flexible

2. Select a Recommended Action

Action	Description
✓ Crack and Seat existing rigid pavement and overlay with thick HMA	Crack and Seat existing rigid pavement to minimize reflection cracking. Refer to section on cracking and seating in the Flexible Best Practices for details.
Rubblize existing PCC pavement and overlay with HMA.	The existing PCC pavement may be rubblized to stop reflection cracking provided the subgrade meets the TTI guidelines for rubblization, then place thick HMA overlay.

3. Select existing Base Modulus 100000 psi

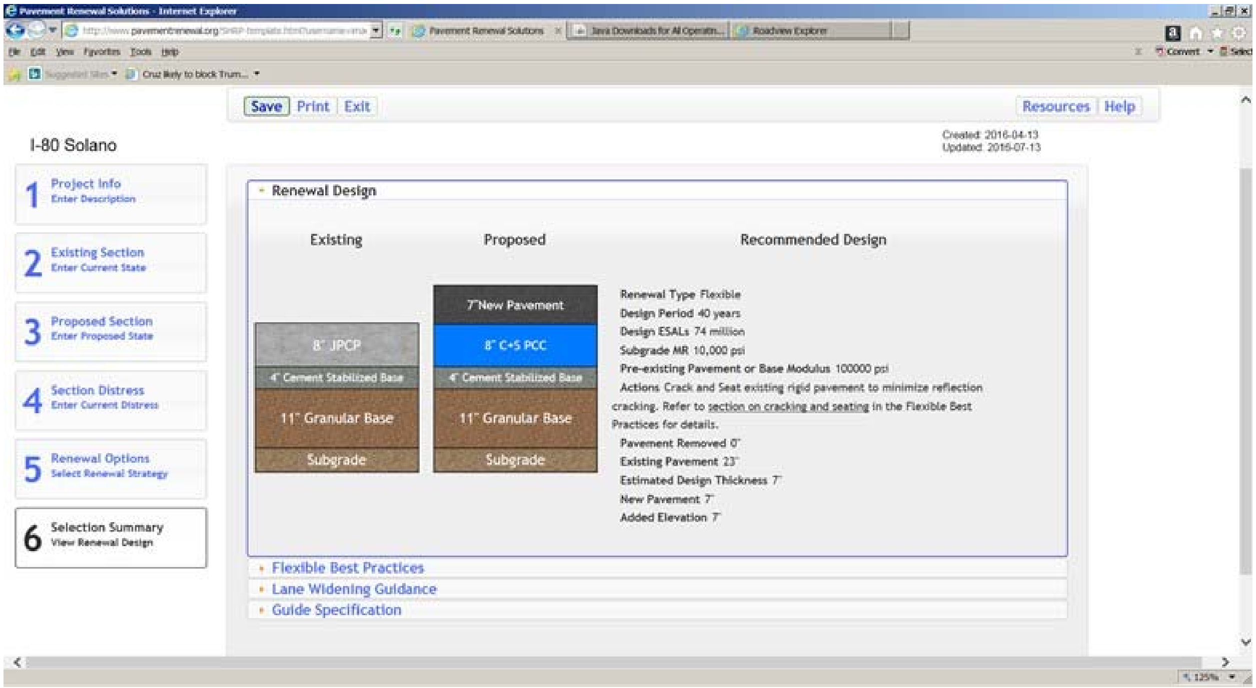
Figure 7-7. Crack, seat and overlay option for Solano JPCP sections.

Based on *rePave* analysis, a total of 7.0 inches of HMA would be needed over the cracked and seated JPCP slabs, as shown in Figure 7-8.

As mentioned in Chapter 6, *rePave* recommends that a base modulus of 75000 psi be used for crack-seat-and-overlay strategy to force thicker HMA overlays needed to mitigate reflection cracking[75]. Using this lower base modulus, the HMA overlay thickness is found to be 8.5 inches. This is 1.5 inches thicker than the overlay obtained using a base modulus of 100000 psi.

---

[75] According to Mr. Newt Jackson from the *rePave* developer team.



I-80 Solano

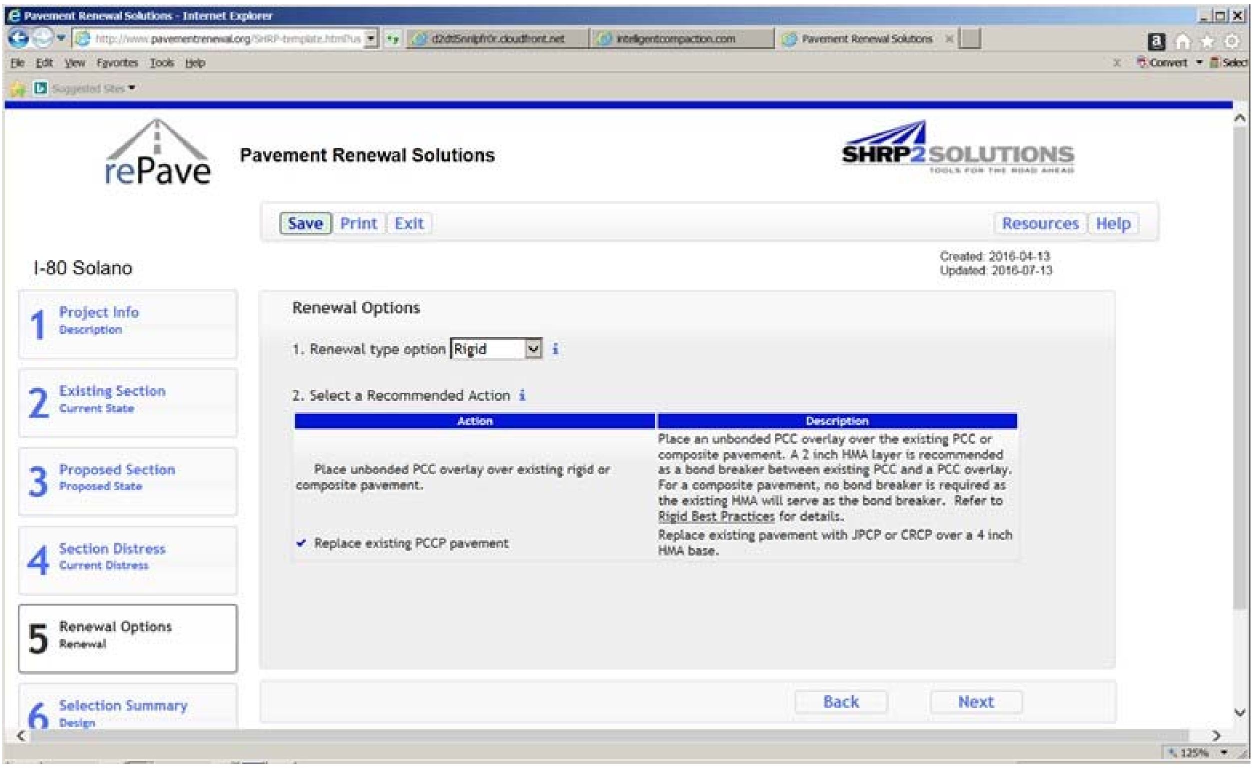
Created: 2016-04-13
Updated: 2016-07-13

Renewal Type Flexible
Design Period 40 years
Design ESALs 74 million
Subgrade MR 10,000 psi
Pre-existing Pavement or Base Modulus 100000 psi
Actions Crack and Seat existing rigid pavement to minimize reflection cracking. Refer to section on cracking and seating in the Flexible Best Practices for details.
Pavement Removed 0"
Existing Pavement 23"
Estimated Design Thickness 7"
New Pavement 7"
Added Elevation 7"

Figure 7-8. ***rePave*** **crack, seat and overlay design for the Solano JPCP sections.**

7.6.2 Reconstruction

The reconstruction option offered by *rePave* includes removal of the existing PCC slabs and the placement of a 4-inch HMA base followed by a new JPCP. Figure 7-9 shows a screenshot of the available two actions under the “Rigid” option.



I-80 Solano

Created: 2016-04-13
Updated: 2016-07-13

Renewal Options

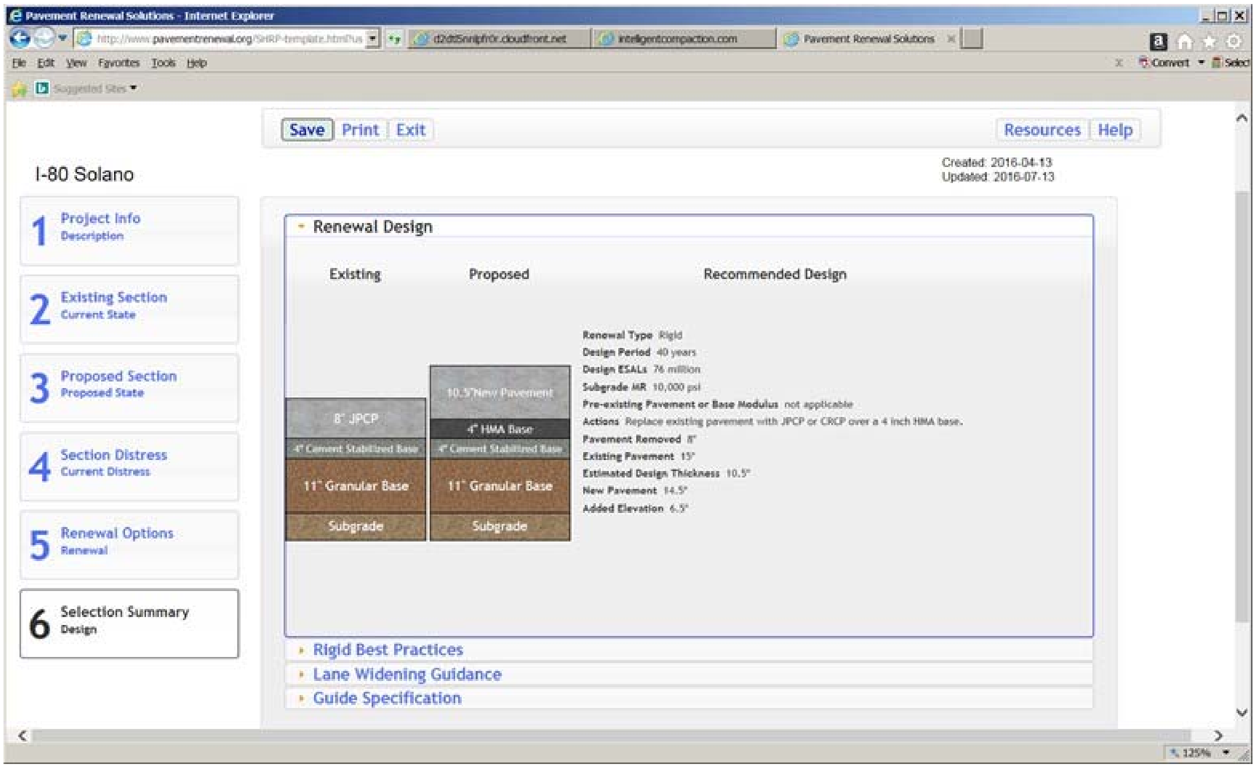
1. Renewal type option Rigid

2. Select a Recommended Action

Action	Description
Place unbonded PCC overlay over existing rigid or composite pavement.	Place an unbonded PCC overlay over the existing PCC or composite pavement. A 2 inch HMA layer is recommended as a bond breaker between existing PCC and a PCC overlay. For a composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to Rigid Best Practices for details.
✓ Replace existing PCCP pavement	Replace existing pavement with JPCP or CRCP over a 4 inch HMA base.

Figure 7-9. The two actions of the “Rigid” option.

Based on project inputs, *rePave* determines that the existing PCC slabs be replaced with 10.5 inch of JPCP over 4 inches of HMA base. This structure is shown in Figure 7-10.



I-80 Solano

Created: 2016-04-13
Updated: 2016-07-13

Renewal Design

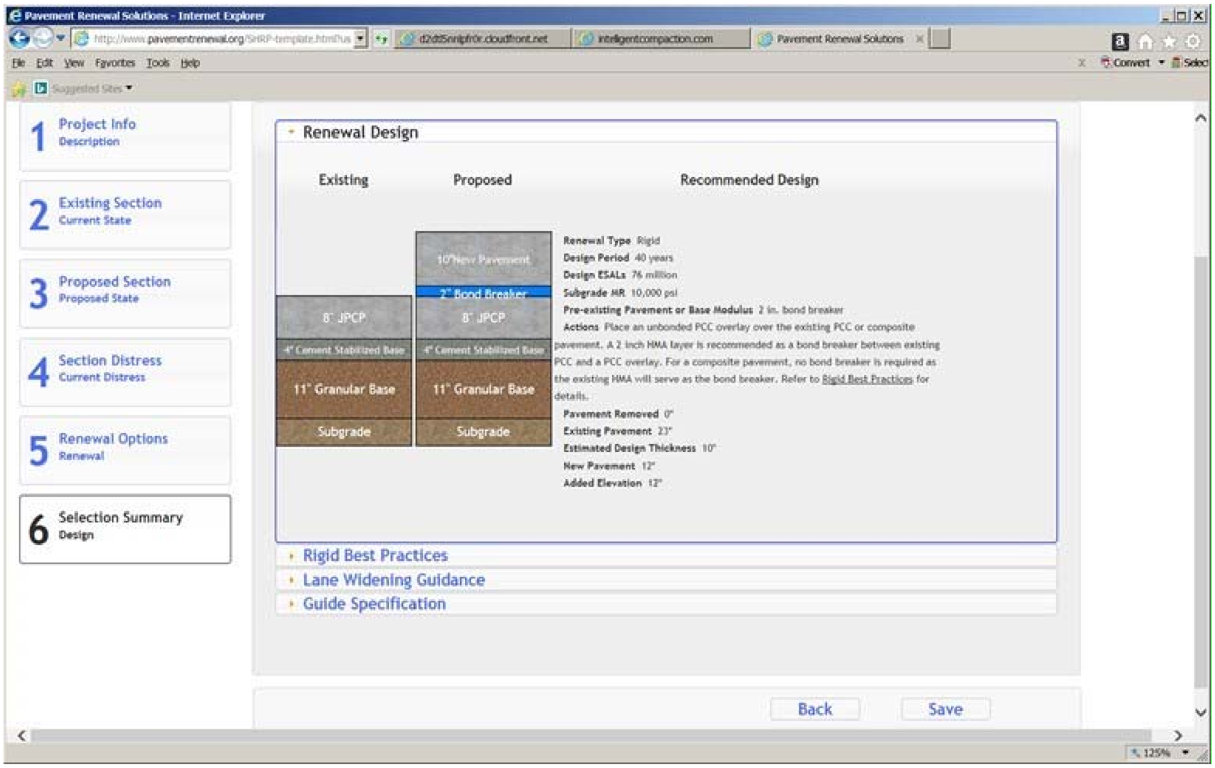
Recommended Design

Renewal Type Rigid
Design Period 40 years
Design ESALs 76 million
Subgrade MR 10,000 psi
Pre-existing Pavement or Base Modulus not applicable
Actions Replace existing pavement with JPCP or CRCP over a 4 inch HMA base.
Pavement Removed 8"
Existing Pavement 15"
Estimated Design Thickness 10.5"
New Pavement 14.5"
Added Elevation 6.5"

Figure 7-10. *rePave* design of the replaced PCC pavement of the Solano project.

7.6.3 Unbonded Concrete Overlay

The unbonded concrete overlay proposed by *rePave* includes the placement of 2 inch HMA bond breaker on top of the existing concrete slabs followed by the placement of a 10-inch JPCP layer. This strategy is shown in Figure 7-11.



Renewal Type Rigid
Design Period 40 years
Design ESALs 76 million
Subgrade MR 10,000 psi
Pre-existing Pavement or Base Modulus 2 in. bond breaker
Actions Place an unbonded PCC overlay over the existing PCC or composite pavement. A 2 inch HMA layer is recommended as a bond breaker between existing PCC and a PCC overlay. For a composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to Rigid Best Practices for details.
Pavement Removed 0"
Existing Pavement 23"
Estimated Design Thickness 10"
New Pavement 12"
Added Elevation 12"

Figure 7-11. Unbonded concrete overlay of the Solano project.

7.7 SCOPING DESIGN USING CALTRANS TOOLS

The Solano project was actually designed and constructed using the crack, seat and overlay with HMA long-life rehabilitation strategy. CalME was used to determine the required thickness of the HMA overlay; which was split into two structural asphaltic layers. At scoping phase, other options will also be available including the “Rigid” strategies presented above. The Caltrans HDM rigid Catalog can be used for designing a reconstruction strategy as well as an unbonded concrete overlay. Although the Catalog constitutes a “final” design, it can also be used for scoping since it can be used with minimal inputs. The three “final” design are discussed below.

7.7.1 Crack, Seat and HMA Overlay Design with CalME

The Caltrans mechanistic-empirical based CalME software was used in the final 40-year design of this project. The final rehabilitation steps that provide for 90% reliability are as follows:

1. Crack and seat existing JPCP slabs,
2. Place 0.10 ft (1.2”) PG 64-10 Type A leveling course
3. Place stress absorption membrane interlayer-fabric (SAMI-F),
4. Place 0.25 ft (3.0”) HMA PG 64-16 with 25% RAP,
5. Place 0.20 ft (2.4”) HMA PG 64-28 PM, and
6. Place 0.10 ft (1.2”) open graded friction course (OGFC).

Figure 7-12 is a schematic of the rehabilitated pavement structure. The leveling course is normally considered a non-structural layer. Therefore, the total structural HMA is equal to 0.45

ft (5.4 inch). The SAMI-Fabric is a geosynthetic pavement interlayer (GPI) that has been conventionally assumed by the Caltrans HDM to be equivalent to 0.1 ft (1.2 inch) HMA. The fabric is used to retard reflective cracking and prevent water intrusion. The wearing course is composed of open graded friction course which is a non-structural material and normally used to improve skid resistance and provide additional protection for the structural HMA layer against detrimental weather conditions. This wearing course must be replaced regularly. Therefore, the total structural HMA; including the contribution from the SAMI-F, is equal to 0.55 ft (6.6 inch).

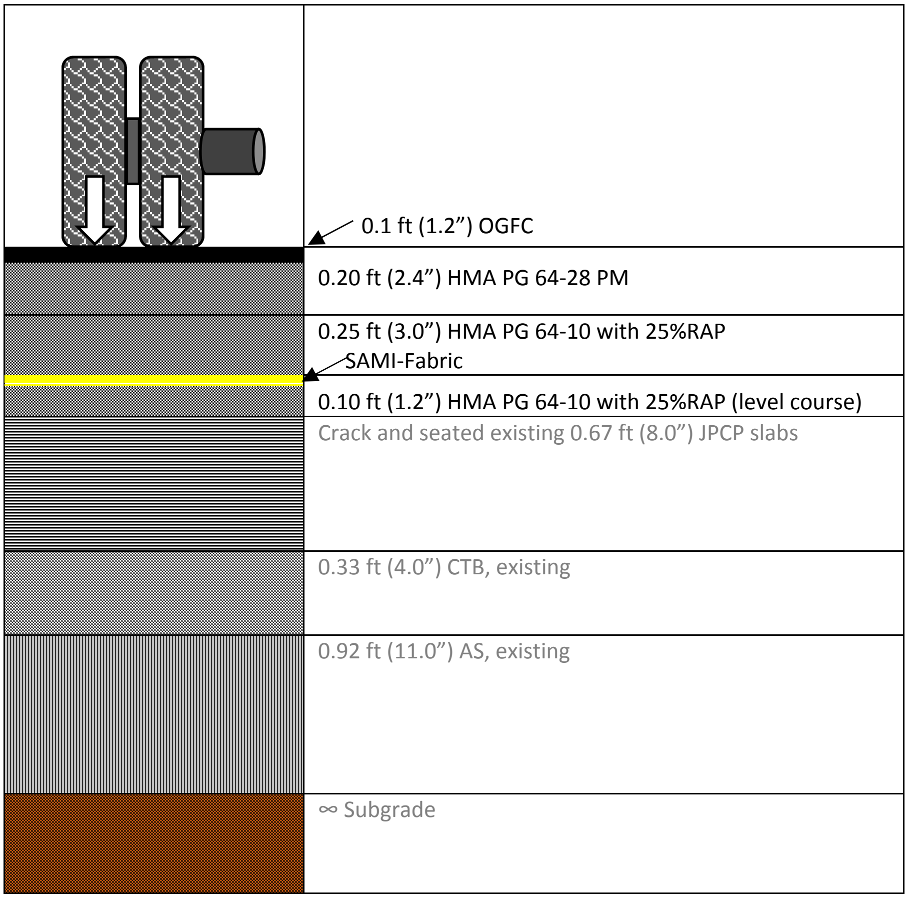


Figure 7-12. Crack, seat and overlay for the Solano project in the concrete lanes designed with CalME.

7.7.2 Reconstruction of JPCP Slabs

The reconstruction of the PCC pavement consists of the full replacement of the entire structure. However, it is possible to keep the existing base and subbase if there are no signs of failure of these layers. For this project, *rePave* removed the PCC slabs and replaced with a 4-inch HMA base followed by a new JPCP layer, as was previously shown in Figure 7-10. The Caltrans HDM Catalog for rigid pavement design can be used to develop the rehabilitation design for this project. The following inputs would be required:

1. Climate: Inland valley for I-80 between PM 30.55 and PM 38.70.
2. Soil Type: Soil subgrade has an R-value of 20 (M_r=10000 psi). The soil Type is II based on Caltrans HDM (Chapter 620).

3. Traffic Index: TI_{40}=15.0.
4. Later support: No lateral support (only flexible shoulders are available).

Based on the HDM Catalog (Table 623.1G), the structure is 1.15 ft JPCP over 0.25 ft HMA base over 0.70 ft AS. Note that the HDM Catalog designs are for new construction. Caltrans does not allow using CTB as a base layer in new JPCP construction. Therefore, the CTB layer must be removed (unlike *rePave* which did not remove the existing CTB layer). This is necessary since the HMA base may crack by reflection from the existing CTB layer causing it to lose its structural integrity as a base layer. Then, the HMA base (4 inch thick) must be placed on the existing granular layer prior to the placement of the 1.15 ft JPCP. Therefore, the final recommendations based on the Caltrans rigid Catalog are as follows:

1. Remove the existing PCC slabs,
2. Remove existing CTB layer,
3. Place 0.25 ft (3.0 inch) HMA base,
4. Place 1.15 ft (~14 inch) dowelled JPCP, and
5. Place 0.03 ft (~0.5 inch) OGFC.

Prior to placement of the HMA base, the existing AS layer must be re-compacted and any failed areas repaired or removed and replaced.

7.7.3 Unbonded Concrete Overlay

Topic 625 of the Caltrans HDM[76] provides guidance for designing unbonded rigid overlay for an existing rigid pavement. The overlay must be preceded by a 0.10 ft minimum flexible interlayer placed on top of the existing rigid pavement. The HMA interlayer acts as a bond breaker between the existing concrete and the new JPCP[77]. The HMA interlayer may need to be thicker if it is used temporarily for traffic handling. The thickness of the unbonded concrete overlay (JPCP) is obtained from the HDM rigid Catalog. Based on the project inputs given in the previous section, Table 623.1G is selected, and the concrete overlay thickness is found to be 1.15 ft (steel-dowelled). Therefore, the final rehabilitation recommendations for the unbonded concrete overlay strategy are as follows:

1. Place 0.15 ft (~2 inch) HMA interlayer over the existing concrete,
2. Place 1.15 ft (~14 inch) JPCP.

7.8 COMPARISON

---

[76] http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0620.pdf

[77] Bonding can force cracks and joints in the existing concrete to reflect through the new concrete leading to premature cracking in the new pavement.

In the preceding, all the designs produced by Caltrans CalME, Caltrans rigid Catalog, or the scoping tool *rePave* offer 90% reliability. The following can be concluded from comparing the scoping designs via *rePave* and the available Caltrans scoping tools:

1. **Crack, seat and overlay:** The thickness of the HMA overlay needed after cracking and seating concrete slabs was found to be 7.0 inches using *rePave* based on a base modulus of 100000 psi. Based on 75000 psi modulus recommended by *rePave*, the overlay thickness is 8.5 inches. Using CalME, the final design constituted of a leveling course of 0.1 ft HMA (with no structural value assigned), a SAMI-F (equivalent to 0.1 ft HMA; 1.2 inches), a 3.0 inch HMA PG 64-16, and 2.4 inch HMA PG 64-28PM for a total thickness of 6.6 inches of HMA. This total thickness designed with CalME is very close to the total thickness obtained with the scoping tool *rePave* when 100000 psi base modulus used, and lower (by 1.9 inches) than *rePave*'s scoping design when the recommended base modulus of 75000 psi is used in *rePave*. The use of polymer modified surface layer in the final design using CalME can provide superior performance than unmodified HMA, and therefore may have contributed to the reduced total HMA thickness obtained with CalME. Therefore, the scoping tool *rePave* generally produced a more conservative design thickness than final design CalME. This finding supports the appropriateness and reasonableness of rePave as a coping tool.

2. **Reconstruction:** Based on *rePave*, after removing existing PCC, a 4 inch HMA base is placed followed by 10.5 inches of new JPCP. This is to be compared to the "final" design obtained using the Caltrans HDM Catalog which requires removal of both the PCC and CTB layers, then the placement of 3 inches of HMA base followed by the placement of 14 inches of new JPCP. There is significant difference between the two methods; with Caltrans Catalog resulting in thicker PCC. Note that the Caltrans Catalog was originally developed for designing new rigid pavement and not for rehabilitation of existing pavements. As such, it is expected that the use of such catalog in rehabilitation (while ignoring much of the existing lower layer) can result in concrete thicknesses that exceeds the thickness demanded based on project needs.

3. **Unbonded concrete overlay:** *RePave* recommends a 10 inch new JPCP placed over a 2 inch HMA bond breaker. In comparison, the Caltrans rigid Catalog requires 14 inch of new dowelled JPCP placed over a 2 inch HMA bond breaker. Using the Caltrans Catalog as a rehabilitation scoping or final design tool is believed to produce an overconservative design compared to *rePave* since the Catalog has been originally developed for designing new rigid pavement.

8 CASE STUDY 4 (I-710 LONG BEACH)

8.1 PROJECT DESCRIPTION

The I-710 long life project (referred to herein as the “LA-710 freeway project”) is the first long-life pavement rehabilitation project designed with the Mechanistic-Empirical (ME) procedure and constructed in California in 2003. The project is located within the Los Angeles County limits near the City of Long Beach in Southern California between the Pacific Coast Highway (Route 1) and Interstate 405 and extending between PM 6.8 to PM 9.7. Figure 8-1 is an aerial map showing the approximate project location limits. The project is a six-lane divided highway with three lanes in each direction.

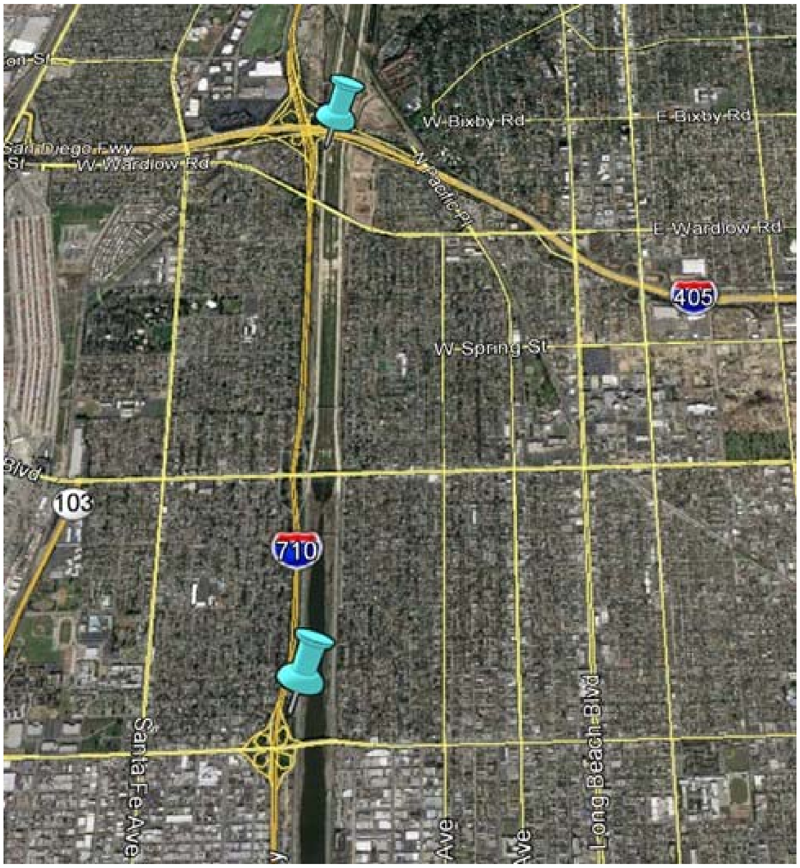


Figure 8-1. Aerial map of the LA-710 freeway project location.

This project consisted of JPCP. Prior to rehabilitation, the pavement within the project limits exhibited 1st and 3rd stage cracking (according to Caltrans distress identification system) as well as extensive corner breaks, faulting, and ride quality issues. The actual rehabilitation strategies selected for this project comprised of both crack, seat and HMA overlay for the majority of the project mainline lanes, and a full depth HMA under overcrossings. The analysis provided here will compare both of these two rehabilitation strategies to *rePave* scoping design estimates.

8.2 TRAFFIC

The average one-way ADT for this interstate segment is equal to 155,000 with trucks making up about 13% of the total traffic[78]. Rehabilitation designs were originally developed for a service life of 30 years using the Caltrans ME procedure. The 30-year traffic index (TI_{30}) for the mainline lanes was 17.0.

The traffic growth rate was determined from the traffic data available in the CalME software and was found to be equal to ~ 5.0%.

8.3 "ESALS PER YEAR" CALCULATIONS

The "ESALs per year" is an input needed in the *rePave* scoping tool and was calculated in the same way as previously done for the other projects (see Chapters 5, 6, and 7). For the LA-710 freeway project, the total 30-year design ESALs was 209,000,000 (209 mESALs). Using the ESAL accumulation Excel spreadsheet developed for this study with a growth rate of 5%, the initial ESALs was found to be equal to 3.2 mESALs. Therefore, starting with a 3.2 mESALs and a compound growth rate of 5% over a 30-year period, the pavement will receive 209 mESALs by the end of the 30th year of trafficking; corresponding to TI_{30} of 17.0. It is noted here that this cumulative ESAL number slightly exceeds the maximum 200 mESALs currently supported by *rePave.* The issue of exceeding the maximum ESAL limit will be addressed later in this chapter.

8.4 EXISTING PAVEMENT STRUCTURE

The "average" structure representing the project is shown in Figure 8-2. It consists of 0.67 ft (8.0 in.) JPCP over 0.33 ft (4.0 in.) cement treated base (CTB) over 0.33 ft (4.0 in.) aggregate base (AB) over 0.92 ft (11.0 in.) aggregate subbase (AS) over subgrade. Based on available District Materials Report, the existing PCC is believed to have been constructed in 1980, and the CTB, AB, and AS layers constructed in 1952.

Previous design reports indicated that the subgrade has a resilient modulus varying between 8000 psi and 12000 psi based on FWD testing and backcalculation of resilient moduli[79]. Therefore, an average modulus of 10,000 psi will be used[80]. The AS resilient modulus was assumed to be 25000 psi and the AB modulus 32000 psi. The CTB was assumed to have an elastic modulus of 400000 psi (based on typical modulus found from the Red Bluff project).

8.5 DISTRESS CONDITION

Since construction of this project was completed in 2003, the 2002 Caltrans Pavement Condition Report (PCR) was selected to obtain the distresses that existed prior to rehabilitation. The

---

[78] See report written by Monismith et al. (2009), page 18: http://www.dot.ca.gov/newtech/researchreports/reports/2009/2009-02_task_1891_pavement.pdf).

[79] See http://www.dot.ca.gov/newtech/researchreports/reports/2009/2009-02_task_1891_pavement.pdf).

[80] This subgrade modulus corresponds with an R-value of ~16 using the Asphalt Institute relationship Mr=1155+555×R-value.

majority of distresses were 3rd and 1st stage cracking, corner breaks, faulting, and poor ride quality. The following average distress quantities were finally assumed based on the 2002 PCR data:

- 1st stage cracking=60%,
- 3rd stage cracking=15%,
- Corner breaks=10%, and
- IRI (average all lanes)=220 in/mile.

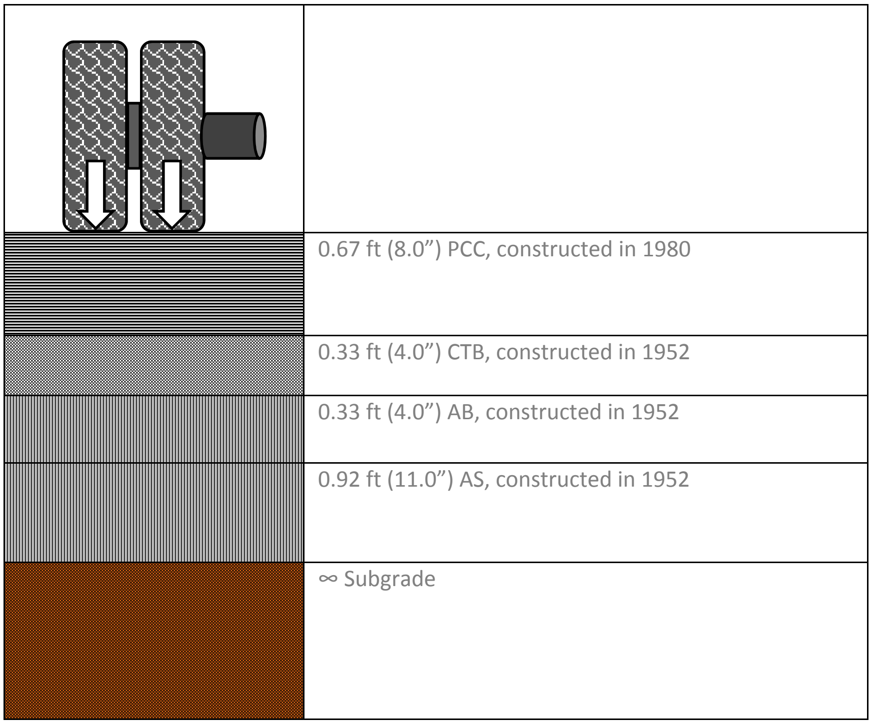
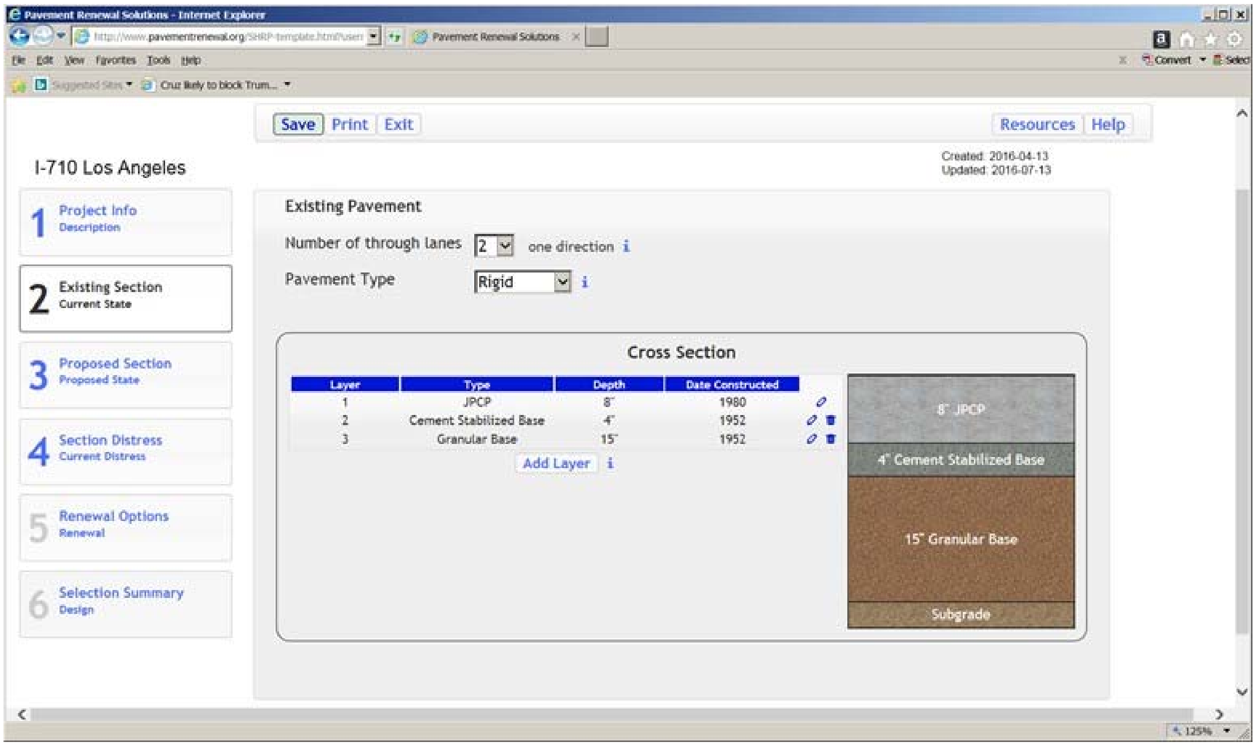


Figure 8-2. Existing pavement structure for the LA-710 freeway project.

8.6 REPAVE DESIGN

The existing structure for the Solano project concrete lanes entered in *rePave* scoping tool is shown in Figure 8-3.



I-710 Los Angeles

Created: 2016-04-13
Updated: 2016-07-13

Existing Pavement

Number of through lanes: 2 one direction

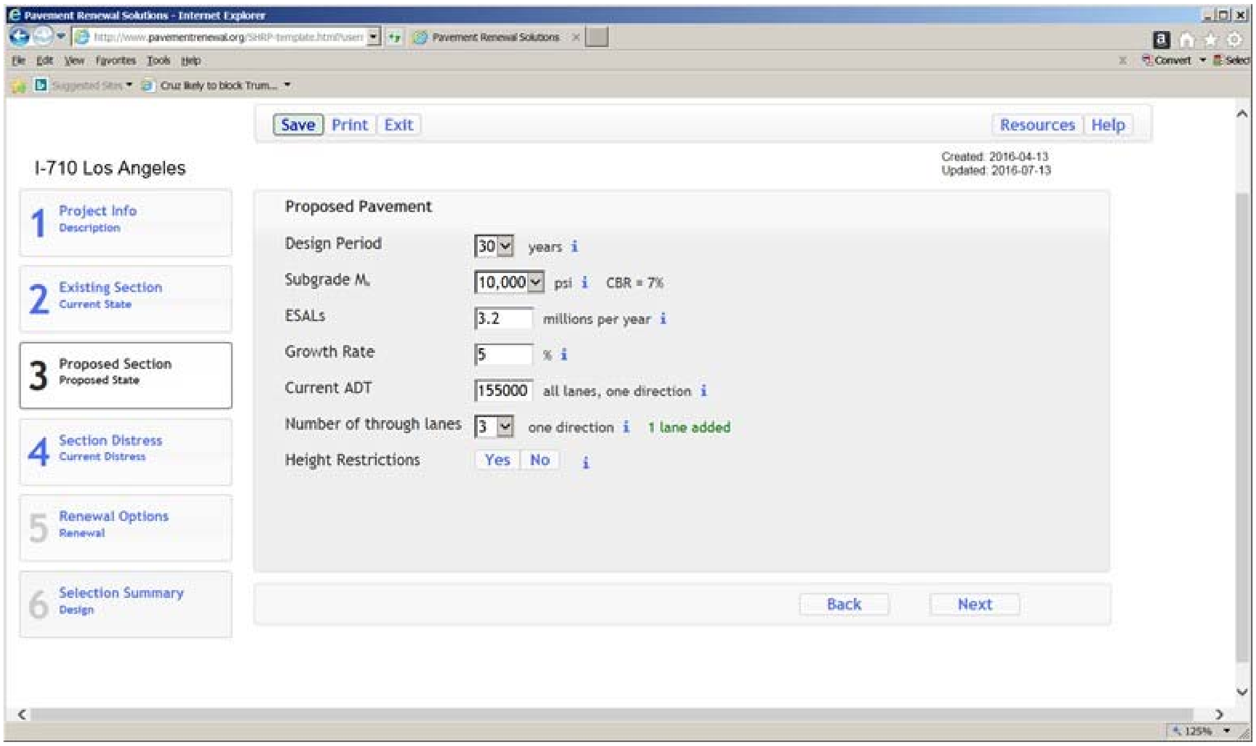
Pavement Type: Rigid

Cross Section

Layer	Type	Depth	Date Constructed
1	JPCP	8"	1980
2	Cement Stabilized Base	4"	1952
3	Granular Base	15"	1952

Figure 8-3. The existing pavement structure of the LA-710 freeway entered in *rePave*.

The general inputs for this project are displayed in Figure 8-4.



I-710 Los Angeles

Created: 2016-04-13
Updated: 2016-07-13

Proposed Pavement

Design Period: 30 years

Subgrade M_r: 10,000 psi CBR = 7%

ESALs: 3.2 millions per year

Growth Rate: 5 %

Current ADT: 155000 all lanes, one direction

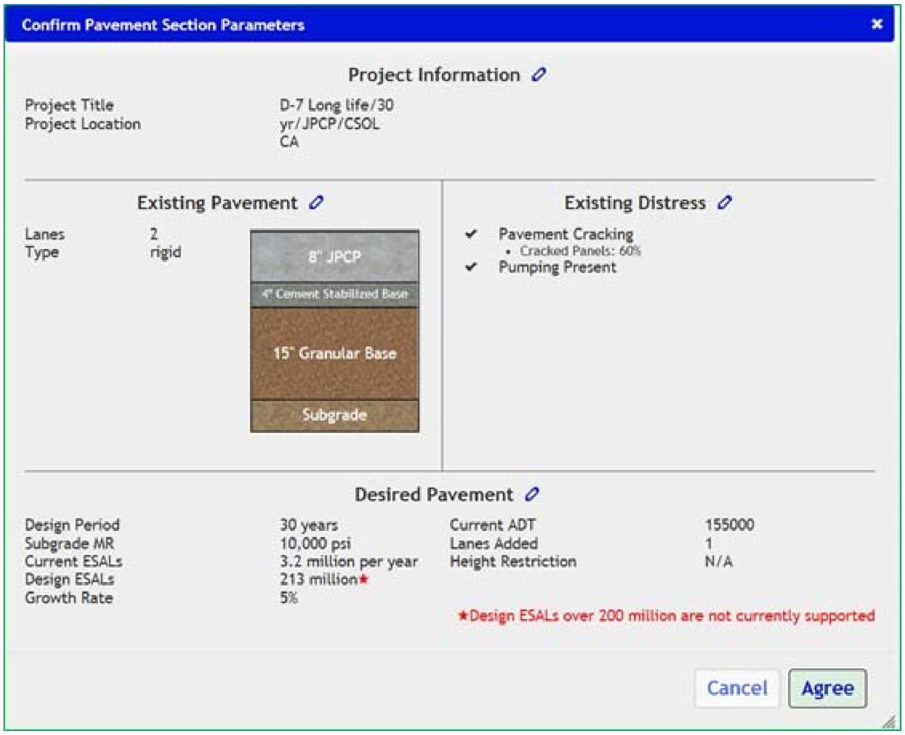
Number of through lanes: 3 one direction 1 lane added

Height Restrictions: Yes No

Figure 8-4. A screenshot of the general inputs for the LA-710 freeway.

For the existing section provided, the *rePave* tool requires the amount of pavement cracking in terms of cracked panels and whether pumping exists. The following was entered in *rePave*: (i) 60% of panels were assumed to be cracked, and (ii) pumping was present throughout the project.

A summary of the entered project information displayed by the *rePave* tool is shown in Figure 8-5. Note that based on traffic data provided, the total number of ESALs exceeds the 200 mESALs level supported by *rePave*. According to Mr. Newt Jackson (from the *rePave* Development Team), increasing the total number of ESALs to 400,000,000 would only require an additional ~ ½ inch of asphalt overlay design thickness based on the limited strain criteria used in developing the *rePave* decision trees. Therefore, increasing the total ESALs from 200 to 209 mESALs (less than 5% increase) will have an insignificant effect on the required design thickness.



Confirm Pavement Section Parameters

Project Information

Project Title	D-7 Long life/30 yr/JPCP/CSOL
Project Location	CA

Existing Pavement

Lanes	2
Type	rigid

Existing Distress

✓ Pavement Cracking
  - Cracked Panels: 60%

✓ Pumping Present

Desired Pavement

Design Period	30 years	Current ADT	155000
Subgrade MR	10,000 psi	Lanes Added	1
Current ESALs	3.2 million per year	Height Restriction	N/A
Design ESALs	213 million★		
Growth Rate	5%		

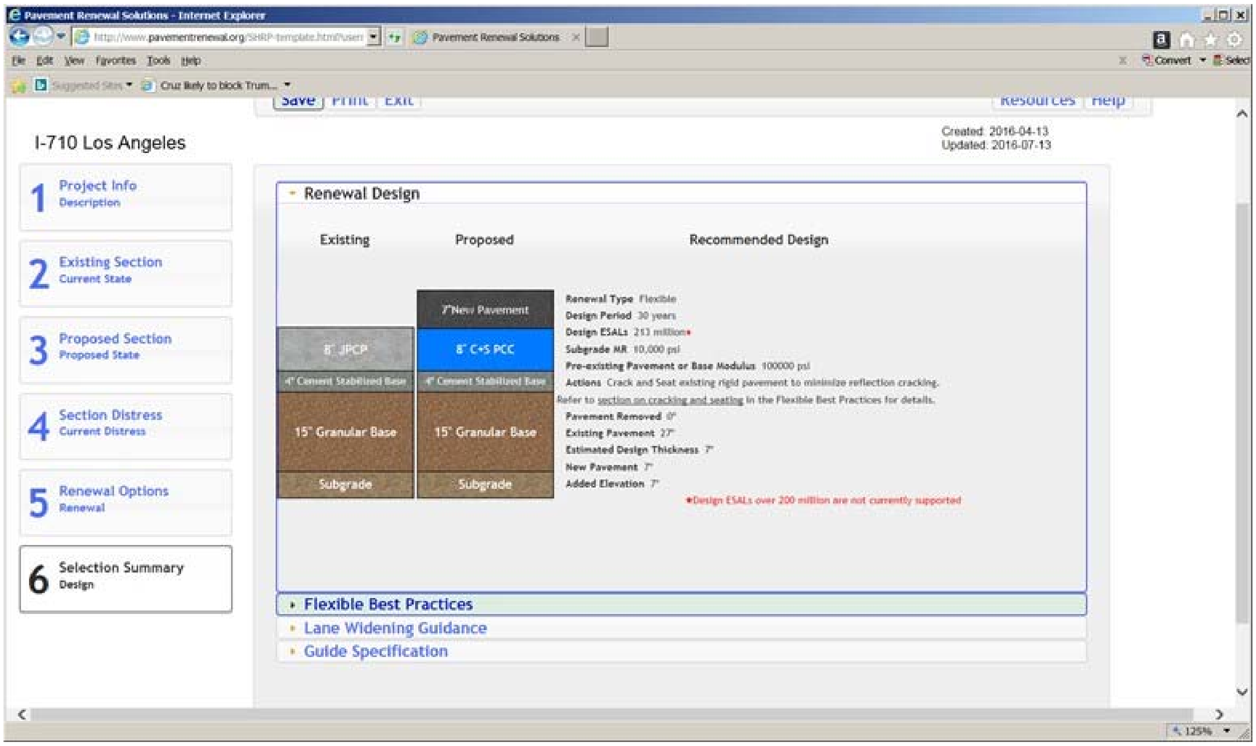
★Design ESALs over 200 million are not currently supported

Figure 8-5. Summary of project inputs for LA-710 freeway.

As mentioned earlier, two rehabilitation strategies were originally designed (and constructed):

1. One strategy for rehabilitating pavement sections under the overcrossings consisting of a full depth asphalt concrete to maintain existing profile grade and vertical clearance, and
2. Another strategy for rehabilitating pavement sections elsewhere consisting of cracked-seated-and-HMA overlay.

For the pavement sections not controlled by vertical clearance (i.e., outside under-overcrossing locations), the *rePave* renewal option selected was “flexible”. From this option, the “crack and seat” renewal action was also selected. Assuming a base modulus value of 100,000 psi, the HMA overlay thickness over the cracked-and-seated JPCP slabs was found to be equal to 7.0 inches. Figure 8-6 shows the suggested renewal design.



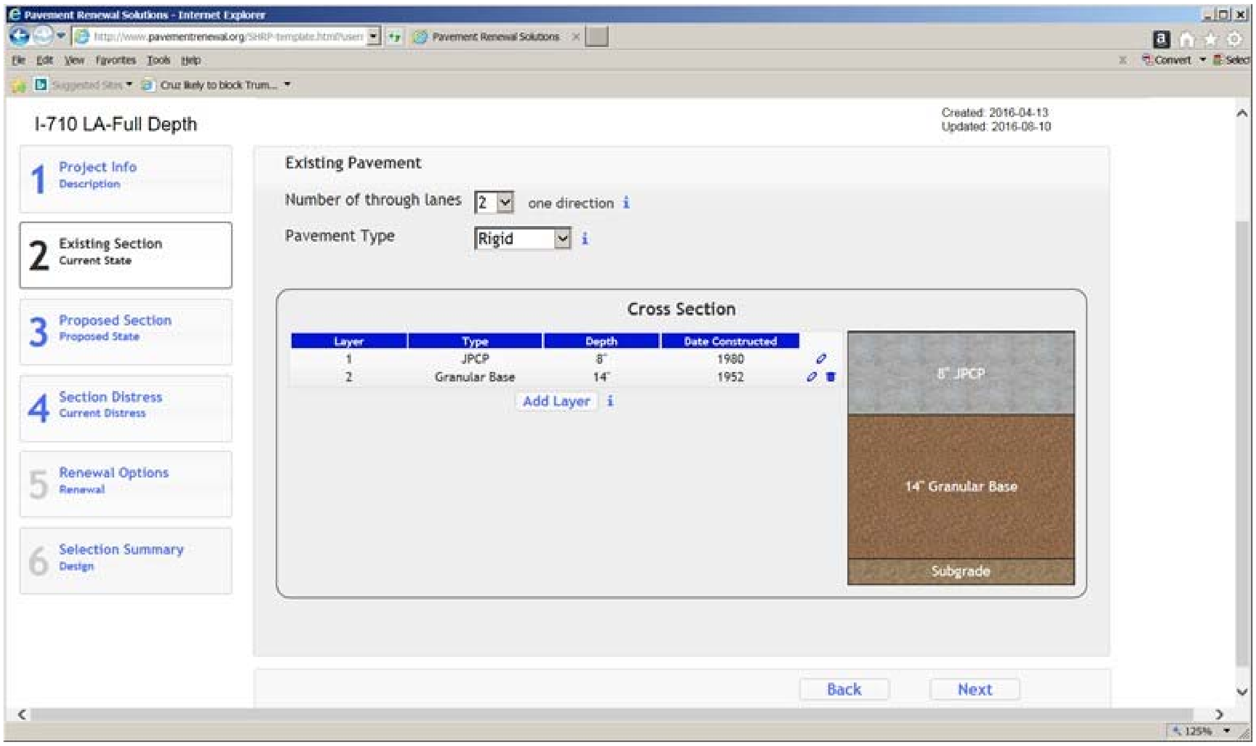
Created: 2016-04-13
Updated: 2016-07-13

Renewal Type Flexible
Design Period 30 years
Design ESALs 213 million*
Subgrade MR 10,000 psi
Pre-existing Pavement or Base Modulus 100000 psi
Actions Crack and Seat existing rigid pavement to minimize reflection cracking.
Refer to section on cracking and seating in the Flexible Best Practices for details.
Pavement Removed 0"
Existing Pavement 27"
Estimated Design Thickness 7"
New Pavement 7"
Added Elevation 7"
*Design ESALs over 200 million are not currently supported

Figure 8-6. *rePave* crack-and-seat-and HMA overlay design for the LA-710 freeway JPCP sections.

Using a base modulus of 75000 psi (as recommended by the *rePave* Development Team) would produce an HMA overlay thickness of 8.5 inches which would force a thicker overlay thickness that is would be in line with the Transport Research Laboratory's general guidelines.

For scoping rehabilitation of segments under overcrossings, a similar analysis was also performed. However, in this case, to force *rePave* to produce a full depth section that maintains the existing profile grade elevation, some alteration to the existing section was made. This included eliminating the CTB layer and an additional one inch of the aggregate base. Figure 8-7 shows the final pavement section used in the analysis.



I-710 LA-Full Depth

Created: 2016-04-13
Updated: 2016-08-10

Existing Pavement

Number of through lanes 2 one direction

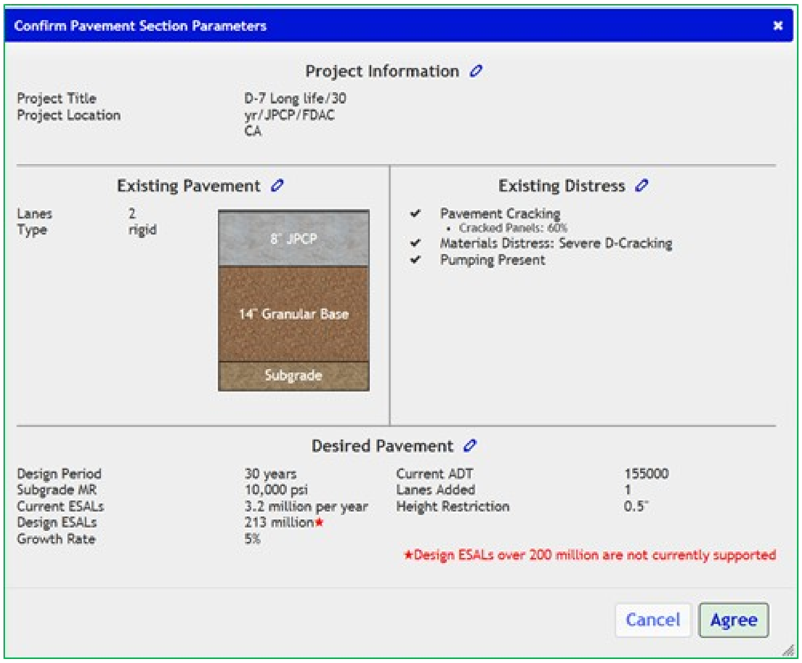
Pavement Type Rigid

Cross Section

Layer	Type	Depth	Date Constructed
1	JPCP	8"	1980
2	Granular Base	14"	1952

Figure 8-7. Revised pavement structure used in scoping rehabilitation under overcrossings.

For this section, *rePave* requires the following distresses: (i) the pavement cracking in terms of % of cracked panels (assumed 60%), (ii) materials distress (assumed D-cracking to be moderate to severe), and (iii) presence of pumping. The general inputs for *rePave* are shown in Figure 8-8.



Project Information

Project Title D-7 Long life/30 yr/JPCP/FDAC
Project Location CA

Existing Pavement

Lanes 2
Type rigid

Existing Distress

- ✓ Pavement Cracking
  - Cracked Panels: 60%
- ✓ Materials Distress: Severe D-Cracking
- ✓ Pumping Present

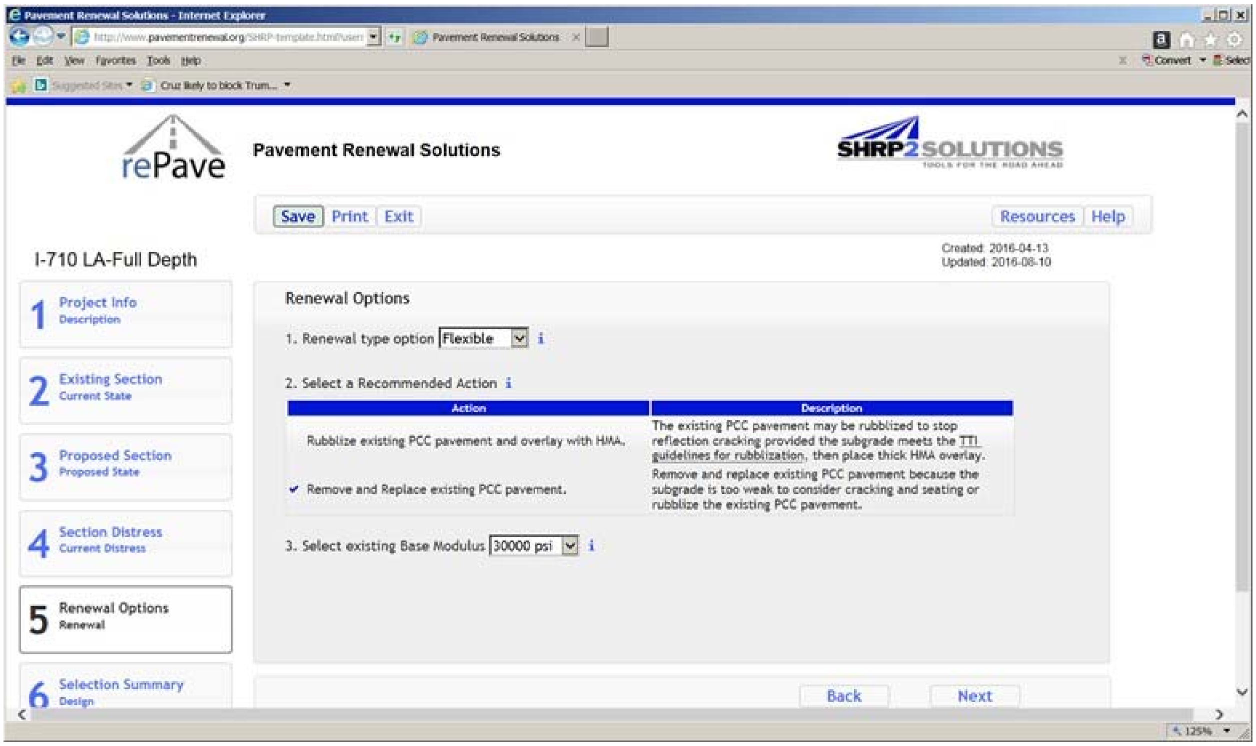
Desired Pavement

Design Period	30 years	Current ADT	155000
Subgrade MR	10,000 psi	Lanes Added	1
Current ESALs	3.2 million per year	Height Restriction	0.5"
Design ESALs	213 million*		
Growth Rate	5%		

*Design ESALs over 200 million are not currently supported

Figure 8-8. Summary of inputs for the revised structure.

The renewal actions under the renewal option “flexible” as proposed by *rePave* for under overcrossing locations are shown in Figure 8-9. For this structure the base is assumed to have a resilient modulus of 30000 psi representing the subgrade modulus. As seen in Figure 8-9 *rePave* suggests either rubblization or remove-and-replace renewal actions. For a full depth asphalt concrete section, the remove-and-replace action was selected as shown in Figure 8-9.



Pavement Renewal Solutions

I-710 LA-Full Depth

Created: 2016-04-13
Updated: 2016-08-10

Renewal Options

1. Renewal type option Flexible

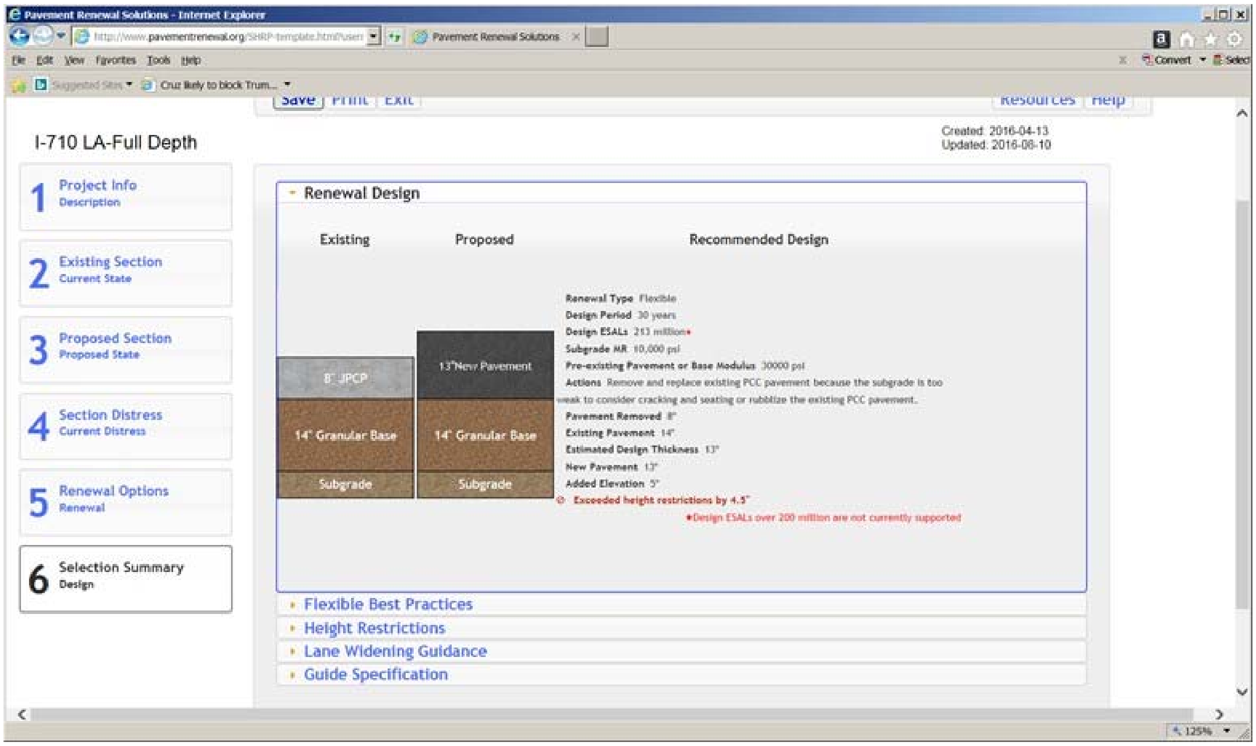
2. Select a Recommended Action

Action	Description
Rubblize existing PCC pavement and overlay with HMA.	The existing PCC pavement may be rubblized to stop reflection cracking provided the subgrade meets the TTI guidelines for rubblization, then place thick HMA overlay.
✓ Remove and Replace existing PCC pavement.	Remove and replace existing PCC pavement because the subgrade is too weak to consider cracking and seating or rubblize the existing PCC pavement.

3. Select existing Base Modulus 30000 psi

Figure 8-9. Renewal actions available for the revised structure.

For the revised structure, the renewal full depth strategy proposed by *rePave* is shown in Figure 8-10. As shown, the full depth section will require 13 inches of HMA. Note that this section will maintain the existing profile grade elevation. Initially, the total depth is composed of 8.0” PCC, 4.0” CTB, and 15.0” granular material for a total depth of 27.0”. The full depth asphalt concrete section now has 13.0” HMA over 14.0” of granular materials for a total depth of 27.0”. The granular material will mainly provide a construction platform for the placement of the HMA. Note in Figure 8-10 that the shown grade difference is due to ignoring the CTB layer.



Created: 2016-04-13
Updated: 2016-08-10

Renewal Type Flexible
Design Period 30 years
Design ESALs 213 million*
Subgrade MR 10,000 psi
Pre-existing Pavement or Base Modulus 30000 psi
Actions Remove and replace existing PCC pavement because the subgrade is too weak to consider cracking and seating or rubblize the existing PCC pavement.
Pavement Removed 8"
Existing Pavement 14"
Estimated Design Thickness 13"
New Pavement 13"
Added Elevation 5"
Exceeded height restrictions by 4.5"
*Design ESALs over 200 million are not currently supported

Figure 8-10. Full depth design for the LA-710 freeway under overcrossing locations.

8.7 FINAL MECHANISTIC-EMPIRICAL (ME) DESIGN

Two pavement structures were considered for the long-life rehabilitation of the LA-710 freeway. The crack-and-seat-and-HMA overlay was used on the concrete pavement in locations not affected by vertical clearance, while the full depth asphalt concrete section was selected for locations under overcrossing to maintain the existing profile grade. The Caltrans mechanistic-empirical procedure (earlier versions of today's CalME) was used in the final 30-year design of this project for both locations.

The crack, seat and overlay "final" design (90%-based reliability) was as follow:

1. Crack and seat existing JPCP slabs,
2. Place 0.10 ft (1.2") AR-8000 leveling course,
3. Place stress absorption membrane interlayer-fabric (SAMI-F),
4. Place 0.42 ft (5.0") HMA AR-8000 (now equivalent to PM 70-10),
5. Place 0.25 ft (3.0") HMA PBA-6a (now equivalent to PM 64-28 PM), and finally
6. Place 0.10 ft (1.2") open graded friction course (OGFC).

Note the binder types (AR-8000 and PBA-6a) that Caltrans used prior to the introduction of the PG grading system. Figure 8-11 is a schematic of the rehabilitated pavement structure. The leveling course and OGFC are normally considered non-structural layers. Therefore, the total structural HMA is equal to 0.67 ft (8.0 inch) plus the nonwoven asphalt binder-saturated fabric, which has been conventionally assumed to provide the benefit of an equivalent 0.1 ft (1.2 inch) HMA[81]. Therefore, the total equivalent structural HMA is 0.77 ft (9.2 inch).

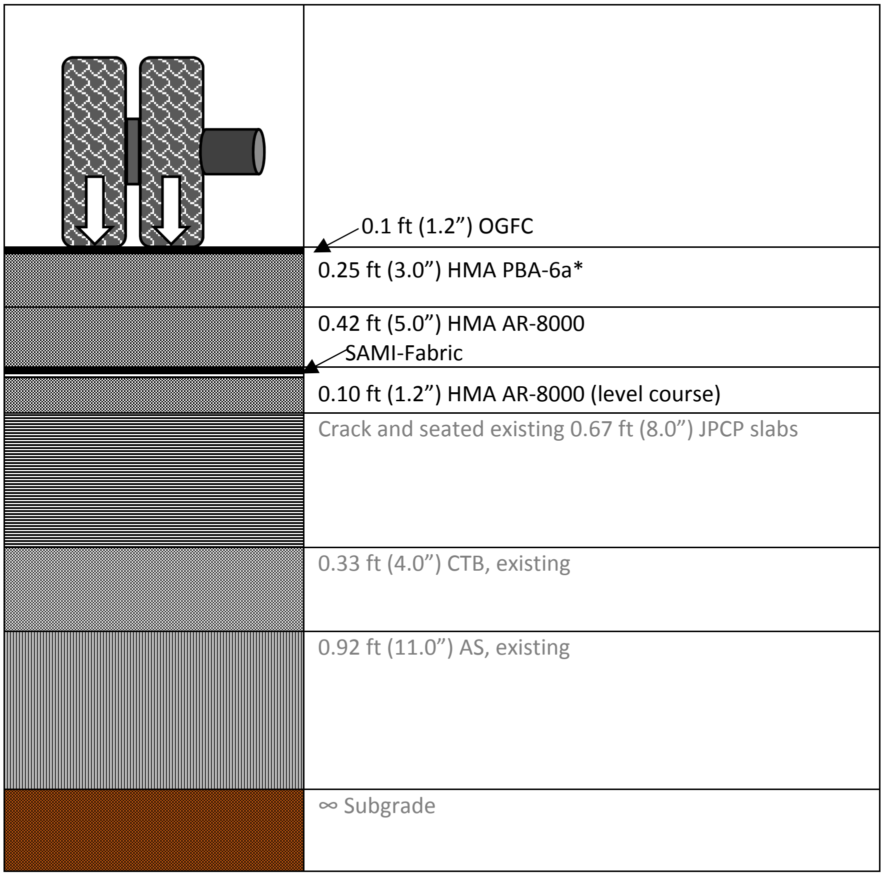


Figure 8-11. Final structure section for the LA-710 freeway utilizing crack-seat-and overlay strategy.

The "final" design of the full depth section (using ME analysis and utilizing advanced laboratory testing for the HMAs) is comprised of the following construction steps:

1. Remove existing structure (PCC and CTB) 12 inches deep. This will expose the AB layer which must be graded and re-compacted, if necessary,
2. Place 0.25 ft (3.0") HMA AR-8000 rich bottom layer (5.2% binder content, 3% air voids),
3. Place 0.50 ft HMA (6.0") HMA AR-8000 intermediate layer (4.7% binder content, 6% air voids),
4. Place 0.25 ft (3.0") HMA PBA-6a top layer, and finally
5. Place 0.10 ft (1.2") OGFC.

---

[81] In Caltrans HDM, the SAMI-F belongs to the group Geosynthetic Pavement Interlayers (GPI) and it is equivalent to 0.1 ft HMA, see page 630-15 here http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0630.pdf

The HMA mix for the rich bottom layer is similar to that of the intermediate layer except that it has 0.5% higher binder content. The total thickness of HMA is 1.0 ft (12.0 inches). Figure 8-12 shows the full depth section designed with ME method for undercrossing locations.

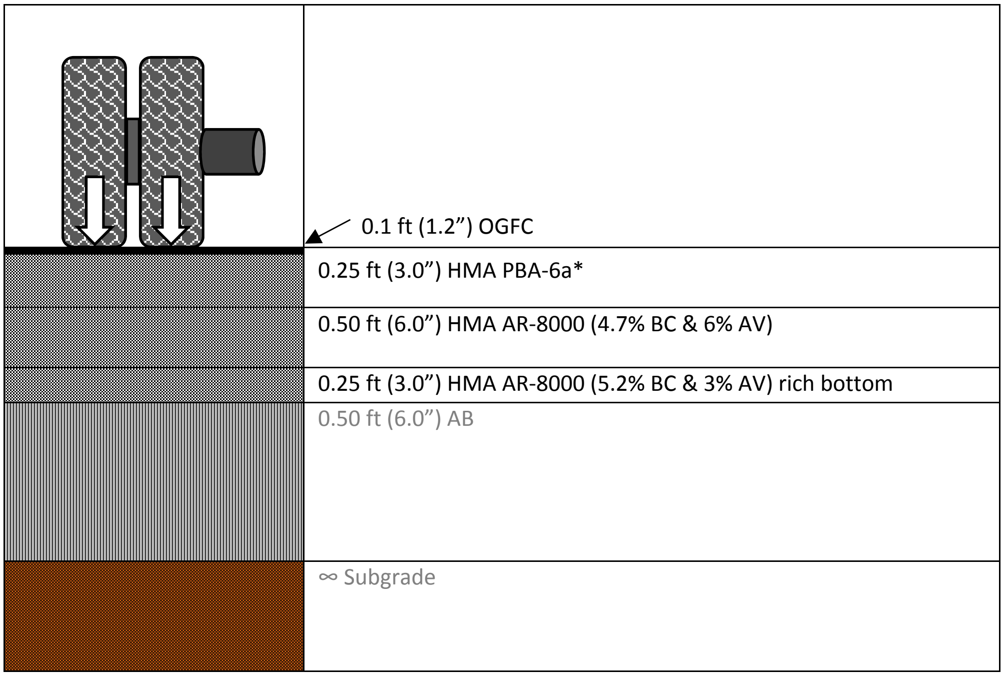


Figure 8-12. Final structure section for the LA-710 freeway utilizing full depth asphalt concrete strategy at undercrossing locations.

8.8 COMPARISON

The comparison is conducted between the *rePave* scoping designs and the corresponding “final” designs discussed in the previous section. Note that both *rePave* and final designs provide at least 90% reliability.

For crack, seat and HMA overlay strategy, the *rePave* scoping HMA overlay thickness was 8.5 inches based on the recommended base modulus of 75000 psi. This design is 0.7 inches thinner than the final design obtained with the ME method. It is not clear whether the rePave scoping design considers the placement of a fabric at the bottom of the overlay to improve reflective cracking resistance (equivalent to 1.2 inches HMA). If that is the case, then the rePave design would offer a thicker overlay of 9.7 inches which would also exceed the total HMA determined with the ME procedure (9.2 inches).

For the full depth section, the *rePave* scoping design came out to be very close to the ME “final” design. Actually, the *rePave* design (13.0 inches of HMA) was 1.0 inch thicker than the ME design (total of 12.0 inches HMA). This is in fact a good agreement between the two systems knowing that the “final” design account for actual material properties, improved properties of the polymer modification, and the enhanced performance achieved by using three HMA layer configuration for the full depth section.

9 CASE STUDY 5 (I-10 RIVERSIDE)

9.1 PROJECT DESCRIPTION

This project is currently (April 2017) under construction by the District. The project is located on I-10 in Riverside County from 1.9 miles east of Cactus City Rest Area at approximately PM R74 to 0.40 miles east of Desert Center Rice Road at approximately PM R105. This project will be referred to in this Chapter as the “Riverside project”. Figure 9.1 shows a Google Earth photo of the location of the project. The facility is comprised of four-lane divided freeway with two lanes in each direction, inside shoulders 5 ft wide, and outside shoulders 10 ft wide. The pavement within the project limits is an asphalt pavement.

Figure 9-1. Google Earth map of the project location.

Deflection testing with FWD and visual distress survey were conducted in both directions by the District Materials Engineer’s Office in January 2015 to assess the structural condition of the pavement and determine prevailing distress types and quantities within the project limits. The distress survey indicated that the asphalt pavement surface had moderate to high severity fatigue cracking, bleeding, pumping, rutting, and lane shoulder drop off. Figure 9-2 shows sample photos of the distressed pavement in eastbound and westbound direction (taken from the Caltrans Roadview Explorer with 2009 data). Additionally, Figure 9-3 shows severe pumping in the cracked asphalt. According to the distress survey, the project condition was qualitatively described as follows: (1) between PM 74.0 and PM 87.0 least distressed, (2) between PM 87.0 and PM 95.0 moderately distressed, and (3) between PM 95.0 to PM 105.0 severely distressed.

Figure 9-2. Distressed pavement in the EB direction at PM 86.7 (left) and in the WB direction at PM 101.5 of the Riverside I-10 project.

Figure 9-3. Photo showing pumping in the fatigue cracked wheel path taken at PM 104 Eastbound.

9.2 TRAFFIC

The original traffic report prepared for the project indicated that the “current” 2015 two-way ADT is 27600, and the estimated 40-year ADT is 55400. The 10-year and 40-year Traffic Indices (TI_{10} and TI_{40}, respectively) for the mainline lanes were also determined based on project ESALs as follows:

- TI_{10}=14.0, and
- TI_{40}=17.5.

Based on the reported TI’s, the total number of ESALs for 10-year and 40-year design lives were determined as 41 mESALs and 267 mESALs, respectively. Note that the 267 mESASLs value exceeds the upper limit of the *rePave* tool; but this will be addressed later in this Chapter. Based on these ESAL estimates, the growth rate (GR) was calculated as:

$$GR = \left(\frac{267{,}000{,}000}{41{,}000{,}000}\right)^{\frac{1}{30}} - 1.0\text{=0.065=6.5\%}$$

Since the *rePave* scoping tool does not allow GR above 5%, a growth rate of 5% was used in the analysis.

9.3 “ESALS PER YEAR” PARAMETER

“ESALs per year” is another input in *rePave* and was calculated in the same way it was calculated previously. For the Riverside project, the total design 40-year ESALs is 267 mESALs. The actual growth rate was found to be 6.5%, but then assumed to be equal to 5%. Using the ESAL accumulation Excel spreadsheet, the initial ESALs was found to be equal to 2.25 mESALs. This means that starting with 2.25 mESALs and a compound growth rate of 5% over 40-year service period, the pavement is expected to have been subjected to 267 million ESAL repetitions by the end of the 40th year of trafficking; corresponding to a TI_{40} of 17.5.

9.4 EXISTING PAVEMENT STRUCTURE

The “average” structure representing the project is shown in Figure 9-4. The existing pavement consists of the following layers (from top to bottom): 0.20 ft (2.4”) rubberized hot mix asphalt-gap graded (RHMA-G), 0.20 ft (2.4”) hot mix asphalt (HMA), 0.25 ft (3.0”) asphalt concrete base (ACB), 0.60 ft (7.2”) aggregate base (AB), and 1.50 ft (18.0”) aggregate subbase (AS) placed over compacted subgrade soil. The year of construction of the various layers is as shown in Figure 9-4. Previous design reports classified the subgrade soils as predominantly loamy sand, gravelly loam, gravelly sand. The average R-value was assumed to be 50. The corresponding resilient modulus is ~30000 psi.

9.5 DISTRESS CONDITION

The 2013 Caltrans Pavement Condition Report (PCR) was used to obtain the types and quantities of existing distresses within the project limits. The following average distress quantities were estimated:

- Alligator A cracking=0 to 26%,
- Alligator B cracking=0 to 50%,
- Rutting=0-4 inch, and
- IRI=80-180 in/mile (with an average of 120 in/mile).

The *rePave* tool requires amount of fatigue cracking, patching, rutting, transverse cracking, and whether stripping exists. These were estimated as follows based on obtained data from the 2013 PCR:

a) Fatigue cracking: 25% high severity, top down,
b) Patching=10%, Surface,
c) Rutting=1 inch,
d) Transverse cracking=5 per 100 ft, and
e) Stripping exists in the HMA.

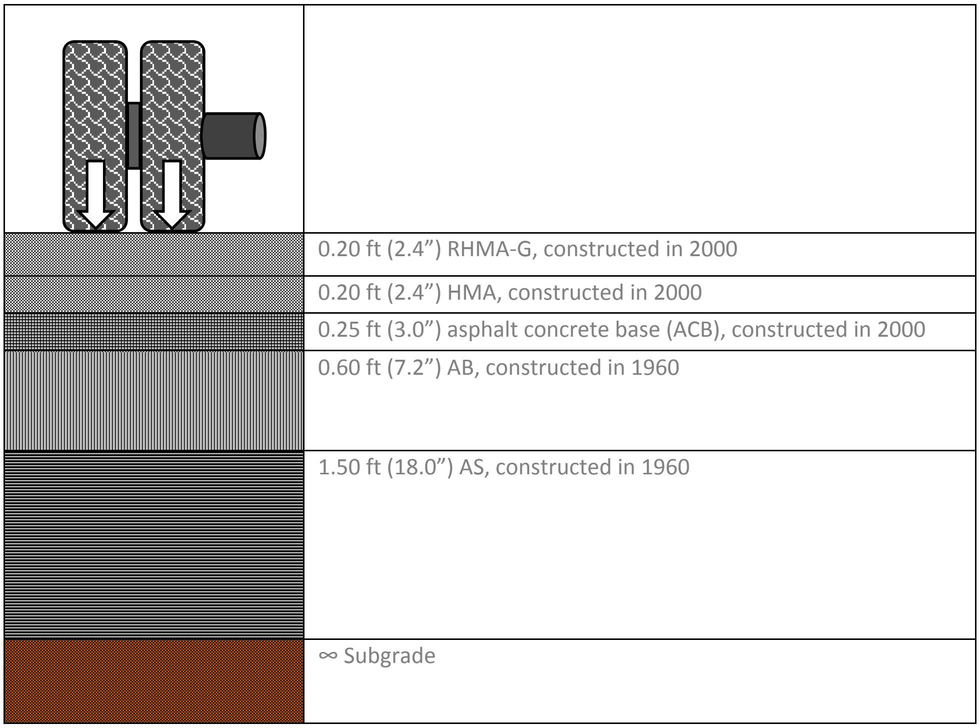


Figure 9-4. Existing pavement structure for Riverside project.

9.6 SCOPING DESIGN WITH REPAVE

The District designed the project based on FWD deflection data collected from the pavement. No HMA characterization using advanced laboratory testing was performed to obtain materials properties needed for the design[82]. Instead, materials from the CalME library were used. Therefore, the District design is considered to some degree a scoping design. The deflection data was used in the backcalculation of in-situ modulus of all the pavement layers including the subgrade and then used in developing the long-life rehabilitation strategies.

Two strategies representing both flexible and rigid options were developed by the District:

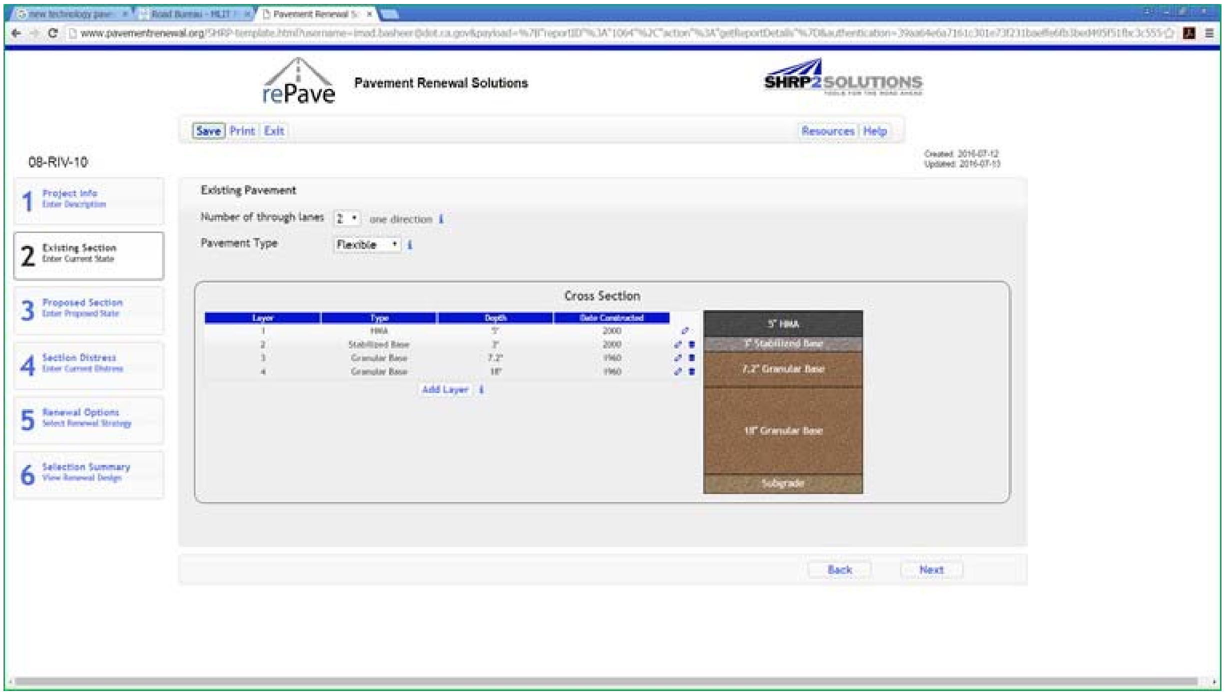
1. Cold plane existing pavement and replace with asphalt concrete, and
2. Unbonded concrete overlay (whitetopping).

Both of these strategies were analyzed using *rePave* and will be discussed below.

The existing structure as entered in *rePave* scoping tool is as shown in Figure 9-5.

---

[82] For scoping purposes, selecting conservative HMA material constants from available materials data in CalME should be sufficient (for stiffness and rutting and fatigue performance). Final design and specifications development must be based on actual materials testing.



08-RIV-10

Created: 2016-07-12
Updated: 2016-07-13

Existing Pavement

Number of through lanes: 2 one direction

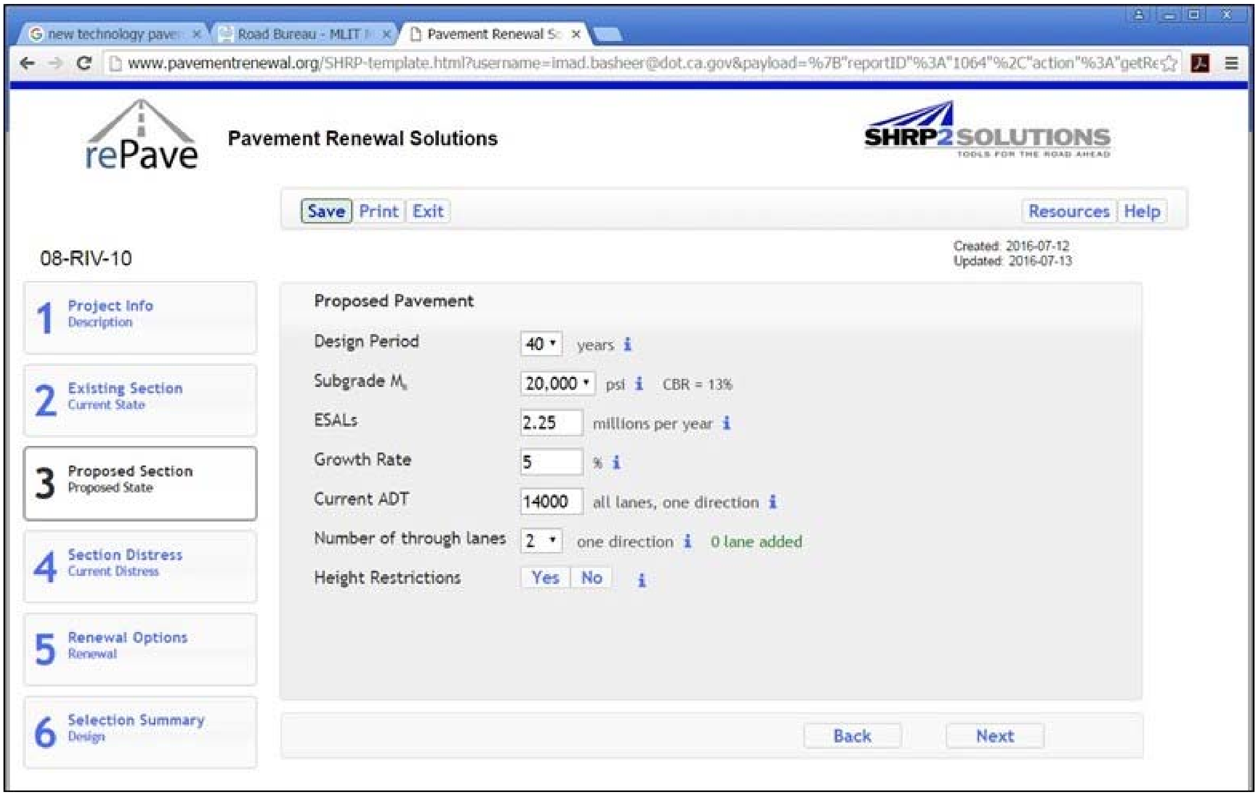
Pavement Type: Flexible

Cross Section

Layer	Type	Depth	Date Constructed
1	HMA	5"	2000
2	Stabilized Base	3"	2000
3	Granular Base	7.2"	1960
4	Granular Base	18"	1960

Figure 9-5. The existing structure of the Riverside project as entered in *rePave*.

The general inputs needed for *rePave* for this project is shown in Figure 9-6.



08-RIV-10

Created: 2016-07-12
Updated: 2016-07-13

Proposed Pavement

Design Period: 40 years

Subgrade M_r: 20,000 psi CBR = 13%

ESALs: 2.25 millions per year

Growth Rate: 5 %

Current ADT: 14000 all lanes, one direction

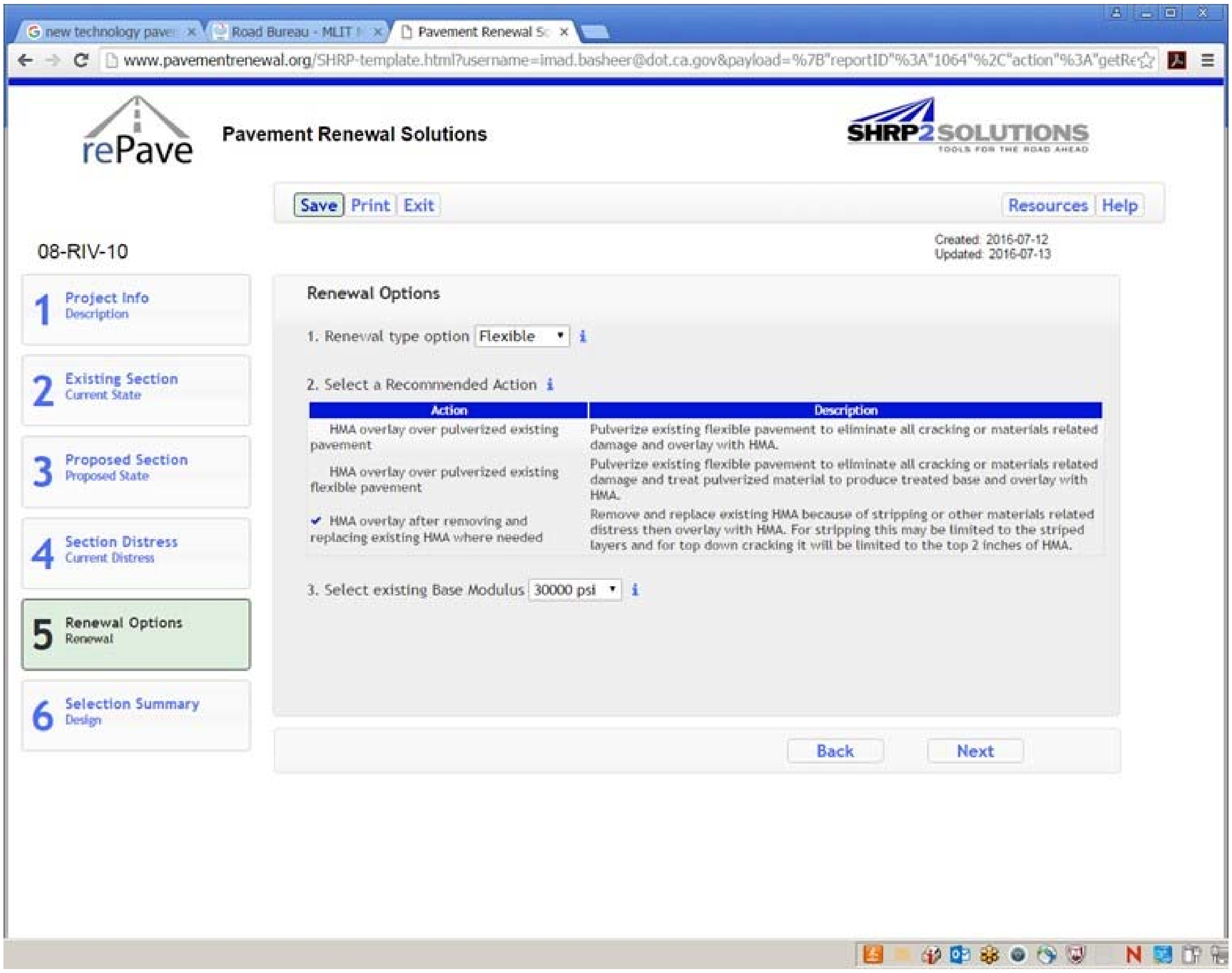
Number of through lanes: 2 one direction 0 lane added

Height Restrictions: Yes No

Figure 9-6. General inputs for the Riverside project.

9.6.1 Flexible Option (Cold Plane and Replace)

In the flexible renewal option, the removal by milling will be done for all the existing asphalt concrete (both RHMA and HMA layers). The asphalt concrete base (ACB) could be saved, but it was recommended that it be removed as well. Running the flexible option in *rePave* results in a number of actions as shown in Figure 9-7. The “remove and replace existing AC” action was used. Because the base below the ACB is granular base (AB), the base modulus was selected as 30000 psi as also shown in Figure 9-7.



Created: 2016-07-12
Updated: 2016-07-13

Renewal Options

1. Renewal type option Flexible

2. Select a Recommended Action

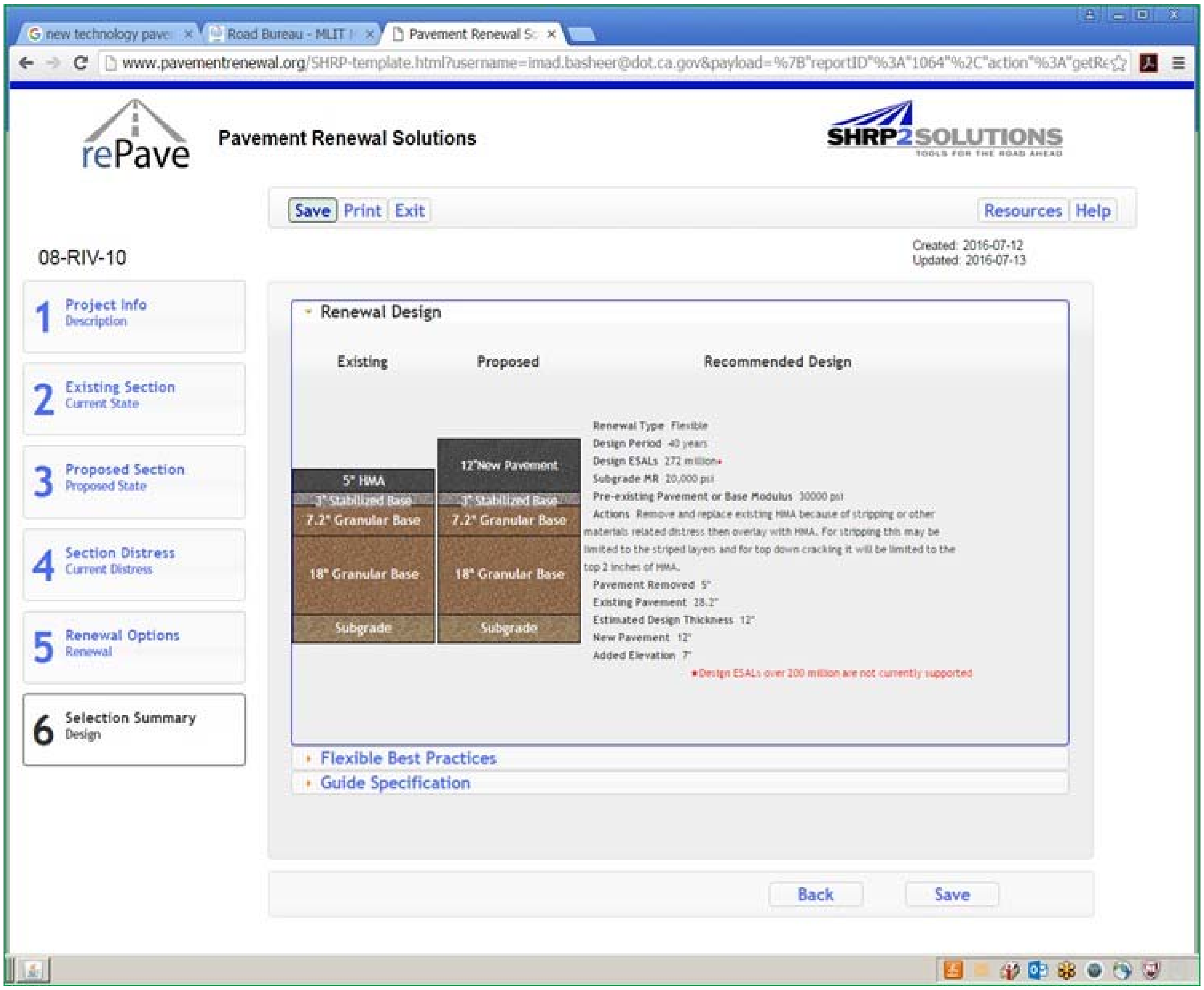
Action	Description
HMA overlay over pulverized existing pavement	Pulverize existing flexible pavement to eliminate all cracking or materials related damage and overlay with HMA.
HMA overlay over pulverized existing flexible pavement	Pulverize existing flexible pavement to eliminate all cracking or materials related damage and treat pulverized material to produce treated base and overlay with HMA.
✓ HMA overlay after removing and replacing existing HMA where needed	Remove and replace existing HMA because of stripping or other materials related distress then overlay with HMA. For stripping this may be limited to the striped layers and for top down cracking it will be limited to the top 2 inches of HMA.

3. Select existing Base Modulus 30000 psi

Figure 9-7. The flexible renewal option showing available actions for the Riverside project.

The *rePave* design in shown in Figure 9-8, and indicates that a total of 12 inches of HMA would be required for this rehabilitation strategy. Note that the *rePave* tool did not remove the ACB because it assumed it to be in good condition; <u>but it is necessary to remove it to eliminate any potential of stripping in this asphalt concrete base</u>. Therefore, this strategy must remove 8 inches of asphalt concrete and asphalt concrete base and replace with 12 inches of HMA. In order to verify that the removal of ACB would not compromise the rehabilitation structural adequacy, the existing section entered in *rePave* was adjusted so that the HMA is combined with the ACB to form one HMA layer 8 inches thick. The results are shown in Figure 9-9. As seen, the required HMA thickness after removing all HMA and ACB is 12 inches.

Because the total number of ESALs expected during the 40-year design life exceeded the 200 mESALs supported by *rePave*, an additional HMA may be needed in addition to the 12 inches found by *rePave*. Per the *rePave* Development Team[83], simulation runs performed using the “limit strain criteria” indicated that an additional ½ inch of HMA would be needed if the total number of ESALs was increased from 200 mESALs to 400,000,000. Since the total ESALs is 267 mESALs, proportionally the increase in required HMA thickness would be insignificant.



08-RIV-10

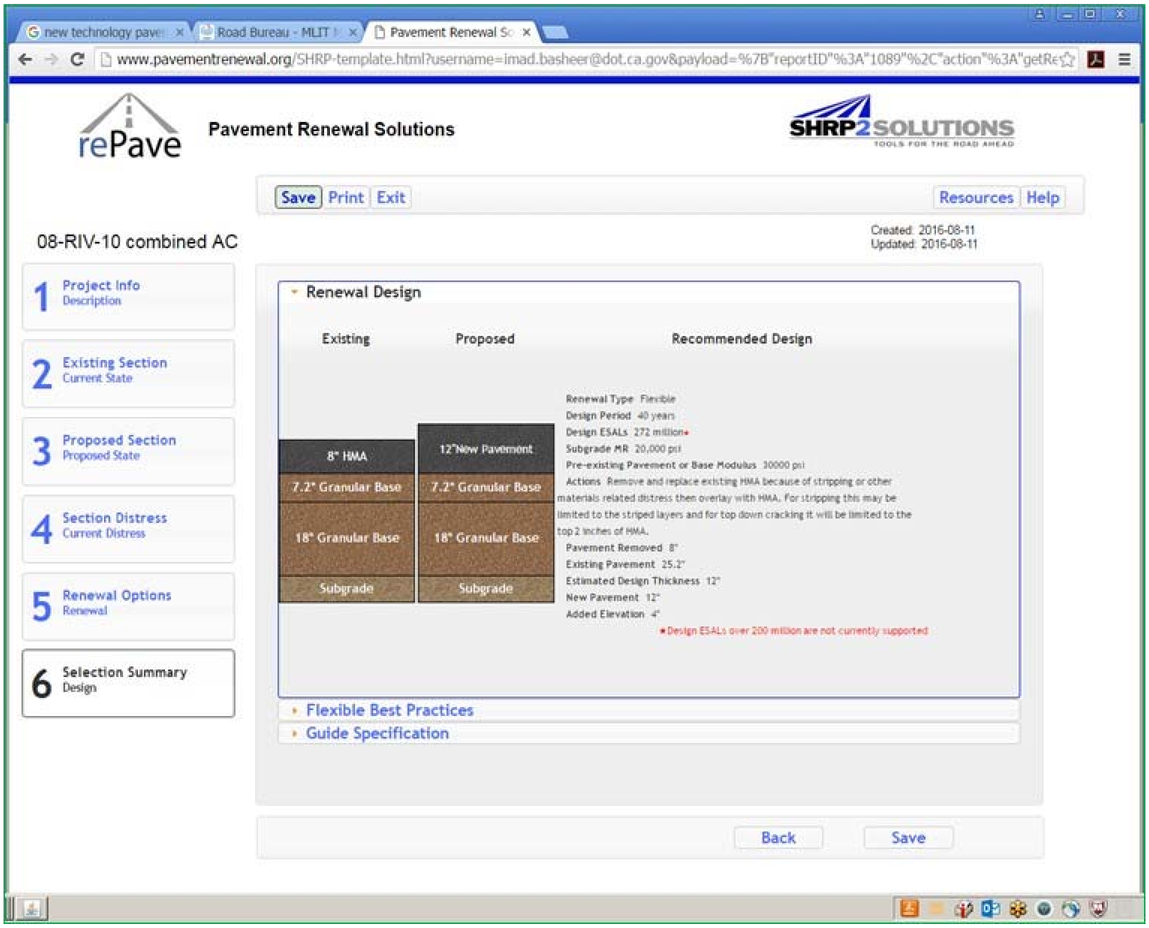
Created: 2016-07-12
Updated: 2016-07-13

Renewal Type Flexible
Design Period 40 years
Design ESALs 272 million*
Subgrade MR 20,000 psi
Pre-existing Pavement or Base Modulus 30000 psi
Actions Remove and replace existing HMA because of stripping or other materials related distress then overlay with HMA. For stripping this may be limited to the striped layers and for top down cracking it will be limited to the top 2 inches of HMA.
Pavement Removed 5"
Existing Pavement 28.2"
Estimated Design Thickness 12"
New Pavement 12"
Added Elevation 7"
*Design ESALs over 200 million are not currently supported

Figure 9-8. Remove and replace design with *rePave* for the Riverside project.

---

[83] Communication with Newt Jackson.

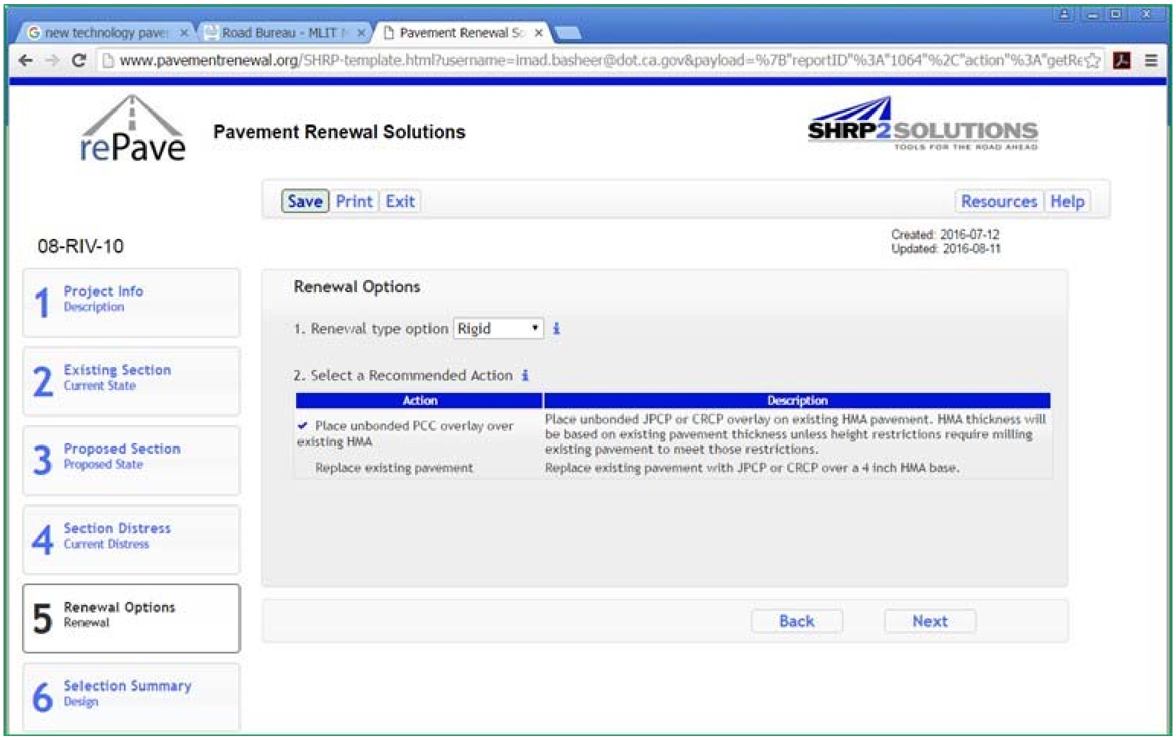


Renewal Type Flexible
Design Period 40 years
Design ESALs 272 million*
Subgrade MR 20,000 psi
Pre-existing Pavement or Base Modulus 30000 psi
Actions Remove and replace existing HMA because of stripping or other materials related distress then overlay with HMA. For stripping this may be limited to the striped layers and for top down cracking it will be limited to the top 2 inches of HMA.
Pavement Removed 8"
Existing Pavement 25.2"
Estimated Design Thickness 12"
New Pavement 12"
Added Elevation 4"
*Design ESALs over 200 million are not currently supported

Figure 9.9. Structural section with combined asphalt layers (RHMA+HMA+ACB).

9.6.2 Unbonded Concrete Overlay (Whitetopping)

The “Rigid” renewal option in *rePave* offers a whitetopping strategy. This is shown in Figure 9-10. In this case, an unbonded JPCP will be placed on top of the existing asphalt pavement. Figure 9-11 shows the *rePave* design recommendations. As seen, the unbonded PCC was found to be at least 11.5 inches thick. *rePave* provides the option of placing either an unbonded JPCP or unbonded CRCP for the same thickness.



08-RIV-10

Created: 2016-07-12
Updated: 2016-08-11

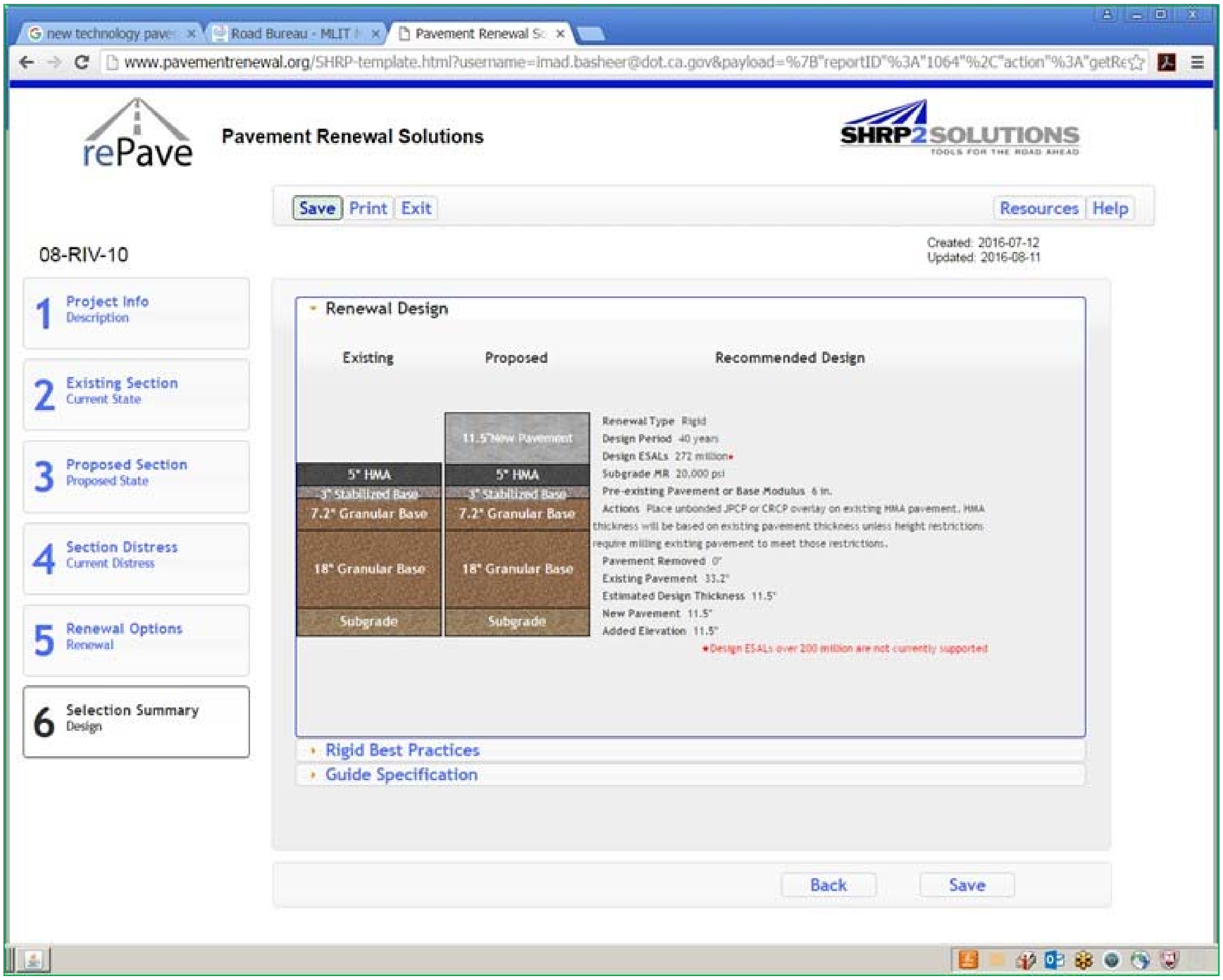
Renewal Options

1. Renewal type option Rigid

2. Select a Recommended Action

Action	Description
✓ Place unbonded PCC overlay over existing HMA	Place unbonded JPCP or CRCP overlay on existing HMA pavement. HMA thickness will be based on existing pavement thickness unless height restrictions require milling existing pavement to meet those restrictions.
Replace existing pavement	Replace existing pavement with JPCP or CRCP over a 4 inch HMA base.

Figure 9-10. Rigid renewal option for the Riverside project showing whitetopping strategy.



Created: 2016-07-12
Updated: 2016-08-11

Renewal Type Rigid
Design Period 40 years
Design ESALs 272 million*
Subgrade MR 20,000 psi
Pre-existing Pavement or Base Modulus 6 in.
Actions Place unbonded JPCP or CRCP overlay on existing HMA pavement. HMA thickness will be based on existing pavement thickness unless height restrictions require milling existing pavement to meet those restrictions.
Pavement Removed 0"
Existing Pavement 33.2"
Estimated Design Thickness 11.5"
New Pavement 11.5"
Added Elevation 11.5"

*Design ESALs over 200 million are not currently supported

Figure 9-11. The *rePave* unbonded concrete design for the Riverside project.

9.7 SCOPING DESIGNS WITH CALTRANS TOOLS

Scoping using Caltrans procedures for the two long-life rehabilitation strategies involved in the Riverside project are discussed below.

9.7.1 Cold Plane and Replace

A preliminary design was developed by the District Materials Engineer Office for the mill-and-replace option using the Caltrans mechanistic-empirical (ME) method. First, the FWD data collected from the project was used in determining the resilient moduli of in-situ pavement layers using the backcalculation method encoded into the Caltrans backcalculation software CalBack. The backcalculated modulus values were then uploaded into the Caltrans pavement structure design program CalME to develop this particular mill-and-fill rehabilitation strategy. The CalME design strategy based on TI_{40} of 17.5 was as follows (with 90% reliability):

1. Mill off the existing asphalt concrete to a depth of 0.65 ft (8.0 inch) to remove the existing RHMA, HMA, and ACB layers and expose the AB layer. Re-compact the AB layer, if necessary,

2. Place 0.70 ft (8.4”) HMA (Type A, 1” mix) PG 64-28 PM, and
3. Place 0.20 ft (2.4”) RHMA-G (¾” mix), with binder base PG 64-16.

Figure 9-12 is a schematic of the rehabilitated pavement structure. The total asphalt concrete thickness is 0.90 ft (10.8 inch). This strategy will raise the current profile grade elevation by 0.15 ft (2.8 inch).

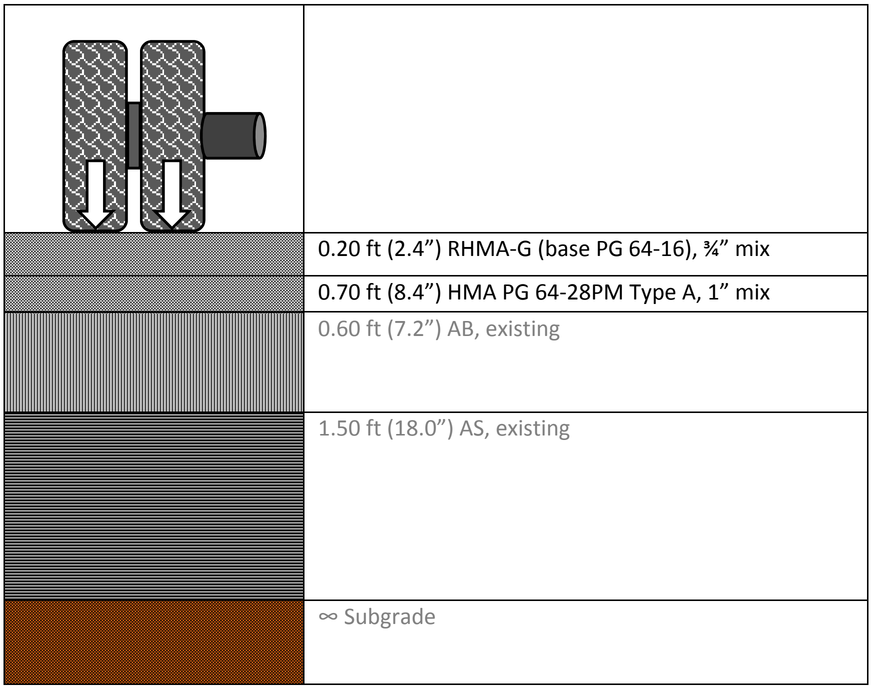


Figure 9-12. Schematic of the rehabilitated pavement structure based on CalME design for the Riverside project.

9.7.2 Unbonded Concrete Overlay (Whitetopping)

This strategy involves the placement of a jointed pavement concrete pavement on top of the existing asphalt concrete surface; also called whitetopping. The unbonded concrete overlay design was based on the Caltrans Highway Design Manual’s (HDM) catalog (Table 623.1). In determining the required HMA overlay thickness, the procedure described in Section 623.1 of the HDM for new rigid pavement design was used. The following was needed:

1. Soil type: Type I,
2. Climate: Desert,
3. No lateral support (no concrete shoulders), and
4. TI_{40}=17.5.

Table 623.1 (H) of the HDM provides the various alternative structures based on these inputs. For this project the total JPCP thickness required was found to be 1.3 ft (15.6 inch).

The existing pavement distresses should be repaired prior to overlaying the pavement with PCC. Cracks wider than ¼-inch should be sealed, loose pavement should be removed/replaced, and localized failures repaired. It is recommended also that the top 0.20 ft of the existing asphalt concrete pavement be milled off to provide uniform base support for the JPCP. If needed, a 0.10 ft (1.2 inch) HMA overlay should be placed on top of the milled surface before JPCP placement. Figure 9-13 is a schematic of the whitetopping strategy.

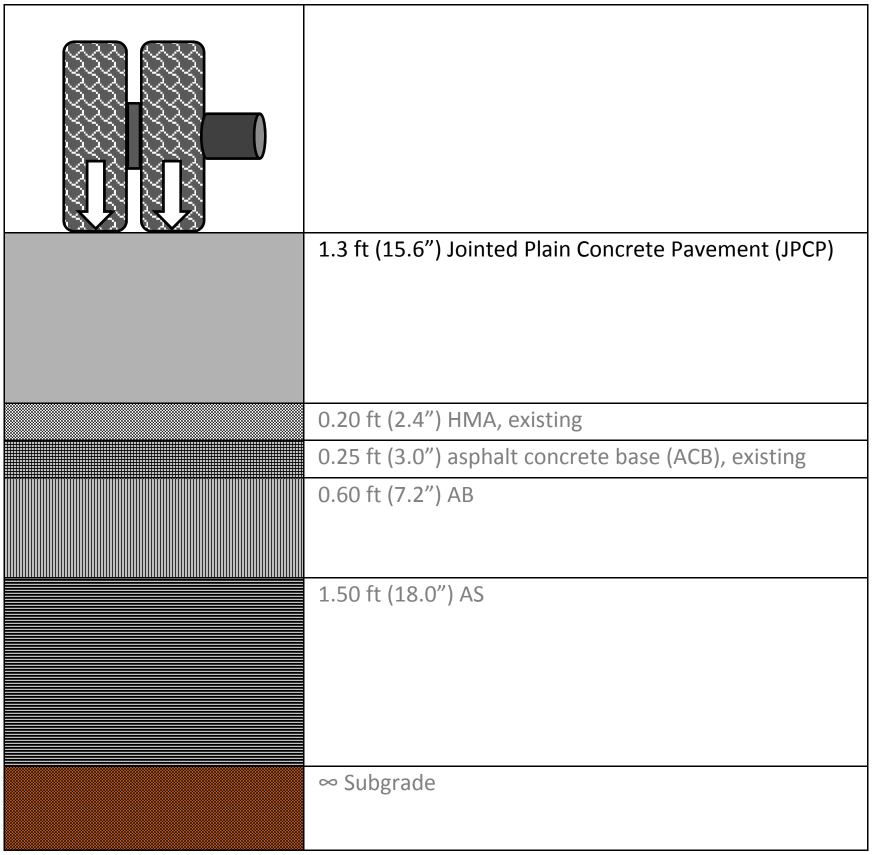


Figure 9-13. Schematic of the rehabilitated structure of the Riverside project using unbonded JPCP (whitetopping).

9.8 COMPARISON

The *rePave* scoping design for the mainline using flexible renewal option consisted of milling existing asphalt concrete and replacement with 1.0 ft (12.0 in.) HMA. In comparison, the preliminary design using CalME indicated an overall asphalt concrete overlay thickness of 0.9 ft (10.8 in.) consisting of a polymer modified HMA layer and an RHMA-G placed after milling off the existing asphalt concrete and asphalt concrete base. It is evident that the two estimates compare reasonably well when considering the differences in asphalt concrete materials properties used in both design tools. Note that both the polymer modified asphalt concrete and the rubberized asphalt concrete used in the CalME design provide for an additional improvement in performance that may have resulted in the overall thinner asphalt overlay.

Using the rigid renewal option (whitetopping), a total of 11.5 inches of JPCP were found to be required based on the *rePave* scoping tool. In comparison, a total thickness of 1.3 ft (15.6 in.) JPCP was found based on the Caltrans HDM. As discussed previously, the Caltrans HDM catalog is primarily used for designing new rigid pavements and not for concrete overlay; which in the latter case tends to be overconservative because of not accounting for the structural contribution of the various layers in the existing pavement.

10 SUMMARY, DISCUSSION AND RECOMMENDATIONS

10.1 OVERVIEW

The primary objective of this funded study was to evaluate one of the SHRP 2 Program's product (*rePave*) developed for scoping of long-life pavement projects (30-50 service life) as a tool to be added to or used in place of currently available scoping tools at Caltrans. This comes in response to the implementation plan developed by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) aiming to support the adoption by State Departments of Transportation (DOTs) of this *Pavement Renewal Solutions* product. As part of this implementation, this support has been provided in the form of outreach, technical assistance, and training of individual state transportation agencies. The results of this evaluation by Caltrans will help the Agency in its decision to adopt this product for scoping of their long-life pavement rehabilitation projects at the early phase of project development process.

Typically, each individual district in Caltrans identifies rehabilitation projects to include in the two-year and five-year plans in consultation with Headquarters' Project Management. The projects are then scoped by District staff from Materials and Project Management, and structural rehabilitation recommendations for those projects are developed.

All rigid options consisting of reconstruction of rigid pavements or unbonded concrete overlays are currently designed for 40-year service life. These design are typically performed by the District Materials Engineers using the Caltrans Highway Design Manual (HDM) rigid catalog.

Flexible rehabilitation design lives are typically 10 or 20 years and design for these lives can be performed using the HDM empirical procedures for 20-year designs, or using the Caltrans' Capital Preventive Maintenance (CAPM)[84] fixed rehabilitation strategies (without evaluation and design) for 10-year designs. Long-life flexible pavement designs (40-years) utilizing asphalt concrete as the rehabilitation material are also options considered by the Districts but these designs are treated as special designs and are, at the present, only designed by the Headquarters Pavement Program. The Caltrans HDM typically requires designers to consider both 20 and 40 year designs based on AADTT.

Since *rePave* was developed for scoping of long-life pavement design between 30 and 50 years, its use is unrestricted on projects utilizing Portland cement concrete in surface layer while its use for flexible pavement rehabilitation will be limited to long-life designs. Life-cycle cost analysis (LCCA) is mandatory in the selection of the most economical rehabilitation procedure and design life, and the Districts have often requested scoping of their project for design lives comparable to the rigid rehabilitation options (i.e., 40 years).

---

[84] See Topic 634 in Caltrans HDM at http://www.dot.ca.gov/hq/oppd/hdm/pdf/english/chp0630.pdf

At the present, only little guidance and a few tools are available for scoping long-life pavement rehabilitation projects, as previously discussed in Chapter 2 of this report. These tools include the 40-year based rigid catalog provided in the Caltrans HDM for designing new concrete pavements. Beside new JPCP and CRCP designs, the Catalog may also be used for designing unbonded Portland cement concrete rehabilitation overlays. In the asphalt rehabilitation areas, the "basic overlay" thickness scoping design is available. Additionally, the Caltrans mechanistic-empirical (ME) pavement design methodology encoded in the CalME software can be used for scoping of long-life rehabilitation projects. These include the design of asphalt concrete overlays over both concrete- and asphalt-surfaced pavements. Whereas CalME has been developed to design (final) rehabilitation and new pavements utilizing asphalt concrete and based on materials and field test data, it can be used for scoping purposes using default values of material properties without the need to perform detailed advanced testing. However, a good level of knowledge in running the design software is still needed which could restrict its use as a practical scoping tool. In comparison, *rePave* is easier to learn and requires only a few inputs; which are typically available for almost all projects, for long-life scoping of pavement rehabilitation projects.

In the remainder of this chapter, the major results and findings from the evaluations conducted in this study are summarized and general conclusions derived. In addition, recommendations and actions to be taken by Caltrans regarding the adoption and implementation of the *rePave* scoping program are presented.

10.2 SUMMARY OF EVALUATION RESULTS

Table 10-1 provides a summary of the project data for the five case studies used in the evaluation of the reasonableness and accuracy of the scoping designs obtained with the SHRP 2 *rePave* scoping tool. The evaluation was performed by comparing *rePave* scoping designs against both scoping design performed using available Caltrans tools as well as final designs performed with available final design procedures and software. Besides the summary of input parameters and scoping design results, Table 10-1 also provides some observations based on comparison of results between scoping tools (see row labelled as Notes in Table 10-1).

As seen in Table 10-1, the five projects selected for evaluation have the following features:

- They are located in various climatic zones.
- The subgrade in all the projects was comprised of a relatively low-modulus soil with a resilient modulus (M_r) averaging 10,000 psi.
- They exhibited various levels of truck traffic and traffic index values. On a 40-year design life basis, the traffic index (TI) ranged from 15.0 to 18.0; with the latter representing the LA-710 freeway extrapolated for 40 years based on the 30-year design TI value.
- They included both asphalt- and concrete-surfaced pavements. The asphalt-surfaced structures consisted of either a composite section involving an asphalt layer underlain by a rigid layer or a basic flexible pavement in which the asphalt layers are constructed over granular bases.
- They exhibited different types, extent, and severity of surface distresses.

- Four out of the five projects are currently in service with the oldest being in service for as long as 14 years (the LA-710 freeway) and the remaining three projects 4-5 years (Red Bluff, Weed, Solano). The construction of the Riverside project started in March 2017 and the projected construction completion is expected to be in August 2017.

10.3 CONCLUSIONS

As mentioned earlier, the objective of this evaluation is to help Caltrans in determining whether the SHRP 2 *rePave* scoping tool is reasonably accurate to be used as an additional tool in addition to the currently available tools needed for scoping of long-life rehabilitation projects. The current tools that Caltrans engineers use in scoping their long-life rehabilitation are found to be either seriously limited or require extensive familiarity in available pavement design software. Additionally, the use of available design software primarily developed for designing new pavements requires employing a number of engineering judgements to be able to develop long-life rehabilitation designs. Because engineering judgment can vary between engineers, long-life project scoping using available design software can result in inconsistent results statewide.

Although a limited number of case studies were analyzed, the following can be concluded about the scoping tool *rePave*:

1. The use of the Caltrans rigid pavement Catalog for the scoping of long-life unbonded concrete overlays of existing asphalt pavements tends to result in extremely overconservative designs. This is primarily attributed to the fact that the Catalog was originally developed for new rigid pavement designs. It is likely though that *rePave* provides more reasonable concrete overlay thicknesses than the Catalog; however, it is recommended that Caltrans evaluate the *rePave* scoping design of unbonded concrete overlays against the "AASHTOWare Pavement ME" design system[85]. Once a reasonable level of confidence in the scoping design has been achieved, Caltrans mat then adopt *rePave* for such type of long-life rehabilitation.
2. For crack, seat and HMA overlay of existing concrete-surfaced pavements, standard designs are available in the Caltrans HDM; however they are only applicable for a 20-year design life. Therefore, other tools for long-life scoping design are needed. In this evaluation, it was found that long-life scoping with *rePave* of existing jointed plain concrete pavements (JPCP) using the crack, seat and HMA overlay agrees reasonably well with CalME final design or when CalME is used (at default values) as a scoping tool. This observation is encouraging since the use of CalME requires a much higher level of familiarity even when used at default input values than using *rePave*. Therefore, *rePave* may be used in the scoping of long-life designs of crack, seat and overlay of existing concrete pavements. "Final" designs should always be performed using appropriate design tools and actual input materials parameters (based on field and laboratory testing).

---

[85] Note that the MEPDG (which evolved into the "AASHTOWare Pavement ME" program) was used in developing both the Caltrans rigid pavement Catalog and *rePave.*

Table 10-1. Summary of the five case studies used in evaluating *rePave*.

Case study	Red Bluff	Weed	Solano	LA-710	Riverside
Location & post mile limits	I-5 northern California, Tehama County, near Red Bluff PM 37.5/41.5	I-5 northern California, Siskiyou County, near Weed PM 19.0/25.2	I-80 northern California, Solano County, between Dixon & Vacaville PM 30.55/38.7	I-710 southern California, Los Angeles County, near Long Beach PM 6.8/9.7	I-10 southern California, Riverside County, in Riverside county PM R74.0/R105.4
Current status	In-service since 2012	In-service since 2012	In-service since 2013	In-service since 2003	In construction (as of March 2017
Existing structure [a]	10”AC/6”CTB/12”AS/SG	5.5”AC/8”JPCP/5.5”CTB/6” AS/SG	8”JPCP/4”CTB/11”AS/SG	8”JPCP/4”CTB/ 4”AB/11”AS/SG	5”AC/3”ACB/7.2”AB/ 18”AS/SG
Existing average all-lane distresses and ride quality	Alligator A cracking=20%, Alligator B cracking=20%, IRI=100 in/mile.	Alligator A cracking=15%, Alligator B cracking=30%, IRI=130 in/mile.	1st stage cracking=40%, 3rd stage cracking=30%, Corner breaks=30%, Faulting=1/4”, IRI=130 in/mile.	1st stage cracking=60%, 3rd stage cracking=15%, Corner breaks=10%, IRI=220 in/mile.	Alligator A cracking=13%, Alligator B cracking=25%, Rutting=2 inch, IRI=120 in/mile.
Subgrade soil M_r [b]	10,000 psi	10,000 psi	10,000 psi	10,000 psi	20,000 psi
Climate region [c]	Inland Valley	High Mountain/High Desert	Inland Valley	South Coast	Desert
Design life	40 years	40 years	40 years	30 years	40 years
Initial mESALs [d]	1.1 mESALs	0.7 mESALs	0.61 mESALs	3.2 mESALs	2.25 mESALs
Growth rate [e]	5.0% (actual 7.4%)	5.0% (actual 6.7%)	5.0% (actual 6.6%)	5.0% (actual 5.1%)	5.0% (actual 6.5%)
Total mESALs	126 mESALs	73 mESALs	74 mESALs	209 mESALs [f]	267 mESALs[f]
Traffic Index (TI)	16.0	15.0	15.0	17.0	17.5
rePave scoping-1	**Remove/Replace:** Mill off existing HMA and replace with 8.5” HMA (for base modulus of 75000 psi), or 7.0” HMA (for base modulus of 100000 psi). For actual modulus of 90,000 psi HMA is 7.6”. [g]	**Remove existing HMA, crack, seat and overlay:** Mill off existing HMA, crack and seat (or simply re-seat of previously cracked slabs) and place 8.5” HMA overlay (using recommended base modulus of 75000 psi).	**Crack, seat and overlay:** Crack existing PCC slabs, seat and overlay with **8.5”** HMA (using recommended base modulus of 75000 psi).	**Crack, seat and overlay:** Crack existing PCC slabs, seat and overlay with 8.5” HMA (using recommended base modulus of 75000 psi).	**Remove existing AC and overlay:** Remove existing AC and ACB and replace with 12.0” HMA.
Caltrans scoping-1 (or final design)	**Remove/Replace (final design):** Mill off existing HMA and replace with a total of 0.70’ HMA (8.4”).[h]	**Remove existing HMA, crack, seat and overlay (final design):** Mill off existing HMA, re-seat slabs, and place a total of 0.6’ (7.2”) structural HMA over SAMI-R over level course [i]. The equivalent total HMA including SAMI-R=8.3”.	**Crack, seat and overlay (final design):** Crack existing PCC slabs and place a total of 0.45’ (5.5”) HMA [j] (with SAMI-F contribution the total HMA is 0.55’ (6.7”).	**Crack, seat and overlay (final design):** Crack existing PCC slabs and place a total of 0.67’ (8.0”) HMA [k] (with SAMI-F contribution the total HMA is 0.77’ (9.2”).	**Remove existing AC and overlay (scoping design):** Remove existing AC and ACB and replace with 0.90’ (10.8”) HMA. [l]
rePave scoping-2	**Unbonded PCC overlay:** Place 11.5” PCC overlay (JPCP or CRCP).	**Unbonded PCC overlay:** Place 10” PCC overlay.	**Unbonded PCC overlay:** Place 2” HMA bond breaker, then place 10” PCC overlay.	**Reconstruct (full depth under overcrossing):** Remove existing pavement and replace with 13” HMA.	**Unbonded PCC overlay:** Place 11.5” PCC overlay (JPCP or CRCP).
Caltrans scoping-2 (or final design)	**Unbonded PCC overlay (final design):** Place 1.20’ (14.5”) JPCP overlay.	**Unbonded PCC overlay (final design):** Place 1.25’ (15”) JPCP overlay.	**Unbonded PCC overlay (final design):** Place 0.15’ (1.8”) HMA bond breaker then 1.15’ (14”) JPCP overlay.	**Reconstruct (full depth under overcrossing, final design):** Remove existing pavement and replace with a total of 1.0’ (12.0”) HMA. [m]	**Unbonded PCC overlay (final design):** Place 1.3’ (15.6”) JPCP overlay.
rePave scoping-3			**Reconstruct:** Remove existing PCC slabs, place 4” HMA, then 10.5” JPCP.		
Caltrans scoping-3 (or final design)			**Reconstruct (final design):** Remove existing PCC slabs, remove existing CTB, place 0.25’ (3”) HMA base, then 1.15’ (14”) JPCP, and 0.03’ (0.5”) OGFC.		
Notes	The flexible scoping design with *rePave* is reasonable compared to the final design with Caltrans ME system. Note that for 90000 psi base modulus		The HMA overlay in the crack and seat option is nearly similar between the Caltrans final design and *rePave* scoping design. The unbonded overlay final	The *rePave* scoping design for crack, seat and overlay is an under-design compared to the final design by Caltrans ME method. The full depth	The flexible option scoping with Caltrans ME method (using FWD data but not actual material test results) yielded approximately one inch lesser HMA than using

	both *rePave* and CalME designs are almost identical. For the Rigid option, the Caltrans design is overconservative compared to *rePave* but that is expected since the Caltrans rigid catalog was developed for a new pavement (generally does not account for thicker base and subbase originally found in existing pavements). It is recommended that the use of Caltrans rigid catalog for unbonded overlay be revisited and a new overlay table developed based on the AASHTO ME design program.		design with Caltrans rigid catalog is overconservative and far exceeds the *rePave* scoping design. The reconstruction option using the Caltrans rigid catalog is also overconservative here compared to the *rePave* scoping design.	section for under overcrossing final design with Caltrans ME is only one inch HMA thinner than the *rePave* scoping design.	*rePave* scoping. This is considered to be a reasonable deviation between the two methods. For the rigid option (unbonded overlay), the final PCC overlay design with Caltrans rigid catalog is about 4 inches thicker than with *rePave*. As mentioned previously, the use of Caltrans rigid catalog for PCC overlay design tends to be overconservative.

(a) AB: Aggregate base. AC: Asphalt concrete. ACB: Asphalt concrete base. AS: Aggregate subbase, CTB: Cement treated base, SG: Subgrade

(b) M_r is the resilient modulus of material

(c) Based on Figure 615.1 of the Caltrans HDM Chapter 610

(d) mESALs: million 18-kip Equivalent Single Axle Loads. The initial mESALs calculated with a spreadsheet based on total ESALs expected in the design life and the growth rate.

(e) Growth rate exceeding 5% was changed to 5.0% and the initial mESALs was re-calculated.

(f) Changed to 200 mESALs the maximum allowed by *rePave*. Effect on rehabilitation needs is believed to be minimal.

(g) The actual base modulus of 90,000 psi is within this range of modulus values and therefore the required thickness is within the reported two thicknesses and calculated by interpolation.

(h) The HMA was placed in three layers as follows: 0.2 ft PG 64-10 RB (rich bottom), 0.20 ft PG 64-10 with 25% reclaimed asphalt pavement (RAP), 0.30 ft PG 64-28PM, and 0.10 ft open graded friction course (OGFC).

(i) The leveling course 0.15 ft (1.8”) thick is not considered structural. First layer placed on stress absorption membrane interlayer-rubberized (SAMI-R) is 0.25 ft (3”) PG 64-16 HMA with 25% RAP, then 0.35 ft (4.2”) PG 64-28PM, then 0.1ft (1.2”) OGFC. SAMI-R equivalent to 0.10 ft (1.2 inch) HMA.

(j) The 0.10’ (1.2”) leveling course (PG 64-10 with 25% RAP) is not counted structural. Place SAMI-fabric over leveling course, then 0.25’ (3”) PG 64-10 with 25% RAP, then 0.20’ (2.4”) PG 64-28PM, and finally 0.10’ (1.2”) OGFC.

(k) Place 0.10’ (1.2”) level course AR-8000, SAMI-F, 0.42’ (5”) AR-8000, 0.25’ (3”) PBA-6a HMA, and finally 0.10’ (1.2”) OGFC.

(l) After milling off all AC and ACB place 0.70’ (8.4”) PG 64-28PM HMA then 0.20’ (2.4”) RHMA-G base PG 64-16.

(m) Place 0.25’ (3”) AR-8000, 0.50’ (6”) AR-8000 rich bottom, 0.25’ (3”) PBA-6a HMA, and finally 0.10’ (1.2”) OGFC.

1. There is a good general agreement in long-life rehabilitation strategy involving the use of hot mix asphalt overlay between *rePave* and scoping using the CalME procedure (including final design).
2. Despite the fact that *rePave* was developed with climate, traffic, and materials inputs that were possibly different from those encountered in the five case studies analyzed, it was generally capable of producing long-life rehabilitation strategies that were *reasonably* comparable with those developed with (i) the Caltrans CalME software for the flexible options, and (ii) the Caltrans HDM rigid Catalog for the rigid options.
3. *rePave* provides a more diverse set of rehabilitation strategies than what the existing Caltrans scoping tools can provide at the present time. The use of *rePave* is expected to provide Caltrans engineers with access to a larger number of long-life rehabilitation strategies to select from for scoping their projects. Unfortunately, the adoption of some of these strategies may be hindered by the unavailability of "final" design tools for those strategies, or the fact that such strategies are not common practice[86]. *rePave* would expand Caltrans' scoping tools currently available to the engineers for considering on their long-life projects.
4. After extensively using the *rePave* tool, it appears that it is a user-friendly and efficient tool that requires only minimal amount of data; most of which are routinely collected by Caltrans engineers during project development and is usually available at the earliest phase of the project. Therefore, no additional cost would be incurred in obtaining the input data needed to run *rePave*.
5. A discrepancy was observed in the scoped "basic" asphalt overlay thickness of existing asphalt-surfaced pavement between *rePave* and the Caltrans scoping overlay table (given in Figure 2-4 in this report). A "basic" overlay is defined as that overlay which is placed directly on existing asphalt pavement without the milling off (full or partial thickness) of the existing asphalt concrete. Out of the five case studies evaluated in this report, three consisted of an asphalt-surfaced pavement. In all these three cases, the recommended rehabilitation or current pavement condition required the removal of the existing asphalt as triggered by the provided distress data. For this reason, it was not possible to compare long-life basic overlay scoping design between *rePave* and Caltrans scoping tool for the 5 case studies. Therefore, in order to have *rePave* produce "basic" overlays, the distress that triggers the need to remove the existing asphalt concrete has to be zeroed out. This distress is the thermal cracking given in the *rePave*'s "Section Distress" tab as "Transverse Cracking". According to *rePave*, an existing asphalt pavement exhibiting any thermal cracking indicates a poor-quality material for an asphalt overlay to be directly placed on, and therefore, must be removed[87]. Note that the primary intent of the Caltrans 40-year scoping basic overlay designs is to allow project engineers to make a reasonable estimate for rehabilitation cost for their project rather than provide a design thickness that would

---

[86] One example is rubblization which is not common on Caltrans projects.

[87] This was also suggested by Newt Jackson in personal communication.

be selected for the project. The 40-year thicknesses shown in Figure 2-4 were also derived by extrapolating the 5- and 10-year thicknesses that were originally established using probabilistic analysis of overlay design conducted by the author of this Report[88]. As can be seen in Figure 2-4, the 40-year basic HMA overlay is 0.65 ft (~8.0") thick for traffic index TI of 11.0-15.0 and 0.80 ft (~10.0") for TI>15.0 (note that TI of 15.0 is equivalent to ~75 million ESALs).

In order to compare *rePave* "basic" overlay with the Caltrans scoping overlay table, the Riverside project was used (see Chapter 9). The transverse cracking of the existing asphalt surface was assumed to be zero while the other distresses were kept unchanged. Even with zero transverse cracking, *rePave* still required milling off the top 2 inches of the existing asphalt concrete to remove any stripping or weathered asphalt concrete material prior to placement of the new HMA. Two scenarios were analyzed differing in the total design ESALs:

a) Using actual project truck traffic volume with initial 2.25 mESALs/year growing at a rate of 5% per year for 40 years resulting in a total design ESALs of 275 mESALs (TI=17.5). This TI represents the "high TI" scenario, and

b) Using reduced truck traffic volume with initial 0.20 mESALs/year growing at a rate of 5% per year for 40 years resulting in a total design ESALs of 24 mESALs (TI=13.0). This TI represents the "lower TI" scenario.

For the "high TI" scenario, the Caltrans scoping Table (Figure 2-4) recommends a 10" thick HMA overlay. Using *rePave* with zero transverse cracking (and 30000 psi base modulus), *rePave* calls for a 6.0" HMA overlay after milling the top 2" existing AC to eliminate weathered material. Alternatively, for the "lower TI" scenario, the Caltrans scoping Table recommends using an 8.0" HMA overlay. Running *rePave* with the lower TI and zero transverse cracking (and 30000 psi base modulus) resulted in 4.0" AC after milling off the top 2" of weathered AC. Evidently, there is a great difference in the basic HMA overlay thickness between the two scoping tools, with the *rePave* tool "felt" to produce (to some degree) underdesigned overlays for the 40-year design life. The difference in design thickness is even greater than it is seen when reliability is also taken into consideration since the Caltrans scoping Table thicknesses provide 80% reliability whereas the *rePave*'s designs provide 90% reliability. According to *rePave* Development Team[89], the overlay design module in *rePave* starts with designing a "new" pavement structure, then compares the asphalt concrete thickness obtained for this new structure against the "existing" pavement after removing all distressed materials that must be removed

---

[88] Basheer I. (2006). Alternative Procedure to Estimate Flexible Pavement Rehabilitation Requirements for Project Scoping. Pavement Tech Note, November 1, 2006. This document can be found on the web at http://Www.Dot.Ca.Gov/Hq/Maint/Pavement/Offices/Pavement_Engineering/PDF/Flex_Pav_Rehab_Final_071101.Pdf

[89] Communication with Newt Jackson.

(cracked, stripped, etc.). The overlay thickness needed is then determined as the difference in the "remaining" asphalt concrete thickness and that thickness determined for the new design. It is believed that because this approach is fairly simplistic and does not take into account the deteriorated condition of non-asphaltic layers of existing pavements, it may have contributed to the greater difference in the scoped basic overlay thickness between *rePave* and Caltrans scoping Table. Further investigation is still warranted to determine the major cause of discrepancy between the two scoping methods in estimating long-life HMA overlay needs.

10.4 RECOMMENDATIONS AND ACTIONS

Based on the detailed evaluation of *rePave* conducted in this study using a number of actual projects, the following is recommended:

1. *The* scoping tool *rePave* should be considered for adoption by Caltrans to enrich the available project scoping tools as it provides the pavement engineer with a broader variety of long-life rehabilitation strategies to consider at the early phase of their projects. The *rePave* tool must not be used in lieu of existing tools but in addition to them. When there is considerable discrepancy in scoping results of a given rehabilitation strategy between a Caltrans available tool and *rePave* (for example the basic overlay strategy), the engineer must take into consideration all available project variables in their final determination as to which tool's results to use.

2. It is recommended that *rePave* be made available to the District materials engineers to enable them to consider the full range of applicable rehabilitation techniques available for their projects. Because the use of *rePave* offers the engineer with a wider array of structurally and functionally comparable strategies to compare and select from than the currently available Caltrans scoping tools, it is possible that significant cost savings on many projects may be realized.

3. It is believed that either minimal or no additional cost would be incurred when using *rePave* since nearly all needed inputs (materials, traffic, and general design inputs) are routinely collected for any project even at its earliest phase.

4. In order to expedite the use of the *rePave* scoping tool by the Districts, the Caltrans Headquarters Pavement Program will develop and deliver the necessary training materials on this tool to the District engineers responsible for scoping of pavement rehabilitation projects. Actually, training materials are currently being developed for this purpose.

5. Because the evaluations presented in this report were based on a limited number of case studies, Caltrans engineers who are familiar with both CalME design software and *rePave* tool will need to continue performing comparative analysis between these tools to assure themselves that *rePave* produces reasonable pavement design configurations and thicknesses that can be confidently used for scoping purposes.

6. It is to be emphasized that the *rePave* scoping tool must not be employed as a substitute for “final” design in which a more detailed design approach must be used in conjunction with collected project-level field and laboratory data. It is recommended that the final long-life structural rehabilitation design be developed in the Districts with consultation with HQ Pavement Program.

10.5 LIMITATIONS OF REPAVE

Some limitations were noticed when *rePave* was evaluated in this study. Addressing these limitations in future versions of this tool will expand its usage domain for scoping of long-life projects[90]. These limitations include the following:

a. Existing pavements that are cracked, seated and HMA overlaid can’t be analyzed at this time. This is because this structure can’t be entered in the current version of the *rePave* program.

b. Total design truck traffic is currently limited to 200 mESALs. There are long-life projects (especially those on major highways) that can easily exceed this limit. According to the *rePave* Development Team[91], increasing total ESALs by up to 100 mESALs (i.e., up to 300 mESALs total) would only require an additional HMA thickness of no more than one inch based on conducting additional limiting strain criteria analysis.

c. Traffic growth rate in *rePave* is currently limited to 5.0%. Many projects in California (including those studied in this report) indicated a higher growth rate. In the current study, all projects with reported growth rates exceeding 5.0% were adjusted to 5.0%; but then a compensation to this change was carried out by recalculating the initial ESALs count.

d. The HMA thickness proposed for rehabilitation by *rePave* does not distinguish between the PG grades and modification of the asphalt binder (e.g., with polymer or crumb rubber) and their effect on the estimated thickness. It is understood that while for scoping purposes this issue may not of great importance, the grade and improvements can often offer enhanced performance characteristics resulting in reduced HMA thickness. For future versions of the *rePave* tool, it would be beneficial if some reductions in HMA thickness are proposed to account for binder improvement. This may prevent scoped thicknesses to become cost-prohibitive in some cases which may occasionally risk some projects from securing the needed funding or changing scope.

END OF REPORT

I. Basheer, Ph.D., P.E.

Caltrans, 2017

---

[90] The limitations identified in this study will be discussed with FHWA and the rePave Development Team.

[91] Communication with Newt Jackson.