NHDOT SPR2 Program

Project 26962N: Layer Coefficients for NHDOT Pavement Design

Appendix to Quarterly Report (April – June 2017)

Draft Task-1 (Literature Review) Report
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1. Introduction

At present, New Hampshire Department of Transportation (NHDOT) employs 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 provide by each pavement layer. As the definition provided by AASHTO design guide, layer coefficient is the empirical relationship between the structural number of a pavement structure and layer thickness, which indicates the relative ability of a material to function as a structural component of a pavement. The current layer coefficients used by NHDOT are a combination of the original values proposed by AASHTO in 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, aggregate courses and recycled stabilized base course (RSB).

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 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 lack of reliable layer coefficient values, there is high potential for over-design of pavements that translate in 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 State for determination of the actual layer coefficient values for those materials.
2. Literature Review

2.1 AASHTO 1993 Design Guide
Currently, New Hampshire Department of Transportation (NHDOT) uses the AASHTO 1993 guide to design the structure of pavements. This design guide is based on the American Association of State Highway Officials (AASHO) road test that was performed in the late 1950s and early 1960s in Ottawa, Illinois.

The primary goal in this test was to come up with a relationship between the number of axle load repetitions and the pavement performance during the pavement service life. The AASHO test was conducted on six different loops and the loading started in October 1958 and ended in November 1960[1]. The main variables in this road test were the hot mix asphalt, base and subbase thicknesses as well as the different axle configurations that were applied on the different test loops. The observations and data obtained from this test were converted into different parts of a design equation which relates the number of applied axle loads to the required thickness of the pavement. AASHTO road test resulted in major findings in the pavement engineering science such as the relationship between the load and the damage called as Fourth Power Law. It also introduced important factors such as Serviceability, Equivalent Single axle load (ESAL) and the Structural Number (SN). The first AASHO design guide was published in 1961 as the “AASHO Interim Guide for the Design of Rigid and Flexible Pavements”. Since the equations derived from AASHO test were based on limited data from two years of loading and only one climatic condition (Ottawa, Illinois), the design guide was significantly updated in 1972 and 1993 to meet different nationwide requirements and climatic conditions. The latter update is called as the AASHTO 1993 design guide and has not changed since then. Although major steps have been taken to switch from this empirical guide to a mechanistic-empirical pavement design guide (MEPDG) in the past three decades, the high costs and lack of available database for regionally calibrating such design guide has become an issue for many of the state DOTs. Hence, AASHTO 1993 design equation (Equation.1) is still being used as a reliable pavement structure design tool in many states in US and other countries around the world[2].

\[
\log_{18} w = Z_R S_0 + 9.36 \log(SN + 1) - 0.2 + \frac{\Delta PSI}{0.4+10^{0.94(SN+1)^{0.19}}} + 2.32 \log M_r - 8.07 \quad \text{Equation (1)}
\]

2.2 AASHTO 1993 Design Factors

2.2.1 Equivalent Single Axle Load (ESAL)
AASHTO 1993 design procedure for determining the thickness of different layers is based on the total number of applied wheel load over the design life of the pavement. Since the axle loads and configurations vary among different vehicle types, as a result, the damage induced by them would
be different. One of the important achievements by the AASHO road test was the concept of Equivalent Axle Load Factor (EALF) which basically converts the amount of induced damage to the pavement from any type of vehicle to the equivalent damage caused by an 18kip (80kN) single axle load. Then the summation of equivalent damage over the pavement design life is considered as the Equivalent Single Axle Load (ESAL) which is the only traffic factor in the design[1].

2.2.2 Reliability
This parameter is defined as the probability that the design will perform its intended function over the pavement design life and changes based on the type and importance of the road. Reliability is indeed the factor of safety of the pavement design that is implemented in the AASHTO 1993 design guide. In other words, reliability of the design is used to ensure that the actual ESALs over the design life will not exceed the estimated ESALs. For instance, a 50% reliability means that the actual ESALs will be equal to the estimated ESALs at the end of the design period.

2.2.3 Present Serviceability Index (PSI)
The serviceability of a pavement is essentially evaluated by the ride quality experienced with the road users. The serviceability index is ranked from 5 to 1 as the best and worst ride quality respectively. This factor is mainly used as a tool to determine the proper time for the correct type of maintenance, rehabilitation or even reconstruction of the pavement by the Pavement Management System (PMS). The initial serviceability of the pavement is a function of pavement type and construction quality and the typical value for the flexible pavements is considered as 4.2 whereas the adopted value for the terminal serviceability for this type of pavement is typically 1.5.

2.2.4 Structural Number (SN)
Structural number of pavement is defined as a criteria to measure the ability of pavement to withstand the applied load. The primary purpose of any pavement design is to protect the subgrade soil from the stresses due to the loading, as well as penetration of surface water into the subgrade soil which can significantly decrease its modulus and result in different types of damages. Therefore, the structural number of a pavement is a function of type, thickness, and drainage capability of different materials used in the pavement structure. The weaker the subgrade soil the higher the required structural number will be for the same loading and climatic conditions. Equation (2) defines the structural number for a pavement structure with “n” layers.

\[ SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots + a_iD_im_i \]  
Equation (2)

Where:
\[ a \]: Layer coefficient
\[ D \]: Layer thickness
\[ m \]: Drainage coefficient

2.2.5 Soil Resilient Modulus
The resilient modulus of the soil is an important factor in AASHTO 1993 design guide. The resilient modulus of the subgrade soil is subjected to significant changes due to weather conditions during the year. Therefore, the effective resilient modulus which is the representative modulus
value for different weather conditions is calculated based on the damage that could occur to the pavement during different seasons with different subgrade soil modulus. This value is the only subgrade soil property that is considered in AASHTO 1993 and because of that is highly influential in determining the structural number (SI) of the overall design.

2.3 Layer Coefficient

As it was mentioned earlier one of the important factors that contributes to the Structural Number is the type of material that is covered in the form of the layer coefficient (a-value). As the definition provided by AASHTO design guide, layer Coefficient is the empirical relationship between the structural number of a pavement structure and layer thickness, which indicates the relative ability of a material to function as a structural component of a pavement [2]. Layer coefficients (in this report will be denoted as a-value) were originally derived as the regression coefficients in relating the SN to the thickness of different layers in AASHTO road test. In other words, for a given pavement structure the SN value was first determined through using equation 1 and then based on the configuration of the pavement the calculated SN value was correlated to different layer thicknesses through equation 2 and finally the regression coefficients (a-values) were determined. The main factors affecting the a-value are:

1- Material type and properties
2- Layer thickness and location
3- Failure criterion
4- Loading level

In terms of asphalt material, the layer coefficient is not only based on the asphalt material properties and thickness but it is highly affected by the underlying material’s properties.

2.4 Layer coefficient calibration

Research conducted in National Center for Asphalt Technology (NCAT) revealed that the layer coefficient followed by traffic level and resilient modulus are the most influential factors in determination of the pavement thickness considering the AASHTO 1993 design equation[3]. Although the original layer coefficients from the AASHTO road test are reliable, they are applicable only to the types of material, traffic and the environmental conditions under which they have been generated. Since layer coefficient has a significant influence in determining the layer thickness and consequently on the construction expenses as well as the long term performance of the pavement, it is essential to determine the calibrated and reliable a-values for different regions and materials. For this purpose, many of the states that implement AASHTO 1993 design procedure or use layer coefficient as part of their specific design methodology have tried to evaluate their own commonly used materials and assign new a-values to them. Old studies which are mainly experimental based have shown that a-values are correlated with gradation, thickness, abrasion of aggregate and more important the strength or stability of asphalt mixtures[4].

Layer coefficient Recalibration are conducted based on different methodologies which will be discussed briefly in this section.

2.4.1 Pavement Structural Response

Some mechanistic based studies have tried to use the concept of equivalent deflection by assigning a reference mixture with a defined thickness and compare other mixtures to that by determining
the required thickness to result in the identical deflection to that of the reference mixture under same loading magnitude. Similarly, the identical maximum vertical stress on top of subgrade soil for different types of hot mix asphalt mixtures has widely been used to recalculate the a-values. Maximum tensile strain at the bottom of asphalt layer has also been used to determine the layer coefficient of recycled mixes. The thickness of the recycled layer to give the equivalent number of load repetitions to failure (Nf) of the standard reference hot mix asphalt on the same subgrade soil is used to determine the layer coefficient since the SN is equal for both cases[4].

2.4.2 Pavement Performance
AASHTO pavement performance analysis has also been used as another practical method for layer coefficient calibration. This method monitors the serviceability indicators (rut depth, cracks, patching, IRI and etc.) and calculates the PSI. The rate of change in serviceability for a given pavement structure with known thicknesses for different layers is then converted to SN value. Running the regression analysis on the SN (Equation 2) results in the new layer coefficients. This method has been successfully used by NCAT to recalibrate the a-value of the asphalt layer used by Alabama Department of Transportation (ALDOT). Using the IRI value and converting that to PSI for the known cross sections, researchers in NCAT suggested a new layer coefficient of 0.54 instead of 0.44 for the hot mixed asphalt which can reduce the construction costs by approximately 18%[3, 5].

2.4.3 Mechanistic-Empirical Design Approach
A more sophisticated way to calibrate the a-value is to use the mechanistic-empirical method (MEPDG). This method which has been used by Washington State is highly data intensive and is recommended to be used by the agencies that are in the process of transforming from the empirical to the mechanistic-empirical design approach and have enough database available for the calibration. Once the database is available the calibration can be simply done by designing the required thickness through MEPDG approach and then calibrate the a-value in the AASHTO design method to obtain the same thickness for the structure. Using this method by WSDOT the a-value of hot mixed asphalt increased from 0.44 to 0.50 which significantly reduces the construction costs[5].

2.4.4 Material Properties Characterization
Among all the factors that influence the layer coefficient the material type and properties have the highest impact and to account for these factors AASHTO 1993 design guide proposes the resilient modulus (Mr) of the material [2] since it is not only a measure of stiffness but also can be an indicator of strength of the material.

The relationship between the asphalt mixture’s layer coefficient and the elastic resilient modulus at 70 °F was established in 1972. This relationship (Equation 3) which is shown in Figure 1 is valid for a dense graded asphalt mixture and can only be used if the elastic modulus is between 110000 psi and 450000 psi. AASHTO 1993 design guide proposes the value of 0.44 as the layer coefficient for Mr corresponding to 450000 psi[1].

$$a_i = 0.4 \log(M_r) - 0.951$$  \text{Equation (3)}
Research conducted at University of Wisconsin for recalibrating the a-values of commonly asphalt mixes used by Wisconsin Department of Transportation (WisDOT) implemented the $M_r$ measurement in lab. The test was performed in accordance to the AASHTO T-294-94 standard (which is not the common test method for $M_r$) in 20 °C. Using equation 3 new layer coefficients were derived. The main concern stated by researchers was that the resilient modulus measurements for different types of mixtures at the aforementioned temperature were so close and as a result the a-values were turned out to be nearly the same. As a solution and for better differentiating the mixtures, a triaxial testing apparatus was used to measure the rutting at 52 °C and 64 °C. The researchers proposed the correlation of the a-value with the combination of resilient modulus, rutting performance and any other available damage factor to calculate the new a-values[6].

Among many state agency DOTs that use empirical design methods, South Carolina is using the AASHTO 1972 design guide and is trying to switch into the mechanistic-empirical (MEPDG) design method. Research was performed to enhance the precision of the a-values used for the asphalt base mixtures in South Carolina. The procedure included running the dynamic modulus test on the mixtures and prediction of the $M_r$ value from the E* master curve at the frequency of 1.59 Hz at 68 °F which is indeed equal to 0.1 second of loading on the specimen (same loading time for $M_r$ test in accordance to ASTM D7369). Once the $M_r$ was predicted, equation 3 was utilized to calculate the new a-values that were increased from the initial value of 0.34 to higher than 0.44[7].

![Figure. 1: Estimating layer coefficient of dense-graded asphalt concrete based on elastic modulus](image-url)
2.4.5 Falling Weight Deflectometer

According to the AASHTO 1993 design guide a more reliable way to determine the layer coefficients is to back calculate the moduli from Falling Weight Deflectometer (FWD) test on the road in lieu of lab testing since there might be a variation between the lab made samples and the mixture placed in the field[2] and also FWD is considered as a way to simulate the dynamic loading of a moving wheel in a wide range of loading level which is a more realistic way of loading.

Perhaps, New Hampshire Department of Transportation (NHDOT) has been one of the leading State DOTs in the nation to use FWD for recalibration of layer coefficient values for its pavement materials. Research conducted in 1994 by Dr. Janoo on a segment of I-93 between exit 18 and 19 through construction of ten test sections with different combination of materials for the same structural number. The primary purpose of testing was to evaluate the a-value used for the Reclaimed Stabilized Base (RSB) that had been used during the construction since the sections constructed with this type of material revealed higher surface deflections compared to other sections of the road. The results from FWD and back calculated moduli confirmed the hypotheses of using the incorrect a-value for this type of material as well as some other material in the design and the new a-value for RSB decreased from 0.17 to 0.14. The layer coefficient of the asphalt material used by NHDOT ranges between 0.34-0.38 and back calculations from FWD in this research resulted in a-value of 0.37 for the wearing course[8].

2.5 Review of Layer Coefficients used by Other Agencies

For the purpose of the literature review a survey was conducted from 21 State DOTs that currently use any of the AASHTO based empirical design methods to see what a-values they use for the surface and non-surface course asphalt mix materials. The survey was not limited to any specific region or climatic condition but the main aim was to evaluate the current NHDOT’s layer coefficients and to see if there is potential possibility to obtain new layer coefficients for the asphalt materials as the asphalt mix design method, production and construction techniques have changed quite extensively since the last evaluation done in 1994. Table 1 shows the result of the survey and it can be seen that New Hampshire is using one of the lowest a-values compared to other states even in the New England area that the environmental and perhaps the traffic loading doesn’t seem to be significantly different.
Table 1. Layer coefficient used by other agencies

<table>
<thead>
<tr>
<th>Layer type</th>
<th>Layer coefficient (a)</th>
<th>DOTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Course</td>
<td>0.54</td>
<td>ALDOT</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>WSDOT</td>
</tr>
<tr>
<td></td>
<td>0.44</td>
<td>FDOT, SCDOT, CTDOT, MaineDOT, MassDOT, IADOT, PADOT, WisDOT, NJDOT, MDOT, GeDOT, ConnDOT</td>
</tr>
<tr>
<td></td>
<td>0.43</td>
<td>ODOT</td>
</tr>
<tr>
<td></td>
<td>0.42</td>
<td>NYCDOT</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>DelDOT, IDOT</td>
</tr>
<tr>
<td></td>
<td><strong>0.38</strong></td>
<td><strong>NHDOT</strong></td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>NDOT, VTDOT</td>
</tr>
<tr>
<td>Non-Surface Course</td>
<td>0.44</td>
<td>FDOT, PADOT, SCDOT</td>
</tr>
<tr>
<td></td>
<td>0.42</td>
<td>NYCDOT</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>DelDOT, ConnDOT</td>
</tr>
<tr>
<td></td>
<td>0.36</td>
<td>ODOT</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>NDOT</td>
</tr>
<tr>
<td></td>
<td><strong>0.34</strong></td>
<td><strong>NHDOT, MassDOT, MaineDOT, MDOT</strong></td>
</tr>
<tr>
<td></td>
<td>0.33</td>
<td>VTDOT</td>
</tr>
<tr>
<td></td>
<td>0.31</td>
<td>WisDOT</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>GeDOT, IDOT</td>
</tr>
</tbody>
</table>

2.6 Summary of Literature Review

As part of the project, an in depth literature review was conducted to explore and discuss different aspects and design variables of the AASHTO 1993 pavement structure design guide which is the most commonly used pavement design standard in the nation and worldwide. The influential variables are listed below:

1- Equivalent Single Axle Load (ESAL)
2- Reliability
3- Present Serviceability Index (PSI)
4- Structural Number (SN)
5- Soil resilient modulus
Among these variables, the structural number of the pavement is the factor which directly relates the required structure configuration and thickness to the material quality and properties using the layer coefficient values (a-value).

As the definition provided by AASHTO design guide, layer Coefficient is the empirical relationship between the structural number of a pavement structure and layer thickness, which indicates the relative ability of a material to function as a structural component of a pavement.

Factors affecting the layer coefficient are listed below:

1- Material type and properties
2- Layer thickness and location
3- Failure criterion
4- Loading level

The original layer coefficients derived in the AASHO road test were based on the material and environmental conditions and the limited traffic during this road test. As the material production and construction techniques evolve, it is necessary to recalibrate the a-values by considering diverse material, climatic conditions and increasing traffic levels.

Researchers have tried different methods to recalibrate the a-values. These methods have tried to correlate some pavement structure or material attributes to the layer coefficient and derive new a-values on basis of that correlation. These methods were discussed in the literature review and are listed here:

1- Pavement Structural Response
2- Pavement Performance
3- Mechanistic-Empirical Design Approach
4- Material Properties Characterization
5- Falling Weight Deflectometer

All of these methods have shown to be reliable in recalibration of a-values. AASHTO 1993 design guide recommends the use of Resilient Modulus ($M_r$) of the asphalt mixtures for a-value recalibration purposes. AASHTO also proposes a regression based equation between $M_r$ and a-value (equation3) which can be used for preliminary estimation of a-values since this equation is developed for resilient modulus ranging from 110000-450000 psi and anything above this range should be further characterized using other fundamental properties or performance based tests.

As the final step in this literature review a survey was conducted from 21 state DOTs that are currently implementing the AASHTO 1993 design guide. The main objective was to evaluate the current NHDOT’s layer coefficients and to see if there is potential possibility to obtain new layer coefficients for the asphalt materials as the asphalt mix design method, production and construction techniques have changed quite extensively since the last evaluation conducted in 1994 by Janoo. Based on this survey many states have been able to successfully recalibrate the original a-values and many others are using values higher than what NHDOT uses. The survey reveals that even in New England area which is supposed to have nearly the same climatic and traffic level conditions among the states, New Hampshire is using one of the lowest a-values which can be potentially reevaluated.
3. Experimental Plan

3.1 Material Selection

The material in this study were selected based on the most commonly used asphalt mixtures in New Hampshire highways. Total number of 14 mixtures are selected and divided into three different categories as wearing, binder and base courses in accordance to the lift position in the pavement structure. Also two additional mixes were selected as the cold mix interlayer which increase the total number of studied mixtures to 16. These materials vary significantly in terms of binder type, nominal maximum aggregate size and mix volumetric characteristics which lets better differentiating the mixtures and consequently the layer coefficient values that will be assigned to them. Selected mixes and their properties are shown in Table 2.

Table 2. Selected asphalt mixes for the study

<table>
<thead>
<tr>
<th>Course</th>
<th>Mix Type</th>
<th>Gyration/Traffic Level</th>
<th>Binder Types</th>
<th>TRB</th>
<th>Selected for Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearing Course</td>
<td>ARGG</td>
<td>75</td>
<td>AR</td>
<td>---</td>
<td>1 AR</td>
</tr>
<tr>
<td></td>
<td>ARGG</td>
<td>75</td>
<td>AR</td>
<td>0.5%</td>
<td>1 AR</td>
</tr>
<tr>
<td>12.5 mm</td>
<td>75</td>
<td>PG 70-34 PMA</td>
<td>---</td>
<td>1 PMA</td>
<td></td>
</tr>
<tr>
<td>9.5 mm</td>
<td>75</td>
<td>PG 76-28</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>9.5 mm</td>
<td>75</td>
<td>PG 64-28</td>
<td>---</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>9.5 mm</td>
<td>75</td>
<td>PG 58-28</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>12.5 mm</td>
<td>75</td>
<td>PG 64-28</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>75</td>
<td>PG 76-28</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>75</td>
<td>PG 58-28</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>PG 58-34</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>19 mm</td>
<td>75</td>
<td>PG 64-28</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>19 mm</td>
<td>75</td>
<td>PG 58-28</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>19 mm</td>
<td>50</td>
<td>PG 58-34</td>
<td>1% Allowed</td>
<td>1 Mix</td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>24 mm</td>
<td>50</td>
<td>PG 64-28 or PG 58-28</td>
<td>1% Allowed</td>
<td>1 Mix</td>
</tr>
<tr>
<td>Cold Mix Interlayer</td>
<td>PMRAP</td>
<td>N/A</td>
<td>Emulsion (MS-4)</td>
<td>N/A</td>
<td>1 Mix</td>
</tr>
</tbody>
</table>
3.2 Laboratory Testing

3.2.1 Resilient Modulus ($M_r$)

As mentioned earlier in section 2.4.4, AASHTO 1993 design guide recommends the resilient modulus value of the asphalt mixtures to be used as the basis of recalibration of $a$-values. Hence, the work conducted in this study is primarily based on resilient modulus testing in accordance to the ASTM D7369-11 standard. The test is conducted on 150 mm diameter disks that are 50±1mm in thickness and are conditioned in 25 °C. The disks are cut from gyratory compacted samples that are 140mm in height and 150mm in diameter. Three replicates with 6±0.5% air-void are tested for each mixture. The reason for this choice is to be consistent with other performance based tests (dynamic complex modulus) that will be conducted in this study.

The testing procedure includes the application of a haversine wave form load in 0.1 second which is followed by a 0.9 second rest period. The test is done in 105 cycles where each cycle of test includes one loading and one rest period. Horizontal and vertical deformation measurement gauges are mounted on both faces of the sample to measure the strain during the test. The deformation gauge length is determined to be 76.2mm. The resilient modulus value is calculated based on the average measured value of the last five cycles. Figure 2 indicates the resilient modulus test setup.
3.2.2. Complex Modulus (E*)

In this study complex modulus (E*) is used as a primary input to verify and validate the layer coefficients through running a viscoelastic performance based pavement structural design software like FlexPave or PavementME to simulate the long term pavement performance. The test is performed in accordance to AASHTO TP-79 on three replicates, cored and cut from the gyratory compacted samples that are 180mm in height and 150 mm in diameter. The cored cylindrical replicates are compacted to 6±0.5% air-void level and are 150mm in height and 100mm in diameter.

The sinusoidal load form is applied in six different frequencies (25Hz, 10Hz, 5Hz, 1Hz, 0.5Hz, 0.1Hz) and in three different temperatures (4.4 °C, 21.1 °C, 37.8 °C) using an Asphalt Mixture Performance Test (AMPT) machine. E* master curve is then constructed based on the time-temperature superposition principle to predict the stiffness of mixture in various temperature and loading frequencies. The test setup for complex modulus is shown in Figure 3.
3.3 Proposed Analysis

According to literature review in this study while AASHTO 1993 design guide recommends the usage of resilient modulus of asphalt mixtures, the obtained values for layer coefficient from equation 3 might not be reliable enough for these reasons:

1- The equation is an empirical regression based relationship
2- The equation is developed for certain type of mixtures and might not provide reliable results for new mixtures that are produced with new or modified binders
3- The equation can be valid for resilient modulus values ranging from 110000 psi to 450000 psi
4- Resilient modulus is not a fundamental property of asphalt mixtures and is subjected to change based on loading time and level
5- Although material properties can be characterized to some extent, resilient modulus is incapable of predicting the long term mixture performance alone and should be used besides other mix characterization techniques

To achieve the highest possible accuracy for a-values in this research, the actual field performance of the similar mixtures used in this study will be used as part of layer coefficient calibration procedure. This involves acquiring Pavement Management System (PMS) data from the roads that have been constructed with the material tested in this study. These are the data collected by New Hampshire Department of Transportation (NHDOT) and contain the track of any type of damage (Fatigue, Rutting, Thermal cracks, Reflective cracks, IRI, etc.) after construction up to the analysis procedure. These values will be converted to PSI and the a-values will be calibrated in accordance to AASHTO 1993 design equation.
As the final step in a-value refinement, advanced mechanical tools like Flexpave, PavementME, and other softwares will be implemented to validate the a-values through simulating the long term performance of some typical cross sections. The analysis procedure is depicted in Figure 4.

![Flowchart](image)

Figure 4. Analysis procedure for a-value recalibration
4. Summary of Task-1

New Hampshire Department of Transportation uses AASHTO 1993 design guide for pavement design purposes. Hence, this report mainly discusses different aspects of the AASHTO 1993 design method in terms of design variables and their importance that are explained in section two in this report. The design factors include:

1- Equivalent Single Axle Load (ESAL)
2- Reliability
3- Present Serviceability Index (PSI)
4- Structural Number (SN)
5- Soil resilient modulus

The AASHTO design equation (Equation 1) is a regression based relationship between these variables. The pavement material properties is covered in the form of a multiplier in determining the structural number. This multiplier is called as the layer coefficient (a-value) and is a function of material type, thickness and position in the structure.

According to the research conducted in National Center for Asphalt Technology (NCAT) a-value followed by the traffic and resilient modulus are the most impressive factors in design. This means that the a-values should be selected accurately since they significantly affect the overall design expenses and more importantly, the long-term pavement performance and costs associated with maintenance and rehabilitations.

The original layer coefficients were derived based on the material type and climatic conditions under which the AASHO road test was performed. The AASHTO design guide recommends the development of new layer coefficients for different states based on their local material and environmental conditions.

In the literature there are many different approaches that have been tried successfully by different researchers for development of new a-values. Some of most commonly used methods are listed below:

1- Pavement Structural Response
2- Pavement Performance
3- Mechanistic-Empirical Design Approach
4- Material Properties Characterization
5- Falling Weight Deflectometer

AASHTO 1993 design guide recommends the implementation of resilient modulus of asphalt mixture as a factor for material properties characterization to develop new a-values. The resilient modulus test for asphalt mixtures is conducted based on the ASTM D7369 in indirect tensile mode on asphalt disks. This value is then converted to a-value using the AASHTO empirical equation (Equation 2) between resilient modulus and corresponding a-value.

To develop new a-values for asphalt mixture used by NHDOT in this research, 16 most commonly used mixtures in New Hampshire highways were selected. These mixtures are set into three different categories as wearing, binder and base with respect to the lift position.
To obtain a-values with the highest possible accuracy, actual field performance data will be gathered from the pavement management system (PMS) database and the layer coefficients will be recalibrated based on these data.

The final step in a-value validation procedure includes running the dynamic complex modulus as a primary input for mechanistic based pavement design software like FlexPave, MnPAVE and PavementME.
References