SHRP 2 Reliability Project R23

Guide to Using Existing Pavement in Place and Achieving Long Life

Addendum 2

NOT EDITED

STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

SHRP 2 Reliability Project R23

Guide to Using Existing Pavement in Place and Achieving Long Life

Addendum 2

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Introduction

The first two phases of the R23 project dealt with conducting the literature review, establishing a detailed work plan and developing the guidelines with the help and support from seven State Highway Agencies (SHAs). The design guidance was produced using an Adobe Air and Flash based program to support the decision and design logic and to provide access to the documentation developed to aid in designing and constructing long life pavements. That documentation consisted of the following:

- Project Assessment Manual
- Flexible Best Paving Practices
- Rigid Best Paving Practices
- Guide Specifications
- Life Cycle Cost Analysis
- Scoping Methodology (Decision and Design tables)

In working with the seven agencies it became clear that the original guidance that was directed to producing 50 year pavement designs would not be used because most agencies did not use 50 year designs. In Phase 3, the design guidance was changed to produce 30 to 50 year design guidance. The interactive program was also changed from the Adobe Air and Flash based program intended to be delivered on a CD to a web-compliant HTML 5 based platform. The interactive program now meets all requirements for a web-based program.

In Phase 4, the approaches used to reconstruct or renew existing pavements were expanded to include the use of composite and modular pavements based on SHRP 2 projects R21 and R05.

The tasks to complete Phase 4 included the following.

Task 15: Web hosting and support.

This task provided for hosting the interactive program on a web site and providing necessary support through December 31, 2014. This included:

- Web-based platform hosting and technical support through 2014.
- Free access of application to stakeholders around the world.
- Application technology updates as needed (to support latest formats and standards).
- Email technical support.

Task 17: Develop decision matrix, design tables, and application logic to incorporate R05 and R221 Projects in the scoping tool.

- Revise decision tables to include R05 and R21 products.
    - Add, remove and replace options for most pavement conditions.
        - Add conventional flexible options.
        - Add conventional rigid options and modular and composite pavement options.
    - Add modular and composite design options to unbonded overlay options of flexible and rigid pavements.
- Revise the action descriptions logic and supporting information.
- Revise the design rules consistent with the changes in the decision tables and populate new design tables required by the added options.
- Prepare an amendment to the final report that describes the changes to the Guidelines.
- Circulate the revised guidelines through a number of SHAs for feedback on changes.
- Develop additional logic in decision flow to facilitate additional options.
- Develop data structures for additional thickness design tables.
- Develop additional logic to extract the appropriate thickness (design rules) from multiple design tables for different design options.
- Design report formats within the interactive software to most effectively show design sections and actions.

Task 18: Revise existing interactive program to add additional design elements from Task 17.

- Add additional inputs and validation to allow for user selection of various remove and replace alternatives. This includes a redesign of the user interface elements in step 4 to accommodate the additional R05 and R21 design options.
- Update recommended cross section to display new alternatives for composites (PCC and HMA), precast, and additional surface preparation recommendations.
- Update summary interface to display additional report data for additional renewal options. This includes customizing the display for modular and composite pavements.
- Update printable report to display new cross section and additional renewal alternative information including custom display for replacement options including modular and composite pavement selection as well as conventional pavement sections.
- Integrate R05 and R21 general guidance into application and dynamically link published reports within summary page, as relevant.
- Provide, review and comment as the program elements and refined mockups are developed.
- Provide extensive testing of the program before it is released to participating SHAs for their review and comment.
- Work with participating SHAs to exercise the revised program and obtain their comments.

Task 19: Develop Expanded Case Studies as Design Examples

- Develop design information from test cases following the Pavement Assessment Manual.

- Perform runs using the program for all rigid and flexible treatments including designs for new lanes. Since these will be run on the new HTML5 program, all runs will be saved on the web site for easy access by all members of the team as well as SHAs involved.
- Develop commentary on use of guide specification elements as well as traffic impacts and life cycle assessment.
- Review examples with Agencies involved via web meeting and respond to any comments or concerns.
- Develop narrated application describing example use of guidelines including step-by step instructions.
- Travel to Agencies, Workshops, on Conferences to present the R23 Guidelines, and Case Studies as needed and approved by NAS Program Officer.

Tasks 17, 18 and 19 were conducted sequentially because the expansion of the decision and design tables were required before the interactive program could be modified to include the new logic and the revised interactive program needed to be in place to complete the case studies. A more detailed discussion of what was accomplished in each task follows.

Detailed Activities Performed under Task 17

Task 17 required a major expansion of the decision logic and design tables developed in Phase 3. The following is a simplified example of that expansion for the single case of an existing flexible pavement with environmental cracking present.

The existing guidelines had two options for a thermally cracked flexible pavement, 1) Pulverize (with or without treating) and overlay with flexible pavement or 2) overlay with an unbonded PCC pavement. In Phase 3, bonded PCC overlays were added to the list of options. In Phase 4 one additional option was added to the flexible treatments (remove and replace) and five additional options to the rigid approaches (unbonded PCC overlay with modular or composite pavement, remove and replace with conventional rigid, modular, or composite pavement) Both the modular and composite pavements provide two design choices, where applicable. The possible design outcomes go from three in Phase 2 to four in Phase 3 to 14 in Phase 4.

Table 1. Example of the Expanded Decision Matrix in Phase 4

<table>
<tr><th>Distress Category</th><th>Specific Distress Description</th><th>Distress present?</th><th>Renewal Option</th><th colspan="2">Action</th><th>Design Resources</th></tr>
<tr><td rowspan="8">Environmental Cracking</td><td rowspan="8">Transverse or Block Cracking</td><td rowspan="7">Yes</td><td rowspan="3">Flexible</td><td colspan="2" rowspan="3">Pulverize pavement structure full-depth followed by a thick AC overlay or remove and replace with HMA.</td><td>Pulverize and use residual material as untreated base (50 ksi). Apply AC thickness from Tables E.37- E.39.</td></tr>
<tr><td>Pulverize and treat residual material with emulsion or foamed asphalt resulting in a treated base (100 ksi). Apply AC thickness from Tables E.37- E.39.</td></tr>
<tr><td>Remove and replace with AC—use new Table xxx.</td></tr>
<tr><td rowspan="4">Rigid</td><td rowspan="2">No mitigation required, place an unbonded PCC overlay, or remove and replace with a standard PCC pavement, modular pavement or composite pavement</td><td>< 40 years</td><td>Use Table E.22 for thickness determination of an unbonded PCC overlay.

Use two new Design tables for R05 (Standard Design and Prestressed).

Use new design tables for R21 (Standard design for wet on wet and new table for flexible on rigid).</td></tr>
<tr><td>≥ 40 years</td><td>Use Table E.22 for thickness determination of an unbonded PCC overlay.

Use new design tables for R21 (Standard design for wet on wet and new table for flexible on rigid).</td></tr>
<tr><td rowspan="2">Place bonded PCC overlay.</td><td>< 40 years</td><td>Apply Rule 4 (yet to be developed) if design life is less than 40 years.</td></tr>
<tr><td>≥ 40 years</td><td>Do not use a bonded PCC overlay if the design life is greater than 40 years.</td></tr>
<tr><td>No</td><td>--</td><td colspan="2">Continue to Materials Caused Distress.</td><td>--</td></tr>
</table>

Proposed Phase 4 Changes

The following outline provides more detail on the design outcomes from the preceding table.

List of Outcomes from Phase 3 (final outcomes underlined)

Flexible Outcomes

- Rubblize and overlay
    - <u>Standard Design 50 kSI base</u>
- Rubblize treat and overlay
    - <u>Standard Design 100 kSI base</u>

Rigid Outcomes

- Unbonded overlay
    - <u>Standard Design(MEPDG)</u>
- Bonded overlay (<40 years)
    - <u>Standard Design MEPDG)</u>

List of Potential Design Outcomes for Phase 4 (final outcomes underlined)

Flexible Outcomes

- Rubblize and overlay
    - <u>Standard Design 50 kSI base</u>
- Rubblize treat and overlay
    - <u>Standard Design 100 kSI base</u>
- Remove and Replace
    - <u>Standard Design 30 kSI base</u>

Rigid Outcomes

- Unbonded overlays
    - Conventional PCC
        - <u>Standard Design (MEPDG)</u>
    - Modular Pavement (<40 years)
        - <u>Standard Design (MEPDG)</u>
        - <u>Prestressed Design (MEPDG 850 psi)</u>
    - Composite Pavement
        - <u>Wet on wet (standard design MEPDG)</u>
        - <u>flexible on rigid (MEPDG R21)</u>
- Bonded PCC overlay (<40 years)
    - Conventional PCC
        - <u>Standard Design (MEPDG)</u>
- Remove and Replace
    - Conventional PCC
        - <u>Standard Design (MEPDG)</u>
    - Modular Pavement (<40 years)
        - <u>Standard Design(MEPDG)</u>
        - <u>Prestressed Design(MEPDG 850 psi)</u>
    - Composite Pavement
        - <u>Wet on wet (standard design MEPDG)</u>
        - <u>flexible on rigid (MEPDG R21)</u>

The addition of the composite and modular pavement options as well as adding more remove and replace options for flexible and rigid options to be consistent with the other changes more than tripled the size of the decision matrix and consequently the decision tables.

The full set of expanded decision tables are included in the revised "Scoping Methodology" which is included as Appendix 4-A to this report.

Additional design tables were developed to supplement the expanded decision logic. New design tables were developed for both the composite and modular pavement design options. In addition, the existing Jointed Plain Concrete (JPC) design table was expanded to be consistent with the Precast Concrete Pavement design tables and both were combined into one table. Those design tables were based on extensive pavement design runs using the AASHTOWARE Pavement M-E software version 1.3. These computer runs followed the same procedures described in R23 Final Report Appendix D. The revised rigid and precast tables are shown below in Tables 2 and 3.

Table 2. Unbonded PCC and Precast Pavement Thicknesses for Remove and Replace and Overlays over Existing HMA

Unbonded JCP or PCP over Existing HMA: Subgrade M_R = 5,000 psi

ESALs (millions)	Existing HMA Thickness							
	4 in.		6 in.		8 in.		10 in.	
	JCP	PCP	JCP	PCP	JCP	PCP	JCP	PCP
≤10	9	8.5	8.5	8.0	8.5	8.0	8.5	8.0
10-25	9.5	9.0	9.0	8.5	9.0	8.5	9.0	8.5
25-50	9.5	9.0	9.5	9.0	9.5	9.0	9.5	9.0
50-100	10.0	9.5	10.0	9.5	10.0	9.5	10.0	9.5
100-200	13.0	12.5	12.5	12.0	12.0	11.5	11.5	11.0

Unbonded JCP or PCP over Existing HMA: Subgrade M_R = 10,000 psi

ESALs (millions)	Existing HMA Thickness							
	4 in.		6 in.		8 in.		10 in.	
	JCP	PCP	JCP	PCP	JCP	PCP	JCP	PCP
≤10	8.5	8.0	8.5	8.0	8.0	8.0	8 .0	8.0
10-25	9.0	8.5	9.0	8.5	9.0	8.5	9.0	8.5
25-50	9.5	9.0	9.5	9.0	9.5	9.0	9.5	9.0
50-100	10.5	10.0	10.0	9.5	10.0	9.5	10.0	9.5
100-200	12.0	11.5	12.0	11.5	11.5	11.0	11.5	11.0

Unbonded JCP or PCP over Existing HMA: Subgrade M_R = 20,000 psi

ESALs (millions)	Existing HMA Thickness							
	4 in.		6 in.		8 in.		10 in.	
	JCP	PCP	JCP	PCP	JCP	PCP	JCP	PCP
≤10	8.5	8.0	8.0	8.0	8.0	8.0	7.5	7.5
10-25	9.0	8.5	9.0	8.5	8.5	8.0	8.5	8.0
25-50	10.0	9.5	9.5	9.0	9.5	9.0	9.5	9.0
50-100	10.5	10.0	10.0	9.5	10.0	9.5	10.0	9.5
100-200	11.5	11.0	11.5	11.0	11.5	11.0	11.0	10.5

Note: Unbonded precast PCC thicknesses after Table 8.3 "Precast Concrete Pavement Technology," Final Report, March 2012 at: http://www.trb.org/Main/Blurbs/167788.aspx A project specific design is required.

Table 3. Unbonded PCC and Precast Pavement Overlay over Existing PCC
Unbonded PCC or PCP over PCC with 2 inch HMA bond breaker

ESALs (millions)	Subgrade Modulus					
	5,000 psi		10,000 psi		20,000 psi	
	JCP	PCP	JCP	PCP	JCP	PCP
≤10	8.5	8.0	8.0	8.0	8.0	8.0
10-25	9.0	8.5	9.0	8.5	8.5	8.0
25-50	9.5	9.0	9.5	9.0	9.5	9.0
50-100	10.0	9.5	10.0	9.5	10.0	9.5
100-200	12.0	11.5	11.5	11.0	11.5	11.0

The thickness for the pre-stressed precast concrete pavement, which was listed as 8 inches for all cases, came directly from results provided in the SHRP 2 R05 report "Precast Concrete Pavement Technology" at http://www.trb.org/Main/Blurbs/167788.aspx.

In addition, NCE subcontracted with ARA to produce the design tables for the composite pavements. The details on the work to develop those design tables can be found in Appendix 4-B1 on HMA/PCC pavement and Appendix 4-B2 on PCC/PCC pavements in this report. Tables 4 through 8 below summarize the results from the ARA report.

Table 4. Unbonded Composite HMA/ PCC Pavement Overlay over Existing HMA

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/7	2/7	2/7
10-25	2/7.5	2/7.5	2/7
25-50	2/8	2/8	2/8
50-100	2/9	2/9	2/9
100-200	2/10	2/10	2/10

Notes: (1) The two values shown represent HMA thickness over PCC thickness in inches, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches

Table 5. Unbonded Composite PCC/ PCC Pavement Overlay over Existing HMA

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/7	2/7	2/7
10-25	2/7.5	2/7.5	2/7
25-50	2/8	2/8	2/8
50-100	2/9	2/8.5	2/8.5
100-200	2/13.5	2/12.5	2/12

Notes: (1) The two values shown represent PCC thickness over PCC thickness in inches with the first thickness representing higher quality PCC than the second, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches

Table 6. Unbonded Composite HMA/ PCC Pavement Overlay over Existing PCC Existing PCC with 2 inch thick bond breaker

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/7	2/7	2/7
10-25	2/7	2/7	2/7
25-50	2/7.5	2/7.5	2/7.5
50-100	2/8.5	2/8.5	2/8.5
100-200	2/9	2/9	2/9

Notes: (1) The two values shown represent HMA thickness over PCC thickness in inches, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches. (3) This table also applies to existing composite pavement (HMA/PCC) without the 2 inch HMA bond breaker.

Table 7. Unbonded Composite PCC/ PCC Pavement Overlay over Existing PCC
Existing PCC with 2 inch thick bond breaker

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/6.5	2/6	2/6
10-25	2/7	2/7	2/6.5
25-50	2/7.5	2/7.5	2/7.5
50-100	2/8.5	2/8	2/8
100-200	2/11.5	2/10.5	2/10

Notes: (1) The two values shown represent PCC thickness over PCC thickness in inches with the first thickness representing higher quality PCC than the second, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches, (3) Existing PCC pavement is assumed to be 9 inches of PCC over a 6 inch granular base. (4) This table also applies to existing composite pavement (HMA/PCC) without the 2 inch bond breaker.

In addition to the expanded decision tables and design tables, the rules developed in Phase 3 were also expanded to connect the decision and design tables. Verbal descriptions and directions used in the interactive program were also updated.

The information contained in the Scoping Methodology document included as Appendix 4-A was used to document the work from Task 17 and to provide the information needed to revise the interactive program in Task 18. The information was structured (decision tables, design tables, and rules) to provide the best layout for developing the programming logic used in the interactive program. The Scoping Methodology document is also accessible through the interactive program as a resource for users to learn more about the decision logic and design tables used in the interactive program.

Phase IV Enhancements Task 18

Data structure

The Phase IV additions of precast and composite renewal options almost tripled the amount of logical outcomes available in the data structure. To account for the additional options and continue to provide a lightweight data structure the research team reformatted the XML document to consolidate the data structure into a series of rules. These rules were developed and are outlined in the scoping methodology. An example of the reformatted data structure for a single “action” can be seen below.

```xml
<?xml version="1.0" encoding="utf-8"?>
<pavementassessment>
  <pavementtype value="Flexible">
    <pavementcondition>flexible</pavementcondition>
    <distressespresent>
      <distress rank="1" value="Transverse Cracking">
        <category>Environmental Cracking</category>
        <renewaltypeoption value="Flexible">
          <actions>
            <action rank="1" renewalrule="1" designperiodmin="30" designperiodmax="50">
              <title>HMA overlay over pulverized existing pavement</title>
              <description>Pulverize existing flexible pavement to eliminate all cracking or materials related damage and overlay with HMA.</description>
              <existing value="Base Modulus">
                <option>50000 psi</option>
                <option>30000 psi</option>
                <option>75000 psi</option>
                <option>100000 psi</option>
              </existing>
              <pretreatment>
                <name>Pulverize</name>
                <pavementremoved>0</pavementremoved>
                <pavementretained>0</pavementretained>
              </pretreatment>
              <guidespecs>
                <link>
                  <name>Guide Specification</name>
                  <url>docs/GuideSpecifications.pdf</url>
                  <description>The guide specifications developed by the SHRP2 R23 team are contained in this document. They are organized into three sections which
                  are: (1) guide specifications for pavement components that are not contained within the AASHTO Guide Specifications, (2) elements that can be added to
                  or otherwise modify existing AASHTO Guide Specifications, and (3) summaries for relevant State DOT and AASHTO specifications that were used to produce
                  the "elements" in item 2.</description>
                </link>
              </guidespecs>
              <bestpractices>
                <link>
                  <name>Flexible Best Practices</name>
                  <url>docs/FlexibleBestPractices.pdf</url>
                  <description>The intention of the long-life pavement concept is to significantly extend current pavement design life by restricting distress, such as
                  cracking and rutting, to the pavement surface. Common distress mechanisms such as bottom-up fatigue cracking and rutting in the unbound layers should
                  be, in principle, completely eliminated. These best practices provide insight into design and construction options that will have achieve the
                  long-life goal.</description>
                </link>
              </bestpractices>
            </action>
```

Figure 1. Example "action" node in XML describing one outcome in the logic tree.

Additional modifications to the XML were required to accommodate the Precast and Composite logic to allow for new pretreatment actions to be undertaken on the pavement. This included both non-structural bond breakers and HMA Base layers. To account for these additions, a pretreatment node was established within the XML data structure with various opportunities to specify non structure additions or removals of pavement. An example of an addition of a 4" HMA Base Layer along with the removal of all existing structural pavement can be seen below.

```xml
<pretreatment>
  <name>HMA Base Layer</name>
  <pavementremoved>All</pavementremoved>
  <pavementretained>0</pavementretained>
  <pavementadded>4</pavementadded>
</pretreatment>
```

Figure 2. Example XML snippet showing pretreatment node elements for non-structural pavement actions.

In addition, additional new data thickness lookup elements were added to account for differentiation between design methodologies for precast panels and to account for additional thickness design tables for composite pavements which would provide more than one layer of treatments. An example of the updated XML structure for one logical outcome for a composite pavement is seen below.


```xml
<lookuptables renewalrule="12A">
  <lookuptable subgrademodulus="5000">
    <lookupcolumn existing="not applicable">
      <item>
        <esalrange min="0" max="10"><![CDATA[< 10]]></esalrange>
        <thickness>9.0</thickness>
        <layers>
          <layer rank="1" type="HMA" thickness="2" />
          <layer rank="2" type="PCC" thickness="7" />
        </layers>
      </item>
      <item>
        <esalrange min="10" max="25"><![CDATA[10 - 25]]></esalrange>
        <thickness>9.5</thickness>
        <layers>
          <layer rank="1" type="HMA" thickness="2" />
          <layer rank="2" type="PCC" thickness="7.5" />
        </layers>
      </item>
      <item>
        <esalrange min="25" max="50"><![CDATA[25 - 50]]></esalrange>
        <thickness>10.0</thickness>
        <layers>
          <layer rank="1" type="HMA" thickness="2" />
          <layer rank="2" type="PCC" thickness="8" />
        </layers>
      </item>
      <item>
        <esalrange min="50" max="100"><![CDATA[50 - 100]]></esalrange>
        <thickness>11.0</thickness>
        <layers>
          <layer rank="1" type="HMA" thickness="2" />
          <layer rank="2" type="PCC" thickness="9" />
        </layers>
      </item>
      <item>
        <esalrange min="100" max="1000"><![CDATA[100 - 1000]]></esalrange>
        <thickness>12.0</thickness>
        <layers>
          <layer rank="1" type="HMA" thickness="2" />
          <layer rank="2" type="PCC" thickness="10" />
        </layers>
      </item>
    </lookupcolumn>
  </lookuptable>
```


Figure 3. Snippet of XML describing the lookup table used for a composite renewal rule on pavements with a subgrade modulus of 5,000psi.

Business logic

The new business logic required to include both composite and precast pavement renewal options required significant modifications to the calculation engine. To manage the additional complexities, several new data structures were introduced as well as calculation rules to match the corresponding rules in the scoping methodology. For example, in order to account for the additional remove and replace options that were identified during Phase IV, the application needed to account for both non-structural base layer additions (i.e., 4" HMA base layer on remove and replace jobs) and to account for multiple structural layer additions in the case of a composite pavement renewal when reporting back to the user in the summary form as seen below.

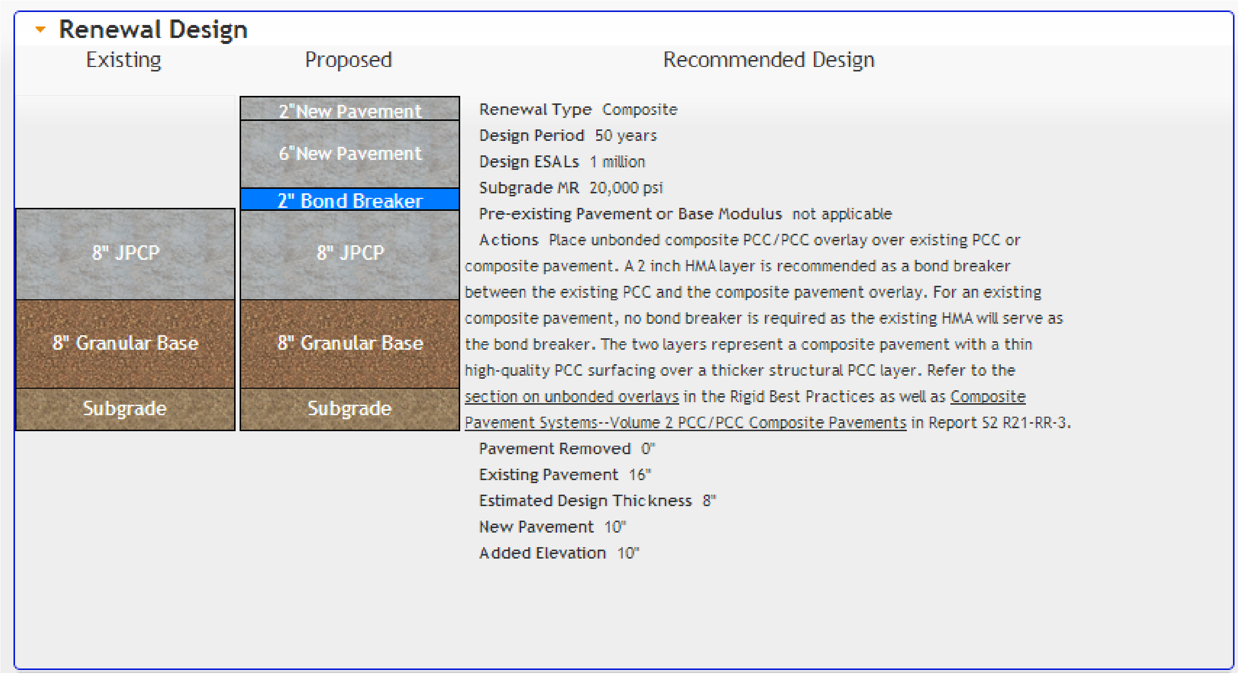


Figure 4. Screenshot of summary page with Composite renewal option selected.

In addition, the research team modified the existing logic as follows:

- Developed additional layer of logic in decision flow to facilitate additional options for remove and replace for both precast and composite pavements within the current decision matrix. This includes an additional level of decision nodes that will in effect over triple the number of options available to the user for any given scenario from the current format.
- Developed logic to extract the appropriate thickness(es) from multiple tables when performing a composite pavement design
- Developed new application business logic to accommodate design rule changes from Phase III work. For example, rule 7 as described in the scoping methodology was modified to provide alternate outcomes.
- Developed logic to determine when certain design tables for precast and composite can be used based on base courses and subgrade selections

User Interface Enhancements

Additional inputs and validation were added to the application to allow for user selection of various remove and replace alternatives. This includes a redesign of certain user interface elements in the program to accommodate the additional R-05 and R-21 design options.

Cross section updates

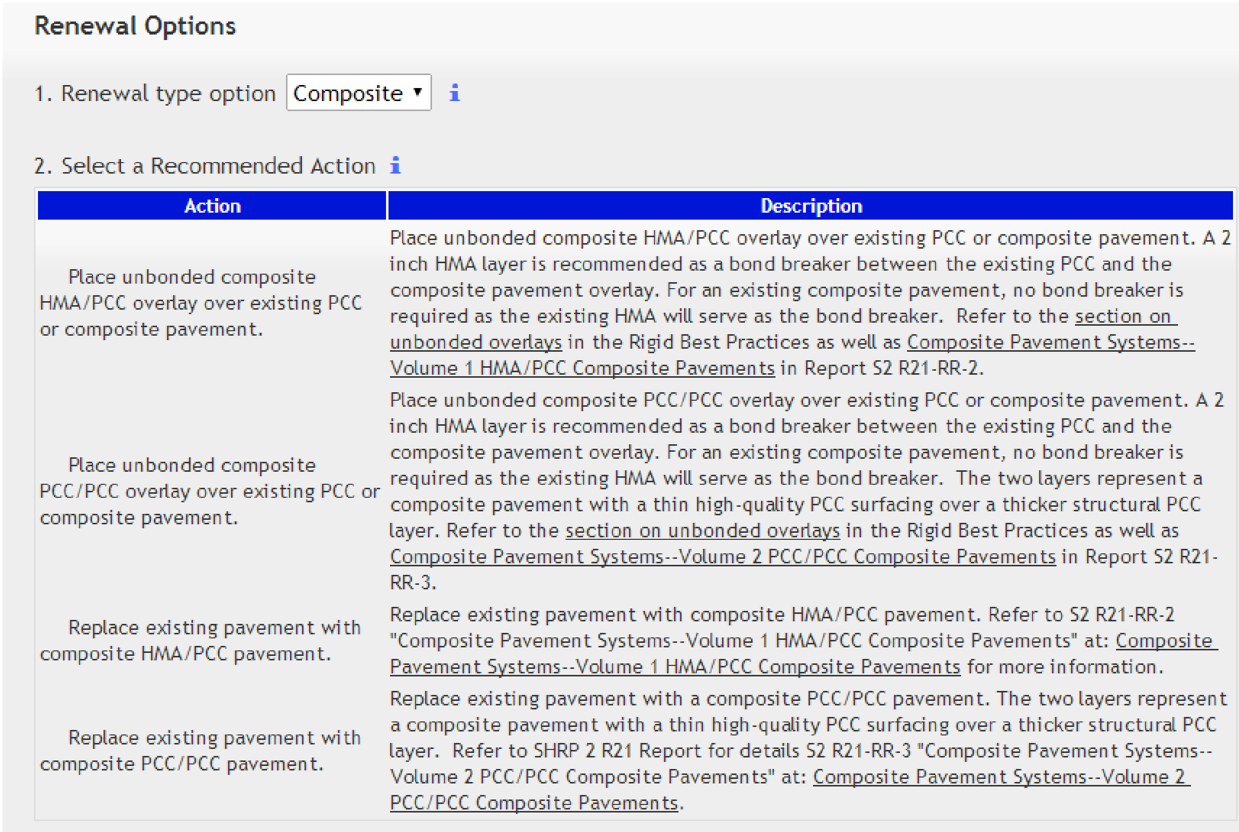
Interface enhancements were made to the cross section generation element to display new alternatives for composites (PCC and HMA), precast, and additional surface preparation recommendations. This included adding logic to identify and label new layers and scale appropriately when multiple layers were added. Several examples can be seen below.

Figure 5. Example of cross section generated for wet on wet PCC composite renewal strategy.

Figure 6. Example of cross section generated for HMA/PCC Composite renewal strategy.

Dynamic linking

In order to better integrate R-05 and R-21 reports into the application and logic, dynamic links were added to the decision matrix to display during the option selection and summary pages. These links opened up reports that were updated during this Phase by the research team. Where appropriate, bookmarks were added to the documents to allow the end user to jump to the section in the report that related to the given section. An example of the composite links can be seen below.



Renewal Options

1. Renewal type option Composite

2. Select a Recommended Action

Action	Description
Place unbonded composite HMA/PCC overlay over existing PCC or composite pavement.	Place unbonded composite HMA/PCC overlay over existing PCC or composite pavement. A 2 inch HMA layer is recommended as a bond breaker between the existing PCC and the composite pavement overlay. For an existing composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to the section on unbonded overlays in the Rigid Best Practices as well as Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements in Report S2 R21-RR-2.
Place unbonded composite PCC/PCC overlay over existing PCC or composite pavement.	Place unbonded composite PCC/PCC overlay over existing PCC or composite pavement. A 2 inch HMA layer is recommended as a bond breaker between the existing PCC and the composite pavement overlay. For an existing composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. The two layers represent a composite pavement with a thin high-quality PCC surfacing over a thicker structural PCC layer. Refer to the section on unbonded overlays in the Rigid Best Practices as well as Composite Pavement Systems--Volume 2 PCC/PCC Composite Pavements in Report S2 R21-RR-3.
Replace existing pavement with composite HMA/PCC pavement.	Replace existing pavement with composite HMA/PCC pavement. Refer to S2 R21-RR-2 "Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements" at: Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements for more information.
Replace existing pavement with composite PCC/PCC pavement.	Replace existing pavement with a composite PCC/PCC pavement. The two layers represent a composite pavement with a thin high-quality PCC surfacing over a thicker structural PCC layer. Refer to SHRP 2 R21 Report for details S2 R21-RR-3 "Composite Pavement Systems--Volume 2 PCC/PCC Composite Pavements" at: Composite Pavement Systems--Volume 2 PCC/PCC Composite Pavements.

Figure 7. Screenshot of Composite Actions with dynamic links to report sections.

Testing Process

There were three components implemented during the application testing cycle as described below.

Unit Tests were performed to validate that individual functional elements were working as planned. These were conducted on each of the functions to ensure that an appropriate output was generated. For example, you might have a function that takes in an email address and determines whether it is valid, returning a boolean to indicate whether it is acceptable. The unit test for this function would pass in multiple known values for the email address to the function and inspect the response to ensure the proper value was returned. Unit tests are designed to be quickly and often and don't require any specific environmental or service configuration to work. They are often incorporated into build processes and the resulting output can be used to automatically reject a build or flag it for review.

Integration Tests were the second level of testing designed to test the code at a higher level that includes service calls, database responses, and multiple function calls. These types of tests often require that certain data or services exist and are functioning correctly in order for them to succeed. An example of an integration test would be creating a user account or executing a lookup from the logic table. In the first case, the account credentials were established and passed to the appropriate handler. The system then was asked to query on the account and return an object that can be compared to the original object to ensure that it matches. These tests are more intuitive from a use case scenario as they test a full scenario and not just discrete units of it. However, if they fail, they provide less clarity as to exactly which portion of the test failed.

An example test seen below is the **Insert Report w/ Permissions** test. This creates a Report object from pre-defined test data. It then utilizes the secret key from a user account created in a prior integration test to sign that report object. The object and signature are then passed to the service layer via an AJAX call. The test will then wait for a response from the server and inspect that response for specific values. If the values match, then the service can be judge to have handled that use case correctly, even though we don't know exactly what it did to handle it. It is crucial that both positive and negative cases are tested. A failure use case is judged as passing if the service rejects it and responds with an appropriate message.

Figure 8. Screenshot of an Integration Test result from the application.

The goal with all of this testing was to lower bugs and expedite change requests since automated tests allow the full system to be quickly tested for breaking changes prior to any code being deployed. Human time can then be spent testing more subtle errors such as layout and content.

Logic Tests were used as a final step once the function was verified using unit and integration tests. This testing process involved running the application from end to end around a specific case from the Scoping Methodology to verify the outcome matched what was in the document. Where there was deviation, XML modifications were made to the data structure to ensure accuracy.

As a final step in the testing process members of the R 23 team spent close to a month beta testing the program looking at as wide a range of cases and inputs as possible. Once that effort was completed the program was made public on the www.pavementrenewal.org web site. The team received few comments from the public as to the designs and output from the program but there was occasional access problems usually associated with an Agencies server and the use of somewhat outdated software. After the program was placed on the public website the R23 team continued to test the program and program logic, and a few more errors were found in the business logic and in the graphic displays which have been corrected.

Additional User Capabilities

Based on feedback from users of the ***rePave Scoping Tool***, the project team has developed a series of additional user capabilities to aid in the implementation of the ***rePave Scoping Tool*** to create a more seamless experience for the user and aid in overall usability of the application. This included the following elements:

1. New entry page for application to promote tool, resources, and SHRP 2 R23 project
    a. Home page with functions for rotating banner/content to feature products

   b. Provide ability for user to learn of the benefits from using the products
   c. Provide ability for user to access the rePave Scoping Tool
   d. Linkable to other HTML pages
   e. Access to Registration or log in for existing users
   f. Access to resources (without login)
2. Provide user management/registration to reduce login time and redundancy
   a. Provide single sign in
   b. Eliminate need for creating a new user profile for each run with rePave
   c. Create centralized user management for single login and password
   d. Provide user registration to better understand who is using the application
3. Provide Report Management to centrally store and access all designs
   a. Accessible from personalized page following login
   b. Features and capabilities
      i. Create reports
      ii. Clone reports
         1. user owned reports
         2. shared reports from others
      iii. Share reports
         1. share via email address
         2. quick print function – ideally to pdf
      iv. Categorize and organize reports
         1. nested folder structure
         2. my reports folder
         3. shared reports
         4. drag and drop to and between folders for easy handling
4. Provide the ability to compare reports side by side
   a. pick multiple reports and compare fields
   b. visually highlight key differences
   c. printable for portability

To develop the above, the project team utilized the following common requirements developed earlier in the project:

- Input and form validation
- Responsive design for UI
- CSS styling to match template
- Browser compatibility (Firefox, IE, Chrome, Safari)
- Device compatibility (responsive design, target iPad, laptop, larger)

Printability User Element Descriptions

The following section details the look, feel, and function of the various elements added to enhance the user experience.

Home Page

The following is a screenshot of the Home page. It is the first page accessible to any user coming to the site. It allows users to access the resources of the R23 work directly and also access the ***rePave Scoping Tool*** via a log in schema. This is done to allow users to save/store/share their designs. Once a user has registered, they will only need an email and password to regain access.

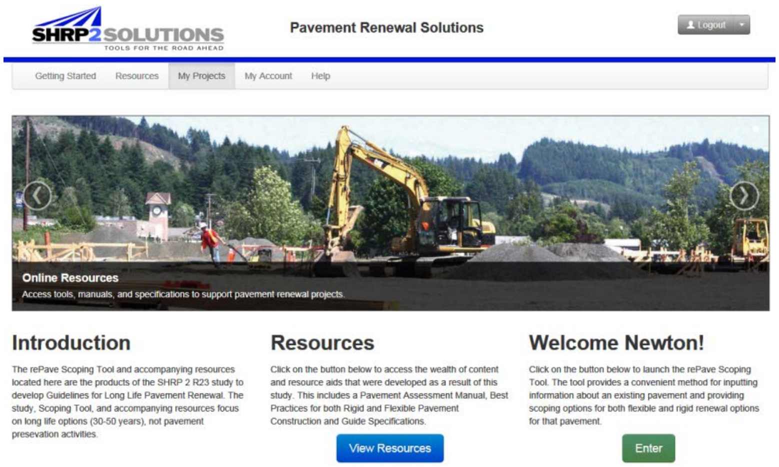


Figure 9. rePave Home Page

Getting Started

The following is an example of an interior content page that was developed to provide getting started information directly from the Home page. It contains information and training information in the form of videos that users need to utilize the ***rePave Scoping Tool***.

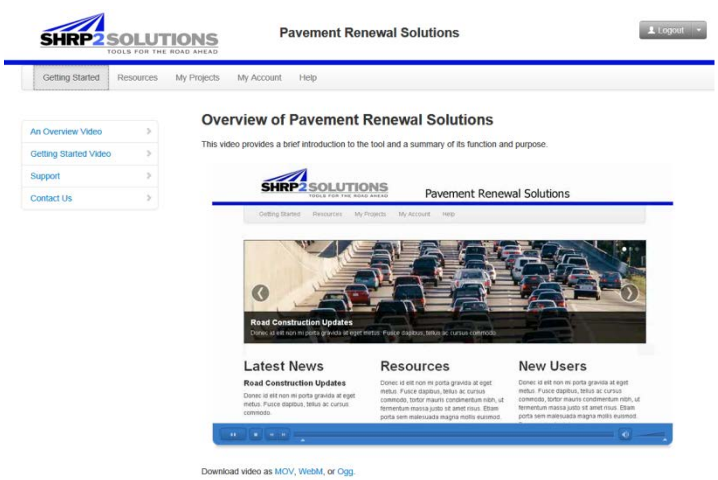


Figure 10. repave Overview Page

Registration

The registration page was designed to allow the user to provide basic information on sign up to the site to allow for easy storing and retrieval of their designs. Below is a screenshot of the user registration page content to illustrate the fields and user experience.

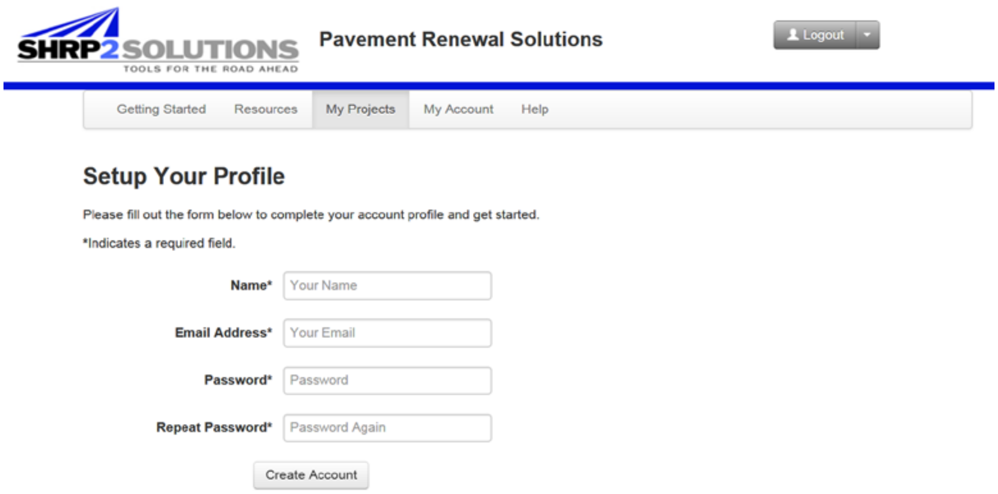


Figure 11. rePave user sign up screen

Report Management

A Report Management interface was developed to allow the user to create and organize project sections and alternative outcomes within the web interface. In addition, the user can easily compare, edit, or share any of the project sections and corresponding renewal options at the click of a link. The screenshot below illustrates how the interface provides a familiar folder based navigation.

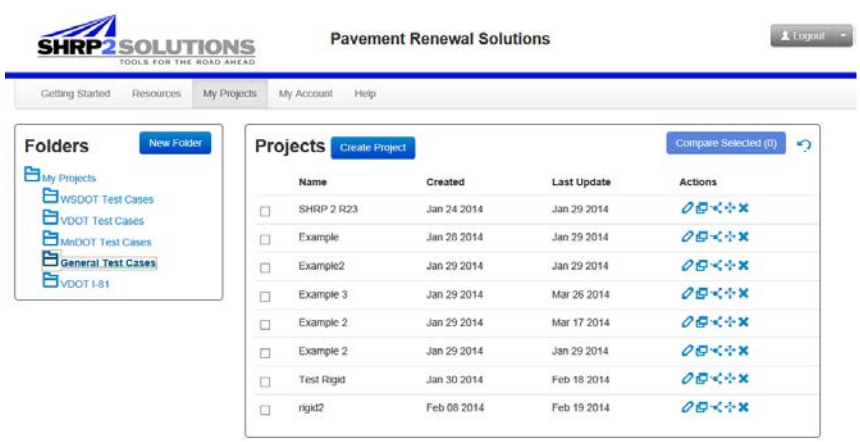


Figure 12. rePave Project Folders and File access

Compare Projects

The compare projects feature is used to show different designs side by side for easy comparison. The example seen below shows the same existing pavement section with different renewal options shown in the summary allowing a user to quickly see how each recommended renewal strategy compares with one another.

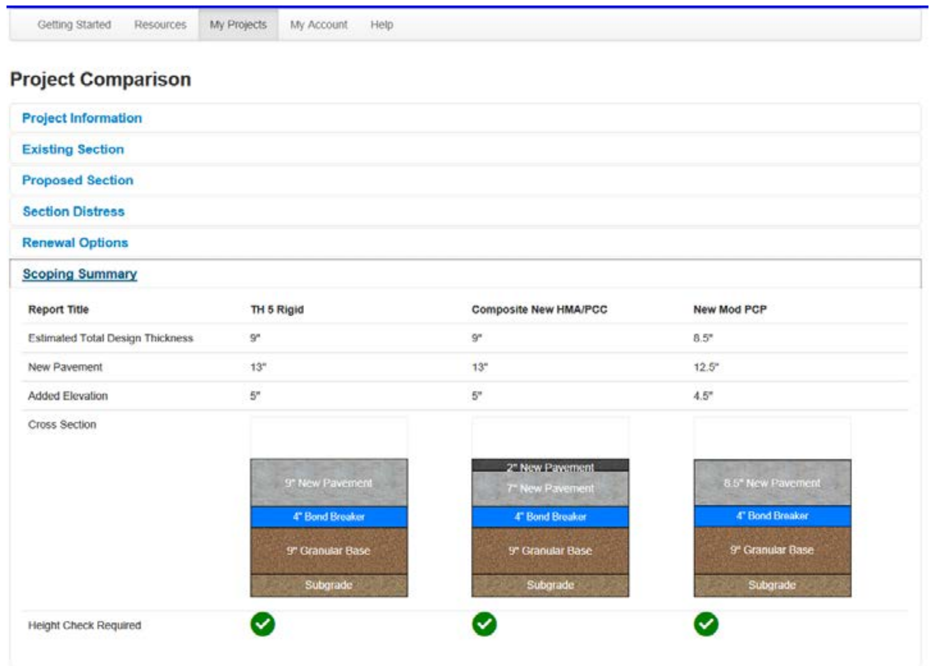


Figure 13. Project comparison screen

Another use of the compare tool is when a user has different design sections within a single project. When we started this project we thought about how to handle different sections within the same project and ended up instructing the user to separate the project into different sections and run the scoping tool on the different sections. They can now do that using the compare tool described here and show the design for up to 3 sections.

Share Projects

Users are allowed to share any project they create with other users for review and collaboration using the Share Project feature. The following is an example of the fields and display of a dialog for when the user selects to share their report from the interface described above.

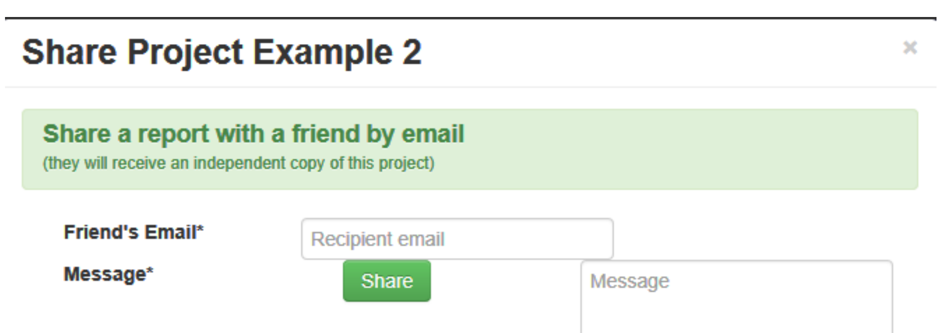


Figure 14. rePave File share page

Style enhancements

In addition to the new usability enhancements and elements described earlier, the project team improved the layout and design and shift to a more 2D look to match current graphic and web design trends. The screenshot below provides an example of elements display style in the new application.

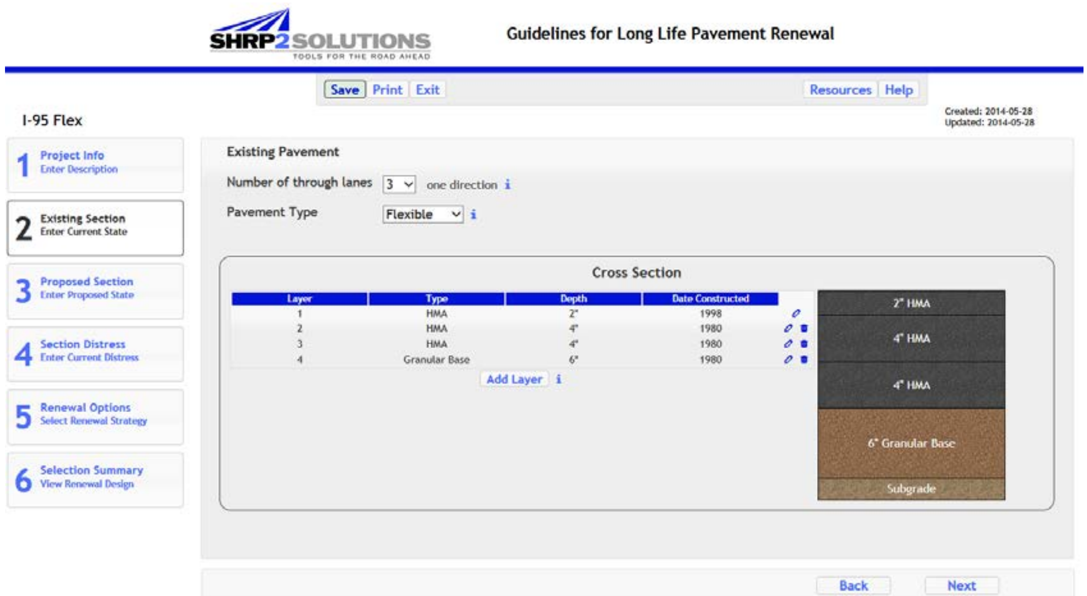


Figure 15. rePave screen

Work Flow Diagram

The following diagram depicts the interaction points and flow between each of the elements described above. This includes streamlining the various UI elements to reduce the number of popups and dialogs for the user throughout the experience.

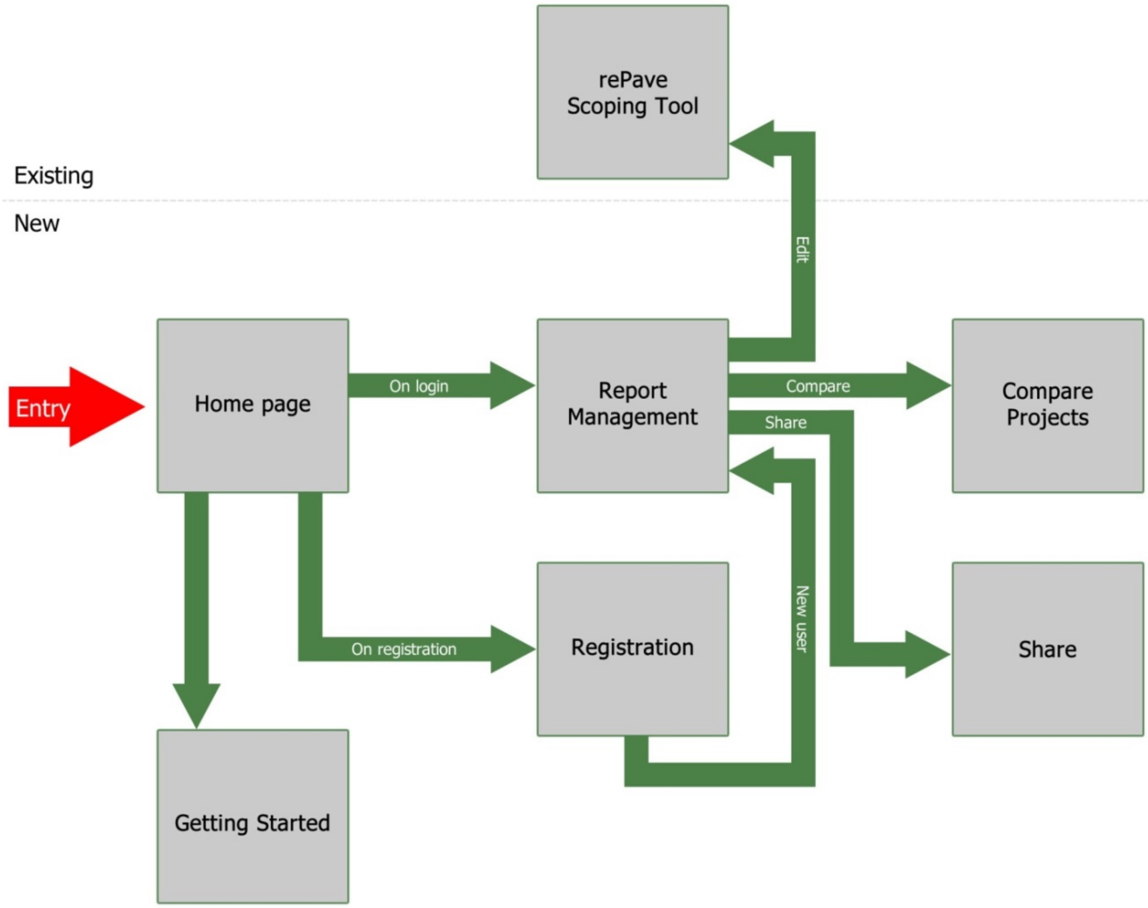


Figure 16. Work flow diagram

Detailed Activities Performed Under Task 19

As part of this task, four case studies were developed and one was used as an example in the training videos developed by Pavia which are accessible through the Getting Started page on rePave program (see figure 10 "Overview Page" in the section on Task 18 above). Two videos were developed. The first video provides a general overview of the rePave program and the second includes a more in depth discussion and examples of the features in the program.

The four Case Studies were:

- TH-5 Minnesota
- I-90 Washington State
- I-81 Virginia
- I- 95 Virginia

The project on TH-5 in Minnesota represented a lower volume two lane principal arterial highway while the projects in Virginia and Washington involved higher volume four and six lane Interstate highways.

The full documentation for the case studies are included in Appendix 4-C1, 4-C2, 4-C3, and 4-C4.

The following is a summary of the results of the four case studies.

TH-5 Minnesota

TH -5 is a two lane principal highway with fairly high traffic for a two lane roadway (17,300 AADT). The existing pavement consists of 8 to 11 inches of HMA over about 8 inches of untreated granular base. The pavement has extensive thermal cracking and fatigue cracking. The cores indicate areas where the HMA is striping either between layers or within different layers.

The following traffic loading was estimated for both 20 and 35 year designs for rigid and flexible pavement.

- 20 year Flexible ESAL 1,995,000
- 20 year Rigid ESAL 2.753,000
- 35 year Flexible ESAL 4,071,000
- 35 year Rigid ESAL 5, 618,000

In the January 31, 2014 MnDOT Pavement Design Structure Memo Mr. Tim Clyne[i] recommended the following flexible and rigid pavement design.

Section 1

Flexible 20 year design - Pre grind 10 inches of the existing pavement using full depth reclamation (FDR) and treat 6 inches with engineered emulsion then overlay with HMA. The resulting pavement section would be:

- 5/8" UTBWC
- 2.5" SPWEA34OC
- 6.0" Engineered Emulsion Treated Base
- 4.0" FDR Base
- 8.0" Granular Base
- 21 1/8" Total

Section 2

Section 2 is much the same except the existing pavement is thinner (8 inches), so the pre-grind depth is less. The resulting pavement section is:

- 5/8" UTBWC
- 2.5" SPWEA34OC
- 6.0" Engineered Emulsion Treated Base
- 2.0" FDR Base
- 8.0" Granular Base
- 19 1/8" Total

The 35 year rigid design is the same for both sections; just the thickness of the existing pavement changes because it is thicker in section 1. The recommendations included milling 5 " of the existing pavement in section 1 and 4" in section 2. The resulting pavement thickness was:

- 7.0' PCC (15'X13" Panels w/ 1" Dowels)
- 6.0" Existing HMA (which changes to 4.0" in section 2)
- 8.0" Granular Base (9" in section 2)
- 21" Total

The following tables show the comparison between the MnDOT design shown above and the designs produced by rePave.

Table 8. Comparison of flexible pavement designs

	MnDOT	rePave	rePave
Design Life	20 years	35 years	35 years
ESALs	2 Million	10 Million	10 Million
Approach	Reclaim	Reclaim	Reconstruct
HMA	3.1"	6"	10"
Emulsion treated base	6"	6"	
Aggregate Base	11"	11"	9"
	SG	SG	SG

The most significant difference noted between the MnDOT design and the rePave design is in the HMA Pavement thickness. This is largely due to the traffic levels used in the design. MnDOt's standard design life for flexible pavements is 20 years while the minimum design life considered in rePave is 30 years for long life design. Additionally, the minimum design traffic considered in rePave is ≤ 10 million ESALs.

The next table shows the difference between the rigid pavement design developed by MnDOT and that provided by rePave.

Table 9. Comparison of rigid pavement designs

	MnDOT	rePave	rePave
Design Life	35 years	35 years	35 years
ESALs	5 Million	10 Million	10 Million
Approach	UBOL*	UBOL*	Reconstruct
PCC	7"	8.5"	9"
HMA	5"**	5"	4
Aggregate Base	9"	9"	9"
	SG	SG	SG

*Unbonded Overlay

** MnDOT milled off all but 5" of the existing HMA to reduce the pavement elevation.

For the rigid pavement design the MnDOT design is also thinner than the rePave design. Similar to the flexible design the traffic loading in terms of ESALS is lower in the MnDOT design compared to that used in the rigid design tables in rePave. The MnDOT design is for 5 million ESALs, while the minimum rePave design is for 10 million ESALs. The rePave designs are also a little bit thicker because of the more conservative nature of the long life criteria under which they were developed.

In addition to the standard PCC designs rePave can also provide design options for "Composite" pavements based on the SHRP 2 R21 Research Project[iii] and "Modular" pavements based on the SHRP 2 R05 Research Project[iv]. Those designs are shown in the following two tables.

Table 10. Comparison of "Composite" pavement designs

	MnDOT	rePave	rePave	rePave	rePave
Design Life	35 years	35 years	35 years	35 years	35 years
ESALs	5 Million	10 Million	10 Million	10 Million	10 Million
Approach	UBOL*	UBOL*	Reconstruct	UBOL*	Reconstruct
PCC	7"	2/7"**	2/7"**	2/7"***	2/7"***
HMA	5"	8"	4	8"	4
Aggregate Base	9"	9"	9"	9"	9"
	SG	SG	SG	SG	SG

*Unbonded Overlay
**HMA over PCC
***PCC over PCC

Table 11. Comparison of "Modular" pavement designs

	MnDOT	rePave	rePave	rePave	rePave
Design Life	35 years	35 years	35 years	35 years	35 years
ESALs	5 Million	10 Million	10 Million	10 Million	10 Million
Approach	UBOL*	UBOL*	Reconstruct	UBOL*	Reconstruct
PCC	7"	8"**	8.5"**	8"***	8"***
HMA	5"	8"	4	8"	4
Aggregate Base	9"	9"	9"	9"	9"
	SG	SG	SG	SG	SG

*Unbonded Overlay
**Precast PCC
***Prestressed Precast PCC

The somewhat thinner nature of the composite and modular pavement systems can be seen in these last two tables in comparison to the rigid designs in table 8.

I- 90 Washington

The project is located on Interstate 90 a little over 85 miles east of Seattle Washington.

The existing PCC pavement was constructed in 1967 as a 9 inch thick plain jointed PCCP with 15 ft joint spacing and no dowels over 9 inches of gravel surfacing. Most of the native soils through this area consist of glacial till or alluvial washes (silty sandy gravels) with some pockets of clay. There were no soil stiffness values reported for these soils. Typically the resilient modules values range from 15,000 psi to 30,000 psi

By the mid 1990's the pavement had experienced a little over 1/4 inch of faulting but little or no slab cracking, nor joint spalling. In 1997 the pavement was restored by retrofitting dowels, grinding the surface and re-sealing the joints.

The WSDOT resurfacing report dated February 2013[ii] indicated the following existing pavement conditions.

".... widespread distress in the form of numerous multi-cracked panels, and dowel bar retrofit failure.... There is also significant continuous panel to panel cracking propagation from a corner of the dowel bar slot in a panel to a corner of an adjacent dowel bar slot in the next panel. "

The 2012 WSPMS was used to estimate future ESALS which indicated 1.1 Million ESALS in each direction for the 2016 design year. WSDOT estimated the 50 year design ESAL as 150 M ESAL in each direction using their customary 2% rate of annual growth. They reduced the design ESAL to 120 M ESALs assuming a 20%/80% lane distribution. The 2015 traffic value was 25,000 AADT with 23.4% trucks.

The following design summary shows both the WSDOT and rePave pavement designs.

Design Approach	WSDOT	rePave (120 M ESAL)
Crack & Seat + HMA Overlay	0.75 ft (9 in) HMA	9.0 in HMA
Unbonded PCC Overlay	0.90 ft (10 3/4 in) PCC	11.5 in PCC
New PCC Pavement	1.05 ft (12 3/4 in) PCC	12.0 in PCC

The designs were very similar. The differences are probably due to the fact that for the rePave design that traffic level fits within the 100-200 Million ESAL table row which is in fact a 200 Million ESAL design while the WSDOT was for 120 Million ESALs. In addition the WSDOT design considered a 14 ft wide outside lane which would have reduced the pavement thickness but it also included additional PCC thickness to allow for future grinding. With the heavy tire chain and stud wear experienced on this section of I-90 there will be several grinding cycles in 50 years. These details provide a very good example why the rePave program needs to be considered a scoping tool to look at different approaches but the Agency must perform its own design process to finalize the design.

In addition to the standard rigid and flexible design approaches the program also provides guidance on composite and modular pavements developed under SHRP 2 R21[iii] for composite pavements and SHRP 2 R05[iv] for modular pavement systems.

The four composite designs can be compared to the WSDOT designs as shown below.

Design Approach	WSDOT	rePave (HMA/PCC)	rePave (PCC/PCC)
Unbonded PCC Overlay (with 2 in. bondbreaker)	0.90 ft (10 3/4 in) PCC	2/9 in HMA/PCC	2/10 in PCC/PCC
New PCC Pavement (over 4 in. HMA + 9 in. AB)	1.05 ft (12 3/4 in) PCC	2/10 in HMA/PCC	2/12.5 in PCC/PCC

The HMA/PCC composite pavements are somewhat thinner than the WSDOT design because of the reduced warping and curling stress in the HMA/PCC composite pavements. The PCC/PCC composite pavement designs are thicker than the WSDOT designs because that design allows for the use of lower quality cement concrete or aggregate in the lower section of the pavement.

These four precast designs are compared to the WSDOT designs as shown below.

Design Approach	WSDOT	rePave (precast)	rePave (pre-stressed precast)
Unbonded PCC Overlay	0.90 ft (10 3/4 in) PCC	9.5 in PCP	8.0 in PPCP
New PCC Pavement	1.05 ft (12 3/4 in) PCC	10.0 in PCP	8.0 in PPCP

The precast concrete pavements are somewhat thinner than the WSDOT design based on the shorter design life of 35 years vs 50 years and improved construction procedures for the precast units.

I-81 Virginia

This project calls for the reconstruction of 3.66 miles of pavement southbound on I-81 in Augusta County near Stanton VA.

The existing pavement was constructed in 1968 with about 10 inches of HMA over about 10 to 12 inches of granular base. The pavement has been resurfaced repeatedly since construction and was found to be experiencing structural deterioration largely due to striping between and within the various pavement layers. The current HMA thickness ranges from 11 to 12.5 inches thick.

The subgrade soils stiffness in terms of resilient modulus (M_R) ranged from about 24,000 psi to 38,000 psi, with the 85% values ranging from 15,000 to 24,000 psi.

The traffic volumes consisted of one direction average daily traffic of 22,000 vehicles per day in 2008. Truck traffic made up 33% of the traffic with 90% of those trucks traveling in the outside lane. The predicted 30 year ESAL values used in their design was 102,600,000 ESALS. The original design recommendations were to remove and replace the outside lane with 10 inches of base course, 2 inches of 3/4 in binder course and a 2 inch surface course of 1/2 inch SMA mix.

The design was changed to reclaim the existing HMA and base. All but 12 inches of the reclaimed material would be removed which would then be surfaced with 6 inches of cold central plant recycled material (CCPR) made from the reclaimed asphalt, and 6 inches of HMA. The primary reason for removing the material was to address weak spots that were evident in the FWD survey and would likely show up during construction. Additionally there were provisions for detouring the traffic so that the outside lane could be removed for a short period of time.

The comparison between the VDOT design for this project and the design from rePave are very similar.

	VDOT Design	rePave	rePave (grindings removed)
HMA	6 inches	7 inches	7 inches
Emulsion treated base	6 inches	11.5 inches	6 inches
Granular base	12 inches	10 inches	10 inches
Total	24 inches	28 inches	23 inches

The only difference between the VDOT design and the rerun of rePave with grindings removed is an extra inch of HMA. The difference is due to a combination of factors. The VDOT design used the 93 AASHTO Guide and a traffic loading of 102, 600,000 ESALS. The rePave design came from a set of design tables where the last ESAL category was 100 - 200 million ESALS. The rePave design was based on the MEPDG and PerRoad runs using 200 million ESALs.

The VDOT elected to use the cold plant recycling design which was successfully constructed in 2011[v]

In addition to the standard rigid and flexible design approaches the program also provides guidance on composite and modular pavements developed under SHRP 2 R21[vi] for composite pavements and SHRP 2 R05[vii] for modular pavement systems.

A summary of the composite designs are as follows:

Design Approach	rePave (HMA/PCC)	rePave (PCC/PCC)
Unbonded PCC Overlay (over existing HMA)	2/10 in HMA/PCC	2/12 in PCC/PCC
New PCC Pavement (over 4 in. HMA + 10 in. AB)	2/10 in HMA/PCC	2/12.5 in PCC/PCC

A summary of the modular pavement designs are as follows:

Design Approach	rePave (precast)	rePave (pre-stressed precast)
Unbonded PCC Overlay (over existing HMA)	9.5 in PCP	8.0 in PPCP
New PCC Pavement (over 4 in. HMA + 10 in. AB)	10.0 in PCP	8.0 in PPCP

The VDOT elected to use the cold plant recycling design which was successfully constructed in 2011[viii]

I-95 Virginia

This project was first reported in the Draft Final Report for R23 as one of 6 test cases and was used as the basis for a workshop conducted in Virginia as part of the project. Because of publication limits the test cases were not included in the Final Report for R23. This test case contained features that were not included in the other three case studies including a ground penetrating radar survey and a traffic study using CA4PRS. Because of these features this test case was re-run to update the rePave screen shots and include composite and modular pavements in the study.

The design elements that apply to the R-23 Guidelines are as follows:

Existing Pavement (two outside lanes)

- 1980 Add two lanes
  - 2” S-5
  - 8” B-3
  - 6” Pervious Aggregate Sub-base Type I Number 21 or 21A
  - 6” Pervious Select Material (minimum CBR of 30)
- 1999 Mill 2” place 2” SM-12.5 D overlay

- Current traffic
    - 78,000 AADT
    - 1.8 million ESAL's per year
        - 1.4% growth (assume outside lane reaches capacity in 15 to 20 years)
- Assumed fatigue cracking 18 % wheelpath, with 8 % patching
- Subgrade AASHTO A-2-6 (0) soil, (Reddish Brown Sandy Lean Clay) M_r = 10,000 psi

Extensive asphalt striping was found intermittently throughout the project to a depth of 6 inches.

A pavement design was conducted by VDOT based on the 1993 AASHTO Guide for Design of Pavement Structures called for milling and filling the right lane to a depth of 4 inches and the two interior lanes to a depth of 2 inches, followed by a 4 inch overlay.

The design summary from rePave called for milling and filling the right lane to a minimum depths of 6 inches to eliminate all striping asphalt and then placing a 3 inch overlay over the full pavement section.

Again the designs were similar to that considered by the DOT however in milling 6 inches of HMA in the right lane traffic control became more of an issue which is the reason a traffic analysis was also included in the study. The design now being considered by VDOT is to remove all of the outside lane and shoulder to eliminate any risk to leaving any striped material in place and to facilitate improving drainage from the roadway section.

The full case study with rigid, composite, and modular pavement designs is included in the case studies contained in Appendix xxx.

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[i] Minnesota Department of Transportation, Office Memorandum To Scott McBride District Engineer, from Tim Clyne Materials Program Delivery Engineer dated January 31, 2014 Subject Pavement Design Structure.

[ii] I-90 / Oaks Ave Vic to Elk Heights Rd Vic WB- Replace /Rehab Concrete" Pavement Type Selection April 30, 2013 by Andrew Byrd PE. and Greg Barrett South Central Region WSDOT

[iii] SHRP 2 R21 Report S2 R21-RR-2 "Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-2.pdf.

[iv] Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.

[v] Diefenderfer, Brian, C. Et. Al.,, "In-Place Pavement Recycling on I-81 in Virginia" *Transportation Research Record: Journal of the Transportation Research Board, No. 2306,* Transportation Research Board of the National Academies, Washington, D.C.

[vi] SHRP 2 R21 Report S2 R21-RR-2 "Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-2.pdf.

[vii] Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.

[viii] Diefenderfer, Brian, C. Et. Al., "In-Place Pavement Recycling on I-81 in Virginia" *Transportation Research Record: Journal of the Transportation Research Board, No. 2306,* Transportation Research Board of the National Academies, Washington, D.C.

Appendix 4-A

SHRP 2 R23 Scoping Methodology

Including Advanced Renewal Systems

Appendix A

SHRP 2 R23 Scoping Methodology including Advanced Renewal Systems

Introduction

The SHRP 2 R23 project has developed scoping guidelines for long-life design and construction using existing pavements. The principal guidelines include decision matrices and associated rules supported by layer thickness tables. A web-based interactive program was developed to simplify the use of this decision-making process. The program provides a set of approaches and estimates of pavement thicknesses for project scoping. This document includes renewal methods that include pavement systems developed for the SHRP 2 R05 (precast pavements) and R21 (composite pavement) studies.

Scoping Methodology

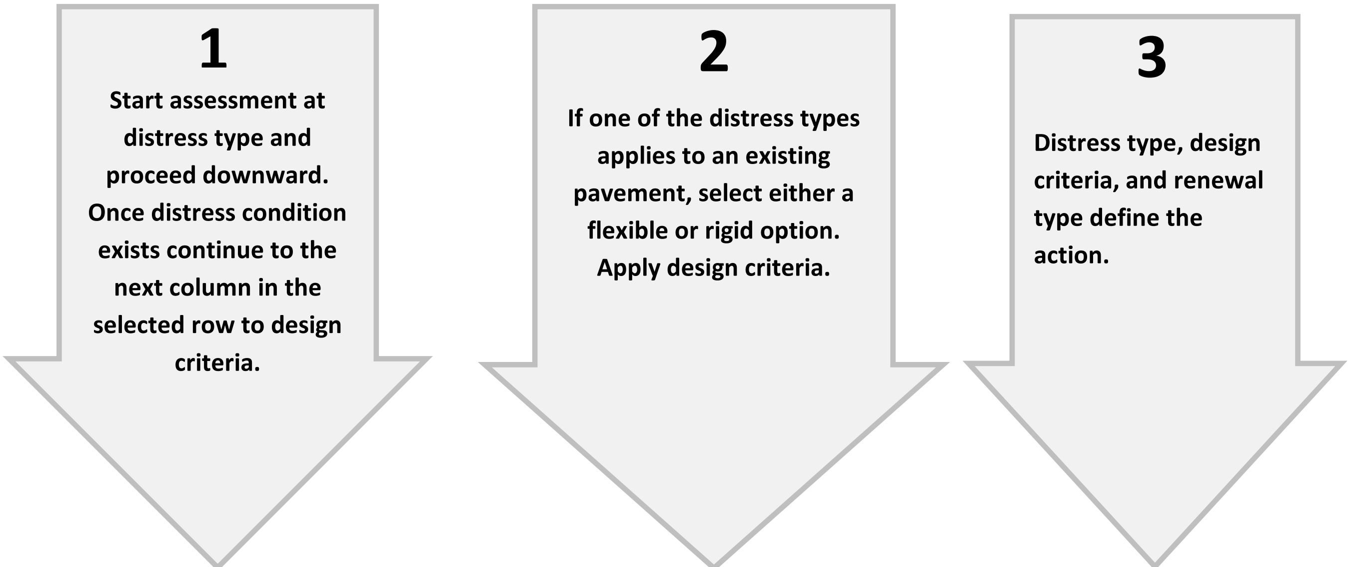
A simplified view of the layout and use of the R23 decision tables used in the scoping tool is shown in Figure 4-A-1 for existing flexible pavements. The first distress type considered, environmental cracking, is illustrated. Similar layouts with different distress types apply to rigid and composite pavements. The scoping process uses a cascading decision order. In accordance with the figure: **(1)** The order is based on the condition that requires the most aggressive renewal approach to that requiring the least. Each type of existing pavement distress is checked but once the first identified distress type is addressed the subsequent distress types are not further considered. **(2)** Once a specific distress type is identified, either flexible or rigid options are selected for renewal. **(3)** An action is defined for each flexible or rigid option. This action describes treatments for the existing pavement and the appropriate thickness for the new pavement structure to be added to the existing pavement. Tables 4-A-1 through 4-A-5 show the specific order of the scoping process with respect to pavement distress and existing pavement type. If one wishes to consider renewal options for multiple types of pavement distress for an existing pavement, each distress type can be quickly entered via the scoping tool and the results viewed.

There are limitations as to what this scoping tool can or should do. These include: (1) This is a scoping tool not a final design process. It is expected that all agency/owners will use their approved design processes for final design. (2) The interactive program does not provide guidance on short life overlay or maintenance projects. (3) It may be that local pavement practices that provide long-life solutions (30 to 50 years) are not considered by the scoping tool.

Supporting Features

The program also provides a platform for information that aid users in designing and building long life pavements using existing pavements. These include:

- Project Assessment Manual
- Best Practices
    - Rigid Pavements
    - Flexible Pavements
- Guide Specifications
- Life-Cycle Cost Analysis
- Life-Cycle Assessment (describes processes to assess environmental impact)
- Emerging Technologies or Renewal Strategies That May Merit Use in the Future.



Distress Type and Description (Scoping Order Varies)	Renewal Pavement Type and Design Criteria		Action
Environmental Related Cracking • Transverse Cracking • Block Cracking	Flexible	Three renewal options are available. The design period (30 to 50 years), the subgrade M_R, and characterization of the existing pavement are required inputs.	Pulverize existing + thick HMA overlay
			Pulverize existing, stabilize + thick HMA overlay
			Remove and replace with HMA
	Rigid	Two options are available. The design period (30 to 50 years) and the subgrade M_R, and characterization of the existing pavement are required inputs.	Place unbonded PCC overlay
			Remove and replace with PCC
Subsequent distress types…	Flexible	…	…
	Rigid	…	…

Figure 4-A-1 Simplified View of Decision Table Layout for Existing Flexible Pavements.

(Note: M_R = resilient modulus, PCC = portland cement concrete, HMA = hot-mix asphalt).

Decisions Tables and Decision Rules

The decision tables are provided as Tables 4-A-6 through 4-A-23. The decision rules for the scoping tool follow the decision tables.

Table 4-A-1 Scoping Methodology Decision Order—Existing HMA Pavements.

Existing Pavement Type	Scoping Order	Distress	
		Type	Criteria
HMA	1	Transverse or Block Cracking	Present
HMA	2	Full Depth Fatigue Cracking in Wheelpath	≥ 10%
HMA	3	Stripping	Full Depth
HMA	4	Stripping	Partial Depth
HMA	5	Top Down Longitudinal and Alligator Cracking in Wheelpath	≥ 10%
HMA	6	Full Depth Fatigue Cracking in Wheelpath	< 10%
HMA	7	Top Down Longitudinal and Alligator Cracking in Wheelpath	< 10%

Table 4-A-2 Scoping Methodology Decision Order—Existing Jointed Plan Concrete Pavements (JPCP).

Existing Pavement Type	Scoping Order	Distress	
		Type	Criteria
JPCP	1	D-Cracking	Moderate to High Severity
JPCP	2	D-Cracking	Light Severity
JPCP	3	Alkali-Silica Reactivity (ASR)	Present
JPCP	4	% Cracked Panels	Moderate to Severe ≥ 10%
JPCP	5	% Cracked Panels	Low to Moderate < 10%
JPCP	6	Joint Faulting	≥ 0.25 in. + D ≥ 0.04 in.
JPCP	7	Joint Faulting	≥ 0.25 in. + D < 0.04 in.
JPCP	8	Joint Faulting	< 0.25 in.
JPCP	9	Pumping	Present + D ≥ 0.04 in.
JPCP	10	Pumping	Present + D < 0.04 in.

Note: JPCP = jointed plain concrete pavement.

Table 4-A-3 Scoping Methodology Decision Order—Existing Jointed Reinforced Concrete Pavements (JRCP).

Existing Pavement Type	Scoping Order	Distress	
		Type	Criteria
JRCP	1	D-Cracking	Moderate to High Severity
JRCP	2	D-Cracking	Light Severity
JRCP	3	Alkali-Silica Reactivity (ASR)	Present
JRCP	4	Cracked Panels	Moderate to Severe ≥ 10%
JRCP	5	Cracked Panels	Low to Moderate < 10%
JRCP	6	Joint Faulting	≥ 0.25 in. + D ≥ 0.04 in.
JRCP	7	Joint Faulting	≥ 0.25 in. + D < 0.04 in.
JRCP	8	Joint Faulting	< 0.25 in.
JRCP	9	Pumping	Present + D ≥ 0.04 in.
JRCP	10	Pumping	Present + D < 0.04 in.

Note: JRCP = jointed reinforced concrete pavement.

Table 4-A-4 Scoping Methodology Decision Order—Existing Continuously Reinforced Concrete Pavements (CRCP).

Existing Pavement Type	Scoping Order	Distress	
		Type	**Criteria**
CRCP	1	Punchouts	> 5 per Mile
CRCP	2	D-Cracking	Moderate to High Severity
CRCP	3	D-Cracking	Light Severity
CRCP	4	Alkali-Silica Reactivity (ASR)	Present
CRCP	5	Punchouts	≤ 5 per mile

Note: CRCP = continuously reinforced concrete pavement.

Table 4-A-5 Scoping Methodology Decision Order—Existing Composite Pavements.

Existing Pavement Type	Scoping Order	Distress	
		Type	Criteria
JPCP Composite	1	General Pavement Condition	Poor: Indicating Damaged PCC with Severe D Cracking ASR etc
JPCP Composite	2	General Pavement Condition	Fair: Largely Reflection Cracking
CRCP Composite	1	General Pavement Condition	Poor: as indicated by > 5 punchouts per mile or other distress
CRCP Composite	2	General Pavement Condition	Fair: as indicated ≤ 5 punchouts per mile
JRCP Composite	1	General Pavement Condition	Poor: Indicating Damaged PCC with Severe D Cracking ASR etc
JRCP Composite	2	General Pavement Condition	Fair: Largely Reflection Cracking

Note: ASR = alkali-silica reactivity.

Table 4-A-6 Scoping Process for Existing HMA Pavement and Environmental Cracking.

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
HMA	Transverse or Block Cracking	Present	Flexible	30 – 50	5, 10 or 20	1A	Pulverize Existing + Thick HMA
						1B	Pulverize Existing + Treat with Cement, Emulsion or Foamed Asphalt + Thick HMA
						1C	Remove and Replace Existing with HMA
			Rigid	30 – 50	5, 10, or 20	4A	Unbonded PCC OL**
						4B	Remove and Replace with PCCP
			Precast	30 - 39	5, 10, or 20	8A	Unbonded Precast PCC OL**
						8B	Unbonded Prestressed Precast PCC OL**
						8C	Remove and Replace with Precast PCCP
						8D	Remove and Replace with Prestressed Precast PCCP
			Composite	30 – 50	5, 10, or 20	10A	Unbonded HMA/PCC Composite OL**
						10B	Unbonded PCC/PCC Composite OL**
						12A	Remove and Replace with HMA/PCC Composite
						12B	Remove and Replace with PCC/PCC Composite
	See Table 4-A-1 for decision order						

Note: OL = overlay.

**When Height Restrictions are present, may remove HMA layers to help meet elevation limits.

Table 4-A-7 Scoping Process for Existing HMA Pavement and Full Depth Fatigue Cracking.

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
HMA	Full Depth Fatigue Cracking in Wheelpath	< 10%	Flexible	30 – 50	5, 10, or 20	1D	Full Depth Patch + HMA OL***
			Rigid	30 – 50	5, 10, or 20	4A	Unbonded PCC OL**
			Precast	30 – 39	5, 10 or 20	8A	Unbonded Precast PCC OL**
						8B	Unbonded Prestressed Precast PCC OL**
			Composite	30 – 50	5, 10 or 20	10A	Unbonded HMA/PCC Composite OL
						10B	Unbonded PCC/PCC Composite OL
		≥ 10%	Flexible	30 – 50	5, 10, or 20	1A	Pulverize Existing + Thick HMA
						1B	Pulverize Existing + Treat with Cement Emulsion or Foamed Asphalt + Thick HMA
						1C	Remove and Replace Existing with HMA
			Rigid	30 – 50	5, 10 or 20	4A	Unbonded PCC OL **
						4B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10 or 20	8A	Unbonded Precast PCC OL**
						8B	Unbonded Prestressed Precast PCC OL**
						8C	Remove and Replace with Precast PCCP
						8D	Remove and Replace with Prestressed Precast PCCP
			Composite	30 – 50	5, 10 or 20	10A	Unbonded HMA/PCC Composite OL**
						10B	Unbonded PCC/PCC Composite OL**
						12A	Remove and Replace with HMA/PCC Composite
						12B	Remove and Replace with PCC/PCC Composite
	See Table 4-A-1 for decision order						

**When Height Restrictions are present, may remove HMA layers to help meet elevation limits.

***Treat as remove and replace but subtract remaining HMA from the total HMA OL thickness.

Table 4-A-8 Scoping Process for Existing HMA Pavement and Materials-Related Distress

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
HMA	Stripping	Full Depth	Flexible	30 – 50	5, 10, or 20	1A	Pulverize Existing + Thick HMA
						1B	Pulverize Existing + Treat with Cement. Emulsion or Foamed Asphalt + Thick HMA
						1C	Remove and Replace Existing with HMA
			Rigid	30 – 50	5, 10, or 20	4A	Unbonded PCC OL***
						4B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, or 20	8A	Unbonded Precast PCC OL***
						8B	Unbonded Prestressed Precast PCC OL***
						8C	Remove and Replace with Precast PCCP
						8D	Remove and Replace with Prestressed Precast PCCP
			Composite	30 – 50	5, 10, or 20	10A	Unbonded HMA/PCC Composite OL***
						10B	Unbonded PCC/PCC Composite OL***
						12A	Remove and Replace with HMA/PCC Composite
						12B	Remove and Replace with PCC/PCC Composite
		Partial Depth	Flexible			1C	Remove Stripped Layers + Thick HMA OL**
			Rigid	30 – 50	5, 10, or 20	4A	Unbonded PCC OL ***
						4B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, or 20	8A	Unbonded Precast PCC OL***
						8B	Unbonded Prestressed Precast PCC OL***
						8C	Remove and Replace with Precast PCCP
						8D	Remove and Replace with Prestressed Precast PCCP
			Composite	30 – 50	5, 10, or 20	10A	Unbonded HMA/PCC Composite OL***
						10B	Unbonded PCC/PCC Composite OL***
						12A	Remove and Replace with HMA/PCC Composite
						12B	Remove and Replace with PCC/PCC Composite
	See Table 4-A-1 for decision order						

** Treat as remove and replace but subtract remaining HMA layers from total HMA OL thickness.

***When Height Restrictions are present, may remove stripped HMA layers to help meet elevation limits.

Table 4-A-9 Scoping Process for Existing HMA Pavement and Top-Down Cracking.

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
HMA	Top Down Longitudinal and Alligator Cracking in Wheelpath	< 10%	Flexible	30 – 50	5, 10, or 20	1D	Patch Cracked Area + HMA OL**
			Rigid	30 – 50	5, 10, or 20	4A	Unbonded PCC OL***
			Precast	30 – 39	5, 10, or 20	8A	Unbonded Precast PCC OL***
						8B	Unbonded Prestressed Precast PCC OL***
			Composite	30 – 50	5, 10, or 20	10A	Unbonded HMA/PCC Composite OL
						10B	Unbonded PCC/PCC Composite OL
		≥ 10%	Flexible	30 – 50	5, 10, or 20	1C	Remove Cracked Layer + HMA OL**
			Rigid	30 – 50	5, 10 or 20	4A	Unbonded PCC OL ***
			Precast	30 – 39	5, 10, or 20	8A	Unbonded Precast PCC OL***
						8B	Unbonded Prestressed Precast PCC OL***
			Composite	30 – 50	5, 10, or 20	10A	Unbonded HMA/PCC Composite OL***
						10B	Unbonded PCC/PCC Composite OL***

** Treat as remove and replace but assume 2-inch removal of cracked wearing surface and subtract remaining HMA layers from replacement thickness for HMA OL thickness.

***When Height Restrictions are present may remove HMA thickness to help meet elevation limits.

Table 4-A-10 Scoping Process for Existing JPCP and D-Cracking

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JPCP	D-Cracking	Light Severity	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	3A	Crack and Seat JPCP + HMA OL
						2B	Check Subgrade Guidelines for Rubblizing JPCP + HMA OL
					> 10	3A	Crack and Seat JPCP + HMA OL
						2C	Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, or 20-	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, or 20	9A	Unbonded Precast PCC OL
						9B	Unbonded Prestressed Precast PCC OL
						9C	Remove and Replace with Precast PCCP
						9D	Remove and Replace with Prestressed Precast PCCP
			Composite	30 – 50	5, 10, or 20	11A	Unbonded HMA/PCC Composite OL
						11B	Unbonded PCC/PCC Composite OL
						12A	Remove and Replace with HMA/PCC Composite
						12B	Remove and Replace with PCC/PCC Composite
		Moderate to High Severity	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing JPCP + HMA OL
						2A	Subgrade Guidelines Not Met: Remove and Replace JPCP with HMA
					> 10	2C	Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, or 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, or 20	****	****
			Composite	30 – 50	5, 10, or 20	****	****
		See Table 4-A-2 for decision order					

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking.

Table 4-A-11 Scoping Process for Existing JPCP and Alkali-Silica Reactivity.

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JPCP	Alkali-Silica Reactivity (ASR)	Present	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing JPCP + HMA OL
						3A	Crack and Seat JPCP + HMA OL
					> 10	2C	Rubblize JPCP + HMA OL
						3A	Crack and Seat JPCP + HMA OL
			Rigid	30 – 50	5, 10, or 20	7A	Repair JPCP, Then Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, or 20	9A	Unbonded Precast PCC OL
						9B	Unbonded Prestressed Precast PCC OL
						9C	Remove and Replace with Precast PCCP
						9D	Remove and Replace with Prestressed Precast PCCP
			Composite	30 – 50	5, 10, or 20	11A	Unbonded HMA/PCC Composite OL
						11B	Unbonded PCC/PCC Composite OL
						12A	Remove and Replace with HMA/PCC Composite
						12B	Remove and Replace with PCC/PCC Composite
	See Table 4-A-2 for decision order						

Table 4-A-12 Scoping Process for Existing JPCP and Slab Cracking.

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JPCP	% Cracked Panels	Low to Moderate < 10%	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	3A	Crack and Seat JPCP + HMA OL
						2B	Check Subgrade Guidelines for Rubblizing JPCP + HMA OL
					> 10	3A	Crack and Seat JPCP + HMA OL
						2C	Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, or 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, or 20	****	****
			Composite	30 – 50	5, 10, or 20	****	****
		Moderate to Severe ≥ 10%	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	3A	Crack and Seat JPCP + HMA OL
						2B	Check Subgrade Guidelines for Rubblizing JPCP + HMA OL
					> 10	3A	Crack and Seat JPCP + HMA OL
						2C	Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, or 20	7A	Replace Shattered Slabs + Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, or 20	****	****
			Composite	30 – 50	5, 10, or 20	****	****
	See Table 4-A-2 for decision order						

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown Table 4-A-10.

Table 4-A-13 Scoping Process for Existing JPCP and Joint Faulting

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JPCP	Joint Faulting	<0.25 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	3A	Crack and Seat JPCP + HMA OL
						2B	Check Subgrade Guidelines for Rubblizing JPCP + HMA OL
					> 10	3A	Crack and Seat JPCP + HMA OL
						2C	Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, or 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, or 20	****	****
			Composite	30 – 50	5, 10, or 20	****	****
		≥0.25 in. + D <0.04 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	3A	Crack and Seat JPCP + HMA OL
						2B	Check Subgrade Guidelines for Rubblizing JPCP + HMA OL
					> 10	3A	Crack and Seat JPCP + HMA OL
						2C	Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
		≥0.25 in. + D ≥ 0.04 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	3A	Crack and Seat JPCP + HMA OL
						2B	Check Subgrade Guidelines for Rubblizing JPCP + HMA OL
					> 10	3A	Crack and Seat JPCP + HMA OL
						2C	Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Consider Crack and Seat JPCP + UBOL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
	See Table 4-A-2 for decision order and repeat ****sequence for **precast** and **composite pavements** as shown in Table 4-A-10.						

Note: UBOL = unbonded overlay

Table 4-A-14 Scoping Process for Existing JPCP and Pumping

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JPCP	Pumping	Present + D < 0.04 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	3A	Improve Drainage + Crack and Seat JPCP + HMA OL
					> 10	3A	Improve Drainage + Crack and Seat JPCP + HMA OL
						2C	Improve Drainage + Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Improve Drainage + Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
		Present + D ≥ 0.04 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JPCP with HMA
					6 – 10	3A	Crack and Seat JPCP + HMA OL
					> 10	3A	Improve Drainage + Crack and Seat JPCP + HMA OL
						2C	Improve Drainage + Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Improve Drainage and consider Crack and Seat JPCP + Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-15 Scoping Process for Existing JRCP and D-Cracking

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JRCP	D-Cracking	Light Severity	Flexible	30 – 50	< 6	2A	Remove and Replace JRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
					> 10	2C	Rubblize JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
		Moderate to High Severity	Flexible	30 – 50	< 6	2A	Remove and Replace JRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing JRCP + HMA OL
						2A	Subgrade Guidelines Not Met: Remove and Replace JRCP with HMA
					> 10	2C	Rubblize JRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
	See Table 4-A-3 for decision order						

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-16 Scoping Process for Existing JRCP and Alkali-Silica Reactivity

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JRCP	Alkali-Silica Reactivity (ASR)	Present	Flexible	30 – 50	< 6	2A	Remove and Replace JRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
					> 10	2C	Rubblize JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Repair JRCP, Then Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
	See Table 4-A-3 for decision order						

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-17 Scoping Process for Existing JRCP and Slab Cracking

<table>
<tr><th rowspan="2">Existing Pavement Type</th><th colspan="2">Distress Identification</th><th rowspan="2">Pavement Renewal Type</th><th colspan="2">Design Criteria</th><th colspan="2">Action</th></tr>
<tr><th>Type</th><th>Criteria</th><th>Period (years)</th><th>Subgrade M_R (1,000 psi)</th><th>Rule</th><th>Notes</th></tr>
<tr><td rowspan="23">JRCP</td><td rowspan="22">Cracked Panels</td><td rowspan="11">Low to Moderate < 10%</td><td rowspan="5">Flexible</td><td rowspan="5">30 – 50</td><td>< 6</td><td>2A</td><td>Remove and Replace JRCP with HMA</td></tr>
<tr><td rowspan="2">6 – 10</td><td>2B</td><td>Check Subgrade Guidelines for Rubblizing JRCP + HMA OL</td></tr>
<tr><td>3B</td><td>Saw, Crack, and Seat JRCP + HMA OL</td></tr>
<tr><td rowspan="2">> 10</td><td>2C</td><td>Rubblize JRCP + HMA OL</td></tr>
<tr><td>3B</td><td>Saw, Crack and Seat JRCP + HMA OL</td></tr>
<tr><td rowspan="2">Rigid</td><td rowspan="2">30 – 50</td><td rowspan="2">5, 10, 20</td><td>7A</td><td>Unbonded PCC OL</td></tr>
<tr><td>7B</td><td>Remove and Replace with PCCP</td></tr>
<tr><td>Precast</td><td>30 – 39</td><td>5, 10, 20</td><td>****</td><td>****</td></tr>
<tr><td>Composite</td><td>30 – 50</td><td>5, 10, 20</td><td>****</td><td>****</td></tr>
<tr><td rowspan="11">Moderate to Severe ≥ 10%</td><td rowspan="5">Flexible</td><td rowspan="5">30 – 50</td><td>< 6</td><td>2A</td><td>Remove and Replace JRCP with HMA</td></tr>
<tr><td rowspan="2">6 – 10</td><td>2B</td><td>Check Subgrade Guidelines for Rubblizing JRCP + HMA OL</td></tr>
<tr><td>3B</td><td>Saw, Crack, and Seat JRCP + HMA OL</td></tr>
<tr><td rowspan="2">> 10</td><td>2C</td><td>Rubblize JRCP + HMA OL</td></tr>
<tr><td>3B</td><td>Saw, Crack, and Seat JRCP + HMA OL</td></tr>
<tr><td rowspan="2">Rigid</td><td rowspan="2">30 – 50</td><td rowspan="2">5, 10, 20</td><td>7A</td><td>Replace Shattered Slabs + Unbonded PCC OL</td></tr>
<tr><td>7B</td><td>Remove and Replace with PCCP</td></tr>
<tr><td>Precast</td><td>30 – 394</td><td>5, 10, 20</td><td>****</td><td>****</td></tr>
<tr><td>Composite</td><td>30 – 50</td><td>5, 10, 20</td><td>****</td><td>****</td></tr>
<tr><td colspan="7">See Table 4-A-3 for decision order</td></tr>
</table>

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-18 Scoping Process for Existing JRCP and Joint Faulting

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JRCP	Joint Faulting	<0.25 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
					> 10	2C	Rubblize JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
		≥0.25 in. + D <0.04 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
					> 10	2C	Rubblize JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
		≥0.25 in. + D ≥ 0.04 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
					> 10	2C	Rubblize JRCP + HMA OL
						3B	Saw, Crack, and Seat JRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Consider Saw, Crack, and Seat JRCP + UBOL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
	See Table 4-A-3 for decision order and repeat ****sequence for **precast** and **composite pavements** as shown in Table 4-A-10.						

Table 4-A-19 Scoping Process for Existing JRCP and Pumping

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
JRCP	Pumping	Present + D < 0.04 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JRCP with HMA
					6 – 10	3B	Saw, Crack and Seat JRCP + HMA OL
					> 10	3B	Improve Drainage + Saw, Crack and Seat JRCP + HMA OL
						2C	Improve Drainage + Rubblize JRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Unbonded PCC OL + Improve Drainage
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	9A	Unbonded **Precast** PCC OL + Improve Drainage
						9B	Unbonded **Prestressed Precast** PCC OL + Improve Drainage
						9C	Remove and Replace with **Precast** PCCP
						9D	Remove and Replace with **Prestressed Precast** PCCP
			Composite	30 – 50	5, 10, 20	11A	Unbonded HMA/PCC Composite OL + Improve Drainage
						11B	Unbonded PCC/PCC Composite OL + Improve Drainage
						12A	Remove and Replace with HMA/PCC Composite
						12B	Remove and Replace with PCC/PCC Composite
		Present + D ≥ 0.04 in.	Flexible	30 – 50	< 6	2A	Remove and Replace JRCP with HMA
					6 – 10	3B	Saw, Crack, and Seat JRCP + HMA OL
					> 10	3B	Improve Drainage + Saw, Crack and Seat JRCP + HMA OL
						2C	Improve Drainage + Rubblize JRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Improve Drainage and Consider Saw, Crack, and Seat or Rubblization JRCP + UBOL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	9A	Unbonded **Precast** PCC OL + Improve Drainage and consider Saw, Crack, and Seat or Rubblization of JRCP
						9B	Unbonded **Prestressed Precast** PCC OL + Improve Drainage and consider Saw, Crack, and Seat or Rubblization of JRCP
						9C	Remove and Replace with **Precast** PCCP
						9D	Remove and Replace with **Prestressed Precast** PCCP
			Composite	30 – 50	5, 10, 20	11A	Unbonded HMA/PCC Composite OL + Improve Drainage and consider Saw, Crack, and Seat or Rubblization of JRCP
						11B	Unbonded PCC/PCC Composite OL + Improve Drainage and consider Saw, Crack, and Seat or Rubblization of JRCP
						12A	Remove and Replace with HMA/PCC Composite
						12B	Remove and Replace with PCC/PCC Composite

Table 4-A-20 Scoping Process for Existing CRCP and Punchouts

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
CRCP	Punchouts	≤ 5 per Mile	Flexible	30 – 50	5, 10 or 20	5	Repair Punchouts + HMA OL
			Rigid	30 – 50	5, 10 or 20	7A	Repair Punchouts + Unbonded PCC OL
						7B	Remove and Replace with PCCP
				30 – 39	5, 10 or 20	6	Repair All Punchouts + Bonded PCC OL
			Precast	30 – 39	5, 10 or 20	****	****
			Composite	30 – 50	5, 10 or 20	****	****
		> 5 per Mile	Flexible	30 – 50	< 6	2A	Remove and Replace CRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing CRCP + HMA OL
						2A	Subgrade Guidelines Not Met: Remove and Replace CRCP with HMA
					> 10	2C	Rubblize CRCP + HMA OL
			Rigid	30 – 50	5, 10 or 20	7A	Replace Shattered Slabs + Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10 or 20	****	****
			Composite	30 – 50	5, 10 or 20	****	****

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-21 Scoping Process for Existing CRCP and D-Cracking

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
CRCP	D-Cracking	Light Severity	Flexible	30 – 50	< 6	2A	Remove and Replace CRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing CRCP + HMA OL
					> 10	2C	Rubblize CRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
		Moderate to High Severity	Flexible	30 – 50	< 6	2A	Remove and Replace CRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing CRCP + HMA OL
						2A	Subgrade Guidelines Not Met: Remove and Replace CRCP with HMA
					> 10	2C	Rubblize CRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
	See Table 4-A-4 for decision order						

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-22 Scoping Process for Existing CRCP and Alkali-Silica Reactivity

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
CRCP	Alkali-Silica Reactivity (ASR)	Present	Flexible	30 – 50	< 6	2A	Remove and Replace CRCP with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblizing CRCP + HMA OL
					> 10	2C	Rubblize CRCP + HMA OL
			Rigid	30 – 50	5, 10, 20	7A	Repair CRCP, Then Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10, 20	****	****
			Composite	30 – 50	5, 10, 20	****	****
	See Table 4-A-4 for decision order						

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-23 Scoping Process for Existing HMA/JPCP Composite Pavement and General Pavement Condition

Existing Pavement Type	Distress Identification		Pavement Renewal Type	Design Criteria		Action	
	Type	Criteria		Period (years)	Subgrade M_R (1,000 psi)	Rule	Notes
HMA/JPCP Composite Pavement	General Pavement Condition	Fair Largely Reflection Cracking	Flexible	30 – 50	<6	2A	Remove and Replace Composite with HMA
					6-10	3A	Remove HMA + Crack and Seat JPCP + HMA OL
						2B	Check Subgrade Guidelines for Rubblization if satisfied: Remove HMA + Rubblize JPCP + HMA OL
					>10	3A	Remove HMA + Crack and Seat JPCP + HMA OL
						2C	Remove HMA + Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10 or 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10 or 20	****	****
			Composite	30 – 50	5, 10 or 20	****	****
		Poor Indicating Damaged PCC with Severe D Cracking ASR etc	Flexible	30 – 50	< 6	2A	Remove and Replace Composite with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblization, If satisfied: Remove HMA + Rubblize JPCP + HMA OL
						2A	If Guidelines Not Met: Remove and Replace with HMA
					> 10	2C	Remove HMA + Rubblize JPCP + HMA OL
			Rigid	30 – 50	5, 10 or 20	7A	Replace Shattered Slabs + Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10 or 20	****	****
			Composite	30 – 50	5, 10 or 20	****	****

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-24 Scoping Process for Existing HMA/JRCP Composite Pavement and General Pavement Condition

Existing Pavement Type	Distress Identification: Type	Distress Identification: Criteria	Pavement Renewal Type	Design Criteria: Period (years)	Design Criteria: Subgrade M_R (1,000 psi)	Action: Rule	Action: Notes
HMA/JRCP Composite Pavement	General Pavement Condition	Fair Largely Reflection Cracking	Flexible	30 – 50	<6	2A	Remove and Replace Composite with HMA
					6-10	2B	Check Subgrade Guidelines for Rubblization if satisfied: Remove HMA + Rubblize JRCP + HMA OL
						3B	Remove HMA + Saw, Crack, and Seat JRCP + HMA OL
					>10	2C	Remove HMA + Rubblize JRCP + HMA OL
						3B	Remove HMA + Saw, Crack, and Seat JRCP + HMA OL
			Rigid	30 – 50	5, 10 or 20	7A	Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10 or 20	****	****
			Composite	30 – 50	5, 10 or 20	****	****
		Poor Indicating Damaged PCC with Severe D Cracking ASR etc	Flexible	30 – 50	< 6	2A	Remove and Replace Composite with HMA
					6 – 10	2B	Check Subgrade Guidelines for Rubblization, If satisfied: Remove HMA + Rubblize JRCP + HMA OL
						2A	If Guidelines Not Met, Remove and Replace with HMA
					> 10	2C	Remove HMA + Rubblize JRCP + HMA OL
			Rigid	30 – 50	5, 10 or 20	7A	Replace Shattered Slabs + Unbonded PCC OL
						7B	Remove and Replace with PCCP
			Precast	30 – 39	5, 10 or 20	****	****
			Composite	30 – 50	5, 10 or 20	****	****

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 4-A-10.

Table 4-A-25 Scoping Process for Existing HMA/CRCP Composite Pavement and General Pavement Condition

<table>
<tr><th rowspan="2">Existing Pavement Type</th><th colspan="2">Distress Identification</th><th rowspan="2">Pavement Renewal Type</th><th colspan="2">Design Criteria</th><th colspan="2">Action</th></tr>
<tr><th>Type</th><th>Criteria</th><th>Period (years)</th><th>Subgrade M_R (1,000 psi)</th><th>Rule</th><th>Notes</th></tr>
<tr><td rowspan="15">HMA/CRCP Composite Pavement</td><td rowspan="15">General Pavement Condition</td><td rowspan="6">Fair Some reflection cracking</td><td>Flexible</td><td>30 – 50</td><td>5, 10 or 20</td><td>5</td><td>Repair Punchouts + HMA OL</td></tr>
<tr><td rowspan="3">Rigid</td><td rowspan="2">30 – 50</td><td rowspan="2">5, 10 or 20</td><td>7A</td><td>Repair Punchouts + Unbonded PCC OL</td></tr>
<tr><td>7B</td><td>Remove and Replace with PCCP</td></tr>
<tr><td>30 – 39</td><td>5, 10 or 20</td><td>6</td><td>Repair all Punchouts + Bonded PCC OL</td></tr>
<tr><td>Precast</td><td>30 – 39</td><td>5, 10 or 20</td><td>****</td><td>****</td></tr>
<tr><td>Composite</td><td>30 – 50</td><td>5, 10 or 20</td><td>****</td><td>****</td></tr>
<tr><td rowspan="9">Poor Indicating Damaged PCC with Severe D Cracking ASR etc</td><td rowspan="4">Flexible</td><td rowspan="4">30 – 50</td><td>< 6</td><td>2A</td><td>Remove and Replace Composite with HMA</td></tr>
<tr><td rowspan="2">6 – 10</td><td>2B</td><td>Check Subgrade Guidelines for Rubblization, If satisfied: Remove HMA + Rubblize CRCP + HMA OL</td></tr>
<tr><td>2A</td><td>If Guidelines Not Met: Remove and Replace CRCP with HMA</td></tr>
<tr><td>> 10</td><td>2C</td><td>Remove HMA + Rubblize CRCP + HMA OL</td></tr>
<tr><td rowspan="2">Rigid</td><td rowspan="2">30 – 50</td><td rowspan="2">5, 10 or 20</td><td>7A</td><td>Replace Shattered Slabs + Unbonded PCC OL</td></tr>
<tr><td>7B</td><td>Remove and Replace with PCCP</td></tr>
<tr><td>Precast</td><td>30 – 39</td><td>5, 10 or 20</td><td>****</td><td>****</td></tr>
<tr><td>Composite</td><td>30 – 50</td><td>5, 10 or 20</td><td>****</td><td>****</td></tr>
</table>

**** Repeat sequence as listed for **precast** and **composite pavements** with light severity D-cracking as shown in Table 10.

Decision Rules

1. Rule 1: Hot-mix asphalt (HMA) overlay over existing flexible pavement <u>or</u> remove and replace with HMA

This rule has four subgroups that define the action as well as the design table and the base value to be used in that table.

- **Rule 1A: HMA overlay over existing, pulverized full-depth flexible pavement—pulverized material used as untreated base**. Use Table 4-A-26 and 50 ksi base.
  Action: HMA overlay over pulverized existing flexible pavement
  Description: Pulverize existing flexible pavement to eliminate all cracking or materials related damage and overlay with HMA.
- **Rule 1B: HMA overlay over existing, pulverized full-depth flexible pavement—pulverized material used as treated base with cement, emulsion, or foamed asphalt binder**. Use Table 4-A-26 and 100 ksi base.
  Action: HMA overlay over pulverized existing flexible pavement.
  Description: Pulverize existing flexible pavement to eliminate all cracking or materials related damage and treat pulverized material to produce treated base and overlay with HMA.
- **Rule 1C**: **Remove and replace with HMA over untreated base**. Use Table 4-A-26 and 30 ksi base.
  Action: HMA overlay after removing and replacing existing HMA where needed.
  Description: Remove and replace existing HMA because of fatigue cracking, top down cracking, thermal cracking, 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.
- **Rule 1D**: **Patch and overlay with HMA**. Use Table 4-A-26 and 30 ksi base to determine new HMA depth but subtract existing HMA depth from new HMA depth to determine overlay depth.
  Action: HMA overlay after patching existing HMA where needed.
  Description: Patch existing HMA where fatigue cracking or top down cracking is < 10%, then overlay with HMA.

2. Rule 2: HMA overlay over existing, rubblized portland cement concrete (PCC) pavement <u>or</u> remove and replace with HMA

This rule has three subgroups based on suitability of the subgrade soil to support *rubblization* of the existing PCC pavement.

- **Rule 2A: Remove and replace with HMA. If subgrade resilient modulus M_R is < 6,000 psi** or California bearing ratio (CBR) is < 4%, do not rubblize or crack and seat. Do remove and replace the existing jointed plain concrete pavement (JPCP) or jointed reinforced cement concrete (JRCP) with HMA over flexible base. Use Table 4-A-26 with 5 ksi subgrade and 30 ksi base.

Action: Remove and Replace existing PCC pavement.

Description: Remove and replace existing PCC pavement because the subgrade is too weak to consider cracking and seating or rubblize the existing PCC pavement.

- **Rule 2B: Rubblize + HMA overlay**. **If subgrade M_R is ≥ 6,000 psi but < 10,000 psi**, consult the Texas A&M Transportation Institute (TTI) rubblization guidelines as to whether rubblization is viable. If viable, use Table 4-A-26 with 10 ksi subgrade and 50 ksi base.

  Action: Rubblize existing PCC pavement and overlay with HMA.

  Description: 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. See the description of the *TTI guidelines* in the Project Assessment Manual.
- **Rule 2C: Rubblize + HMA overlay. If subgrade M_R is ≥ 10,000 psi**, then rubblization is a viable option. Apply Table 4-A-26 with 20 ksi subgrade and 50 ksi base.

  Action: Rubblize existing PCC pavement and overlay with HMA.

  Description: Rubblize the existing rigid pavement to minimize or eliminate reflection cracking then place thick HMA overlay. Refer to section on rubblization in the Rigid Pavement Practices for rubblization details.

Note

Rubblization guidelines include the following:

a. If the subgrade M_R is < 6,000 psi or the CBR is < 4%, do not rubblize. Perform remove and replace with HMA.
b. If the subgrade M_R is ≥ 6,000 psi but < 10,000 psi, consult the TTI rubblization guidelines as to whether rubblization is viable.
c. If the subgrade M_R is ≥ 10,000 psi, then rubblization is a viable option.
d. The selection of the HMA thickness is based on a drop-down menu of subgrade moduli of 5,000 psi, 10,000 psi, or 20,000 psi. The existing pavement should be characterized by one of four possible moduli: 30,000 psi, 50,000 psi, 75,000 psi, or 100,000 psi. It is recommended that an existing pavement modulus of 50,000 psi be used to reflect rubblized PCC.

3. Rule 3: HMA overlay over crack and seat of existing JPCP or saw, crack, and seat of existing JRCP

This rule has two subgroups, one for cracking and seating JPCP and a second that requires cutting the steel in JRCP before cracking and seating to minimize reflection cracking

- **Rule 3A: HMA overlay after cracking and seating the existing JPCP.** Use Table4-A-26 with 75 ksi base.

  Action: Crack and Seat existing rigid pavement and overlay with thick HMA

  Description: Crack and Seat existing rigid pavement to minimize reflection cracking. Refer to section on cracking and seating in the Rigid Pavement Practices for details.
- **Rule 3B: HMA overlay after saw crack and seating the existing JRCP**. Use Table 4-A-26 with a 75 ksi base.

  Action: Saw, crack and seat existing JRCP and overlay with thick HMA

Description: Saw, crack and seat existing JPCP to cut reinforcing steel and minimize reflection cracking. Refer to section on saw, crack and seating in the Rigid Pavement Practices for details.

The thicknesses for the HMA overlay is shown in Table 4-A-26. The selection of the HMA thickness is based on a drop-down menu of subgrade moduli of 5,000 psi, 10,000 psi, or 20,000 psi. The existing pavement shall be characterized by one of four possible moduli: 30,000 psi, 50,000 psi, 75,000 psi, or 100,000 psi. It is recommended that an existing pavement modulus of 75,000 psi be used to reflect crack and seated PCC.

4. Rule 4: Unbonded PCC overlay over existing HMA pavement <u>or</u> remove and replace

This rule has two subgroups, one for placing an unbonded PCC overlay over existing HMA, and the other for replacing an existing pavement with PCCP placed on a flexible base.

- **Rule 4A: Unbonded PCC overlay w**here base type is shown as flexible and thickness comes from existing pavement description rounded to the closest thickness in Table 4-A-27.
  Action: Place unbonded PCC overlay over existing HMA.
  Description: 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.
- **Rule 4B: Remove and Replace with PCCP** where base type is shown as flexible and thickness comes from Table 4-A-27 with minimum 4-inch HMA base.
  Action: Replace existing pavement.
  Description: Replace existing pavement with JPCP or continuously reinforced concrete pavement (CRCP) over a 4-inch HMA base.

5. Rule 5: HMA overlay over existing CRCP

Thickness determination of an HMA overlay where base type is shown as CRCP, use Table 4-A-28 shown below.
Action: HMA overlay of existing CRCP.
Description: HMA overlay over existing CRCP that has experienced no more than 5 punchouts per mile that have been repaired before placing overlay. Note sufficient surfacing is also provided for periodic replacement of the wearing surface

6. Rule 6: Bonded CRCP overlay over existing CRCP

This rule applies to **bonded PCC overlays over CRCP.** Presumably, this type of PCC overlay would be CRCP (welded wire fabric for bonded concrete overlay (BCO) thicknesses less than 8 in.; regular rebar for ≥ 8 in.). A statement is included in the interactive software on surface texture of the existing pavement prior to overlay will be required (such as cold milling, shot blasting, etc). Apply Table 4-A-29 below with the base type shown as CRCP and the thicknesses rounded to the closest thickness shown on the table.
Action: Bonded CRCP overlay over existing CRCP
Description: Place a bonded CRCP overlay over existing CRCP which has experienced no more than 5 punchouts per mile which have been repaired prior to placing overlay. Refer to the section on bonded overlays in the Rigid Pavement Practices for details.

7. **Rule 7: Unbonded PCC overlay over existing PCC pavement, composite pavement or remove and replace**
    - **Rule 7A: Unbonded PCC overlay.** Thickness determination of an **unbonded PCC overlay** where base type is shown as rigid and PCC overlay thickness from Table 30. This rule applies to existing composite (HMA/PCC) as well.
      Action: Place unbonded PCC overlay over existing rigid or composite pavement.
      Description: Place an unbonded PCC overlay over the existing PCC or composite pavement. A 2-inch HMA layer is recommended as a bond breaker between the existing PCC and the PCC overlay. For a composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to the section on unbonded overlays in the Rigid Pavement Practices for details.
    - **Rule 7B: Remove and replace with PCC** where base type is shown as rigid and thickness comes from Table 4-A-27 with 4-inch HMA base.
      Action: Replace existing PCCP pavement.
      Description: Replace existing pavement with JPCP or CRCP over a 4 inch HMA base.

8. **Rule 8: Unbonded precast overlay over existing HMA pavement <u>or</u> remove and replace**
   This rule has four subgroups, one using a precast pavement with a standard design and the other using a precast pavement with a prestressed design.
    - **Rule 8A: Unbonded precast overlay** where the base type is shown as flexible and thickness comes from Table 4-A-27.
      Action: Place unbonded Precast Pavement overlay over existing HMA
      Description: Place unbonded Precast Pavement 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. Refer to Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.for more information.
    - **Rule 8B: Unbonded prestressed precast overlay** where the base type is shown as flexible and thickness comes from Table 4-A-31 for prestressed pavement design.
      Action: Place unbonded Prestressed Precast Pavement overlay over existing HMA.
      Description: Place unbonded Prestressed Precast Pavement 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. Refer to Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.for more information.
    - **Rule 8C: Remove and replace with precast pavement** where base type is shown as flexible and thickness comes from Table 4-A-27 with minimum 4-inch HMA base.
      Action: Replace existing pavement with precast pavement.
      Description: Replace existing pavement with precast over a 4-inch HMA base. Refer to Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.for more information.
    - **Rule 8D: Remove and replace with prestressed precast pavement** where base type is shown as flexible and thickness comes from Table 4-A-31 with minimum 4 inch HMA base.
      Action: Replace existing pavement with prestressed precast pavement.
      Description: Replace existing pavement with prestressed precast over a 4-inch HMA base. Refer to Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.for more information.

9. Rule 9: Unbonded precast overlay over existing PCC pavement, composite pavement, or remove and replace

This rule has four subgroups, one using a precast pavement with a standard design and the other using a precast pavement with a prestressed design.

- **Rule 9A: Unbonded precast overlay** where the base type is shown as rigid with 2-inch HMA bond breaker and thickness comes from Table 30. This rule applies to existing composite (HMA/PCC) as well.
  Action: Place unbonded Precast Pavement overlay over existing PCC or composite pavement.
  Description: Place unbonded Precast Pavement overlay on existing PCC or composite pavement. A 2-inch HMA layer is recommended as a bond breaker between the existing PCC and the precast pavement overlay. For a composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to the section on unbonded overlays in the Rigid Pavement Practices for details. Refer to Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.for more information.
- **Rule 9B: Unbonded prestressed precast overlay** where the base type is shown as rigid with 2-inch HMA bond breaker and thickness comes from Table 4-A-32 for pre-stressed pavement design. This rule applies to existing composite (HMA/PCC) as well.
  Action: Place unbonded Prestressed Precast Pavement overlay over existing PCC or composite pavement.
  Description: Place unbonded Prestressed Precast Pavement overlay on existing PCC pavement. A 2-inch HMA layer is recommended as a bond breaker between the existing PCC and the precast pavement overlay. For a composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to the section on unbonded overlays in the Rigid Pavement Practices for details. Refer to Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.for more information.
- **Rule 9C: Remove and replace with precast pavement** where original pavement type is shown as rigid and thickness comes from Table 4-A-27 with minimum 4-inch HMA base.
  Action: Replace existing pavement with precast pavement.
  Description: Replace existing pavement with precast over a 4-inch HMA base. Refer to Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.for more information.
- **Rule 9D: Remove and replace with prestressed precast pavement** where the original pavement type is shown as rigid and thickness comes from Table 4-A-31 with minimum 4-inch HMA base.
  Action: Replace existing pavement with prestressed precast pavement.
  Description: Replace existing pavement with prestressed precast over a 4-inch HMA base. Refer to Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.for more information.

10. Rule 10: Unbonded composite overlay over existing HMA pavement

This rule has two subgroups, one using a composite pavement with HMA/PCC design and the other using a composite pavement with PCC/PCC "wet on wet" design.

- **Rule 10A: Unbonded composite HMA/PCC overlay** where the base type is shown as flexible pavement and apply thicknesses from Table 4-A-33.

Action: Place unbonded composite HMA/PCC overlay over existing HMA.
Description: Place unbonded composite HMA/PCC overlay on existing HMA pavement. Refer to Report S2 R21-RR-2 "Composite Pavement Systems-- Volume 1 HMA/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-2.pdf

- **Rule10B: Unbonded composite PCC/PCC overlay** where the base type is shown as flexible pavement and apply thicknesses from Table 4-A-34 for PCC/PCC pavement design.
  Action: Place unbonded composite PCC/PCC overlay over existing HMA.
  Description: Place unbonded composite PCC/PCC overlay on existing HMA pavement. The two layers represent a composite pavement with a thin high-quality PCC surfacing over a thicker structural PCC layer. Refer to Report S2 R21-RR-3 "Composite Pavement Systems--Volume 2 PCC/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-3.pdf.

11. Rule 11: Unbonded composite overlay over existing PCC pavement or composite pavement

This rule has two subgroups, one using a composite pavement with a HMA/PCC design and the other using a composite pavement with a PCC/PCC "wet on wet" design.

- **Rule 11A: Unbonded composite HMA/PCC overlay** where the base type is shown as rigid with 2-inch HMA bond breaker and apply thicknesses from Table 4-A-35. This rule applies to existing composite (HMA/PCC) as well.
  Action: Place unbonded composite HMA/PCC overlay over existing PCC or composite pavement.
  Description: Place unbonded composite HMA/PCC overlay over existing PCC pavement. A 2-inch HMA layer is recommended as a bond breaker between the existing PCC and the composite pavement overlay. For an existing composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. Refer to the section on unbonded overlays in the Rigid Pavement Practices for details, as well as the SHRP 2 R21 Report S2 R21-RR-2 "Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-2.pdf.
- **Rule 11B: Unbonded composite PCC/PCC overlay** where the base type is shown as rigid with a 2-inch bond breaker and apply thicknesses from Table 4-A-36. This rule applies to existing composite (HMA/PCC) as well.
  Action: Place unbonded composite PCC/PCC overlay over existing PCC or composite pavement.
  Description: Place unbonded composite PCC/PCC overlay over existing PCC pavement. A 2-inch HMA layer is recommended as a bond breaker between the existing PCC and the composite pavement overlay. For an existing composite pavement, no bond breaker is required as the existing HMA will serve as the bond breaker. The two layers represent a composite pavement with a thin high-quality PCC surfacing over a thicker structural PCC layer. Refer to the section on unbonded overlays in the Rigid Pavement Practices and the SHRP 2 R21 Report for details S2 R21-RR-3 "Composite Pavement Systems--Volume 2 PCC/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-3.pdf.

12. Rule 12: Remove and replace existing pavement with composite pavement

This rule has two subgroups, one using a composite pavement with a HMA/PCC design and the other using a composite pavement with a PCC/PCC "wet on wet" design with a flexible base.

- **Rule 12A: Remove and Replace with composite HMA/PCC pavement** and apply thicknesses from Table 4-A-37 with a minimum of 4-inch HMA over a 6-inch thick granular base.

Action: Replace existing pavement with composite HMA/PCC pavement.
Description: Replace existing pavement with composite HMA/PCC pavement. Refer to S2 R21-RR-2 "Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-2.pdf for more information.

- **Rule 12B: Remove and Replace with composite PCC/PCC pavement** and apply thicknesses from Table 4-A-38 with a minimum of 4-inch HMA over a 6-inch thick granular base.
  Action: Replace existing pavement with composite PCC/PCC pavement.
  Description: Replace existing pavement with a composite PCC/PCC pavement. The two layers represent a composite pavement with a thin high-quality PCC surfacing over a thicker structural PCC layer. Refer to SHRP 2 R21 Report for details S2 R21-RR-3 "Composite Pavement Systems--Volume 2 PCC/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-3.pdf.

Table 4-A-26 HMA Thicknesses for Remove and Replace and Overlays.

HMA Overlay for Subgrade M_R = 5,000 psi.

ESALs (millions)	**Existing Pavement or Base Modulus**			
	30,000 psi	**50,000 psi**	**75,000 psi**	**100,000 psi**
≤10	10.0	9.0	8.0	6.0
10-25	11.0	10.0	8.5	6.5
25-50	12.0	11.0	9.0	7.0
50-100	13.0	11.5	9.5	7.5
100-200	14.0	12.0	10.0	7.5

HMA Overlay for Subgrade M_R = 10,000 psi.

ESALs (millions)	**Existing Pavement or Base Modulus**			
	30,000 psi	**50,000 psi**	**75,000 psi**	**100,000 psi**
≤10	10.0	8.0	7.0	6.0
10-25	11.0	9.0	8.0	6.5
25-50	12.0	9.5	8.5	7.0
50-100	12.0	10.0	8.5	7.0
100-200	13.0	11.0	9.0	7.0

HMA Overlay for Subgrade M_R = 20,000 psi.

ESALs (millions)	**Existing Pavement or Base Modulus**			
	30,000 psi	**50,000 psi**	**75,000 psi**	**100,000 psi**
≤10	9.5	7.5	6.5	5.5
10-25	10.0	8.5	7.0	6.0
25-50	11.0	9.0	7.5	6.5
50-100	11.5	9.5	8.0	6.5
100-200	12.0	10.0	8.5	7.0

Table 4-A-27 Unbonded PCC and Precast Pavement Thicknesses for Remove and Replace and Overlays over Existing HMA.

Unbonded JCP or PCP over Existing HMA: Subgrade M_R = 5,000 psi.

ESALs (millions)	Existing HMA Thickness							
	4 in.		6 in.		8 in.		10 in.	
	JCP	PCP	JCP	PCP	JCP	PCP	JCP	PCP
≤10	9	8.5	8.5	8.0	8.5	8.0	8.5	8.0
10-25	9.5	9.0	9.0	8.5	9.0	8.5	9.0	8.5
25-50	9.5	9.0	9.5	9.0	9.5	9.0	9.5	9.0
50-100	10.0	9.5	10.0	9.5	10.0	9.5	10.0	9.5
100-200	13.0	12.5	12.5	12.0	12.0	11.5	11.5	11.0

Unbonded JCP or PCP over Existing HMA: Subgrade M_R = 10,000 psi.

ESALs (millions)	Existing HMA Thickness							
	4 in.		6 in.		8 in.		10 in.	
	JCP	PCP	JCP	PCP	JCP	PCP	JCP	PCP
≤10	8.5	8.0	8.5	8.0	8.0	8.0	8 .0	8.0
10-25	9.0	8.5	9.0	8.5	9.0	8.5	9.0	8.5
25-50	9.5	9.0	9.5	9.0	9.5	9.0	9.5	9.0
50-100	10.5	10.0	10.0	9.5	10.0	9.5	10.0	9.5
100-200	12.0	11.5	12.0	11.5	11.5	11.0	11.5	11.0

Unbonded JCP or PCP over Existing HMA: Subgrade M_R = 20,000 psi.

ESALs (millions)	Existing HMA Thickness							
	4 in.		6 in.		8 in.		10 in.	
	JCP	PCP	JCP	PCP	JCP	PCP	JCP	PCP
≤10	8.5	8.0	8.0	8.0	8.0	8.0	7.5	7.5
10-25	9.0	8.5	9.0	8.5	8.5	8.0	8.5	8.0
25-50	10.0	9.5	9.5	9.0	9.5	9.0	9.5	9.0
50-100	10.5	10.0	10.0	9.5	10.0	9.5	10.0	9.5
100-200	11.5	11.0	11.5	11.0	11.5	11.0	11.0	10.5

Note: Unbonded precast PCC thicknesses after Table 8.3 "Precast Concrete Pavement Technology," Final Report, March 2012 at: http://www.trb.org/Main/Blurbs/167788.aspx A project specific design is required.

Table 4-A-28 HMA Overlay Thicknesses over Existing CRCP with Existing Pavement or Base Modulus = 100,000 psi.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	**10,000 psi**	**20,000 psi**
≤10	6.0	6.0	5.5
10-25	6.5	6.5	6.0
25-50	7.0	7.0	6.5
50-100	7.5	7.0	6.5
100-200	7.5	7.0	7.0

Table 4-A-29 Bonded CRCP Overlay Thicknesses over Existing CRCP.

Bonded CRCP Overlay over CRCP: Subgrade M_R = 5,000 psi.

ESALs (millions)	Existing PCC Thickness (CRCP)		
	8 in.	**10 in.**	**12 in.**
≤10	6.0	6.0	6.0
10-25	7.0	6.5	6.5
25-50	8.0	7.0	7.0
50-100	10.0	8.0	8.0

Bonded CRCP Overlay over CRCP: Subgrade M_R = 10,000 psi.

ESALs (millions)	Existing PCC Thickness (CRCP)		
	8 in.	**10 in.**	**12 in.**
≤10	6.0	6.0	6.0
10-25	7.0	6.5	6.5
25-50	8.0	7.0	7.0
50-100	10.0	8.0	8.0

Bonded CRCP Overlay over CRCP: Subgrade M_R = 20,000 psi.

ESALs (millions)	Existing PCC Thickness (CRCP)		
	8 in.	**10 in.**	**12 in.**
≤10	6.0	6.0	6.0
10-25	7.0	6.5	6.5
25-50	8.0	7.0	7.0
50-100	10.0	8.0	8.0

Table 4-A-30 Unbonded PCC and Precast Pavement Overlay over Existing PCC.
Unbonded PCC or PCP over PCC with 2-inch HMA bond breaker.

ESALs (millions)	Subgrade Modulus					
	5,000 psi		10,000 psi		20,000 psi	
	JCP	PCP	JCP	PCP	JCP	PCP
≤10	8.5	8.0	8.0	8.0	8.0	8.0
10-25	9.0	8.5	9.0	8.5	8.5	8.0
25-50	9.5	9.0	9.5	9.0	9.5	9.0
50-100	10.0	9.5	10.0	9.5	10.0	9.5
100-200	12.0	11.5	11.5	11.0	11.5	11.0

Notes: (1) Unbonded precast PCC thicknesses after Table 8.3 "Precast Concrete Pavement Technology," Final Report, March 2012 at: http://www.trb.org/Main/Blurbs/167788.aspx A project specific design is required. (2) This table also applies to existing composite pavement (HMA/PCC) without the 2 inch HMA bond breaker

Table 4-A-31 Unbonded Prestressed Precast Pavement Overlay Thicknesses over Existing HMA.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	8.0	8.0	8.0
10-25	8.0	8.0	8.0
25-50	8.0	8.0	8.0
50-100	8.0	8.0	8.0
100-200	8.0	8.0	8.0

Note: Thickness estimates from Table 8.4 "Precast Concrete Pavement Technology" at http://www.trb.org/Main/Blurbs/167788.aspx a project specific design is required.

Table 4-A-32 Unbonded Prestressed Precast PCC Pavement Overlay over Existing PCC.
Unbonded Prestressed Precast PCC over PCC with 2-inch bond breaker*.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	8.0	8.0	8.0
10-25	8.0	8.0	8.0
25-50	8.0	8.0	8.0
50-100	8.0	8.0	8.0
100-200	8.0	8.0	8.0

Notes: (1) Thickness estimates from Table 8.4 "Precast Concrete Pavement Technology" at: http://www.trb.org/Main/Blurbs/167788.aspx a project specific design is required. (2) This table also applies to existing composite pavement (HMA/PCC) without the 2 inch HMA bond breaker.

Table 4-A-33 Unbonded Composite HMA/ PCC Pavement Overlay over Existing HMA.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/7	2/7	2/7
10-25	2/7.5	2/7.5	2/7
25-50	2/8	2/8	2/8
50-100	2/9	2/9	2/9
100-200	2/10	2/10	2/10

Notes: (1) The two values shown represent HMA thickness over PCC thickness in inches, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches

Table 4-A-34 Unbonded Composite PCC/ PCC Pavement Overlay over Existing HMA.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/7	2/7	2/7
10-25	2/7.5	2/7.5	2/7
25-50	2/8	2/8	2/8
50-100	2/9	2/8.5	2/8.5
100-200	2/13.5	2/12.5	2/12

Notes: (1) The two values shown represent PCC thickness over PCC thickness in inches with the first thickness representing higher quality PCC than the second, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches

Table 4-A-35 Unbonded Composite HMA/ PCC Pavement Overlay over Existing PCC. Existing PCC with 2-inch thick bond breaker.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/7	2/7	2/7
10-25	2/7	2/7	2/7
25-50	2/7.5	2/7.5	2/7.5
50-100	2/8.5	2/8.5	2/8.5
100-200	2/9	2/9	2/9

Notes: (1) The two values shown represent HMA thickness over PCC thickness in inches, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches. (3) This table also applies to existing composite pavement (HMA/PCC) without the 2 inch HMA bond breaker.

Table4-A-36 Unbonded Composite PCC/ PCC Pavement Overlay over Existing PCC. Existing PCC with 2-inch thick bond breaker.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/6.5	2/6	2/6
10-25	2/7	2/7	2/6.5
25-50	2/7.5	2/7.5	2/7.5
50-100	2/8.5	2/8	2/8
100-200	2/11.5	2/10.5	2/10

Notes: (1) The two values shown represent PCC thickness over PCC thickness in inches with the first thickness representing higher quality PCC than the second, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches, (3) Existing PCC pavement is assumed to be 9 inches of PCC over a 6 inch granular base. (4) This table also applies to existing composite pavement (HMA/PCC) without the 2 inch bond breaker.

Table 4-A-37 Remove and Replace with Composite HMA/ PCC Pavement. Composite HMA/PCC over 4-inch of HMA and 6-inch Granular Base.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/7	2/7	2/7
10-25	2/7.5	2/7.5	2/7
25-50	2/8	2/8	2/8
50-100	2/9	2/9	2/9
100-200	2/10	2/10	2/10

Notes: (1) The two values shown represent HMA thickness over PCC thickness in inches, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches

Table 4-A-38 Remove and Replace with Composite PCC/ PCC Pavement. Composite PCC/PCC over 4-inch HMA and 6-inch Granular Base.

ESALs (millions)	Subgrade Moduli		
	5,000 psi	10,000 psi	20,000 psi
≤10	2/7	2/7	2/7
10-25	2/7.5	2/7.5	2/7
25-50	2/8	2/8	2/8
50-100	2/9	2/8.5	2/8.5
100-200	2/13.5	2/12.5	2/12

Note: (1) The two values shown represent PCC thickness over PCC thickness in inches with the first thickness representing higher quality PCC than the second, (2) 1.25 inch dowels for total PCC thickness < 9 inches and 1.5 inch dowels for thickness ≥ 9 inches

Note: ESAL = equivalent single-axle load.

Appendix 4-B1

SHRP 2 R21 HMA/PCC

Report and Design Tables prepared by ARA for NCE
January 9, 2014

Appendix 4-B1

HMA/PCC Composite Pavement Renewal Thickness Design Table Development

Introduction

The HMA/PCC composite pavement "overlay" designs contained in the interactive software and design guidelines were developed using AASHTO Ware Pavement ME Design Version 1.3, Build 1.3.29. As part of SHRP 2 R21 "Composite Pavement Systems" project, Rao et al. 2013, identified the AC Overlay of PCC Pavements in Pavement ME software (originally MEPDG) as being suitable for the design of HMA/PCC composite pavements, with specified changes to the program default calibration coefficients for modeling rutting in the HMA surface layer. This reference can be accessed at TRB's website http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/CompositePavementSystems.aspx. MEPDG was selected for this task due to its versatility and focus on long-lasting pavement design. The MEPDG software also represents the latest technology in the analysis and design of pavement systems.

MEPDG

The MEPDG has numerous features and inputs that need to be addressed. Because the MEPDG was not originally developed for new HMA/PCC composite pavements, the "AC Overlay of PCC Pavements" was modified by the SHRP 2 R21 team, for the AC/PCC design, by changing the rutting calibration coefficients. No other changes were made. The MEPDG has three levels of inputs and for this assessment Level 3 was used. Some of the required decisions and inputs are:

1. There are three major input types for the MEDPG: (1) Traffic, (2) Climate, and (3) Structure.
2. One pavement type was analyzed via the MEPDG which was **HMA/PCC** with five distress/performance types: (1) Rutting (surface HMA), (2) HMA bottom-up fatigue cracking, (3) HMA top-down longitudinal cracking, (4) JPCP transverse cracking, and (5) IRI. The MEDPG inputs that follow are for **HMA/PCC** only.
3. General Information required to define the analysis period and type of design
    a. Design life = **50 years for JPCP; 30 years for HMA distresses and IRI – HMA/PCC pavement designed for remove and replace HMA layer after 30 years.**
    b. Construction month = **June**
    c. Traffic opening month = **July**
    d. Pavement type: **HMA/PCC**
    e. Shoulder condition: **No tied shoulder**.
4. Climate
    a. Data used to interpolate for **Baltimore, Maryland** (Table .4-B1)

Table 4-B1-1. Location information for climate data

	BALT-WASH INTL ARPT	RON-REAGAN INTL ARPT	WASH-DULLES INTL ARPT	YORK ARPT	NEW CASTLE CO ARPT	HDRTWN RGNL FLD APRT
Latitude (degrees)	39.1	38.52	38.56	39.55	39.4	39.43
Longitude (degrees)	-76.41	-77.02	-77.27	-76.52	-75.36	-77.44
Elevation (ft)	196	3	309	475	95	737
Dist from given location (mi)	0.0	28.0	44.2	52.7	67.3	67.7

5. Traffic
   a. General inputs for MEPDG (Table 4-B1-2)

Table 4-B1-2. General inputs

Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	100
Operational speed (mph):	60

b. Conversion of default load spectra (which was used to calculate performance for the various slab thicknesses) to equivalent ESALs (required for the R23 design guidelines) involved several steps. The following tables provide information on how this was done. The steps include:

i. The overall calculation of ESALs for a design life of 50 years is: ((ESALs/truck)(% of total truck traffic/vehicle class)/10 vehicle classes)(AADT/2)(365)(($(1+i)^n$ -1)/i)) = Total ESALs. Where i = truck growth rate and n = 50 years.

ii. ESALs/truck by vehicle class is the key element for converting load spectra to ESALs. Table 4-B1-3 shows a summary of ESALs/truck along with the percent of total truck traffic (from Table 2.4.9 (NCHRP, 2004b)).

iii. Table 4-B1-4 through Table 4-B1-6 illustrate the needed information for detailed calculations to estimate ESALs/truck. Table 4-B1-4 is from NCHRP (2004b) and shows the average number of axles per vehicle. Table 4-B1-5 illustrates how default load spectra for Class 4 single axles are converted to ESALs/axle. ESALs/truck is then the sum of ESALs/axle x average number of axles per truck. Table 4-B1-6 is a summary of ESALs/axle for the various vehicle classes and axle types.

iv. Table 4-B1-7 illustrates the level of daily truck traffic required to achieve the design ESALs used in the R23 design guidelines.

Table 4-B1-3. Calculation process for converting load spectra to ESALs

Vehicle Class	ESAL/truck[1]	% of Total Truck Traffic[2]
4	0.67	3.3
5	0.30	34.0
6	0.68	11.7
7	1.34	1.6
8	0.69	9.9
9	1.03	36.2
10	1.06	1.0
11	1.69	1.8
12	1.42	0.2
13	2.18	0.3

[1] ESAL/truck based on Level 3 default values from two sources; (1) Table 2.4.11 from NCHRP (2004b) "Suggested default values for the average number of single, tandem, and tridem axles per truck class, and (2) ESALs/axle calculated from MEPDG default axle load spectra (such as Tables 2.4.9 (single axles) and 2.4.10 (tandem axles) from NCHRP (2004b)). Refer to Table 4-B1-4, Table 4-B1-5, and Table 4-B1-6.
[2] Percentages for total truck traffic from Table 2.4.4 (NCHRP, 2004b) for TTC 9 (Intermediate light and single-trailer truck route).

Table 4-B1-4. Average number of Single, tandem, tridem, and quad axles per truck - based on LTPP data (from NCHRP, 2004b)

Vehicle Classification	Number of Axles per Truck			
	Singles	Tandems	Tridems	Quads
4	1.62	0.39	0	0
5	2.00	0	0	0
6	1.02	0.99	0	0
7	1.00	0.26	0.83	0
8	2.38	0.67	0	0
9	1.13	1.93	0	0
10	1.19	1.09	0.89	0
11	4.29	0.26	0.06	0
12	3.52	1.14	0.06	0
13	2.15	2.13	0.35	0

Table 4-B1-5. Example data for conversion of single axle load distribution
Default values to ESAL/Axle for Vehicle Class 4

Mean Axle Load (lbs)	ESAL/Axle[1]	Axle %[2]	Mean Axle Load (lbs)	ESAL/Axle[1]	Axle %[2]
3000	0.0008	1.80	22000	2.23	0.66
4000	0.0023	0.96	23000	2.66	0.56
5000	0.006	2.91	24000	3.16	0.37
6000	0.0123	3.99	25000	3.72	0.31
7000	0.0229	6.80	26000	4.35	0.18
8000	0.039	11.45	27000	5.06	0.18
9000	0.0625	11.28	28000	5.85	0.14
10000	0.095	11.04	29000	6.74	0.08
11000	0.139	9.86	30000	7.72	0.05
12000	0.198	8.53	31000	8.80	0.04
13000	0.272	7.32	32000	9.99	0.04
14000	0.366	5.55	33000	11.3	0.04
15000	0.482	4.23	34000	12.7	0.03
16000	0.624	3.11	35000	14.3	0.02
17000	0.80	2.54	36000	16.0	0.02
18000	1.00	1.98	37000	17.8	0.01
19000	1.24	1.53	38000	19.9	0.01
20000	1.52	1.19	39000	22.0	0.01
21000	1.85	1.16	40000	24.4	0.01

Σ(ESAL/Axle)(Axle%)[3]

[1] ESAL/Axle approximated with $(\text{Mean Axle Load}/18000)^4$
[2] Axle Percentages from Table 2.4.9 (NCHRP, 2004b)
[3] Σ [(ESAL/Axle)(Axle Percentage)] = 0.35 ESAL/Class 4 Axle

Table 4-B1-6. ESAL/Axle for all vehicle classes from default load spectra

Vehicle Classification	Single Axle	Tandem Axle	Tridem Axle
4	0.35 (see example calculation in Table 4-B1-5)	0.27	0
5	0.15	0.16	0
6	0.29	0.39	0
7	0.66	0.80	0.58
8	0.25	0.15	0
9	0.20	0.42	0
10	0.21	0.56	0.22
11	0.37	0.32	0.10
12	0.29	0.33	0.34
13	0.29	0.62	0.61

Table 4-B1-7. Daily trucks to achieve design ESALs along with Level 3 default load spectra

Average Annual Daily Trucks to achieve Design ESAL Level with Default Load Spectra (two-way)	ESALs (millions)
500	10
1,250	25
2,500	50
5,000	100
10,000	200

6. Analysis parameters--Performance criteria (**30 years for HMA surface which is expected to be milled and resurfaced at age 30; 50 years for JPCP layer**).
   a. Reliability for all distresses = **90%.**
   b. Transverse slab cracking (JPCP, maximum allowable over the 50-year design period): Range is given as 10 to 45% of the slab (NCHRP, 2004). **Use 10% at 50 years.**
   c. HMA rutting. **Used 0.25 in at 30 years.**
   d. HMA bottom-up alligator (fatigue) cracking. **Used 10% at 30 years.**
   e. HMA top-down longitudinal cracking. **Used 1000 ft/mile at 30 years.**
   f. Smoothness range for terminal IRI is given as 150 to 250 inches/mile (NCHRP, 2004). **Used 170 inches/mile at 30 years** (or 2.7 m/km which is the FHWA break point from "acceptable" to "not acceptable"). Please refer to Table 4-B1-8 .

Table 4-B1-8. FHWA smoothness criteria

FHWA Ride Quality Terms	**All Functional Classifications**	
	IRI, m/km (inches/mile)	**PSR Rating**
Good	< 1.5 (95)	Good
Acceptable	≤ 2.7 (170)	Acceptable
Not Acceptable	> 2.7 (170)	Not Acceptable

      i. Initial IRI (as-constructed smoothness): Range is given as 50-100 inches/mile (NCHRP, 2004). Use **60 inches/miles** (or about 1.0 m/km).
      ii. Terminal IRI = **170 in./mi.**
7. Structure and Materials
   a. JPCP Properties (Layer 2). See Table 4-B1-9 through Table 4-B1-12.

Table 4-B1-9. General Properties

General Properties	
PCC material	**JPCP**
Layer thickness (in):	**Varied**
Unit weight (pcf):	**150**
Poisson's ratio	**0.2**

Table 4-B1-10. Thermal Properties

Thermal Properties	
Coefficient of thermal expansion (per F° x 10- 6):	**5.5**
Thermal conductivity (BTU/hr-ft-F°) :	**1.25 (see NCHRP, 2004a)**
Heat capacity (BTU/lb-F°):	**0.28 (see NCHRP, 2004a)**

Table 4-B1-11. Mixture Properties

Mix Properties	
Cement type:	**Type II**
Cementitious material content (lb/yd^3):	**560**
Water/cement ratio:	**0.42**
Aggregate type:	**Limestone**
PCC zero-stress temperature (F°)	**Derived**
Ultimate shrinkage at 40% R.H (microstrain)	**Derived**
Reversible shrinkage (% of ultimate shrinkage):	**50**
Time to develop 50% of ultimate shrinkage (days):	**35**
Curing method:	**Curing compound**

[1] A range of cementitious contents could be used. For example, Minnesota specifies a minimum cement content of 530 lb/CY, Missouri 560 lb/CY, and WSDOT 564 lb/CY (see R23 specification summary in Appendix E-4). The FHWA (2007) notes that Germany and the Netherlands specify a minimum content of 540 lb/CY. Austria uses 540 lb/CY for fix-form paving and 594 lb/CY for slip-form paving. Thus, 500 lb/CY represents a lower bound and 560 lb/CY is the middle of the range.

Table 4-B1-12. Strength Properties

Strength Properties	
Input level:	**Level 3**
28-day PCC modulus of rupture (psi):	**690**
28-day PCC compressive strength (psi):	**Derived**

b. HMA Properties (Layer 1 and Layer 3). Please refer to Table 4-B1-13 through Table 4-B1-16.

Table 4-B1-13. AC, General Properties

Layer 1 and Layer 3 -- Asphalt Concrete	
Material type:	**Asphalt concrete**
General reference temperature (°F)	**70**
Surface Layer Thickness (in)	**2**
Base Layer thickness (in):	**4 (for remove and replace option) 10 (to simulate unbonded overlay option)**
Poisson’s Ratio	**0.35 (user entered)**
Erodibility index	**Erosion Resistant (Class 3)**
PCC-Base Interface	**Full friction contact**
Loss of full friction (age in months)	**361**

Table 4-B1-14. AC Volumetric Properties

HMA Volumetric Properties as Built	
Effective binder content (%):	**11.6**
Air voids (%):	**7**
Total unit weight (pcf):	**150**

Table 4-B1-15. AC Mixture Properties

Asphalt Mix	
Cumulative % Retained 3/4 inch sieve:	**0**
Cumulative % Retained 3/8 inch sieve:	**23**
Cumulative % Retained #4 sieve:	**40**
% Passing #200 sieve:	**6**

Table 4-B1-16. AC Binder Properties

Asphalt Binder	
Option:	**Superpave binder grading**
A	**9.4610 (correlated)**
VTS:	**-3.1340 (correlated)**

c. Layer 4. Granular Base Properties. Please refer to Table 4-B1-17 and Table 4-B1-18.

Table 4-B1-17. Granular Base Type

Layer 4 -- A-6	
Unbound Material:	**Crushed Stone**
Thickness(in):	**6**

Table 4-B1-18. Granular Base Strength Properties

Strength Properties	
Input Level:	**Level 3**
Analysis Type:	**Representative value (User Input Modulus)**
Poisson's ratio:	**0.35**
Coefficient of lateral pressure, Ko:	**0.5**
Modulus (input) (psi):	**30000**
Moisture Content(%):	**-9999**

d. Layer 5. Subgrade properties. Please refer to Table 4-B1-19 and Table 4-B1-20.

Table 4-B1-19. Subgrade Type

Layer 5 -- A-6	
Unbound Material:	**A-6**
Thickness(in):	**Semi-Infinite**

Table 4-B1-20. Subgrade Strength Properties

Strength Properties	
Input Level:	**Level 3**
Analysis Type:	**Representative value (User Input Modulus)**
Poisson's ratio:	**0.35**
Coefficient of lateral pressure, Ko:	**0.5**
Modulus (input) (psi):	**5000**
Moisture Content(%):	**-9999**

e. All runs were done without tied shoulders.
f. Surface short-wave absorptivity: Ranges between 0 and 1 with 1 implying that all solar energy is absorbed by the pavement surface. **Use default = 0.85** (recommended by NCHRP (2004)). Ranges provided by the FHWA are included in Table 4-B21.

Table 4-B1-21. Surface Properties

Material	Surface Shortwave Absorptivity
Weathered asphalt (gray)	0.80-0.90
Fresh asphalt (black)	0.90-0.98
Aged PCC layer	0.70-0.90

g. JPCP Design Features: Input the following:
   i. Slab thickness: Varies
   ii. Permanent curl/warp effective temperature difference: **-10°F** (recommended by NCHRP (2004a)).
h. Joint Design
   i. Joint spacing: Fixed as **15 ft.**
   ii. Dowel transverse joints: Dowel diameter is **1.25 inches for PCC thickness < 9 inches and 1.5 inches for PCC thickness >= 9 inches. Dowel spacing 12 inches**.

8. Other considerations
   a. Reliability for performance predictions (Figure 4-B1-1). Figure 4-B1-1 show that the application of reliability shifts the predicted performance upward (in this case an illustration of slab cracking). Figure source: NCHRP, 2004a.

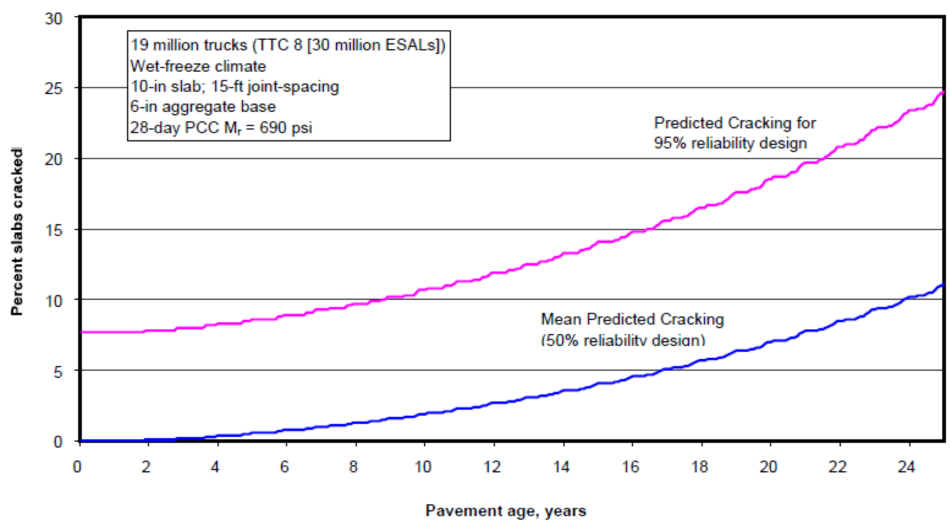


Figure 4-B1-1. Slab Cracking

Trial Runs

The MEPDG runs are summarized in Table 4-B1-22 and Table 4-B1-23. Table 4-B1-22 is for the remove-and-replace option with the HMA/PCC pavement over a base of 4 inch HMA and 6 inch crushed stone. Table 4-B1-23 is for the unbonded HMA/PCC overlay option of an existing PCC pavement simulated by using 10 inch HMA over 6 inch crushed stone base.

Table 4-B1-22. Results of MEPDG runs for remove-and-replace option

Traffic MESAL/ AADTT	Performance Criteria	Subgrade Modulus											
		5,000 psi				10,000 psi				15,000 psi			
		HMA/PCC Depth	DP[1]	RP[2]	A[3]	HMA/PCC Depth	DP[1]	RP[2]	A[3]	HMA/PCC Depth	DP[1]	RP[2]	A[3]
10/ 500	Terminal IRI (30 year)	2/7	87	n/a	Yes	2/7	87	n/a	Yes	2/7	87	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.9	97.2	Yes		0.5	98.3	Yes		0.4	98.7	Yes
	HMA Rutting (30 year)		0.09	n/a	Yes		0.09	n/a	Yes		0.09	n/a	Yes
25/ 1250	Terminal IRI (30 year)	2/7.5	88	n/a	Yes	2/7.5	88	n/a	Yes	2/7	88	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.3	98.9	Yes		0.2	99.4	Yes		2.3	91.3	Yes
	HMA Rutting (30 year)		0.11	n/a	Yes		0.11	n/a	Yes		0.11	n/a	Yes
50/ 2500	Terminal IRI (30 year)	2/8	89	n/a	Yes	2/8	89	n/a	Yes	2/8	89	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.4	98.7	Yes		0.1	99.5	Yes		0.1	99.6	Yes
	HMA Rutting (30 year)		0.13	n/a	Yes		0.13	n/a	Yes		0.13	n/a	Yes
100/ 5000	Terminal IRI (30 year)	2/9	90	n/a	Yes	2/9	90	n/a	Yes	2/9	90	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.0	99.8	Yes		0.0	99.9	Yes		0.0	99.9	Yes
	HMA Rutting (30 year)		0.16	n/a	Yes		0.15	n/a	Yes		0.15	n/a	Yes
200/ 10000	Terminal IRI (30 year)	2/10	91	n/a	Yes	2/10	91	n/a	Yes	2/10	91	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.0	99.9	Yes		0.0	99.9	Yes		0.0	99.9	Yes
	HMA Rutting (30 year)		0.19	n/a	Yes		0.18	n/a	Yes		0.18	n/a	Yes

[1]DP: Distress Prediction [2]RP: Reliability Prediction [3]A: Acceptable

Limiting Values: (1) Terminal IRI = 170 in./mi, (2) Transverse Cracking = 10%, (3) HMA Rutting = 0.25 in.

Because of PCC stiffness, HMA fatigue cracking and HMA longitudinal cracking very low (mean value ~ 0) and not reported in above table.

AADTT = Average Annual Daily Truck Traffic

1.25 inch dowels for PCC thickness < 9 inches and 1.5 inch dowels for PCC thickness >= 9 inches

Table 4-B1-23. Results of MEPDG runs for unbonded overlay option

Traffic MESAL/ AADTT	Performance Criteria	Subgrade Modulus											
		5,000 psi				10,000 psi				15,000 psi			
		HMA/PCC Depth	DP[1]	RP[2]	A[3]	HMA/PCC Depth	DP[1]	RP[2]	A[3]	HMA/PCC Depth	DP[1]	RP[2]	A[3]
10/ 500	Terminal IRI (30 year)	2/6.5	87	n/a	Yes	2/6.5	87	n/a	Yes	2/6.5	87	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.5	98.4	Yes		0.3	99.1	Yes		0.2	99.2	Yes
	HMA Rutting (30 year)		0.09	n/a	Yes		0.09	n/a	Yes		0.09	n/a	Yes
25/ 1250	Terminal IRI (30 year)	2/7	88	n/a	Yes	2/7	88	n/a	Yes	2/6.5	88	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.8	97.3	Yes		0.4	98.7	Yes		1.3	95.4	Yes
	HMA Rutting (30 year)		0.11	n/a	Yes		0.11	n/a	Yes		0.11	n/a	Yes
50/ 2500	Terminal IRI (30 year)	2/7.5	89	n/a	Yes	2/7.5	89	n/a	Yes	2/7.5	89	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.3	98.9	Yes		0.1	99.5	Yes		0.1	99.6	Yes
	HMA Rutting (30 year)		0.13	n/a	Yes		0.13	n/a	Yes		0.13	n/a	Yes
100/ 5000	Terminal IRI (30 year)	2/8.5	90	n/a	Yes	2/8.5	90	n/a	Yes	2/8.5	90	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.0	99.8	Yes		0.0	99.9	Yes		0.0	99.9	Yes
	HMA Rutting (30 year)		0.16	n/a	Yes		0.15	n/a	Yes		0.15	n/a	Yes
200/ 10000	Terminal IRI (30 year)	2/9	91	n/a	Yes	2/9	91	n/a	Yes	2/9	91	n/a	Yes
	JPCP Transverse Cracking (50 year)		0.0	99.8	Yes		0.0	99.9	Yes		0.0	99.9	Yes
	HMA Rutting (30 year)		0.19	n/a	Yes		0.18	n/a	Yes		0.18	n/a	Yes

[1]DP: Distress Prediction [2]RP: Reliability Prediction [3]A: Acceptable

Limiting Values: (1) Terminal IRI = 170 in./mi, (2) Transverse Cracking = 10%, (3) HMA Rutting = 0.25 in.

Because of PCC stiffness, HMA fatigue cracking and HMA longitudinal cracking very low (mean value ~ 0) and not reported in above table.

AADTT = Average Annual Daily Truck Traffic

1.25 inch dowels for PCC thickness < 9 inches and 1.5 inch dowels for PCC thickness >= 9 inches

Final HMA/PCC Renewal Design Table

The final slab thicknesses selected for use in the R23 design guidelines are shown below.

Table 4-B1-A. Thickness design table for HMA/PCC composite pavement for the remove and replace option (Base is 4 in HMA over 6 in of crushed stone)

ESALs (millions)	Subgrade Modulus		
	5,000 psi	**10,000 psi**	**15,000 psi**
≤10	2/7*	2/7*	2/7*
10-25	2/7.5*	2/7.5*	2/7*
25-50	2/8*	2/8*	2/8*
50-100	2/9	2/9	2/9
100-200	2/10	2/10	2/10

*1.25 inch dowels for thickness < 9 inches and 1.5 inch dowels for thickness >= 9 inches

Table 4-B1-B. Thickness design table for HMA/PCC composite pavement for unbonded PCC overlay (Base is 2 in HMA over a 9 in. existing PCC pavement and 6 in crushed stone)

ESALs (millions)	Subgrade Modulus		
	5,000 psi	**10,000 psi**	**15,000 psi**
≤10	2/6.5*	2/6.5*	2/6.5*
10-25	2/7*	2/7*	2/6.5*
25-50	2/7.5*	2/7.5*	2/7.5*
50-100	2/8.5*	2/8.5*	2/8.5*
100-200	2/9	2/9	2/9

Note: Used 10 inch HMA to simulate existing PCC pavement.

*1.25 inch dowels for thickness < 9 inches and 1.5 inch dowels for thickness >= 9 inches

References

Rao et al. 2013. *Composite Pavement Systems: Volume 2: PCC/PCC Composite Pavements*. SHRP 2 Report S2-R21-RR-3. Transportation Research Board. Washington D.C. 20001.

Appendix 4-B2

SHRP 2 R21 PCC/PCC

Report and Design Tables prepared by ARA for NCE
January 9, 2014

Appendix 4-B2

PCC/PCC Composite Pavement Renewal Thickness Design Table Development

The PCC/PCC composite pavement "overlay" designs contained in the interactive software and design guidelines were developed using the MEPDG v.1.3:R21 that was developed as part of SHRP 2 R21 "Composite Pavement Systems" project (Rao et al. 2013) that can be accessed at TRB's website http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/CompositePavementSystems.aspx. The SHRP 2 R21 research team modified the MEPDG code specifically for the design of PCC/PCC composite pavements. The MEPDG software was selected for this task due to its versatility and focus on long-lasting pavement design. The MEPDG software also represents the latest technology in the analysis and design of pavement systems.

MEPDG

The MEPDG has numerous features and inputs that need to be addressed. Because the MEPDG was not originally developed for new PCC/PCC composite pavements, the "Bonded PCC Overlay of PCC Pavements" was modified by the SHRP 2 R21 team, for the PCC/PCC design. The MEPDG has three levels of inputs and for this assessment Level 3 was used. Some of the required decisions and inputs are:

5. There are three major input types for the MEDPG: (1) Traffic, (2) Climate, and (3) Structure.
6. One pavement type was analyzed via the MEPDG which was **PCC/PCC** with three distress/performance types: (1) joint faulting, (2) transverse cracking, and (3) IRI. The MEDPG inputs that follow are for **PCC/PCC** only.
7. General Information required to define the analysis period and type of design
    a. Design life = **50 years.**
    b. Construction month = **June**
    c. Traffic opening month = **July**
    d. Pavement type: **PCC/PCC**
    e. Shoulder condition: **No tied shoulder**.
8. Climate
    a. Data used to interpolate for **Baltimore, Maryland** (Table 4-B2-1)

Table 4-B2-24. Location information for climate data

	BALT-WASH INTL ARPT	RON-REAGAN INTL ARPT	WASH-DULLES INTL ARPT	YORK ARPT	NEW CASTLE CO ARPT	HDRTWN RGNL FLD APRT
Latitude (degrees)	39.1	38.52	38.56	39.55	39.4	39.43
Longitude (degrees)	-76.41	-77.02	-77.27	-76.52	-75.36	-77.44
Elevation (ft)	196	3	309	475	95	737
Dist from given location (mi)	0.0	28.0	44.2	52.7	67.3	67.7

6. Traffic
    a. General inputs for MEPDG (Table 4-B2-2)

Table 4-B2-25. General inputs

Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	100
Operational speed (mph):	60

b. Conversion of default load spectra (which was used to calculate performance for the various slab thicknesses) to equivalent ESALs (required for the R23 design guidelines) involved several steps. The following tables provide information on how this was done. The steps include:

v. The overall calculation of ESALs for a design life of 50 years is: ((ESALs/truck)(% of total truck traffic/vehicle class)/10 vehicle classes)(AADT/2)(365)(($(1+i)^n$ -1)/i)) = Total ESALs. Where i = truck growth rate and n = 50 years.

vi. ESALs/truck by vehicle class is the key element for converting load spectra to ESALs. Table D. 3 shows a summary of ESALs/truck along with the percent of total truck traffic (from Table 2.4.9 (NCHRP, 2004b)).

vii. Table 4-B2-4 through Table4-B2-6 illustrate the needed information for detailed calculations to estimate ESALs/truck. Table 4-B2-4 is from NCHRP (2004b) and shows the average number of axles per vehicle. Table 4-B2-5 illustrates how default load spectra for Class 4 single axles are converted to ESALs/axle. ESALs/truck is then the sum of ESALs/axle x average number of axles per truck. Table 4-B2-6 is a summary of ESALs/axle for the various vehicle classes and axle types.

viii. Table 4-B2-7 illustrates the level of daily truck traffic required to achieve the design ESALs used in the R23 design guidelines.

Table 4-B2-26. Calculation process for converting load spectra to ESALs

Vehicle Class	ESAL/truck[1]	% of Total Truck Traffic[2]
4	0.67	3.3
5	0.30	34.0
6	0.68	11.7
7	1.34	1.6
8	0.69	9.9
9	1.03	36.2
10	1.06	1.0
11	1.69	1.8
12	1.42	0.2
13	2.18	0.3

[1] ESAL/truck based on Level 3 default values from two sources; (1) Table 2.4.11 from NCHRP (2004b) “Suggested default values for the average number of single, tandem, and tridem axles per truck class, and (2) ESALs/axle calculated from MEPDG default axle load spectra (such as Tables 2.4.9 (single axles) and 2.4.10 (tandem axles) from NCHRP (2004b)). Refer to Table 4-B2-4, Table 4-B2-5, and Table 4-B2-6.

[2] Percentages for total truck traffic from Table 2.4.4 (NCHRP, 2004b) for TTC 9 (Intermediate light and single-trailer truck route).

Table 4-B2-27. Average number of Single, tandem, tridem, and quad axles per truck - based on LTPP data (from NCHRP, 2004b)

Vehicle Classification	Number of Axles per Truck			
	Singles	Tandems	Tridems	Quads
4	1.62	0.39	0	0
5	2.00	0	0	0
6	1.02	0.99	0	0
7	1.00	0.26	0.83	0
8	2.38	0.67	0	0
9	1.13	1.93	0	0
10	1.19	1.09	0.89	0
11	4.29	0.26	0.06	0
12	3.52	1.14	0.06	0
13	2.15	2.13	0.35	0

Table 4-B2-28. Example data for conversion of single axle load distribution. Default values to ESAL/Axle for Vehicle Class 4

Mean Axle Load (lbs)	ESAL/Axle[1]	Axle %[2]	Mean Axle Load (lbs)	ESAL/Axle[1]	Axle %[2]
3000	0.0008	1.80	22000	2.23	0.66
4000	0.0023	0.96	23000	2.66	0.56
5000	0.006	2.91	24000	3.16	0.37
6000	0.0123	3.99	25000	3.72	0.31
7000	0.0229	6.80	26000	4.35	0.18
8000	0.039	11.45	27000	5.06	0.18
9000	0.0625	11.28	28000	5.85	0.14
10000	0.095	11.04	29000	6.74	0.08
11000	0.139	9.86	30000	7.72	0.05
12000	0.198	8.53	31000	8.80	0.04
13000	0.272	7.32	32000	9.99	0.04
14000	0.366	5.55	33000	11.3	0.04
15000	0.482	4.23	34000	12.7	0.03
16000	0.624	3.11	35000	14.3	0.02
17000	0.80	2.54	36000	16.0	0.02
18000	1.00	1.98	37000	17.8	0.01
19000	1.24	1.53	38000	19.9	0.01

Mean Axle Load (lbs)	ESAL/Axle[1]	Axle %[2]	Mean Axle Load (lbs)	ESAL/Axle[1]	Axle %[2]
20000	1.52	1.19	39000	22.0	0.01
21000	1.85	1.16	40000	24.4	0.01

Σ(ESAL/Axle)(Axle%)[3]

[1] ESAL/Axle approximated with $(\text{Mean Axle Load}/18000)^4$

[2] Axle Percentages from Table 2.4.9 (NCHRP, 2004b)

[3] Σ [(ESAL/Axle)(Axle Percentage)] = 0.35 ESAL/Class 4 Axle

Table 4-B2-29. ESAL/Axle for all vehicle classes from default load spectra

Vehicle Classification	Single Axle	Tandem Axle	Tridem Axle
4	0.35 (see example calculation in Table 4-B2-5)	0.27	0
5	0.15	0.16	0
6	0.29	0.39	0
7	0.66	0.80	0.58
8	0.25	0.15	0
9	0.20	0.42	0
10	0.21	0.56	0.22
11	0.37	0.32	0.10
12	0.29	0.33	0.34
13	0.29	0.62	0.61

Table 4-B2-30. Daily trucks to achieve design ESALs along with Level 3 default load spectra

Average Annual Daily Trucks to achieve Design ESAL Level with Default Load Spectra (two-way)	ESALs (millions)
500	10
1,250	25
2,500	50
5,000	100
10,000	200

9. Analysis parameters--Performance criteria
   g. Reliability for terminal IRI, transverse cracking, and mean joint faulting = **90%.**
   h. Transverse slab cracking (JPCP, maximum allowable over the design period): Range is given as 10 to 45% of the slab (NCHRP, 2004). **Use 10%.**
   i. Transverse joint faulting (JPCP, upper limit over the design period), Range is given as 0.1 to 0.2 in. (NCHRP, 2004). **Used 0.1 and 0.15 in.**
   j. Smoothness range for terminal IRI is given as 150 to 250 inches/mile (NCHRP, 2004). **Used 170 inches/mile** (or 2.7 m/km which is the FHWA break point from “acceptable” to “not acceptable”). Please refer to Table4-B2-8 .

Table 4-B2-31. FHWA smoothness criteria

FHWA Ride Quality Terms	**All Functional Classifications**	
	IRI, m/km (inches/mile)	**PSR Rating**
Good	< 1.5 (95)	Good
Acceptable	≤ 2.7 (170)	Acceptable
Not Acceptable	> 2.7 (170)	Not Acceptable

iii. Initial IRI (as-constructed smoothness): Range is given as 50-100 inches/mile (NCHRP, 2004). Use **60 inches/miles** (or about 1.0 m/km).

iv. Terminal IRI = **170 in./mi.**

10. Structure and Materials
    a. PCC/JPCP Properties (Layer 1 and Layer 2). See Table 4-B2-9 through Table 4-B2-12.

Table 4-B2-32. General Properties

General Properties	
PCC material	**PCC/JPCP**
Layer thickness (in):	**2 in. Upper Lift PCC (Layer 1) Varied Lower Lift PCC (Layer 2)**
Unit weight (pcf):	**150**
Poisson's ratio	**0.2**

Table 4-B2-33. Thermal Properties

Thermal Properties	
Coefficient of thermal expansion (per F° x 10- 6):	**5.5**
Thermal conductivity (BTU/hr-ft-F°) :	**1.25 (see NCHRP, 2004a)**
Heat capacity (BTU/lb-F°):	**0.28 (see NCHRP, 2004a)**

Table 4-B2-34. Mixture Properties

Mix Properties	
Cement type:	**Type I**
Cementitious material content (lb/yd^3):	**650 Upper Lift PCC 500 Lower Lift PCC**
Water/cement ratio:	**0.42**
Aggregate type:	**Granite Upper Lift PCC Limestone Lower Lift PCC**
PCC zero-stress temperature (F°)	**Derived**
Ultimate shrinkage at 40% R.H (microstrain)	**Derived**
Reversible shrinkage (% of ultimate shrinkage):	**50**
Time to develop 50% of ultimate shrinkage (days):	**35**
Curing method:	**Curing compound**

[1] A range of cementitious contents could be used. For example, Minnesota specifies a minimum cement content of 530 lb/CY, Missouri 560 lb/CY, and WSDOT 564 lb/CY (see R23 specification summary in Appendix E-4). The FHWA (2007) notes that Germany and the Netherlands specify a minimum content of 540 lb/CY. Austria uses 540 lb/CY for fix-form paving and 594 lb/CY for slip-form paving. Thus, 500 lb/CY represents a lower bound and 560 lb/CY is the middle of the range.

Table 4-B2-35. Strength Properties

Strength Properties	
Input level:	**Level 3**
28-day PCC modulus of rupture (psi):	**775 Upper Lift PCC 650 Lower Lift PCC**
28-day PCC compressive strength (psi):	**Derived**

    b. Base Properties (Layer 3). Please refer to Table 4-B2-13 through Table 4-B2-16.

Table 4-B2-36. AC, General Properties

Layer 2 -- Asphalt concrete	
Material type:	**Asphalt concrete**
General reference temperature (°F)	**70**
Layer thickness (in):	**4 (for remove and replace option) 10 (to simulate unbonded overlay option)**
Poisson's Ratio	**0.35 (user entered)**
Erodibility index	**Erosion Resistant (Class 3)**
PCC-Base Interface	**Full friction contact**
Loss of full friction (age in months)	**361**

Table 4-B2-37. AC Volumetric Properties

HMA Volumetric Properties as Built	
Effective binder content (%):	**11.6**
Air voids (%):	**7**
Total unit weight (pcf):	**150**

Table 4-B2-38. AC Mixture Properties

Asphalt Mix	
Cumulative % Retained 3/4 inch sieve:	**0**
Cumulative % Retained 3/8 inch sieve:	**23**
Cumulative % Retained #4 sieve:	**40**
% Passing #200 sieve:	**6**

Table 4-B2-39. AC Binder Properties

Asphalt Binder	
Option:	**Superpave binder grading**
A	**9.4610 (correlated)**
VTS:	**-3.1340 (correlated)**

c. Layer 4. Granular Base Properties. Please refer to Table 4-B2-17 and Table 4-B2-18.

Table 4-B2-40. Granular Base Type

Layer 3 -- A-6	
Unbound Material:	**Crushed Stone**
Thickness(in):	**6**

Table 4-B2-41. Granular Base Strength Properties

Strength Properties	
Input Level:	**Level 3**
Analysis Type:	**Representative value (User Input Modulus)**
Poisson's ratio:	**0.35**
Coefficient of lateral pressure, Ko:	**0.5**

Modulus (input) (psi):	**30000**
Moisture Content(%):	**-9999**

d. Layer 5. Subgrade properties. Please refer to Table 4-B2-19 and Table 4-B2-20.

Table 4-B2-42. Subgrade Type

Layer 5 -- A-6	
Unbound Material:	**A-6**
Thickness(in):	**12**

Table 4-B2-43. Subgrade Strength Properties

Strength Properties	
Input Level:	**Level 3**
Analysis Type:	**Representative value (User Input Modulus)**
Poisson's ratio:	**0.35**
Coefficient of lateral pressure, Ko:	**0.5**
Modulus (input) (psi):	**5000**
Moisture Content(%):	**-9999**

e. Layer 6—Same as Layer 5 but thickness is semi-infinite.
f. All runs were done without tied shoulders.
g. Surface short-wave absorptivity: Ranges between 0 and 1 with 1 implying that all solar energy is absorbed by the pavement surface. **Use default = 0.85** (recommended by NCHRP (2004)). Ranges provided by the FHWA are included in Table 4-B2-21.

Table 4-B2-44. Surface Properties

Material	Surface Shortwave Absorptivity
Weathered asphalt (gray)	0.80-0.90
Fresh asphalt (black)	0.90-0.98
Aged PCC layer	0.70-0.90

h. JPCP Design Features: Input the following:
   i. Slab thickness: Varies
   ii. Permanent curl/warp effective temperature difference: **-10°F** (recommended by NCHRP (2004a)).
i. Joint Design
   i. Joint spacing: Fixed as **15 ft.**
   ii. Dowel transverse joints: Dowel diameter is **1.25 inches for total PCC thickness < 10 inches and 1.5 inches for total PCC thickness >= 10 inches. Dowel spacing 12 inches**.

11. Other considerations
   a. Reliability for performance predictions (Figure 4-B2-1). Figure 4-B2-1 below show that the application of reliability shifts the predicted performance upward (in this case an illustration of slab cracking). Figure source: NCHRP, 2004a.

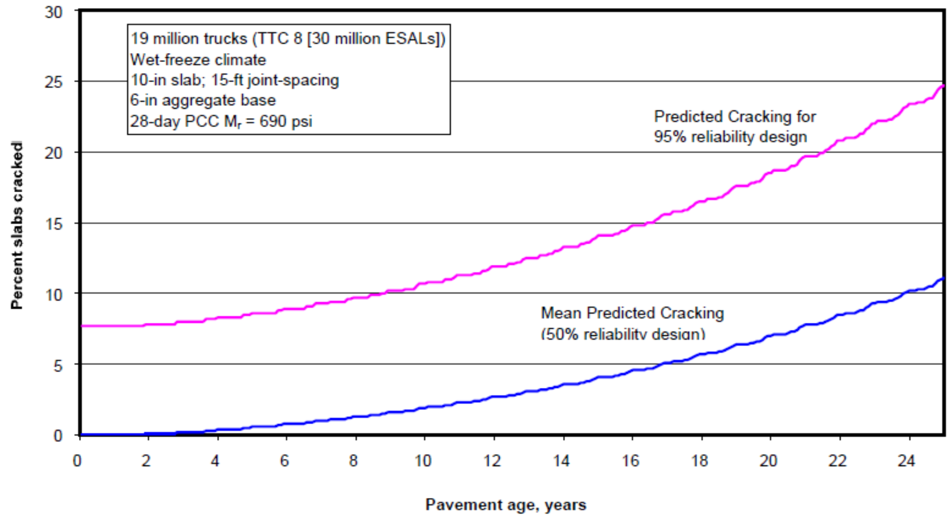


Figure 4-B2-2. Slab Cracking

Trial Runs

The MEPDG runs are summarized in Table 4-B2-22 and Table 4-B2-23. Table 4-B2-22 is for the remove-and-replace option with the PCC/PCC pavement over a base of 4 inch HMA and 6 inch crushed stone. Table 4-B2-23 is for the unbonded PCC/PCC overlay option of an existing PCC pavement simulated by using 10 inch HMA over 6 inch crushed stone base.

Table 4-B2-45. Results of MEPDG runs for remove-and-replace option

Traffic MESAL/ AADTT	Performance Criteria	Subgrade Modulus											
		5,000 psi				10,000 psi				15,000 psi			
		PCC Depth	DP[1]	RP[2]	A[3]	PCC Depth	DP[1]	RP[2]	A[3]	PCC Depth	DP[1]	RP[2]	A[3]
10/ 500	Terminal IRI	2/6.5	92	99.2	Yes	2/6.5	90	99.5	Yes	2/6.5	89	99.6	Yes
	Transverse Cracking		1.6	94.2	Yes		0.7	97.8	Yes		0.5	98.4	Yes
	Mean Joint Faulting		.031	99.2	Yes		.027	99.5	Yes		0.025	99.7	Yes
25/ 1250	Terminal IRI	2/7.5*	107	95.3	Yes	2/7.5*	105	96.2	Yes	2/7	105	96.3	Yes
	Transverse Cracking		0.2	99.2	Yes		0.1	99.6	Yes		0.6	97.9	Yes
	Mean Joint Faulting		.061	86.5	No*		0.057	89.5	No*		0.056	90.2	Yes
50/ 2500	Terminal IRI	2/8	100	97.6	Yes	2/8	97	98.3	Yes	2/8	96	98.5	Yes
	Transverse Cracking		0.1	99.5	Yes		0.1	99.7	Yes		0.1	99.7	Yes
	Mean Joint Faulting		0.049	94.1	Yes		0.043	96.4	Yes		0.041	97.0	Yes
100/ 5000	Terminal IRI	2/9*	110	93.9	Yes	2/8.5*	109	94.5	Yes	2/8.5*	108	94.9	Yes
	Transverse Cracking		0	99.9	Yes		0	99.8	Yes		0	99.8	Yes
	Mean Joint Faulting		0.068	81.2	No*		0.065	83.2	No*		0.063	84.9	No*
200/ 10000	Terminal IRI	2/13.5* #	111	93.8	Yes	2/12.5*#	109	94.5	Yes	2/12*#	110	94.1	Yes
	Transverse Cracking		0	99.9	Yes		0	99.9	Yes		0	99.9	Yes
	Mean Joint Faulting		0.068	80.9	No*#		0.065	83.2	No*#		0.067	81.9	No*#

[1]DP: Distress Prediction [2]RP: Reliability Prediction [3]A: Acceptable

Limiting Values: (1) Terminal IRI = 170 in./mi, (2) Transverse Cracking = 10%, (3) Mean Joint Faulting = 0.1 in.

AADTT = Average Annual Daily Truck Traffic

1.25 inch dowels for total PCC thickness < 10 inches and 1.5 inch dowels for total PCC thickness >= 10 inches

* Faulting limit of 0.1 inches (90% reliability) not met at 50 years, but met at 40+ years (assume one diamond grinding of surface lasting 10 years at age 40). Faulting limit of 0.12 inches met at 50 years. Thickness reflects addition of 0.5 inches to thickness to account for grinding. Note if faulting limit is set at 0.12 inches then the pavement will pass the faulting criteria and predicted reliability will be > 90%.

If faulting limit is set at 0.15 inches, then the pavement will pass the criteria at lower thicknesses (2/10 for 200 MESALs).

Table 4-B2-46. Results of MEPDG runs for unbonded overlay option

Traffic MESAL/ AADTT	Performance Criteria	Subgrade Modulus											
		5,000 psi				10,000 psi				15,000 psi			
		PCC Depth	DP[1]	RP[2]	A[3]	PCC Depth	DP[1]	RP[2]	A[3]	PCC Depth	DP[1]	RP[2]	A[3]
10/ 500	Terminal IRI	2/6.5	86	99.8	Yes	2/6	84	99.8	Yes	2/6	83	99.9	Yes
	Transverse Cracking		0.5	98.3	Yes		1.4	95.3	Yes		1.1	96.5	Yes
	Mean Joint Faulting		0.020	99.9	Yes		0.016	99.9	Yes		0.015	99.9	Yes
25/ 1250	Terminal IRI	2/7	99	98.0	Yes	2/6.5	96	98.6	Yes	2/6.5	95	98.8	Yes
	Transverse Cracking		0.6	98.0	Yes		1.3	95.5	Yes		1.0	96.7	Yes
	Mean Joint Faulting		0.045	95.8	Yes		0.039	97.7	Yes		0.036	98.2	Yes
50/ 2500	Terminal IRI	2/7.5*	112	93.1	Yes	2/7.5*	110	94.3	Yes	2/7.5*	109	94.7	Yes
	Transverse Cracking		0.3	99.0	Yes		0.1	99.5	Yes		0.1	99.5	Yes
	Mean Joint Faulting		0.070	78.8	No*		0.066	82.8	No*		0.064	84.0	No*
100/ 5000	Terminal IRI	2/8.5*	104	96.3	Yes	2/8	102	97.1	Yes	2/8	101	97.4	Yes
	Transverse Cracking		0	99.8	Yes		0.1	99.6	Yes		0.2	99.3	Yes
	Mean Joint Faulting		0.056	89.8	No*		0.052	92.5	Yes		0.049	93.7	Yes
200/ 10000	Terminal IRI	2/11.5* #	110	94.2	Yes	2/10.5*#	110	94.1	Yes	2/10*	110	93.9	Yes
	Transverse Cracking		0	99.9	Yes		0	99.9	Yes		0	99.9	Yes
	Mean Joint Faulting		0.066	82.37	No*		0.067	81.9	No*		0.068	81.2	No*

[1]DP: Distress Prediction [2]RP: Reliability Prediction [3]A: Acceptable

Limiting Values: (1) Terminal IRI = 170 in./mi, (2) Transverse Cracking = 10%, (3) Mean Joint Faulting = 0.1 in.

AADTT = Average Annual Daily Truck Traffic

1.25 inch dowels for total PCC thickness < 10 inches and 1.5 inch dowels for total PCC thickness >= 10 inches

* Faulting limit of 0.1 inches (90% reliability) not met at 50 years, but met at 40+ years (assume one diamond grinding of surface lasting 10 years at age 40). Faulting limit of 0.12 inches met at 50 years. Thickness reflects addition of 0.5 inches to thickness to account for grinding. Note if faulting limit is set at 0.12 inches then the pavement will pass the faulting criteria and predicted reliability will be > 90%.

If faulting limit is set at 0.15 inches, then the pavement will pass the criteria at lower thicknesses (2/10 for 200 MESALs).

Final PCC/PCC Renewal Design Table

The final slab thicknesses selected for use in the R23 design guidelines are shown below.

Table 4-B2-24. Thickness design table for PCC/PCC composite pavement for the remove and replace option (Base is 4 in HMA over 6 in of crushed stone)

ESALs (millions)	**Subgrade Modulus**		
	5,000 psi	**10,000 psi**	**15,000 psi**
≤10	2/6.5*	2/6.5*	2/6.5*
10-25	2/7.5*(**)	2/7.5*(**)	2/7*
25-50	2/8	2/8	2/8
50-100	2/9**	2/8.5**	2/8.5**
100-200	2/13.5**#	2/12.5**#	2/12**#

*1.25 inch dowels for thickness < 10 inches and 1.5 inch dowels for thickness >= 10 inches

** Faulting limit of 0.1 inches not met at 50 years, but met at 40+ years (assume one diamond grinding of surface lasting 10 years at age 40). Faulting limit of 0.12 inches met at 50 years. Thickness reflects addition of 0.5 inches to thickness to account for grinding.

#If faulting limit is set at 0.15 inches then the pavement will pass the criteria at lower thicknesses (2/10 for 100-200 MESALs).

Table 4-B2-25. Thickness design table for PCC/PCC composite pavement for unbonded PCC overlay (Base is 2 in HMA over a 9 in. existing PCC pavement and 6 in crushed stone)

ESALs (millions)	**Subgrade Modulus**		
	5,000 psi	**10,000 psi**	**15,000 psi**
≤10	2/6.5*	2/6*	2/6*
10-25	2/7*	2/6.5*	2/6.5*
25-50	2/7.5*(**)	2/7.5*(**)	2/7.5*(**)
50-100	2/8.5**	2/8	2/8
100-200	2/11.5**#	2/10.5**#	2/10**

Note: Used 10 inch HMA to simulate existing PCC pavement.

*1.25 inch dowels for thickness < 10 inches and 1.5 inch dowels for thickness >= 10 inches

** Faulting limit of 0.1 inches not met at 50 years, but met at 40+ years (assume one diamond grinding of surface lasting 10 years at age 40). Faulting limit of 0.12 inches met at 50 years. Thickness reflects addition of 0.5 inches to thickness to account for grinding.

#If faulting limit is set at 0.15 inches then the pavement will pass the criteria at lower thicknesses (2/10 for 100-200 MESALs).

References

Rao et al. 2013. *Composite Pavement Systems: Volume 2: PCC/PCC Composite Pavements*. SHRP 2 Report S2-R21-RR-3. Transportation Research Board. Washington D.C. 20001.

Appendix 4-C1

MnDOT SHRP 2 R23 Test Case

SP # 1002-101

TH - 5

From Just East of Scandia Rd to Rolling Acre Rd/Bavaria Rd

RP 34.474 to RP 40.403

Appendix 4-C1

SP # 1002-101

TH - 5

From Just East of Scandia Rd to Rolling Acre Rd / Bavaria Rd

RP 34.474 to RP 40.403

Introduction

The project calls for the resurfacing of the existing pavement using a 35 year design life. The existing pavement and the pavement condition are described in the MnDOT Pavement Design Memo authored by Tim Clyne dated January 31 2014[i]. A copy of that Memo is included in this report as Appendix A. The history of the pavement structure is shown in table 1 from that report.

Table 4-C1-1. Pavement history for TH 5

RP 34.474 to RP 40.403 - Location Description				
Year	**SP**	**Activity**	**Width**	**Depth**
1996	1002-63	Mill 2.5", overlay 4.0" or No mill, overlay 1.5"	28'	1.5"
1989	1002-49	Mill 3.0", overlay 3.0"	24'	3.0"
1976	1002-30	Misc. turn lane & bypass construction 3.5' Selected Grading Material, Var. Class 3 Agg, Var. (3.0"-8.0") Bituminous	13'	3.0"-8.0"
1969	1002-23	Overlay 3.0" (minimum)	24'	3.0"
1954	1002-14	Spot Grading 8"-14" Sand Gravel Subbase, 4" bituminous stabilized base, 2" bituminous	40' (grading) 24' (top)	2.0"
1950 1951	1002-09 1002-11	Bituminous 1.0"	13'	1.0"
1950 1949	1002-07 1002-02	Partial Regrading	36'	-
1934	-	1.0" Asphalt treated gravel added to existing gravel road		1.0"
-	-	Multiple maintenance activities since 1947: frost boil corrections, spot surface repairs, seal coats, crack seals, bituminous overlays	-	-

The existing pavement condition was described as:

> "Significant bottom up fatigue crackling and thermal cracking. Cracks deteriorate in wheel paths and where cracks intersect. Stripping in lower bituminous layers."

The pavement was cored and surveyed with GPR. The pavement depths were found to be highly variable but averaged 11.0 inches of Bituminous over 8 inches of Aggregate Base between RP 34.474 and RP 36.o8, and 8.0 inches of Bituminous over 9 inches. Aggregate Base between RP 36.08 and 40.403. Falling Weight Deflectometer test results indicated that the average R - Value for the subgrade soil was 12.2.

The bituminous depths shown from the GRP data are shown in the following plot from a GPR report and accompanying Excel file by Amy Grotbaus from Braun Intertec dated July 16, 2012.[ii]

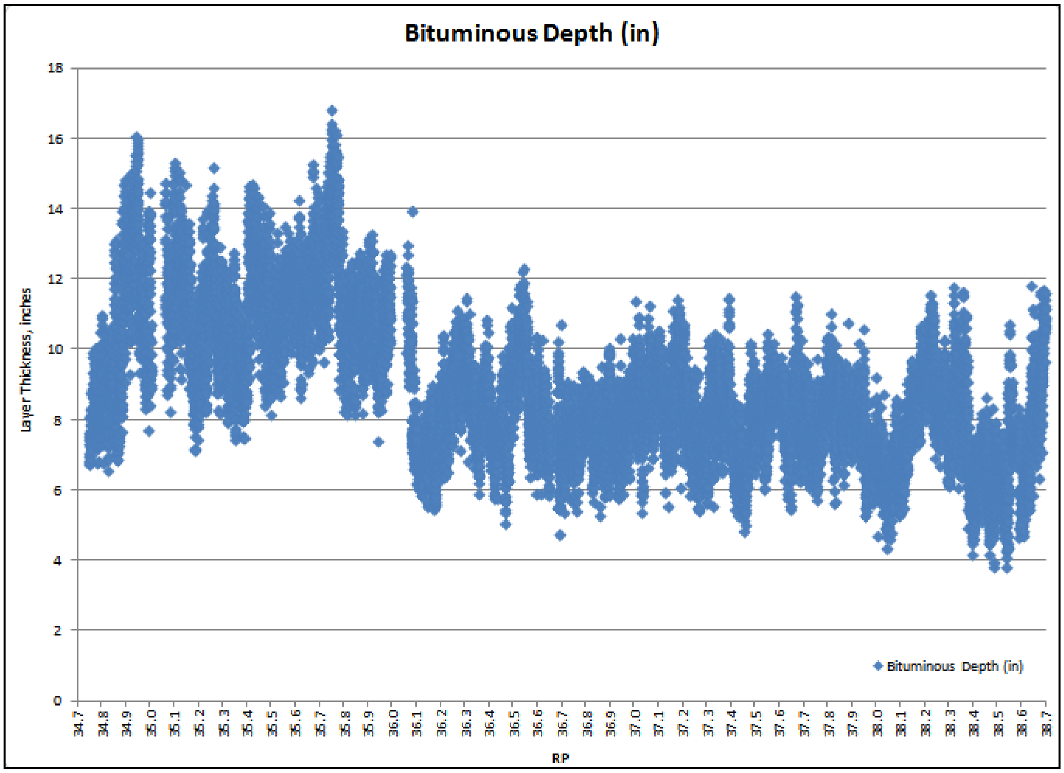


Figure 4-C1-1. Plot of bituminous thickness (Braun Intertec July 16 2012)

Photographs of typical pavement conditions observed along the project were provided by MnDOT from their photo log, two of which are shown below.


Figure 4-C1-2. Photos of TH 5 from MnDOT photo log files

The following figure shows several of the pavement cores taken on the project by Braun Intertec and included in their report.

Figure 4-C1-3. Photos of pavement cores from TH 5 (Braun Intertec)

The traffic Equivalent Single Axle Load (ESAL) prediction for the project was provided by a MnDOT Memo by Michael Corbett[iii]. The Memo provided the following ESAL estimates.

20 year Flexible ESAL 1,995,000
20 year Rigid ESAL 2.753,000
35 year Flexible ESAL 4,071,000
35 year Rigid ESAL 5, 618,000

The 2015 AADT was 17,300 and the growth rate was around 3.4%.

In the January 31, 2014 MnDOT Pavement Design Structure Memo, Mr. Tim Clyne recommended the following flexible and rigid pavement designs.

Section 1

Flexible 20 year design - Pre grind 10 inches of the existing pavement using full depth reclamation (FDR) and treat 6 inches with engineered emulsion then overlay with HMA. The resulting pavement section would be:

5/8" UTBWC
2.5" SPWEA34OC
6.0" Engineered Emulsion Treated Base
4.0" FDR Base
8.0" Granular Base
21 1/8" Total

Section 2

Section 2 is much the same except the existing pavement is thinner (8 inches), so the pre-grind depth is less. The resulting pavement section is:

5/8" UTBWC
2.5" SPWEA34OC
6.0" Engineered Emulsion Treated Base
2.0" FDR Base
8.0" Granular Base
19 1/8" Total

The 35 year rigid design is the same for both sections; just the thickness of the existing pavement changes because it is thicker in section 1. The recommendations included milling 5 " of the existing pavement in section 1 and 4" in section 2. The resulting pavement thickness is:

7.0' PCC (15'X13" Panels w/ 1" Dowels)
6.0" Existing HMA (which changes to 4.0" in section 2)
8.0" Granular Base (9" in section 2)
21" Total

rePave Scoping Design Runs

The following figures will show the screen shots from the rePave program based on the data provided from MnDOT on this project.

The first screen for rePave is for the user to enter general project location information.

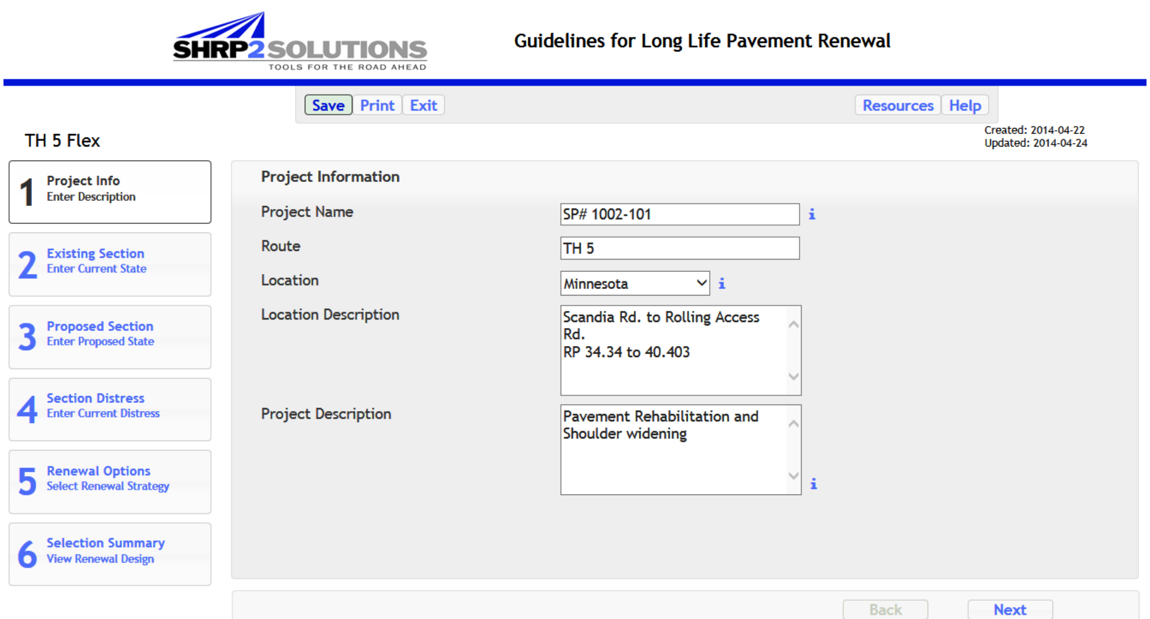


Figure 4-C1-4. rePave project information screen with general information on project

The second step in the rePave program is to enter the typical pavement section information for the existing pavement. In this case since the project is separated into two sections based on the thickness of the existing pavement the second section with the thinner pavement will be used in the runs. Check runs will then be made on the first section to see if there is a change in the scoping design recommendations. The following rePave screen shows the existing pavement for section 2.

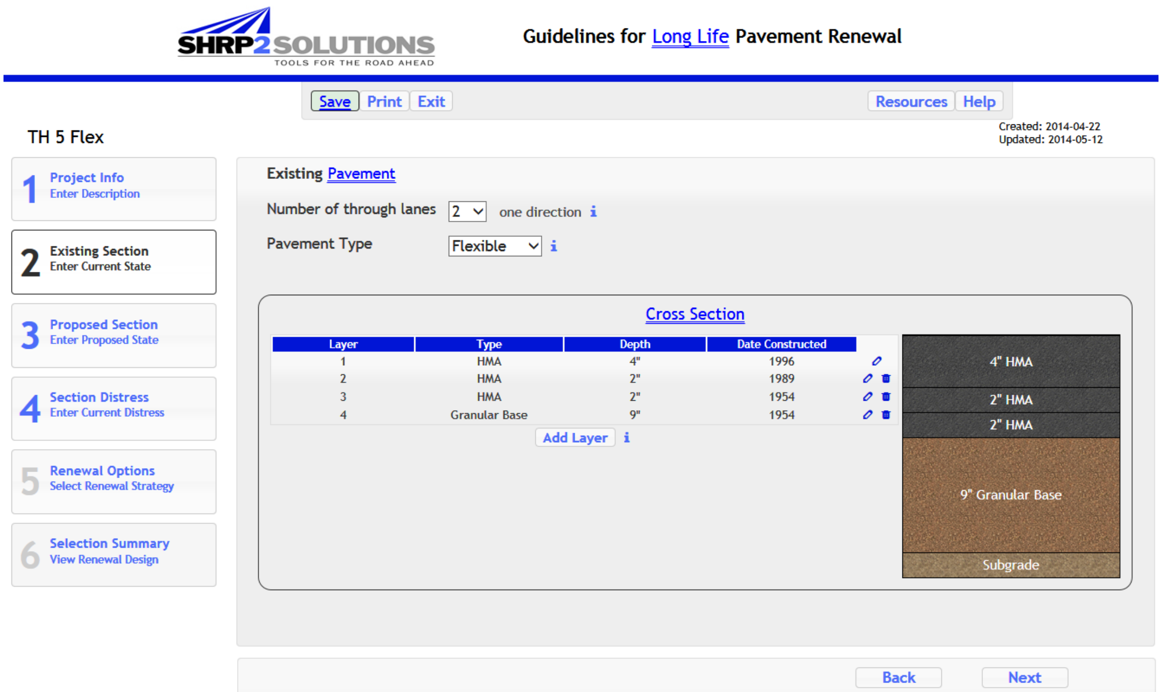


Figure 4-C1-5. rePave screen for existing pavement section

The third step in the process is to enter the basic design information for the project. The traffic information was adjusted to match the ESAL estimates from MnDOT for the project. A height restriction was also entered just to show how that feature adds a warning in the design summary.

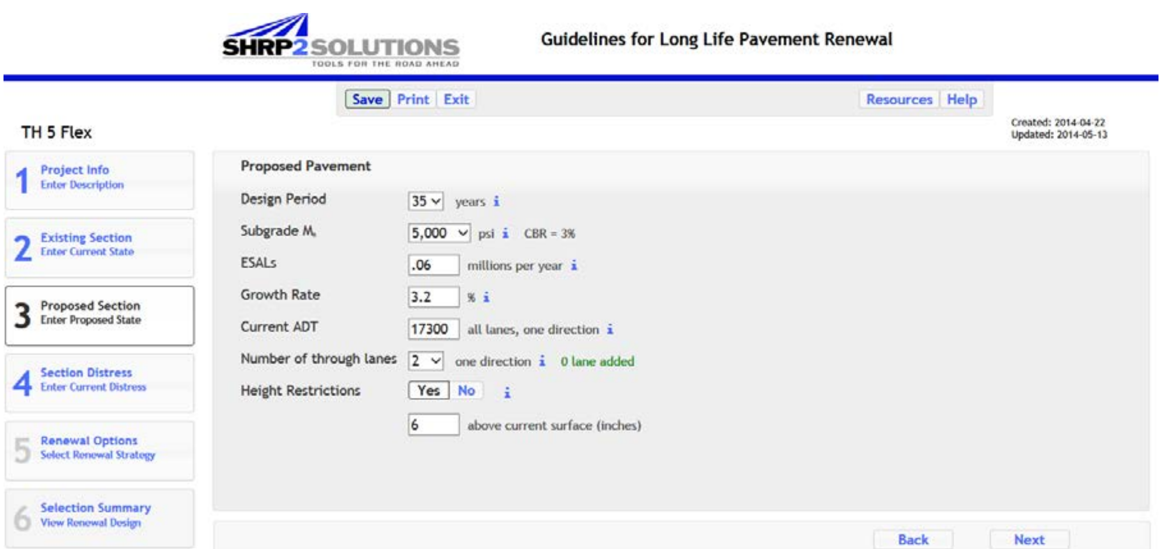


Figure 4-C1-6. rePave screen for traffic and soils information

The fourth screen deals with the condition of the existing pavement. Distresses common for both flexible and rigid pavement are included. In this case since the pavement is flexible only those distressed are shown. The MnDOT report indicated longitudinal cracking which can be seen in the photos in Fig. 4-C1-2. This type of distress can also be characterized as low severity fatigue cracking as shown in Fig. 4-C1-7.

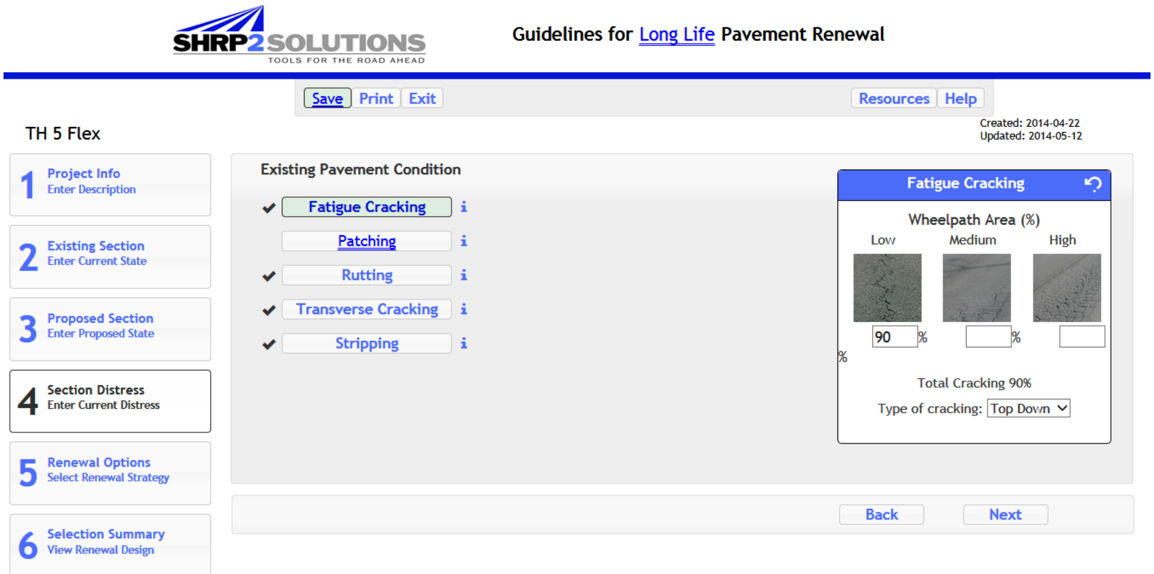


Figure 4-C1-7. rePave screen 4 showing entry for fatigue cracking

There are also provisions for adding quantities for the remaining distress categories. There was only a limited amount of patching so no value was entered for that distress category.

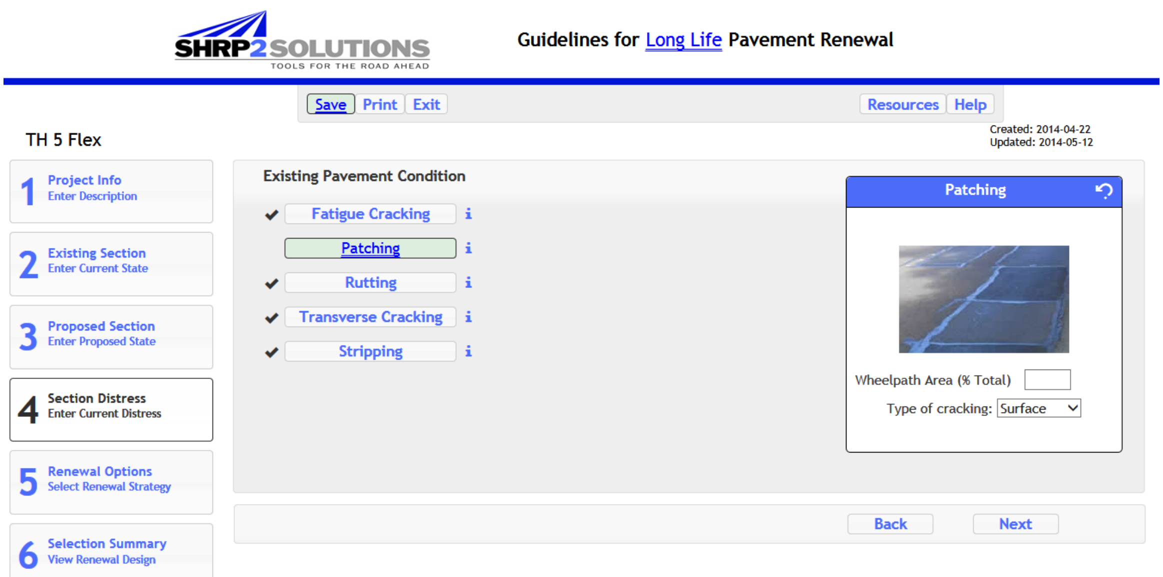


Figure 4-C1-8. rePave screen for patching quantities - no quantity entered

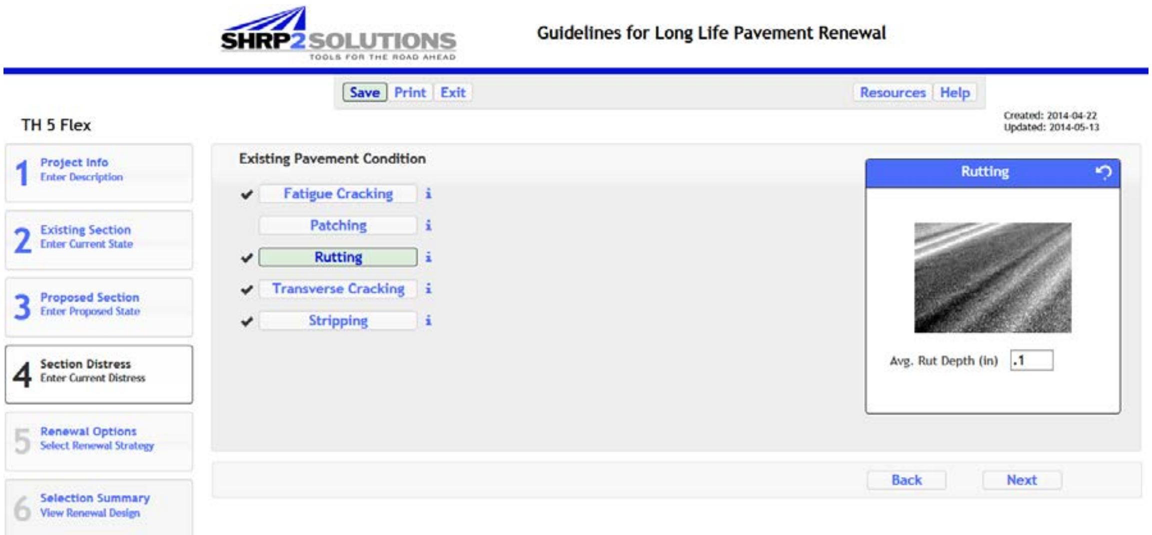


Figure 4-C1-9. rePave screen for rutting quantities

The rePave screen for transverse cracking asks for the crack spacing to be entered in terms of the number of cracks per 100 ft. Crack spacing or length of transverse crack should be converted to the number of cracks per 100 ft. Quantities are entered to provide a record of the distress. The long life guidance from the SHRP R23 Project will require mitigation of the transverse cracking for any flexible renewal approach.

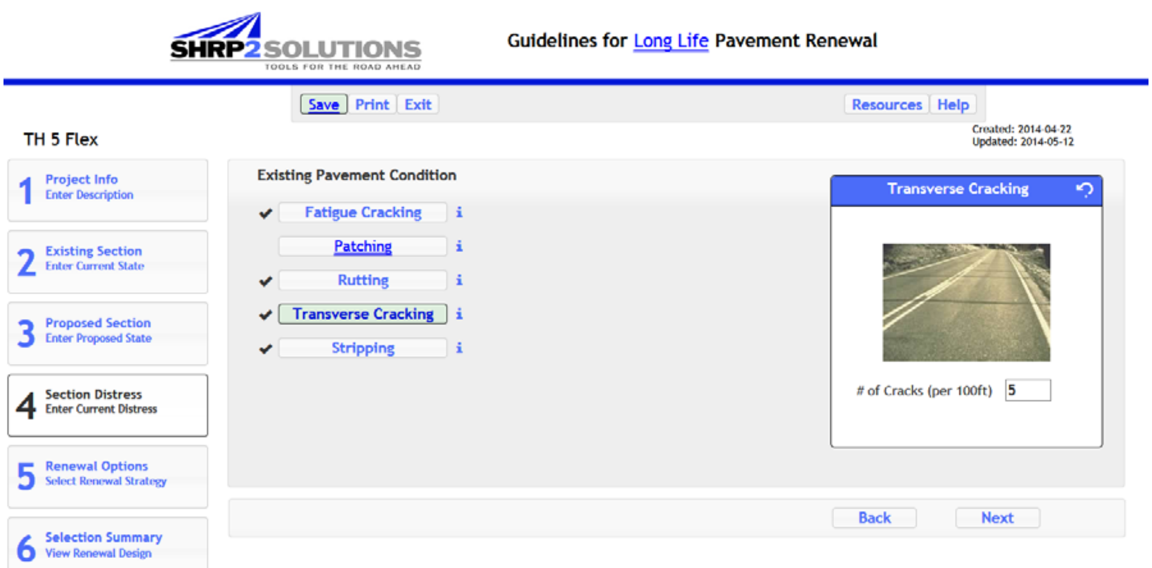


Figure 4-C1-10. rePave screen for transverse cracking

The next pavement distress screen will show if stripping is present and which layers are involved. As with transverse cracking the long life guidance from the SHRP 2R 23 Project will require some form of mitigation of the stripped layers for any flexible renewal approach.

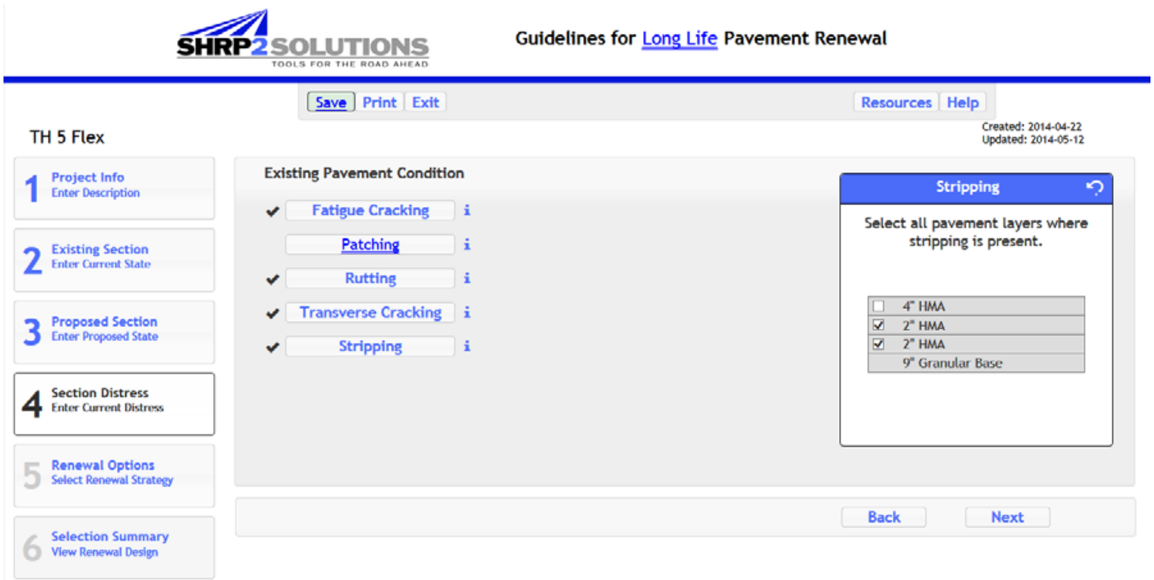


Figure 4-C1-11. rePave screen for entering layers where stripping is present

After entering the project data the program asks the user to confirm that the data entered is correct as shown in the screen shot below.

Figure 4-C1-12. rePave screen to confirm Input data

After confirming the design data the next step is to select one of the potential options available to reconstruct the existing pavement. The alternatives may be either flexible or rigid and could also include composite or modular pavements. All approaches will be presented starting with flexible.

In the first case replacement of the existing pavement with a flexible pavement is checked.

Figure 4-C1-13. rePave screen with flexible treatments and replacement checked

The next rePave screen shows a summary of the design approach selected.

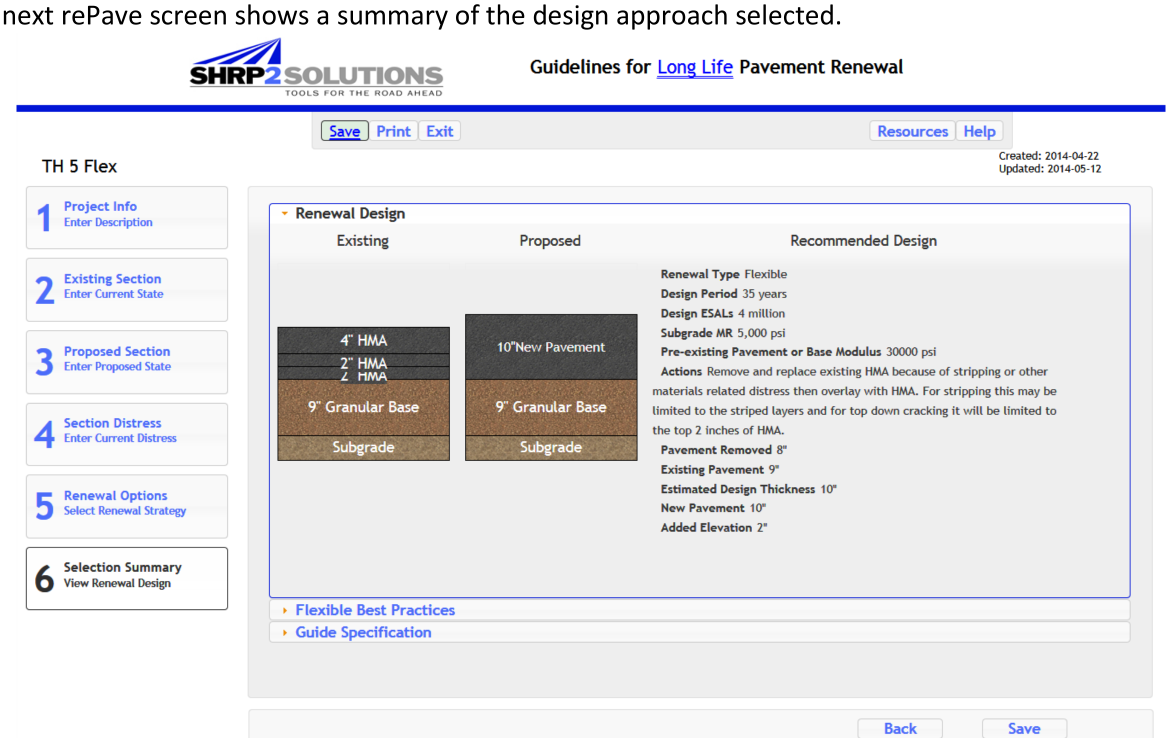


Figure 4-C1-14. rePave screen where flexible replacement was selected

At this point in the program a number of alternative approaches can be considered for both flexible and rigid approaches as well as composite and modular pavements. The last two are based on the research performed under SHRP 2 Project R21 and Project R05. For the flexible pavement two other approaches are available, one for simple reclaiming of the existing HMA and one for reclaiming and treating the reclaimed material to build a bound base. This approach can be seen in the next two figures.

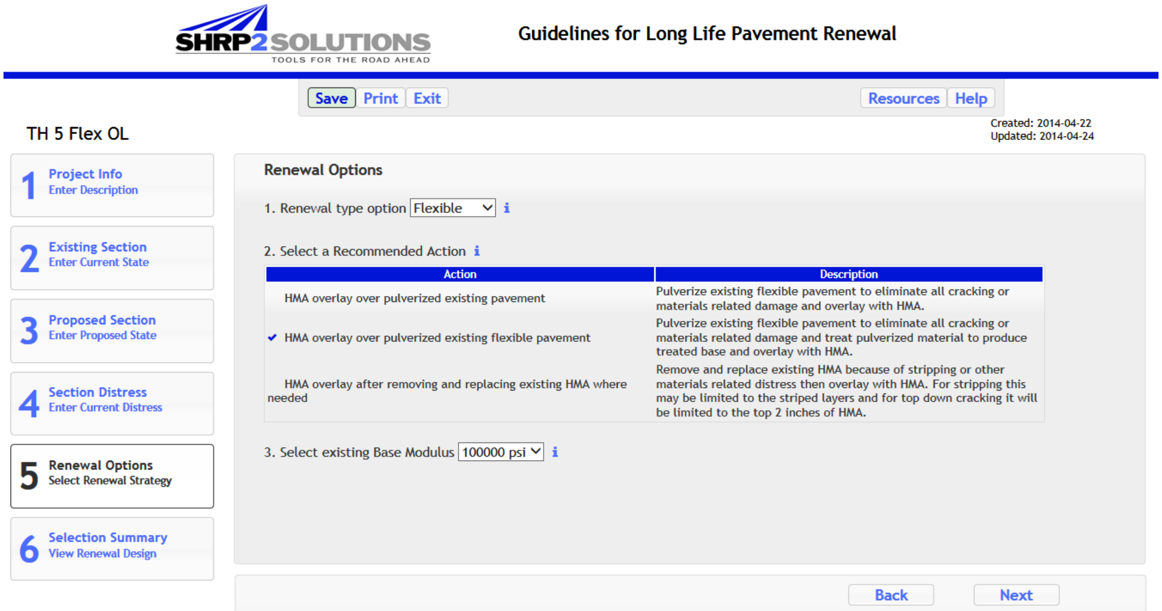


Figure 4-C1-15. rePave screen showing reclamation option with emulation treatments

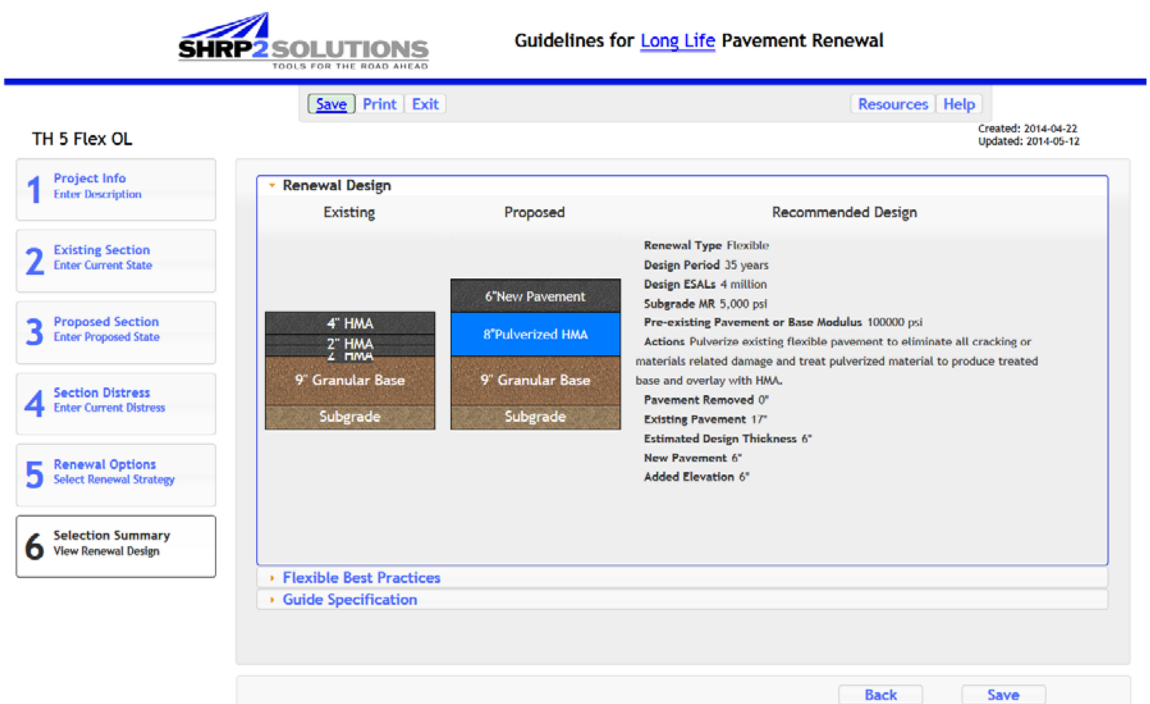


Figure 4-C1-16. rePave screen with design summary for reclaiming the existing pavement

MnDOT did consider full depth reclamation of the existing pavement but they treated the top 6" of the reclaimed material with emulsion and 3 1/8 inch of HMA. The difference between the rePave design guidance and MnDOT will be discussed later but it's due to the ESAL ranges in the design tables. In short the MnDOT design is for 20 years and a little less than 2 million ESALs while the minimum design table in rePave is <10 million ESALs even though the program shows about 4 million ESALs over 35 years.
The next set of design options will be for rigid approaches which consist of a remove and replace option with new pavement and an unbonded PCC overlay option which are shown in the next 4 screen shots.

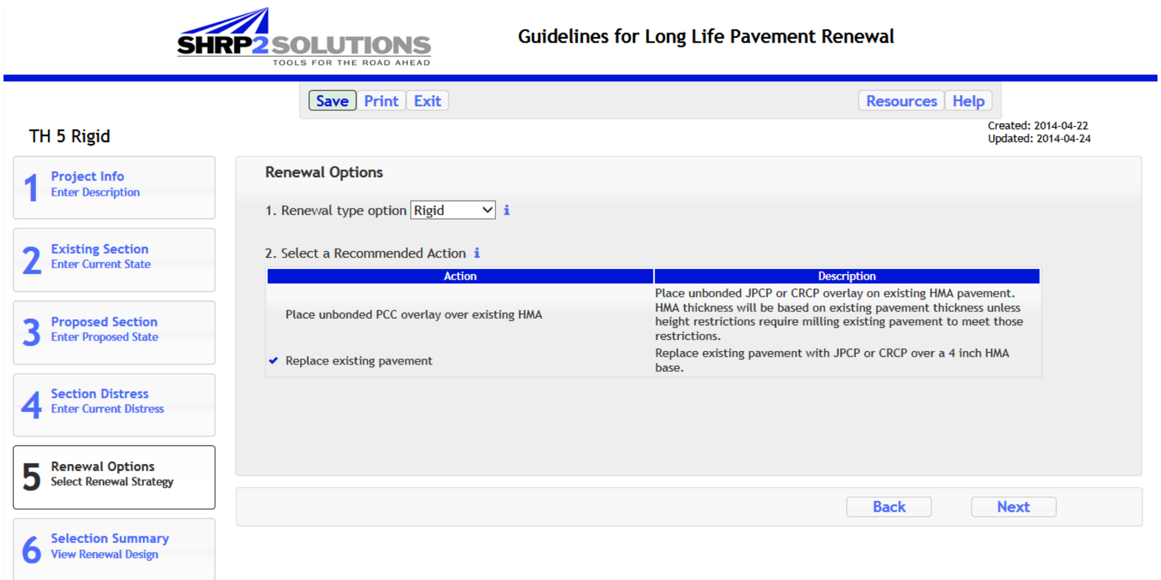


Figure 4-C1-17. rePave screen showing rigid remove and replace option

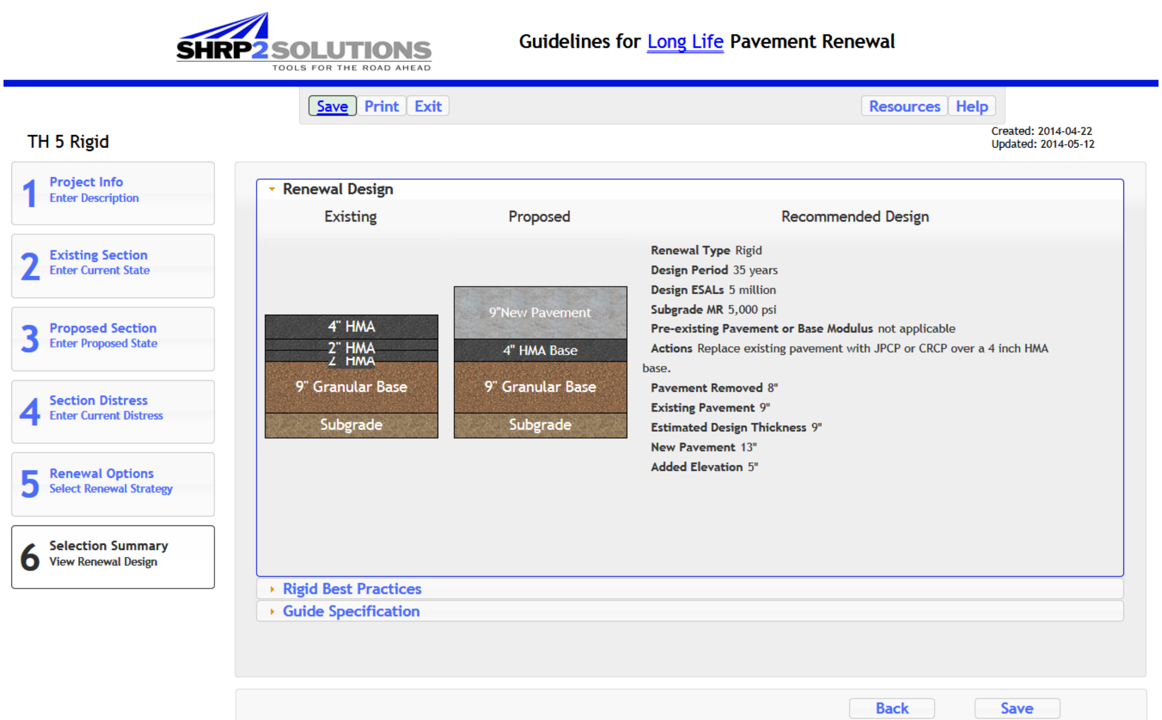


Figure 4-C1-18. rePave screen showing design summary for rigid remove and replace

The following two figures show the rePave screens for the unbonded PCC overlay options.

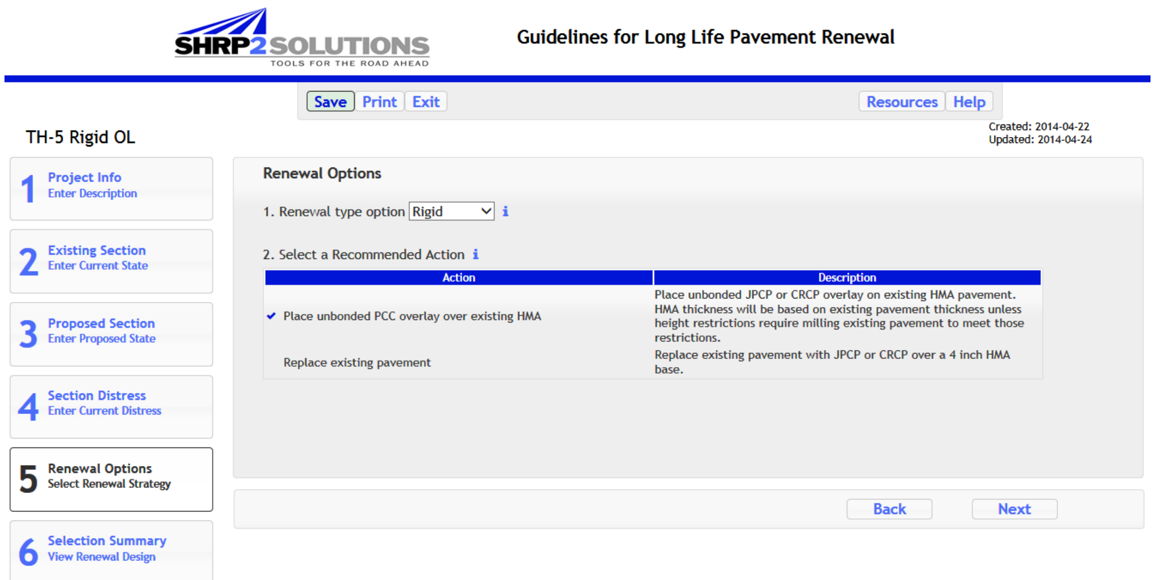


Figure 4-C1-19. rePave screen showing unbonded PCC overlay option

Figure 4-C1-20. repave screen showing design summary for the unbonded PCC overlay

In this particular case the design summary shows a warning that the design thickness exceeded the height restriction (entered in step 3 and seen in figure 4-C1-6). To check on the possibility of milling off some of the existing HMA the existing roadway section in step 2 can be reduced 3 inches or more and program re-run to check for design changes as shown below.

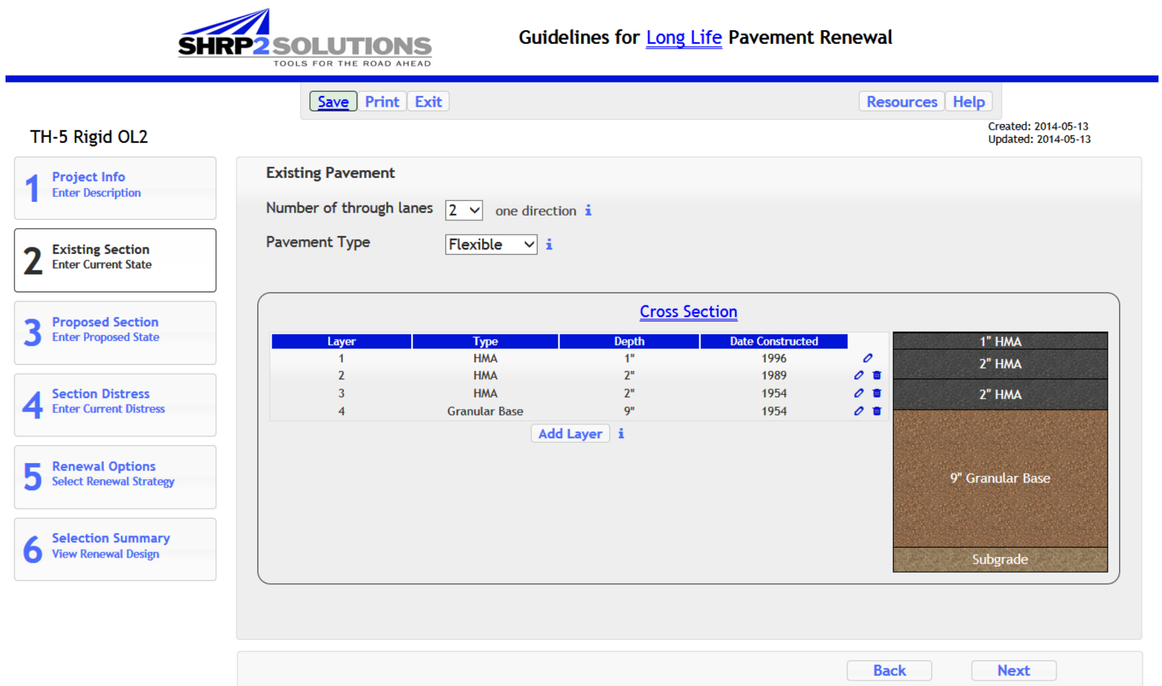


Figure 4-C1-21. rePave screen showing the editing of the existing HMA to match a 3 inch removal

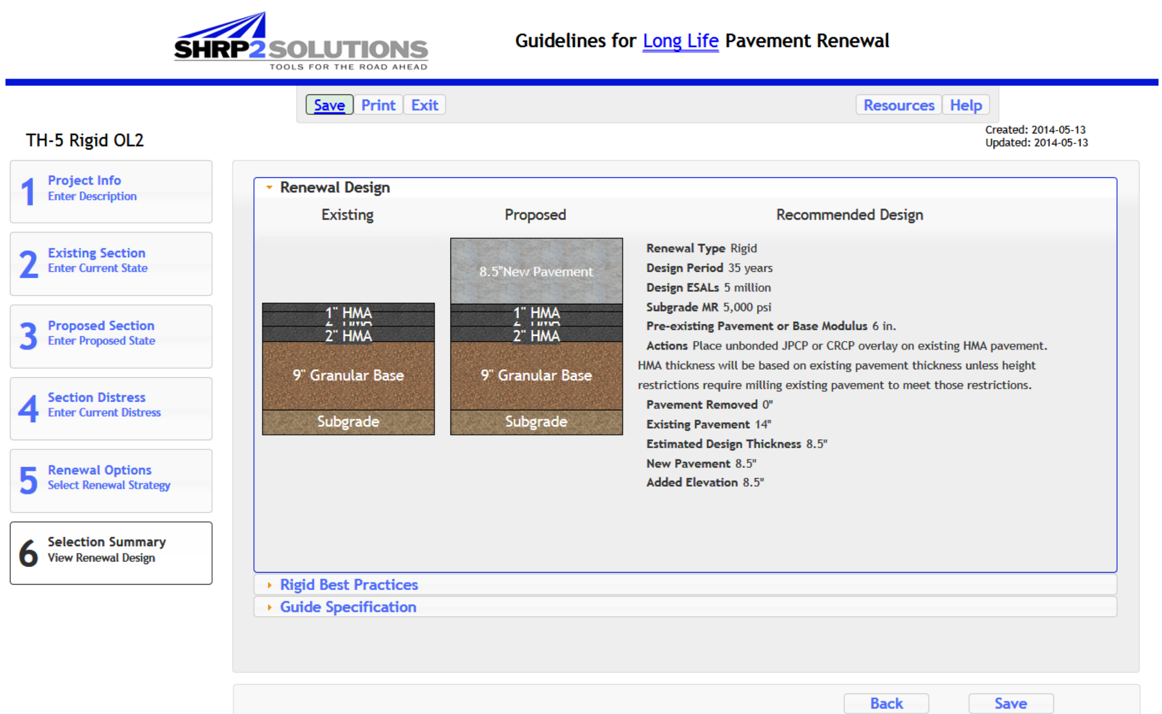


Figure 4-C1-22. rePave screen showing design summary for unbonded PCCX overlay after milling 3" HMA

This design is similar to that established by MnDOT for this project. Again there is a difference in pavement design thickness that will be discussed later in this report. The MnDOT design has 7 inches of PCC while the rePave design shows an 8 1/2 inch overlay thickness. The difference is due to the minimum ESAL levels included in rePave, 10 million ESALs vs 5 Million ESALs in the MnDOT design. The rePave design tables also include a minimum thickness to ensure long life performance of 35 to 50 years.

The next set of design options are for composite pavements based on the SHRP 2 R21 Project, "Composite Pavement Systems Volume 1 HMA/PCC Composite Pavements in Report S2 R21-RR2" and "Composite Pavement Systems Volume 2 PCC/PCC Composite Pavements in Report S2 R21-RR3.

The following figure shows the four options available for composite pavements removing and replacing the existing pavements as well as for unbonded overlays using both HMA/PCC and PCC/PCC composite pavements.

Figure 4-C1-23. rePave screen showing the four approaches using composite pavements

The following four figures show the design summary for the four composite approaches shown in figure 4-C1-23 above. The design summaries will be shown in the order listed in the action list. In the program the description of the action also includes a hot link to the SHRP 2 Report that describes the composite pavement research.

In the first case the PCC pavement thickness is similar to the MnDOT rigid design based on the advantage of the composite pavement where the asphalt layer in the HMA/PCC pavement can effectively reduce the thickness of the PCC layer. Details can be found in Report S2 R21-RR2 noted above.

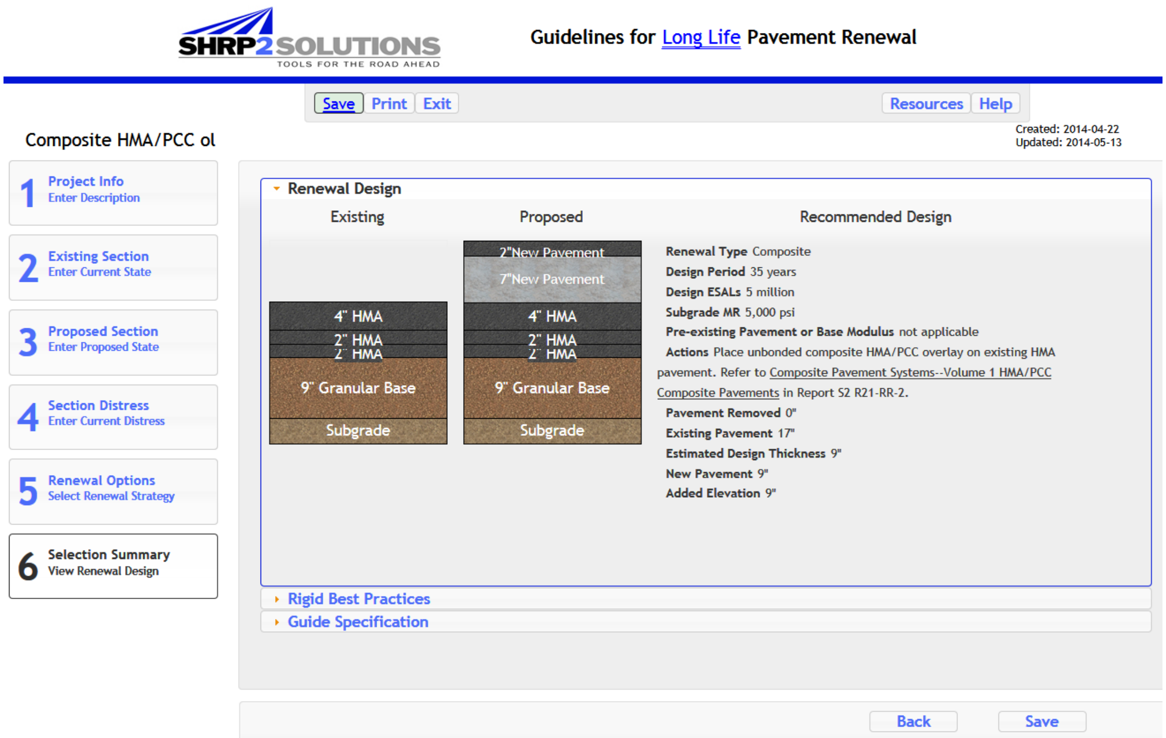


Figure 4-C1-24. rePave screen showing design summary for an unbonded composite HMA/PCC overlay

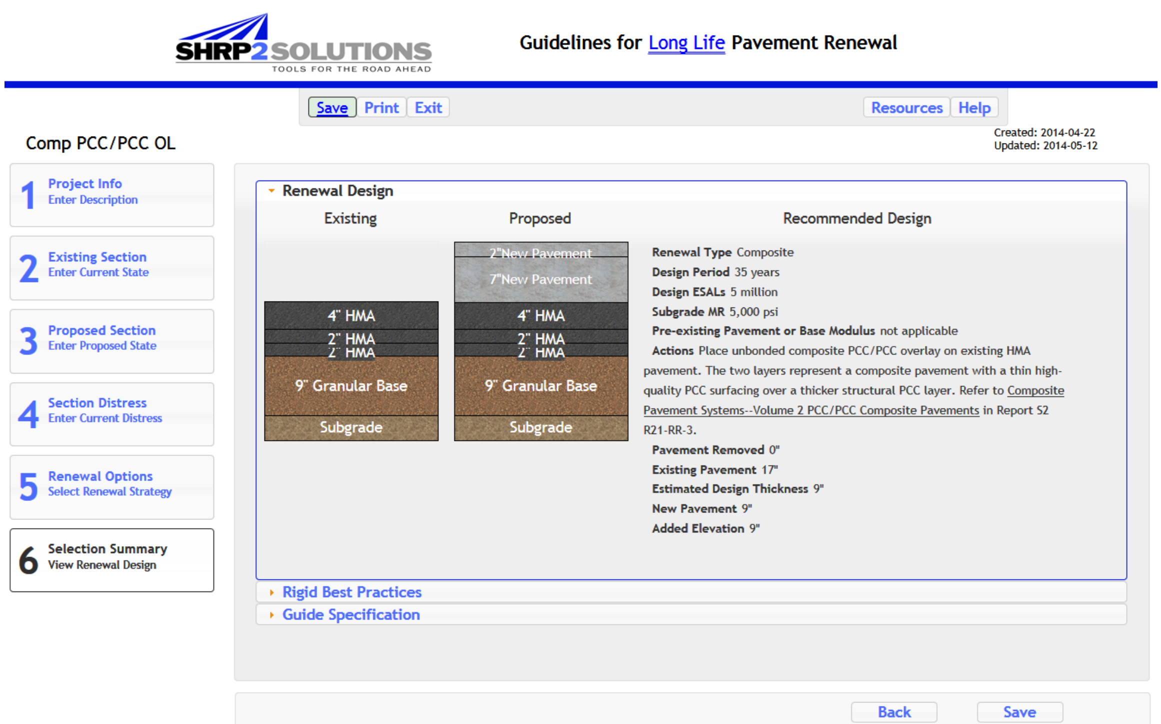


Figure 4-C1-25. rePave screen showing design summary for unbonded PCC/PCC composite overlay

The following two design summaries for replacing with composite pavement includes the use of a HMA base layer the same as that used for rigid pavements to reduce the risk of pumping and faulting.

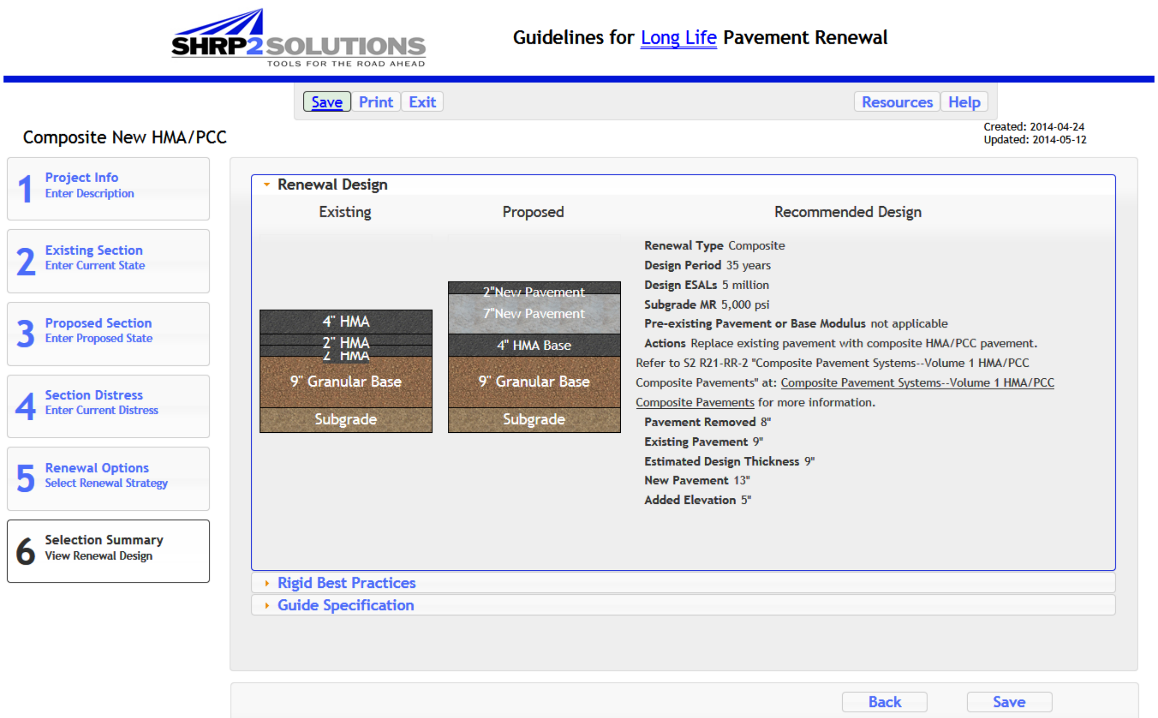


Figure 4-C1-26. rePave screen showing design summary for replacement with HMA/PCC Composite pavement

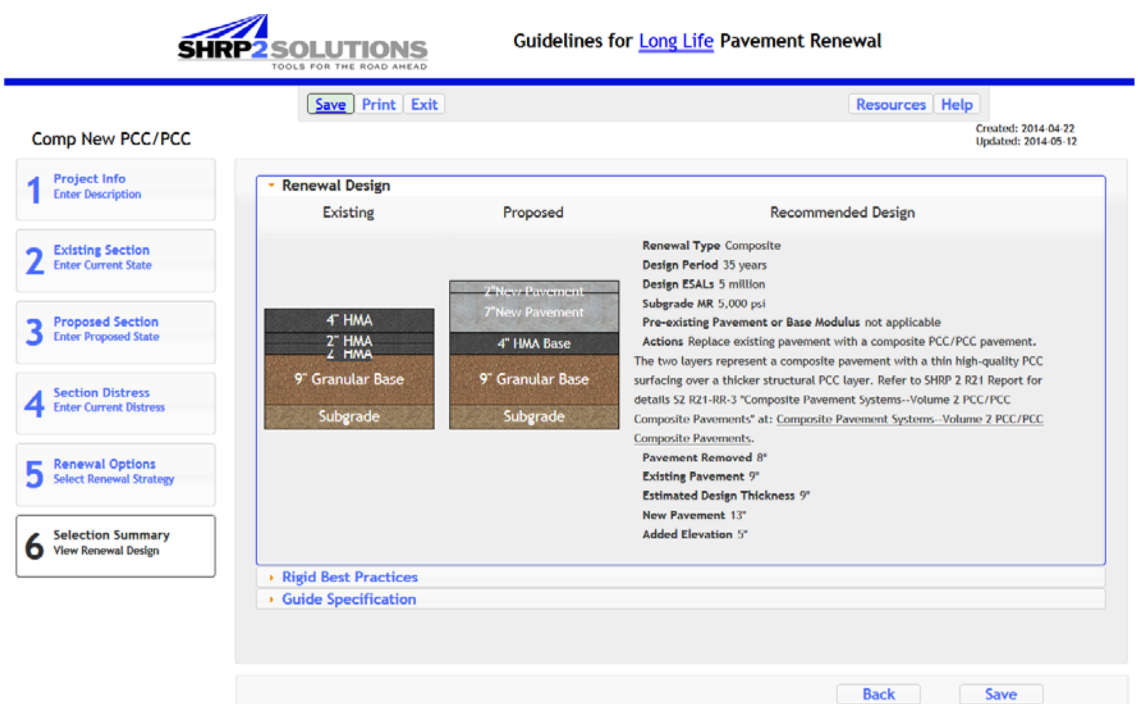


Figure 4-C1-27. rePave screen showing design summary for replacement with HMA/PCC Composite pavement

The last four designs options are for modular pavement systems. Guidance for the design and use of modular of pre-cast pavement systems can be found in the SHRP 2 report S2 - R05-RR-2 "Precast Concrete

Pavement Technology". The following figure shows the list of pre-cast pavement options considered in the rePave guidance. Standard precast pavement is considered as well as pre-stressed precast pavement for both unbonded overlays and removed and replaced pavement.

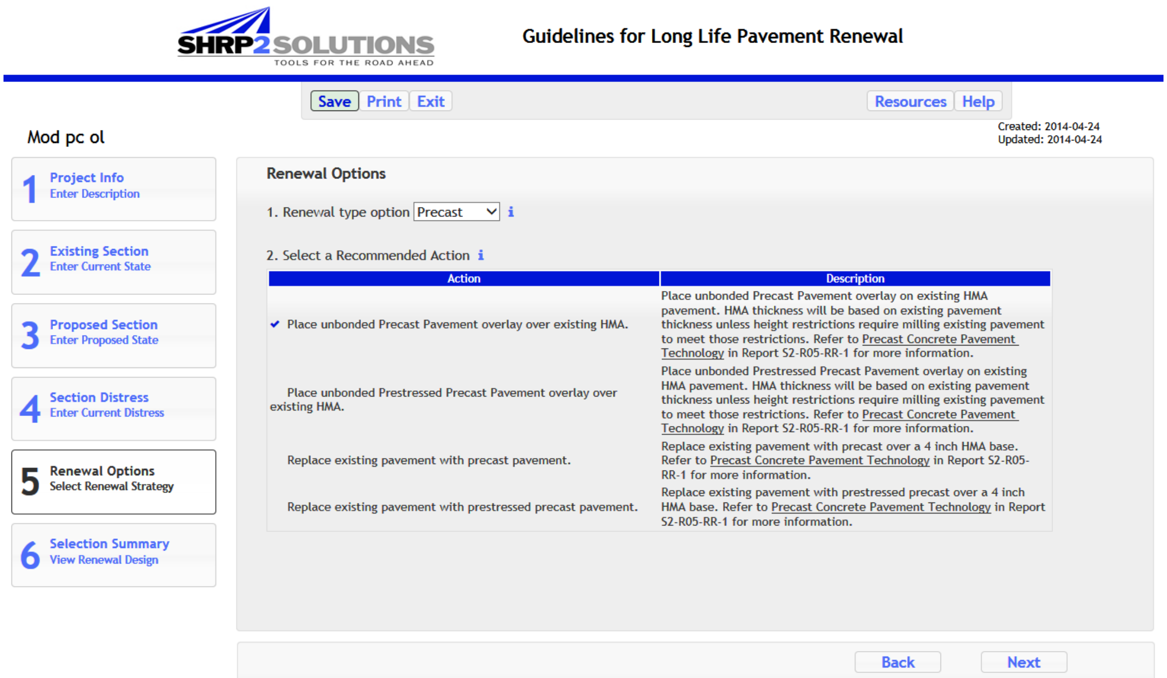


Figure 4-C1-28. rePave screen showing list of pre-cast pavement actions

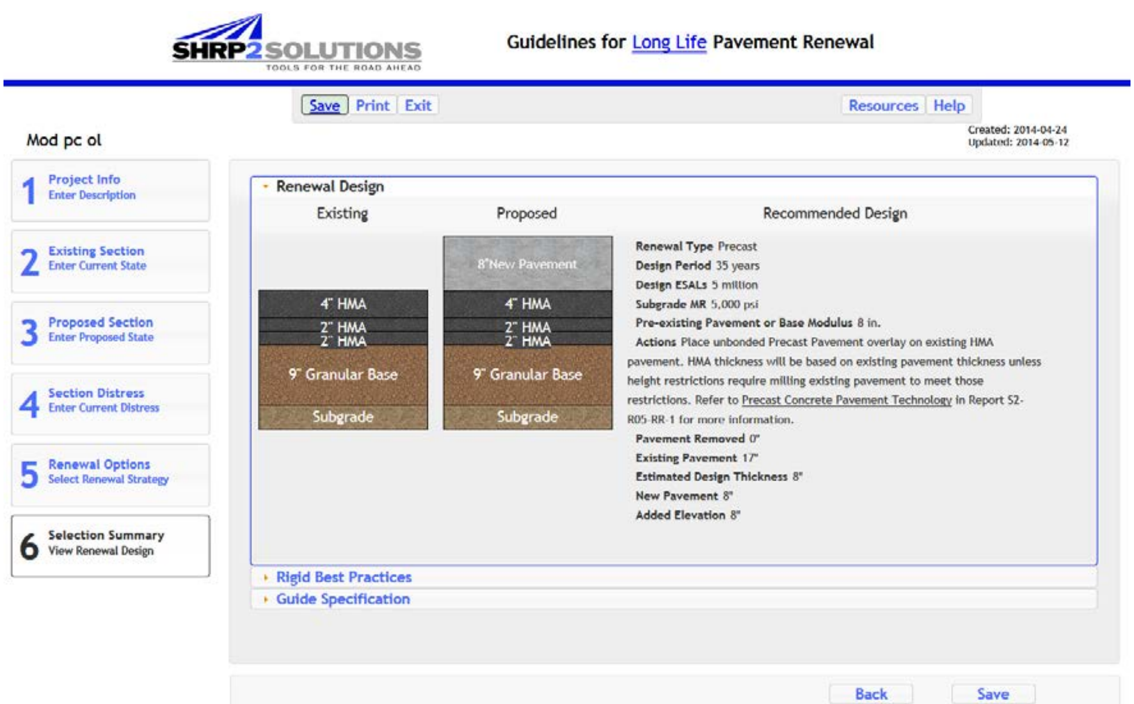


Figure 4-C1-29. rePave screen showing design summary for unbonded pre-cast PCC overlay

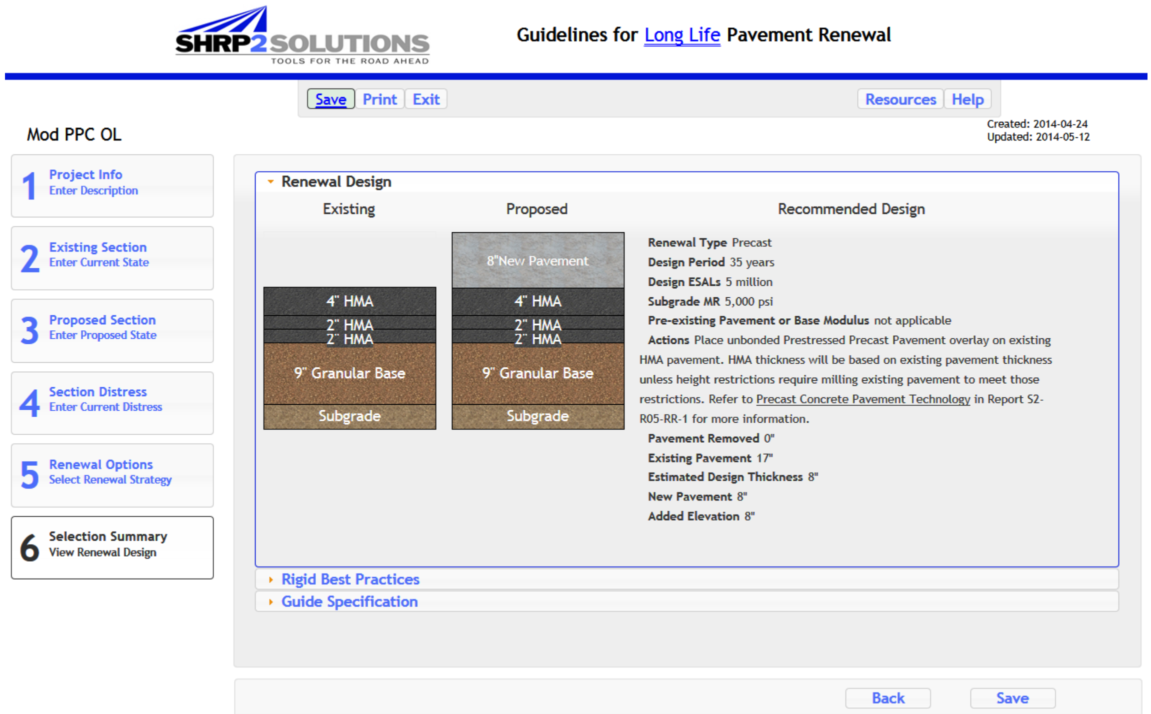


Figure 4-C1-30. rePave screen showing design summary for unbonded pre-stressed pre-cast PCC overlay

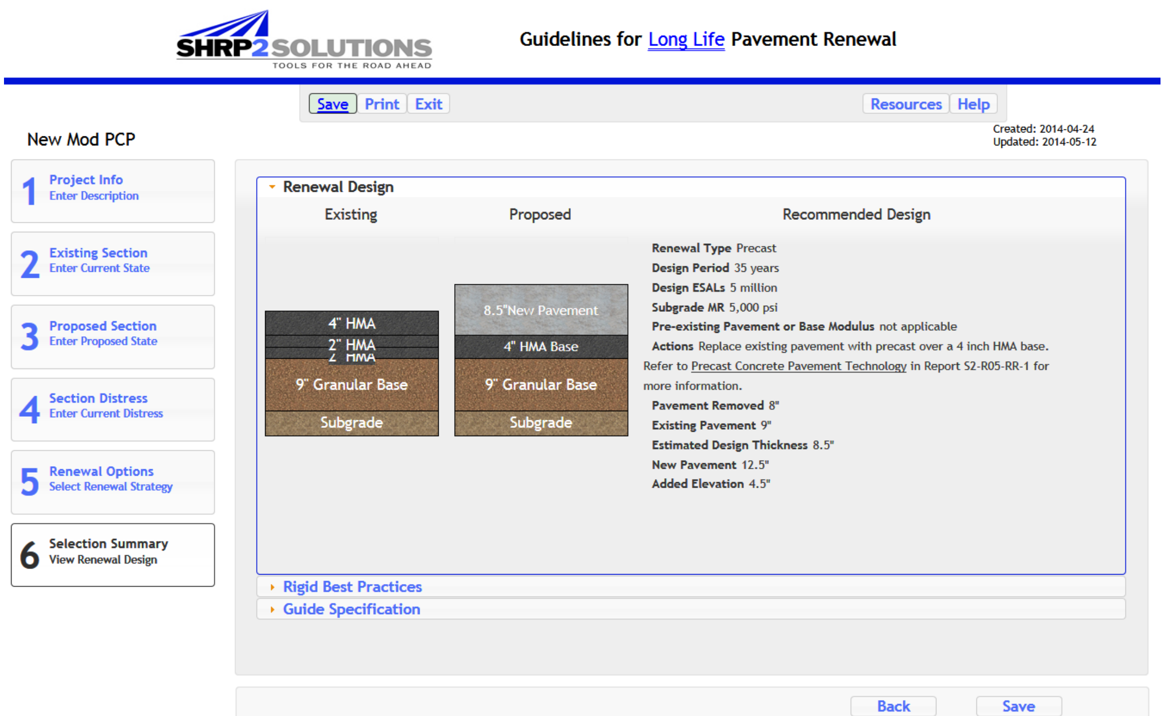


Figure 4-C1-31. rePave screen showing design summary for replacement with pre-cast PCC

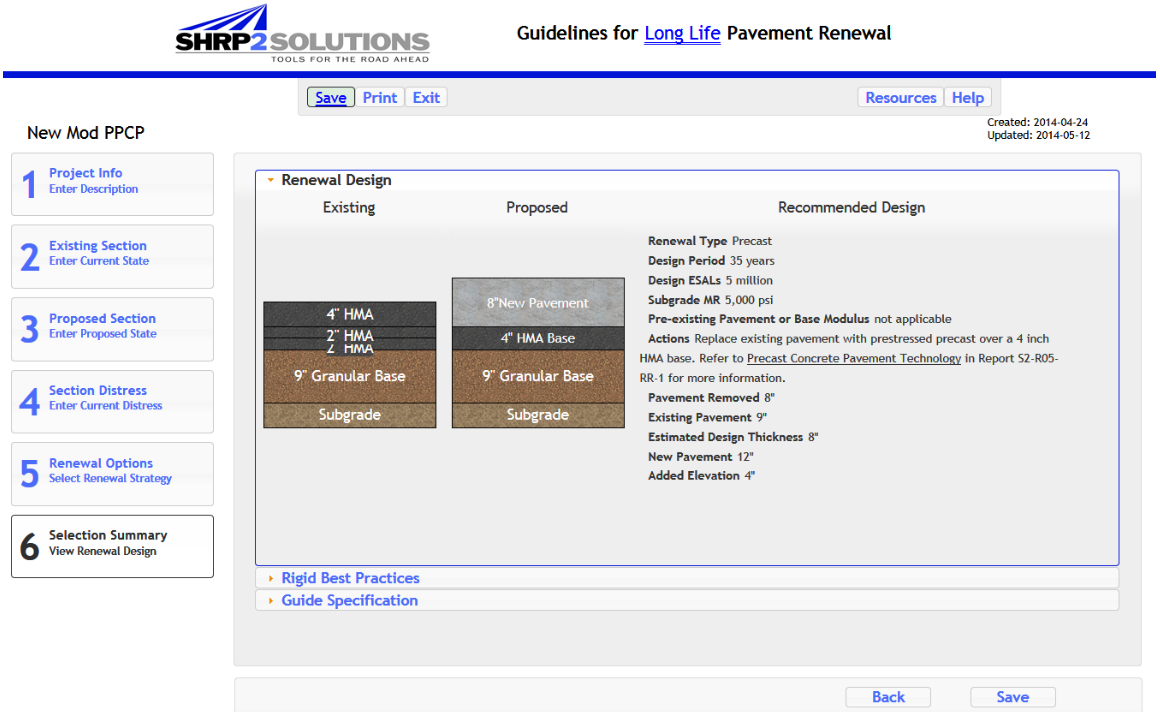


Figure 4-C1-32. rePave screen showing design summary for replacement with pre-stressed pre-cast PCC

Summary

The following is a comparison between the pavement designs developed by MnDOT for TH 5 and the R23 design guidance produced by rePave.

The first table shows the difference between the flexible pavement design developed by MnDOT and that provided by rePave.

Table 4-C1-2. Comparison of flexible pavement designs

	MnDOT	rePave	rePave
Design Life	20 years	35 years	35 years
ESALs	2 Million	10 Million	10 Million
Approach	Reclaim	Reclaim	Reconstruct
HMA	3.1"	6"	10"
Emulsion treated base	6"	6"	
Aggregate Base	11"	11"	9"
	SG	SG	SG

The most significant difference noted between the MnDOT design and the rePave design is in the HMA pavement thickness. This is largely due to the traffic levels used in the design. MnDOt's standard design life for flexible pavements is 20 years while the minimum design life considered in rePave is 35 years for long life design. Additionally, the minimum design traffic considered in rePave is ≤ 10 million ESALs. The design table (excerpt from table 4-A-26 "Scoping Methodology") in rePave for flexible pavements is shown below.

Table 4-C1-3. Excerpt from Table 26 in Scoping Methodology resource in rePave

HMA Overlay for Subgrade M_R = 5,000 psi.

ESALs (millions)	Existing Pavement or Base Modulus			
	30,000 psi	50,000 psi	75,000 psi	100,000 psi
≤10	10.0	9.0	8.0	6.0
10-25	11.0	10.0	8.5	6.5
25-50	12.0	11.0	9.0	7.0
50-100	13.0	11.5	9.5	7.5
100-200	14.0	12.0	10.0	7.5

The lowest ESAL value considered in rePave is ≤10 million ESALs, which is a 10 million ESAL design even though it is indicated as equal to or less than.

The 35 year flexible ESAL value for the project would be 4 million ESALs. MnDOT did not provide a 35 year flexible pavement design but that design probably would have increased the pavement thickness about an inch. Clearly the difference in HMA thickness between the MnDOT design and rePave is the minimum traffic loading developed for rePave based on long life freeway type applications. Additionally, there may also have been a difference in the stiffness value attributed to the emulsion treated base. The maximum base stiffness set in the rePave design tables for flexible pavements is a resilient modulus of 100,000 psi. It is not clear what value was considered in the MnDOT design, but it may have been higher.

The next table shows the difference between the rigid pavement design developed by MnDOT and that provided by rePave.

Table 4-C1-4. Comparison of rigid pavement designs

	MnDOT	rePave	rePave
Design Life	35 years	35 years	35 years
ESALs	5 Million	10 Million	10 Million
Approach	UBOL*	UBOL*	Reconstruct
PCC	7"	8.5"	9"
HMA	5"**	5"	4
Aggregate Base	9"	9"	9"
	SG	SG	SG

*Unbonded Overlay

** MnDOT milled off all but 5" of the existing HMA to reduce the pavement elevation.

For the rigid pavement design the MnDOT design is also thinner than the rePave design. Similar to the flexible design the traffic loading in terms of ESALS is lower in the MnDOT design compared to that used in the rigid design tables in rePave. The MnDOT design is for 5 million ESALs, while the minimum rePave design is for 10 million ESALs. This difference would increase the pavement thickness about one inch. During the R23 study it was found that there appeared to be a minimum thickness threshold at about 8.5 inches where the risks of not providing long life performance increased significantly. One example is shown in the following figure from a report by Smith et al.[iv] This reference and others can be found in the Rigid Best Paving Practices resource document that can be downloaded from rePave. Because of this finding the minimum unbonded PCC pavements thickness used in rePave have been limited to 8.5".

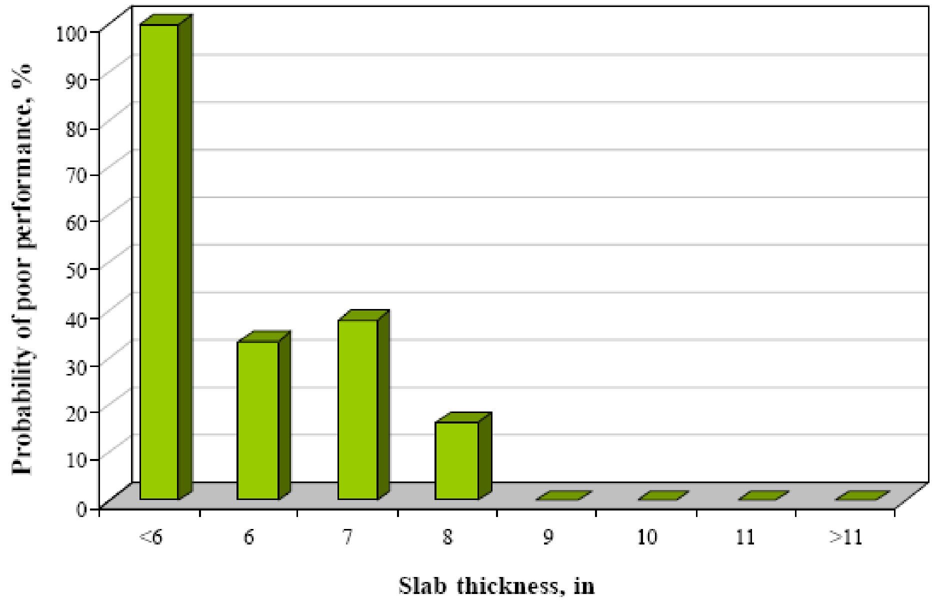


Figure 4-C1-33. Slab thickness versus probability of poor performance for unbonded JPCP overlays (Smith et al, 2002)

In addition to the standard PCC designs rePave can also provide design options for "Composite" pavements based on the SHRP 2 R21 Research Project and "Modular" pavements based on the SHRP 2 R05 Research Project. Those designs are shown in the following two tables.

Table 4-C1-5. Comparison of "Composite" pavement designs

	MnDOT	rePave	rePave	rePave	rePave
Design Life	35 years	35 years	35 years	35 years	35 years
ESALs	5 Million	10 Million	10 Million	10 Million	10 Million
Approach	UBOL*	UBOL*	Reconstruct	UBOL*	Reconstruct
PCC	7"	2/7"**	2/7"**	2/7"***	2/7"***
HMA	5"	8"	4	8"	4
Aggregate Base	9"	9"	9"	9"	9"
	SG	SG	SG	SG	SG

*Unbonded Overlay
**HMA over PCC
***PCC over PCC

Table 4-C1-6. Comparison of "Modular" pavement designs

	MnDOT	rePave	rePave	rePave	rePave
Design Life	35 years	35 years	35 years	35 years	35 years
ESALs	5 Million	10 Million	10 Million	10 Million	10 Million
Approach	UBOL*	UBOL*	Reconstruct	UBOL*	Reconstruct
PCC	7"	8"**	8.5"**	8"***	8"***
HMA	5"	8"	4	8"	4
Aggregate Base	9"	9"	9"	9"	9"
	SG	SG	SG	SG	SG

*Unbonded Overlay

**Precast PCC

***Prestressed Precast PCC

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[1] Minnesota Department of Transportation, Office Memorandum To Scott McBride District Engineer, from Tim Clyne Materials Program Delivery Engineer dated January 31, 2014 Subject Pavement Design Structure.

[1] Letter Report from Amy Grotbaus Bran Intertec to Mr Chris Kufner MnDOT "Ground Penetrating Radar Evaluation Results "Trunk Highway (TH 5) between Norwwood Young America and Victoria Minnesota", July 16, 2012.

[1] MnDOT Memo from Michel Corbertt (Metro District ESAL forecaster) to Gean Hicks (Section Director) July 25th 2012 Subject : Traffic Forecast.

[1] Smith, K., Yu, H., and Peshkin, D. (2002), “Portland Cement Concrete Overlays: State of the Technology Synthesis,” Report No. FHWA IF-02-045, Federal Highway Administration, April 2002.

Appendix 4-C2

WSDOT SHRP 2 R23 Test Case

I-90/Oaks Ave Vic to Elk Heights Rd Vic WB–

Replace/Rehab Concrete

I-90 MP 84.21 to 93.3

Appendix 4-C2

I-90/Oaks Ave Vic to Elk Heights Rd Vic WB – Replace/Rehab Concrete

I-90 MP 84.21 to 93.3

Introduction

The project is located on Interstate 90 a little over 85 miles east of Seattle Washington.

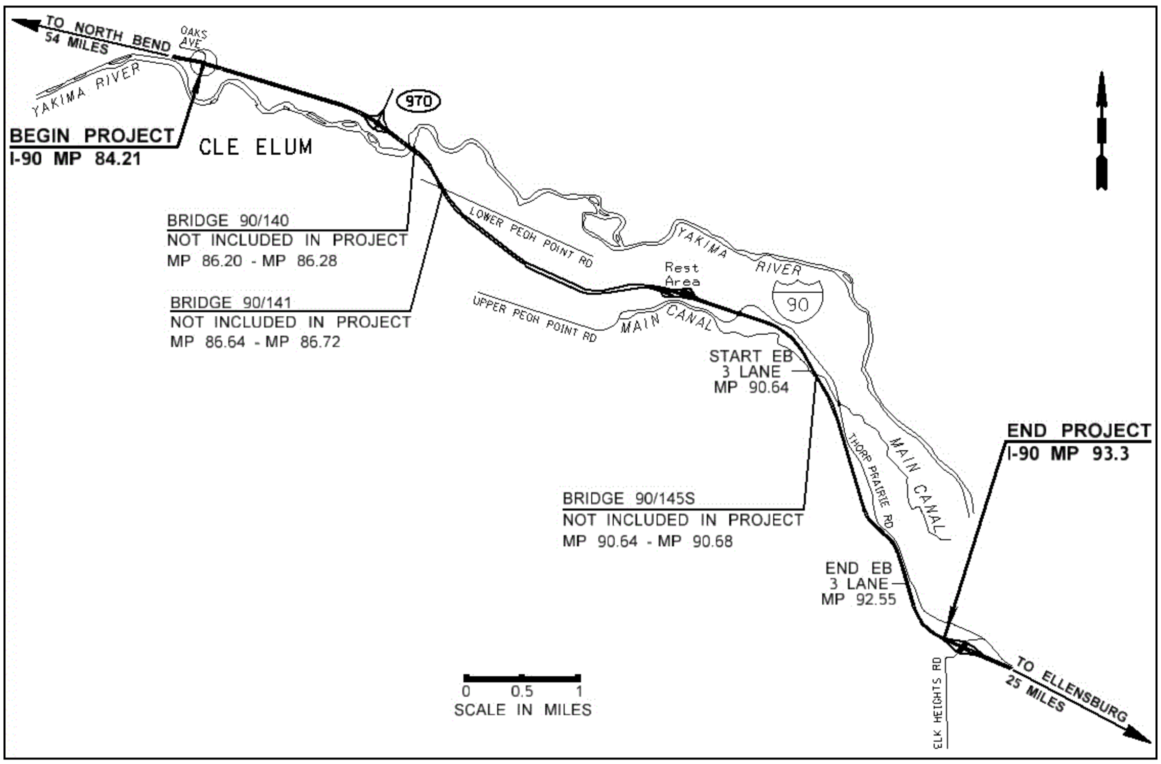

Figure 4-C2-1. Vicinity Map

The existing PCC pavement was constructed in 1967 as a 9 inch thick plain jointed PCCP with 15 ft joint spacing and no dowels over 9 inches of gravel surfacing. Most of the native soils through this area consist of glacial till or alluvial washes (silty sandy gravels) with some pockets of clay. There were no soil stiffness values reported for these soils. Typically the resilient modules values range from 15,000 psi to 30,000 psi

By the mid 1990's the pavement had experienced a little over 1/4 inch of faulting but little or no slab cracking, nor joint spalling. In 1997 the pavement was restored by retrofitting dowels, grinding the surface and re-sealing the joints.

The WSDOT resurfacing report dated February 2013, which is included as Appendix 4-C2A, indicated the following existing pavement conditions.

"…. widespread distress in the form of numerous multi-cracked panels, and dowel bar retrofit failure…. There is also significant continuous panel to panel cracking propagation from a corner of the dowel bar slot in a panel to a corner of an adjacent dowel bar slot in the next panel. "

The following photos taken in the summer of 2013 show the conditions described.

Figure 4-C2-2. Photographs of typical cracking found on project

The cracking shown above is indicative of the cracking where it occurs but there are also stretches of pavement with little or no cracking. There was also a section which was deemed poor enough that it was overlaid with 0.25 ft of HMA.

The 2012 Washington State Pavement Management System (WSPMS) was used to estimate future ESALS which indicated 1.1 Million ESALS in each direction for the 2016 design year. WSDOT estimated the 50 year design ESAL as 150 M ESAL in each direction using their customary 2% rate of annual growth. This reduced the design ESAL to 120 M ESALs assuming a 20%/80% lane distribution.

Additional traffic data reported in the Pavement Type determination Report indicated the 2015 initial traffic as 25,000 AADT for two way traffic with 23.4% trucks. Maximum AADT in both directions was set as 70,000.

WSDOT's pavement design options were 1) crack and seat and place a 0.75 ft HMA overlay, 2) Place a 0.90 ft unbonded PCC overlay, or 3) remove and replace with 1.05 ft PCC pavement placed over 0.25 ft HMA and 0.25 ft CSBC. Both the PCC replacement and the PCC overlays would have a 14 ft widened right lane.

The following design values were used as input into the rePave program.

Existing Pavement is 9 in JPCP over 9 inches gravel surfacing.
Assume 28 % cracking, 0.10 inch faulting, and 0.0020 inch deflection at Joint.
Traffic is 12,500 AADT in each direction with 2% growth expected, and the average annual ESAL is 1.1MESAL
Assume subgrade Mr is 10,000 psi, but could easily be 20,000 psi.

rePave Scoping Design Runs

The following figures will show the screen shots from the rePave program based on the data provided from WSDOT on this project.

The first screen for rePave is for the user to enter general project location information.

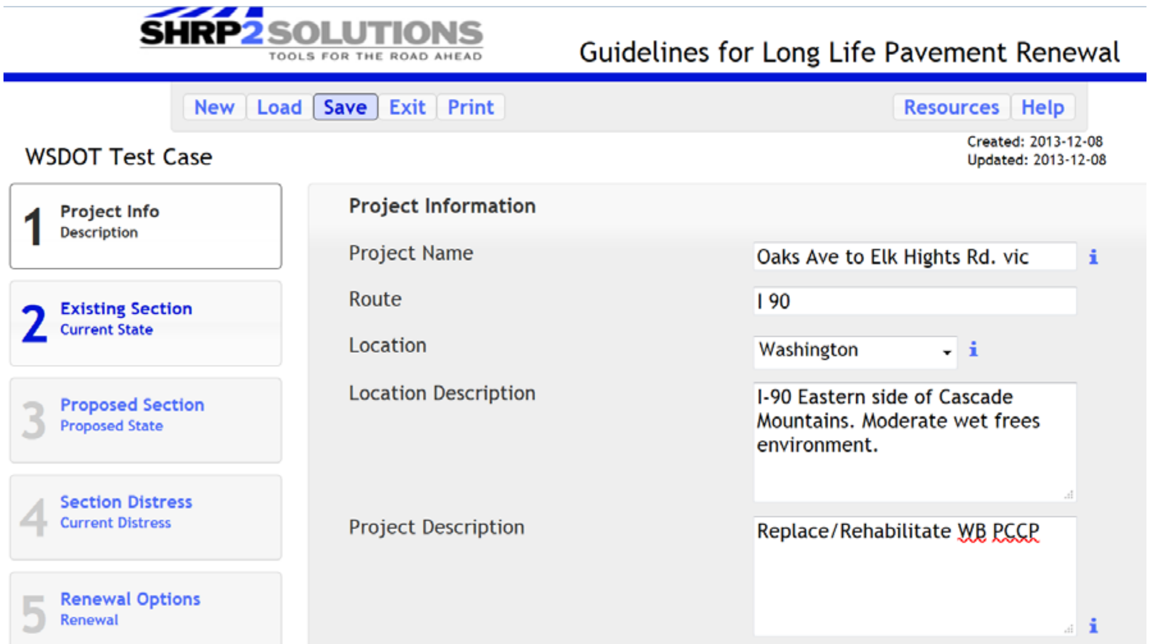

Figure 4-C2-3. rePave Project Information screen shot

The second step in the rePave program is to enter the typical pavement section information for the existing pavement.

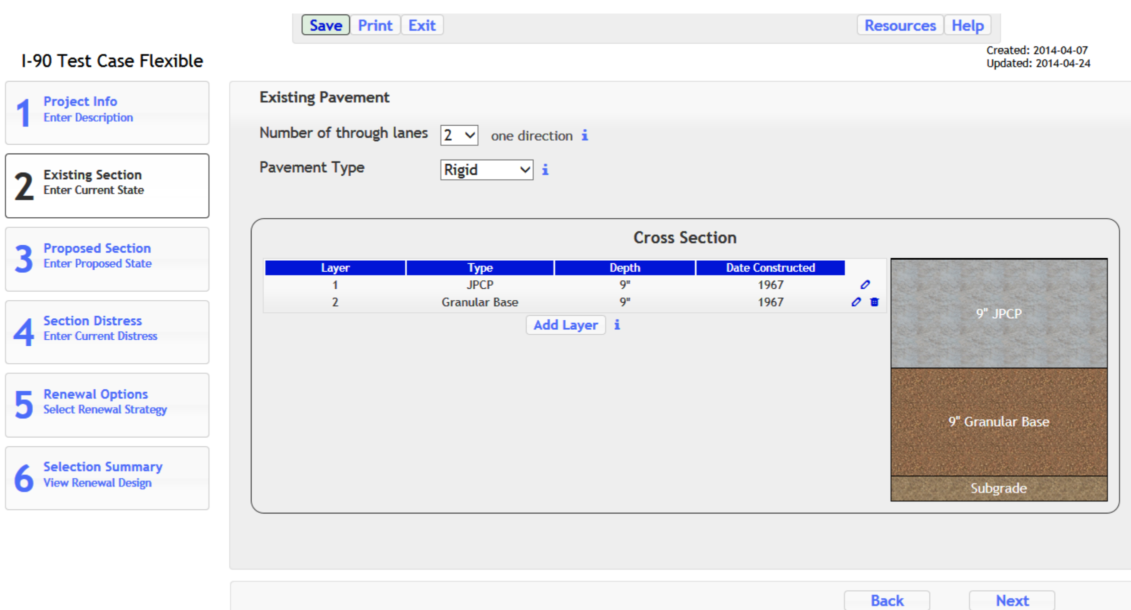

Figure 4-C2-4. Existing Pavement Section

The third step in the process is to enter the basic design information for the project. The traffic information was adjusted to match the ESAL estimates from WSDOT for the project.

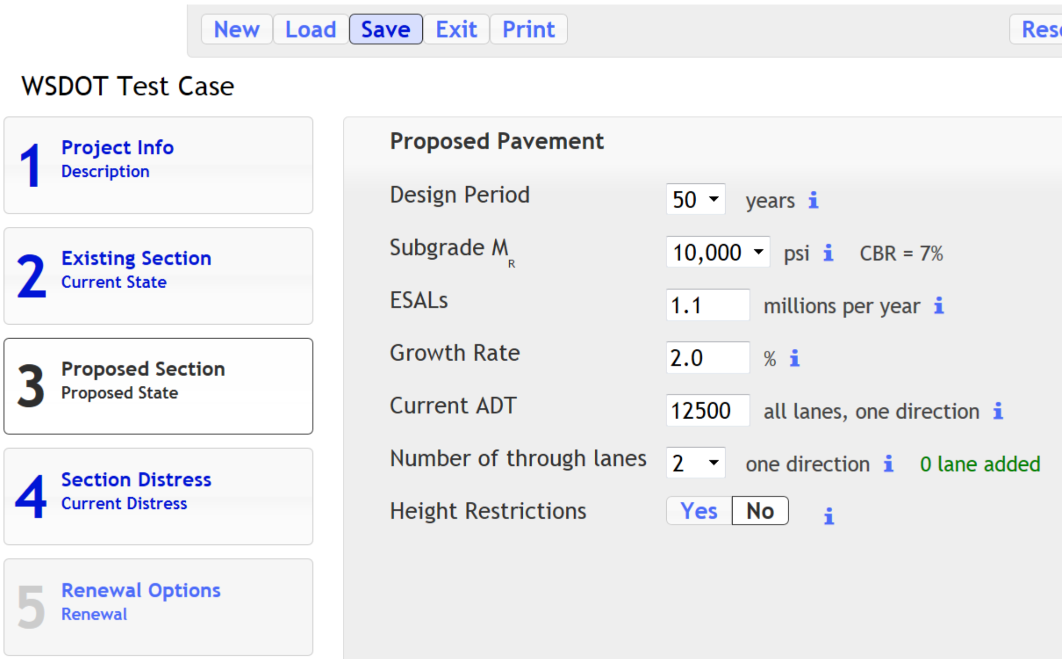

Figure 4-C2-5. Proposed Pavement design information

The fourth screen deals with the condition of the existing pavement. Distresses common for both flexible and rigid pavement are included. In this case since the pavement is rigid only those distressed are shown.

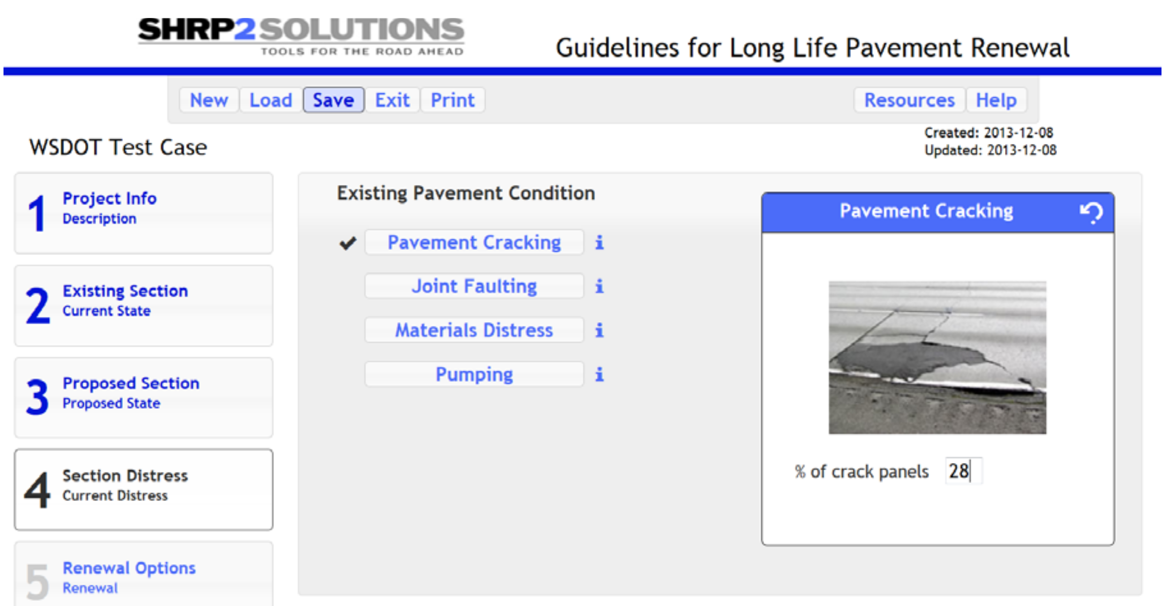

Figure 4-C2-6. Cracking Distress

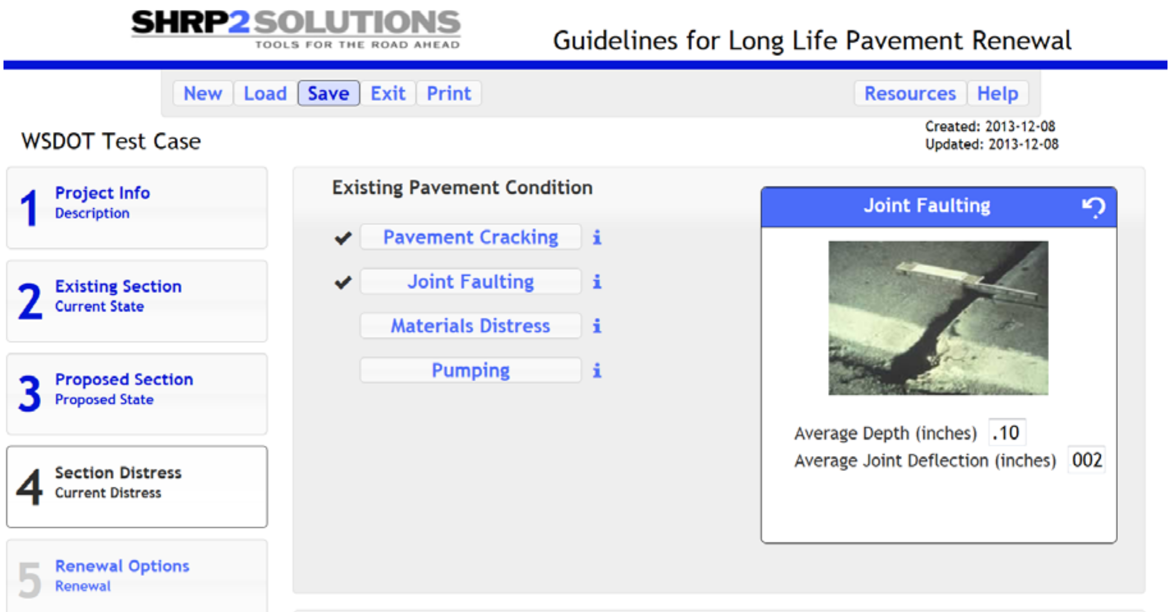

Figure 4-C2-7. Faulting information

After entering the project data the program asks the user to confirm that the data entered is correct as shown in the screen shot below.

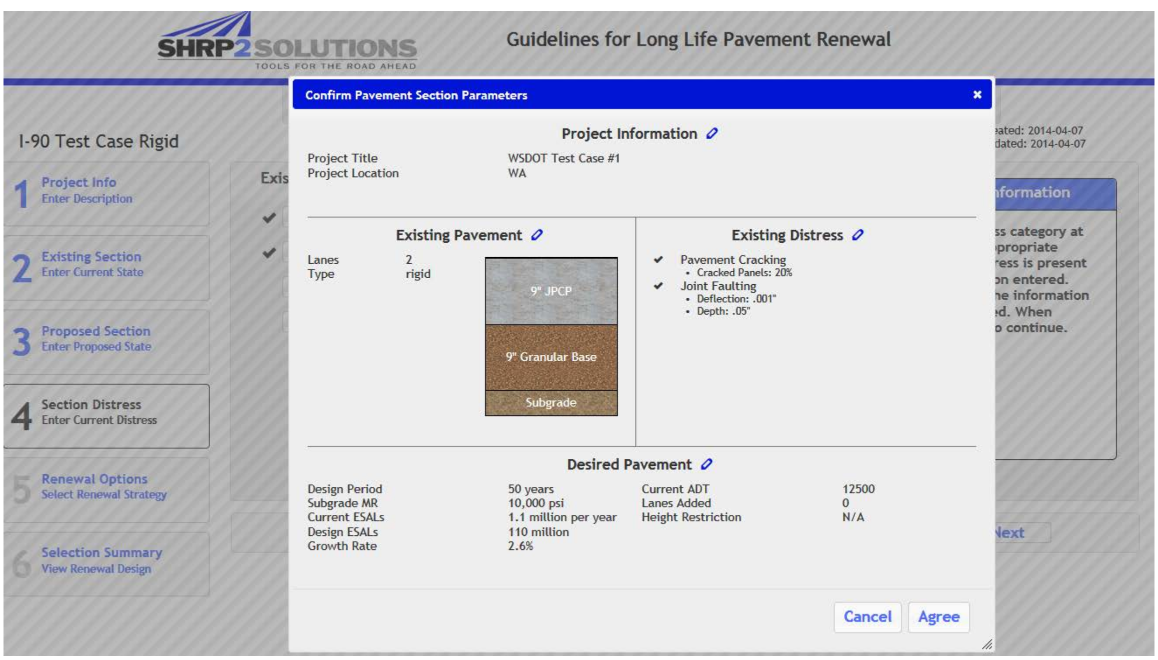

Figure 4-C2-8. Design data summary sheet

After confirming the design data the next step is to select one of the potential options available to reconstruct the existing pavement. The alternatives may be either flexible or rigid and could also include composite or modular pavements. All approaches will be presented starting with flexible.

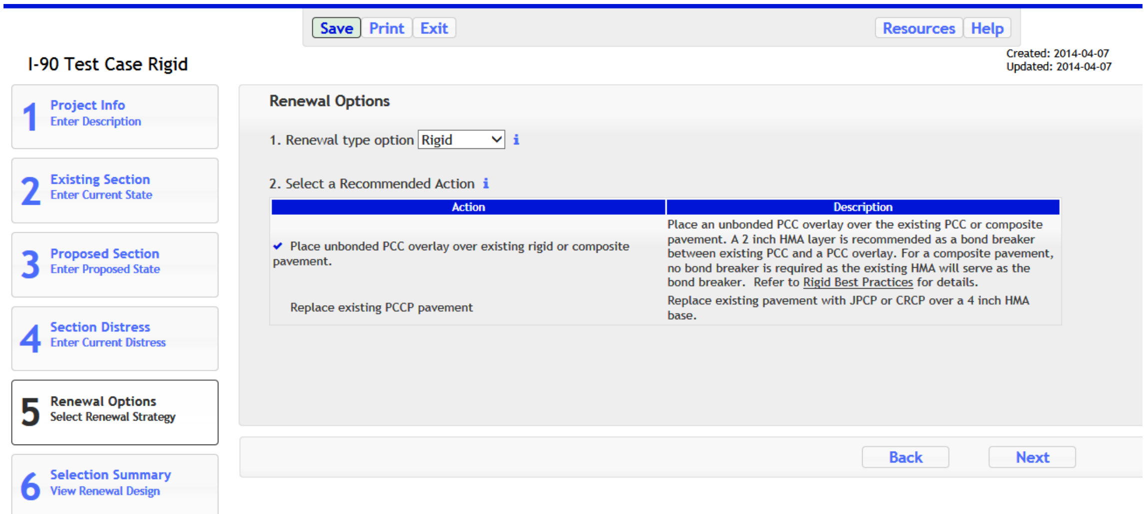

Figure 4-C2-9. Renewal options listed for a flexible renewal

The final screen is the design summary screen. In this case the design option selected was crack and seat the existing PCC pavement and overlay with HMA. The existing and proposed design is shown.

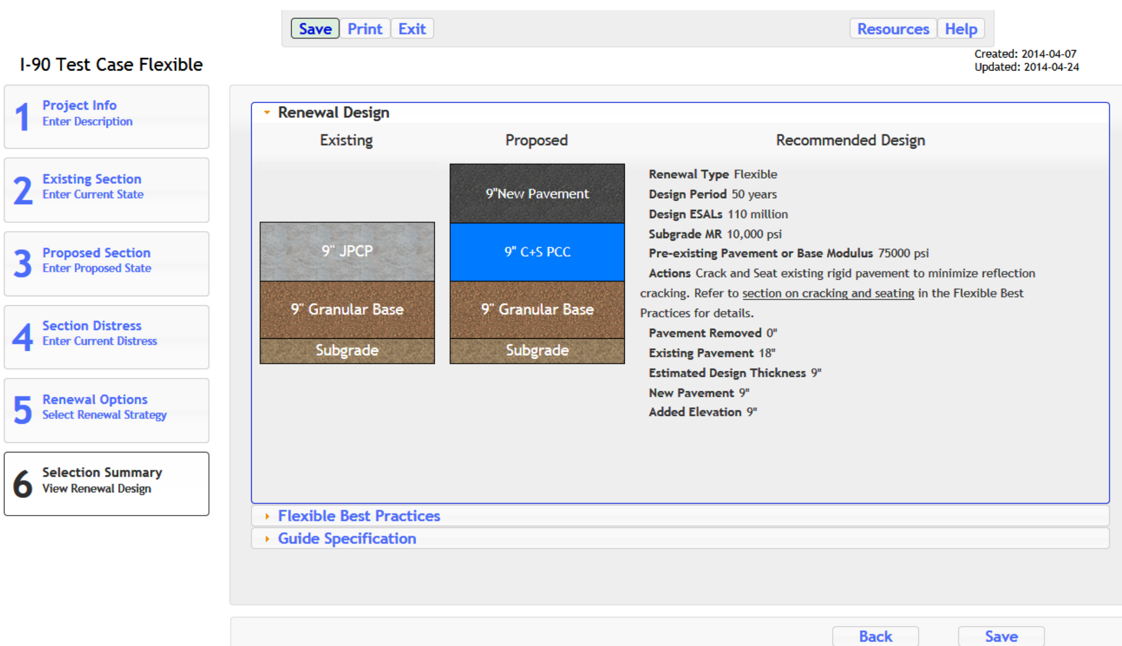

Figure 4-C2-10. Summary of the Renewal Design for C&S + HMA overlay

One can go back and select another renewal option for the specific project. In the next example, a Rigid renewal option was checked.

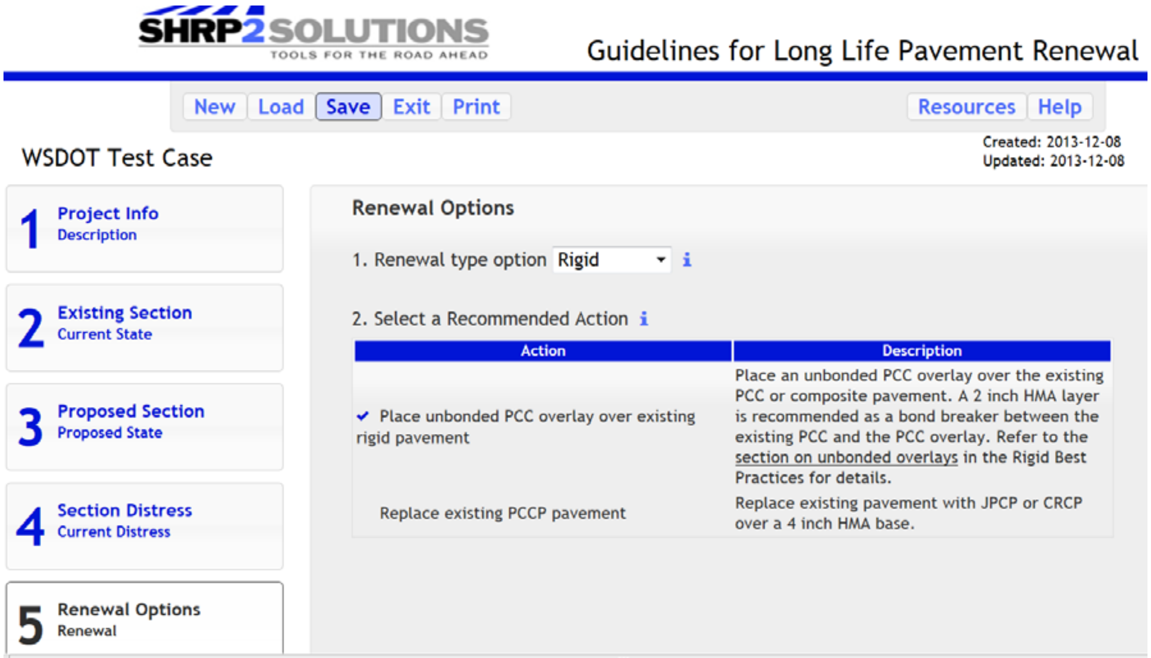

Figure 4-C2-11. Renewal options listed for Rigid Renewal using an unbonded overlay

For this run an unbonded PCC overlay was checked with the resulting design summary.

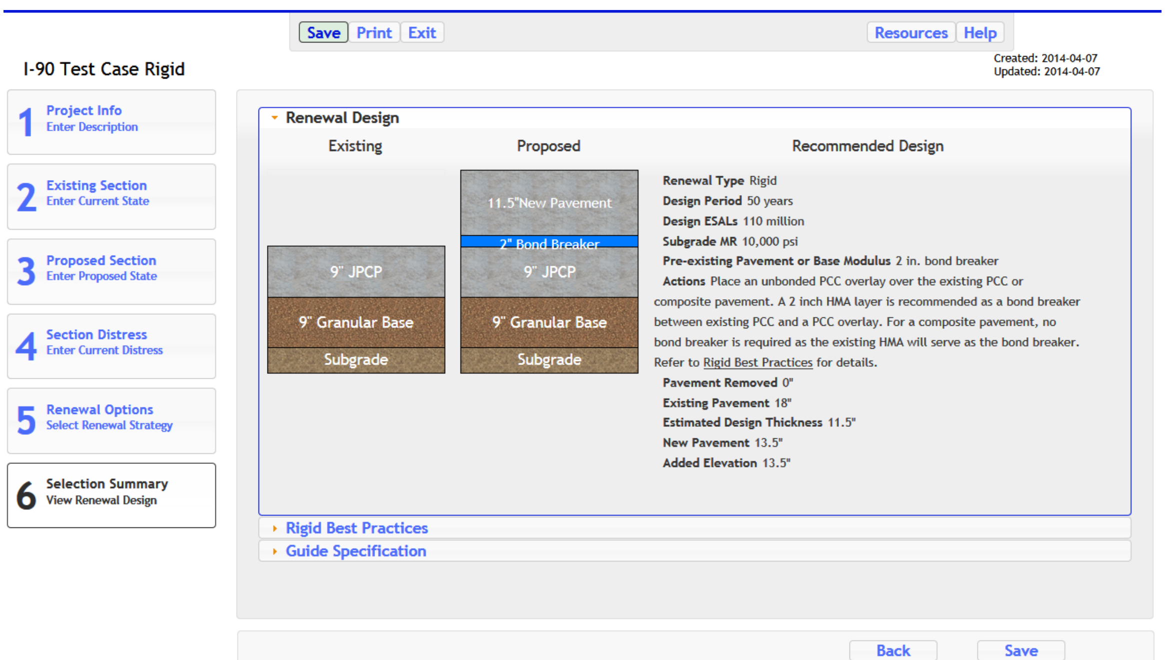

Figure 4-C2-1.2 Design Summary for an Unbonded PCC Overlay

The following figures show the rePave guidance for replacing the existing pavement with new PCC.

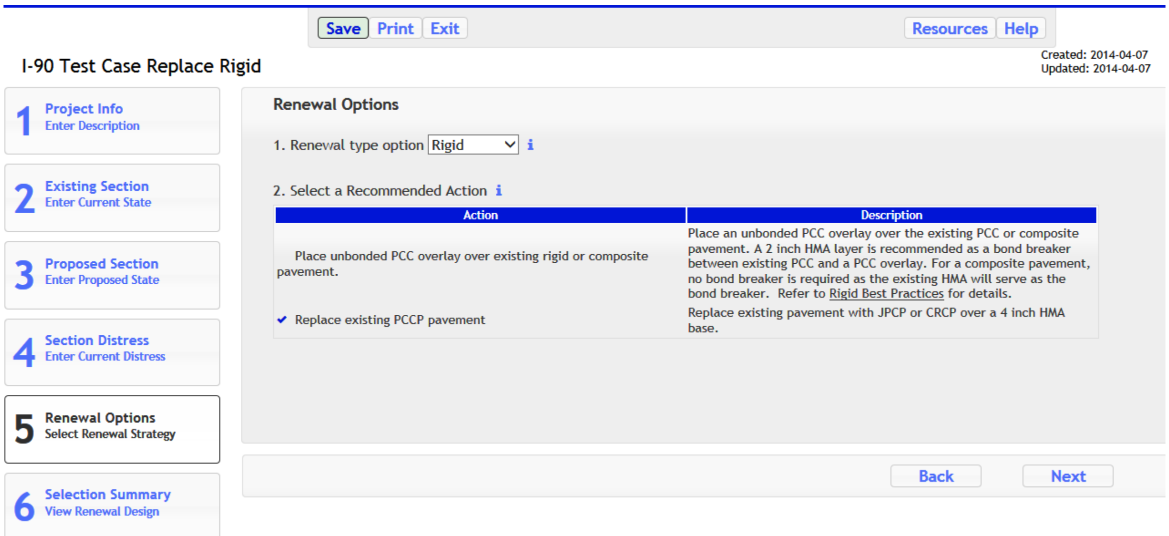

Figure 4-C2-13. rePave screen showing replacement approach selected

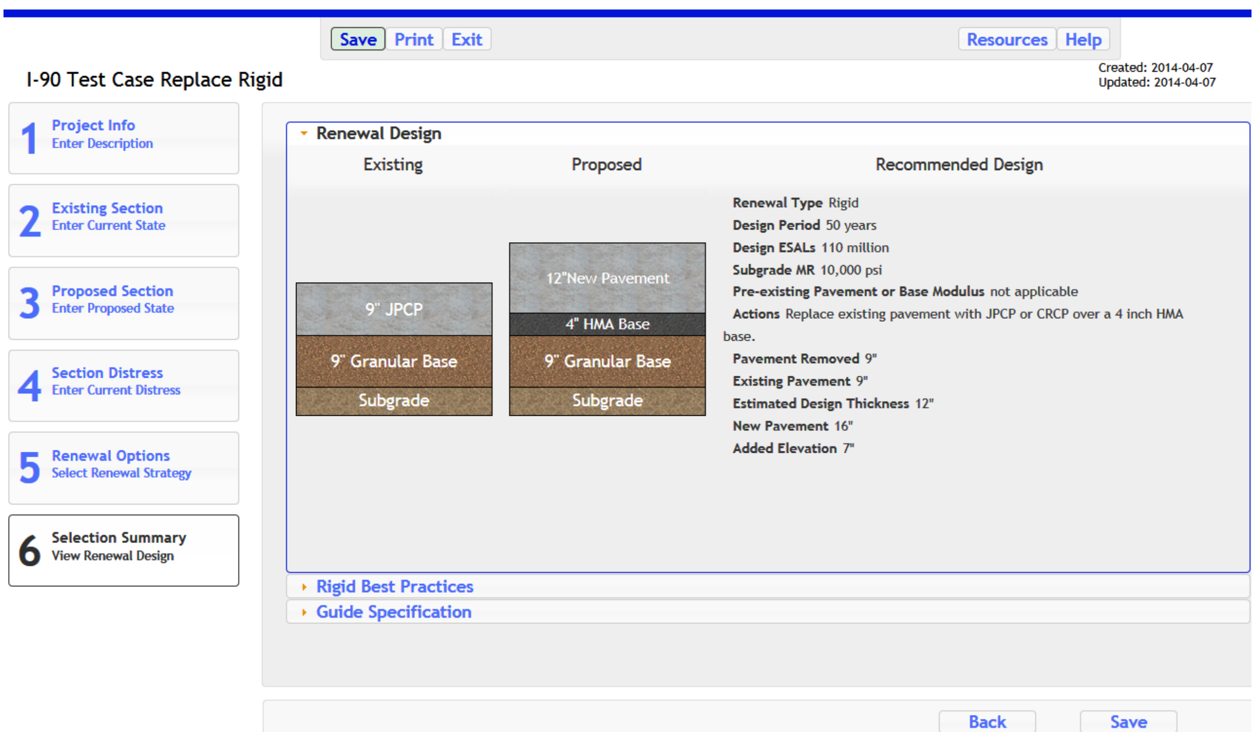

Figure 4-C2-14. rePave screen showing design summary for replacement design

Design Summary

Based on these rePave runs the following comparison can be made between the WSDOT pavement design considered for this project and the design guidance from rePave.

Design Summary	WSDOT	rePave (120 M ESAL)
Crack & Seat + HMA Overlay	0.75 ft (9 in) HMA	9.0 in HMA
Unbonded PCC Overlay	0.90 ft (10 3/4 in) PCC	11.5 in PCC
New PCC Pavement	1.05 ft (12 3/4 in) PCC	12.0 in PCC

Note, the WSDOT ESAL calculation indicated 120 MESALs while rePave indicated 93 MESAL's so the input traffic was adjusted to produce 110 MESALs which falls within the rePave table group of 100 to 150 MESAL, in line with the WSDOT design traffic values.

WSDOT also included a 14 ft widened lane which effectively reduces PCC design depths by about 1 inch. The rePave design tables do not consider the effect of widened lanes on the pavement depth. However WSDOT also often includes additional PCC depth to allow for future grinding, though that is not mentioned in the design report. Considering both lane widening and added depth for grinding there is little difference between the design guidance from rePave and the WSDOT design for this project.

The Washington State DOT considered all three pavement designs shown above. The new PCC pavement design was modified to consider only removing and replacing the outside lane with major rehabilitation of the inside lane at year 20 similar to what was done on another project several years earlier. Cost analysis of all three options indicated that the single lane replacement design was 27% higher than the crack seat and overlay option so that design was not considered in the final pavement type selection process. In the cost analysis for the pavement type selection both standard deterministic life cycle cost analysis and probabilistic life cycle cost analysis were performed.

The life cycle cost analysis indicated that the present value of the unbonded PCC overlay was about 8.1 percent higher than the crack seat and overlay option. However, as WSDOT's pavement type selection policy states that s where cost differences are within 15percent, the cost difference can be considered equivalent, and an engineering analysis is required to select the pavement type. In the engineering analysis WSDOT determined that the risk associated with poor HMA performance, (in this Mountain Pass area where the pavement is exposed to heavy stud and chain wear) was greater than that experienced with PCC. WSDOT selected the unbonded PCC overlay option to reconstruct the pavement on this project.

A copy of the pavement design report and the pavement type selection report are attached as Appendix A to this report.

Composite Pavement Design Approaches

In addition to the flexible and rigid pavement design rePave also provides design guidance for composite pavements based on the SHRP 2 R21 Project. The following figures show the rePave screens for designs using composite and modular approaches. The reports for both projects can be found at:

- http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-1.pdf
- http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-2.pdf

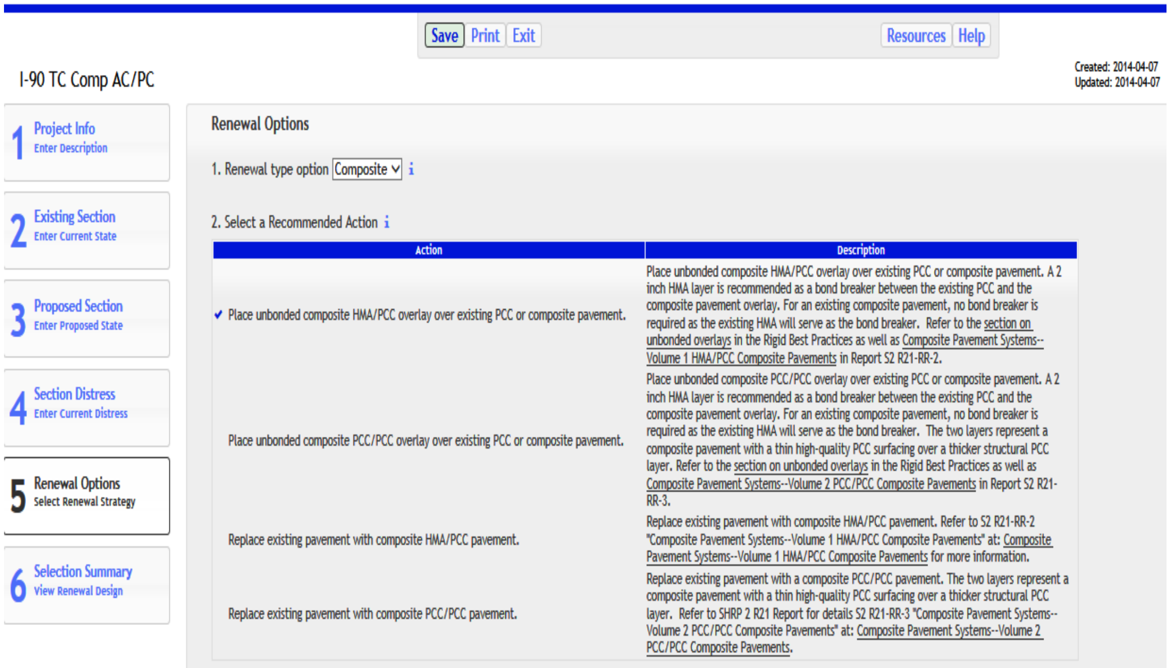

Figure 4-C2-15. rePave screen with composite pavement approaches with unbonded HMA/PCC overlay selected

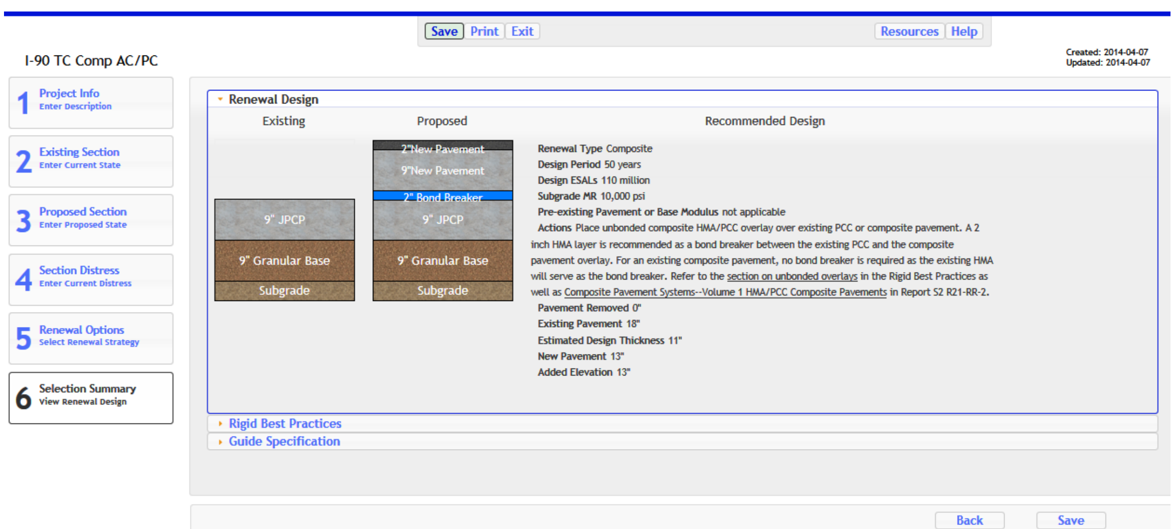

Figure 4-C2-16. rePave screen showing design summary of an unbonded HMA/PCC composite overlay

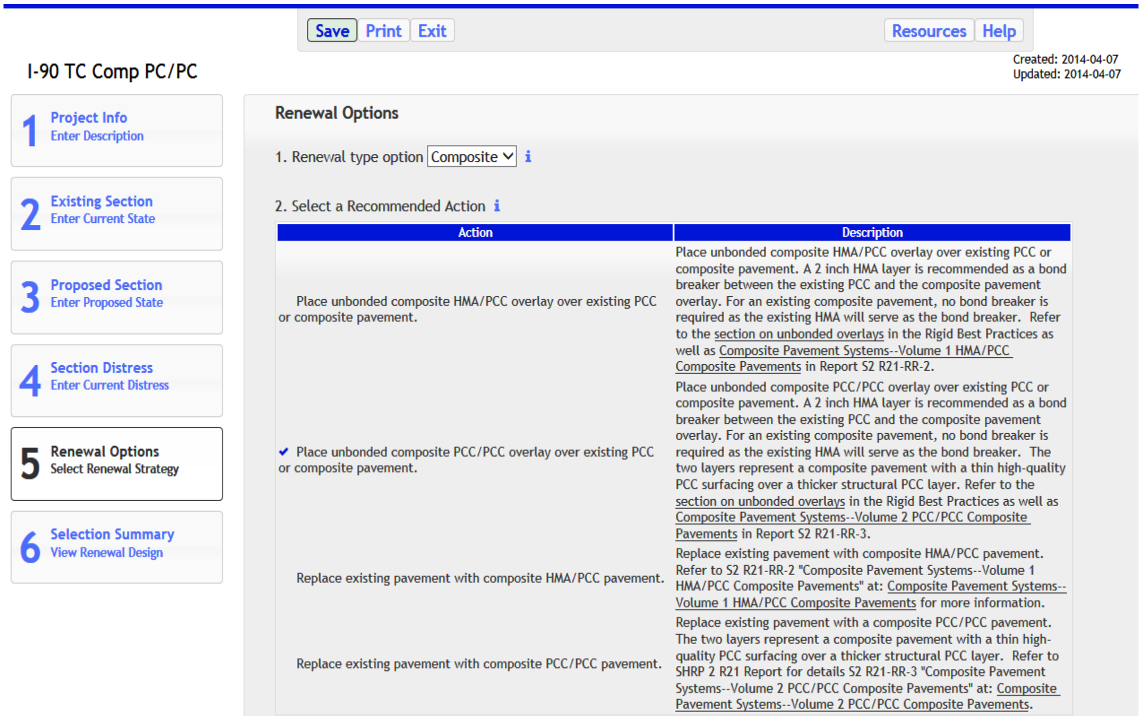

Figure 4-C2-17. rePave screen showing modular approaches with unbonded PCC/PCC composite overlay

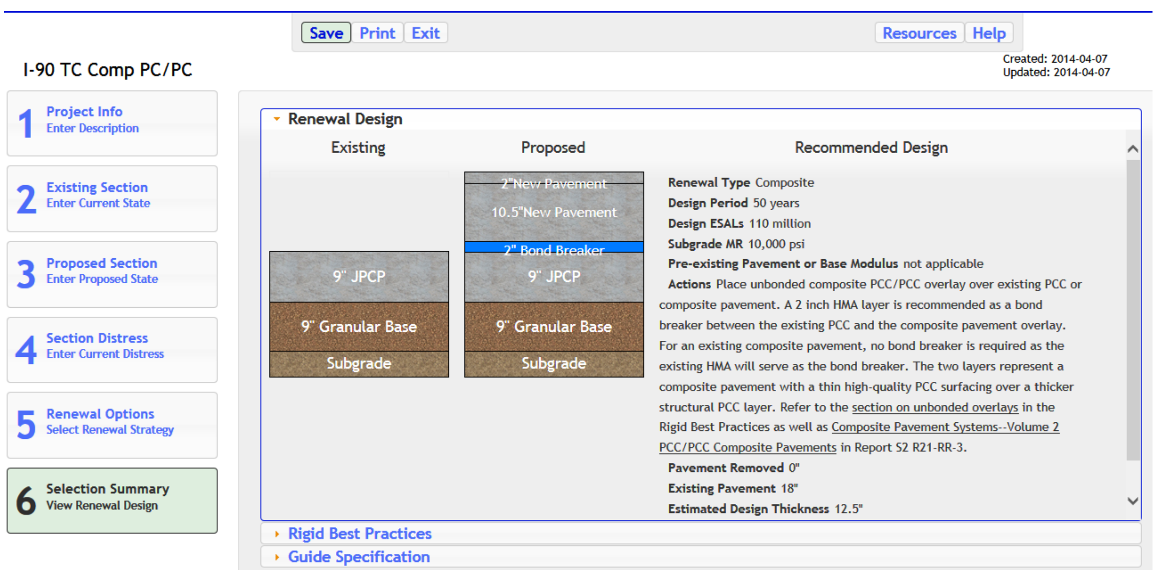

Figure 4-C2-18. rePave screen showing design summary of an unbonded PCC/PCC composite overlay

Similar approaches can be checked for replacing the existing pavement with composite pavements.

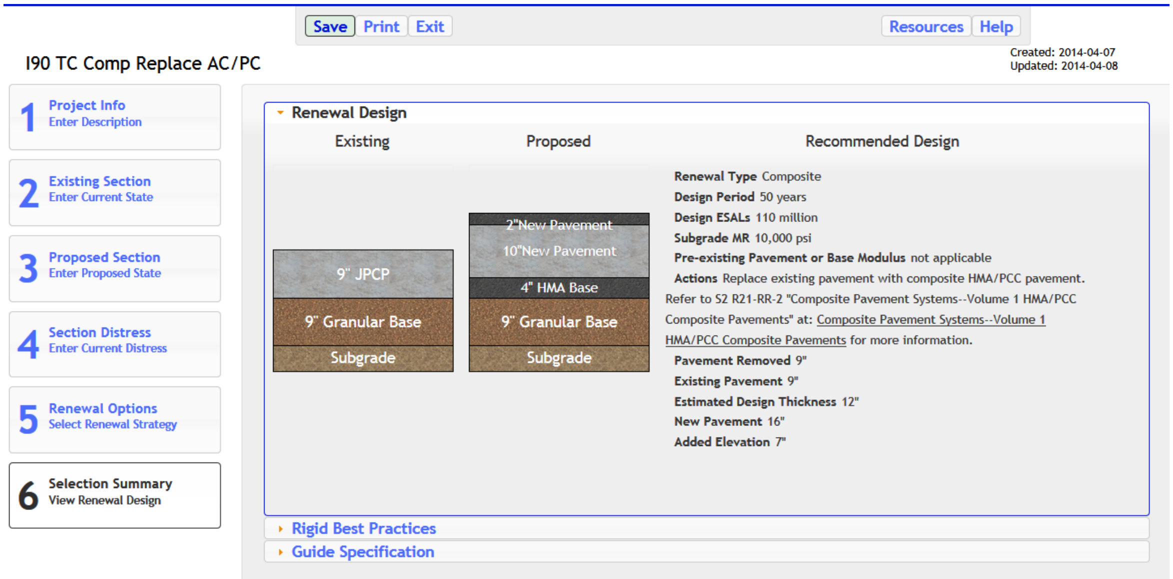

Figure 4-C2-19. rePave screen showing the design summary for replacement with a composite HMA/PCC pavement

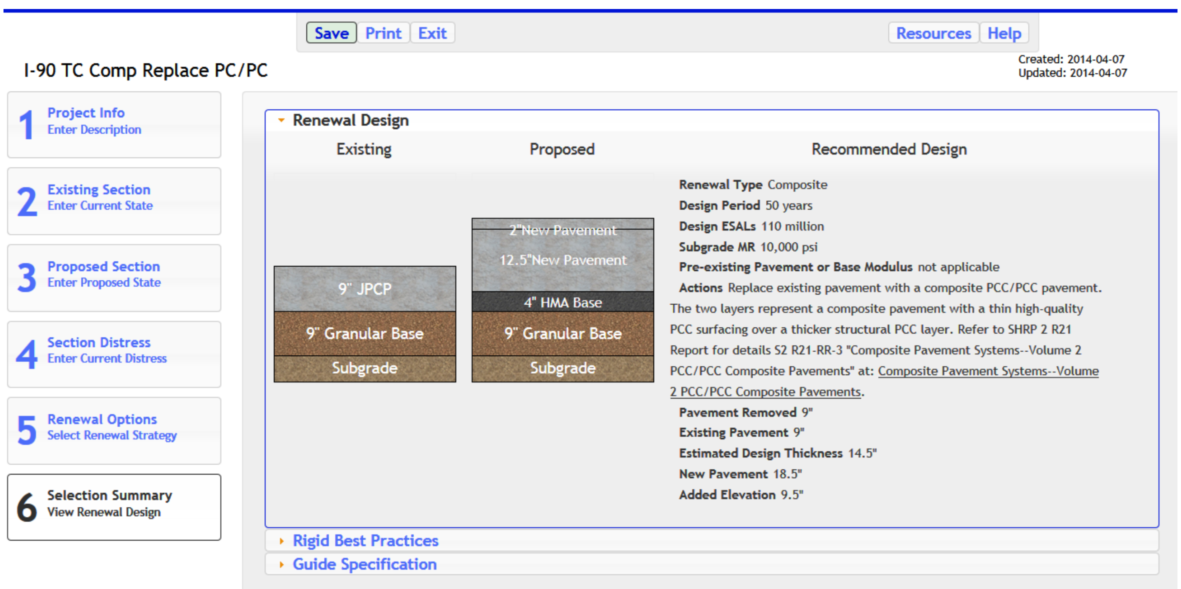

Figure 4-C2-20. rePave screen showing the design summary for replacement with a PCC/PCC composite pavement

These four composite designs can be compared to the WSDOT designs as shown below:

Design Summary	WSDOT	rePave (HMA/PCC)	rePave (PCC/PCC)
Unbonded PCC Overlay	0.90 ft (10 3/4 in) PCC	2/9 in HMA/PCC	2/10 in PCC/PCC
New PCC Pavement	1.05 ft (12 3/4 in) PCC	2/10 in HMA/PCC	2/12.5 in PCC/PCC

The HMA/PCC composite pavements are somewhat thinner than the WSDOT design because of the reduced warping and curling stress in the HMA/PCC composite pavements. The PCC/PCC composite pavement designs are thicker than the WSDOT designs because that design allows for the use of lower quality cement concrete or aggregate in the lower section of the pavement.

Modular Pavement Designs

Modular pavement designs were also run on the WSDOT test case site. rePave limits the design life for modular pavements to 35 years, thus direct correlations to 50 year designs could not be made. The same traffic loading (1.1 MESALs/year) was used for the modular pavement designs but for a ?35 year design that produced only 62 MESALs as the design loading.

Accounting for the reduced design life the following five figures show the rePave screens for both precast PCC and pre-stressed precast PCC pavements, both used as unbonded PCC overlays and as pavement replacement.

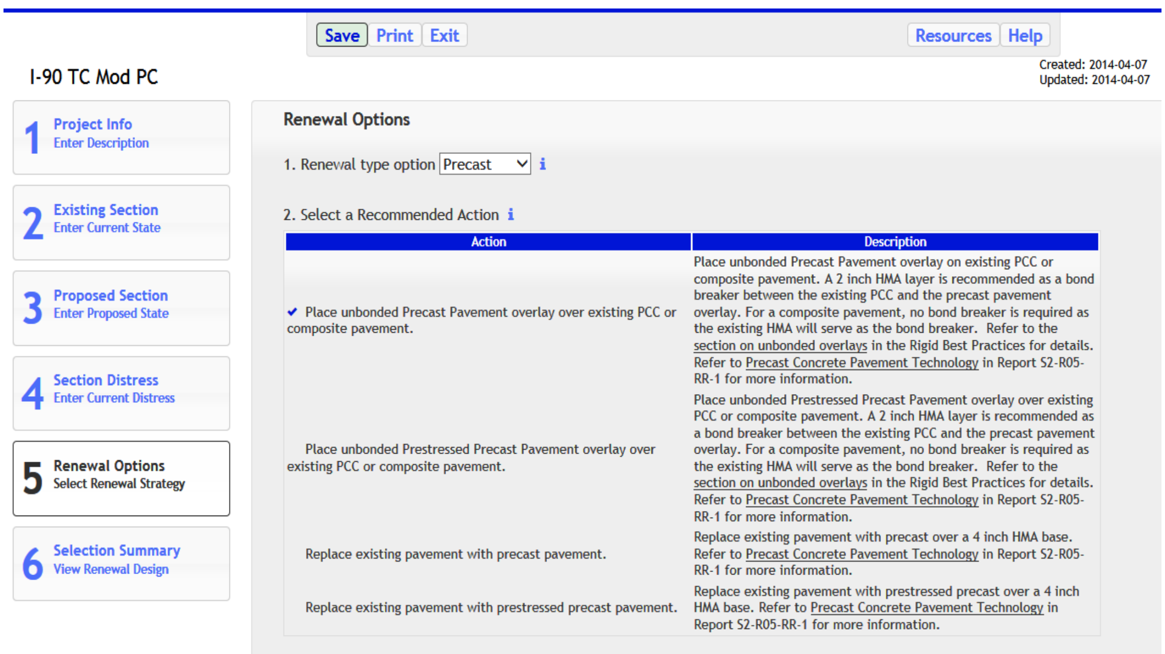

Figure 4-C2-21. rePave screen showing the four approaches considered for modular pavements

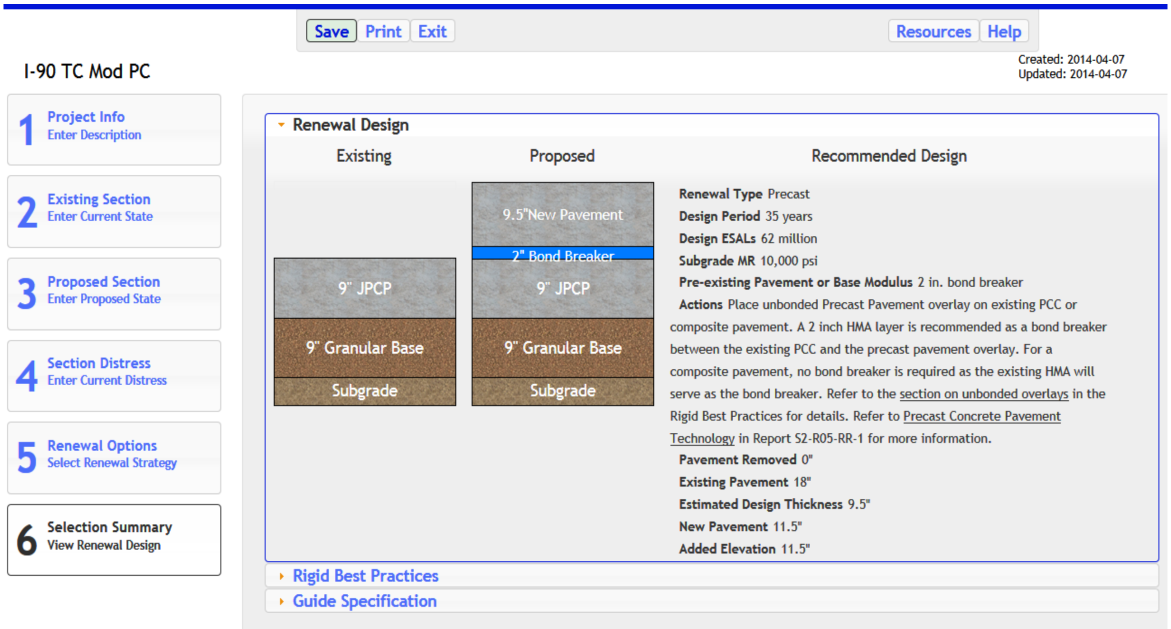

Figure 4-C2-22. rePave screen showing the design summary for an unbonded precast pavement overlay

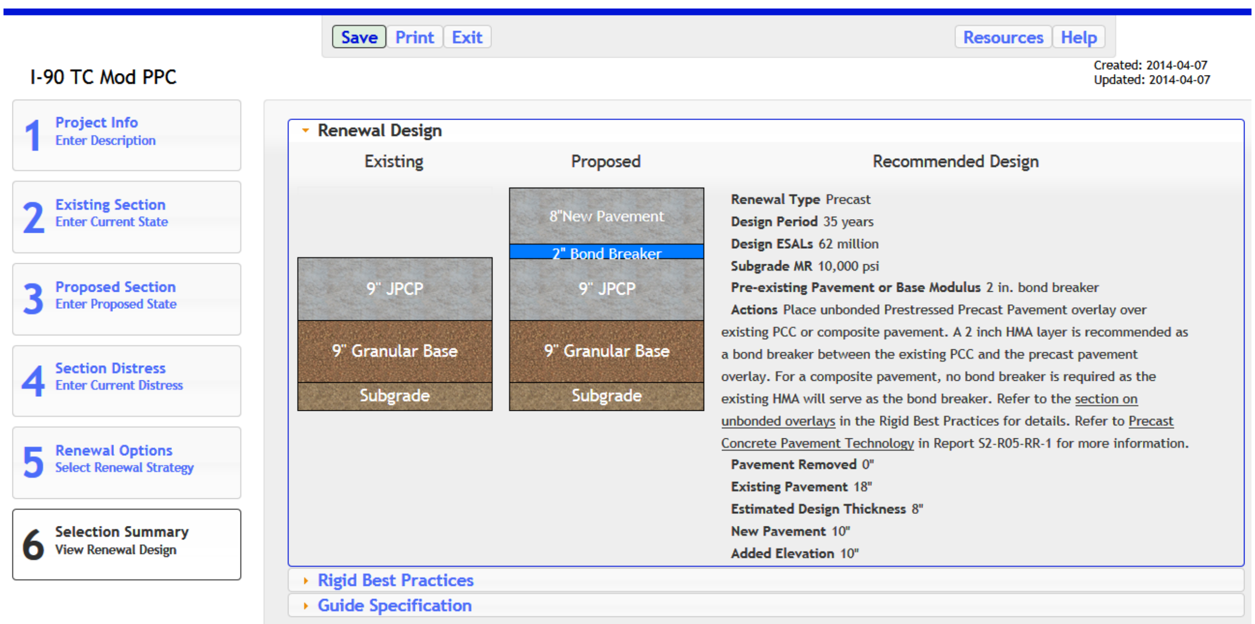

Figure 4-C2-23. rePave screen showing the design summary for an unbonded pre-stressed precast pavement overlay

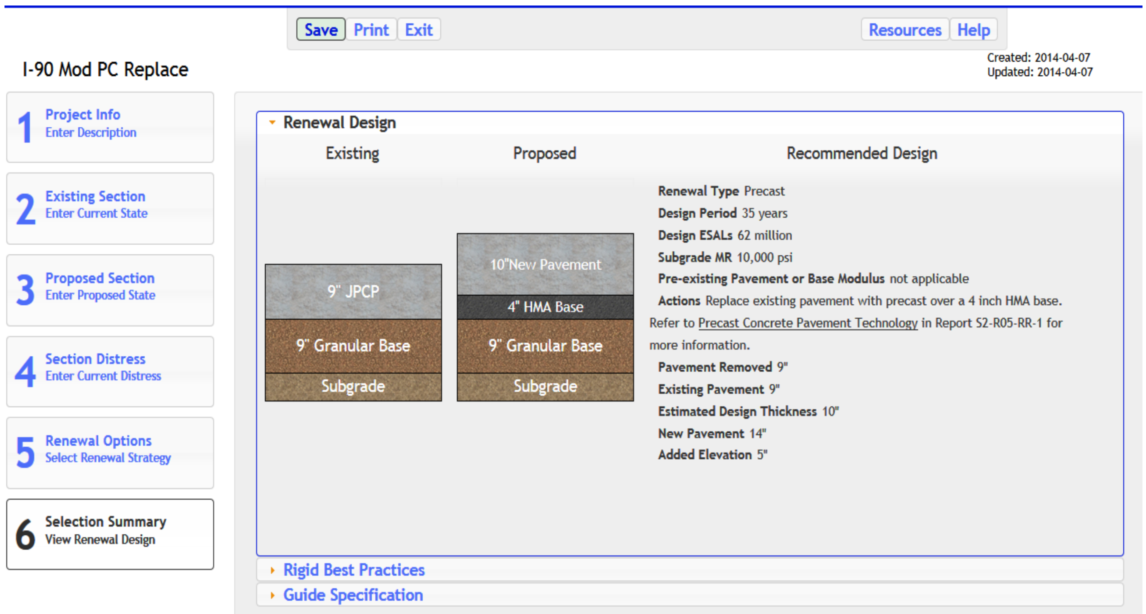

Figure 4-C2-24. rePave screen showing design summary for replacement of existing pavement with a precast pavement

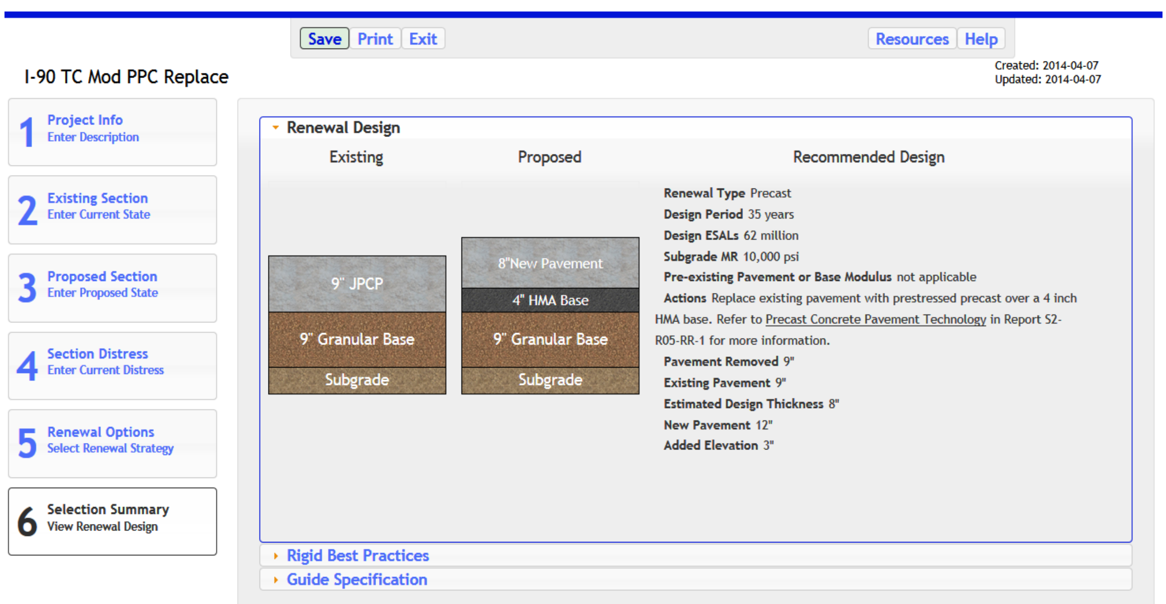

Figure 4-C2-25. rePave screen showing design summary for the replacement of the existing pavement with a pre-stressed precast pavement

These four precast designs can be compared to the WSDOT designs as shown below:

Design Summary	WSDOT	rePave (precast)	rePave (pre-stressed precast)
Unbonded PCC Overlay	0.90 ft (10 3/4 in) PCC	9.5 in. PCP	8.0 in PPCP
New PCC Pavement	1.05 ft (12 3/4 in) PCC	10.0 in PCP	8.0 in PPCP

The precast concrete pavements are somewhat thinner than the WSDOT design based on the shorter design life of 35 years vs 50 years and improved construction procedures for the precast units. The prestressed precast pavements are also thinner than the WSDOT design because of the shorter design life and the pre-stressing significantly reduces the pavement thickness as can be seen between the standard precast design and the pre-stressed precast design. The minimum thickness of the pre-stressed precast unit is set at 8 inches to provide sufficient thickness for pre-stressing.

Appendix 4-C2A

WSDOT Report

I-90/Oaks Ave Vic to Elk Heights Rd Vic WB – Replace/Rehab Concrete

Pavement Type Selection

I-90/Oaks Ave Vic to Elk Heights Rd Vic WB – Replace/Rehab Concrete

Pavement Type Selection

April 30, 2013

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Washington State Department of Transportation

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Pavement Type Selection

The purpose of this document is to recommend a rehabilitation strategy for the I-90/ Oaks Avenue Vicinity to Elk Heights Road Vicinity project. The alternative rehabilitation strategies include, full depth reconstruction of the outside lane with Portland Cement Concrete Pavement (PCCP), Crack and Seat and Overlay (CSOL) with hot mix asphalt (HMA) and an Unbonded PCCP Overlay. The Washington State Department of Transportation (WSDOT) 2011 Pavement Policy provides the selection guidelines used in this process. The selection process evaluates an equivalent structural design for each alternative and makes its recommendation based upon three factors: foundation feasibility, life cycle cost analysis (LCCA), and non-economic factors.

Overview of the Project

This project reconstructs the westbound lanes of I-90 near the city of Cle Elum from MP 84.21 to MP 93.30 in Kittitas County. The 9.09 mile section of I-90 shown in Exhibit 1 is classified as a rural interstate and serves as the primary transportation corridor between Eastern and Western Washington. The roadway has two 12-foot lanes with a 4-foot inside and 10-foot outside shoulder.

Traffic is separated by a wide rural median, and sections of project have moderate grades. There are four access points within the project limits, three interchanges and the Indian John Rest Area. The project also has one county road overcrossing and three at grade bridges.

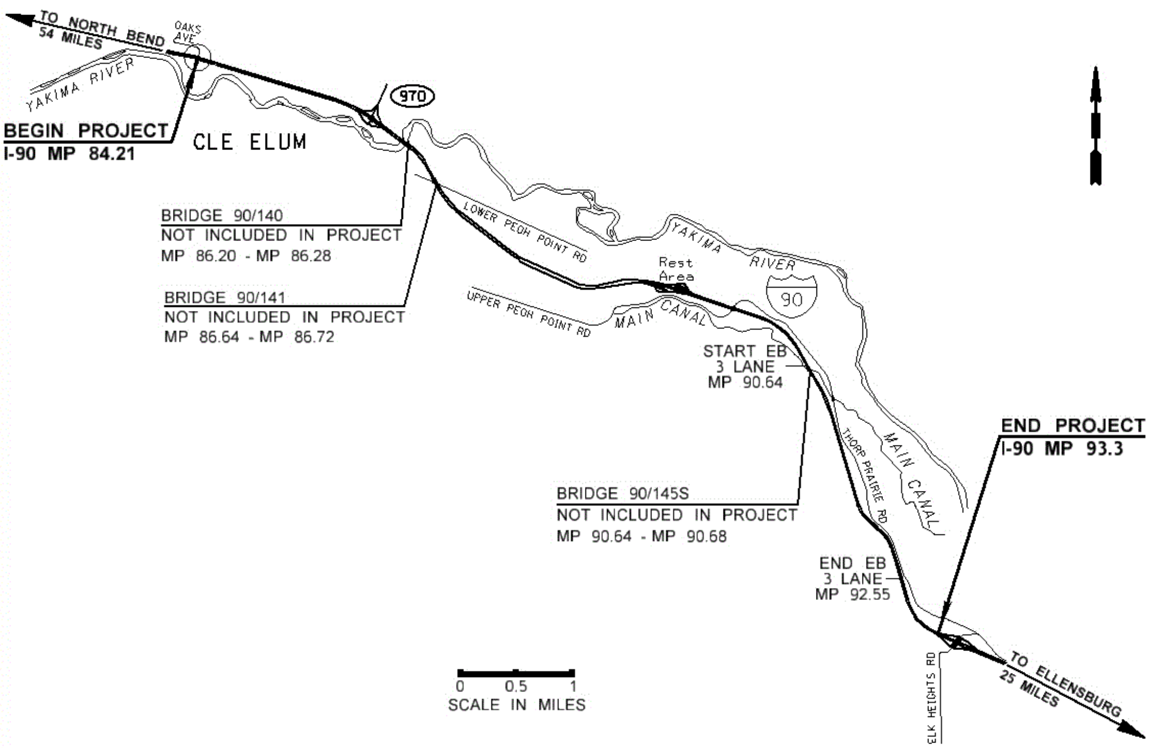

Exhibit 1: Vicinity Map

Foundation Feasibility

The plain jointed PCC pavement lanes were originally constructed in 1967. In 1997 dowel bars were placed in joints to prevent potential future faulting.

Most of the native materials are glacial till or alluvial washes, with the exception of some pockets of clay. A section near Indian John hill has been reconstructed twice and now has been overlaid with HMA due to a localized weak subgrade. The HMA overlay has performed better than expected in that very little reflective crack has occurred in its short two year life. Therefore a CSOL should perform well and is only limited by the relatively short life span of the HMA wearing course, due to the climate and studded tire wear.

A number of sections of I-90 adjacent to the project had unbonded PCCP overlays in the early 1970's. These locations had variable subgrade conditions and have performed much better than the adjacent standard sections and have only just recently had any rehabilitation in the form of grinding to remove ruts. The standard sections have had DBR's (Dowel Bar Retrofits) and now are being reconstructed. The unbonded overlay section was relatively thin, 0.75 ft. PCCP over 0.33 ft. HMA over 0.58 ft. of 1935 vintage PCCP. Therefore unbonded PCCP overlays also are considered viable pavement option for this project.

The Washington State Pavement Management System (WSPMS) records support the viability of PCC pavement on I-90 between MP 84.21 and MP 93.30. The existing PCC pavement has shown little settlement distress over 45 years of use.

Step 1: Pavement Design Analysis

Single lane PCCP inlay Alternative

This alternative would be similar to the rehabilitation projects that have occurred over the last 3 years on I-90 near Easton. This alternative reconstructs the outside lane using 1.0 feet of PCCP over 0.25 feet of HMA and 0.25 feet of CSBC, reconstructs the outside shoulder with 0.35 feet of HMA over CSBC, removes and replaces multi cracked PCCP panels and diamond grinds the inside lane with a 0.15 feet HMA inlay of the inside shoulder. A preliminary LCCA was performed on all three alternatives. This option had a present value cost 27% higher than the unbonded PCCP overlay due to the need to rehabilitate the inside lane and reestablish a counter flow detour at year 20.

This alternative was not considered in the final pavement type determination report based on the findings of the preliminary LCCA and increased construction risk related to potential subgrade issues.

Crack and Seat and Overlay (CSOL) Alternative
The existing PCC pavement will be broken uniformly and seated with a pneumatic roller. A 0.75-foot HMA Class ½ inch PG 64-28 overlay will be placed over the top of the cracked and seated pavement as shown in Exhibit 2. Pavement within 380 feet of either bridge end will reconstructed with a full depth HMA section. Existing shoulders will be overlaid or reconstructed with HMA to match the grade and slope of the pavement in the traveled lanes. On and off ramp tapers will be overlaid or reconstructed to match the new mainline profile.

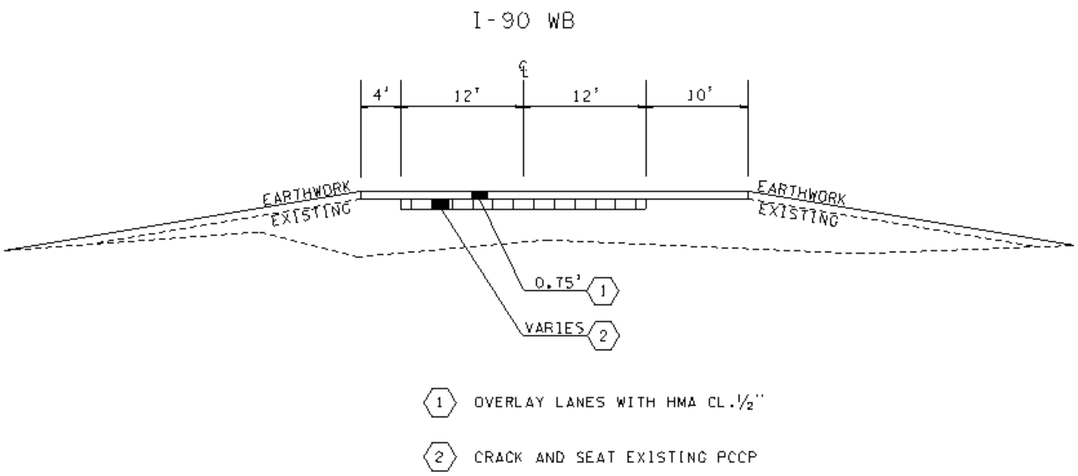

Exhibit 2: CSOL Roadway Section

CSOL Rehabilitation
The long term performance and rehabilitation intervals of the CSOL alternative will be approximately equivalent to full depth HMA pavement. A historical analysis of I-90's past was performed to determine pavement rehabilitation cycles (see Appendix B). Based on this and additional data from I-90 near Easton Hill an eight-year rehabilitation cycle was selected.

The rehabilitation cycles for the HMA are scheduled for the years 2023, 2031, 2039, 2047, 2055, and 2063. The 2031, 2047 and 2063 rehabilitation cycles are full width. All other rehabilitations are 0.15' HMA grind and inlay "lanes only", crack sealing and fog sealing of the shoulders. A summary of the initial construction and anticipated rehabilitations are shown in Exhibit 3. A performance life cycle diagram, Exhibit 4, shows a graphical representation of the HMA Construction and Rehabilitation Summary.

Construction Category	Year	Description
Initial Construction (2015)	0	Rehabilitate two 12-foot lanes in westbound direction and 4-foot inside and 10-foot outside shoulder by: <u>Lanes</u> • Crack and Seat existing PCC Pavement

		• Overlay with 0.75 fee HMA Class ½” PG 64-28 <u>Shoulders</u> • Overlay existing shoulders with 0.75 feet HMA Class ½” PG 64-28 to match traveled lanes
Rehabilitation #1 (2023)	8	Grind & Inlay lanes only with 0.15 ft. HMA Class ½”, crack sealing and fog seal shoulders
Rehabilitation #2 (2031)	16	Grind & Inlay lanes and shoulders with 0.15 ft. HMA Class ½”.
Rehabilitation #3 (2039)	24	Grind & Inlay lanes only with 0.15 ft. HMA Class ½”, crack sealing and fog seal shoulders
Rehabilitation #4 (2047)	32	Grind & Inlay lanes and shoulders with 0.15 ft. HMA Class ½”.
Rehabilitation #5 (2055)	40	Grind & Inlay lanes only with 0.15 ft. HMA Class ½”, crack sealing and fog seal shoulders
Rehabilitation #6 (2063)	48	Grind & Inlay lanes and shoulders with 0.15 ft. HMA Class ½”.

Exhibit 3: CSOL Construction and Rehabilitation Summary

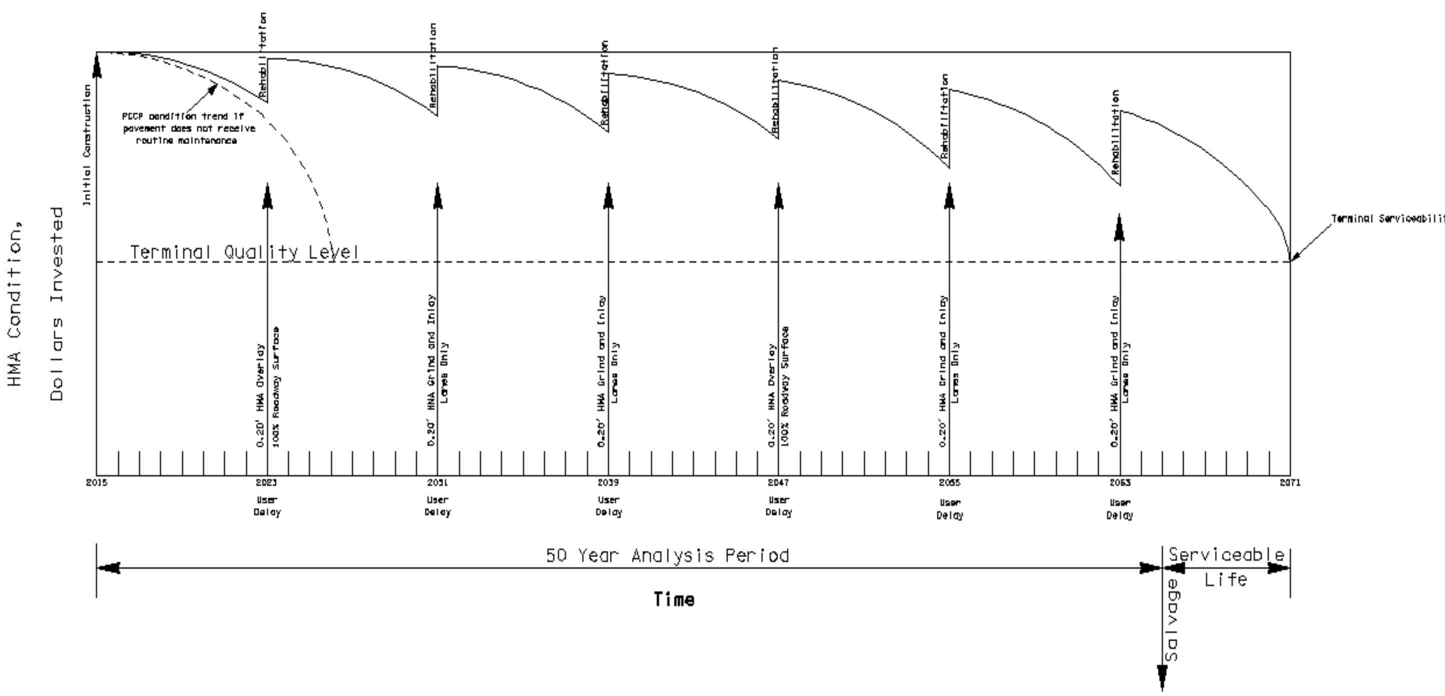

Exhibit 4: HMA Performance Life Cycle Diagram

PCCP Design Alternative
The PCCP alternative includes 0.90 ft. of PCCP, 0.15 ft. Hot Mix Asphalt Base (HMAB) placed over the existing PCCP lanes as shown in Exhibit 5. Both the inside and outside shoulders consist of 0.35 ft. HMA Class ½" placed over 0.70 ft. CSBC.

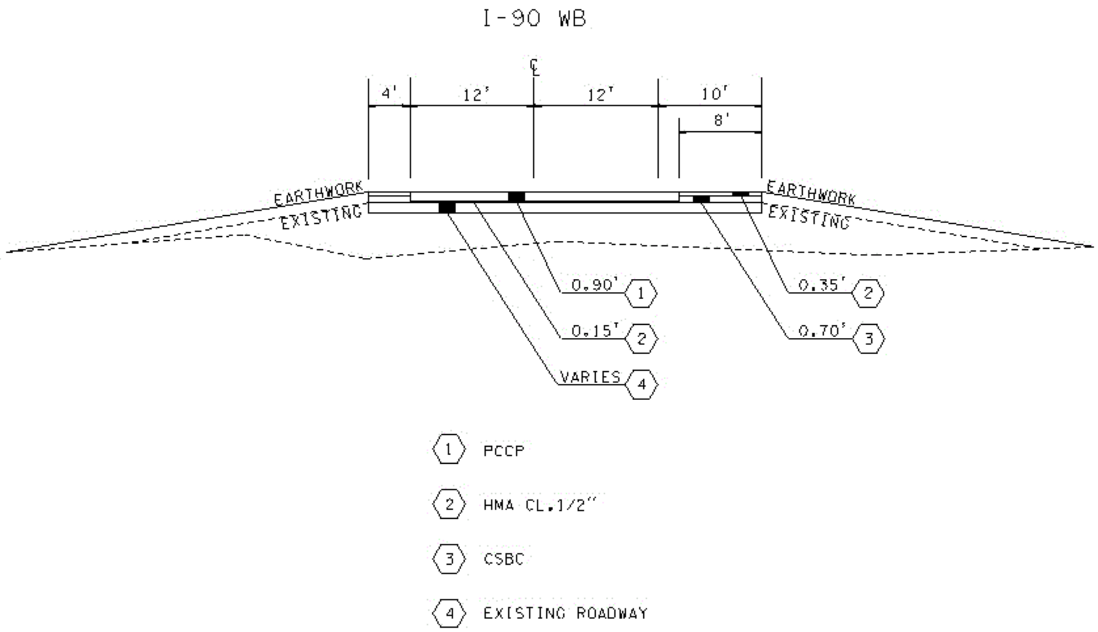

Exhibit 5: PCCP Roadway Section

PCCP Rehabilitations
A 25-year rehabilitation cycle was selected by conducting historical analysis of I-90 Snoqualmie Pass East and a similar section of Interstate 5 (I-5). Both facilities have similar average annual daily traffic (AADT) and truck percentages (see Appendix B).

Rehabilitation for the PCCP option is scheduled for 2040. Diamond grinding will be done to the PCCP wearing surface in addition to grinding and inlaying of the shoulders with 0.15 ft. of HMA and cleaning and resealing of joints and cracks. A summary of the construction and anticipated rehabilitations are shown in Exhibit 6. The performance life cycle diagram shown in Exhibit 7, is a graphical representation of the PCCP Construction and Rehabilitation Summary.

Construction Category	Year	Description
Initial Construction (2015)	0	Rehabilitate two 12-foot lanes in westbound direction and 4-foot inside and 10-foot outside shoulder by: Lanes • Overlay existing PCC pavement with 0.15 feet

		HMA • Overlay with 0.90 feet PCCP Shoulders • Overlay existing shoulders with 0.70 feet CSBC • Overlay with 0.35 feet HMA Class ½" PG 64-22 to match traveled lanes
Rehabilitation #1 (2040)	25	PCCP diamond grind, clean and reseal joints, grind and inlay shoulders with 0.15' HMA
Rehabilitation #2 (2055)	50	PCCP diamond grind, clean and reseal joints, grind and inlay shoulders with 0.15' HMA

Exhibit 6: PCCP Construction and Rehabilitation Summary

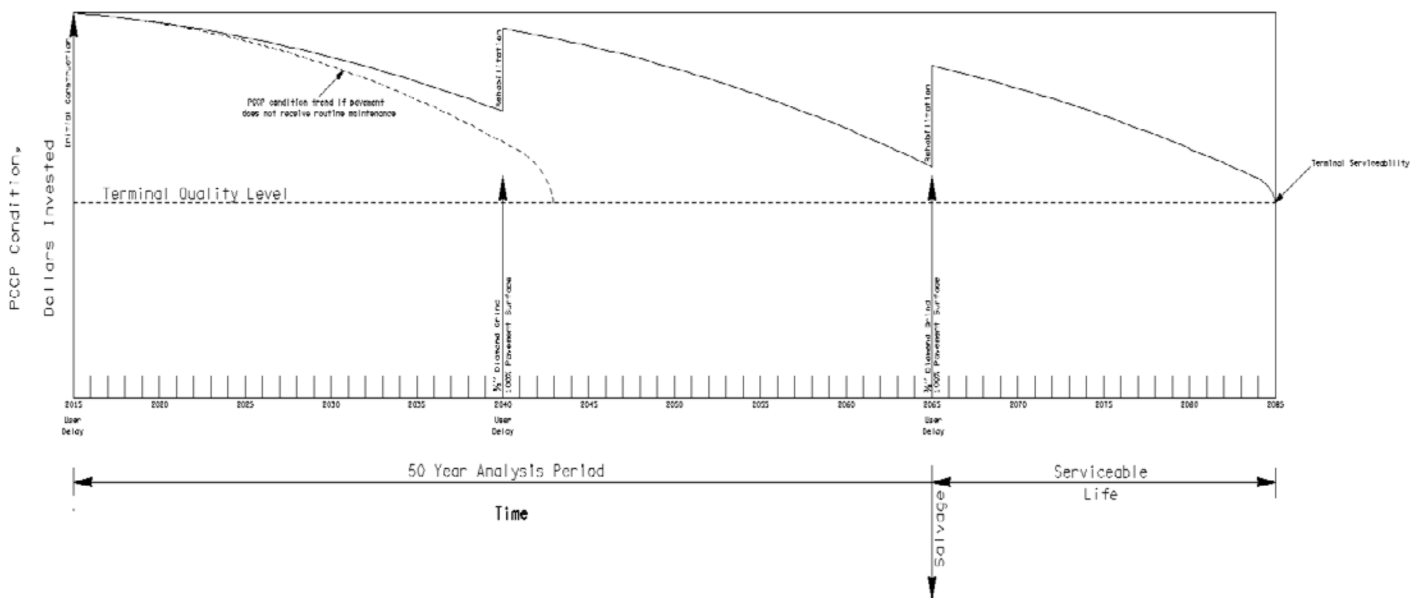

Exhibit 7: PCCP Performance Life Cycle Diagram

Step 2: Life-Cycle Cost Analysis

The following section describes the Life-Cycle Cost Analysis (LCCA). The first section describes the variables used in the analysis followed by the results.

Program Variables

Representative Section

Costs in this report are representative of the entire 9.09 miles of this project length as described.

Economic Variables

Estimated initial construction costs, future rehabilitation costs, and user costs for the one-mile analysis are in 2013 net present value dollars using a 4% discount rate.

Traffic Data

Traffic analysis over a 50-year period with a 2015 construction year was conducted using the following:

- A four-lane roadway.
- 2015 initial traffic volume of 25,000 AADT, as provided by the WSDOT. Transportation Data Office (TDO).
- Straight-line annual traffic growth rate of 2.0% as per WSDOT TDO.
- Speed under normal operating conditions, 65 miles per hour.
- Maximum AADT (both directions) of 70,000 as provide by SCR Traffic.

Truck Percentages

The initial truck volumes of single, double, and triple units per day are provided by the WSDOT TDO. Truck percentages, as percentages of AADT, are as follows:

- Total Truck Percentage 23.4%
- Single Unit Trucks as percentage of July-August AWDT (6.9%)
- Combination Trucks as a percentage of July-August AWDT (16.5%)

Free Flow Capacity

Free Flow Capacity of 1300 vehicles per hour per lane (vphpl) was determined by WSDOT SCR Traffic office.

Traffic Speed during Work Zone Conditions

A 45 mph reduced speed limit for detours was used during the work zone lane closure periods.

Functional Classification

This highway is assigned a “Rural” functional classification due to its location and population density.

Queue Dissipation Capacity

Queue Dissipation Capacity of 1323 vphpl was used for all rehabilitation cycles on both alternatives as per the WSDOT TDO.

Maximum Queue Length (Miles)

Based on the lack of availability of off-ramp exits traveling towards the project limits in either direction, a maximum queue length of 20 miles is used.

Lane Closures

This hourly input is based on a 24-hour clock and marks the beginning and ending hours when a lane reduction will be in place during construction activities:

- Initial construction PCCP Design
  - 24 hour Monday through Thursday WB single lane closure
  - Closure period traffic operation
  - 2 WB and 2 EB lanes open to traffic
  - Improve EB and WB shoulders for temporary usage
  - Provide WB to EB crossover lane for barrier separated EB counter-flow operation
- Initial Construction CSOL
  - CSOL WB lanes
    - Nighttime 10 hour Monday through Thursday WB single lane closure 8 PM to 6 AM
  - Lane reconstruction for grade adjustment at bridges and ends
    - 24 hour Monday through Thursday WB single lane closure
    - Closure period traffic operation
    - 2 WB and 2 EB lanes open to traffic
    - Improve EB and WB shoulders for temporary usage
    - Provide WB to EB crossover lane for barrier separated EB counter-flow operation
- Rehabilitations
  - Nighttime 10 hour Monday through Thursday WB single lane closure8 PM to 6 AM

Estimates

The costs do not reflect the actual estimated cost to complete the project. The estimated initial construction and future rehabilitation costs include only those items directly related to pavement construction. The costs reflect past WSDOT project bidding, neat line quantities, traffic control, engineering, and sales tax. (See Appendix C-2 through C-9, p. 40-47)

Work Zone Capacity and Speed

- Initial construction PCCP Design
  - EB 900 vphpl at 65 mph
  - WB 750 vphpl at 50 mph
- Initial Construction CSOL initial construction
  - EB 900 vphpl at 65 mph
  - WB 750 vphpl at 50 mph
- Rehabilitations
  - WB 750 vphpl at 50 mph

Equivalent Uniform Annual Cost (EUAC)

EUAC analysis produces the yearly cost of an alternative as if they occurred uniformly throughout the analysis period.

Net Present Value

Predicted future costs converted to present dollars through an economic technique known as discounting.

Deterministic

Uses single set of input values to calculate a single solution.

Traffic 24-Hour Distribution

The number of vehicles during each hour segment of a normal 24-hour period based on distribution provided by the WSDOT TDO was calculated as follows:

Hour	BW %	Inbound %	Outbound %
0-1	1.07	45.7	54.3
1-2	0.79	47.0	53.0
2-3	0.71	49.6	50.4
3-4	0.80	58.5	41.5
4-5	1.22	65.8	34.2
5-6	2.09	63.6	36.4
6-7	2.94	52.2	47.8
7-8	3.52	47.4	52.6
8-9	4.30	45.8	54.2
9-10	5.31	45.7	54.3
10-11	6.47	43.0	57.0
11-12	6.99	44.5	55.5
12-13	7.08	47.5	52.5
13-14	7.18	51.1	48.9
14-15	7.41	50.3	49.7
15-16	7.36	48.5	51.5
16-17	7.10	47.2	52.8
17-18	6.34	48.6	51.4
18-19	5.47	50.8	49.2
19-20	4.85	49.9	50.1
20-21	4.04	49.7	50.3
21-22	3.13	49.6	50.4
22-23	2.24	48.7	51.3
23-24	1.59	45.7	54.3

Exhibit 8: I-90 July-August Average Weekday ’05 AWDT Rural %

Estimates

The costs do not reflect the actual estimated cost to complete the project. The estimated initial construction and future rehabilitation costs include only those items directly related to pavement construction. The costs reflect past WSDOT project bidding, neat line quantities, traffic control, engineering, and sales tax. (See Appendix C)

Probabilistic

An iterative calculating process using various frequency distribution inputs for a set of multiple distributed solutions.

LCCA Analysis Software

Real Cost Version 2.5.4 software was used to perform the analysis (See Appendix D for initial construction and rehabilitation input data sheets.

Probabilistic Inputs

Probabilistic models and inputs were selected based on the most likely type of distribution and variation and anticipated. Exhibit 12, 13, and 14 show the Normal, Truncated Normal, and Triangular distribution model and input values used for iterative solutions in the Probabilistic Analysis. Input models and values were selected based on the input type or guidelines established in the Washington State Pavement Guide, Volume 1,Pavement Policy. Traffic data was provided by the WSDOT TDO and reviewed by South Central Region Traffic Office.

Normal Model Inputs		
Description	Means	Standard Deviation
Discount Rate	4%	1%
Normal Operations Capacity (vphpl)	1300	100
Queue Dissipation Capacity (vphpl)	1323	100

Exhibit 12 Normal Model Input Values

Normal Truncated Model Inputs				
Item Description	Means	Standard Deviation	Minimum	Maximum
PCCP ($/CY)	$140	$5	$130	$150
HMA- Initial Construction ($/ton)	$62	$5	$52	$72
HMA-Rehabs ($/ton)	$65	$5	$55	$75
Diamond Grinding ($/SY)	$9	$1	$7	$11
Planing Bituminous Pavement ($/SY)	$1.5	$0.3	$1	$2
Corrosion Resistant Dowel Bars ($/Each)	$15.5	$1	$13.5	$17.5

Miscellaneous	10%	3%	5%	15%

Exhibit 13 Normal Truncated Model Input Values

Triangular Model Inputs			
Description	Minimum	Most Likely	Maximum
Closures Periods	-10%	Exhibit 10	+10%
PCCP Service Years	21	25	29
Time Value Pass Car*	$12	$13.96	$14
Time Value Single Unit Truck*	$20	$22.34	$24
Time Value Combination Unit Truck*	$25	$26.89	$29
HMA Service Year	6	8	10
PCCP Design Workzone initial construction			
Description	Minimum	Most Likely	Maximum
EB Capacity (vphpl)	1200	1300	1400
EB Speed (mph)	55	65	75
WB Capacity (vphpl)	650	750	850
WB Speed (mph)	40	50	60
CSOL initial construction and rehabilitations			
Description	Minimum	Most Likely	Maximum
WB Capacity (vphpl)	650	750	850
WB Speed (mph)	40	50	60

***2006 cost shown inflated to 2112 dollars**

Exhibit 14 Triangular Model Input Values

LCCA Results

This LCCA was performed using both the deterministic and risk based probabilistic methods. The results are present below.

Deterministic Method

The deterministic present value life cycle cost Agency, User, and Combined cost are shown in Exhibit 15. The CSOL alternative present value agency costs and combined cost and 8.9% and 8.1% lower respectively than the PCCP Design alternative, but the CSOL user cost are 11.7% higher than PCCP Design alternative.

The undiscounted agency and user cost expenditure stream is shown in Exhibit 16.

PV Cost	Alternatives ($1000)		Percentage of additional cost required for the PCCP Design Alternative
	CSOL	PCCP Design	
Agency	$27,041	$29,446	8.9%
User	$1,081	$954	-11.7%
Combined	$28,122	$30,400	8.1%

Exhibit 15: Deterministic Results

Expenditure Stream				
	CSOL		PCCP Design	
Year	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
2015	$21,036.00	$212.81	$27,993.00	$794.06
2016				
2017				
2018				
2019				
2020				
2021				
2022				
2023	$2,181.00	$34.37		
2024				
2025				
2026				
2027				
2028				
2029				
2030				
2031	$3,588.00	$82.77		
2032				
2033				
2034				
2035				
2036				
2037				
2038				
2039	$2,181.00	$207.27		
2040			$3,874.00	$427.22
2041				
2042				
2043				
2044				
2045				
2046				
2047	$3,588.00	$899.21		
2048				
2049				
2050				
2051				
2052				
2053				
2054				
2055	$2,181.00	$1,387.69		
2056				
2057				
2058				
2059				
2060				
2061				
2062				
2063	$3,588.00	$3,710.11		
2064				
2065	($2,691.00)	($2,782.58)		

Exhibit 16: Undiscounted Expenditure Streams

Probabilistic Method

The probabilistic present value life cycle cost Agency, User, and Combined cost are shown in Exhibit 18. Based on the analysis the PCCP design has less risk than the CSOL. This is shown by the PCCP alternatives smaller standard deviation.

Total Cost (Present value)	CSOL			PCCP Design		
	Agency Cost ($1000)	User Cost ($1000)	Sum	Agency Cost ($1000)	User Cost ($1000)	Sum
Mean	$27,060	$1,450	$28,510	$29,450	$1,280	$30,730
Standard Deviation	$1,170	$1,150		$810	$530	
Minimum	$23,600	$240		$27,110	$440	
Maximum	$30,760	$11,210		$31,950	$5,830	

Exhibit 18: Probabilistic Results

The Agency Cost distributions are shown in Exhibit 19. The CSOL distribution is broader and less defined than PCCP design alternative's making it a higher risk choice.

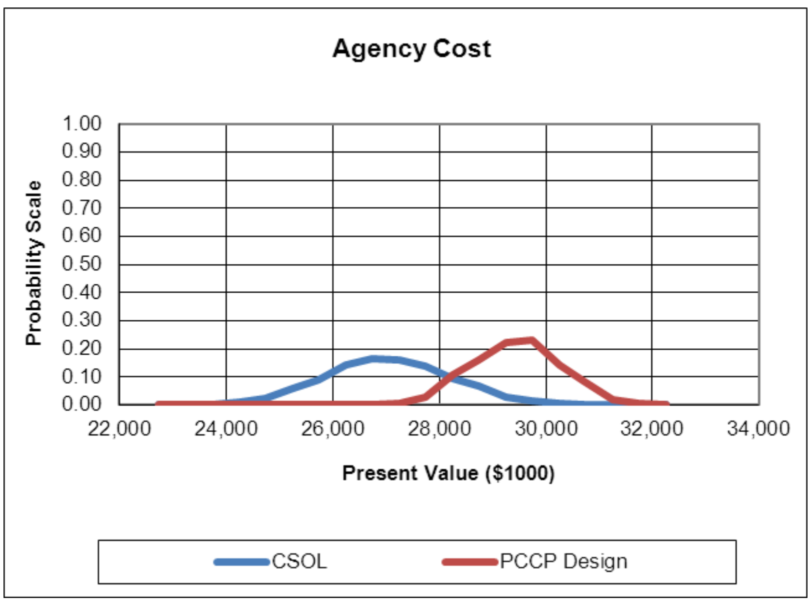

Exhibit 19: Probabilistic Agency Cost Distribution

The cumulative Agency Costs are shown in Exhibit 20. Only about 20% of the PCCP design costs exceed the range of the CSOL alternative.

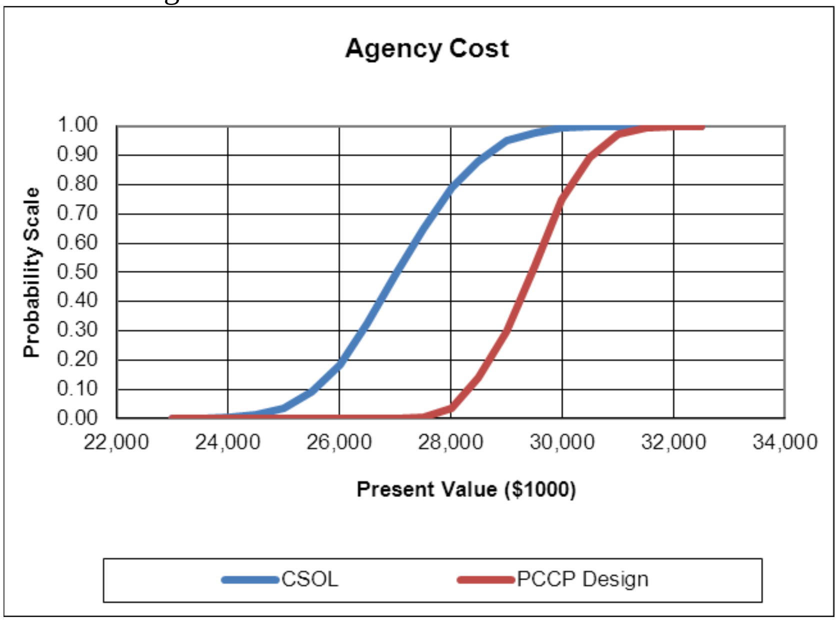

Exhibit 20: Probabilistic Agency Cost Cumulative

The User Cost distributions are shown in Exhibit 21. The distribution of the CSOL alternative is broader than the PCCP Design alternative, again making it the risker option.

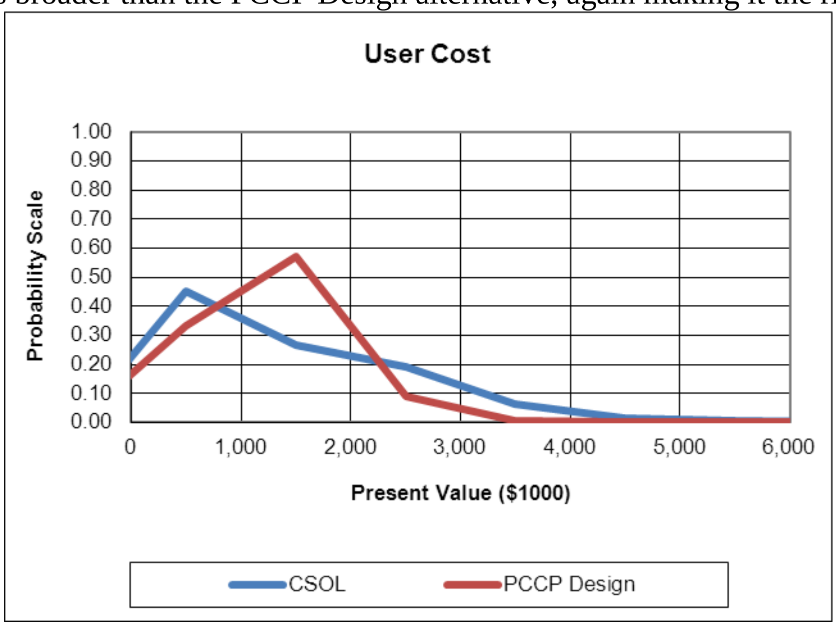

Exhibit 21: Probabilistic User Cost Distribution

The cumulative User Costs are shown in Exhibit 22. About 10% of the upper range of the CSOL user costs are greater than PCCP Design user costs.

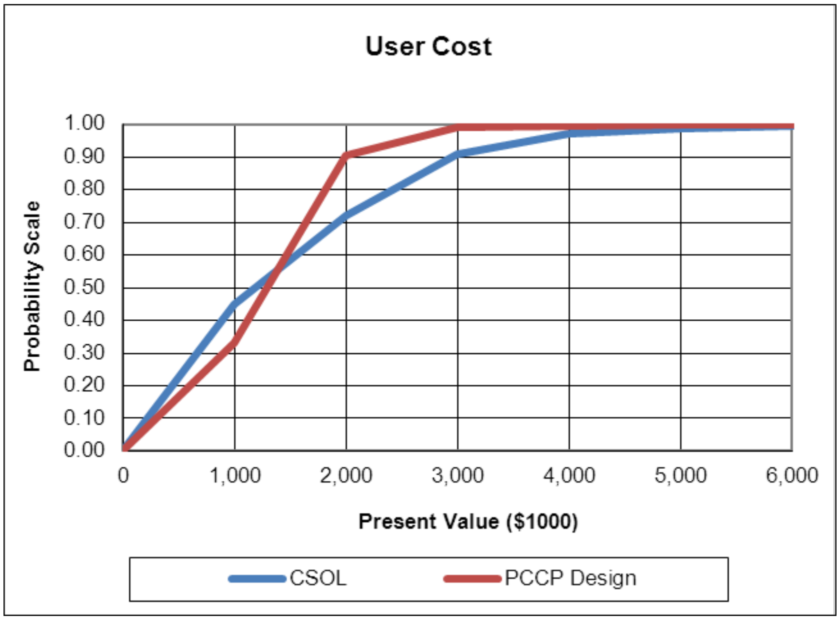

Exhibit 22: Probabilistic User Cost Cumulative

Step 3: Engineering Analysis

The alternative pavement types are considered equal since the results of the LCCA are within 15%. An engineering analysis is required whenever the cost difference between the HMA (CSOL) and PCCP design alternatives are within 15%. As discussed in the LCCA section the PCCP alternative's combined cost is 8.1% higher than the HMA.

Route Continuity
Pavement-type continuity should be maintained with existing I-90 PCCP lanes. Generally it is not desirable to switch pavement types over relatively short stretches of highway as the maintenance needs change, as do preservation needs. Further, the change in pavement type impacts the public in various ways, including aesthetics.

Aggregate Sources
Large volumes of quality aggregate meeting the WSDOT's standards for Los Angeles Abrasion and Degradation are not widely available in this area. PCCP is preferred over HMA because rehabilitation using crushed aggregate is less frequent for PCCP and only required for the asphalt shoulders.

Safety
The HMA rehabilitations represent a negative risk opportunity especially considering that all rehabilitations will have to take place a night. The traveling public, WSDOT employees, and the contractor's personnel are exposed to construction activities and traffic over long periods of time and at greater frequency than during PCCP rehabilitations thereby increasing the probability of a serious accident.

Risk
There are higher risks associated with the longevity of the HMA pavement and costs associated with future rehabilitations. WSDOT continues to investigate the use of lower cost HMA alternatives such as CSOL. HMA pavements in Eastern Washington environments, particularly on high ESAL routes west of this study area, have performed poorly. A 2013 project on I-90 from MP 64 to MP 67 will construct as section of CSOL so WSDOT can evaluate the longevity in harsh environments. Once a more defined asphalt performance period can be established CSOL may a viable option on I-90. WSDOT is confident the unbounded PCCP overlay option will perform well unlike the CSOL option where the long-term performance is less certain.

Pavement Type Selection Recommendation

The South Central Region recommends the use of the PCCP Design alternative for construction of the I-90/Oaks Ave Vic to Elk Heights Rd Vic WB project based on the engineering analysis.

Appendix A - Pavement Design

Washington State Department of Transportation

Memorandum

STATE MATERIALS LAB
FEB 22 2013
RECEIVED

February 14, 2013

PAUL J. GONSETH
STATE OF WASHINGTON
27532
REGISTERED PROFESSIONAL ENGINEER
2/19/13

Region Materials Engineer Stamp

TO: Jeff Uhlmeyer, P.E. / Mark Russell P.E.
State Pavement Engineer
MS: 47365

THRU: BW Brian White, P.E.
SCR Assistant Regional Administrator
for Project Development

FROM: Paul Gonseth, P.E.
SCR Planning & Materials Engineer

SUBJECT: XL 4316, PIN#: 509007T, I-90, MP: 84.21 to 93.30
"I-90/Oakes Ave I/C to Elk Heights Rd I/C Vic. WB - Replace PCCP"
Pavement Design Report

INTRODUCTION:

The following memorandum details the minimum pavement design to reconstruct/rehabilitate the existing deteriorated Portland Cement Concrete Pavement (PCCP) in the westbound lanes of Interstate 90 from the vicinity of the Oakes Avenue Interchange (I/C) (Exit 84) at MP 84.21 easterly to the vicinity of the Elk Heights I/C (Exit 93) at MP 93.30. The center of the project is situated approximately 5 miles east of the City of Cle Elum, Washington.

The estimated time this project is scheduled to be advertised for contractor bidding is early 2015.

MINIMUM PAVEMENT DESIGN:

MP 84.21 to MP 93.30

Un-bonded PCCP Overlay Section

1. Excavate 2.5 ft. of the existing HMA and surfacing materials directly adjacent to the existing right hand lane to a depth of 0.35 ft. then place 0.35 ft. of HMA Class ½" PG 64-28 in the excavated area.
2. Excavate and replace and existing PCCP panels that are either displacing under traffic load or broken in such a manner that would interfere with the placement and function of the HMA separation layer or PCCP overlay. See discussion section for additional details.
3. Construct un-bonded overlay by placing 0.90 ft. of PCCP over a 0.15 ft. HMA Class ½" PG 64-28 separation layer placed directly on the existing PCCP and new widening.

DOT Form 700-008 EF
Revised 5/99

Prior to placing the separation layer, perform any necessary repairs of holes created by failed dowel bar retrofit (DBR) grout or other irregularities of the existing PCCP by patching with commercial HMA or grout conforming to section 9-20.3(2) of the Standard Specifications.

Mainline Vertical Transition Section

1. Construct new transition traveled lanes by first excavating the existing PCCP, necessary portions of the existing shoulders, surfacing, and sub-grade materials to a depth of 1.55 ft.
2. Place 1.05 ft. of PCCP over 0.25 ft. of HMA Class ½" PG 64-28 over a minimum of 0.25 ft. of CSBC on the excavated area. Restrict the vertical transition rate to no steeper than 0.2%.

Replacement PCCP Section

1. Construct new traveled lanes by first excavating the existing PCCP, necessary portions of the existing shoulders, surfacing, and sub-grade materials to a depth of 1.55 ft. then place 1.05 ft. of PCCP over 0.25 ft. of HMA Class ½" PG 64-28 over 0.25 ft. of CSBC on the excavated area.

Mainline Shoulders (Un-bonded Overlay Sections)

1. Remove the existing HMA from both shoulders in super-elevated sections. Remaining portions of the HMA shoulders may be incorporated into the new shoulders in tangents if desired.
2. Construct new shoulders by placing 0.35 ft. of HMA Class ½" PG 64-28 over 0.70 ft. of CSBC where the existing shoulders have been left intact. Increase the CSBC depth to 0.95 ft. where the shoulders have been removed.

Mainline Shoulders (Replacement PCCP Section)

1. Construct new shoulders by placing 0.35 ft. of HMA Class ½" PG 64-28 over 1.20 ft. of CSBC. Existing surfacing material may be incorporated into the construction of the new shoulders if desired

Ramp and Taper Sections for Both Mainline Pavement Sections

1. Construct ramp tapers adjacent to both the un-bonded PCCP section as well as replacement PCCP section by using the equivalent section of the adjacent mainline roadway (0.90 ft. PCCP over 0.15 ft. HMA Class ½" PG 64-28 & 1.05 ft. PCCP over 0.25 ft. HMA over 0.25 ft. CSBC respectively).
2. Construct shoulders adjacent to ramp tapers, reconstructed ramps (if any), and tie-ins by placing 0.25 ft. of HMA Class ½" PG 64-28 over a sufficient amount of CSBC to perpetuate the section of the adjacent roadway.

3. Construct the tie-ins from the end of the new PCCP tapers constructed adjacent to the un-bonded overlay sections by placing a minimum of 0.75 ft. of HMA Class ½" PG 64-28 over sufficient CSBC. If any ramp reconstruction becomes necessary construct new ramps by placing 0.75 ft. of HMA Class ½" PG 64-28 over 0.50 ft. of CSBC.

Median Crossovers and Detour Lanes

1. Construct median crossovers and detour lanes by placing 0.35 ft. of HMA Class ½" PG 64-28 over 0.65 ft. of CSBC. Increase CSBC depths to an equivalent depth of the adjacent roadway where lanes will be incorporated as permanent shoulders.

Notes:

1. Install corrosion resistant dowel bars at sawcut transverse contraction joint in accordance with Standard Plan A-40.10-00. Seal the longitudinal HMA/PCCP joint with hot poured joint sealant in accordance with Standard Plan A-40.10-00.
2. In order to improve load transfer in the un-bonded PCCP overlay, offset the new transverse sawcut joints (above the middle of the existing PCCP panel is preferable).
3. Employ longitudinal tining.
4. Construct a 14 ft wide right (driving) lane to reduce pavement edge loading. Stripe the widened lane at the standard 12 ft width.
5. The 0.25 ft HMA base under the new PCCP pavement need only extend a maximum of 0.5 ft. past the proposed 14 ft. wide PCCP slab.
6. HMA on the shoulders shall be compacted to the same relative density specifications as the traveled lanes. Section 5-04.3(10)B should be revised to include shoulders.
7. Use an ESAL level of 2.0 million for mix design development of HMA Class ½" PG 64-28.
8. No Contracting Agency source of materials is provided on this project.

GENERAL

Geology, Geography, and Roadway Foundation Soil Description

The west end of the project site is situated on the flood plain in the upper Yakima River Valley. As the project progresses easterly the alignment moves up onto the higher glacial and stream terraces and eventually up onto the north face of the ridge that runs roughly east/west on the south side of the Yakima River Valley.

Valley floor and terrace sediments generally consist of unconsolidated alluvial sediments ranging in size from silt up to gravel and boulders. In addition to the alluvial sediments, pockets of periglacial and recessional outwash material consisting of clay, silt, sand, and gravel were deposited throughout the area. These occur at various depths along the entirety of the current alignment and portions of the existing subgrade were constructed out of these materials. Subsequent construction along this section of roadway that involved working with the finer grained portion of these soils has proved extremely difficult in terms of compaction and moisture control.

The nearest bedrock formations to the project are the lowermost members of the Columbia River Basalt which are exposed along sections of the valley wall along the eastern sections of the alignment. The rock units will most likely not impact construction of the PCCP overlay with the possible exception of re-sloping operations.

Climatology

Climatology data from the weather station located west of Cle Elum is as follows:
Annual precipitation varies between 5.5 in. and 35 in. with a 19.5 in mean yearly average.
Annual snowfall has varied between 23.0 in. and 154.5 in. with a 73.5 in. mean yearly average.
The maximum frost depth recorded in February 1950 is 35 in.

The temperature data is:	Mean	Std	Min	Max	Years
High 7-day Air Temp., C	33.5	1.9	29.1	37.2	46
Low Air Temperature, C	- 22.8	5.7	-36.1	-12.2	46
Low Air Temp. Drop, C	19.0	3.7	13.9	33.9	44
Degree Days over 30 C	79	42	16	269	46

Construction History

This section of I-90 was originally constructed on CT 7880 in 1967. The original section consisted of 0.75 ft. of PCCP over 0.75 ft. (easterly of MP 87.85) to 0.83 ft. (westerly of MP 87.85) of untreated base. The entire section received a dowel bar retrofit and diamond profile grind on CT 4902 in 1997 due to severe faulting.

A small portion of the roadway between MP 87.96 to MP 88.31 received a full width 0.25 ft. HMA overlay.

Original shoulders consisted of 0.15 ft of HMA over a combination of ballast and CSTC. The shoulder HMA depth was increased to 0.25 ft. on the dowel bar retrofit project in 1997.

Interchange speed change lanes were constructed with 0.25 ft of HMA over 0.50 ft of unfinished concrete over a combination of ballast and CSTC.

Existing Pavement Condition

A field review of this section of roadway indicated widespread distress in the form of numerous multi-cracked PCCP panels, corner cracked PCCP panels, and dowel bar retrofit failure (in the form of grout pour-back material erosion as well as pour-back material cracking and removal from the dowel bar slots requiring intensive maintenance patching). There is also significant continuous panel to panel longitudinal wheelpath cracking propagating from a corner of one dowel bar slot in a panel to a corner of an adjacent dowel bar slot in the next panel.

Faulting ranges from 0 in. to 1/8 in. Rut depths average 3/8 in. to 1/2 in. IRI measurements range from 62 inches/mile up to 322 inches/mile with the average being approximately 150 inches/mile to 160 inches/mile being representative of the majority of this section.

The ride quality of the passing lane could be characterized as fair to good although no IRI measurements are available at the time of this report. Faulting is minimal with very few measured reading approaching 1/8 in. The major distress of note is the amount of transverse and longitudinal cracking in these panels.

Traffic ESAL Volumes from WSPMS

Values from 2012 WSPMS were used to estimate future ESALs. The 2011 traffic counts used in the 2012 WSPMS database predicted there would be 1,100,000 ESALs in each direction for the 2016 design year. Fifty year ESAL projections beginning in 2016 will be roughly 150,000,000 in each direction using a customary 2.00% rate of annual growth. Using a 20%/80% lane traffic split indicates that approximately 120,000,000 ESALs are necessary for design calculations and this value was utilized in the software analysis.

ANALYSIS

AASHTO DARWin Discussion

The un-bonded PCCP overlay module of the DARWin pavement design software was utilized to verify the structural requirements for the un-bonded PCCP overlay. Condition survey methodology using an estimated 50 unrepaired deteriorated joints per mile and 50 unrepaired cracks per mile provided an effective existing pavement thickness of approximately 0.67 ft. This value was used in conjunction with the WSDOT Pavement Design Guide 1.08 ft. requirement for a new pavement to compute the un-bonded overlay depth. In summation, the software assigns a "credit" of approximately 2 to 3 inches to the existing PCCP pavement.

Minimum Pavement Design Discussion

After analysis of existing project area conditions, software analysis, literature review, as well as assistance from the SML Pavement Branch with Mechanistic-Empirical (M-E) evaluation of preliminary design concepts, the following pavement sections are specified for this project.

In segments where the existing conditions allow, construct the 0.90 ft. un-bonded PCCP overlay by first excavating 2.5 ft. the existing surfacing materials on the right shoulder directly adjacent to the PCCP lanes to a depth of 0.35 ft. and replace with a like amount of HMA Class ½" PG 64-28. The purpose of this work if to remove any highly distressed shoulder HMA at the lane edge as well as the rumble strips to provide a reasonably stiff layer of material across the entire width of the new 14 ft. wide PCCP lane.

Excavate and replace existing PCCP panels that are either freely displacing when loaded by traffic or have been highly distressed. Stable multi-cracked panels, failed dowel bar slots, corner cracking and minor spalling is not generally sufficient to require panel replacement. Holes created by failed DBR grout or other irregularities, such as large cracks, in the existing PCCP should be patched with commercial HMA or grout conforming to section 9-20.3(2) of the Standard Specifications. The project office should consult the SCR materials office when making final the determination of which ~~planes~~ panels require full replacement or may be patched.

Place a nominal 0.15 ft. HMA Class ½" PG 64-28 pre-leveling course on the existing lanes and new HMA to act as a bond breaker and then place the 0.90 ft. PCCP overlay.

To correct the ride in a small portion of the roadway between MP 87.96 to MP 88.31where the PCCP has begun to rapidly deteriorate the roadway received full width 0.25 ft. HMA overlay. As the condition of this material at the time of construction is impossible to be determined it is recommended that the 0.25 ft. HMA patch be removed and replaced with the 0.15 ft. HMA Class 1/2" PG 64-28 separation layer.

For sections of roadway where constructing the un-bonded overlay is not feasible due to vertical clearance or other issues the roadway is to be reconstructed by first excavating the existing PCCP, surfacing, and any necessary portions of the subgrade to a depth of 1.55 ft. then place 1.05 ft. of PCCP over 0.25 ft. of HMA Class ½" PG 64-28 over 0.25 ft. of CSBC.

Construct mainline vertical transitions where the un-bonded overlay transitions to the existing PCCP or bridge approach slabs with the same 1.55 ft. total pavement section utilized for the reconstruction sections. As a minimum, the existing 0.75 ft. PCCP will require removal at the un-bonded overlay joint. The depth of excavation will gradually increase to 1.55 ft. at the joint with the existing PCCP roadway or bridge approach slab. Construct the new transitions at a slope not steeper than 0.2%.

In general, new mainline shoulders are to be constructed by placing 0.35 ft. of HMA over 1.20 ft. of CSBC which is a sufficient amount of CSBC to perpetuate the existing cross-slope drainage. It is permissible to incorporate whatever remains of the existing 0.25 ft. HMA shoulder that is present along tangents in the un-bonded overlay section and small portions of the transition section, however, the HMA in the existing shoulders will require removal in areas where super-elevations create the possibility of impounding water within the newly constructed pavement structure as well as the reconstruction and the majority of the transition sections.

Per the WSDOT Pavement Design Guide ramp tapers are to be constructed with the same pavement structure as the adjacent mainline roadway, therefore, tapers that are to be constructed adjacent to the un-bonded overlay section are to consist of 1.05 ft. of PCCP over the existing HMA which will act as an HMA base. The concrete taper should continue until the full 15 ft. lane width has been achieved (as a minimum) to allow room to smoothly construct the vertical transitions to the existing HMA ramps.

Ramp tapers constructed adjacent to reconstructed lanes (with no increase in depth) on recent projects have been built in two different manners, one with a portion of the 0.50 ft. un-finished concrete under the tapers remaining in place as well as the other, with complete removal of the unfinished concrete section and substitution of a like depth of HMA. Both of these sections have been successfully constructed, however, there are legitimate concerns about the performance of the 0.25 ft. HMA overlay that is placed over the remaining portions of unfinished PCC.

Therefore the recommended roadway section for ramp tapers constructed adjacent to the 1.05 ft. PCCP mainline reconstruction are to be constructed by placing 1.05 ft. of PCCP over 0.25 ft. of HMA Class ½" PG 64-28 over 0.25 ft. of CSBC after 1.55 ft. of the existing pavement and surfacing materials have been excavated.

Construct shoulders adjacent to any newly constructed ramp tapers by placing 0.25 ft. of HMA Class ½" PG 64-28 over sufficient CSBC to maintain cross-slope drainage. 1.30 ft. of CSBC will be required adjacent to the replacement PCCP section.

The general section for detour lanes, temporary access lanes, and median crossovers is 0.35 ft. of HMA Class ½" PG 64-28 over 0.65 ft. of CSBC. If any of these lanes are to be incorporated into a permanent feature (such as a shoulder) the CSBC depth will need to be increased to the equivalent depth of the roadway it's situated adjacent to in order to perpetuate cross-slope drainage.

For the purposes of performing a life-cycle cost analysis, an alternative HMA roadway section utilizing 0.75 ft. of HMA Class ½" PG 64-28 HMA (with the top 0.25 ft. lift binder being elevated to PG 70-28) placed over the existing PCCP lanes after they have been a crack-and-seated is specified.

Construction Considerations

The proposed utilization of the existing surfacing materials (ballast) during reconstruction of the traveled lanes and right shoulder may require special precautions. Previous field investigation and construction experience on similar projects in this area have indicated that the existing surfacing materials under the PCCP and shoulder may be saturated and/or contaminated with subgrade fines beyond the point that is ideal (not impossible) for compaction. The moisture condition in addition to the un-fractured nature of the existing ballast will complicate compaction efforts after the new grade has been established. Consideration should be given to employing construction techniques (such as prohibiting the use of vibratory rollers) that will provide the minimum disturbance to the existing surfacing materials. In addition caution needs to be exercised to reduce, as much as possible, potential damage to the new grade when trucks delivering paving HMA and concrete arrive on the job. Using a placer for delivering PCC to the project is strongly encouraged. If these materials are re-used space will need to be made available for stockpiling and possible processing as well. This topic will require discussion with Region Construction Office representatives during development of the project. It may be determined that re-utilization of the existing materials for this project is impractical.

If disturbance of the subgrade or existing surfacing material during excavation or recompaction results in a condition where the material begins to exhibit an excessive pumping condition or becomes unable to support the load of construction vehicle traffic provisions should be made in the contract documents for the contractor to have a supply of high survivability construction geotextile material and crushed surfacing on hand to perform necessary stabilization repairs as described below.

The prescribed repair for pumping grade conditions consists of excavating the minimum amount of material deemed necessary to restore the load carrying capacity of the grade or subgrade material. Construction geotextile material is then placed over the material in the over-excavated area and covered with a depth of compacted CSBC equal to the depth of the over-excavation. If the depth of material requiring excavation exceeds 0.50 ft. provisions will need to be made to drain the newly placed CSBC across the shoulders to the ditch or fill slopes at regular intervals or reconstruct the shoulders with a like amount of CSBC thereby perpetuating the cross-slope drainage of the roadway. For this reason, as well as the fact that this operation most likely will be paid for under force-account provisions, it is recommended that project inspectors refrain from performing any over-excavation exceeding 0.50 ft unless absolutely necessary.

Mix Design Considerations

It is recommended that an ESAL level of 2 million be used to develop the HMA mix design for HMA Class ½" PG 64-28 on this project. Given the various levels of duty HMA being placed on this project will be subjected to multiple N Design gyration levels could, at least in theory, be specified. For the purposes of this project the designated N Design compaction level of 75 gyrations will provide a "richer" mix that is slightly higher in asphalt cement content. This property should provide better long-term resistance to environmental aging on the shoulders as well as better fatigue and cracking resistance for the separation layer.

As is the case with the design compaction level, multiple grades of asphalt binder might be specified for HMA being placed on this project. After consideration of constructability and contract administration issues PG 64-28 binder is being specified for all HMA on this project.

Review & Concurrence by:

2/27/13

JEFF UHLMEYER, P.E.
WSDOT State Pavement Engineer

PG:msh
Attachments: DARWin Output

cc: SCR Assistant RA for Project Development
SCR Assistant RA for Construction
SCR Project Office, (Kerry Grant)
SCR Area 1 Maintenance Superintendent
SCR Planning & Materials Engineer
SCR Program Management
SCR Environmental Program Manager

Appendix B - Pavement Performance

Table B-1. Documentation of Past I-90 HMA & PCC Performance

<table>
<tr><th>HMA</th><th colspan="5">Eastern Washington 0.15' HMA Inlay or Overlay Rehab Assessment</th></tr>
<tr><td>Route</td><td>EB I-90</td><td>EB I-90</td><td>WB I-90</td><td>SB SR-195</td><td>EB I-90</td></tr>
<tr><td>Section MP</td><td>257.35 to 265.84</td><td>270.36 - 271.02</td><td>295.50 - 298.13</td><td>82.75 - 85.59</td><td>121.96 - 125.59</td></tr>
<tr><td>Total Lanes</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>Traffic Data</td><td colspan="5">2011</td></tr>
<tr><td>Directional ADT</td><td>8,534</td><td>14,314</td><td>25,924</td><td>3,362</td><td>13,983</td></tr>
<tr><td>Trucks %</td><td>25.6</td><td>25.6</td><td>11.4</td><td>15.6</td><td>25.6</td></tr>
<tr><td>15 year MESAL</td><td>15.7</td><td>19.3</td><td>16.3</td><td>3.4</td><td>13</td></tr>
<tr><td>Design Lane MESAL</td><td>14.1</td><td>17.4</td><td>14.7</td><td>3.1</td><td>11.7</td></tr>
<tr><td>Year</td><td rowspan="8"></td><td></td><td rowspan="8"></td><td rowspan="6"></td><td rowspan="6"></td></tr>
<tr><td>1989</td><td rowspan="8">7</td></tr>
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<tr><td>1992</td></tr>
<tr><td>1993</td></tr>
<tr><td>1994</td><td rowspan="10">9</td><td rowspan="13">12</td></tr>
<tr><td>1995</td></tr>
<tr><td>1996</td><td rowspan="10">9</td><td rowspan="8">7</td></tr>
<tr><td>1997</td><td rowspan="9">8</td></tr>
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<tr><td>2005</td></tr>
<tr><td>2006</td><td rowspan="7"></td><td rowspan="7"></td></tr>
<tr><td>2007</td><td rowspan="6"></td></tr>
<tr><td>2008</td></tr>
<tr><td>2009</td></tr>
<tr><td>2010</td></tr>
<tr><td>2011</td></tr>
<tr><td>2012</td></tr>
<tr><td>Interval Median</td><td>9</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Interval Std Dev</td><td>1.7</td><td></td><td></td><td></td><td></td></tr>
</table>

Table B-2. Documentation of Past I-90 HMA & PCC Performance

<table>
<tr><th>HMA</th><th colspan="5">Eastern Washington 0.15' HMA Inlay or Overlay Rehab Assessment</th></tr>
<tr><td>Route</td><td>EB I-90</td><td>EB I-90</td><td>EB I-90</td><td>WB I-90</td><td>WB I-90</td></tr>
<tr><td>Section MP</td><td>103.25 - 104.71</td><td>295.50 - 298.13</td><td>257.92 - 265.84</td><td>271.00 - 272.62</td><td>169.76-175.62</td></tr>
<tr><td>Total Lanes</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td>Traffic Data</td><td colspan="5">2011</td></tr>
<tr><td>Directional ADT</td><td>25,554</td><td>25,924</td><td>8,560</td><td>13,975</td><td>6,837</td></tr>
<tr><td>Trucks %</td><td>23.33</td><td>11.44</td><td>25.6</td><td>25.6</td><td>25.6</td></tr>
<tr><td>15 year MESAL</td><td>17.8</td><td>16.4</td><td>15.8</td><td>19.1</td><td>12.6</td></tr>
<tr><td>Design Lane MESAL</td><td>16</td><td>14.8</td><td>14.2</td><td>17.2</td><td>11.3</td></tr>
<tr><td>Year</td><td rowspan="10"></td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="9"></td></tr>
<tr><td>1989</td></tr>
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<tr><td>2008</td></tr>
<tr><td>2009</td></tr>
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<tr><td>2011</td></tr>
<tr><td>2012</td></tr>
<tr><td>Interval Median</td><td>9</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Interval Std Dev</td><td>1.7</td><td></td><td></td><td></td><td></td></tr>
</table>

Table B-3. Documentation of Past I-90 HMA & PCC Performance

PCCP	Eastern Washington PCCP Rehab Assessment				
Route	I-90 WB	I-90 EB	I-90 EB	I-90 WB	I-82 WB
MP - MP	76.61 - 78.03	76.61-77.68	85.00 - 86.20	87.85 - 90.00	3.30 - 10.00
Total Lanes	2	2	2	2	2
Traffic Data	2011				
Directional ADT	14,228	14,157	11,988	11,988	7,841
Trucks %	23.3	23.3	23.3	23.3	23.6
15 year MESAL	22.9	22.5	19.3	19.3	12.8
Design Lane MESAL	20.6	20.3	17.4	17.4	11.5
Year					
1964					
1965					
1966					
1967					
1968					
1969					
1970					
1971					
1972					
1973					
1974					
1975					
1976					
1977					
1978					
1979	**30**				
1980			**27**		
1981					
1982				**30**	
1983		**21**			
1984					**26**
1985					
1986					
1987					
1988					
1989					
1990					
1991					
1992					
1993					
1994					
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1997					
1998					
1999					
2000					
2001					
2002					
2003					
2004					
2005					
2006					
2007					
2008					
2009					
2010					
2011					
2012					
Interval Median	26.5				
Interval Std Dev	3.8				

Table B-4. Documentation of Past I-90 HMA & PCC Performance

PCCP	Eastern Washington PCCP Rehab Assessment				
Route	I-82 EB	I-90 EB	I-90 WB	I-82 EB	I-82 WB
MP - MP	11.65 - 13.53	58.59-59.54	58.59 - 59.54	55.66-57.85	72.66-75.00
Total Lanes	2	2	2	2	2
Traffic Data	2011				
Directional ADT	7,924	14,560	14,560	9,959	9,903
Trucks %	23.6	20.9	20.9	16.8	16.6
15 year MESAL	12.9	20.8	20.8	11.4	11.3
Design Lane MESAL	11.6	18.7	18.7	10.3	10.2
Year					
1964					
1965					
1966					
1967					
1968					
1969					
1970					
1971					
1972					
1973					
1974					
1975					
1976					
1977					
1978					
1979					
1980					
1981					
1982					
1983					
1984	**26**				
1985		22	22		
1986					
1987					
1988					
1989					
1990					
1991					
1992					
1993					
1994				31	
1995					
1996					30
1997					
1998					
1999					
2000					
2001					
2002					
2003					
2004					
2005					
2006					
2007					
2008					
2009					
2010					
2011					
2012					
Interval Median	26.5				
Interval Std Dev	3.8				

Appendix C - Pavement Cost

Table C-1. Initial CSOL Construction Cost Estimate

Unit	Item #	Item	Unit Price	Amount	Cost
			CSOL - Oaks to Rd to Elk Hts. MP 84.21 to MP 93.30		
		Section 1 Preparation			
Unit	Item #	Item	Unit Price	Amount	Cost
ACRE	0025	Clearing and Grubbing	$3,000.00	8	$24,000.00
LS	0215	Removing Misc Traffic Item	$5,500.00	1	$5,500.00
LF	0170	Removing Guardrail	$2.50	25,481	$63,702.50
EACH	0182	Removing Guardrail Anchor	$250.00	28	$7,000.00
LF	0187	Removing Paint Line	$0.30	0	
LF	0188	Removing Temporary Pavement Marking	$0.19	0	
LF	0190	Removing Plastic Line	$0.40	48,000	$19,200.00
EACH		Select Tree Removal	$1,000.00	1	$1,000.00
LF		Removing Cable Barrier	$2.00	3,274	$6,548.00
SY		Crack and Seat Concrete Pavement	$1.75	116,695	$204,216.25
		Section 2 Grading			
CY	0310	Roadway Excavation Incl. Haul	$6.00		$0.00
CY	0405	Common Borrow Incl Haul	$8.00	150,000	$1,200,000.00
CY	0470	Embankmenk Compaction	$5.00	150,000	$750,000.00
		Section 4 Drainage			
LF	1184	Schedule A Culv. Pipe 24 IN. Diam.	$75.00	0	$0.00
		Section 5 Storm Sewer			
EACH	1054	Grate Inlet Type 2	$2,000.00	0	$0.00
		Section 9 Surfacing			
TON	5100	Crushed Surfacing Base Course	$20.00	25,000	$500,000.00
MILE		Shoulder Finishing	$2,000.00	3	$6,000.00
		Section 10 Liquid Asphalt			
DOL	5334	Anti Stripping Additive	$42,000.00	1	$42,000.00
		Section 13 Cement Concrete Pavement			
SY	5712	Cement Concrete Pavement Grinding			
DOL	5709	Replace Uncompactable Material			
CY	5625	Cement Conc. Pavement			
EACH	5685	Corrosion Resistant Dowel Bar			
CALC	5637	Ride Smoothness Compliance Adjustment			
CALC	5638	Portland Cement Conc. Compliance Adjustment			
		Secton 14 Hot Mix Asphalt			
SY	5711	Planing Bituminous Pavement	$1.50	0	
TON	5767	HMA CL 1/2 IN. PG 64-28	$72.00	116,141	$8,362,152.00
LF	6514	Longitudinal Joint Seal	$0.90	0	
DOL	5830	Job Mix Compliance Price Adjustment	$250,865.00	1	$250,865.00
DOL	5835	Compaction Price Adjustment	$83,622.00	1	$83,622.00
DOL	5837	Asphalt Cost Price Adjustment	$250,865.00	1	$250,865.00
TON	5875	Commercial HMA	$100.00	0	

		Section 17 Erosion Cntl and Rdside Restoration			
DAY	6403	ESC Lead	$100.00	30	$3,000.00
EACH	6471	Inlet Protection	$100.00	14	$1,400.00
LF	6500	Compost Sock	$3.90	3,300	$12,870.00
DOL	6490	Erosion/Water Pollution Control	$15,000.00	1	$15,000.00
ACRE	6414	Seeding, Fertilizing, and Mulching	$2,000.00	50	$100,000.00
LF	6630	High Visibility Fence	$2.50	2,000	$5,000.00
		Section 18 Traffic			
LF	6757	Beam Guardrail Type 31	$18.50	25,488	$471,518.75
EACH	6760	Beam Guardrail Transition Section Type 23	$2,500.00	5	$12,500.00
EACH	6760	Beam Guardrail Transition Section Type 2	$2,500.00	5	$12,500.00
LF	6727	Extruded Curb	$15.00	530	$7,950.00
EACH	6719	Beam Guardrail Type 31 Non-Flared Terminal	$2,300.00	22	$50,600.00
EACH	6766	Beam Guardrail Anchor Type 10	$700.00	12	$8,400.00

LF	6781	Temporary Conc. Barrier	$6.90	0	
EACH	6830	Barrier Delineator	$10.00	10	$100.00
EACH	7440	Temporary Impact Attenuator	$3,000.00	0	
EACH	7445	Resetting Impact Attenuator	$1,000.00	0	
EACH	7447	Transportable Attenuators	$1,000.00	4	$4,000.00
HR	7449	Operation of Transportable Attenuators	$40.00	3,100	$124,000.00
EST	7450	Repair of Transportable Attenuators	$4,500.00	1	$4,500.00
LF	6784	Removing and Resetting Existing Permanent Barrier	$8.00	740	$5,920.00
LS	7432	High-Tension Cable Barrier (4 Cable)	$15.50	400	$6,200.00
EACH	6832	Flexible Guide Posts	$35.00	320	$11,200.00
LF	6806	Paint Line	$0.10	164,985	$16,498.50
LF	6813	Grooved Plastic Line	$2.00	47,500	$95,000.00
MI	6892	Shoulder Rumble Strip	$800.00	18	$14,400.00
HUND	6889	Recessed Pavement Marker	$1,250.00	6	$7,500.00
LF	6888	Temporary Pavement Marking	$0.11	150,000	$16,500.00
LS	6890	Permanent Signing	$25,000.00	1	$25,000.00
HOUR	6956	Sequential Arrow Sign	$1.75	2,520	$4,410.00
HR	6993	Portable Changeable Message Sign	$1.40	7,056	$9,878.40
LS	6973	Other Temporary Traffic Control	$100,000.00	1	$100,000.00
HR	6992	Other Traffic Control Labor	$45.00	6,151	$276,795.00
LS	6974	Traffic Control Supervisor	$135,000.00	1	$135,000.00
SF	6982	Construction Signs Class A	$22.00	900	$19,800.00
EA	XXXX	Luminaire reset on new base	$5,000.00	10	$50,000.00
0	XXXX	Remove/Reset Radio/Weather Instrument	$15,000.00	2	$30,000.00
		Section 19 Other Items			
LS	7028	Cure Box	$5,000.00	0	
HR	7400	Training	$1.20	2,250	$2,700.00
CY	7005	Structure Excavation Class B	$20.00	0	
EACH	9602	Adjust Inlet	$500.00	10	$5,000.00
SY	7530	Construction Geotextile for Separation	$1.20		
LS	7736	SPCC Plans	$2,000.00	1	$2,000.00
CALC	7730	Fuel Cost Adjustment	$100,000.00	1	$100,000.00
EST	7480	Roadside Cleanup	$15,000.00	1	$15,000.00

BID ITEM SUBTOTAL W/O MOBILIZATION			$13,558,811
MOBILIZATION			$813,529
BID ITEM SUBTOTAL			$14,372,340
DESIGN CONTINGENCIES	WHAT IS THE %?	10	$1,437,234
BID ITEM TOTAL			$15,809,574
SALES TAX	WHAT IS THE %?	8	$1,264,766
700 LEVEL NON-BID ITEMS		WHAT IS THE $	$0
PROJECT SUBTOTAL			$17,074,340
CONSTRUCTION ENGINEERING	WHAT IS THE %?	8	$1,365,947
CONSTRUCTION CONTINGENCIES	WHAT IS THE %?	4	$682,974
CN ESTIMATE			$19,123,261
PE PHASE	WHAT IS THE %?	10	$1,912,326
PROJECT TOTAL			**$21,035,587**

Table C-2. 0.15' HMA Inlay Lanes Cost Estimate

Quantity	Unit	Bid Item		Unit Price	Amount
		Construction Items			
133,320	SY	Planning Bituminous Pavement		$1.50	$199,980
13,699	Ton	HMA CL 1/2" PG 64-22		$75	$1,027,425
13,699	Ton	Anti-Stripping Additive		$1	$13,699
$1,027,425	2%	Compaction Price Adjustment		1%	$10,274
$1,027,425	3%	Job Mix Compliance (HMA CL 1/2" PG 64-22)		3%	$30,823
12.0	Ton	Asphalt For Fog Seal (Shoulders)		$800	$9,600
		Traffic			
1	Calc	Delineation		$20,770	$20,770
1	Calc	Traffic Control - 9-hr Nightime Closures		$172,200	$172,200
				Items Subtotal	$1,484,771
			Design Contingencies	10%	$148,477
				Subtotal	$1,633,248
			Mobilization	10.0%	$163,325
				Subtotal	$1,796,573
			Sales Tax	8.0%	$143,726
				Subtotal	$1,940,299
			Engineering	8.0%	$155,224

Engineering Contingencies	4.0%	$77,612
	Subtotal	$2,173,135
Preliminary Engineering	10.0%	$7,761
	Subtotal	$2,180,896
	Project Total	$2,180,900

Table C-3. 0.15' HMA Inlay Lanes and Shoulders Cost Estimate

Quantity	Unit	Bid Item		Unit Price	Amount
		Construction Items			
202,650	SY	Planning Bituminous Pavement		$1.50	$303,975
13,152	Ton	HMA CL 1/2" PG 64-22 (Lanes)		$75	$986,400
7,671	Ton	HMA CL 1/2" PG 64-22 (Inside and Outside Shoulders)		$75	$575,325
20,823	Ton	Anti-Stripping Additive		$1	$20,823
$986,400	1%	Compaction Price Adjustment		1%	$9,864
$1,561,725	3%	Job Mix Compliance (HMA CL 1/2" PG 64-22)		3%	$46,852
		Traffic			
1	Calc	Delineation		$20,770	$20,770
18.2	MI	Shoulder Rumble Strip Type		$1,500	$27,270
1	Calc	Traffic Control - 9-hr Nightime Closures		$237,000	$237,000
				Items Subtotal	$2,228,279
			Miscellaneous	10%	$222,828
				Subtotal	$2,451,107
			Design Contingencies	10%	$245,111
				Subtotal	$2,696,218
			Sales Tax	8.0%	$215,697
				Subtotal	$2,911,915
			Engineering	8.0%	$232,953
			Engineering Contingencies	4.0%	$116,477
				Subtotal	$3,261,345
			Preliminary Engineering	10.0%	$326,135
				Subtotal	$3,587,480
				Project Total	$3,587,500

Table C-4. Initial PCCP Design Construction Cost Estimate

			PCCP - Oaks to Rd to Elk Hts. MP 84.21 to MP 93.30		
		Section 1 Preparation			
Unit	Item #	Item	Unit Price	Amount	Cost
ACRE	0025	Clearing and Grubbing	$2,500.00	8	$20,000.00
LS	0215	Removing Misc Traffic Item	$5,500.00	1	$5,500.00
LF	0170	Removing Guardrail	$2.50	25,481	$63,702.50
EACH	0182	Removing Guardrail Anchor	$250.00	28	$7,000.00
LF	0187	Removing Paint Line	$0.30	136,100	$40,830.00
LF	0188	Removing Temporary Pavement Marking	$0.19	496,517	$94,338.23
LF	0190	Removing Plastic Line	$0.35	80,118	$28,041.30
EACH		Select Tree Removal	$1,000.00	1	$1,000.00
LF		Removing Cable Barrier	$2.00	3,274	$6,548.00
SY		Crack and Seat Concrete Pavement			$0.00
		Section 2 Grading			
CY	0310	Roadway Excavation Incl. Haul	$5.00	72,000	$360,000.00
CY	0405	Common Borrow Incl Haul	$8.00	93,000	$744,000.00
CY	0470	Embankmenk Compaction	$5.00	165,000	$825,000.00
		Section 4 Drainage			
LF	1184	Schedule A Culv. Pipe 24 IN. Diam.	$75.00	320	$24,000.00
		Section 5 Storm Sewer			
EACH	1054	Grate Inlet Type 2	$2,000.00	5	$10,000.00
		Section 9 Surfacing			
TON	5100	Crushed Surfacing Base Course	$15.00	61,100	$916,500.00
MILE		Shoulder Finishing	$2,000.00	3	$5,000.00
		Section 10 Liquid Asphalt			
DOL	5334	Anti Stripping Additive	$42,000.00	1	$42,000.00
		Section 13 Cement Concrete Pavement			
SY	5712	Cement Concrete Pavement Grinding	$25.00	2,900	$72,500.00
DOL	5709	Replace Uncompactable Material	$75,000.00	1	$75,000.00
CY	5625	Cement Conc. Pavement	$140.00	41,110	$5,755,400.00
EACH	5685	Corrosion Resistant Dowel Bar	$15.50	69,013	$1,069,701.50
CALC	5637	Ride Smoothness Compliance Adjustment	$170,000.00	1	$170,000.00
CALC	5638	Portland Cement Conc. Compliance Adjustment	$225,000.00	1	$225,000.00
		Secton 14 Hot Mix Asphalt			
SY	5711	Planing Bituminous Pavement	$1.50	54,701	$82,051.50
TON	5767	HMA CL 1/2 IN. PG 64-28	$72.00	50,167	$3,612,024.00
LF	6514	Longitudinal Joint Seal	$0.90	134,816	$121,334.40
DOL	5830	Job Mix Compliance Price Adjustment	$108,361.00	1	$108,361.00
DOL	5835	Compaction Price Adjustment	$36,120.00	1	$36,120.00
DOL	5837	Asphalt Cost Price Adjustment	$108,361.00	1	$108,361.00
TON	5875	Commercial HMA	$100.00	2,870	$287,000.00

		Section 17 Erosion Cntl and Rdside Restoration			
DAY	6403	ESC Lead	$85.00	95	$8,075.00
EACH	6471	Inlet Protection	$100.00	14	$1,400.00
LF	6500	Compost Sock	$3.90	3,300	$12,870.00
DOL	6490	Erosion/Water Pollution Control	$15,000.00	1	$15,000.00
ACRE	6414	Seeding, Fertilizing, and Mulching	$2,000.00	52	$104,000.00
LF	6630	High Visibility Fence	$2.50	2,000	$5,000.00
		Section 18 Traffic			
LF	6757	Beam Guardrail Type 31	$18.50	25,488	$471,518.75
EACH	6760	Beam Guardrail Transition Section Type 23	$2,500.00	5	$12,500.00
EACH	6760	Beam Guardrail Transition Section Type 2	$2,500.00	5	$12,500.00
LF	6727	Extruded Curb	$15.00	530	$7,950.00
EACH	6719	Beam Guardrail Type 31 Non-Flared Terminal	$2,300.00	22	$50,600.00
EACH	6766	Beam Guardrail Anchor Type 10	$700.00	12	$8,400.00
LF	6781	Temporary Conc. Barrier	$6.90	76,893	$530,561.70
EACH	6830	Barrier Delineator	$10.00	2,701	$27,010.00
EACH	7440	Temporary Impact Attenuator	$3,000.00	4	$12,000.00
EACH	7445	Resetting Impact Attenuator	$1,000.00	8	$8,000.00
EACH	7447	Transportable Attenuators	$1,000.00	4	$4,000.00
HR	7449	Operation of Transportable Attenuators	$40.00	4,000	$160,000.00
EST	7450	Repair of Transportable Attenuators	$4,500.00	1	$4,500.00
LF	6784	Removing and Resetting Existing Permanent Barrier	$8.00	740	$5,920.00
LS	7432	High-Tension Cable Barrier (4 Cable)	$15.50	400	$6,200.00
EACH	6832	Flexible Guide Posts	$30.00	600	$18,000.00
LF	6806	Paint Line	$0.09	261,982	$23,578.38
LF	6813	Grooved Plastic Line	$0.90	113,811	$102,429.90
MI	6892	Shoulder Rumble Strip	$750.00	25	$18,945.00
HUND	6889	Recessed Pavement Marker	$1,100.00	14	$15,840.00
LF	6888	Temporary Pavement Marking	$0.09	1,150,034	$103,503.06
LS	6890	Permanent Signing	$25,000.00	1	$25,000.00
HOUR	6956	Sequential Arrow Sign	$1.36	17,160	$23,337.60
HR	6993	Portable Changeable Message Sign	$1.40	16,800	$23,520.00
LS	6973	Other Temporary Traffic Control	$95,000.00	1	$95,000.00
HR	6992	Other Traffic Control Labor	$42.00	16,000	$672,000.00
LS	6974	Traffic Control Supervisor	$212,000.00	1	$212,000.00
SF	6982	Construction Signs Class A	$15.00	4,000	$60,000.00
EA	XXXX	Luminaire reset on new base	$5,000.00	10	$50,000.00
0	XXXX	Remove/Reset Radio/Weather Instrument	$15,000.00	2	$30,000.00
		Section 19 Other Items			
LS	7028	Cure Box	$5,000.00	2	$10,000.00
HR	7400	Training	$1.20	2,250	$2,700.00
CY	7005	Structure Excavation Class B	$20.00	120	$2,400.00
EACH	9602	Adjust Inlet	$400.00	10	$4,000.00
SY	7530	Construction Geotextile for Separation	$1.20	25,000	$30,000.00
LS	7736	SPCC Plans	$2,000.00	1	$2,000.00
CALC	7730	Fuel Cost Adjustment	$115,000.00	1	$115,000.00
EST	7480	Roadside Cleanup	$20,000.00	1	$20,000.00

BID ITEM SUBTOTAL W/O MOBILIZATION			18,043,573
MOBILIZATION			1,082,614
BID ITEM SUBTOTAL			19,126,187
DESIGN CONTINGENCIES	WHAT IS THE %?	10	$1,912,619
BID ITEM TOTAL			$21,038,806
SALES TAX	WHAT IS THE %?	8	$1,683,104
700 LEVEL NON-BID ITEMS		WHAT IS THE $	$0
PROJECT SUBTOTAL			$22,721,910
CONSTRUCTION ENGINEERING	WHAT IS THE %?	8	$1,817,753
CONSTRUCTION CONTINGENCIES	WHAT IS THE %?	4	$908,876
CN ESTIMATE			$25,448,540
PE PHASE	WHAT IS THE %?	10	$2,544,854
PROJECT TOTAL			**$27,993,394**

Table C-5. PCCP Diamond Grind Lanes and 0.15' HMA Inlay Shoulders Cost Estimate

Quantity	Unit	Bid Item	Unit Price	Amount
		Construction Items		
138,650	SY	Portland Cement Concrete Pavement Grinding	$9.00	$1,247,850
74,660	SY	Planning Bituminous Pavement (Shoulders)	$1.50	$111,990
7,671	Ton	HMA CL 1/2" PG 64-22 (Shoulder)	$75	$575,325
7,671	Ton	Anti Stripping Additive	$1	$7,671
131,186	LF	Sealing Transverse and Longitudinal Joints	$0.90	$118,067
95,990	LF	Longitudinal Joint Seal	$0.90	$86,391
$575,325	3%	Job Mix Compliance (HMA CL 1/2" PG 64-22)	3%	$17,260
		Traffic		
1	LF	Delineation	$20,770	$65,041
1	LF	Traffic Control - 9-hr Nightime Closures	$176,520	$176,520
			Items Subtotal	$2,406,115
		Miscellaneous	10%	$240,611
			Subtotal	$2,646,726
		Design Contingencies	10%	$264,673

	Subtotal	$2,911,399
Sales Tax	8.0%	$232,912
	Subtotal	$3,144,311
Engineering	8.0%	$251,545
Engineering Contingencies	4.0%	$125,772
	Subtotal	$3,521,628
Preliminary Engineering	10.0%	$352,163
	Subtotal	$3,873,791
	Project Total	$3,873,800

Appendix D - LCCA Worksheets

RealCost Input Data

1. Economic Variables	
Value of Time for Passenger Cars ($/hour)	$14.65
Value of Time for Single Unit Trucks ($/hour)	$23.60
Value of Time for Combination Trucks ($/hour)	$27.46
2. Analysis Options	
Include User Costs in Analysis	Yes
Include User Cost Remaining Service Life Value	Yes
Use Differential User Costs	Yes
User Cost Computation Method	Calculated
Include Agency Cost Remaining Service Life Value	Yes
Traffic Direction	Both
Analysis Period (Years)	50
Beginning of Analysis Period	2015
Discount Rate (%)	4.0
3. Project Details and Quantity Calculations	
State Route	I-90 WB
Project Name	Cle Elum PCCP Rehab
Region	SCR
County	Kittitas
Analyzed By	Charles Kinne
Mileposts Begin	84.21
Mileposts End	93.30
Length of Project (miles)	9.09
Comments	Compare 2 11" Unbonded PCCP overlay to 9" HMA Crack and Seat Overlay
4. Traffic Data	
AADT Construction Year (total for both directions)	27,500
Cars as Percentage of AADT (%)	76.6
Single Unit Trucks as Percentage of AADT (%)	6.9
Combination Trucks as Percentage of AADT (%)	16.5
Annual Growth Rate of Traffic (%)	2.0
Speed Limit Under Normal Operating Conditions (mph)	70
No of Lanes in Each Direction During Normal Conditions	2
Free Flow Capacity (vphpl)	1300
Rural or Urban Hourly Traffic Distribution	Rural
Queue Dissipation Capacity (vphpl)	1323
Maximum AADT (total for both directions)	70,000
Maximum Queue Length (miles)	20.0

CSOL Alternative

Initial Construction	Initial Construction Cost
Agency Construction Cost ($1000)	$21,036.00

User Work Zone Costs ($1000)		
Work Zone Duration (days) (1)	24	
Work Zone Duration (days) (2)	72	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	8.0	
Activity Structural Life (years)	50.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	1.00	
Work Zone Speed Limit (mph)	Inbound 65(1), Outbound 50 (1&2)	
Work Zone Capacity (vphpl)	Inbound 1300 (1), Outbound 750(1&2)	
Traffic Hourly Distribution	Week Day 1	
Inbound(1)	Start	End
First period of lane closure	0	24
Second period of lane closure		
Third period of lane closure		
Outbound (1)	Start	End
First period of lane closure	0	24
Second period of lane closure		
Third period of lane closure		
Outbound (2)	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

Rehabilitation	Inlay Lanes	
Agency Construction Cost ($1000)	$2,181.00	
User Work Zone Costs ($1000)		
Work Zone Duration (days) (1)	35	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	8.0	
Activity Structural Life (years)		
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	1.00	
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	750	
Traffic Hourly Distribution	Week Day 1	
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		

Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

Rehabilitation	Inlay Lanes and Shoulders	
Agency Construction Cost ($1000)	$3,588.00	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	50	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	8.0	
Activity Structural Life (years)		
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	1.00	
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	750	
Traffic Hourly Distribution	Week Day 1	
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

PCCP Design Alternative

Initial Construction	Initial Construction Cost	
Agency Construction Cost ($1000)	$27,993.00	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	125	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	25.0	
Activity Structural Life (years)	50.0	
Maintenance Frequency (years)	0	
Agency Maintenance Cost ($1000)	0	
Work Zone Length (miles)	1.00	
Work Zone Speed Limit (mph)	Inbound 65, Outbound 50	
Work Zone Capacity (vphpl)	Inbound 1300, Outbound 750	
Traffic Hourly Distribution	Week Day 1	
Inbound	Start	End
First period of lane closure	0	24
Second period of lane closure		

Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	24
Second period of lane closure		
Third period of lane closure		

Rehabilitation	Diamond Grind lanes and Inlay Shoulders	
Agency Construction Cost ($1000)	$3,874.00	
User Work Zone Costs ($1000)		
Work Zone Duration (days) (1)	62	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	25.0	
Activity Structural Life (years)		
Maintenance Frequency (years)	0	
Agency Maintenance Cost ($1000)	0	
Work Zone Length (miles)	1.00	
Work Zone Speed Limit (mph)	50	
Work Zone Capacity (vphpl)	750	
Traffic Hourly Distribution	Week Day 1	
Inbound	Start	End
First period of lane closure		
Second period of lane closure		
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

Appendix E – CA4PRS Construction Time Estimate

Unbonded PCCP Overlay							
Items of Work	MP	MP	Miles	Production miles per closures	Closure Type	Days per Closure	Days
WZ EB outside shoulder short term traffic structural improvement	84.21	93.3	9.09	2.87	Continuous 12 hour shift	4	12.7
WZ WB inside shoulder short term traffic structural improvement	84.21	93.3	9.09	4.78	Continuous 12 hour shift	4	7.6
Outside WB shoulder improvements for 2' PCCP widening	84.21	93.3	9.09	13.72	Continuous 12 hour shift	4	2.7
HMA bond-breaker for PCCP overlay	84.21	93.3	9.09	4.6	Continuous 12 hour shift	4	7.9
Unbonded PCCP 11" overlay inside 12' lane	84.21	93.3	9.09	1.97	Continuous 12 hour shift	4	18.5
Unbonded PCCP 11" overlay outside 14' lane	84.21	93.3	9.09	1.69	Continuous 12 hour shift	4	21.5
PCCP reconstruction @ 500:1 profile adjustments for bridges and ends	84.21	93.3	1.2	0.24	Continuous 16 hour shift	3	15
Inside 0.35' HMA shoulder construction	84.21	93.3	9.09	9.45	Continuous 12 hour shift	4	3.8
Outside 0.35' HMA shoulder construction	84.21	93.3	9.09	5.71	Continuous 12 hour shift	4	6.4
						Sub-total	96.1
					Miscellaneous	30%	28.8
						Total Daytime Continuous Closure Days	124.9
						Input +/- 10%	125

CSOL (Nighttime Overlays)							
Items of Work	MP	MP	Miles	Production miles per closures	Closure Type	Days per Closure	Night/ Days
0.20' HMA CSOL inside lane and shoulder	84.21	93.3	9.09	1.34	Nighttime	1	6.8
0.20' HMA CSOL outside lane and shoulder	84.21	93.3	9.09	1.22	Nighttime	1	7.5
0.20' HMA overlay inside lane and shoulder	84.21	93.3	9.09	1.34	Nighttime	1	6.8
0.20' HMA overlay outside lane and shoulder	84.21	93.3	9.09	1.22	Nighttime	1	7.5
0.20' HMA overlay inside lane and shoulder	84.21	93.3	9.09	1.34	Nighttime	1	6.8
0.20' HMA overlay outside lane and shoulder	84.21	93.3	9.09	1.22	Nighttime	1	7.5
0.15' HMA overlay inside lane and shoulder	84.21	93.3	9.09	1.62	Nighttime	1	5.6
0.15' HMA overlay outside lane and shoulder	84.21	93.3	9.09	1.33	Nighttime	1	6.8
						Sub-total	55.3
					Miscellaneous	30%	16.6
						Total Nighttime Closure Days	71.9
						Input +/- 10%	72

CSOL (Reconstruction at Grade Adjustments : Bridges and Ends)							
Items of Work	MP	MP	Miles	Production miles per closures	Closure Type	Days per Closure	Night/ Days
WZ EB outside shoulder short term traffic structural improvement	84.21	93.3	9.09	2.87	Continuous 12 hour shift	4	12.7
HMA Reconstruct Lanes for Grade Adjustments	84.21	93.3	1.2	0.46	Continuous 16 hour shift	2	5.2
						Sub-total	17.9
					Miscellaneous	30%	5.4
					Total Daytime Continuous Closure Days		23.3
						Input +/- 10%	24

Location	MP	MP	Miles	Miles/Closure	Days/Closure	Days
0.15' HMA Inlay Lanes	84.21	93.3	18.18	0.75	1	25
					Sub-total	25
				Miscellaneous	30%	8
					Total	33
					Use	35

Location	MP	MP	Miles	Miles/Closure	Days/Closure	Days
0.15' HMA Inlay Inside Lanes and Shoulder	84.21	93.3	9.09	0.43	1	22
0.15' HMA Inlay Outside Lanes and Shoulder	84.21	93.3	9.09	0.59	1	16
					Sub-total	38
				Miscellaneous	30%	11
					Total	49
					Use	50

Location	MP	MP	Miles	Miles/Closure	Days/Closure	Days
Diamond Grind Lane	84.21	93.3	18.18	0.38	1	48
					Sub-total	48
				Miscellaneous	30%	14
					Total	62
					Use	62

Appendix 4-C3

VDOT SHRP 2 R23 Test Case

I-81 Southbound Lane Pavement Renewal

From Exit 219 to 1.31 Miles North of Rockbridge County Line

Augusta County Virginia

Appendix 4-C3

I-81 Southbound Lane Pavement Renewal
From Exit 219 to 1.31 Miles North of Rockbridge County Line
Augusta County Virginia

Introduction

This project calls for the reconstruction of 3.66 miles of pavement southbound on I-81 in Augusta County near Stanton VA. A pavement design memorandum was prepared by Mr. Chaz Weaver the Stanton District Materials Engineer dated February 22, 2007. A copy of that Memorandum is attached to this report.

The existing pavement was constructed in 1968 with about 10 inches of HMA over about 10 to 12 inches of granular base. The pavement has been resurfaced repeatedly since construction and was found to be experiencing structural deterioration largely due to striping between and within the various pavement layers. The current HMA thickness ranges from 11 to 12.5 inches thick.

The subgrade soils stiffness in terms of resilient modulus ($M_{R)}$ ranged from about 24,000 psi to 38,000 psi, with the 85% values ranging from 15,000 to 24,000 psi.

The traffic volumes consisted of one direction average daily traffic of 22,000 vehicles per day in 2008. Truck traffic made up 33% of the traffic with 90% of those trucks traveling in the outside lane. The predicted 30 year ESAL values used in their design was 102,600,000 ESALS. The original design recommendations were to remove and replace the outside lane with 10 inches of base course, 2 inches of 2/4 in binder course and a 2 inch surface course of 1/2 inch SMA mix.

The design was changed to reclaim the existing HMA and base. All 12 inches of the reclaimed material would be removed and the untreated base would then be surfaced with 6 inches of cold central plant recycled material (CCPR) made from the reclaimed asphalt, and 6 inches of HMA. The primary reason for removing the material was to address weak spots that were evident in the FWD survey and would likely show up during construction. Additionally there were provisions for detouring the traffic so that the outside lane could be removed for a short period of time.

The design data was used as input to the rePave R23 Scoping Tool. The following screen shots show that design process using rePave. The VDOT designs were based on 30 year designs for new flexible pavements. The rePave runs were made using a 50 year design life however the actual thickness would not change that much for a 30 year design life. This is largely because VDOT used the 93 AASHTO Guide for the Structural Design of Pavements and the rePave design tables are based on the MEPDG and PerRoad design programs which experience has shown to be one to two inches thinner.
The general project descriptions are entered as a first step in rePave as seen in the following:

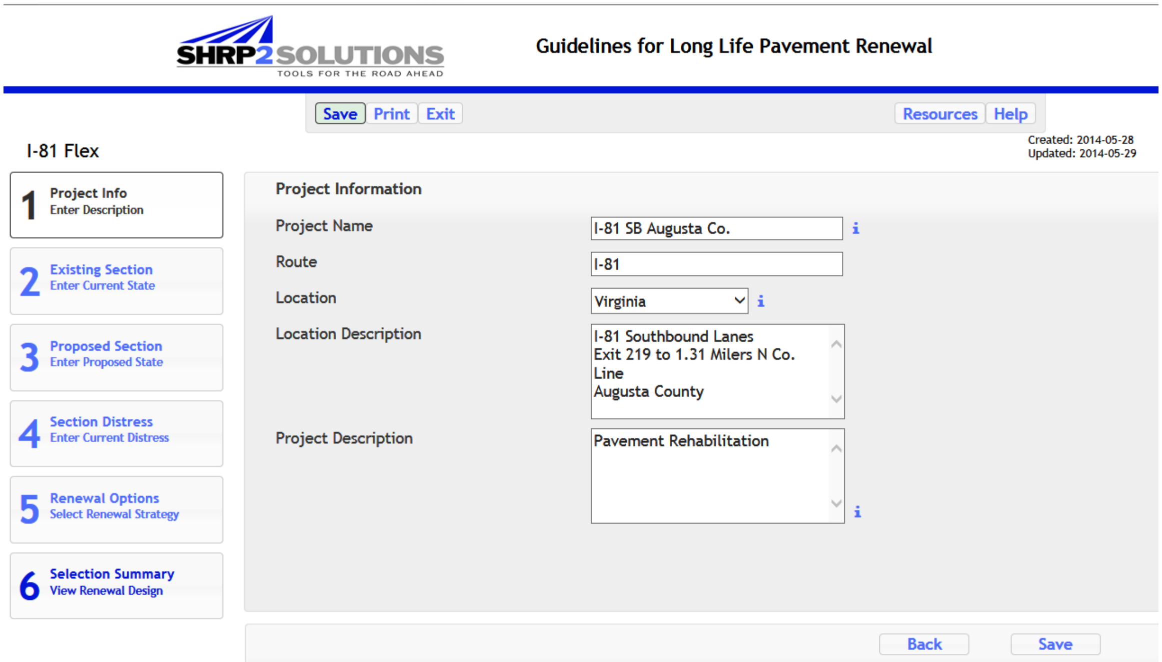

Figure 4-C3-1. rePave screen for Project Information

The second step is to enter the general pavement layer information for the existing pavement.

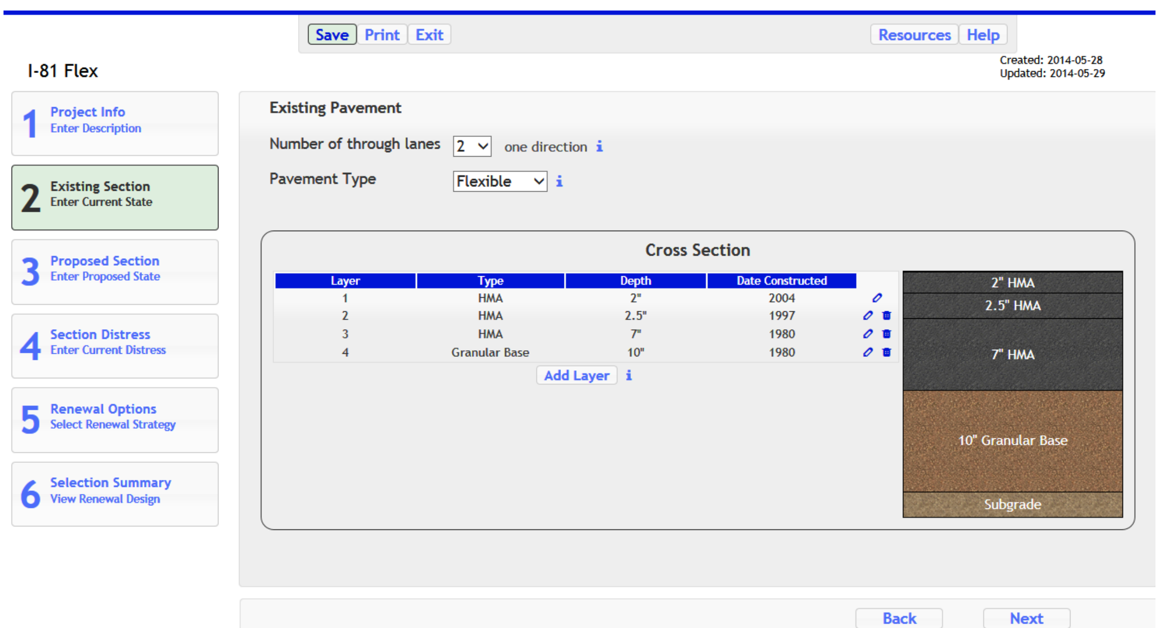

Figure 4-C2-2. rePave screen with existing pavement layer information

The rePave user is encouraged to enter all pavement layers if known, particularly if they have found striping within or between any of the layers.

The next step is to add the general pavement design information for the new pavement section.

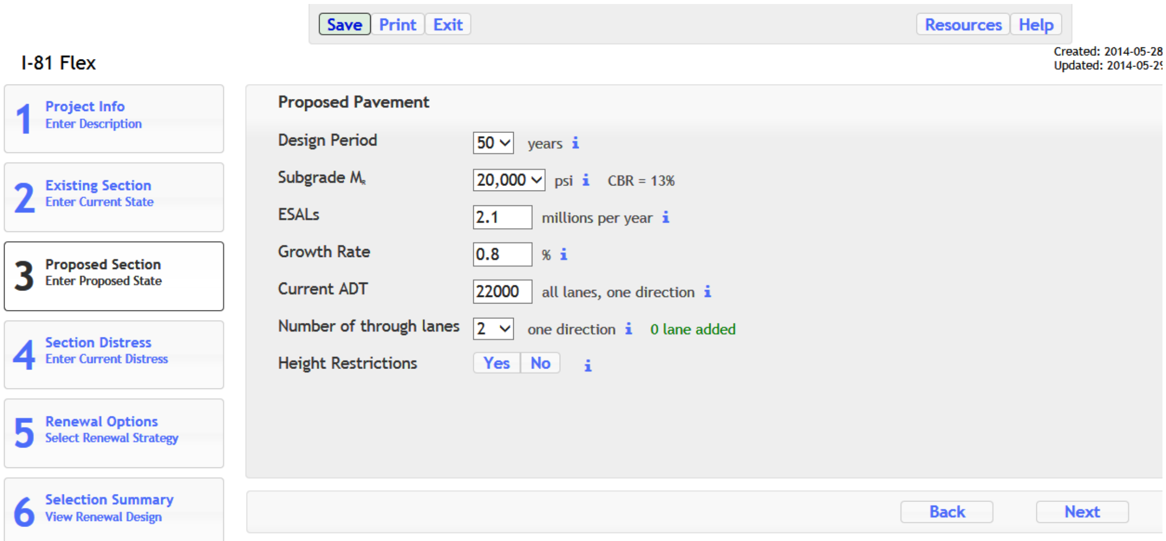

Figure 4-C3-3. rePave screen where general pavement design information is entered

The fourth step in the process is to enter the pavement distress information for the existing pavement.

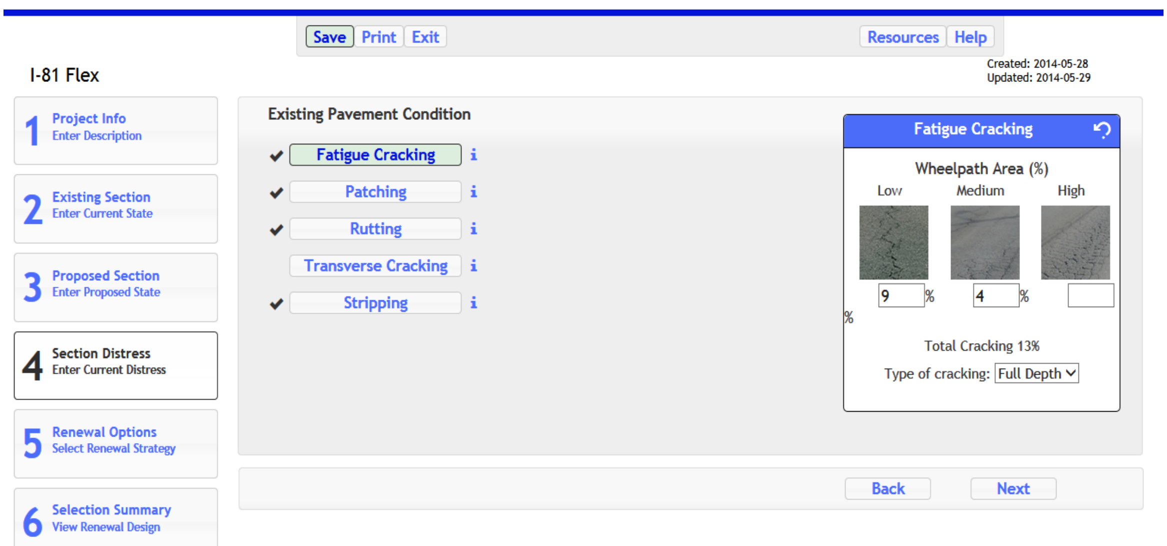

Figure 4-C3-4. rePave screen where pavement distress is entered

In this figure only the fatigue cracking distress screen is shown, but when the user checks any of the other distress screens then that distress is shown along with data entry boxes. In this example striping was indicated in the lower pavement layers.

Step 5 provides a list of approaches depending on the pavement type selected. In this example an approach using a flexible pavement was selected. Of the three options presented, the option of reclaiming the pavement using an emulsion was selected.

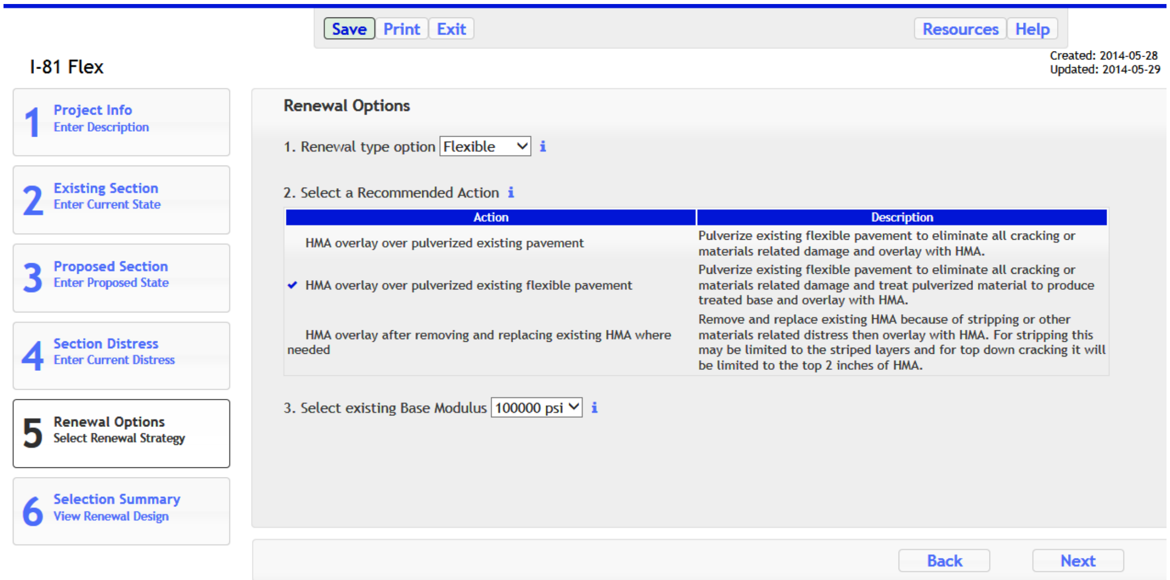

Figure 4-C3-5. rePave screen showing options available for the pavement type selected

The next screen will show the pavement design summary for the pavement condition entered and the approach selected.

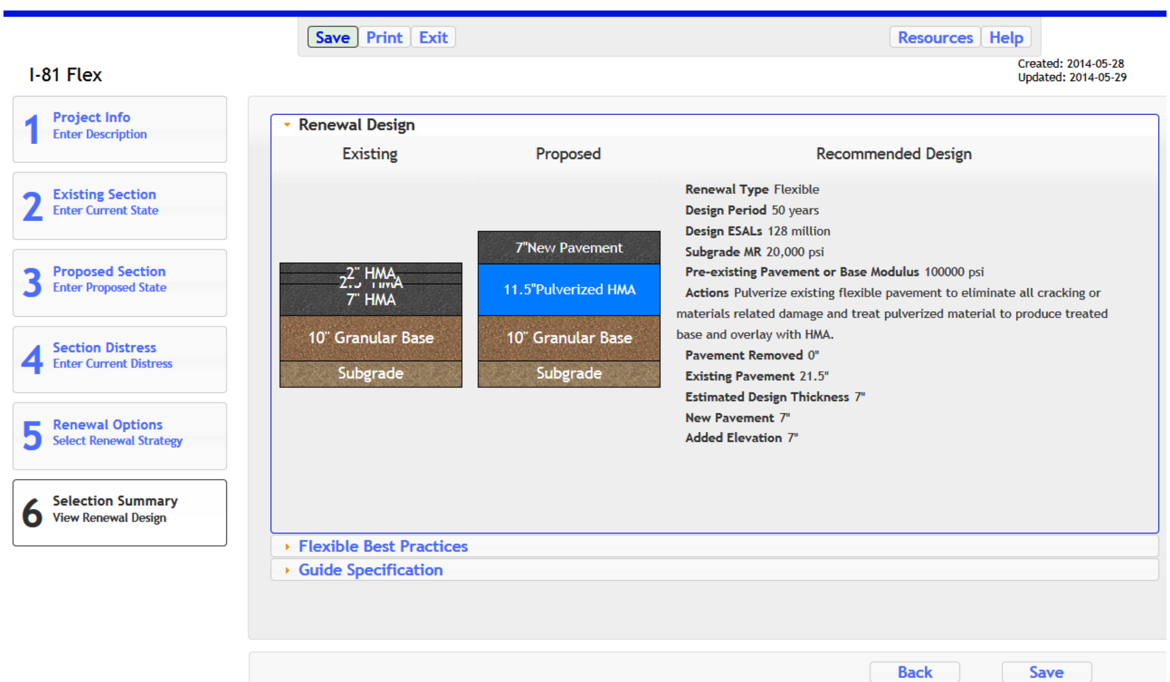

Figure 4-C3-6. rePave screen showing the design summary information for the approach selected

It should be noted that rePave is not a pavement design program but it does include very general pavement thickness tables to provide an example of the general pavement configuration for scoping purposes. The users are expected to perform their own design analysis consistent with their agencies policy and procedures.

Once the project data is set in the program it is easy to go back and rerun different design assumptions or different design approaches. As an example a replacement option is selected.

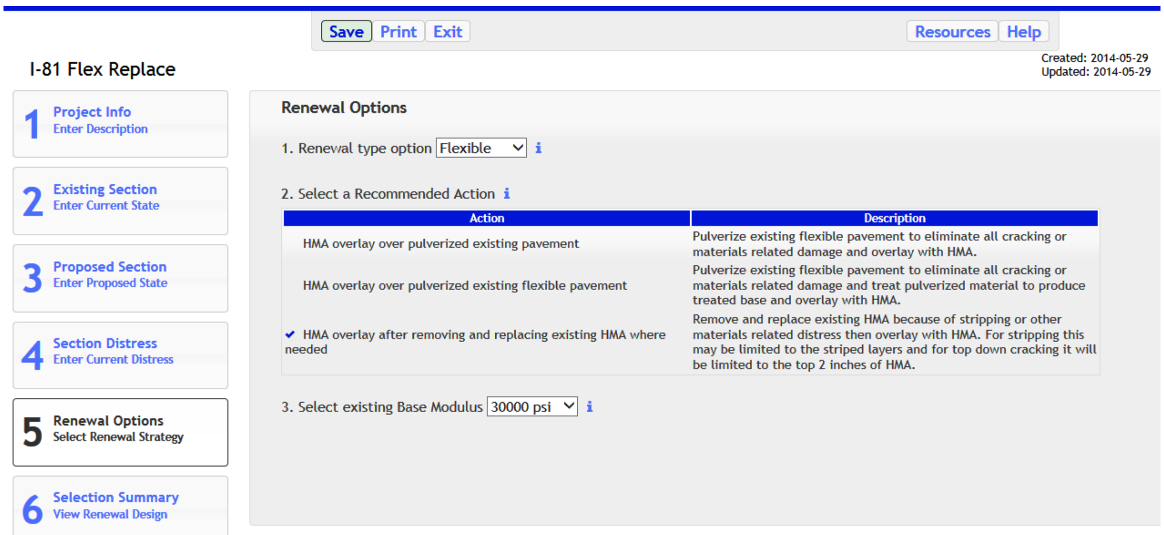

Figure 4-C3-7. rePave screen with replace existing pavement shown

rePave will then show the design summary for removing and replacing the existing HMA.

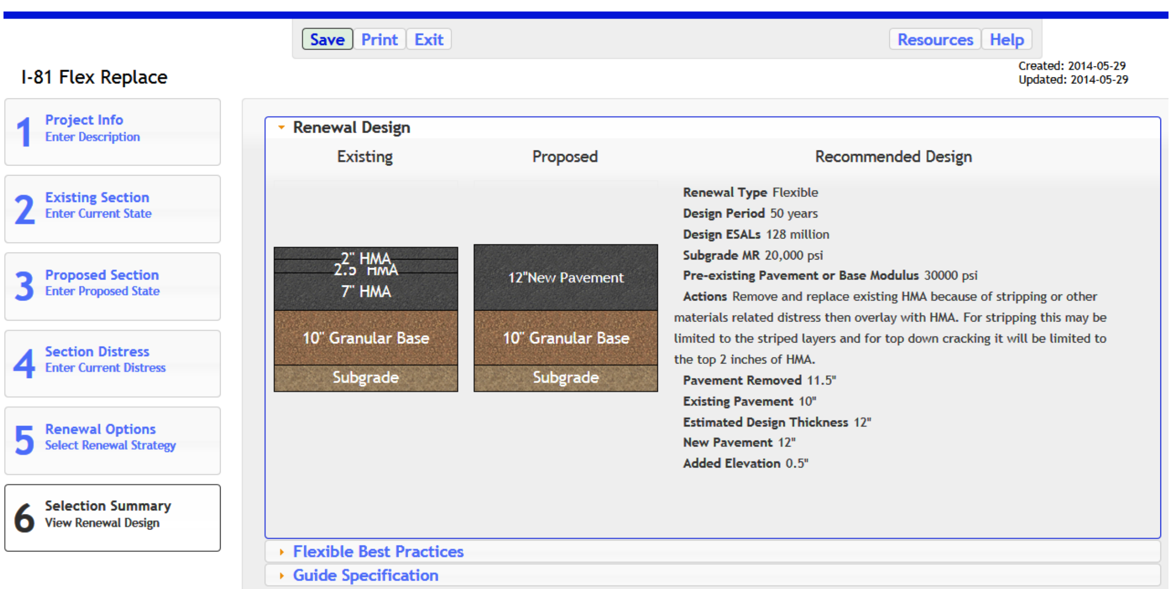

Figure 4-C3-7. rePave screen showing the design summary for replacing the existing pavement

Though the rePave program was developed to provide guidance on designing and building long life pavements <u>using existing pavements in place</u> there is included a remove and replace option for all pavement types to provide a comparative section to that using the existing pavement in place.

To complete the general design options for both pavement types the rigid option is also considered simply by backing up to step 5 and selecting the rigid option.

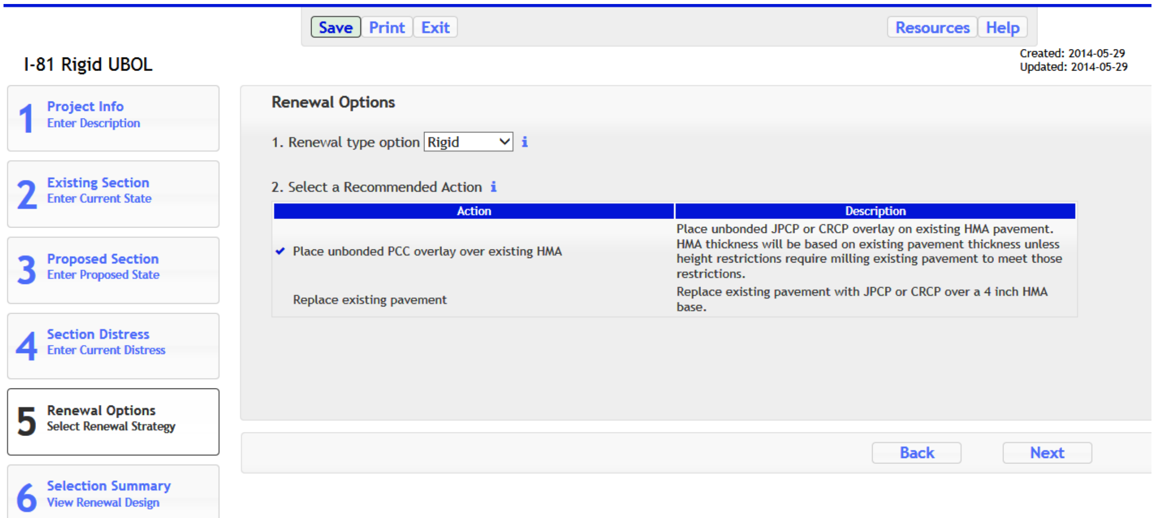

Figure 4-C3-8. rePave screen with an unbonded PCC overlay selected

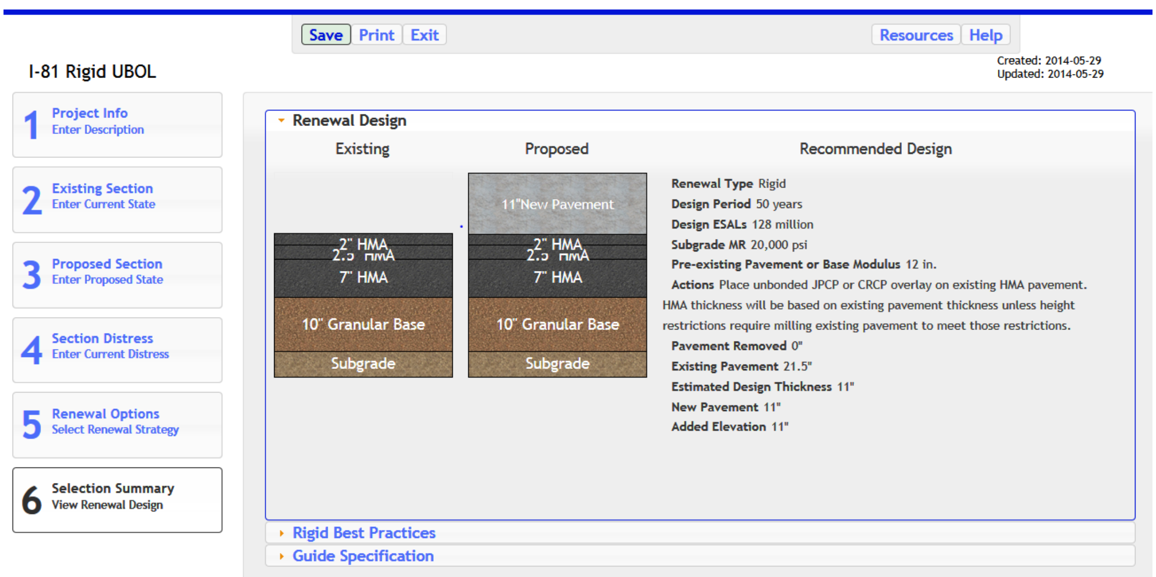

Figure 4-C3-9. rePave screen showing design summary for an unbonded PCC overlay

The repave program does not have an option to let the user call for milling off a specified amount of the existing HMA but the user can go back to step 2 and shown a reduced HMA thickness and rerun the program to account for grinding off a set amount of HMA.

Similar to the flexible treatments, a rigid remove and replace approach was also checked and the resulting design summary screen is shown in Figure 4-C3-9.

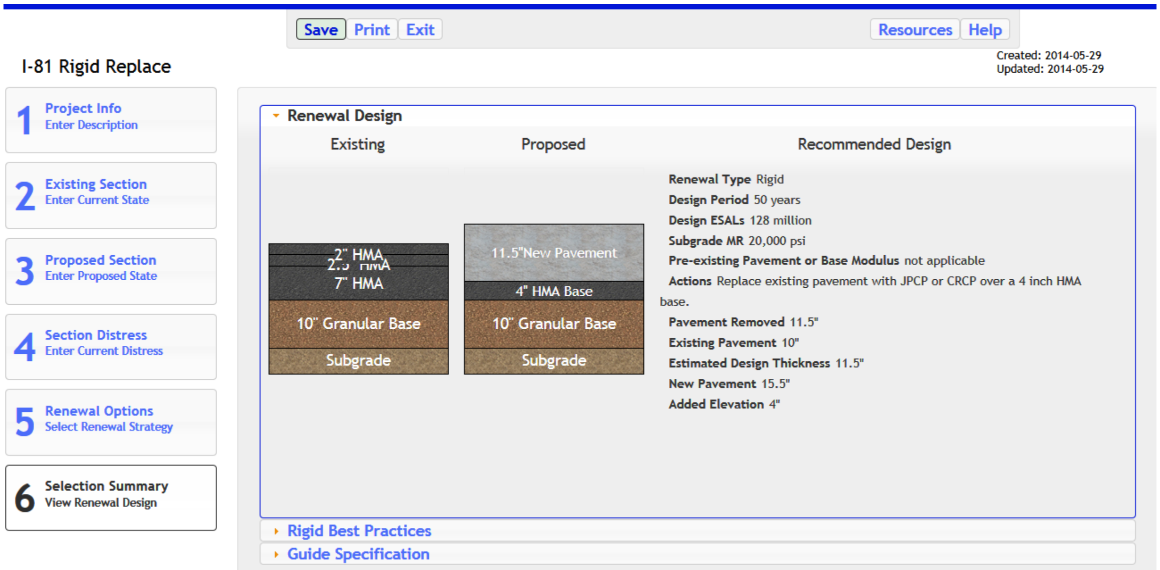

Figure 4-C3-10. rePave screen showing the design summary for removing and replacing with PCC

Pavement Design Comparison

The comparison between the VDOT design for this project and the design from rePave are very similar.

	VDOT Design	rePave	rePave (with grindings removed)
HMA	6 inches	7 inches	7 inches
Emulsion treated base	6 inches	11.5 inches	6 inches
Granular base	12 inches	10 inches	10 inches
Total	24 inches	28 inches	23 inches

The VDOT design called for removing most of the millings and returning only 6 inches of emulsion treated base from a central plant located on the project. To account for the removal of some of the millings rePave was rerun with only a 6 in thick layer of HMA which was then reclaimed using emulsion treatment. The results are shown in the third column. The only difference between the VDOT design and the rerun of rePave with grindings removed is an extra inch of HMA. The difference is due to a combination of factors. The VDOT design used the 93 AASHTO Guide and a traffic loading of 102, 600,000 ESALS. The rePave design came from a set of design tables where the last ESAL category was 100 - 200 million ESALS. The rePave design was based on the MEPDG and PerRoad runs using 200 million ESALS. The traffic loading was higher for rePave but the design programs tend to produce somewhat thinner pavement sections compared to the 93 Guide. In addition the rePave program also includes guidance on how to construct long life pavements with guide specifications and other construction related information which are not found in any other design guidelines.

Composite and Modular Pavement Designs

The rePave program also provides guidance for design approaches using composite pavements based on the research from SHRP 2 R21 project and modular pavement based on the research from SHRP 2 R05 project. Those designs approaches are demonstrated in the following figures.

The first set of designs will consider designs using composite pavements using either HMA/PCC[v] or two lift PCC/PCC[vi] where the lower lift of PCC can be built of lower quality PCC and the top lift of high quality PCC to provide a long life wearing course. Both approaches may be used for either unbonded PCC overlays or for pavement replacement.

Following the same process as the earlier examples the user simply backs up to the renewal options screen and set the renewal option as composite. Four renewal options are available using composite pavements.

The first figure below shows the approach selection screen when composite pavements are selected, and the unbonded HMA/PCC overlay is checked.

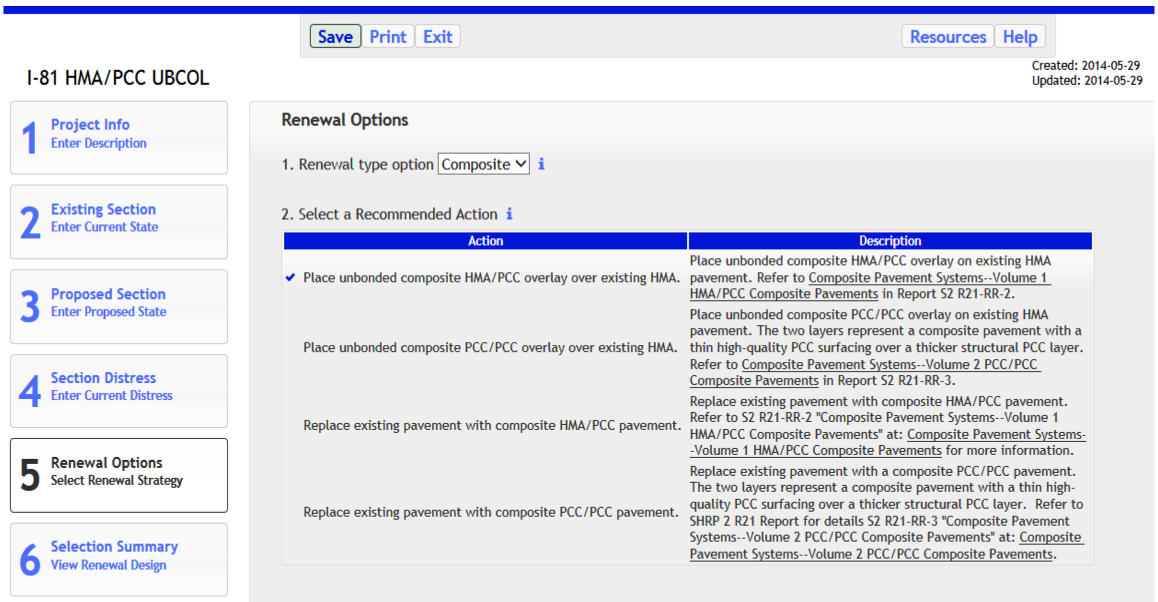

Figure 4-C3-11. rePave screen with composite HMA/PCC overlay selected

The next step is to proceed to the design summary tab and view the design summary information provided for an unbonded HMA/PCC composite overlay of the existing HMA. Just like for the rigid renewal option only the worst pavement distress needs to be corrected before placing the unbonded overlay.

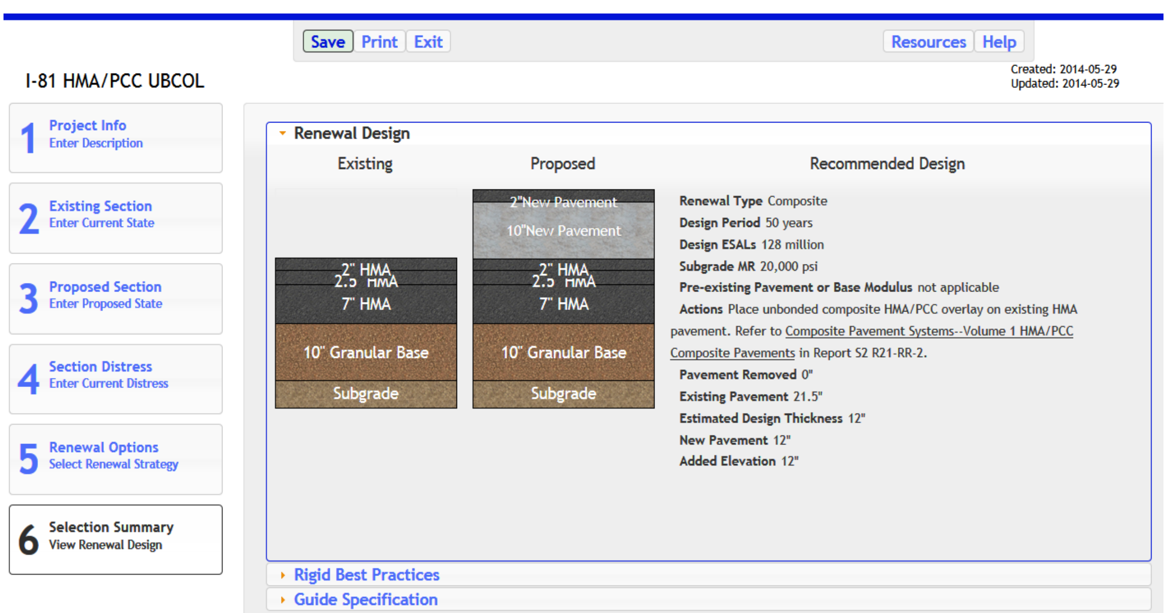

Figure 4-C3-12. rePave screen showing pavement design summary information for unbonded HMA/PCC overlay

If the pavement elevation is too high, some of the existing pavement can be ground off before placing the by revising the pavement in step 2 to show only a 5 inch HMA existing pavement.
The resulting pavement design is shown in the following figure.

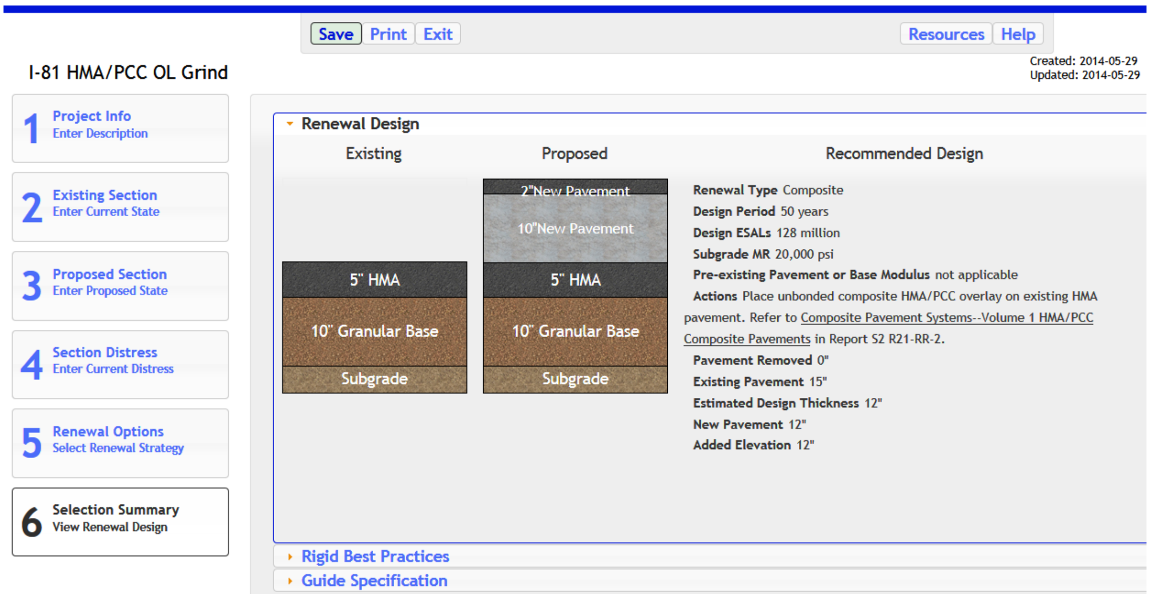

Figure 4-C3-13. rePave screen showing the unbonded HMA/PCC overlay over HMA

In this particular case the reduction of the existing HMA depth from 11 inches to 5 inches did not change the HMA/PCC thickness.

The next approach selected was to place an unbonded PCC/PCC composite overlay.

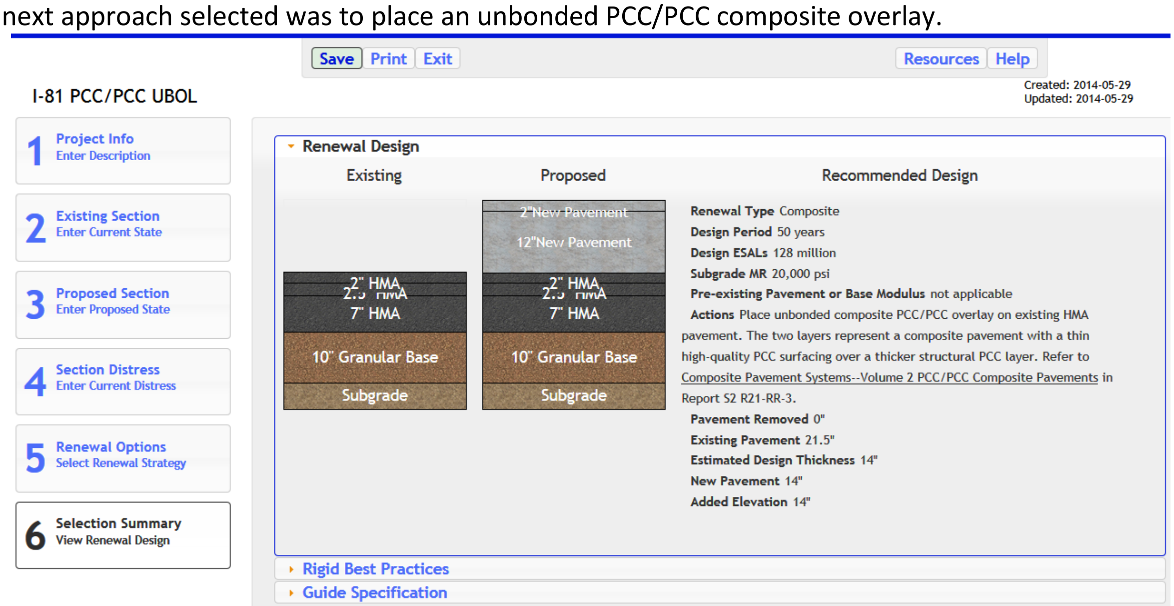

Figure 4-C3-14. rePave screen showing design summary for unbonded PCC/PCC composite overlay

The next two approaches selected were to remove and replace the existing HMA with both a HMA/PCC composite pavement and a PCC/PCC composite pavement.

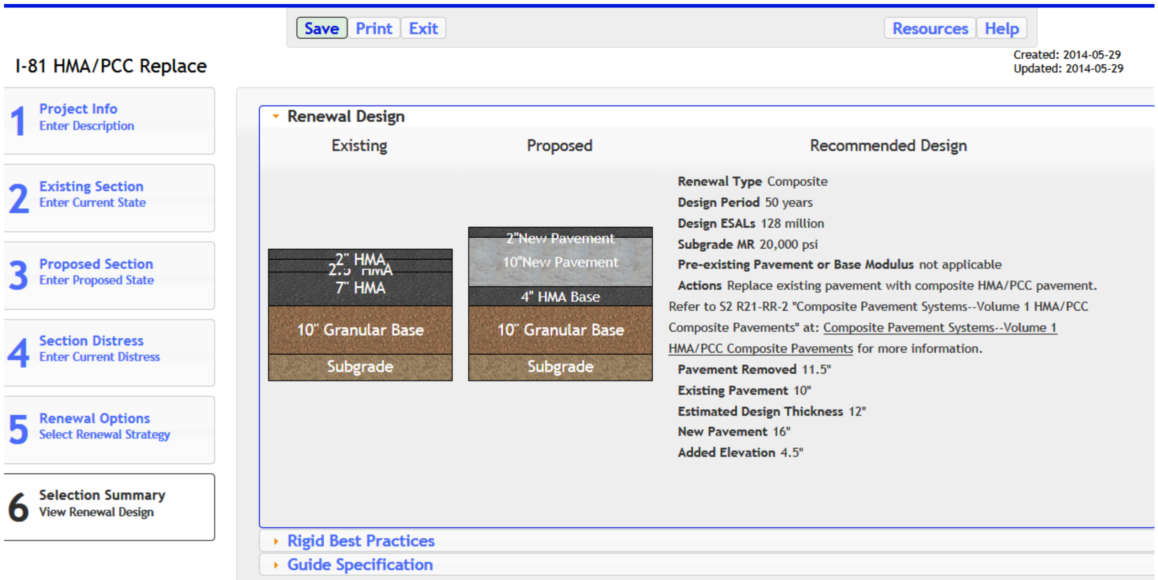

Figure 4-C3-15. rePave screen showing the design summary for a HMA/PCC composite replacement

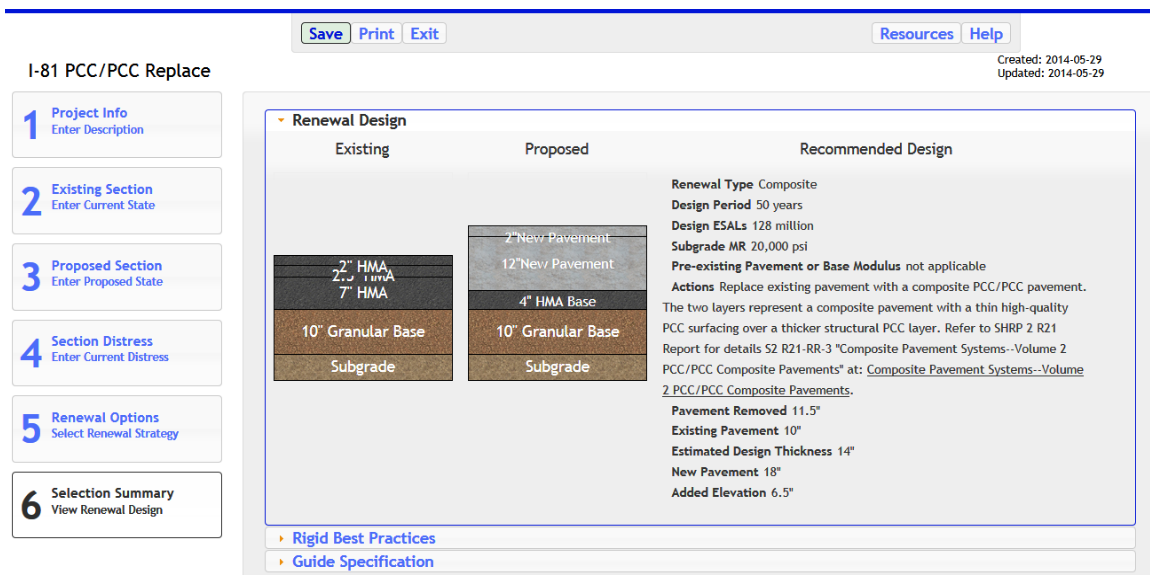

Figure 4-C3-16. rePave screen showing the design summary for PCC/PCC composite replacement

Modular Pavement Designs

The next set of designs will consider the use of modular or precast pavements. The basis for these designs comes from the SHRP 2 R05 project[vii].

There are two basic modular pavement designs considered one using a standard precast design and a second using a pre-tensioned precast design. Both designs are used as an unbonded overlay of the existing HMA and as a replacement for the existing HMA.

The first approach considered is for an unbonded precast overlay of the existing HMA, however there is a service life limit of 35 years placed on the use of the precast pavements, because most precast pavements have not been in service for over 10 years. If the user uses a 50 year design, no precast approach will be present as shown in the following figure.

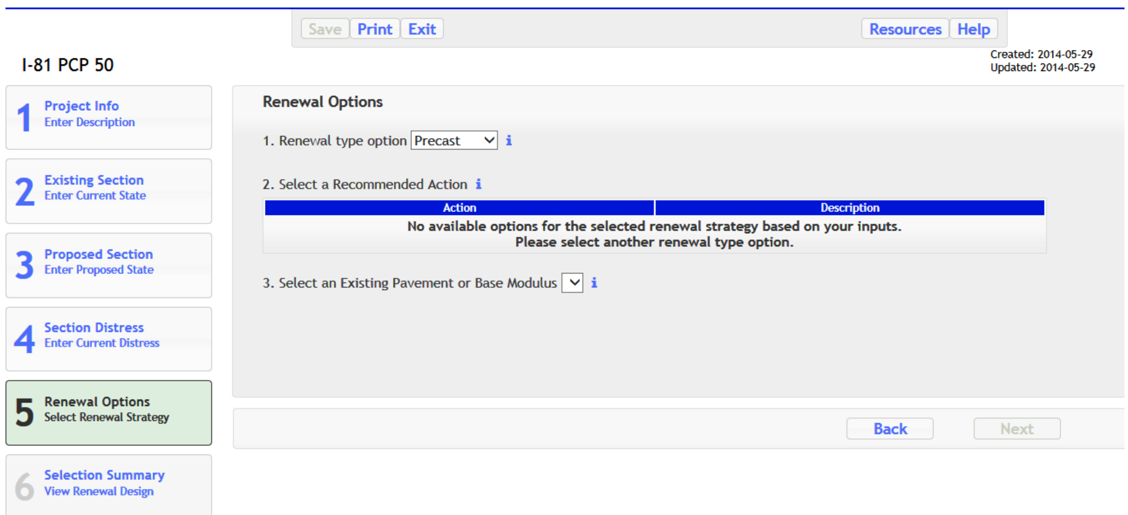

Figure 4-C3-17. rePave screen showing no precast approach with design life is > 35 years

When the user sets the design life at 3o or 35 years, they will see the approach options for the use of precast pavement. The following figure shows the design summary for a standard precast pavement placed as an unbonded overlay over the HMA pavement.

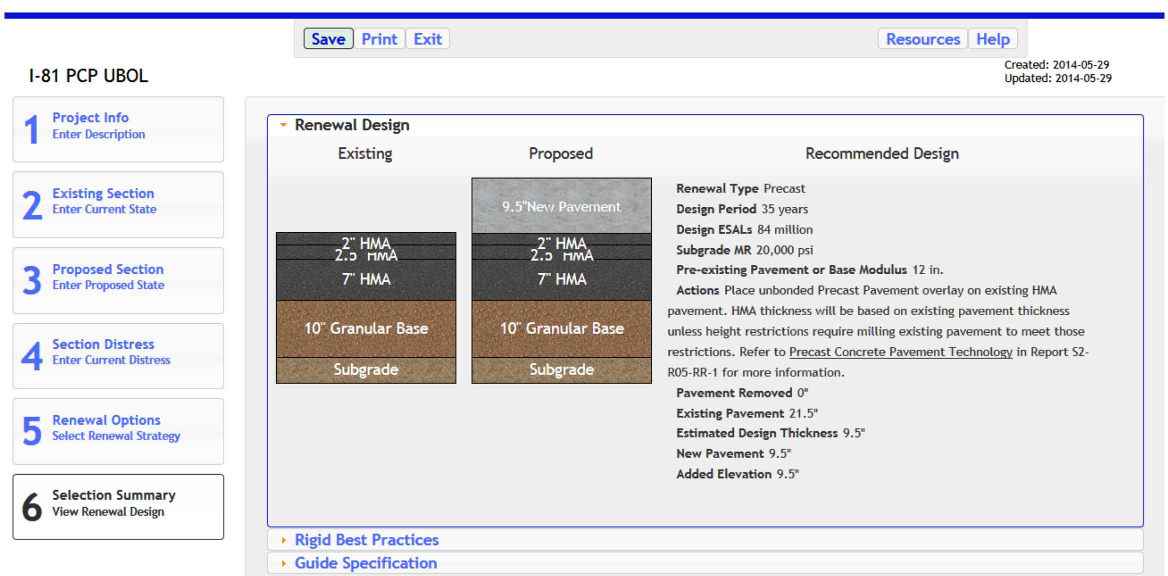

Figure 4-C3-18. repave screen showing an unbonded precast overlay of the existing HMA

The next figure shows the design summary for a pre-stressed precast pavement unbonded overlay of the existing HMA pavement.

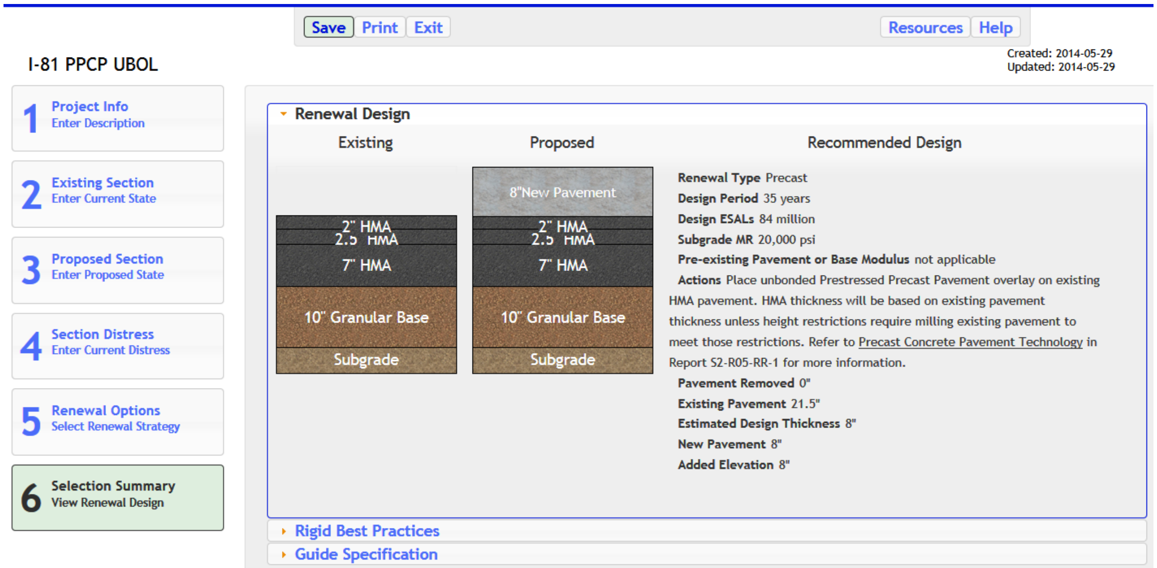

Figure 4-C3-19. rePave screen showing design summary for pre-stressed precast pavement overlay

The next set of designs used standard and pre-stressed precast pavement to replace the existing pavement.

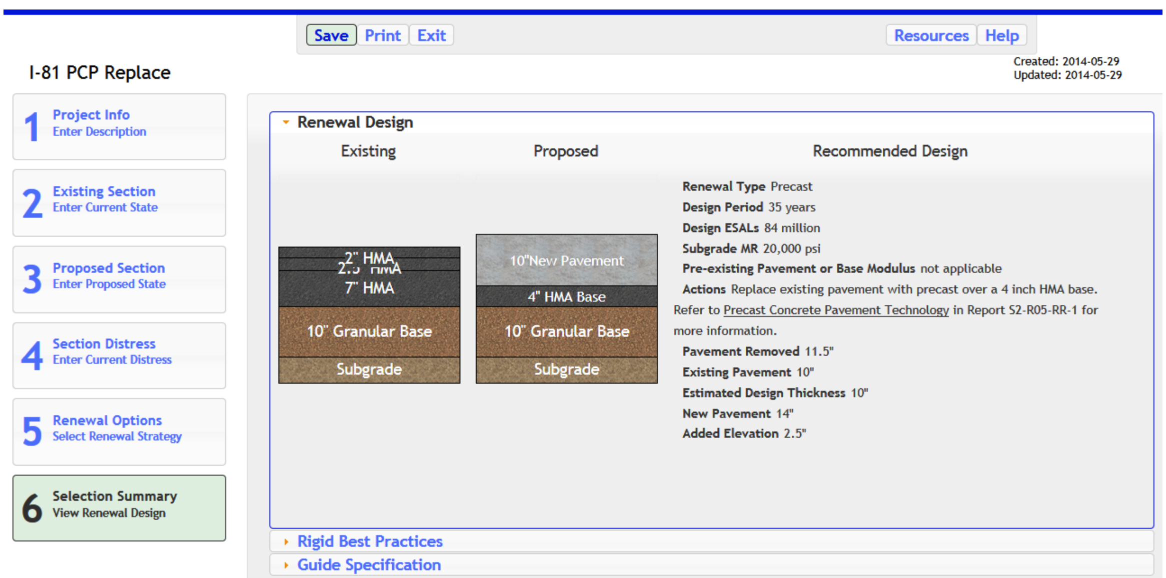

Figure 4-C3-20. rePave screen showing design summary for precast pavement replacement

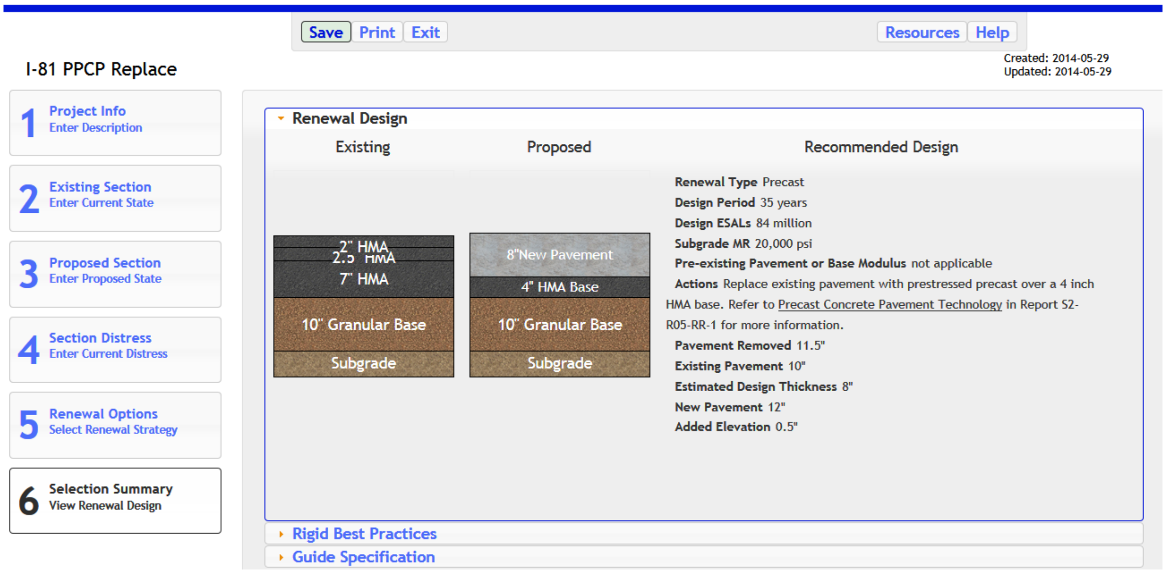

Figure 4-C3-21. rePave screen showing design summary for pre-stressed precast replacement

Summary and Conclusions

This case study was conducted on a project offered by the Virginia Department of Transportation on Interstate 81 near Scranton VA. The existing four lane freeway was constructed in the mid 60 and is now requiring resurfacing on about four to six year cycles. This somewhat poor performance is due in large part to striping in the asphalt layers particularly in the outside truck lane. The VDOT looked as several alternatives to renew the pavement, including continuing the resurfacing program, removing and reconstructing the outside lane and reclaiming the outside lane, by removing some of the reclaimed material constructing a 6 inch bound base using cold central plant recycling and then overlaying the emulsion bound base with 6 inches of HMA.

The VDOT elected to use the cold plant recycling design which was successfully constructed in 2011[viii]

The rePave program provided a similar design when 5 inches of the existing reclaimed HMA was removed and 6 inches of the remaining reclaimed HMA was treated with an asphalt emulsion to produce a cold inplace recycled base. The rePave design called for a 7 inch HMA overlay compared to the 6 inch HMA overlay used by VDOT. The difference was probably due the tabular nature of the rePave design where the design table used one design thickness for 100 to 200 million ESALs while the VDOT design was for only 102 million DSALs.

The rePave program also included two other flexible design approaches; one to reclaim the existing HMA without treatment and then overlay with HMA and one to remove and replace the existing HMA with HMA. Since the existing pavement layers had problems with striping then the rePave guidance for long life flexible pavement will require that problem be addressed either by reclaiming the striped HMA or replacing the striped HMA. For a rigid pavement design the options considered were to place an unbonded PCC overlay over the existing pavement or to remove and replace the HMA with PCC. For the unbonded PCC overlay the existing pavement could remain in place or be milled down to provide a lower profile providing the striping was not too severe.

VDOT also provides their life cycle cost estimates for the project. The cold inplace recycle option provided the lowest life cycle costs of all the options including milling and filling at 4 to 6 year cycles.

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[1] SHRP 2 R21 Report S2 R21-RR-2 "Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-2.pdf.

[1] S2 R21-RR-3 "Composite Pavement Systems--Volume 2 PCC/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-3.pdf.

[1] Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.

[1] Diefenderfer, Brian, C. Et. Al.,, "In-Place Pavement Recycling on I-81 in Virginia" *Transportation Research Record: Journal of the Transportation Research Board,*
No. 2306, Transportation Research Board of the National Academies, Washington,
D.C.,

Appendix 4-C4

VDOT SHRP 2 R23 Test Case

Example Application of the R-23 Interactive Software on a VDOT Project

I-95 MP 108.1 to 103.6 Southbound

Appendix 4-C4

SHRP 2 Project R-23 "Building Long Life Pavements Using Existing Pavements"
Example Application of the R-23 Interactive Software on a VDOT Project
I-95 MP 108.1 to 103.6 Southbound

Background of VDOT Pavement Investigation/Design

The original design Memorandum for this Project was completed on May 8, 2006 and was authored by the following Virginia Department of Transportation (VDOT) personnel:

- Mourand Bouhajja, PE—Asphalt Program Manager
- Todd M Rorrer—Asphalt Program Team

The project information and pavement structure were described in the memorandum as follows:

Project Information

"The project is located in Caroline County. The project limits are from the MP 108.1 (adjacent to the rest area) to MP 103.6 (at bridge B-621 over the R.F. &P RR). Southbound Interstate 95 is comprised of three lanes and is approximately 36 feet wide with full paved shoulders. The original pavement, constructed in 1961 was two-lanes, 24 feet wide and was widened to three lanes in the early 1980's. From approximately MP 108.1 to 107.3, the third lane was added to the inside of the existing two lanes while, from MP 106.92 to 103.6, two new lanes were added to the outside and the existing inside lane was turned into a full 10' shoulder."

Pavement Structure

"The Plan and Profile of the original two lanes constructed in 1961 called for 8" of Bituminous Concrete over 6" of Pervious Aggregate Sub-base Type I No. 21 or 21A over 6" of Pervious Select Material Type I (Min CBR-30). Also based on the respective Plan and Profile of the 1980 widening project, the existing two lanes received ~1.5" inches of new surfacing and the new additional lanes were constructed as 2" of S-5 and 8" of B-3 over the same pervious sub-base and select material as called for in the 1961 Plans. Additionally, based on information contained in HTRIS, the pavement has a SM-12.5D surface placed as mill and inlay in 1999. The exact asphalt thickness along the length of the road was determined through coring. Based on a preliminary analysis of the Falling Weight Deflectometer (FWD) data using the cumulative differences approach outlined in Appendix J of the 1993 Guide for Design of Pavement Structures, the project was divided into 7 sections, which showed similar structural response to the FWD loading."

Table 4-C4-1 provides a summary of the 7 sections that were used in the VDOT pavement analysis.

Table 4-C4-1. Roadway Sections

Section #	From Mile Point	To Mile Points	Section Length (mi)	Associated Core# / MP
H	108.1	107.3	0.8	#1/107.5
G	107.3	106.9	0.4	
F	106.9	105.5	1.4	#2/106.59 #3/105.9
E	105.5	105.2	0.3	
D	105.2	104.9	0.3	#4/105.0
C	104.9	104.3	0.6	
B	104.3	103.6	0.7	#5/103.8
Total Length:			4.5 mi	

Pavement Condition

"The majority of the travel lane is in cut sections while the center and passing lanes are in and out of fill and cut sections. The majority of the distresses identified were medium to high severity fatigue cracking. There are also relatively long sections of surface patches that span from the center of the travel lane to the center of the shoulder. Longitudinal reflective cracking is prevalent in the wheel path of the travel lane, presumably from the longitudinal construction joint in the Asphalt base."

Cores taken along the project exhibit areas of localized stripping in the hot mixed asphalt. FWD measurements were taken along the project and were used to backcalculate Design Resilient Modulus values for the subgrade soils. The M_{sg} values reported from VDOT are shown in Table 4-C4-2. In addition, soil samples were taken along the roadway and the test results can be found in Table 4-C4-3.

Table 4-C4-2. Design Resilient Modulus and SN_{eff} Results from VDOT Design Memorandum

Section	H	G	F	E	D	C	B
Percentile	Sub-grade Resilient Modulus (psi)						
15th	12950	8890	8300	9080	8860	8430	8540
50th	15230	10750	8930	10200	9330	9800	11450
	SN_{eff} to include the measured Bituminous Concrete Thickness and 6" of Crusher Run material serving as the aggregate base.						
15th	6.41	4.00	3.08	4.54	3.32	4.55	3.48
50th	6.69	4.47	3.34	4.77	3.7	4.96	3.96
	SN_{eff} per inch						
15th	0.38	0.28	0.24	0.37	0.27	0.37	0.27
50th	0.40	0.32	0.27	0.39	0.30	0.41	0.31

1. For the 15th Percentile Value, 85% of the results were higher than this value and 15% were lower.
2. For the subgrade modulus, the variation in results along the length of project is typical.

Table 4-C4-3. Soil Sample Summary from VDOT Design Memorandum.

Section	H	F Core 2	F Core 3	E	D	C	B
Test	Result						
AASHTO Soil Classification	Reddish Brown Sandy Lean Clay A-2-6 (0)	Reddish Brown Sandy Lean Clay A-2-6 (0)	Reddish Silty-Sand Non-Plastic A-2-4 (0)		Sandy Fat Clay- CH A-2-7 (0)		Sandy Lean Clay A-2-6 (0)
Maximum Density (lbs/ft^3)	117.7	121.3	122.9		114.7		121.6
Optimum Water Content	12.2%	10.5%	10.5%		13.6%		9.6%
Resilient Modulus (M_r) S_3 = 6psi		12,800 to 11, 700*	10, 500 to 9,800*				
Soaked CBR on Crushed Aggregate Base	32.3%						

*The range of Resilient Modulus Values represent the high and low average values resulting from the increasing cyclic axial stress applied to the specimen while maintaining the 6 psi confining pressure.

VDOT traffic estimates showed that the average daily traffic was 76,000 vehicles per day and the average annual Equivalent Single Axle Loading (ESAL) was around 1,800,000 per year.

A pavement design was conducted based on the 1993 AASHTO Guide for Design of Pavement Structures. The pavement thickness recommendations can be found in Figure 4-C4-1.

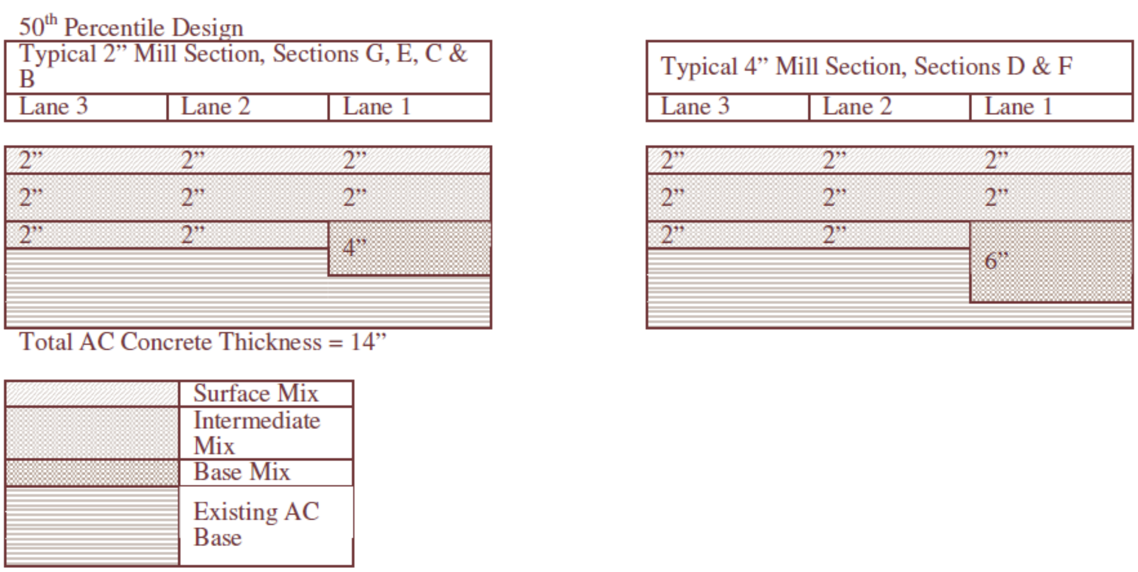


Figure 4-C4-1. Pavement Design Recommendations from 2006 Design Memorandum

R-23 Pavement Assessment

The project was reviewed again by the R-23 team and personnel from VDOT in June of 2010. Figure 4-C4-2 shows an area of extensive patching along the roadway. There was a long section where the DOT had milled out the right half of the lane and paved it back. In some areas, this was holding up well as shown in the following Figure 4-C4-3. In some areas, there was significant distress appearing in the longitudinal patch as shown in Figure 4-C4-4.

Figure 4-C4-2. Photograph of typical cracking in worst areas along project

Figure 4-C4-3. Photograph of longitudinal patch

Figure 4-C4-4. Photograph of area of fatigue cracking in longitudinal patch

Cores taken along the project indicated that some areas of pavement were stripping. A number of cores were taken in sound pavement and a few were taken in areas where the pavement had experienced stripping. Figure 5 shows photographs of a core taken at MP 105 (on the left) and a second supplemental core taken a short distance away (on the right). The stripping appears to occur randomly through the project.

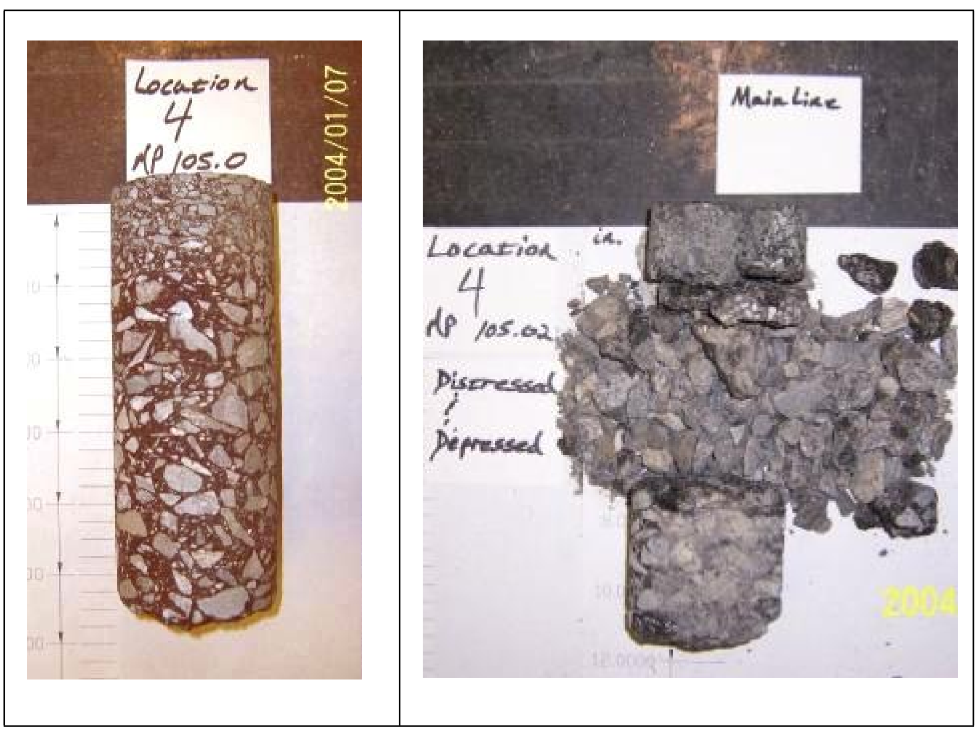


Figure 4-C4-5. Photographs of two cores taken 100 ft apart (from 2006 Design Memorandum)

Since the cores shown in the 2006 Report indicated clear signs of moisture damage and some very open areas in the pavement, a GPR survey was conducted by Brian Diefenderfer from VDOT. The resulting data file was submitted to Tom Scullion at the Texas Transportation Institute. Tom Scullion converted the data to run in his analysis program and provided plots of the interpreted GPR data as well as a summary report describing what the plots show. A copy of that report and the plots are attached as Appendix A. The plots of the interpreted data clearly show some areas where the top lift of pavement has delaminated from the lower lifts. This can be seen as a red line about two inches below the surface and is caused by a reflection of the signal at the delaminating layer interface. In addition, there are very clear areas where there are higher voids in the mix as indicated by the dark blue areas. These areas can be seen at regular intervals through most layers. The repeated pattern suggests that the pavement was placed with cyclic segregation throughout the project and in most lifts. For some reason, it is more prevalent in the outside lane than the middle lane. Cyclic segregation, which would cause localized area of stripping, would explain the reason for the difference between the core taken at MP105.0 and 105.02. An example of the GPR plot by Dr. Scullion is shown in Figure 4-C4-6.

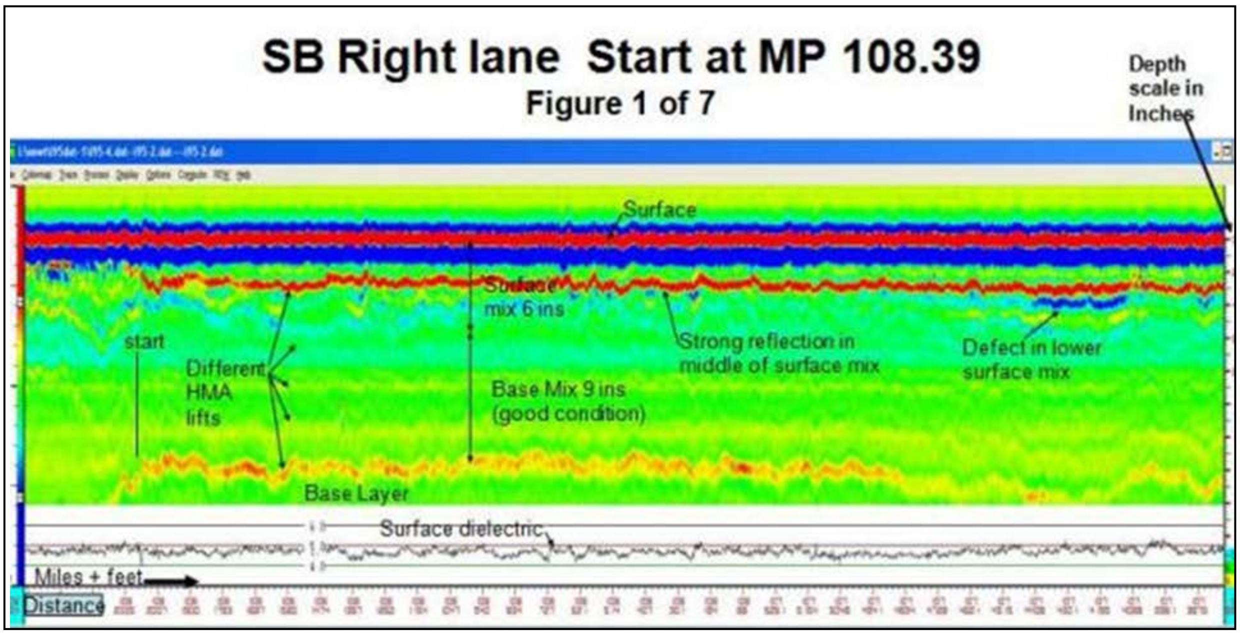
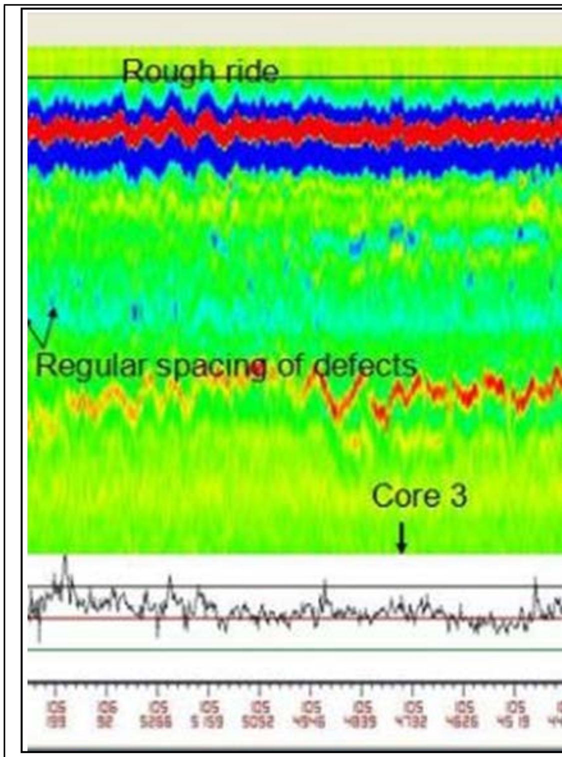


Figure 4-C4-6. Plot of Interpreted GPR Data at the Northern End of the Project

In Figure 4-C4-7, the GPR plot is shown in the location where core 3 was taken. The blue areas seen are probably indicative of the area with voids or stripping as shown in the photograph of Core 3.



Core 3

Figure 4-C4-7. Plot of GPR Data with Photo of Core 3 from Same Location

Based on findings from the coring and GPR data, the minimum recommended removal for the outside lane is 6 inches. For the middle lane the minimum recommended removal is 4 inches, and the outside lane two inches. These removal recommendations will adequately address the stripping and delamination concerns in the existing pavement. Since the total pavement thickness is 10 inches, removal of 6 inches in the outside lane will leave a minimum of 4 inches in place to support the milling operation. Removal of more than 6 inches of the existing pavement runs the risk of damaging the remaining pavement during the milling operation. For practical considerations, removal of more than 6 inches of existing pavement would require removal of all of the pavement in the outside lane.

R-23 Design Elements

The design elements that apply to the R-23 Guidelines are as follows.

Existing Pavement (two outside lanes)

- 1980 Add two lanes
  - 2” S-5
  - 8” B-3
  - 6” Pervious Aggregate Subbase Type I Number 21 or 21A
  - 6” Pervious Select Material (minimum CBR of 30)
- 1999 Mill 2” place 2” SM-12.5 D overlay
- Current traffic
  - 78,000 AADT
  - 1.8 million ESAL's per year

- o 1.4% growth (assume outside lane reaches capacity in 15 to 20 years)
- Assumed fatigue cracking 18 % wheelpath, with 8 % patching
- Subgrade AASHTO A-2-6 (0) soil, (Reddish Brown Sandy Lean Clay) M_r = 10,000 psi

Application of R-23 Long Life Pavement Design Guidelines

The following figures show the sequence of entering data in the R-23 interactive guidelines program "rePave" and the resulting design recommendations. The guidelines include recommendations for project assessment and selecting design sections to analyze using the R-23 Guidelines. The controlling factor for the test case example was the stripped HMA within the existing pavement. There was not sufficient variation along the project to establish separate analysis sections once the stripped HMA was considered. There are some sections that might warrant a reduction in the removal depth around MP 104.5 vicinity which may be considered in a more detailed analysis. For the purpose of this Test Case only one section was considered.

The first rePave screen sets the project description that will then show up in the design summary page.

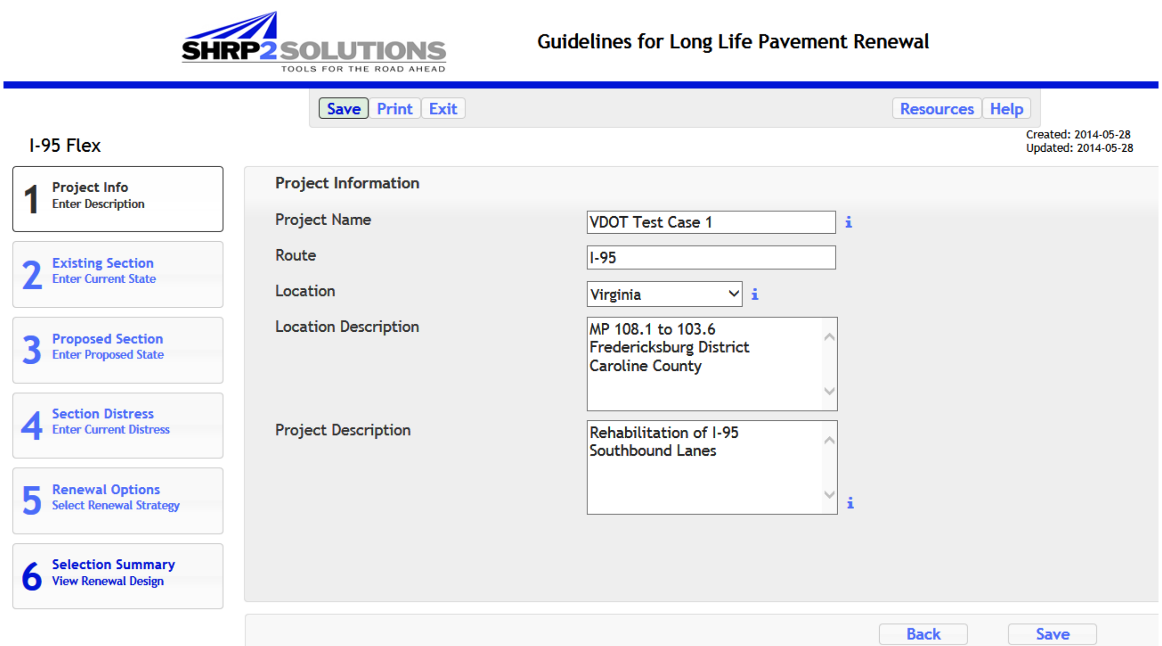


Figure 4-C4-8. rePave screen showing project description

As can be seen on this screen shot there are six steps in the interactive program, ending with the final design summary listed for the approach selected. In the upper right hand side of the screen there is a tab to access the "Resources" which are a number of documents that provide the background information that should be considered to design and build long life pavements. One of those documents is the "Scoping Methodology", documents which provide the decision tables, rules and design tables used in the rePave program to produce the design summary in step 6. The second step in the process is to enter the existing pavement section as shown in figure 4-C4-9.

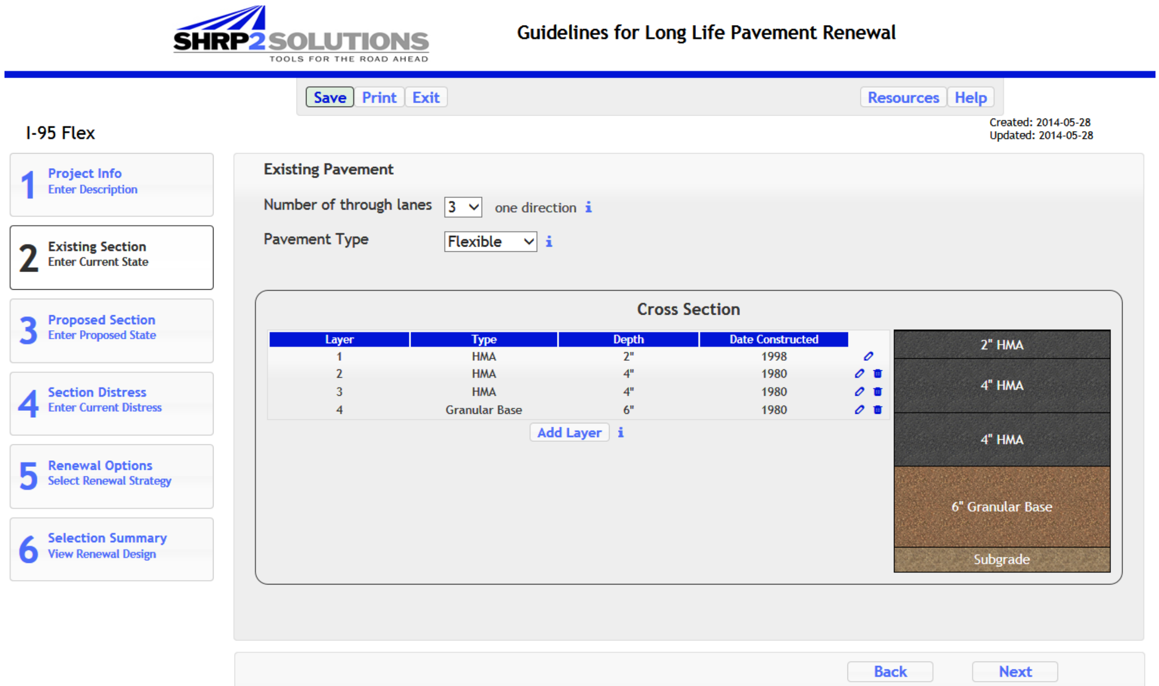


Figure 4-C4-9. rePave screen with the existing I-95 pavement section entered

This screen allows for a number of layers to be entered. All pavement layers can be entered which may be necessary particularly if there is a problem like striping in one or more specific layers. The next screen "step 3" is for the entry of the future design information.

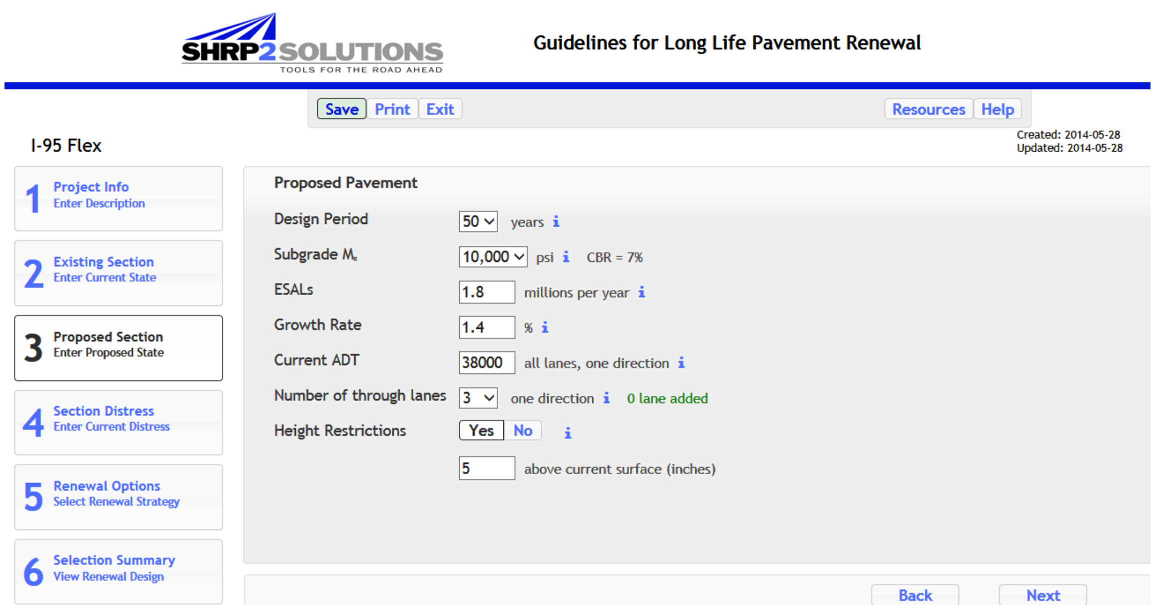


Figure 4-C4-10. rePave screen for entry of future design information

The next step is to describe the pavement condition in terms of the standard pavement distress categories. The following figures show how the most critical distress information is entered.

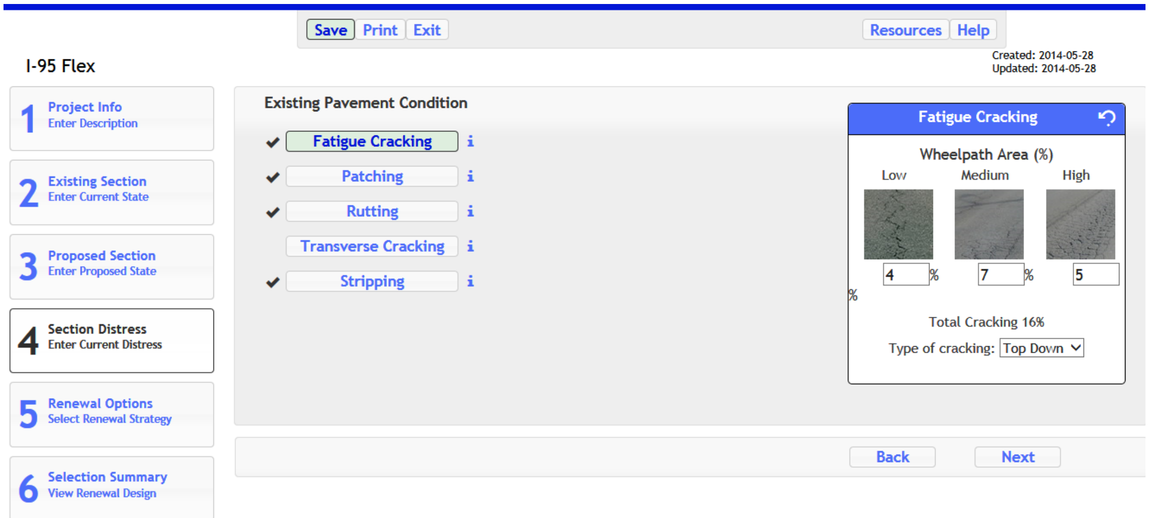


Figure 4-C4-11. rePave screen showing fatigue crack information

Note that for fatigue cracking the program does differentiate between top down and bottom up cracking. In this test case the fatigue cracking was top down though it did extend down to striped layers.

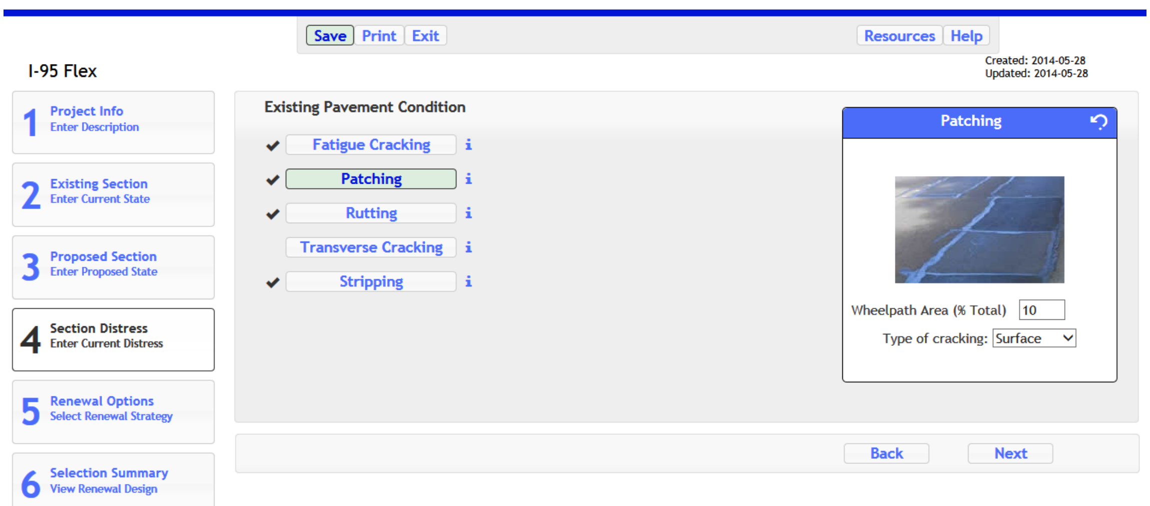


Figure 4-C4-12. rePave screen showing the amount of patching entered

For patching the program also needs to know if the patching is a surface patch or if it is full depth patching.

The final distress screen for flexible pavement is for striping. Striping was found in the intermediate layers throughout the project.

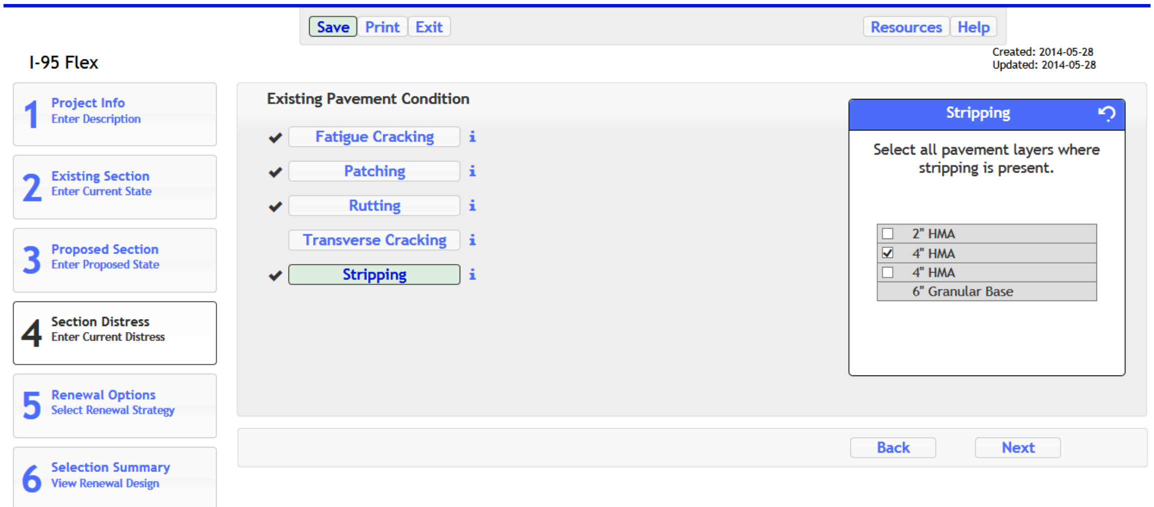


Figure 4-C4-13. rePave screen showing layers where striping was observed

After confirming that the data entered is correct the 5th step is to select the type of pavement to consider. The guidelines do not select between pavement types. It is expected that the engineer select the pavement type to be considered and then consider a number of approaches based on their agencies policy and procedures for pavement type selection.

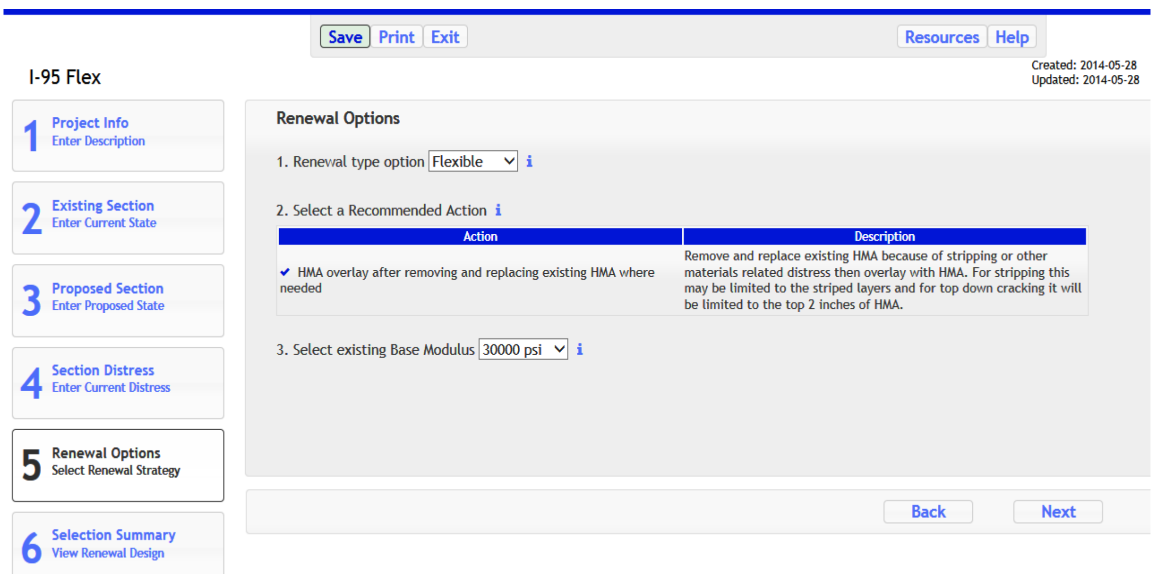


Figure 4-C4-14. rePave screen where the flexible approach is selected

For this test case where a flexible approach was selected only one action is shown and that is to remove the striped pavement and place a thick overlay sufficient to limit the tensile stress at the bottom of the remaining pavement. The resulting design summary is then shown in step 6.

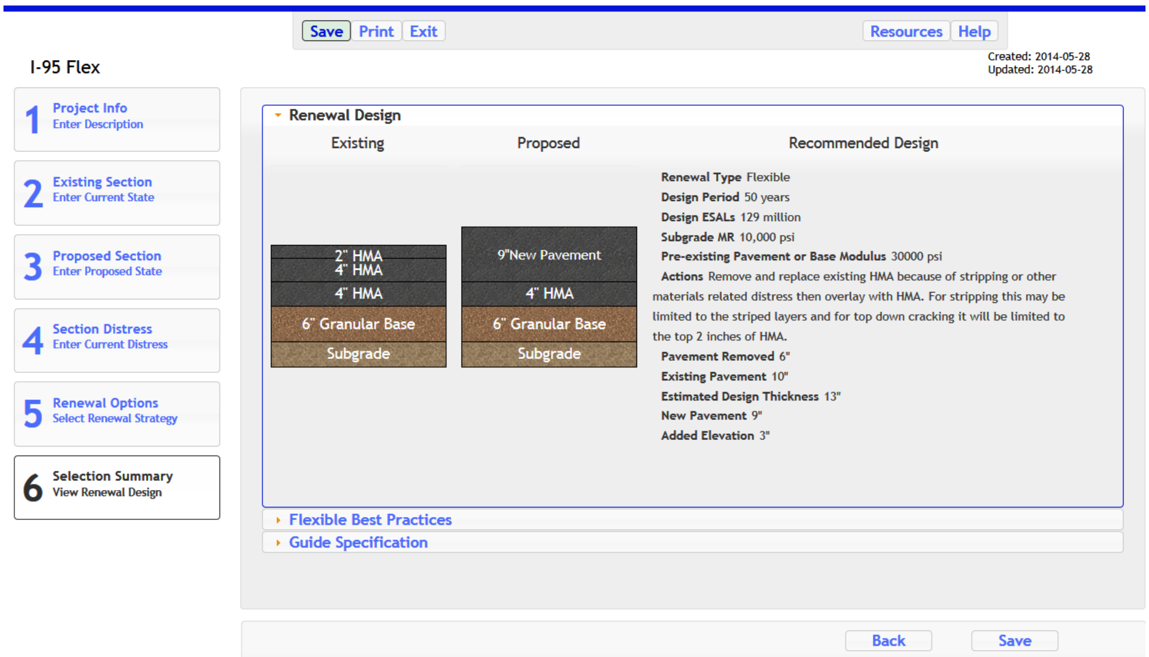


Figure 4-C4-15. rePave screen showing the resulting design summary

The results from figure 4-C4-15 should be compared to the VDOT design for this project shown in Figure 1. The VDOT design called for milling and replacing either 4 inches or 6 inches of the existing pavement depending on the project section, then placing a 4 inch overlay in two 2 inch lifts for a total pavement thickness of 14 inches. The design from rePave calls for removing 6 inches of the existing pavement to eliminate all striped layers and then placing 9 inches of HMA for a total pavement thickness of 13 inches. The difference between the two designs does not look that different but it is significant because the VDOT design is for 20 years while the rePave design is for 50 years. At the high traffic load levels found on this project the difference between the 93 AASHTO Design Guide for the Design of Pavement Structures and the MEPDG or long life design using limiting strain criteria "PerRoad" is significant. These two design procedures limit the pavement design thickness beyond a certain tensile strain level. The design equations in the 93 Guide contain no such limits so it produces very thick pavements at high traffic levels.

To complete the rePave analysis both rigid approaches as well as composite and modular pavements were also considered. The four figures below show the screens for the rigid approach considering either replacement with PCC or an unbonded PCC overlay.

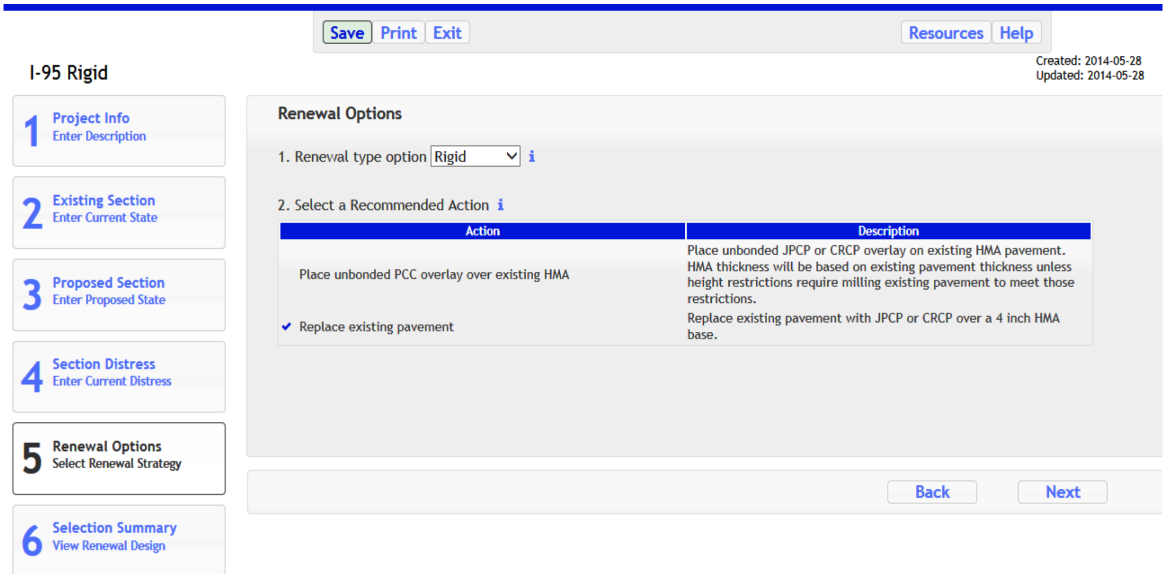


Figure 4-C4-16. rePave screen showing the rigid option with replacement selected

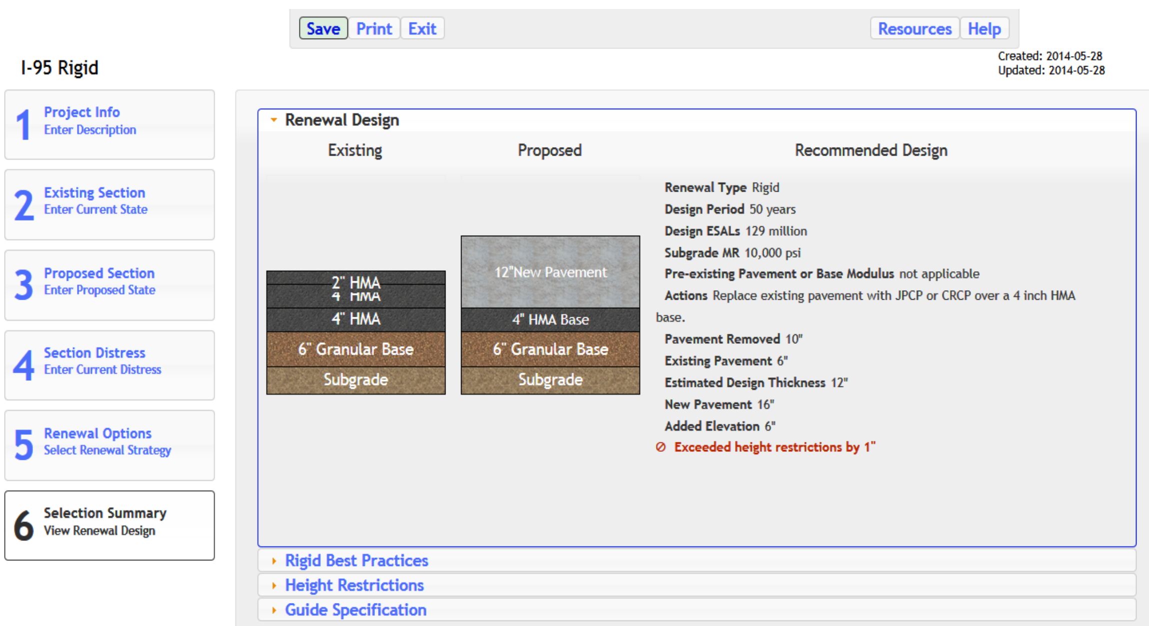


Figure 4-C4-17. rePave screen showing the design summary for PCC replacement

Note the program does include notification if the pavement design does not meet any height restrictions noted in step 3. This warning is shown in the last line which is colored red.

The following two figures show the unbonded PCC overlay approach that could be considered.

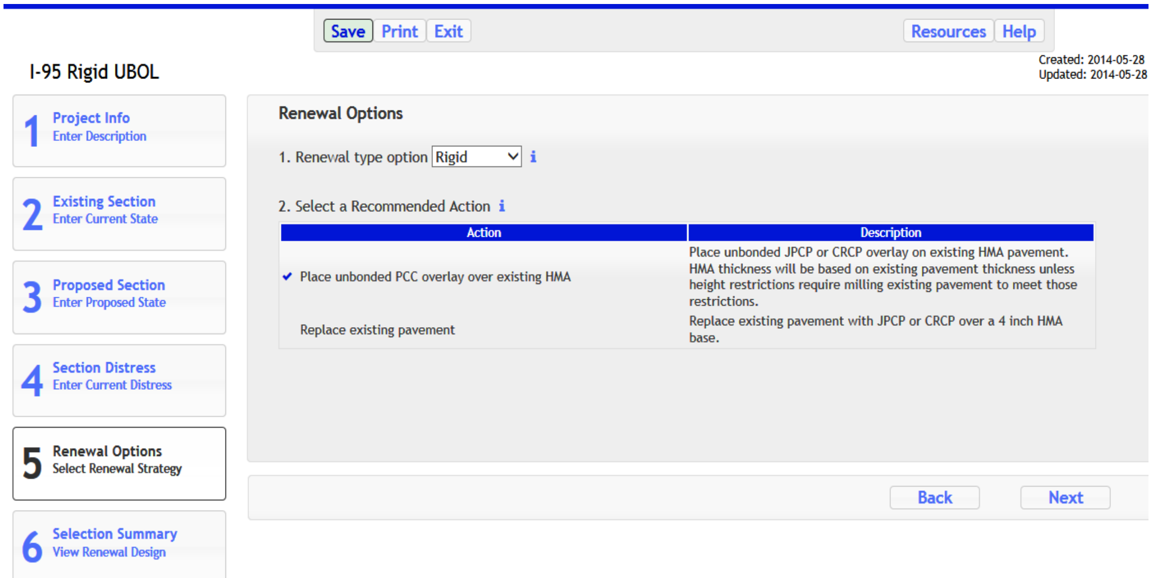


Figure 4-C4-18. rePave screen showing that the unbonded overlay approach was selected

Figure 4-C4-19. rePave screen showing the design summary for unbonded PCC overlay

Similar to figure 4-C4-17, this design summary also indicates that the design will not meet the height restrictions noted in step 3.

Note that in the rigid pavement renewal recommendation for this Test Case, the program does not automatically take out the striped HMA like in the flexible approach. This is because the rigid approach does not require removal of the HMA to provide a long life pavement. The guidance does note that the existing pavement can be milled as needed for grade requirements. The Engineer can go back to step 4 and reduce the existing pavement thickness to represent milling and check to see what that does to the pavement design configuration, which would look similar to figure 4-C4-17.

The rePave program also includes both composite and modular design approaches. However, since the personnel from the Fredericksburg District were largely concerned with the impact of the construction on traffic these approaches were not explored.

Traffic Control and Construction Staging

It is expected that an Agency using these guidelines will take the approaches recommended and fine tune those based on their own pavement design policies. The pavement thickness indicated in the Guidelines should be considered a starting point for the minimum pavement thickness that should be considered to provide long life pavements. For Agencies using the MEPDG or PerRoad limiting strain design, these recommendations will correlate well with their existing designs. Agencies using the 1993 or older AASHTO Guide for the Structural Design of Pavements will find thicker pavement sections than those recommended.

It is also expected that the Agency will look at the traffic impacts and staging requirements for the project. If the Agency is comparing alternative approaches, they will also asses the alternatives using life cycle cost analysis considering both materials and traffic control costs.

A traffic assessment was made by Dr. E.B. Lee using the CA4PRS software. The District wanted to compare traffic impacts based on restricting traffic to two lanes during the daytime and widening the shoulder to allow the use of three lanes during the daytime. The analysis showed significant traffic impacts when restricting the traffic to two lanes during the daytime, but very little impact when the traffic was allowed to use all three lanes during the daytime. Allowing three lanes for daytime traffic would require either widening the existing shoulders or using a movable barrier system. However, when the existing pavement was widened from two lanes to three lanes the DOT added two new outside lanes and used the existing two lanes to carry traffic during the widening. The existing passing lane became the new inside 12 ft wide shoulder. With some widening the existing inside shoulder could carry traffic and maintain three lanes of traffic while the outside third lane was being reconstructed.

The following table summarizes some of the findings from Dr Lee's report.

Table 4-C4-4. Work-zone Traffic Analysis Summary for Various Lane Closure Scenarios

	Max. Delay		Max. Queue		User Cost	
	min.		mile		$M	$M
days	NB	SB	NB	SB	NB	SB
2 lanes open (Day) and 1 lane open (Night)						
Mo-Th	10 min	5 min	0.3 mile	0.1 mile	$0.01 M	$0.01 M
Fri	100 min	75 min	4 mile	6 mile	$0.14 M	$0.19 M
Sat	70 min	60 min	7 mile	12 mile	$0.17 M	$0.33 M
Sun	800 min	60 min	50 mile	12 mile	$2.07 M	$0.42 M
2 lanes open (Day and Night)						
Mo-Th	0	0	0	0	0.00	0.00
Fri	20 min	30 min	4 mile	6 mile	$0.08 M	$0.16 M
Sat	30 min	60 min	7 mile	12 mile	$0.14 M	$0.33 M
Sun	240 min	60 min	50 mile	13 mile	$1.7 M	$0.42 M
3 lanes open (Day and night)						
Mo-Th	0	0	0	0	0.00	0.00
Fri	0	0	0	0	0.00	0.00
Sat	0	0	0	0	0.00	0.00
Sun	0	0	0	0	0.00	0.00

Conclusions

The recommendations from the R23 Guidelines calls for less total thickness for long life than the original VDOT design based on the 1993 AASHTO Guide for the Design of Pavement Structures. That is understandable as the 93 Guide produces very thick pavements which many States are now not using. Washington States maximum HMA thickness is 13 inches for similar traffic which matches the R23 Guidelines. After reviewing the recommendations from the R23 Guidelines the District is planning to remove all of the HMA in the outside lane and replace it with 13 inches of HMA then overlay the center and inside lane with 2 inches of HMA. The CA4PRS traffic study was based on the Districts approach.

Appendix 4-C4A

GPR Report

by
Dr. Tom Scullion

December 1,
2011

Executive Summary of GPR evaluation of IH 95

VDOT personnel collected Ground Penetrating Radar data on all lanes of a distressed section of IH 95 from RM 108.39 to103.69. The following report and attached PowerPoint file contains details of the data collected and interpretation. Based on these data the following tentative conclusions are proposed;

1) The major problems with this highway appear to be construction related in the newer 10 inch thick asphalt pavement. Two problems are apparent; firstly near surface delaminations/low density pockets with trapped moisture and secondly low density pocket at mid depth in the asphalt base layer,
2) The near surface problems are at the bottom of the surface mix and in these areas the highway is now excessively rough,
3) The problems at mid depth in the base layer are periodic most probably caused by segregation of the mat during placement,
4) Major problems existing in the right lanes in both directions,
5) Similar problems but much less severe and less frequent are also found in the middle lanes.
6) The right lanes (old structure) appear to be mostly defect free.
7) The old structure is thicker with 14 to 16 inches of asphalt.

As with any GPR investigation these conclusions should be validated with a directed field coring program. If these are validated than the optimal rehabilitation program for this highway will include full depth milling and replacement of the problem areas in both right lanes. A shallow milling (2 inch) of the middle lane in both directions, this will remove most of the near surface problems. Minimum treatments can be applied to the two left lanes.

To avoid these problems in the future the DOT should consider thermal imaging technologies to detect problems during construction.

Basics of GPR

A typical commercially available 2.2 GHz air-coupled Ground Penetrating Radar unit is shown in Figure 1. This type of system was used to test IH 95. The radar antenna is attached to a fiber glass boom and suspended about 5 feet from the vehicle and about 14 inches above the pavement. This particular GPR unit can operate at highway speeds (70 mph); it transmits and receives 50 pulses per second, and can effectively penetrate to a depth of around 16 to 20 inches. All GPR systems include a distance measuring system and many of the new systems also have synchronized/integrated video logging, so the operator can view both surface and subsurface conditions. GPS is also included in many new systems for identifying problem locations

The advantages of these systems are the speed data collection which does not require any special traffic control. These GPR systems generates clean signals which without filtering are ideal for quantitative analysis using automated data processing techniques to compute layer dielectrics and thickness. These systems are also excellent for locating near surface defects in flexible pavements.

The disadvantages are a) the limit depth of penetration, b) they are not ideal for penetrating thick concrete pavements.

Figure 1 Air Coupled GPR systems for IH 95 testing

Understanding GPR Signals

All GPR systems send discrete pulses of radar energy into the pavement and capture the reflections from each layer interface within the structure. Radar is an electro-magnetic (e-m) wave and therefore obeys the laws governing reflection and transmission of e-m waves in layered media. At each interface within a pavement a part of the incident energy will be reflected and a part will be transmitted. The amount of reflected energy is determined by the difference in electrical properties between layers. Changes in mouture content cause a large reflection.

It is normal to collect between 30 and 50 GPR return signals per second, which for high speed surveys means one trace for every 2 to 3 feet of travel. The captured return signals are often color coded and stacked side by side to provide a profile of subsurface conditions, this is analogous to an "X-Ray" of the pavement structure. Examples of this will be given later in this report. Air coupled signals can also be used to automatically calculate the engineering properties of the pavement layers.

A typical plot of captured reflected energy versus time for one pulse of an air coupled GPR system is shown in Figure 2, as a graph of volts versus arrival time in nanoseconds. To understand GPR signals it is important to understand the significance of this plot.

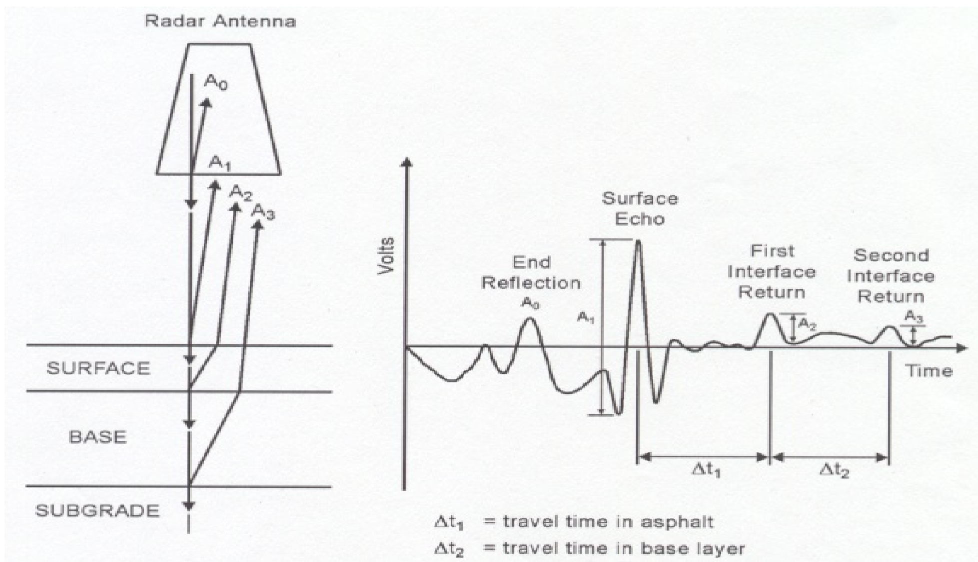


Figure 2 Captured GPR reflections from a typical flexible pavement

The reflection A_0 is known as the end reflection it is internally generated system noise which will be present in all captured GPR waves. The more important peaks are those that occur after A_0. The reflection A_1 (in volts) is the energy reflected from the surface of the pavement and A_2 and A_3 are reflections from the top of the base and subgrade respectively. These are all classified as positive reflections, which indicate an interface with a transition from a low to a high dielectric material (typically low to higher moisture content). These amplitudes of reflection and the time delays between reflections are used to calculate both layer dielectrics and thickness. The dielectric constant of a material is an electrical property which is most influenced by moisture content and density, it also governs the speed at which the GPR wave travels in the layer. An increase in moisture will cause an increase in layer dielectric; in contrast an increase in air void content will cause a decrease in layer dielectric.

In most GPR projects several thousand GPR traces like figure 2 are collected. In order to conveniently display and interpret this information color-coding schemes are used to convert the traces into line scans and these are then stack them side-by-side so that a subsurface image of the pavement structure can be obtained. This approach is shown below in Figure 3.

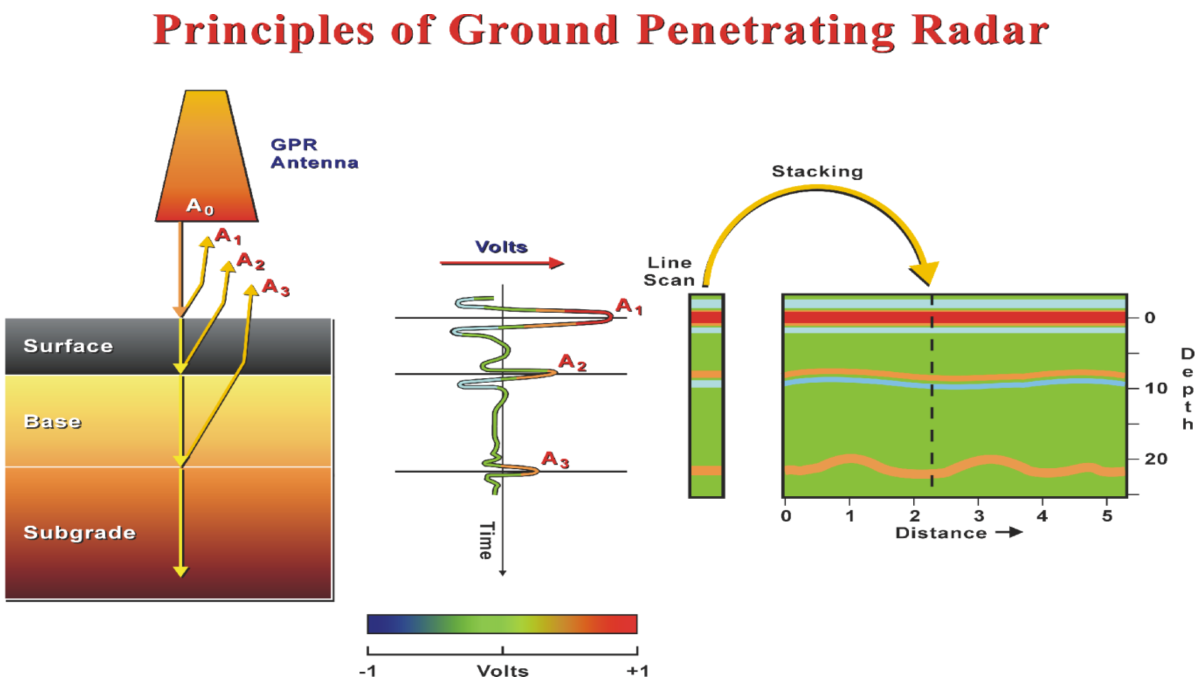


Figure 3 Color Coding and stacking individual GPR images

The raw GPR image collection is displayed vertically in the middle of Figure 3. This image is for one specific location in the pavement. The GPR antenna shoots straight down and the resulting thickness and dielectric estimates are point specific. The single trace generated is color coded into a line scan using the color scheme in the middle of Figure 3. In the current scheme the high positive reflections are colored red and the negatives are colored blue. The green color is used where the reflections are near zero and are of little significance. These individual line scans are stacked so that a display for a length of pavement is developed. Being able to read and interpret these images is critical to effectively using GPR for pavement investigations, to locate section breaks in the pavement structure and to pinpoint the location of subsurface defects.

An example of a typical GPR display for approximately 700ft of IH 95 is shown in Figure 4. In all such displays the x axis is distance (in miles and feet) along the section and the y axis is a depth scale in inches, with zero being the surface.

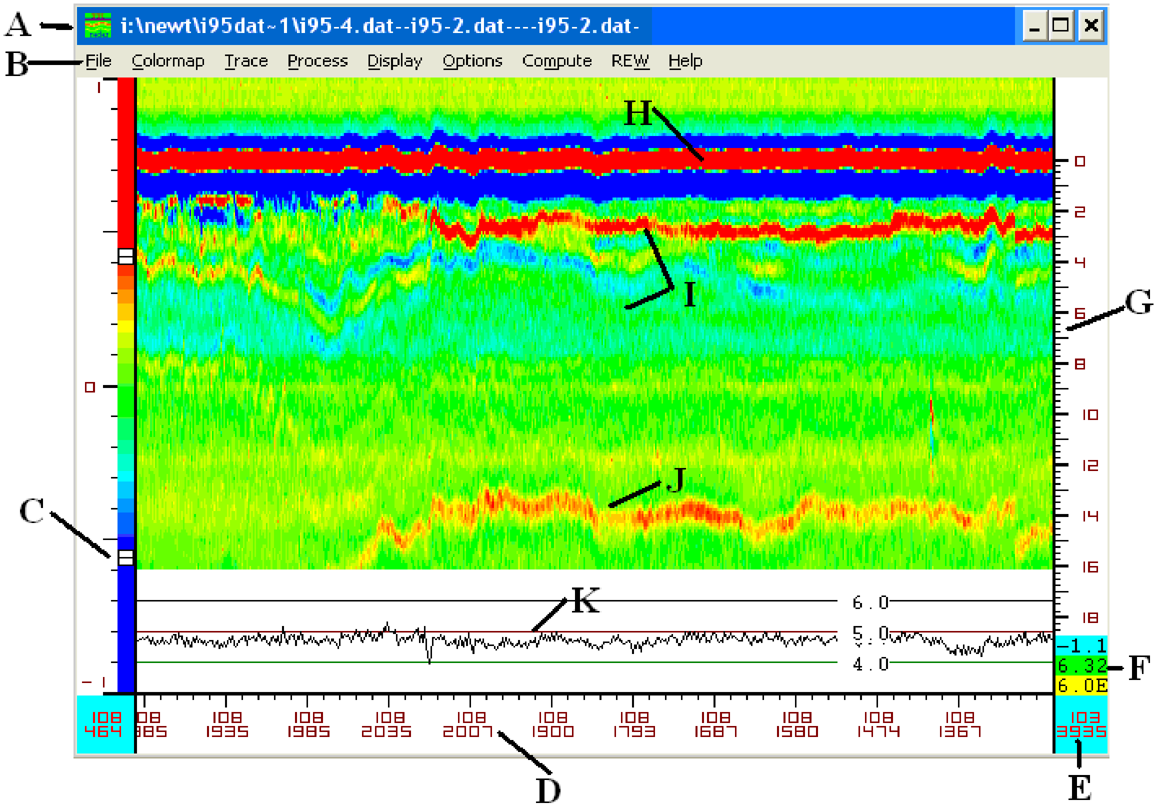


Figure 4 Typical Color Coded GPR data from IH 95

The labels on this figure are as follows

A) GPR filess being used in analysis, (I95-4.dat is the data file -2 is the metal plate file)

B) Main Pull down menu bar of the software used to process the GPR data,

C) Buttons to define the color coding scheme used to convert the GPR reflections into a color scheme as shown in Figure 3,

D) Distance scale (Reference marker miles and feet, these are the actual reference markers on IH 95),

E) End location of data within the GPR file (RM 103mile and 3935 feet), the start location at the other side of the plot is RM 103 + 464 feet

G) Depth scale in inches, with the zero (0) being the surface of the pavement,

F) Default dielectric value used to convert the measured time scale into a depth scale, also other calibration factors (not used in processing IH 95 data)

H) Reflection from the surface of the highway. The blue-red-blue is the typical color scheme for the surface reflection. Rises and dips in this line are actual bumps and dips on the pavement surface.

I) Reflection from within the HMA layer indicating a change in HMA materials. Under normal conditions within a thick HMA layer these reflection are very small or non existent as GPR only gives a reflected signal if there is a change in materials properties. Strong reflections between layers, could indicate potential problems – such as a moisture build up at the interface. In this case the top 6 inches is surface mix, the reflection in the middle is very strong whereas the reflection at the change from surface to base mix is very weak.

J) Reflection from the bottom of the HMA layer, top of the base. The stronger (more intense) the reflection the wetter the base material

K) This is the computed surface dielectric for the surface layer. This is a measure of the electric properties of the top 2 inches of the pavement. The amplitude is related to both the moisture content and density of the top layer. It is a measure of the uniformity of the surface mix. Large increases in this value are caused by moisture (wet areas), sudden drops in the surface dielectric are caused by decreases in mat density. Well constructed dry HMA overlays have a very flat line indicating uniform density.

When processing GPR data the first step is to develop displays such as Figure 4. From this it is possible to identify any clear breaks in pavement structure and as described below to identify any significant subsurface defects.

Identifying Subsurface defects in the GPR Color Displays

When evaluating pavements to determine the cause of pavement distress and locate potential rehabilitation options it is recommended that firstly the GPR data be collected and analyzed to identify potential subsurface defects. Then a directed coring program be undertaken to validate the GPR interpretation. In this section examples will be given of GPR color coded signatures and their interpretation.

With the color scheme used in this analysis the following guidelines are used;

a) the horizontal red lines are significant, they represent layer interfaces with a transition from a low to a high dielectric, for subsurface reflections this indicates a change in moisture content.

b) the faint yellow lines are normal within HMA layers; they indicate an interface with only minor changes in properties (transition from surface to base mix)

c) strong red reflections within HMA layers could be problematic indicating trapped moisture within the HMA (or major changes in materials)

d) blue areas within HMA are normally associated with a low density areas

e) all green area are of no interest, no reflections occurring; uniform material.

The IH 95 data is presented in the accompanying PowerPoint to this document. Several different cases of interest from the IH 95 data are described below.

A) Ideal Case (Figure 5)

This figure shows only a surface reflection and reflection from top of the base (two red lines). No significant reflection within HMA.

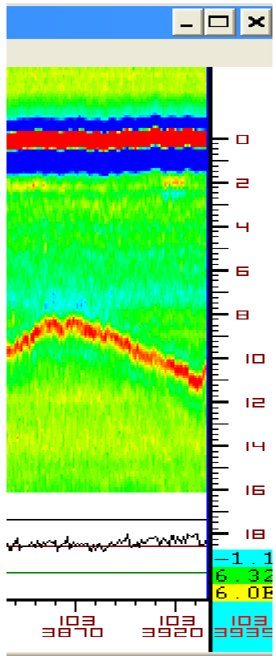


Figure 5 Uniform Case (No problem)

In Figure 5 the asphalt core thickness varies from 8 to 11 inches. The surface dielectric plot at the bottom of the scale is flat indicating uniform surface density for this approximately 200 foot section of pavement. If a core was taken at this location it would be a solid core with no defects.

B) Potential Defects at Layer interface (Figure 6)

In this case the total HMA thickness is around 14 inches, the plans indicate that the top 6 inches is surface mix followed by 8 to 9 inches of base mix. There is a very faint blue-yellow-blue reflection at 6 inches which is normal, if the layers are well bonded and made with similar aggregates. What is not normal is the strong red reflection in the middle of the surface layer at a depth of 3 inches. This location should be cored to determine the cause of this strong reflection. It could be related to poor compaction of the bottom of the top layer with moisture sitting in this interface. Delamination of this layer would also be a concern. In some cases it could be related to a major change in coarse aggregate type, but it is doubtful that this would cause such a major reflection, strong red reflections are almost always moisture related.

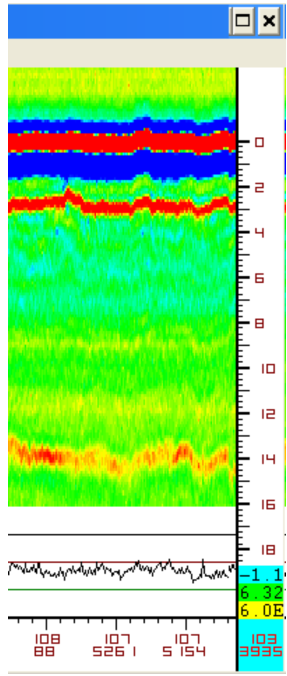


Figure 6   Strong reflections within HMA layers at a depth of 3 ins

Trapped Moisture at interface (Figure 7)

This case is very similar to Figure 6 with the exception of a strong blue reflection below the strong red. Blue reflections are caused when the GPR wave enters an area of lower dielectric. This could be related to moisture trapped at the bottom of the upper HMA lift, when the GPR wave hits the water a strong reflection occurs and this is the red line, when it enters the lower dry HMA layer it enters a layer of lower dielectric and the blue colored reflection is generated.

Another alternative could be a very open layer (low density) at the top of the second HMA layer. This area should be cored to determine the true cause.

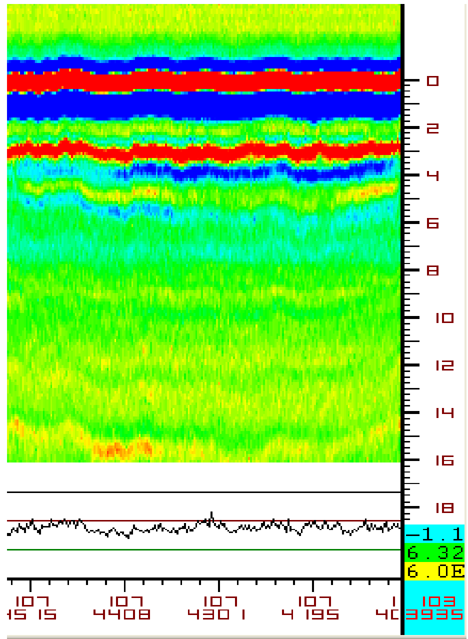


Figure 7 Potentially trapped moisture over dry HMA

Dry Low density layer within HMA (Figure 8)

The area of concern here is the blue reflection at a depth of two inches. This is probably a low density layer starting about 2 inches down. Poorly compacted asphalt layers with significantly higher air voids have a low dielectric values which give a reflection similar to that shown in Figure 8. Check this location for poor compaction at the bottom of the surface layer.

There are some naturally occurring aggregates which give low dielectric signals these are often lightweight type materials. However these would give a continuous blue reflection, this is not the case here.

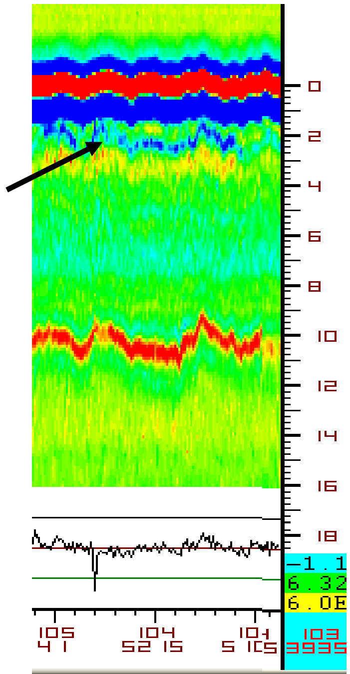


Figure 8 Possible low density layer 2 inches down

Rough Surface and defects at mid depth of base layer (Figure 9)

Several lanes on IH 95 give periodic low density signatures (blue spots) at the middle of the base layer. This could be either poor compaction at the bottom of the upper lift or low density areas at the top of the lower lift. The regular spacing of the blue spots in the IH 95 reflections are indicative of construction problems; possibly thermal segregation. The fact that there are no red signatures at this location indicates that these areas are dry. Water filled voids would give a red/blue signature.

Figure 9 also provides other information about this location. The ripples in the surface echo indicate bumps in the roadway caused by the antenna moving up and down as it goes over rough areas. There are also significant variations in the surface dielectric plot at the bottom of the figure indicating that the top layer density is very variable.

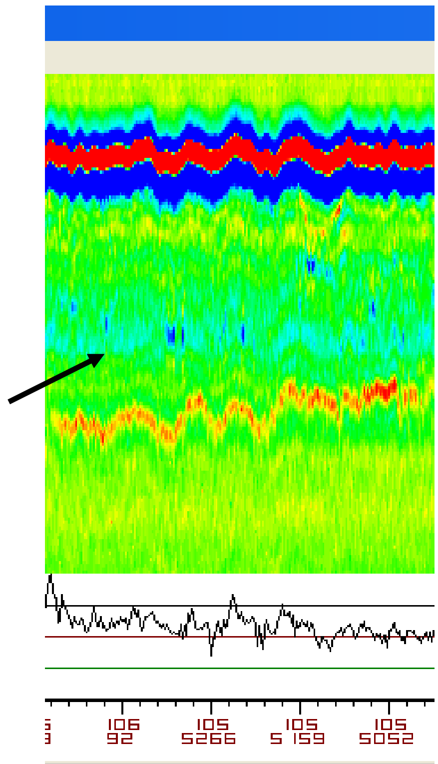


Figure 9 Low density defects at mid depth in HMA base layer

C) Variations in Surface dielectric plots (Figure 10)

The amplitude of the surface reflection from the top layer of the pavement is used to provide very useful information about the uniformity of the top layer. This amplitude in volts is used to compute a surface dielectric for that location and that value is strongly influenced by two factors. Firstly moisture will cause significant increases in the surface dielectric. Secondly density, low density areas will cause a significant decrease in surface dielectric. Examples of each are shown below in Figure 10.

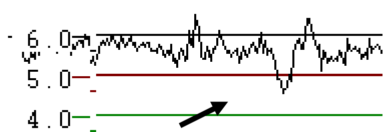


Figure 10 a) Low density location in surface mat

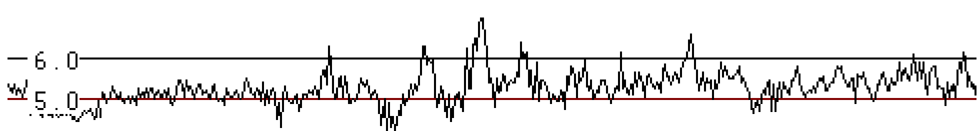


Figure 10 b) Very variable surface reflections indicating both wet and low density spots

If periodic low density spots are found in the surface mat that is indicative of "truck-end" thermal segregation, typically every 150 feet. Conversely well compacted mats have very flat surface dielectric plots. Decreases in surface dielectric of more than 0.8 units are highly significant indicating more than a 6% change on air voids.

G subsurface defect causing bump on surface (Figure 11)

The bump on the pavement is clear in the surface reflection in Figure 11, however the same variations can also be seen in the lower layers even the top of the base. This bump is coming from somewhere deep in the pavement structure

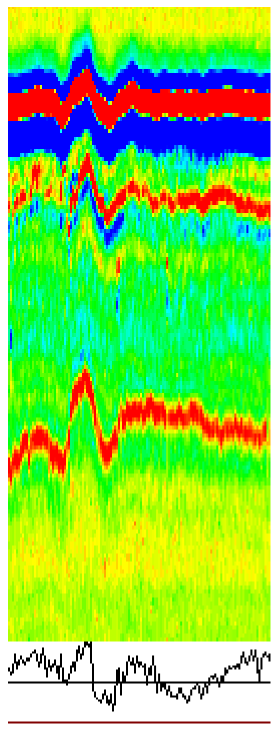


Figure 11 Surface Bump

GPR Color coded data from Core locations Right lane SB

In the VDOT condition assessment memo from 2006 five locations were cored in the SB right lane. An attempt was made to reference these core locations to the data collected in the 2010 GPR survey. With the information available the following 5 figures show the cores taken from each location.

Core 1 MP 107.5

The core taken was in good condition around 15 inches in length with about 5 inches of surface mix over 10 inches of larger stone base mix. No defects are apparent in the core. The

GPR data looks reasonable, the reflection from the top of the base is just at the bottom of the figure at around 16 inches. There are faint reflections at a depth of 5 inches, this would indicate that the bond between layers is good and there is only a small change in material properties between layers. No major strong reflections from within GPR profile implies no buried defects.

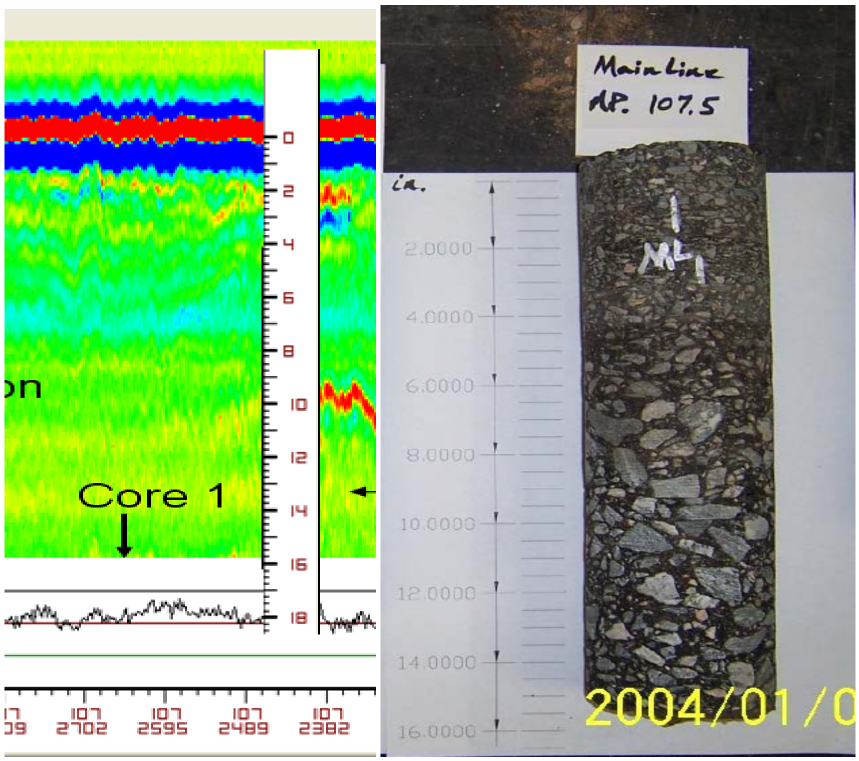


Figure 12 Core 1 MP 107.5 with GPR data

Core 2 RM 106.59

The core from this location is about 10 inches long which matches the GPR profile. There are a lot of localized defects (blue areas) at various locations. There are also some localized red reflections at a depth of 2 inches. The only damage found at the core location was cracking in the upper 2 inches. Clearly this is a variable area moving a few feet could have resulted in a very different core.

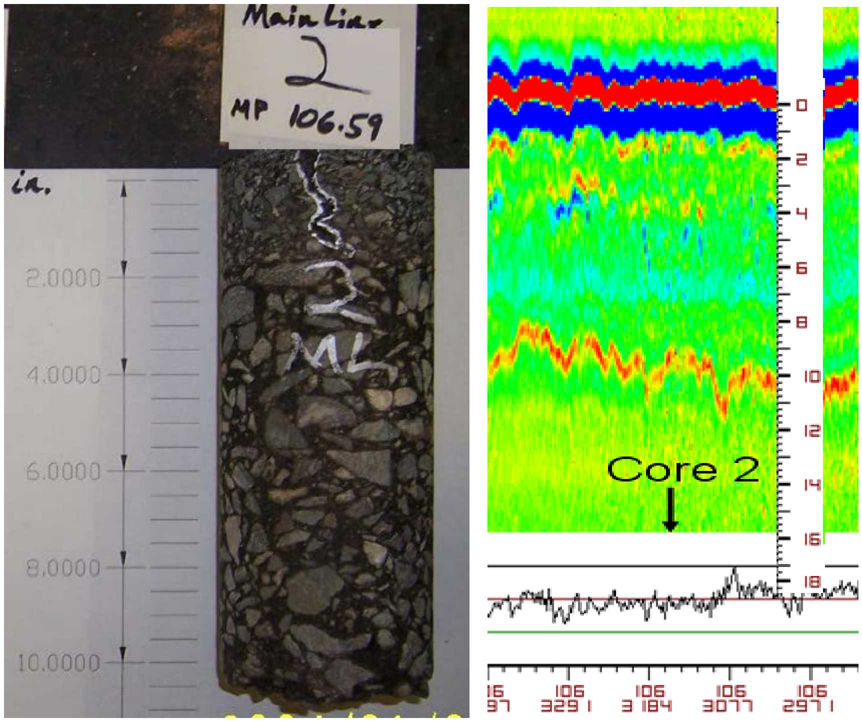


Figure 13 Core 2 M 106.59 with GPR data

Core 3 at RM 105.9

A very poor core was found in this location. The GPR data showed low density areas at a depth of 4 inches and very variable surface dielectric plot indicating problems with the top mat.

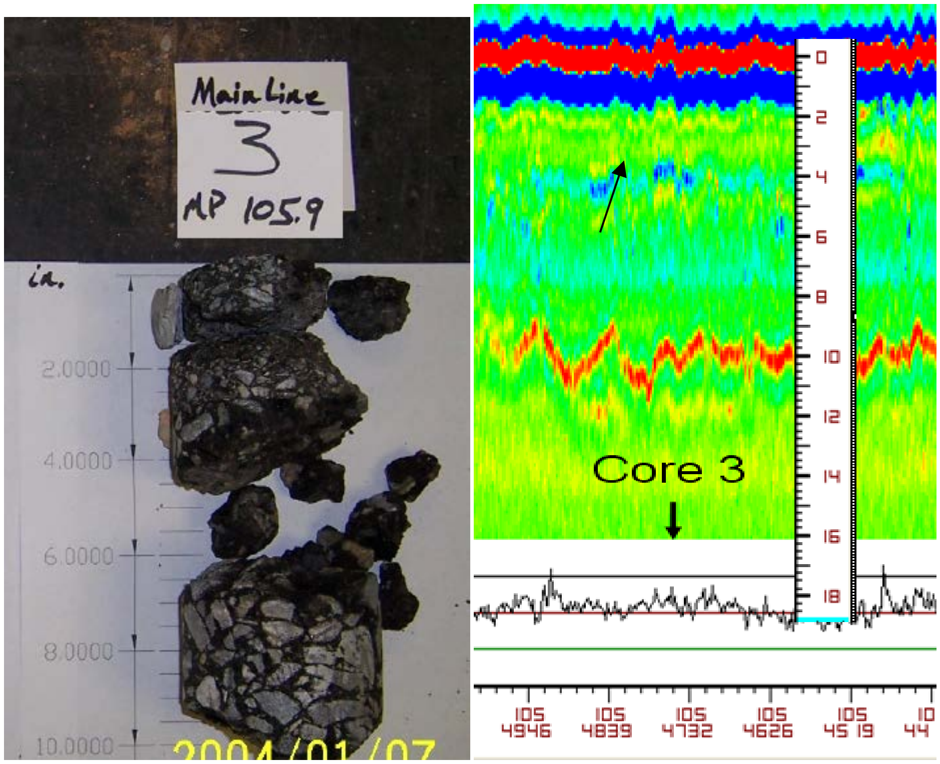


Figure 14 RM 105.9 Problem location

Core 4 at RM 105.02

This is another problem location with severe damage found at a depth of 2 inches. The GPR profile also indicate near surface damage

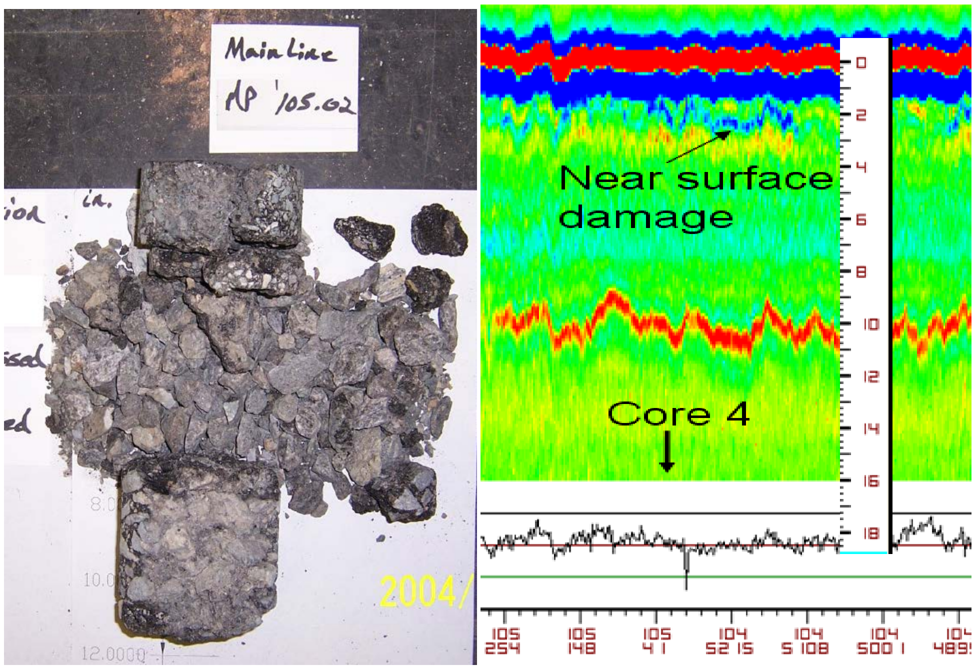


Figure 15 RM 105.02 problem location

Core 5 at RM 103.8

No problems with the core and good clean GPR data with no apparent defects. The reflection at 2 inches is the transition from surface to base mix

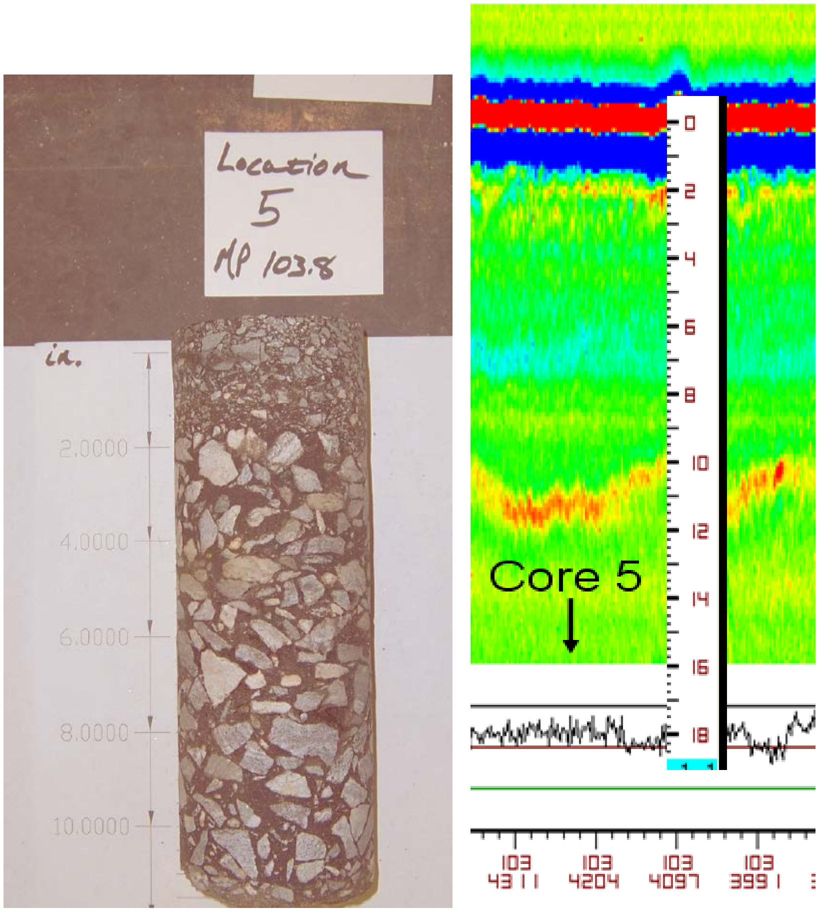


Figure 16 MP 103.8 RM 103.8 Core from a no defect area

Interpretation of GPR images from IH 95

The GPR data from IH 35 is presented in the PowerPoint file which accompanies this report. Data was collected in all directions all lanes.   Each color page represents about 4000 feet of pavement. An entire run takes about 7 pages. Each of these has been annotated showing potential defects and changes in structure.

The data from Page 1 of 7 for the SB lanes starting at RM 108.39 is shown in Figure 15 on the next page. The depth scale is on the right the distance scale is on the bottom axis. The main features of this figure are

1) This is for a section from RM 108+2035 feet to 107 + 3875 ft
2) The hot mix is approximately 14 inches thick in this section,

3) There is a very strong reflection at a depth of 3 inches, the reason for this reflection is not known at this time
4) There is a very faint reflection at 6 5 to 6 inches
5) The red blue interface is marked as a deflect, this could be trapped moisture, should to core to validate

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[i] Minnesota Department of Transportation, Office Memorandum To Scott McBride District Engineer, from Tim Clyne Materials Program Delivery Engineer dated January 31, 2014 Subject Pavement Design Structure.

[ii] Letter Report from Amy Grotbaus Bran Intertec to Mr Chris Kufner MnDOT "Ground Penetrating Radar Evaluation Results "Trunk Highway (TH 5) between Norwwood Young America and Victoria Minnesota", July 16, 2012.

[iii] MnDOT Memo from Michel Corbertt (Metro District ESAL forecaster) to Gean Hicks (Section Director) July 25th 2012 Subject : Traffic Forecast.

[iv] Smith, K., Yu, H., and Peshkin, D. (2002), "Portland Cement Concrete Overlays: State of the Technology Synthesis," Report No. FHWA IF-02-045, Federal Highway Administration, April 2002.

[v] SHRP 2 R21 Report S2 R21-RR-2 "Composite Pavement Systems--Volume 1 HMA/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-2.pdf.

[vi] S2 R21-RR-3 "Composite Pavement Systems--Volume 2 PCC/PCC Composite Pavements" at: http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2_S2-R21-RR-3.pdf.

[vii] Report S2-R05-RR-1 "Precast Concrete Pavement Technology" at: www.trb.org/Main/Blurbs/167788.aspx.

[viii] Diefenderfer, Brian, C. Et. Al.,, "In-Place Pavement Recycling on I-81 in Virginia" *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2306*, Transportation Research Board of the National Academies, Washington, D.C.,