INSTRUCTIONS:
Project Managers and/or research project investigators should complete a progress report at least every three months during the project duration. Reports are due the 5th of the month following the end of the quarter. Please provide a project update even if no work was done during this reporting period.

<table>
<thead>
<tr>
<th>Project # 26962N</th>
<th>Report Period Year: 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>□Q1 (Jan-Mar) □Q2 (Apr-Jun) □Q3 (Jul-Sep) ☒Q4 (Oct-Dec)</td>
</tr>
</tbody>
</table>

Project Title: Layer Coefficients for NHDOT Pavement Design

Project Investigators: Eshan Dave (Co-PI: Jo Sias Daniel)
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Research Start Date: December 1, 2016
Research End Date: December 31, 2018
Project schedule status: ☒ On revised schedule

Brief Project Description:
At present, the New Hampshire Department of Transportation (NHDOT) employs the AASHTO Empirical Pavement Design procedure for structural design of highways (new construction, reconstruction and major rehabilitations). The AASHTO procedure uses material specific coefficients (commonly called layer coefficients) to account for the structural capacity provided by each pavement layer. The current layer coefficients used by NHDOT are a combination of the original values proposed by AASHTO in the 1960s and research conducted by Janoo in 1994 (CRREL Special Report 94-30). The research by Janoo was primarily focused on layer coefficient characterization of subgrade soils and aggregate courses. The asphalt mixtures in use today and vehicle loadings are substantially different from the ones characterized by AASHTO during the development of the design guide in the 1960s. With current use of newer asphalt binder modification technologies, allowance for recycled materials (RAP, ground tire rubber), and newer manufacturing and construction techniques (such as cold in-place recycling) there is an urgent need to reevaluate the layer coefficients for materials that are currently being used in construction of State pavements. Due to the lack of reliable layer coefficient values, there is high potential for over-design of pavements that could translate to substantially higher spending. In order to promote sustainability and to maintain integrity through reliable pavement designs, this research study will characterize asphalt mixtures currently used by the State for determination of the actual layer coefficient values for those materials.

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):
- All of the mechanical characterization of the study mixtures has been completed except for DCT testing on B-3. Table 1 provides the latest status of the experimental component of the study.
- A framework for developing layer coefficients using lab measured performance properties and field distress data has been developed and preliminary validation of the concept has been conducted using the data-set from the I-93 pavement sections that were constructed as part of the High RAP Pooled Fund Study. The appendix to this report provides technical details on the process of layer coefficient development as well as the findings for the I-93 pavement sections.
- At this point the field distress data for nine mixtures (ARGG-1, ARGG-2, T-1, T-2, THS-1, SHM-1, SV-1, B-2 and BB-1) have been provided from the NHDOT. These data have been analyzed by the researchers and based on the preliminary analysis a list of cross sections for each mixture have been provided for NHDOT. The cross sections will be used in order to evaluate and correlate the measured distresses to the pavement structure. Based on the results, the approach to determine the layer coefficients will be finalized.
As the development of layer coefficients with higher reliability requires the validation of the proposed a-values, the researchers are working with NHDOT to continue to obtain the pavement distress data, locations and the structure of all the mixtures similar to study mixtures. So far distress and location data for 9 mixture types have been made available to researchers. Information from 9 other mixture types is still pending and is anticipated to be received over the course of the upcoming quarter. This information is critical for UNH researchers to refine the mechanistically informed layer coefficients and have high confidence in the developed values for adoption by NHDOT for routine design purposes.

Planned Research for next 3 months:

- Laboratory Evaluation: Completion of DCT test for B-3 mixture.
- Analysis: Once the field data and corresponding cross sections are provided, the currently developed preliminary layer coefficients will be reassessed and finalized with respect to their specific individual field performance. As a next step, asphalt mixture layer coefficients as a function of traffic, location in pavement, pavement structure and mixture design variables will be explored. The Appendix to this report provides a general description of the approach to develop the layer coefficients.
- Reporting: The completed analysis of tests along with finalized layer coefficients of the mixtures will be reported for all of the mixtures in the study.
Circumstances affecting project: Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and budget, along with recommended solutions to those problems.

<table>
<thead>
<tr>
<th>Tasks (from Work Plan)</th>
<th>Planned % Complete</th>
<th>Actual % Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature Review and Testing Plan</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Laboratory Characterization</td>
<td>95</td>
<td>99</td>
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<tr>
<td>Development of Layer Coefficient</td>
<td>90</td>
<td>80</td>
</tr>
<tr>
<td>Reporting</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

As discussed and mentioned in this report as well as previous reports, the validation of the layer coefficients proposed through the performance testing and performance modelling conducted in this project depends on the availability of information from NHDOT regarding the pavements that have been constructed in the past with materials similar to the study mixtures. The original work-plan for the project was developed with the assumption that this data will be available to researchers during Fall and Winter of 2017. However, the field data has just begun to be received by researchers in Fall of 2018 and will continue over the quarter 1 of 2019. Thus, project is behind schedule and will not be complete by the original planned date of December 31st 2018. A no-cost extension request for project has been submitted by UNH to NHDOT to change the project end date to June 30th 2019.
Appendix: Finalized approach to develop the layer coefficients

1. Introduction

As discussed in Task 1 (literature review) of the project, different approaches have been investigated and implemented by researchers to update the layer coefficients. Since the nature of the layer coefficients and AASHTO 1993 design equation is based on statistical regression analysis, the layer coefficients of asphalt mixtures are functions of different parameters such as traffic level, weather conditions, subgrade soil modulus, level of reliability as well as the properties of the other underlying layers. Also, layer coefficients may not be constant values even for a single pavement structure, as the material properties and climatic conditions are ever changing throughout the pavement design life, resulting in different overall pavement response even in the relatively small time interval of a day. As a result, determining a fluctuating layer coefficient, if not impossible, will be a significantly challenging task. Moreover, the establishment of a direct correlation between the performance index parameters such as the ones discussed in the previous reports may not be appropriate since the resulting layer coefficients will be solely dependent on the material properties which ignores other effective variables in determining a realistic layer coefficient.

To simplify the stated problem while maintaining a relatively high reliability in developing layer coefficients, the pavement distress data in the form of a standard index parameter can provide a general overview of the pavement response during the design period. This standard index parameter represents the overall interaction of variables such as loading and climatic circumstances, subgrade soil modulus value etc. which affect the pavement performance during the service life. As such, different field distress indicator parameters such as Present Serviceability Index (PSI), Pavement Condition Index (PCI), International Roughness Index (IRI) etc. are available to identify the functional quality of the pavement. Although the functional distresses include different types of non-structurally related damages such as raveling, potholes etc. a significant portion of them are related to structural distresses such as rutting and cracking. Among the available functional distress index parameters, the IRI is more popular since it is measured by a standard vehicle’s accumulated suspension motion and therefore it is less affected by external variables such as visual observations that can reduce the reliability of a functional distress index parameter. Moreover, there are different regression based equations that relate IRI to PSI which is one of the variables in the AASHTO 1993 equation. In addition, many state highway agencies such as NHDOT gather the yearly IRI data for different highways as part of their pavement management system.

2. Proposed methodology to develop the layer coefficients

In order to develop the layer coefficients in this research, advanced statistical techniques will be used to establish a regression based equation which incorporates the fatigue failure criterion with the rutting index parameter (both discussed in the previous reports) to predict the IRI as a function of time. This equation will be used to predict the IRI at the end of the design period (usually 20 years for flexible pavements). Using the available regression based equations such as the one developed by Al-Omari [1], the PSI value can be determined. Then, using the AASHTO 1993 design equation with all other variables available, the structural number (SN) and consequently the layer coefficients will be back-calculated. The flowchart to develop the layer coefficient through the proposed method is provided in Figure 1.
3. Layer coefficients developed for 6 mixtures placed on I-93

3.1. Materials

The proposed approach in development of layer coefficients was investigated through evaluating a set of 6 mixtures that are placed on I-93 as part of the High RAP Pooled Fund Study project. The field distress data for 5 years after construction is available for these mixtures and since the traffic and climatic circumstances as well as structural cross section of the pavement is the same for these mixtures a direct comparison between the mixtures performance and the developed layer coefficients can be made. Table 2 summarizes the mixtures design properties.

Table 2. Mixture design properties

<table>
<thead>
<tr>
<th>Mixture Design</th>
<th>Mix</th>
<th>Total Binder Content, (p_b) (%)</th>
<th>Recycled Binder Ratio</th>
<th>Field Air Void (%)</th>
<th>Air Void Level at Design Gyration, (V_a) (%)</th>
<th>Voids in Mineral Aggregate (%)</th>
<th>Voids Filled with Asphalt (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Virgin 58-28</td>
<td>5.9</td>
<td>0</td>
<td>3.5</td>
<td>4.4</td>
<td>16.8</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>15% RAP 58-28</td>
<td>5.8</td>
<td>13.9</td>
<td>2.5</td>
<td>4.3</td>
<td>16.9</td>
<td>74.2</td>
</tr>
<tr>
<td></td>
<td>25% RAP 58-28</td>
<td>5.8</td>
<td>23.1</td>
<td>2.2</td>
<td>4.1</td>
<td>16.7</td>
<td>75.3</td>
</tr>
<tr>
<td></td>
<td>25% RAP 52-34</td>
<td>5.8</td>
<td>23.1</td>
<td>2.5</td>
<td>3.5</td>
<td>16.5</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>30% RAP 52-34</td>
<td>5.8</td>
<td>27.7</td>
<td>3.7</td>
<td>3.6</td>
<td>16.4</td>
<td>78.1</td>
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<tr>
<td></td>
<td>40% RAP 52-34</td>
<td>5.8</td>
<td>37</td>
<td>3.4</td>
<td>4.2</td>
<td>17</td>
<td>75.2</td>
</tr>
</tbody>
</table>
3.2 Layer coefficients

3.2.1 Rutting index

Following the procedure shown in Figure 1, the rutting index parameter (discussed in the previous reports) was calculated for the mixtures. The correlation between the index parameter and the rut depth is depicted in Figure 2. As it can be seen from the figure there is a high correlation between the developed index parameter and the measured rut depths after 5 years since the mixtures placement.

![Figure 2. Correlation between the rutting index and rutting depth](image)

3.2.2 Fatigue failure criterion

The correlation between the developed fatigue failure criterion and the fatigue cracking length after 5 years of construction is depicted in Figure 3. As it can be seen similar to rutting index parameter, a high correlation is observed between this criterion and the field measurements. It is worth mentioning that that the fatigue cracking length is the normalized cracking length determined from the following equation:

\[
\text{Weighted crack length (m/km)} = (\text{Severity 1 crack length}) + 2(\text{Severity 2 crack length}) + 3(\text{Severity 3 crack length}) + (\text{Sealed crack length})
\]

As it can be seen from the figure, the lower RAP content mixtures have less cracking and the PG 58-28 binder appears to be performing better than the PG 52-34 binder (as seen from the two 25% RAP mixes). The 25% RAP 52-34 section appears to have the worst performance overall, whereas the 15% RAP 58-28 indicates the best fatigue performance among all other mixtures.
Figure 3. Correlation between the fatigue criterion and fatigue cracking

3.2.3 Prediction of IRI value for different sections
Using the statistical analysis the IRI value of each section was predicted using a linear regression equation. The correlation between the measured and predicted values is presented in Figure 4. As it can be seen each mixture has a different trend line with respect to the IRI, however a general trend line is defined for the whole dataset to predict the 20th year IRI value for the mixtures. Further evaluation of the field distress data for the 18 study mixtures in table 1 will help identify the final approach to determine the appropriate trend line.

Figure 4. Correlation between the fatigue criterion and fatigue cracking

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3.2.4 Developed layer coefficients based on the proposed approach

Figure 5 indicates the back-calculated layer coefficients for the mixtures placed on I-93 using the proposed approach in Figure 1. As it can be seen different mixtures have been assigned different a-values based on their performance. The layer coefficients range from 0.39 for the 15% RAP 58-28 mixture to 0.56 for the 40% RAP 52-34 mixture. During the next quarter the approach to develop the layer coefficients will be reevaluated by constructing separate layer coefficients for rutting and fatigue performance and then combining the coefficients by assigning proper weighing scales to the mixtures based on the specific layer course.

![Figure 5. Developed layer coefficients for the mixtures placed on I-93](image-url)