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Improving the Long-Term Condition of Pavements in Massachusetts and Determining Return on Investment: Implementing the AASHTO Mechanistic-Empirical Pavement Design Guide—PHASE II

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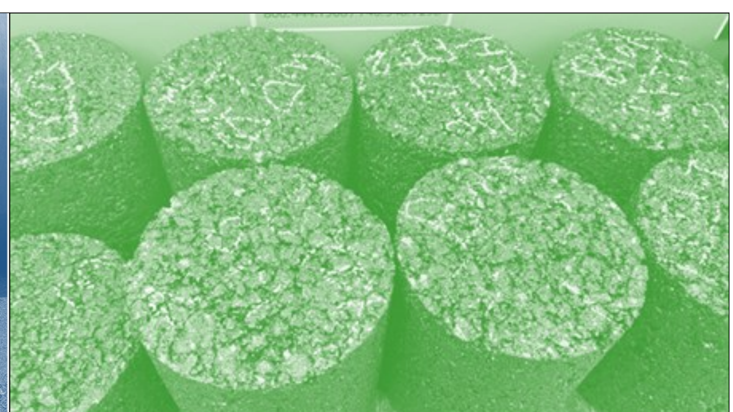

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16. Abstract

The goal of this study was to develop an AASHTOWare® Pavement M-E user's manual and develop a local experimental plan and sampling template for Massachusetts.

A stand-alone software manual was developed that provides a thorough step-by-step procedure on how to use the software. The manual guides users on how to generate the data, in particular, material properties and climatic and traffic data as they relate to local locations within the state of Massachusetts.

A preliminary experimental and sampling plan for local verification/calibration of the distress functions and smoothness regression equations in the AASHTOWare® Pavement Mechanistic-Empirical Design was also developed.

Finally, testing was conducted on typical plant-produced mixtures sampled from across Massachusetts in an attempt to accelerate future phases of this research.

This report outlines the work conducted in phase two of a four phase larger research project aimed at implementing the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) in Massachusetts.

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Improving the Long-Term Condition of Pavements in Massachusetts and Determining Return on Investment: Implementing the AASHTO Mechanistic-Empirical Pavement Design Guide—PHASE II

Final Report

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Disclaimer

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Executive Summary

MassDOT is striving to improve its highway infrastructure's resiliency to climate change, environmental impacts, and traffic loading by implementing new technologies. These improvements should begin with the pavement design process, which currently utilizes antiquated empirical design methods from the 1960s. The development of the mechanistic-empirical pavement design guide (MEPDG) and the release of AASHTOWare® Pavement M-E Design software is a significant improvement to existing pavement design procedures. In pavement M-E design, pavement responses (stresses, strains, and deflections) are calculated and utilized as inputs in empirical distress prediction models called transfer functions. These models are then used to estimate cumulative pavement distresses over time. The various distress prediction models for flexible pavements include total rutting, rutting in each layer (asphalt layer, base and subbase), top-down cracking, bottom-up fatigue cracking, thermal cracking, reflective cracking, and international roughness index (IRI). The predicted distresses allow pavement engineers to define acceptable levels of performance and design pavements to address particular distresses. A key advantage of the M-E design methodology is that its individual components, like transfer functions and performance models, can be enhanced over time to reflect new research in the field.

The MEPDG performance prediction models were developed and nationally calibrated using in-service pavements. These in-service pavements were mainly selected from projects in the Long-Term Pavement Performance (LTPP) program. Accordingly, the prediction models may not accurately predict the performance for localized conditions (environment, traffic, and materials characterization) in Massachusetts. Therefore, prior to M-E design implementation, it will be crucial for MassDOT to recalibrate the standard M-E design guide prediction models to actual data from local projects located in Massachusetts (local calibration). Many state DOTs have already undertaken and completed this process. Local calibration is perhaps the most crucial aspect of implementation of the M-E design process. Local calibration will often remove bias present in the national model, as well as reduce some scatter in the results (i.e., improve precision). As shown in Figure ES1 (*1*), local calibration is a systematic process expected to eliminate potential biases and increase the accuracy of the performance predictions.

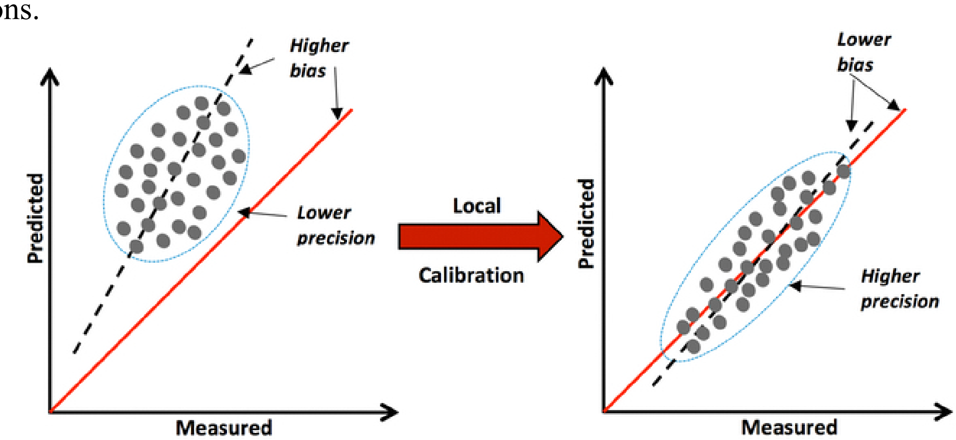

Figure ES1: Precision and bias in local calibration

Local calibration of the distress prediction models helps bridge the gap, if any, between the predicted and the observed performance in the field. Otherwise, some pavements will be under-designed and others over-designed, translating to either premature failure or excessive costs. To date, many states (Arizona, Colorado, Indiana, Missouri, Montana, North Carolina, Ohio, Oregon, Utah, and Washington) have completed local calibrations of M-E design guide asphalt concrete models (flexible pavements). The overall process of local calibration generally consists of three steps:

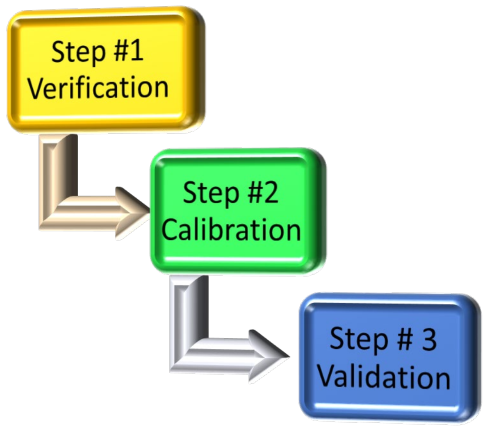

Figure ES2: Process of local calibration

The first step involves verification or evaluation of the existing global models to determine how well the model represents actual distresses and to evaluate the accuracy and bias. The second step is calibration of the model coefficients to improve the model and reduce bias, typically using the same data set as used in the verification step. The third step is validation of the newly calibrated model using a separate data set.

Recognizing the importance of local calibration, this study was undertaken to continue the MEPDG implementation process for Massachusetts. The objective was to develop an AASHTOWare® Pavement M-E user's manual and develop a local experimental plan and sampling template. Additionally, testing of already sampled mixtures continued to be conducted to accelerate future phases of this research.

Due to its complexity and sophistication, the procedure for utilizing the AASHTOWare® Pavement M-E Design software, as well as the required inputs (climate data, traffic data, material data, etc.), is not obvious and intuitive for the user. The user needs experience and knowledge to use the software correctly. Therefore, a stand-alone manual was developed that shows a user a thorough step-by-step procedure on how to use the software (Appendix A). The manual guides users on how to generate the data, in particular, material properties and climatic and traffic data as they relate to local locations within the state of Massachusetts.

A preliminary experimental and sampling plan for local verification/calibration of the distress functions and smoothness (IRI) regression equations in the AASHTOWare® Pavement M-E Design was developed. Relying solely on LTPP site data would have resulted in too few sites for the local calibration process. Additionally, current MassDOT practices are not represented in the available LTTP sections. Hence, it was suggested that new mixtures be tested, and that the sites where these mixtures were placed should be included in the local verification-calibration process.

In addition to the development of a software user's manual and local calibration experimental plan and sampling template, several plant-produced mixtures were tested in this study to generate the inputs necessary to run designs using the AASHTOWare® Pavement M-E Design software. The mixtures selected were those most produced on a regular basis (based on tonnage) in Massachusetts and not developed for a specialized application. The testing of these mixtures included measuring the dynamic modulus at different temperatures and different frequencies using the Asphalt Mixture Performance Tester (AMPT), and determining the complex modulus and the phase angle of the asphalt binder used in each mixture measured using the dynamic shear rheometer. This data was analyzed and combined with the as-built properties of the mixture obtained from production data to create cut-and-paste formatted data that can be directly input into the AASHTOWare® Pavement M-E Design software.

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List of Acronyms

Acronym	Expansion
AASHTO	American Association of State Highway and Transportation Officials
AMPT	Asphalt Mixture Performance Tester
CIP	Capital Investment Plan
DSR	Dynamic Shear Rheometer
E*	Dynamic Modulus
FHWA	Federal Highway Administration
HiMA	Highly Modified Asphalt
HMA	Hot Mix Asphalt
HP	High Performance
IRI	International Roughness Index
LCCA	Life Cycle Cost Analysis
LTPP	Long-Term Pavement Performance
MassDOT	Massachusetts Department of Transportation
M-E	Mechanistic-Empirical
MEPDG	Mechanistic-Empirical Pavement Design Guide
pcf	Pounds per Cubic Foot
RAP	Reclaimed Asphalt Pavement
RTFO	Rolling Thin Film Oven
SGC	Superpave Gyratory Compactor
SMA	Stone Matrix Asphalt
SPR	State Planning and Research
WMA	Warm Mix Asphalt

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1.0 Introduction and Objectives

This study titled "Improving the Long-Term Condition of Pavements in Massachusetts and Determining Return on Investment: Implementing the AASHTO Mechanistic-Empirical Pavement Design Guide—PHASE II" was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

1.1 Introduction

MassDOT is striving to improve its highway infrastructure's resiliency to climate change, environmental impacts, and traffic loading by implementing new technologies that can provide valuable return on investment. These improvements should begin with the pavement design process, which currently utilizes antiquated empirical design methods from the 1960s. Implementing the American Association of State Highway Transportation Officials (AASHTO) new Mechanistic-Empirical (M-E) pavement design method currently used by at least 33 state agencies would be a significant improvement. The M-E design method incorporates performance models that are tailored to the region and form an important component of the design process. Additionally, because the AASHTO M-E design can predict pavement distresses, it could be used as a tool by MassDOT to measure the return on investment when using new technologies such as warm mix, bio-asphalts, modified asphalts, mixtures with increased recycled (sustainable) materials, and so forth. Furthermore, based on the predicted distresses, MassDOT can make decisions on which pavement preservation strategies should be implemented to improve and extend the pavement life of its road network. The AASHTO M-E design method predicts pavement distresses utilizing prediction models that were developed and nationally calibrated using in-service pavements. To accurately predict the performance in Massachusetts, these models will need to be calibrated according to local conditions.

Due to the complexity of the research problem, the following multiphase (four phases) approach over several years was suggested to complete this research:

Phase I: Literature review and state-of-practice assessment [completed in June 2021]

Phase II: Develop an AASHTOWare® Pavement M-E user's manual and develop local experimental plan and sampling template [presented in this report]

Phase III: Sample and test mixtures for local calibration/collect field data [future study]

Phase IV: Calibrate/validate the M-E prediction models (local calibration) [future study]

This report focuses solely on Phase II: Develop an AASHTOWare® Pavement M-E user's manual and develop local experimental plan and sampling template.

1.2 Objectives

For Phase II, the main objective is to develop an AASHTOWare® Pavement M-E user's manual and develop a local experimental plan and sampling template. Additionally, testing of already sampled mixtures will continue to be conducted to accelerate future phases of this research.

2.0 Overview and Experimental Plan

2.1 Overview

The development of the MEPDG and release of AASHTOWare® Pavement M-E Design software is a significant improvement to existing pavement design procedures. In pavement M-E design, pavement responses (stresses, strains, and deflections) are calculated and utilized as inputs in empirical distress prediction models. These models are then used to estimate cumulative pavement distresses over time. The various distress prediction models for flexible pavements include total rutting, rutting in each layer (asphalt layer, base and subbase), top-down cracking, bottom-up fatigue cracking, thermal cracking, reflective cracking, and international roughness index (IRI). The predicted distresses allow pavement engineers to define acceptable levels of performance and design pavements to address particular distresses. A key advantage of the M-E design methodology is that its individual components, like transfer functions and performance models, can be enhanced over time to reflect new research in the field.

The prediction models in the M-E design guide were developed and nationally calibrated using in-service pavements. These in-service pavements were mainly selected from projects in the Long-Term Pavement Performance (LTPP) program. Accordingly, the prediction models may not accurately predict the performance for localized conditions (environment, traffic, and materials characterization) in Massachusetts. Therefore, prior to M-E design implementation, it will be crucial for MassDOT to recalibrate the standard M-E design guide prediction models to actual data from local projects located in Massachusetts (local calibration). Many state DOTs have already undertaken and completed this process. Local calibration is perhaps the most crucial aspect of implementation of the M-E design process. Local calibration will often remove bias present in the national model, as well as reduce some scatter in the results (i.e., improve precision). As shown in Figure 2.1 (*1*), local calibration is a systematic process expected to eliminate potential biases and increase the accuracy of the performance predictions.

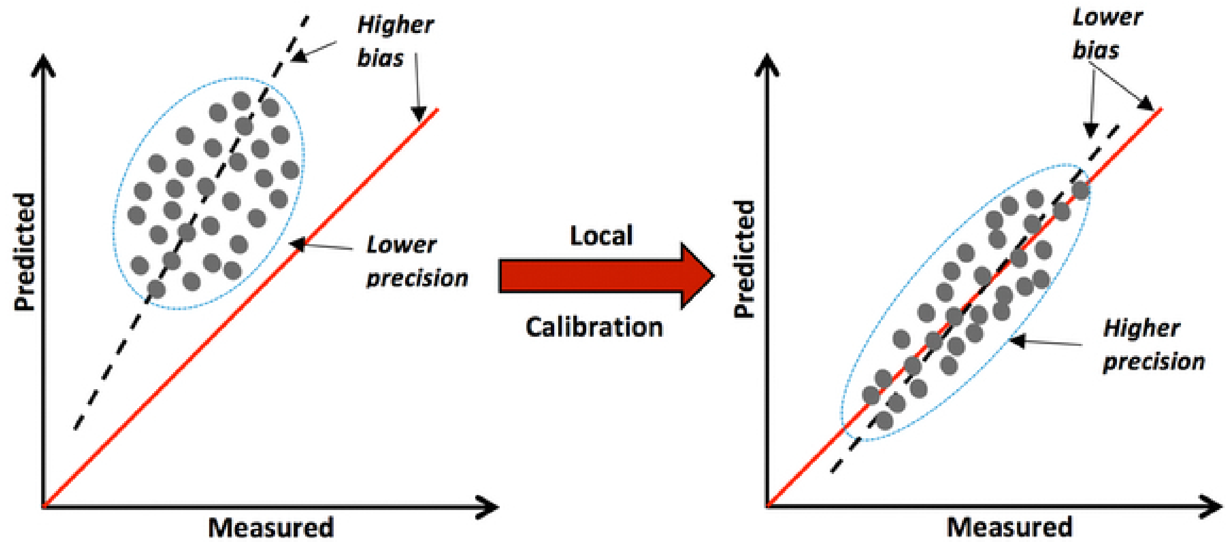

Figure 2.1: Precision and bias in local calibration

Local calibration of the distress prediction models helps bridge the gap, if any, between the predicted and the observed performance in the field. Otherwise, some pavements will be under-designed and others over-designed, translating to either premature failure or excessive costs. To date, at least ten states (Arizona, Colorado, Indiana, Missouri, Montana, North Carolina, Ohio, Oregon, Utah, and Washington) have completed local calibrations of M-E design guide asphalt concrete models (flexible pavements).

Implementation of the AASHTOWare® Pavement M-E Design advances the MassDOT mission to provide a reliable transportation system and supports the MassDOT 2017-2021 Capital Investment Plan (CIP). Utilizing this new design procedure will allow MassDOT to design better performing and cost-effective pavements using a procedure that is based more on the engineering properties of the materials and less on empirical relationships that are highly unreliable. The goals of all four phases of the research project addresses the most difficult and critical parts of M-E design implementation, thus allowing MassDOT to simply utilize the design procedure without the complications of determining how to set it up correctly. This research project would only calibrate/validate models for asphalt concrete pavements type, because Massachusetts has very limited sections of rigid pavement in the state.

Ultimately, pavement condition can be improved by implementing these designs. The design process allows for the identification of the design that will perform well in the field and help eliminate poorer performing options prior to construction, as well as serve as a measure to calculate the return on investment. Identifying the optimal design will allow for the maximization of funding resources, longevity of the pavement infrastructure, and overall improvement of the condition of the pavement network. Finally, implementing the MEPDG will allow MassDOT to construct roads with enhanced durability to compensate for ongoing climatic changes. Current design methods do not consider climatic changes, but the MEPDG is heavily reliant on the climate of the regions for which it is placed.

2.2 Experimental Plan

As noted previously, due to the complexity of the research problem, a multiphase (four phases) approach over several years was suggested to complete this research. The overall experimental plan for all phases of the project is shown in Figure 2.2.

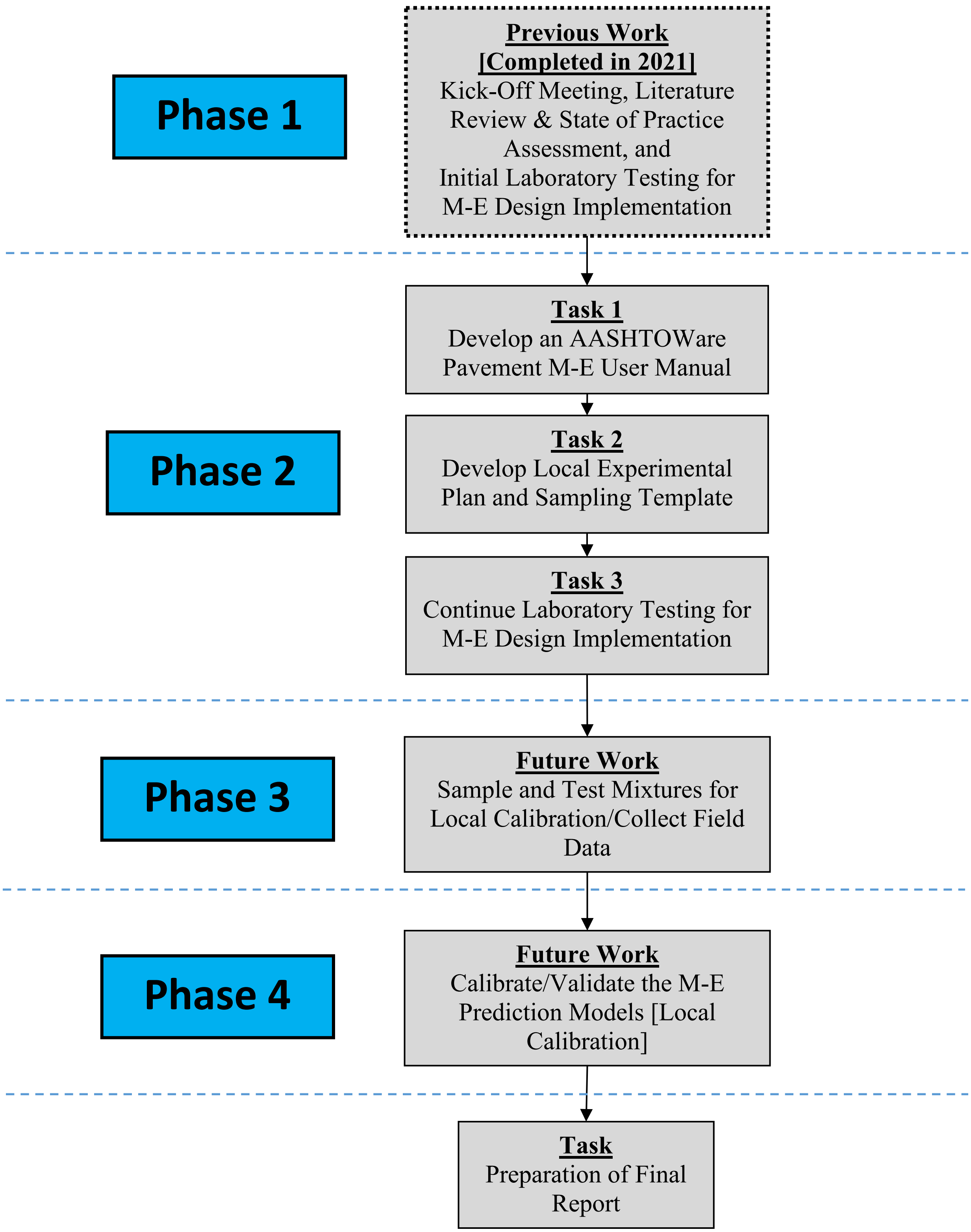

Figure 2.2: Experimental plan (all four phases)

3.0 Development of AASHTOWare® Pavement M-E User Manual for MassDOT

3.1 Introduction

AASHTOWare® Pavement M-E Design is a design and analysis tool for new and rehabilitated pavement structures based on mechanistic-empirical principles. Figure 3.1 shows an example screenshot of the AASHTOWare® Pavement M-E Design software main window. As can be seen in Figure 3.1, there are numerous panes/tabs (Explorer Pane, Project Tab, Output/Error List/Compare Pane, and Progress Pane), each of which serves a different vital function in correctly completing the design. The procedure for using the software, as well as the required inputs (climate data, traffic data, material data, etc.), is not obvious and intuitive for the user. The user needs experience and knowledge to use the software correctly. Therefore, it was proposed in this research to develop a stand-alone manual that provides a thorough step-by-step procedure on how to use the AASHTOWare® Pavement M-E Design software. The manual will guide users on how to generate the data, in particular, material properties and climatic and traffic data as they relate to local locations within the state of Massachusetts.

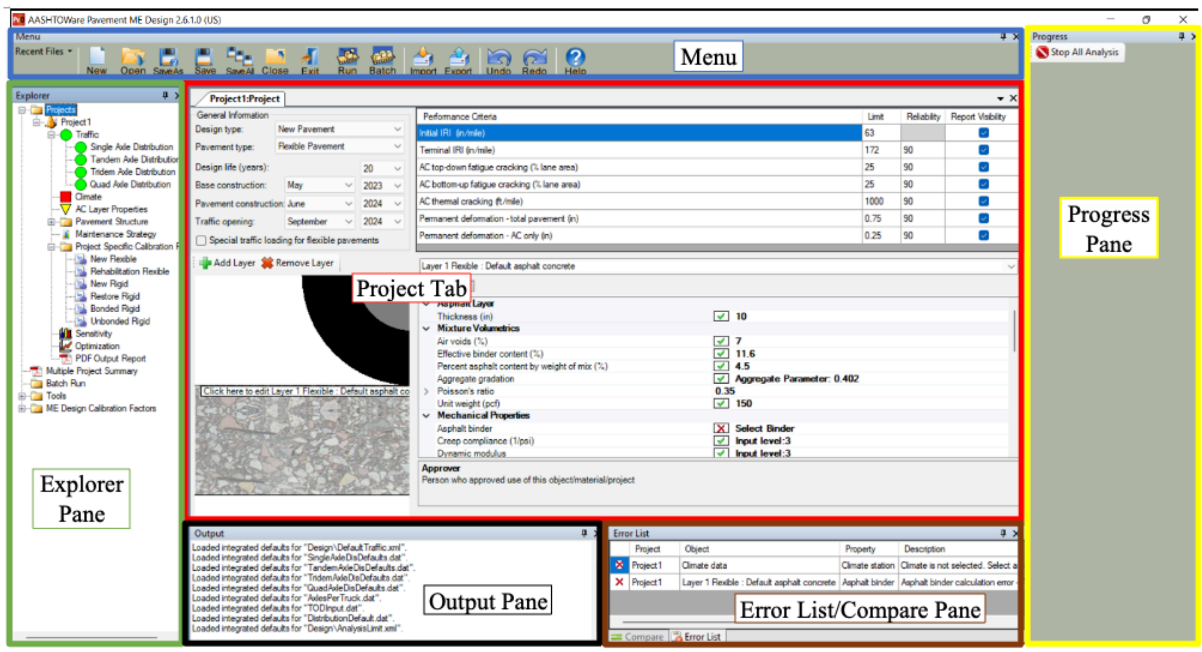

Figure 3.1: AASHTOWare Pavement M-E Design Software main window

3.2 Overview of Complexity of AASHTOWare® Pavement M-E Design Software

Each design using the software requires an iterative process that follows three basic steps:

1. Create a trial design for the project

2. Run AASHTOWare® Pavement M-E Design to predict key distresses and smoothness

3. Review the predicted performance of the trial design against performance criteria and modify trial design as needed to produce a feasible design that satisfies the performance criteria selected by the agency using this tool.

The software provides tools to generate an optimized pavement design based on given requirements and provides extensive reports to evaluate and fine-tune the design. The software allows the user to determine the inputs using a hierarchical structure depending on the user's knowledge of the input parameters. Three levels are available for determining the input values for most of the material and traffic parameters:

- Level 1: The average of laboratory/field test results from standard tests for the specific input property
- Level 2: Properties are estimated from correlations with other standard material tests
- Level 3: Input parameters are based on "best-estimated" or default values

The level of accuracy of the material and traffic parameters inputs is a function of the input level being implemented by the user/agency, with Level 1 being the most accurate and Level 3 being the least accurate. Each level has specific inputs that are required, but generally, Levels 2 and 3 are based on estimation and correlations. For Level 1, the most accurate design, the software requires three input categories (volumetric, mechanical, and thermal) for asphalt concrete layers (flexible pavements). The mechanical category includes asphalt binder and mixture related inputs based on laboratory testing. For asphalt binder, properties such as the performance grade, complex shear modulus (G*) and phase angle at different temperatures are required. For asphalt mixtures, mechanical properties such as dynamic modulus, creep compliance, and tensile strength are required. The gradation of the asphalt concrete mixture and the effective binder content of that mixture, also obtained through laboratory testing, are required inputs for the volumetric category. Finally, the weather station data correlating to the specific project location is required for the thermal category.

The software's design and analysis feature utilize the user's inputs described previously to calculate pavement responses (stresses, strains, and deflections) and uses those responses to compute incremental damage over time (*2*). Using incremental damage over time, transfer functions and regression models are used to predict various performance indicators. For asphalt concrete mixtures, the performance indicators calculated by the design software are

- Total rut depth and HMA, unbound aggregate base, and subgrade rutting

- Non-load-related transverse cracking
- Load-related alligator cracking, bottom initiated cracks
- Load-related longitudinal cracking, surface-initiated cracks
- Reflection cracking in HMA overlays of cracks and joints in existing flexible, semi-rigid, composite, and rigid pavements
- Smoothness (IRI)

An equally important output from the software is an assessment of the design reliability as shown in Table 3.1 (*2*).The target and predicted distresses at specified reliability are shown followed by the target and achieved reliability. If the achieved reliability is greater than the target reliability (specified by the agency), then the pavement design is acceptable. If the reverse is true, then the pavement is unacceptable and should be redesigned. The predicted performance measure and reliability provide a tool to measure and evaluate return on investment. This is especially true when Level 1 design is completed while trying new technologies such as higher reclaimed asphalt pavement (RAP) contents, rejuvenators, warm mix asphalt, and bio-asphalts in the asphalt mixtures. The agency can use the predicted performance measure and reliability to evaluate and justify the use of certain technologies or materials by illustrating that they can achieve a higher design reliability than alternative designs.

Table 3.1: Reliability summary for flexible pavement trial design example

Distress Type	Distress @Specified Reliability		Reliability		Criterion Satisfied?
	Target	Predicted	Target	Achieved	Pass
Terminal IRI (in/miles)	172.00	149.05	90.00	97.90	Pass
Permanent deformation: total pavement (in.)	0.75	0.46	90.00	100.00	Pass
AC bottom-up fatigue cracking (% lane area)	25.00	1.56	90.00	100.00	Pass
AC thermal cracking (ft/mile)	1,000.00	216.30	90.00	100.00	Pass
AC top-down cracking (ft/mile)	2,000.00	2,477.31	90.00	84.67	Fail
Permanent deformation: AC only (in.)	0.25	0.24	90.00	91.79	Pass

Finally, the software outputs month-by-month the key distress types and smoothness over the entire design period. This output information can help agencies decide timing of maintenance and rehabilitation strategies. This can be used alongside a life cycle cost analysis (LCCA) to help prioritize project selection and timing and other critical pavement management activities.

3.3 AASHTOWare® Pavement M-E Design Software User's Manual

A stand-alone manual for the AASHTOWare® Pavement M-E Design software was developed. Due to its length and complexity, this manual is presented in Appendix A. The manual provides a thorough step-by-step procedure on how to use the software and guides users on how to generate and input the data as related to local locations within the state of Massachusetts.

4.0 Local Experimental Plan and Sampling Template

In addition to developing a software user's manual, the research team was tasked with the development of a local verification-calibration experimental plan. This plan is one step of eleven suggested steps in the AASHTO publication "Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide" (*3*) to perform the local calibration. These steps are shown in Figure 4.1.

This task focuses on Step 2 titled "Develop Local Experimental Plan and Sampling Template." The AASHTOWare® Pavement M-E Design software allows the user to determine the inputs using a hierarchical structure depending on the user's knowledge of the input parameters. Three levels are available for determining the input values for most of the material and traffic parameters:

- **Level 1:** The average of laboratory/field test results from standard tests for the specific input property
- **Level 2:** Properties are estimated from correlations with other standard material tests
- **Level 3:** Input parameters are based on "best-estimated" or default values

The level of accuracy of the material and traffic parameter inputs is a function of the input level being implemented by the user/agency, with Level 1 being the most accurate and Level 3 being the least accurate. In MassDOT's efforts to implement the AASHTOWare® Pavement M-E Design, Level 1 accuracy will be used for all new projects and high-volume roads. Materials will be obtained from the contractors that are placing the new projects for testing and determination of input values. For low volume roads, and to reduce the cost of testing, regional values might be used if available.

Figure 4.1: AASHTO Suggested Steps for Local Calibration.

4.1 LTPP Test Sections

The experimental plan must include test sections that represent MassDOT's material specifications, construction practices, and maintenance strategies. Most DOTs that have already conducted the verification-calibration process have used available long-term pavement performance (LTPP) sites within their states. However, there are only three flexible pavement LTPP sections available in Massachusetts (Figure 4.2). These Massachusetts LTPP sections represent an insufficient number of sites for verification-calibration. The AASHTO "Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide" (*3*) provides the following guidance for the minimum number of total test sections for each flexible pavement distress type:

- Distortion (total rutting or faulting): 20 roadway segments
- Load-related cracking: 30 roadway segments
- Non-load-related cracking: 26 roadway segments
- Reflection cracking (HMA surfaces only): 26 roadway segments

As such, selected LTPP sections located near the state line of adjacent states will be used for the verification-calibration process. The additional LTPP sites will be selected so that they have similar pavement characteristics and conditions found in Massachusetts. Figure 4.2 shows the LTPP sites available in Massachusetts and the surrounding states. It is evident that these number of sites are very limited and will not be sufficient to perform the verification-calibration process. Also, these sites do not represent the current mixtures and policies used by MassDOT. For example, MassDOT places a high amount of tonnage of warm mix asphalt (WMA), whereas the LTPP sites in Massachusetts are hot mix asphalt. MassDOT also places asphalt rubber gap-graded mixtures, polymer modified asphalt mixtures, and recently high RAP mixtures. All these mixtures should be included in the verification-calibration process. Hence, in addition to the limited LTPP sites, non-LTPP sites will be selected and included in the verification-calibration process.

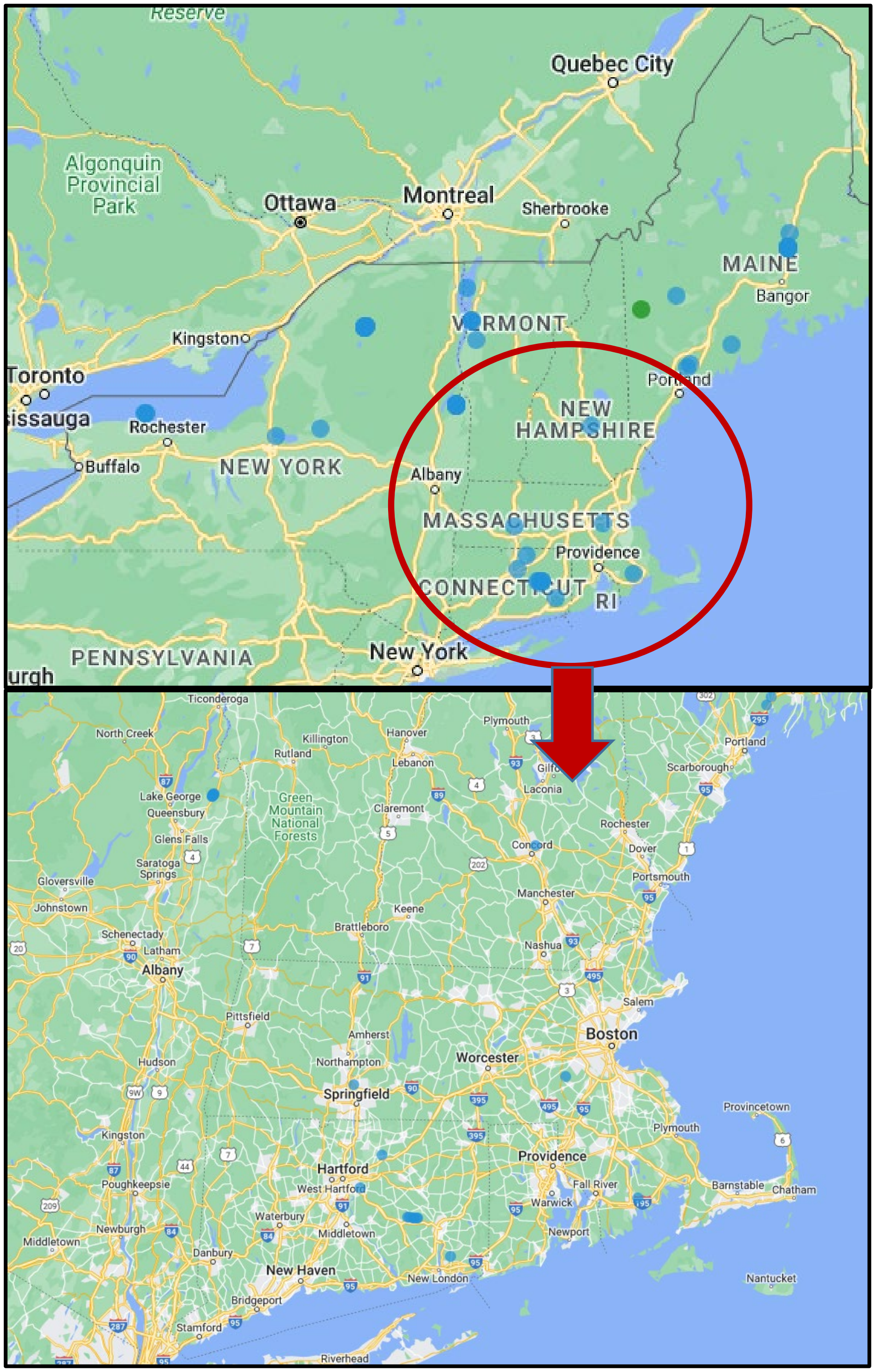

Figure 4.2: LTPP sites in Massachusetts and surrounding states

4.2 Non-LTPP Test Sections

Due to the insufficient number of available LTPP sites in Massachusetts and the surrounding states, several plant-produced mixtures that are representative of MassDOT's material specifications, construction practices, and maintenance strategies were obtained during Phases I and II of this study. During Phase III of this project more plant-produced mixtures will be obtained and included in the experimental plan.

4.2.1 Material Testing for the Non-LTPP Sections

All plant-produced mixtures that were obtained under Phases I and II have been tested to obtain the required data for Level 1 input properties for the AASHTOWare® Pavement M-E Design. Likewise, the plant-produced mixtures that will be obtained under Phase III will be tested to obtain the same inputs. The required tests are the following(*4,5*):

- **Dynamic modulus.** The dynamic modulus is the material property used in Pavement M-E Design to characterize the stiffness of asphalt layers. The structural response model in the software uses the dynamic modulus to calculate the stresses and strains induced in the pavement by traffic loads. The dynamic modulus of asphalt mixtures is measured using the dynamic modulus procedure in AASHTO T 378 "Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)."

- **Repeated load permanent deformation coefficients.** The rutting characteristics of asphalt mixtures are characterized in Pavement M-E Design using two coefficients, intercept and slope, that are used to define repeated load permanent deformation curves in log-log space. The intercept defines the permanent deformation on the first load cycle, and the slope describes how the permanent deformation increases with increasing number of loading cycles. The permanent deformation intercept and slope are measured using a modified version of the confined flow number test from AASHTO T 378 "Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)."

- **Low temperature creep compliance and tensile strength.** Creep compliance and tensile strength properties at low temperatures are used by Pavement M-E Design to predict thermal cracking. Compliance is the inverse of stiffness. Mixtures that are more compliant have lower stiffness. The tensile stresses induced in the pavement during thermal contraction depend on the compliance of the asphalt mixture, whereas the resistance to cracking depends on the tensile strength. Both properties are measured in accordance with AASHTO T 322 "Standard Method of Test for Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device."

- **Fatigue coefficients.** Pavement M-E Design uses a fatigue damage model with three material coefficients. This law expresses the allowable number of loads as a function of the strain induced by traffic loading at the bottom of the asphalt layer and the dynamic modulus of the asphalt mixture. The coefficients for this model are obtained from multiple laboratory fatigue tests conducted in accordance with AASHTO T 321 "Standard Method of Test for Determining the Fatigue Life of Compacted Asphalt Mixtures Subjected to Repeated Flexural Bending."

- **Asphalt binder properties.** The complex shear modulus (G*) and phase angle (δ) of the asphalt binders used in producing the mixtures are determined in accordance with AASHTO T 315 "Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)."

4.2.2 Other Data Needed for Non -LTPP Sections

In addition to the testing noted in Section 4.2.1, other characteristics of the asphalt mixture and the underlying layers are needed. The data that must be collected include initial construction data, current (and historical if available) deflection data, current (and historical) ride quality data, transverse profiles, and detailed distress surveys. Initial construction information is critical to the overall calibration process. This information includes quality assurance data from the initial construction such as, but not limited to the following:

1. Laboratory determined volumetric properties (at the time of construction);
2. Gradation of the aggregate blend, determined from bulk mixture, if available;
3. Effective asphalt content by volume;
4. Asphalt binder properties, not just the performance grade used;
5. In-place density of each layer (flexible pavement and unbound paving layers);
6. In-place moisture content of each unbound paving layer and the embankment soil;
7. Thickness of each layer; and
8. Initial smoothness values, if recorded.

Also, tests needed for the unbound materials and soils include (more tests could be required, particularly for stabilized subgrades)

- Particle size analysis of soils,
- Determining the liquid limits of soils,
- Determining the plastic limit and plasticity index of soils,
- Moisture-density relations of soils,
- Specific gravity of soils,
- Moisture-density relations of soils,
- Resistance r-value and expansion pressure of compacted soils,
- California bearing ratio,
- Soil investigation and sampling by auger borings,
- Penetration test and split-barrel sampling of soils,
- Thin-walled tube sampling of soils,
- Permeability of granular soils (constant head); saturated hydraulic conductivity,
- Determining expansive soils,
- Laboratory determination of moisture content of soils,

- o Resilient modulus of unbound granular base/subbase materials and subgrade soils, and
- o Classification of soils for engineering purposes.

It is important to recognize that as much information as possible should be collected on each layer to assist in fully characterizing the pavement.

4.3 Sampling Matrix for Verification-Calibration

Table 4.1 presents a preliminary experimental plan for verifying/calibrating the distress functions and smoothness (IRI) regression equations in the AASHTOWare® Pavement M-E Design. Relying only on LTPP sites would have resulted in too few sites for the calibration process. Additionally, current MassDOT practices are not represented in the available LTTP sections (e.g., using WMA in lieu of hot mix asphalt, using polymer modified asphalt, and using other types of mixtures that are not included in the LTPP sites). Hence, new mixtures will be tested, and the sites where these mixtures are placed will be included in the verification-calibration process.

Table 4.1: Preliminary experimental factorial or sampling matrix for flexible pavements

LTPP Section				
Flexible Pavement Type		**Site ID**	**Number of Sections**	
New Construction	HMA/WMA			
Rehabilitation	HMW/WMA Overlay			
Non-LTPP Sections				
Flexible Pavement Type	**Mixture Type**	**District**	**WMA**	**Number**
New Construction/Rehabilitation	Superpave – 9.5 mm Unmodified		Yes	6
	Superpave – 9.5 mm Modified		Yes	6
	Superpave – 12.5 mm Unmodified		Yes	6
	Superpave – 12.5 mm Modified		Yes	6
	Superpave – 19.0 mm Unmodified		Yes	6
	Superpave– 19.0 mm modified		Yes	6
	ARGG		Yes	6
	ARGG		No	6
	HP		Yes	6
	HP		No	6
	HiMA		Yes	6
	HiMa		No	6
	High RAP		Yes	2
	HighRAP		No	2
	SMA		Yes	1
	SMA		No	1
Total				78

Notes:

- Field investigations, layer and materials properties, and truck traffic for the LTPP sites are stored in the LTPP database. All data to be used in the verification-calibration study for these sites will be extracted from the LTPP database.
- For the plant-produced mixtures that were placed on a non-LTPP roadway segment, the research team will seek the data from MassDOT's pavement management section. If the data is not available, field investigations will be conducted. These field investigations will include condition surveys to determine the type and severity of pavement distress, a coring program for confirming and measuring layer thicknesses, and recovering materials for laboratory testing (*6*).
- The AASHTOWare® Pavement M-E Design requires the location of a project be defined by its longitude, latitude, and elevation to develop project specific climate data. The climate-specific data for the LTPP and non-LTPP sites will be generated using the closest weather stations.

5.0 Mixture Selection and Initial Testing

To accelerate the future phases of this project (particularly Phase III), testing of plant-produced mixtures continued in Phase II.

5.1 Mixture Selection

Prior to the initiation of this study, mixtures being placed in Massachusetts were already being collected by the research team as part of a different MassDOT study relating to development of a Balanced Mixture Design protocol. These plant-produced mixtures represented a wide variety of mixtures being designed and placed in Massachusetts. The mixtures tested in this study were those most produced on a regular basis (based on tonnage) and not developed for a specialized application. The mixtures shown in Table 5.1 were available for testing in Phase II.

Table 5.1: Mixtures selected for testing in Phase II

Mixture ID	Type	Gyration Level	Binder	Contractor
#37	19.0 mm SIC	75	PG64S-28	Rochester Bituminous
#38	12.5 mm SSC	75	PG64S-28	Aggregate Industries Chelmsford
#39	12.5 mm SSC	75	PG64S-28	Brox Industries Dracut
#40	12.5 mm SSC	75	PG64S-28	Palmer Paving Springfield
#41	12.5 mm SSC	75	PG64S-28	Warner Bros. LLC

Selection was first based on quantity of mixture received because the team needed to make sure there was sufficient material to complete the testing required for the Balanced Mixture Design project and this study. Next, only mixtures with companion asphalt binder samples were considered because the binder must be tested as well for M-E analysis. Next, mixtures were narrowed down by type, gyration level, and binder type. The final mixture selections shown in Table 5.1 represent the typical surface course (12.5 mm SSC) and intermediate course (19.0 mm) mixtures used in Massachusetts. The typical gyration level (75 gyration) and typical binder type (PG64S-28) are represented. These mixtures and the companion binder samples were tested as outlined in the following sections.

5.2 Mixture Dynamic Modulus |E*|

For Level 1 hierarchal M-E analysis, laboratory mixture testing data is required, specifically, dynamic modulus (|E*|) of the mixture. Each plant-produced mixture was reheated, split, and then compacted in the Superpave Gyratory compactor (SGC) to fabricate a cylindrical specimen 180 mm tall by 150 mm in diameter. This process was repeated using different weights of mixture until the compacted specimens had an air void content between 8% and

9%. Four replicate specimens were fabricated at this air void content for each mixture. Next, a 100 mm core was taken out of the middle of each specimen. The ends of this core were then cut to yield a 150 mm tall specimen. The air void content of these cored specimens was then determined with the target being between 6% and 8%. Specimens outside this range were rejected and refabricated. Three of the four specimens for each mixture were allocated for dynamic modulus testing, and the remaining specimen was used to tune the Asphalt Mixture Performance Tester (AMPT) for each specific mixture.

Mixture dynamic modulus testing was conducted in accordance with AASHTO T 378 “Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)” using three test temperatures (4°C, 20°C, and 40°C) and at multiple frequencies per temperature (0.1, 0.5, 1, 5, 10, and 25 Hz).

The dynamic modulus data for the three replicate specimens of each mixture was then entered into an analysis software package called FlexMat™, developed by North Carolina State University. A mixture master curve was created and used to calculate the dynamic modulus at five temperatures (14.0°C, 39.2°C, 68.0°C, 104.0°C, and 129.2°C) and six frequencies (0.1, 0.5, 1, 5, 10, and 25 Hz). The temperatures correspond to −10°C, 4°C, 20°C, 40°C, and 54°C. By utilizing the master curve, the dynamic modulus data at low and high temperature was obtained, which could not be directly measured experimentally at −10°C and 54°C due to machine and specimen limitations.

5.3 Binder Testing

Also required for Level 1 M-E analysis was the properties of the asphalt binder used in the mixture fabrication. Specifically, the binder shear modulus (G*) and phase angle at multiple temperatures was required.

First, each binder was short-term aged in the Rolling Thin Film Oven (RTFO) in accordance with AASHTO T 240 “Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test).” Then the aged binder residue was then tested in the Dynamic Shear Rheometer (DSR) in accordance with AASHTO T 315 “Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)” at typical temperatures of 52°C, 58°C, 64°C, 70°C, and 76°C (125.6°F, 136.4°F, 147.2°F, 158.0°F, and 168.8°F).

5.4 As-Built Properties

Finally, in addition to the mixture and binder properties, the as-built properties of the mixture were required, including total unit weight of the mixture (pcf), mixture effective binder content by volume (%), and mixture air voids (%). These parameters were calculated from the production data supplied by MassDOT for each mixture.

5.5 Level 1 Hierarchical Input Data for Initial Mixtures

The final M-E analysis input data for each mixture tested is presented in Tables 5.2 through 5.6. The format is that of the input cells of the AASHTOWare® Pavement M-E Design software. Thus, the data can be directly cut and pasted into the software.

Table 5.2: M-E analysis input data for Mix #37

Mix ID #:	37
Contractor:	Rochester Bituminous
Mix:	19.0 mm 75G 20% RAP WMA
Binder:	PG64S-28 w/ EVO
MassDOT ID:	RB-19-SIC-75G-20%-2021

	|E*| Dynamic Modulus (psi)					
Temperature (°F)	**0.1 Hz**	**0.5 Hz**	**1 Hz**	**5 Hz**	**10 Hz**	**25 Hz**
14.0	2169767	2546847	2706651	3068090	3218586	3411832
39.2	1039709	1384599	1541646	1916711	2080222	2296194
68.0	294976	471188	566603	832509	964222	1151322
104.0	50425	90082	114980	198466	248232	329419
129.2	17477	31413	40496	72694	93109	128321

Binder Data		
Temperature (°F)	**G* (Pa)**	**Delta (°)**
125.6	15367	70.8
136.4	7183	73.1
147.2	3423	75.5
158.0	1677	78.0
168.8	855	80.3

General: Properties As-Built	
Total Unit Weight (pcf)	151.6
Effective Binder Content by Volume (%)	9.4
Air Voids (%)	4.1

Table 5.3: M-E analysis input data for Mix #38

Mix ID #:	38
Contractor:	Aggregate Industries Chelmsford
Mix:	12.5 mm WMA
Binder:	PG64S-28
MassDOT ID:	AIC-12.5-SSC-75G-15%-2021

	|E*| Dynamic Modulus (psi)					
Temperature (°F)	**0.1 Hz**	**0.5 Hz**	**1 Hz**	**5 Hz**	**10 Hz**	**25 Hz**
14.0	1887737	2214557	2349234	2647990	2771015	2928849
39.2	799523	1117156	1263741	1610975	1759313	1951483
68.0	184723	310356	382952	599823	713813	881196
104.0	31711	55985	71553	125623	159197	216035
129.2	12903	21979	27919	49197	62892	86903

Binder Data		
Temperature (°F)	**G* (Pa)**	**Delta (°)**
125.6	16067	70.5
136.4	7523	72.7
147.2	3577	75.2
158.0	1757	77.7
168.8	894	80.1

General: Properties As-Built	
Total Unit Weight (pcf)	150.6
Effective Binder Content by Volume (%)	12.1
Air Voids (%)	3.4

Table 5.4: M-E analysis input data for Mix #39

Mix ID #:	39
Contractor:	Brox Industries
Mix:	12.5 mm WMA
Binder:	PG64S-28
MassDOT ID:	BD-12.5-SSC-75G-15%-2021

	|E*| Dynamic Modulus (psi)					
Temperature (°F)	**0.1 Hz**	**0.5 Hz**	**1 Hz**	**5 Hz**	**10 Hz**	**25 Hz**
14.0	2186747	2585346	2747552	3099400	3240214	3416818
39.2	934446	1305880	1480152	1898871	2079293	2313109
68.0	235214	383455	468056	719500	851882	1047388
104.0	43711	74370	93543	158438	197893	263819
129.2	17628	28991	36238	61482	77346	104703

Binder Data		
Temperature (°F)	**G* (Pa)**	**Delta (°)**
125.6	14267	69.0
136.4	6833	70.9
147.2	3370	73.2
158.0	1703	75.7
168.8	886	78.1

General: Properties As-Built	
Total Unit Weight (pcf)	158.1
Effective Binder Content by Volume (%)	12.7
Air Voids (%)	3.9

Table 5.5: M-E analysis input data for Mix #40

Mix ID #:	40
Contractor:	Palmer Paving
Mix:	12.5 mm WMA
Binder:	PG64S-28
MassDOT ID:	n/a

	|E*| Dynamic Modulus (psi)					
Temperature (°F)	**0.1 Hz**	**0.5 Hz**	**1 Hz**	**5 Hz**	**10 Hz**	**25 Hz**
14.0	1923710	2267599	2400896	2679772	2788684	2924323
39.2	722525	1078921	1248641	1649937	1816878	2026125
68.0	147225	259597	328607	549341	672559	860147
104.0	29333	49480	62876	111446	142888	197946
129.2	15717	23505	28793	48462	61548	85079

Binder Data		
Temperature (°F)	**G* (Pa)**	**Delta (°)**
125.6	11367	71.5
136.4	5277	74.5
147.2	2497	77.5
158.0	1207	80.2
168.8	610	82.6

General: Properties As-Built	
Total Unit Weight (pcf)	159.0
Effective Binder Content by Volume (%)	11.0
Air Voids (%)	4.0

Table 5.6: M-E analysis input data for Mix #41

Mix ID #:	41
Contractor:	Warner Bros
Mix:	12.5 mm WMA
Binder:	PG64S-28
MassDOT ID:	n/a

	|E*| Dynamic Modulus (psi)					
Temperature (°F)	**0.1 Hz**	**0.5 Hz**	**1 Hz**	**5 Hz**	**10 Hz**	**25 Hz**
14.0	1845256	2151804	2278784	2561239	2677697	2827128
39.2	885738	1184895	1320917	1641645	1778749	1956826
68.0	261793	408771	488952	715412	829035	991486
104.0	54408	90693	112776	184988	227369	296137
129.2	22299	36718	45715	76247	94943	126498

Binder Data		
Temperature (°F)	**G* (Pa)**	**Delta (°)**
125.6	15767	68.5
136.4	7780	69.7
147.2	3917	71.2
158.0	2020	73.0
168.8	1067	75.0

General: Properties As-Built	
Total Unit Weight (pcf)	153.0
Effective Binder Content by Volume (%)	11.5
Air Voids (%)	4.2

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6.0 Discussion

This report outlines the work conducted in the second phase of a four phase larger research project aimed at implementing the AASHTO MEPDG in Massachusetts. The goal of this study was to develop an AASHTOWare® Pavement M-E user's manual and develop a local experimental plan and sampling template. Additionally, testing was conducted on typical plant-produced mixtures sampled from across Massachusetts in an attempt to accelerate future phases of this research.

The AASHTO M-E design method is a sophisticated tool used to design and predict the performance of pavements. It requires rigorous input data relating to traffic, climate, and material properties. This is contrary to MassDOT's current pavement design method, which relies heavily on empirical relationships.

Due to its complexity and sophistication, the procedure for utilizing the AASHTOWare® Pavement M-E Design software, as well as the required inputs (climate data, traffic data, material data, etc.), is not obvious and intuitive for the user. The user needs experience and knowledge to use the software correctly. Therefore, a stand-alone manual was developed that provides a thorough step-by-step procedure on how to use the software (Appendix A). The manual guides users on how to generate the data, in particular, material properties and climatic and traffic data as they relate to local locations within the state of Massachusetts.

A preliminary experimental and sampling plan for local verification/calibration of the distress functions and smoothness (IRI) regression equations in the AASHTOWare® Pavement M-E Design was developed. Relying solely on LTPP site data would have resulted in too few sites for the local calibration process. Additionally, current MassDOT practices are not represented in the available LTTP sections. Hence, it is suggested to test new mixtures, and the sites where these mixtures are placed will be included in the local verification-calibration process.

Finally, in an effort to accelerate future phases of this research, the research team continued generating data for the database needed to conduct the local calibration. Five plant-produced mixtures were sampled and tested. These mixtures represent the most produced (based on tonnage) surface and intermediate course mixtures placed in Massachusetts. From the testing, necessary Level 1 hierarchical inputs for the asphalt layers were determined.

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Appendix A: User Guide for the AASHTOWare® Pavement M-E Design Software Version 2.6

User Guide for the AASHTOWare® Pavement M-E Design Software Version 2.6

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June 2022

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1.0 Introduction

This manual provides a step-by-step procedure on how to install and use the AASHTOWare® Pavement M-E Design software to perform a design of flexible pavements. It provides a graphical presentation of the different panels from the software. It illustrates the data needed to perform the design and the steps necessary to input the data. The data includes materials characteristics, traffic, and weather data.

1.1 Software Description

The AASHTOWare Pavement Design software is based on pavement design models that are presented in the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG). AASHTOWare's Pavement Design software takes into consideration the materials used, changes of traffic and environmental conditions, reliability factors, and pavement structure while also incorporating mechanistic-based algorithms and transfer functions to evaluate the predicted pavement performance. These inputs allow the mechanistic pavement model to predict the pavement's damage and distresses by using a nationally calibrated data set. Although the nationally calibrated data set is useful, the modeling can be greatly improved by utilizing localized calibration factors instead. Local calibration factors can be determined through laboratory testing, collection of data from the field, and the analysis of any historical data for the specific region. The local calibration factors can then be verified with various instruments in test sections of pavement to check the reliability of the model. The flowchart in Figure 1 depicts the three stages of the design-analysis procedure. Stage one is the evaluation phase, stage two is the analysis phase, and stage three is the strategy selection phase.

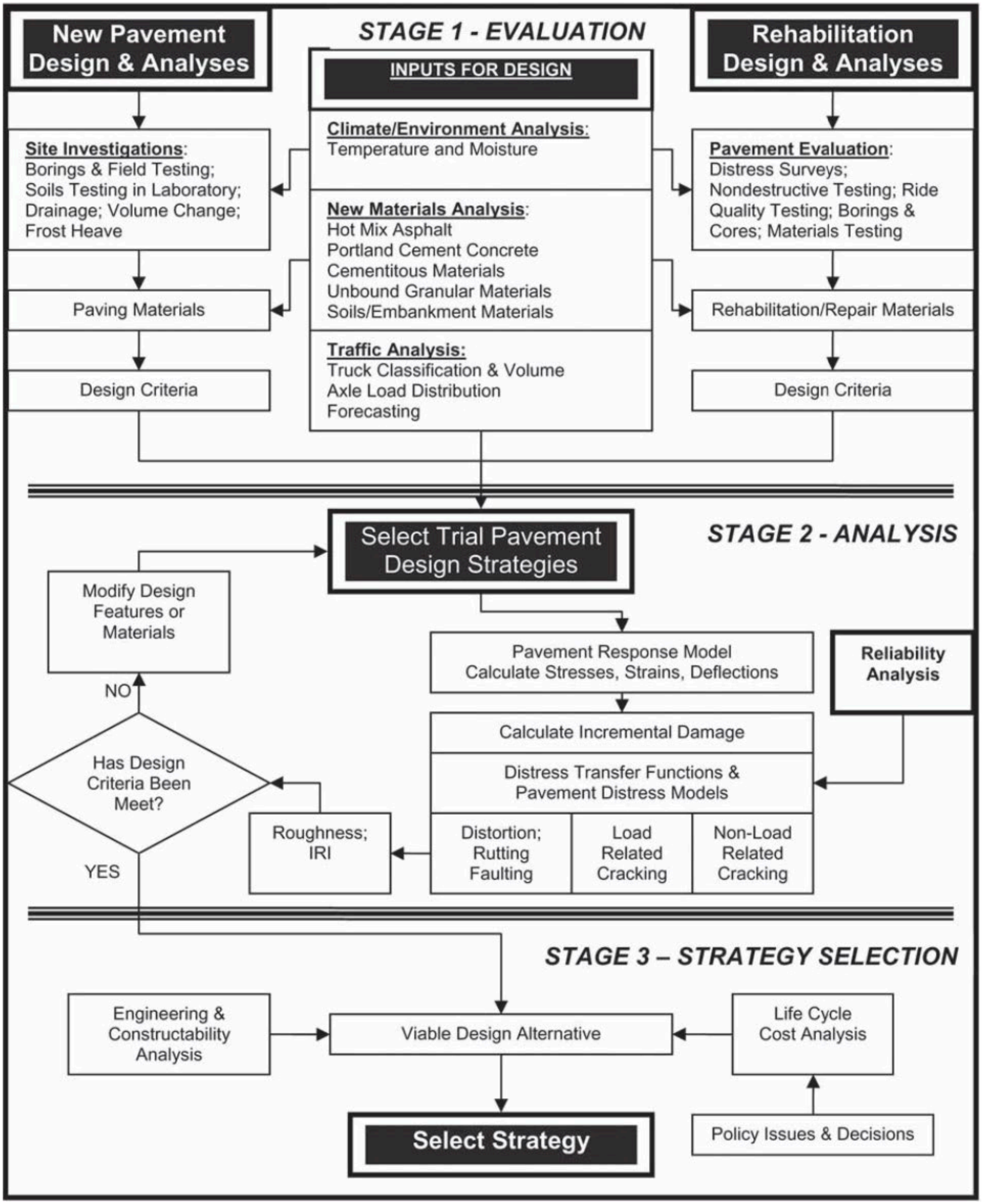


Figure 1. Conceptual flow chart for the MEPDG three-stage design-analysis procedure

Source: AASHTO *Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide*, 2010.

2.0 Installing and Activating AASHTOWare® Pavement M-E Design Software

After purchasing the AASHTOWare Pavement M-E Design Software license, the user will receive a confirmation email. This email will contain the following: product code/customer ID, login name, and password that verifies the software purchase as shown in Figure 2. Next, the user can log on to their account using the provided login credentials to start downloading and activating the software. Here the user can check the latest news regarding M-E Design including updates, feature enhancements, modifications, and so forth, through the website: https://me-design.com/MEDesign/Software.aspx.

Thank you for purchasing AASHTOWare Pavement ME Design!
Important – Please Keep this information

Product Code/Customer ID: [redacted]
Login Name: [redacted]
Password: [redacted]

To ensure the most prompt and efficient service, please always refer to your Customer ID when contacting us.
To download the latest software, please log in to the ME Design website at: http://www.me-design.com using the login credentials provided above. The ME Design website provides instructions on software installation and licensing.
For additional support, please contact the ME Design Help Desk at:
Email: pavementmedesign@ara.com
Phone: 1-877-500-3496
Monday through Friday
8:00am – 5:00pm CST

Figure 2. AASHTOWare Pavement M-E Design Software purchase confirmation email with the user's login credentials

When a user signs in to their account, they will be able to download and install the software. Before moving forward, it should be noted that the user's machine must meet the minimum hardware and software requirements, which can be found under "Software and Hardware Requirements." Download the software by clicking on the AASHTOWare Pavement MEDesign Installer.exe; then extract the zip file that contains the installation file and launch "AASHTOWare Pavement MEDesign Installer" to begin installation of the application. AASHTOWare Pavement M-E Design installation instructions for different Pavement M-E Design license types can be downloaded by clicking on "here" as shown in Figure 3.

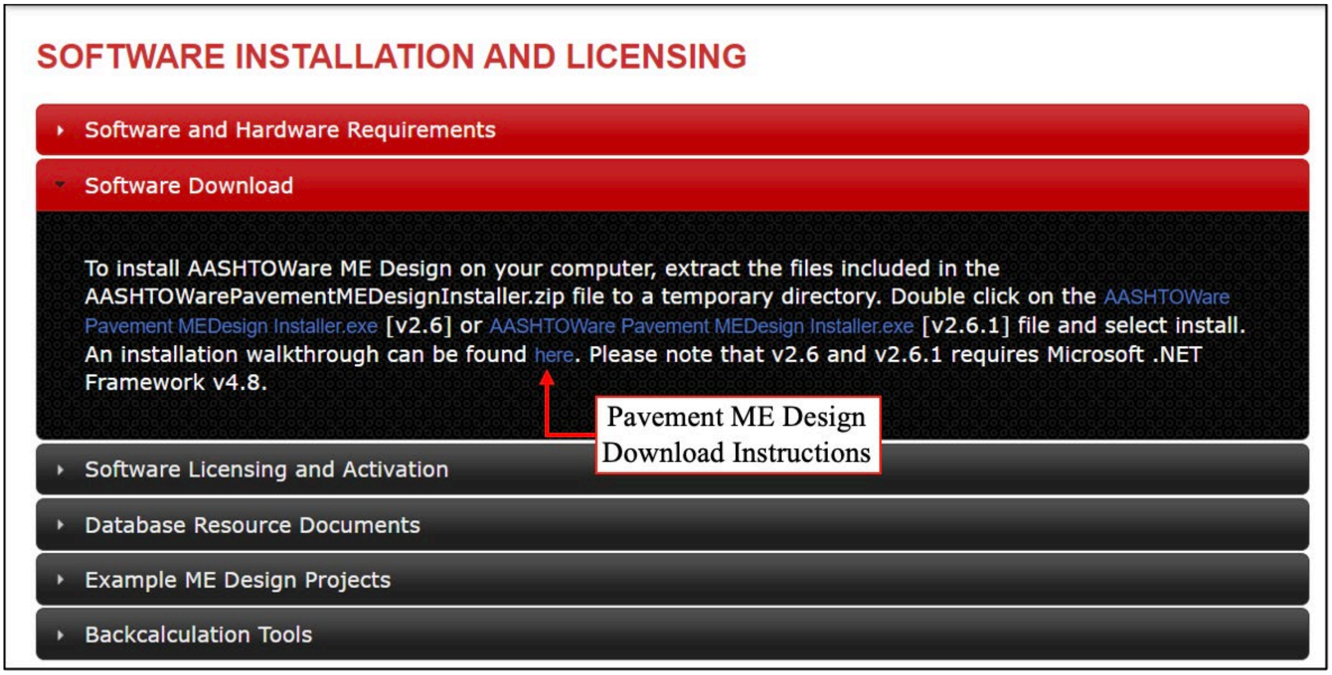


Figure 3. AASHTOWare Pavement M-E Design Software installation and licensing

The AASHTOWare Pavement M-E Design program will be added to the Windows Start menu during installation, and a shortcut icon "Pavement M-E Design" will be added to the desktop. When a user opens AASHTOWare Pavement M-E Design Software for the first time, the login window will appear with a disabled "OK" button. This is due to the software requiring license activation to enable the "OK" button. Users will then be able to access the AASHTOWare Pavement M-E Design database and run analyses.

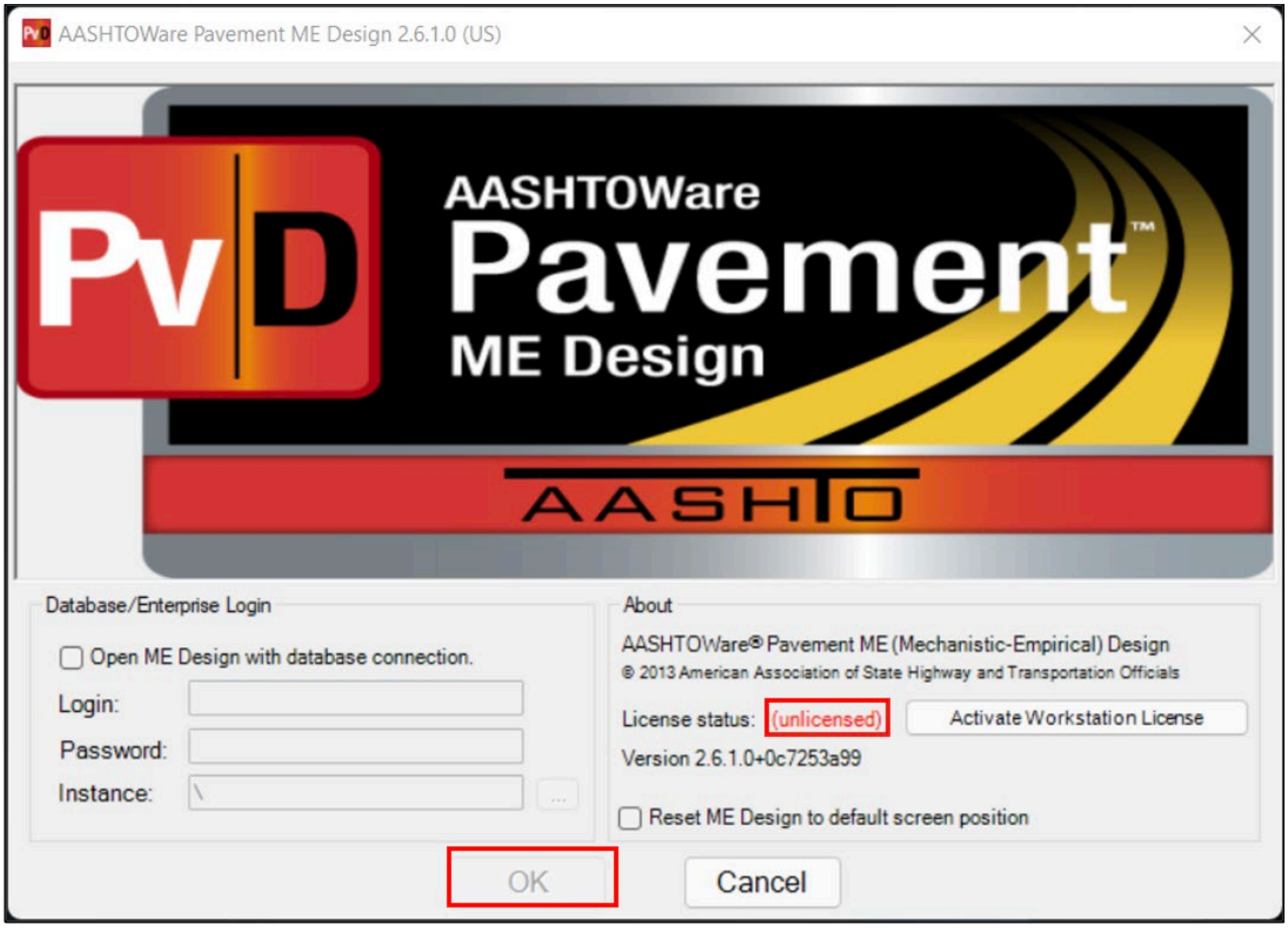


Figure 4. Unlicensed AASHTOWare Pavement M-E Design Software login screen

The following steps outline a summary for manually activating an individual workstation license through AASHTOWare's website:

1. Visit AASHTOWare's website https://me-design.com/MEDesign/activatelicense.aspx and choose the "Workstation License" tab; next, fill out the request form; once the form is filled out, click on the "Submit" button as shown in Figure 4. Note: A user's machine code can be retrieved by clicking on "MachineCode Identifier" then copying that code and pasting it inside the "Machine Code" field. A license code will then be sent to the user's email.
2. Check your email for the license code needed to activate the software as shown in Figure 5. Copy the license code; open the AASHTOWare Pavement M-E Design Software; click on the "Activate Workstation License" button; select "Enter License Code"; paste the license code; finally, click "Activate" as presented in Figure 6.
3. The software will automatically restart. The user should see the license status changed to standard, and the "OK" button is now selectable as shown in Figure 7. The software is ready to launch (Figure 8).

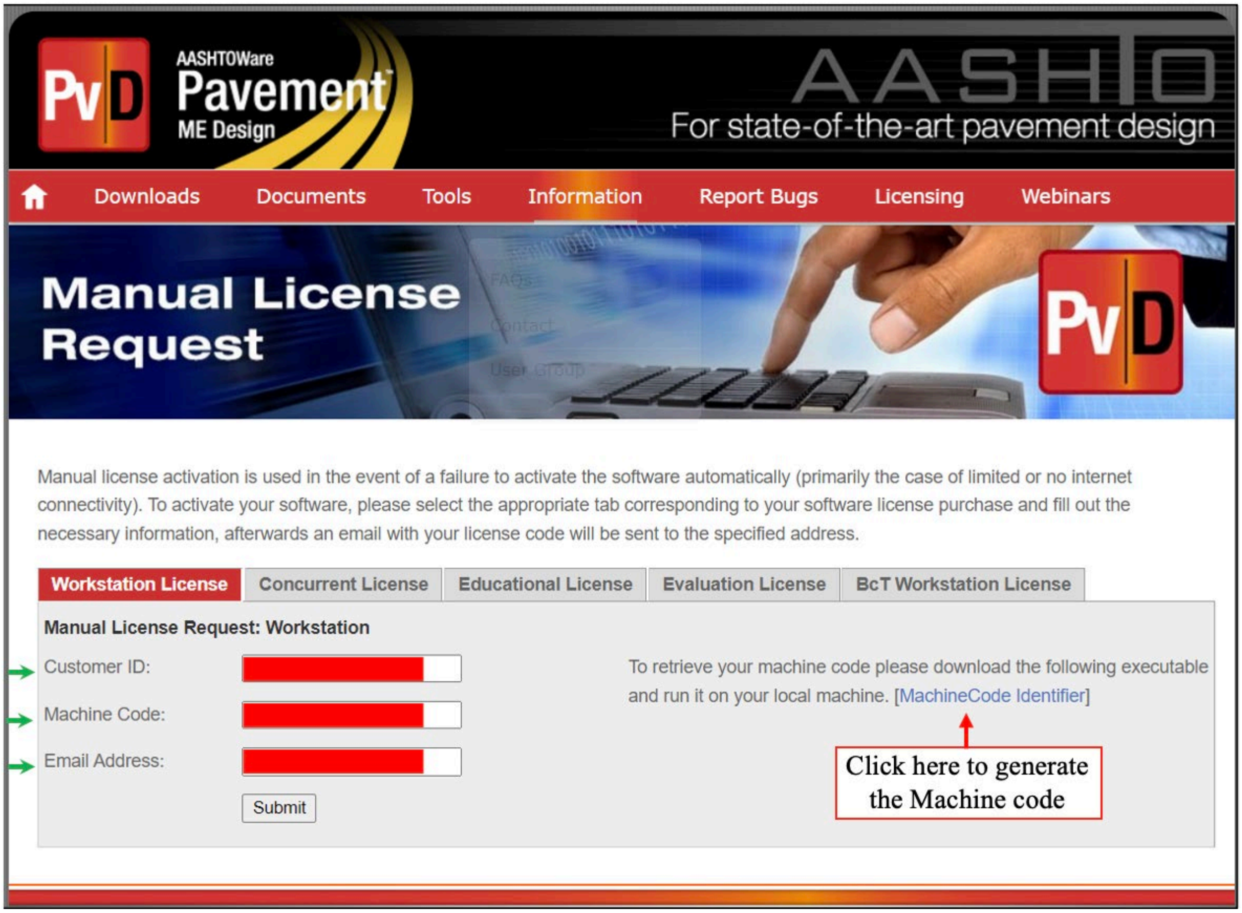


Figure 5. Generating the AASHTOWare Pavement M-E Design Software license code

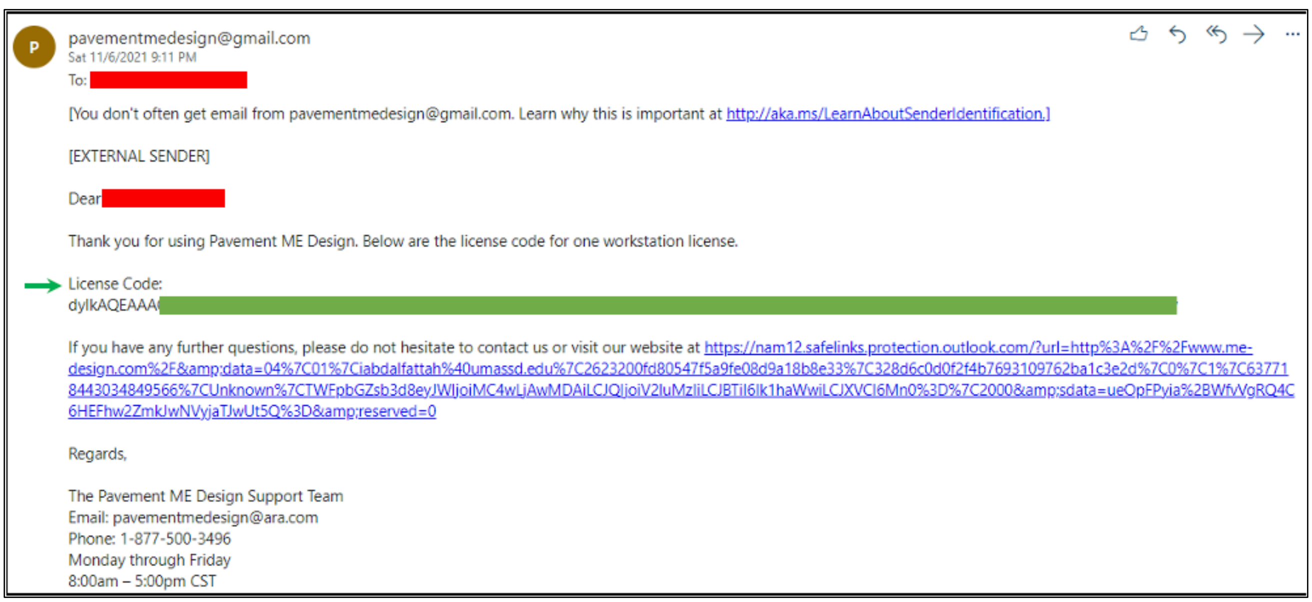


Figure 6. License code email request

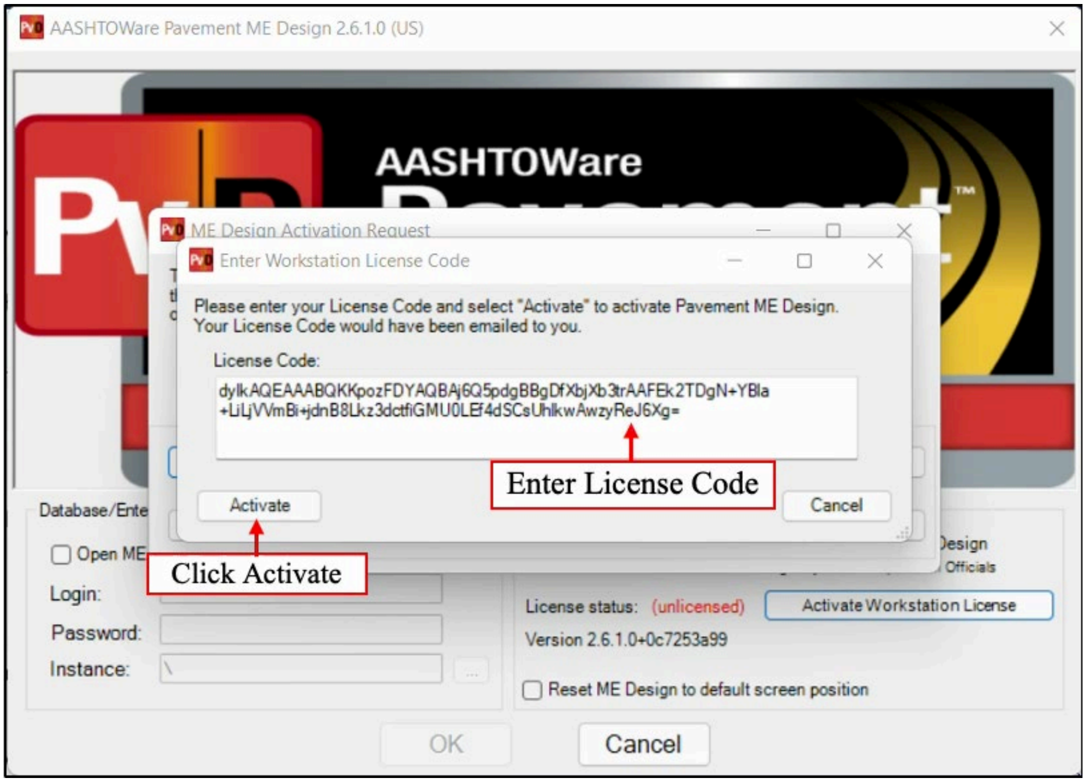


Figure 7. Entering the license code and activating the Pavement M-E Design Software

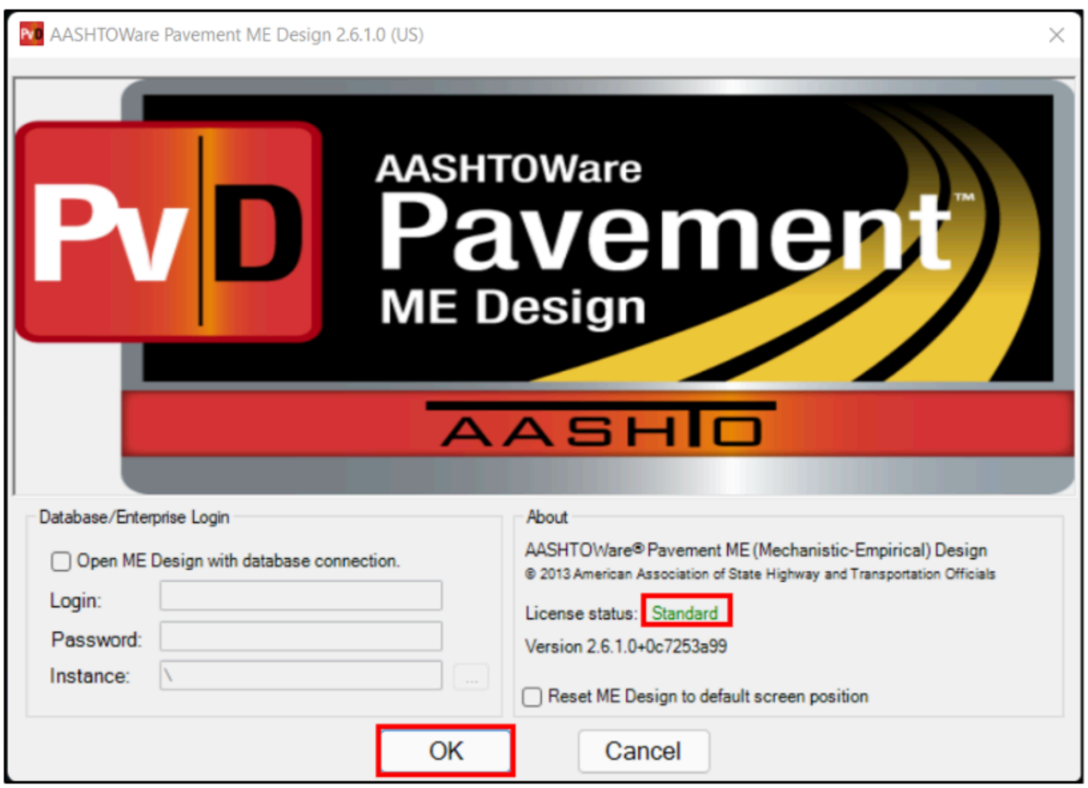


Figure 8. AASHTOWare Pavement M-E Design Software login screen with licensing

3.0 Overview of AASHTOWare Pavement M-E Design Software User Interface

The AASHTOWare Pavement M-E Design Software has a user-friendly interface that guides users during the design process. The main layout consists of several windows/panes as shown in Figure 9: Menu Bar, Explorer Pane, Project Tab, Output/Error List/Compare Pane, and Progress Pane. The user is allowed to create a customized interface by moving, hiding, and changing panels sizes, and the customized window layout will be displayed during the subsequent use of the software. To revert to the default layout, check the "Reset ME Design to default screen position" at the login screen.

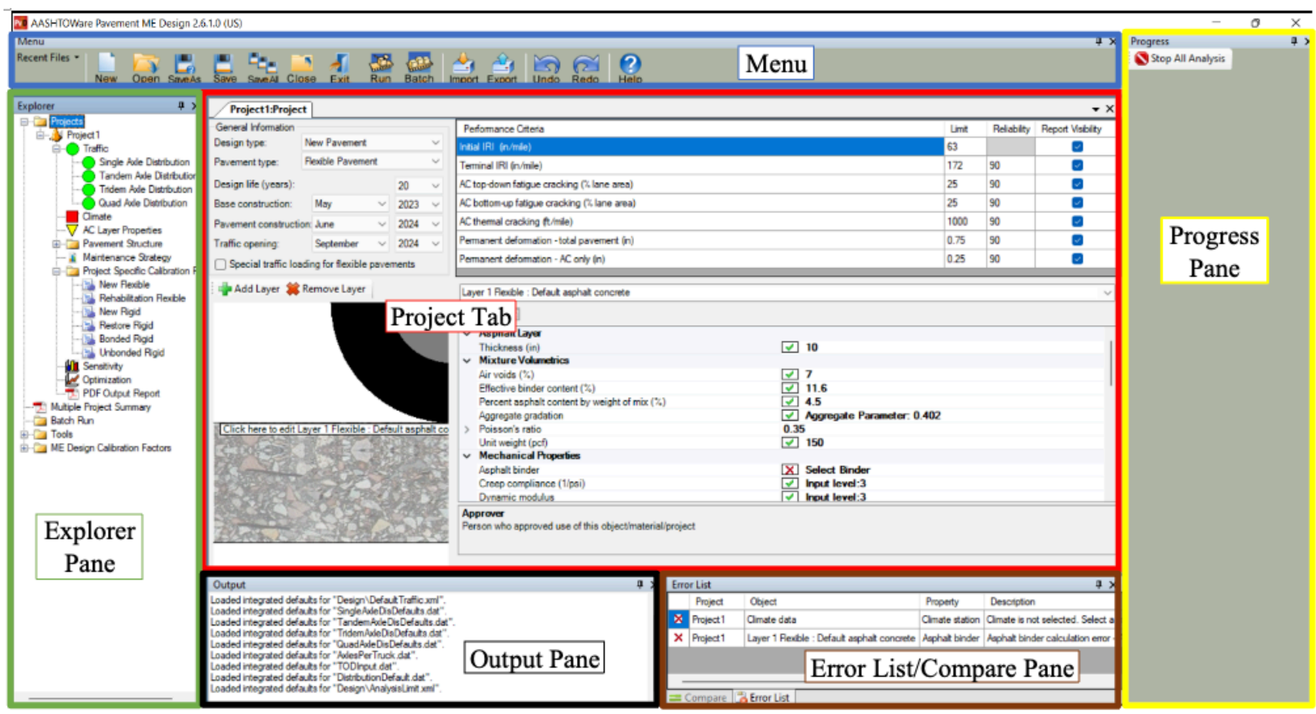


Figure 9. AASHTOWare Pavement ME Design Software main window

3.1 Menu Bar

Located at the top of the screen, the menu bar contains buttons for the most frequently used commands, such as creating a new project, opening existing projects, saving files, accessing the help manual, as shown in Figure 10. The Menu Bar commands are presented in Table 1.

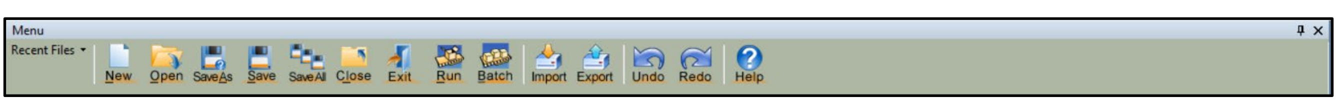


Figure 10. AASHTOWare Pavement ME menu bar

Table 1. Menu bar commands

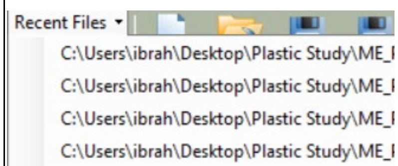
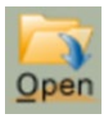
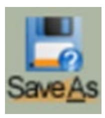
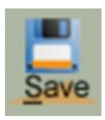
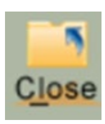
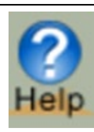
Command	Symbol	Description	Function Keys
Recent Files		Used to view a drop-down menu of the last four recently saved projects. The user can reopen any of these files by clicking on them.	—
New		Opens a new project.	Ctrl + N
Open		Opens a saved project. User can simultaneously open up to 10 projects at a time in the Project Tab.	Ctrl + O
Save As		Saves the current project with a new filename.	Ctrl + A
Save		Saves the current project. If this project has not been previously saved, the user is prompted for a filename.	Ctrl + S
Save All		Saves all the open projects.	—
Close		Closes the current project. If the project has not been saved or if the user made changes after the last save, the software will ask the user whether to save the current unsaved project.	Alt + C
Exit	—	Closes all open projects and exits the program.	—
Run	—	Performs an analysis on the current selected project.	—

Table 1. Menu bar commands (continued)

Command	Symbol	Description	Function Keys
Batch		Runs analyses of multiple projects. The user must load the projects into the “Batch Run” folder located in the Explorer Pane to begin the batch analyses.	—
Import		Imports Traffic, Climate, or back-calculation XML data files.	—
Export		Exports Traffic, Climate, or back-calculation XML data files for the current project.	—
Undo		Undo actions on the current tab.	Ctrl + Z
Redo		Redo actions on the current tab.	Ctrl + Y
Help		Opens the Help manual.	F1

3.2 Explorer Pane

Located at the left of the main screen, the Explorer pane is used for navigating between open projects, running batch analyses, accessing advanced tools, and specifying calibration factors for a single project or all open projects. Figure 11 shows the Explorer Pane. The Explorer Pane consists of a Multiproject Summary feature and four main folders: Projects, Batch Run, Tools, and ME Calibration Factors. Some folders can be expanded to display subfolders or subnodes by clicking the “+” symbol or collapsed by clicking the “-” symbol. Table 2 presents the main commands in the Explorer Pane. The AASHTOWare Pavement M-E Design Software uses three symbols in the Explorer Pane to display the status of different inputs that include traffic, climate, and pavement structure. These symbols are represented by either a green circle, a yellow triangle, or a red square as shown in Figure 12. The green circle indicates that the user has completed entering the specified input value or viewed and accepted the software default value; the analysis is ready to be run. The yellow triangle is a designation that warns the user that the default value will be used during the analysis and that they did not verify and accept the default value. An analysis can still be run even if there are yellow triangles flagging some inputs. The yellow triangle can be converted into a green circle by double-clicking on the input node, which indicates that the user has reviewed and accepted the default value. The red square indicates that there is missing data, and the user is required to enter the specified data for the software to run the analysis. Therefore, to run a trial design, all designations beside the inputs must be either green circles or yellow triangles.

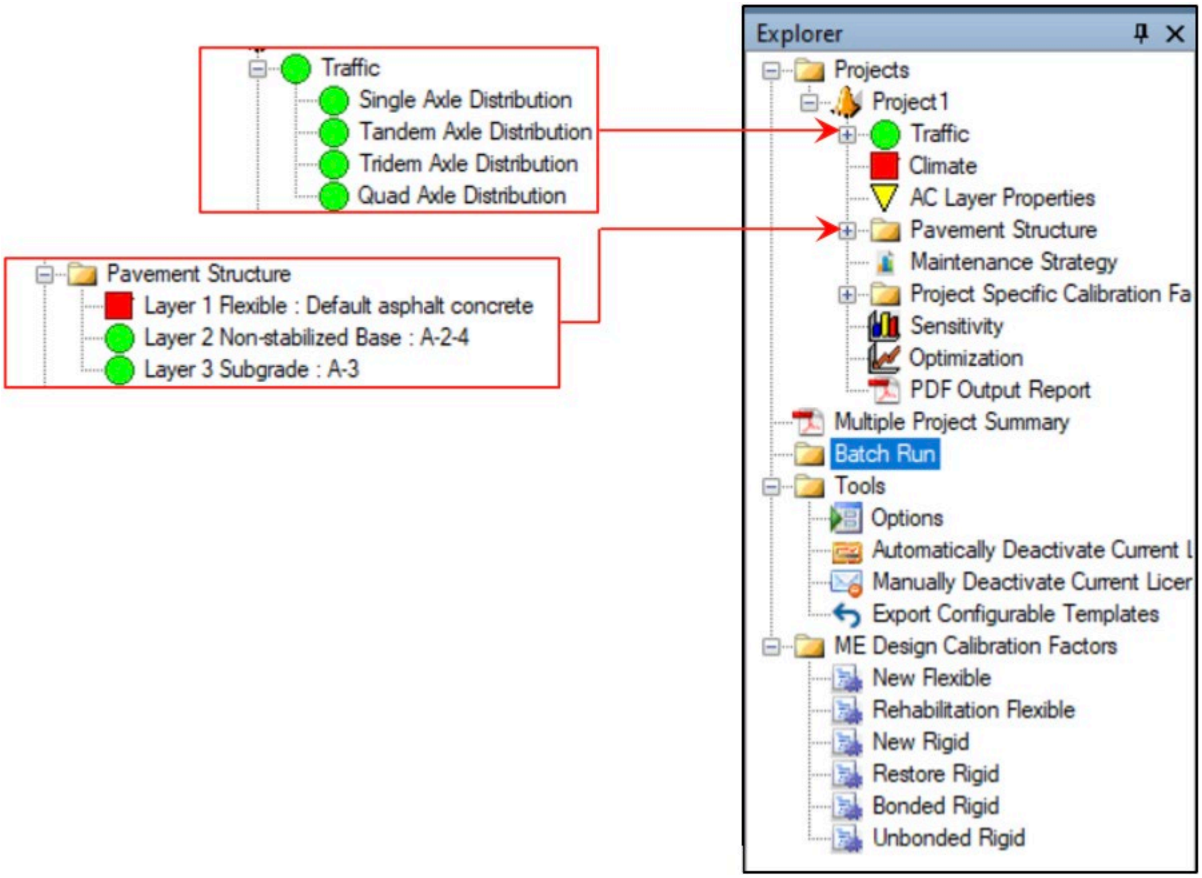


Figure 11. AASHTOWare Pavement ME Explorer pane

Table *2*. Explorer pane main commands

Folder	Description
Projects	Contains information about the open projects, and shows the main design inputs and project outputs: 1. Traffic: Allows the user to enter, modify, import, and export traffic data for the project. 2. Climate: Establishes weather stations used for analyzing the effects of climate variables on pavement response and performance of the project. 3. Pavement Structure: Defines the pavement structure layers, allows for users to edit the thickness and properties of each layer. 4. Project Specific Calibration Factors: Replaces the global calibration coefficients with layer-specific calibration coefficients developed for the current active project only to be used in the design analyses. 5. Sensitivity: Allows the user to examine the sensitivity of the project for specific inputs such as AADTT, thicknesses, base or subgrade resilient moduli, binder contents, air voids, and so forth, by defining minimum and maximum levels for selected parameters. 6. Optimization: Allows the user to optimize the thickness of a single layer above the foundation required for satisfying the performance criteria by defining minimum and maximum thicknesses for the layer that will be optimized. 7. PDF Output Report: Opens the PDF Output Report that generates after successfully completing the analysis for the project. This file contains a summary of inputs and output results of the trial design.
Multiple Project Summary	Displays a summary PDF report for all projects performed using "Batch Run." This generated report contains the first page of the PDF output report for each project.
Batch Run	Allows the user to load multiple projects files and run the analyses for all selected projects without the need to open each project individually.
Tools	Contains options for changing the settings of the ME Design application.
ME Design Calibration Factors	Contains national calibration factors for all prediction models which can be modified with local-specific calibration factors. The new calibration factors will be utilized for any subsequent design. If the user wishes, previously created projects can be updated to the new calibration factors or restored to the default calibration factors.

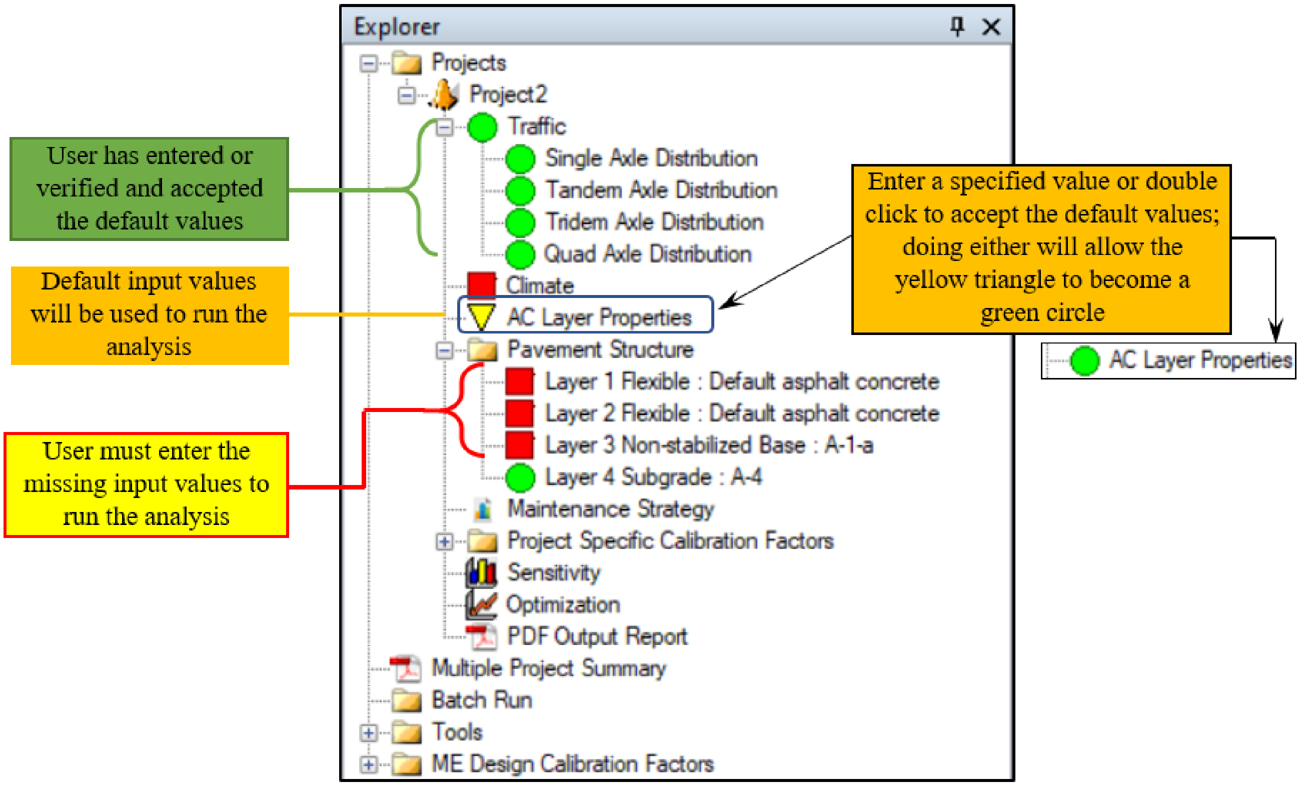


Figure 12. AASHTOWare Pavement ME Explorer pane input color scheme

3.3 Project Tab

Located at the center of the main screen, the Project Tab is used to select the pavement type and enter input data for the trial design. The Project Tab area is divided into different sections as shown in Figure 13. These zones are Tabs, General Information, Performance Criteria, Pavement Structure, and Property Grid. A description of each zone is described as follows:

- **Tabs**: Located at the top of the Project Tab Pane and contains tabs of different open projects. The user can switch between multiple projects by clicking on the project tab or with the drop-down arrow located at the right side of the tab header as shown in Figure 14. The active tab is displayed with a white background and bolded text, while inactive tabs only have gray backgrounds.

- **General Information**: Allows the user to select the design type, pavement type, and other general inputs. These inputs include the design life, construction date of certain pavement layers, traffic opening date, and specific traffic loading options that allow the designer to run the analysis using specific axle load configurations and repetitions. The user should note that all Project Tab zones will not generate until selecting the "Design Type" and "Pavement Type" as shown in Figure 15. Therefore, the general information must be completed before anything else.

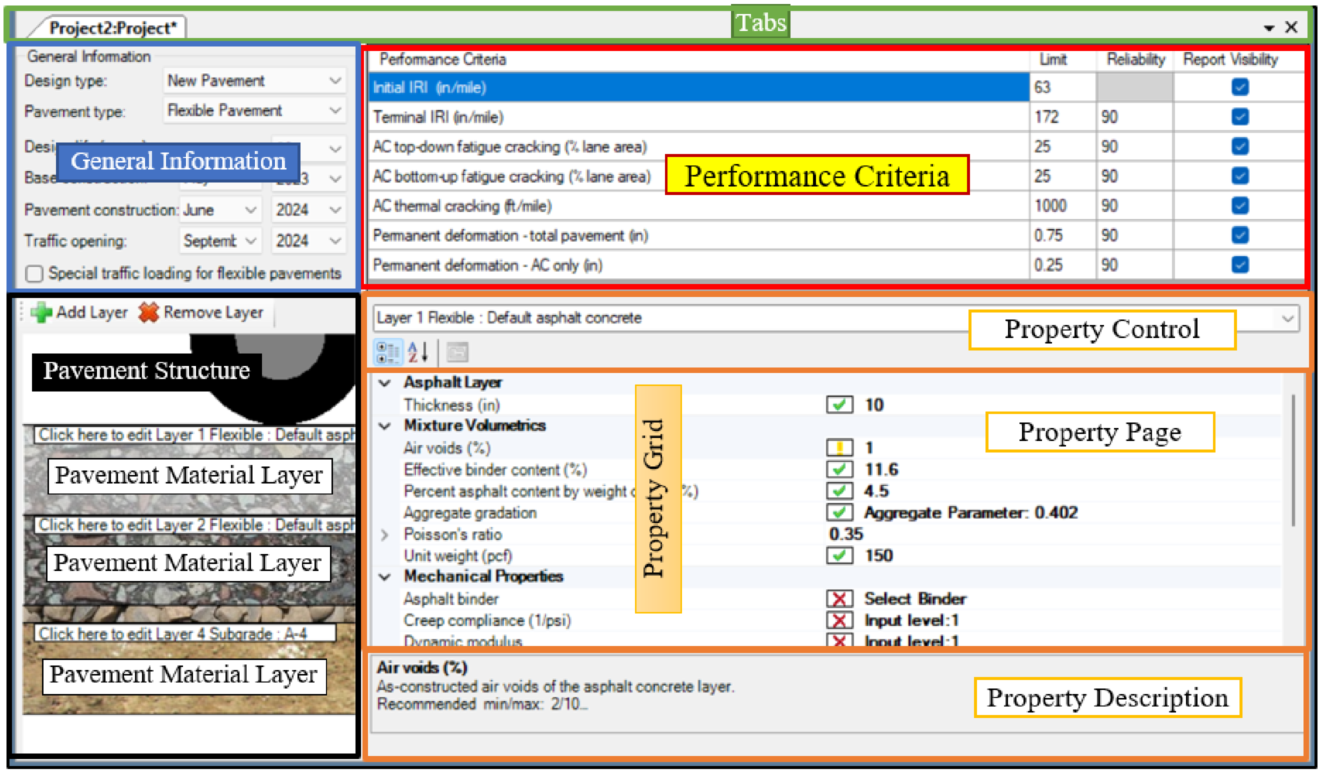


Figure 13. AASHTOWare Pavement ME project tab sections

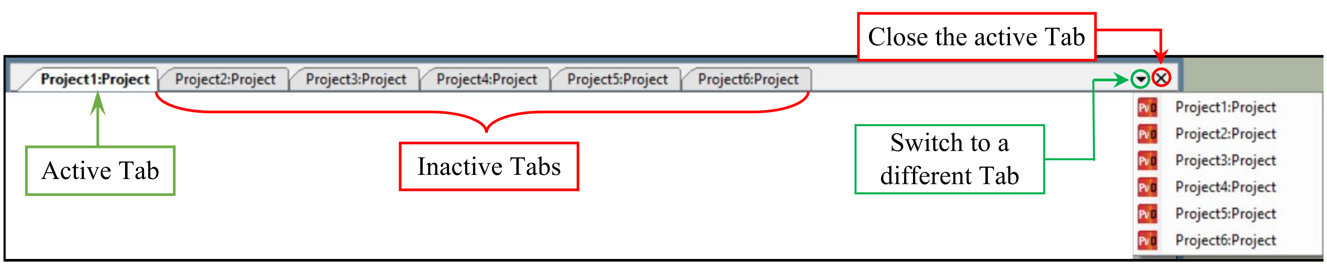


Figure 14. AASHTOWare Pavement ME tab pane

- **Performance Criteria**: Allows the user to select the smoothness and distress limits at specified reliability levels that meet the highway agency's tolerance level at the end of the design life. The populated performance criteria will be dependent on the "Design Type" and "Pavement Type" selected by the designer.

- **Pavement Structure**: Allows the user to add or remove different layers that constitute the trial pavement design cross section. A visual representation of the entered cross section will be seen in the pavement structure section. If the user clicks on any of the pavement material layers, the properties of that layer will appear within the property grid section, which allows the user to enter/edit layer properties.

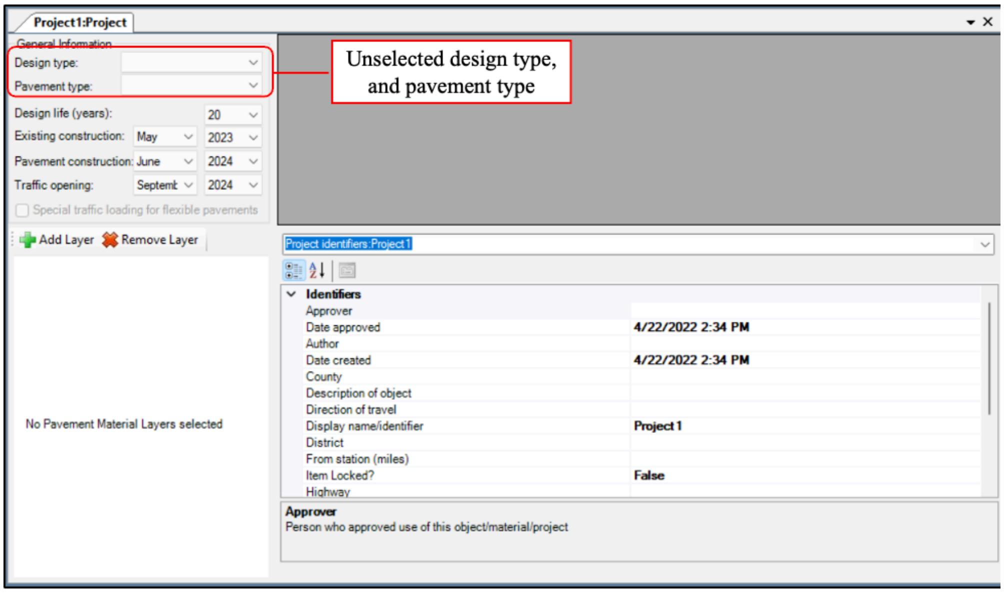


Figure 15. Unpopulated project tab pane

- **Property Grid**: Displays and allows the designer to change the selected item's layer properties, project identifiers, and calibration coefficients. The selected item properties will appear at the Property Page section, and a user can easily switch between different items by using the drop-down arrow located at the right side of the Property Control section as shown in Figure 16. In the Property Page, one of three different symbols will be seen in the box next to each property. These symbols are used to display the status of that property. The symbols are as follows: green check mark, yellow exclamation point, or red "X" as shown in Figure 17. The green check mark indicates that the value inputted is within the recommended range. The yellow exclamation point indicates that the value is not within the recommended range, but the analysis still can be run. The red "X" symbol indicates that either the input is outside the absolute maximum or minimum values or no value has been entered. Therefore, the program will not run until the values have been entered or changed. If the user clicks on any of the input values, a brief description of the selected input with the recommended range will appear in the Property Description section located at the bottom of the Property Grid pane. Figure 18 is an example of the populated Property Description area when selecting the air voids input for an asphalt layer.

Figure 16. Example of different item properties that typically appear in the Property Page

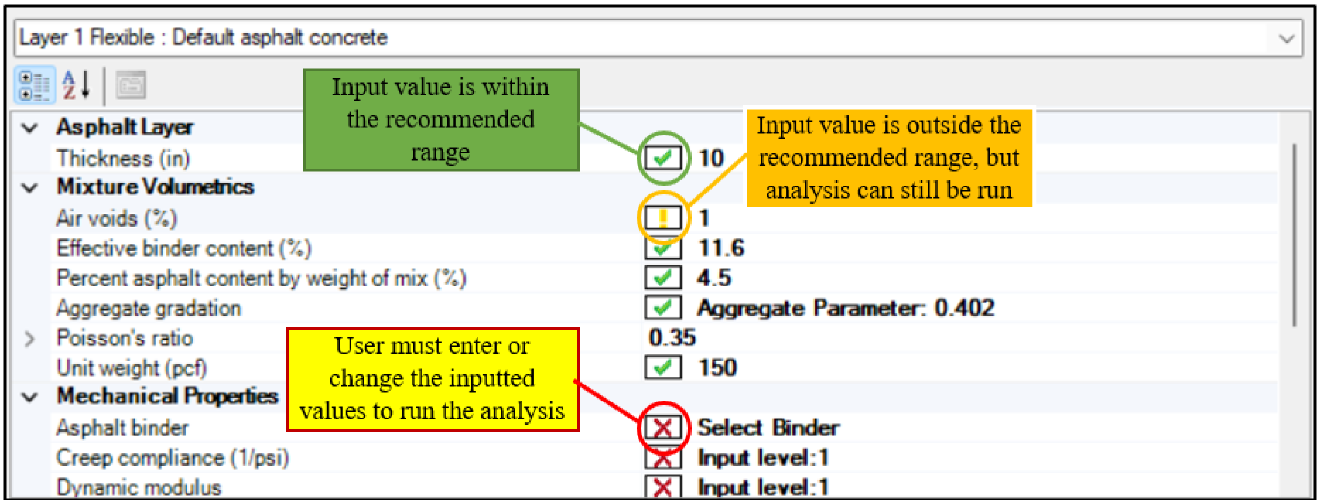


Figure 17. Property Page input color scheme

Figure 18. Property description pane for asphalt layer air voids input

3.4 Output Pane

The Output Pane displays the time when the user starts running the trial design analysis as well as displaying the time at the start and end of each step during the analysis run such as generating inputs, running integrated climatic model, and preparing thermal cracking. This helps the user to calculate how long each step or the completed analysis takes. An example of the generated Output Pane for a completed analysis run is presented in Figure 19.

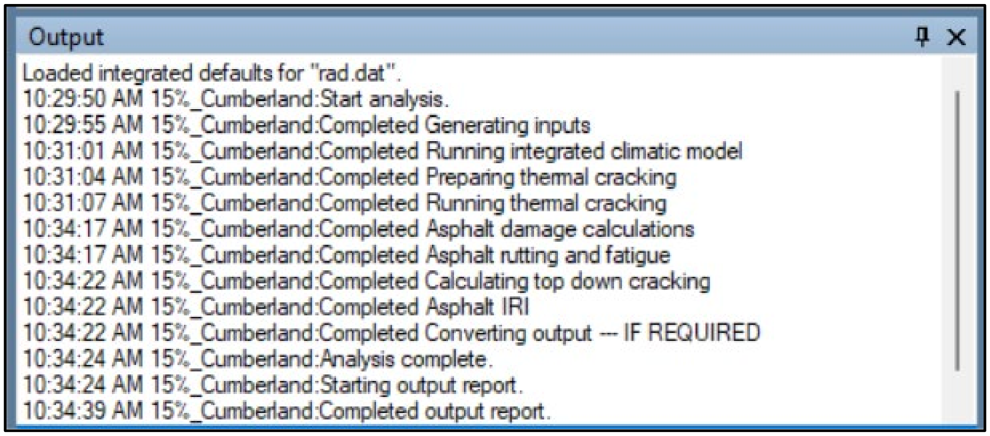


Figure 19. Output pane for asphalt layer air voids input

3.5 Compare Pane/Error List

The user can compare between two open projects through the Compare Pane/Error List. This is done by selecting the projects from the drop-down list beside "Compare To," then clicking on the "Run Compare" button to check the differences between the two selected projects as shown in Figure 20. The Error List displays any input warning messages (yellow "!") or the errors that must be addressed (red "X") to start running the analysis as presented in Figure 21. By double-clicking on any of the error messages that appear in the Error list, the software will take the user to the location of the error to allow for the user to correct the error.

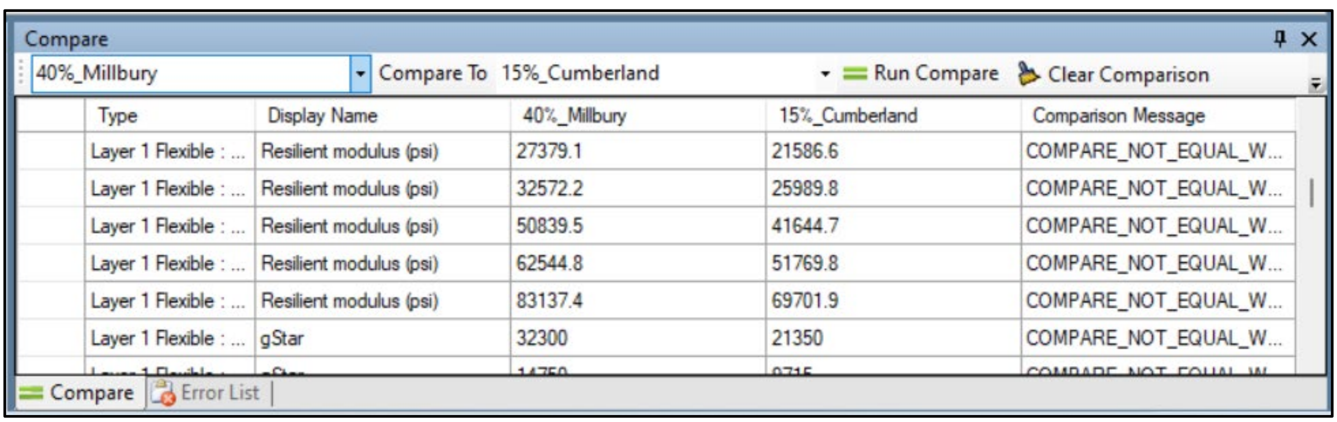


Figure 20. Example of the compare pane

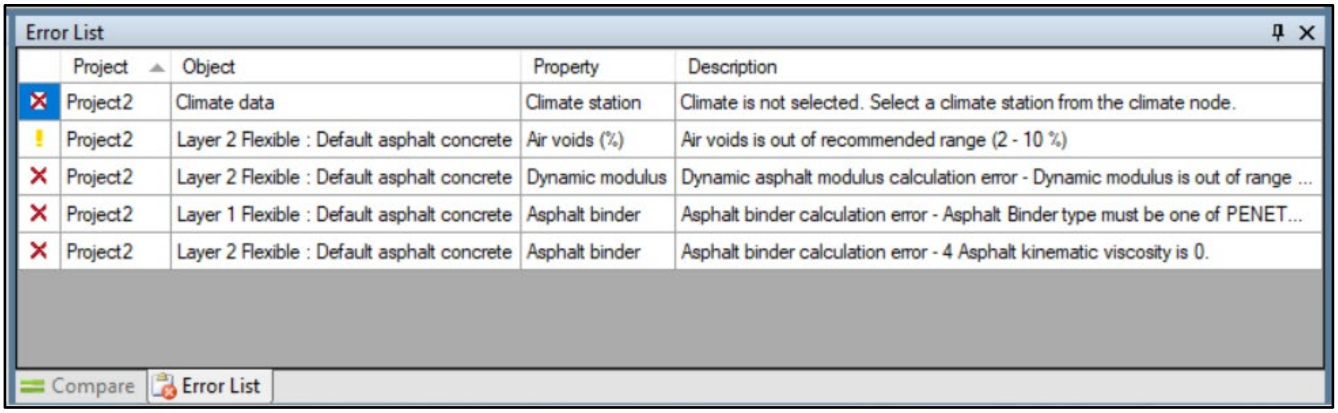


Figure 21. Example of the error list pane

3.6 Progress Pane

The Progress Pane displays the status of any ongoing analyses. The three symbols (green circle, yellow triangle, and red square) used in the Explorer Pane are used in the Progress Pane to show the status of each stage as shown in Figure 22. The user can terminate the ongoing analyses by clicking on the "Stop All Analysis" Button.

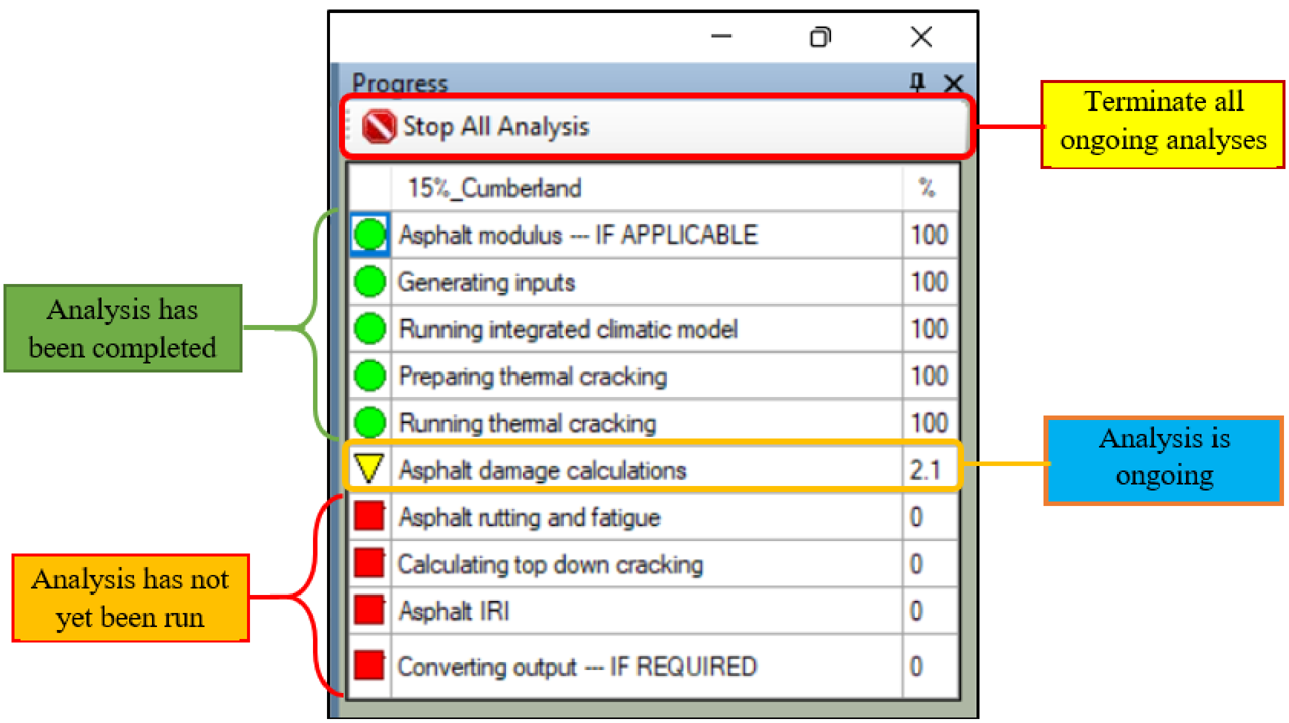


Figure 22. Progress pane

4.0 Flexible Pavement Design Process Using AASHTOWare Pavement M-E (Creating a New Project)

The AASHTOWare Pavement M-E Design process requires information to complete a design/analysis for a pavement structure. This section provides a complete step-by-step guide for creating, saving, and running an AASHTOWare Pavement M-E analysis/design. This example will emphasize flexible pavement.

To start the design process, the user must create a new project by opening the software, then creating a new project using one of three ways:

1. Clicking on the “New” button from the Menu bar,
2. Right clicking on the “Projects” folder located at the Explorer pane and selecting “New” from the drop-down list, or
3. Using a keyboard shortcut by pressing “Ctrl + N.”

Figure 23 presents the first two options for creating a new project.

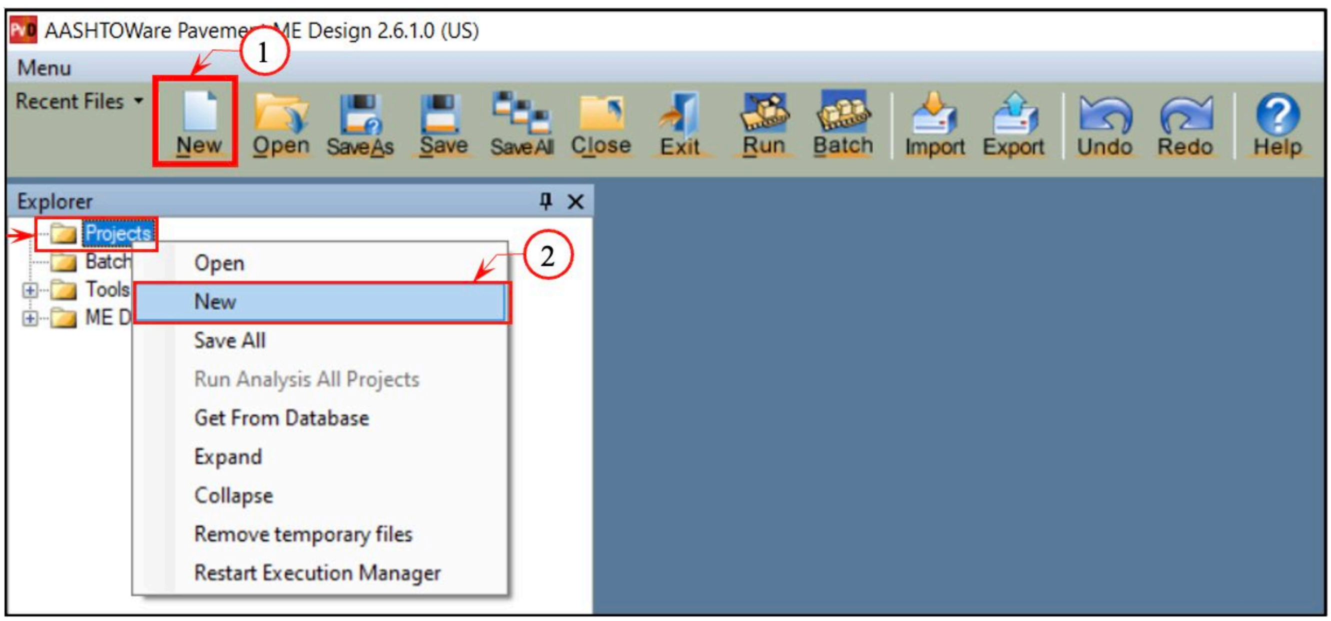


Figure 23. Creating a new project using AASHTOWare Pavement ME main screen

4.1 Input General Information (Design Type/Pavement Type/Design Life)

This section is located at the top left corner of the Project tab and is mainly used to select the basic parameters of the pavement design by providing information such as the design type, pavement type, and design life inputs as well as the construction and traffic opening dates. Figure 24 presents an example of the general design inputs necessary for a new flexible pavement design.

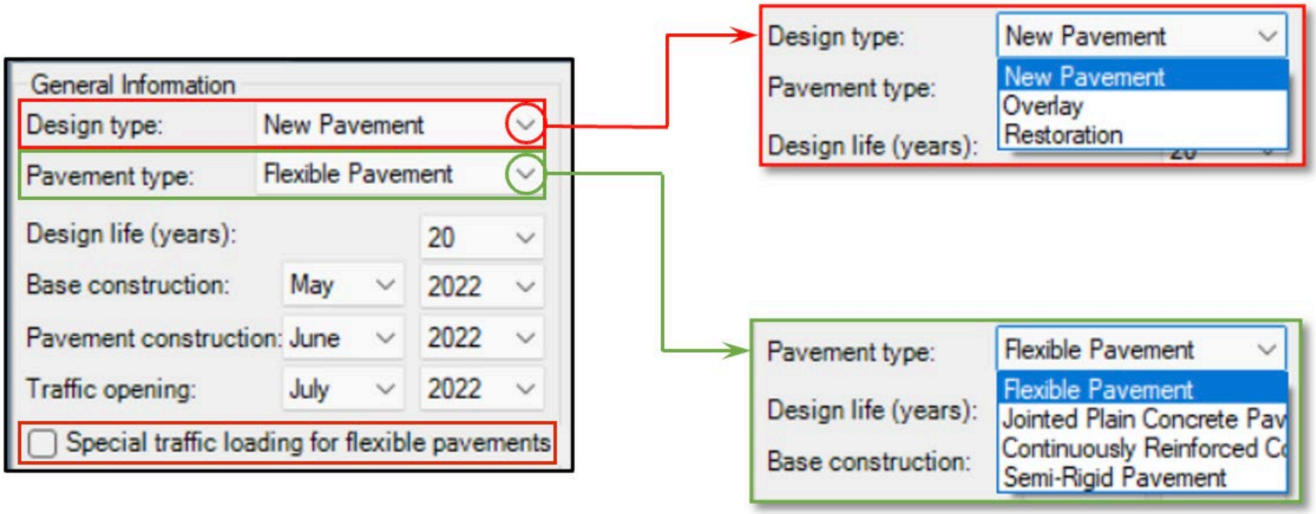


Figure 24. AASHTOWare Pavement ME General Information input pane

The design type options are New Pavement, Overlay, and Restoration. New Pavement is selected when designing a new project. The pavement type choices associated with New Pavement selected are: Flexible Pavement, Jointed Plain Concrete Pavement, Continuously Reinforced Concrete Pavement, and Semi-Rigid Pavement. The Design life (years) option allows the user to select the expected number of years after the completion of the project that the pavement should last. The AASHTOWare Pavement M-E Software will predict the performance on a month-by-month basis over the chosen design period. The selected Base construction date is used for predicting the moisture and temperature profiles of base and foundation layers. The Pavement construction date is important for calculating the change of AC layer properties due to time and environmental conditions. Traffic opening is the anticipated time when the project will be opened to traffic; this is the date the pavement performance prediction begins.

4.2 Input Performance Criteria

The evaluation of a trial design simulated using the AASHTOWare Pavement M-E Software is based on whether the predicted pavement distresses at the end of the design life meet the pavement performance criteria specified by the agency. The user can use the program default values or change performance criteria limits for each pavement distress based on the agency specifications. Figure 25 shows the performance criteria input table for a new flexible pavement design. The international roughness index (IRI) contains top-down and bottom-up fatigue cracking, thermal cracking, AC rutting, and total rutting for all pavement layers and subgrade layers. These distresses are critical to consider when designing a new flexible pavement. For each pavement distress, the user can easily set specific performance limits and reliability values based on the agency's policies. These values can be entered in the second and third columns in the performance criteria dialog box. The limit column is the maximum value of each distress that can be tolerated at the end of the design life, whereas the reliability value is the probability at which the predicted distress will not exceed that distress threshold over the design period. If the user would like a specific design criterion to not be included on the report once the analysis is run, the box in the Report

Visibility column next to that specific design criteria should be unchecked. By default, each criterion will appear in the report unless the user unchecks the box. It should be noted that the predicted distress must be lower than the maximum limit and the reliability must be higher than the target value at the end of the design life in order to consider that trial design as a sufficient pavement design.

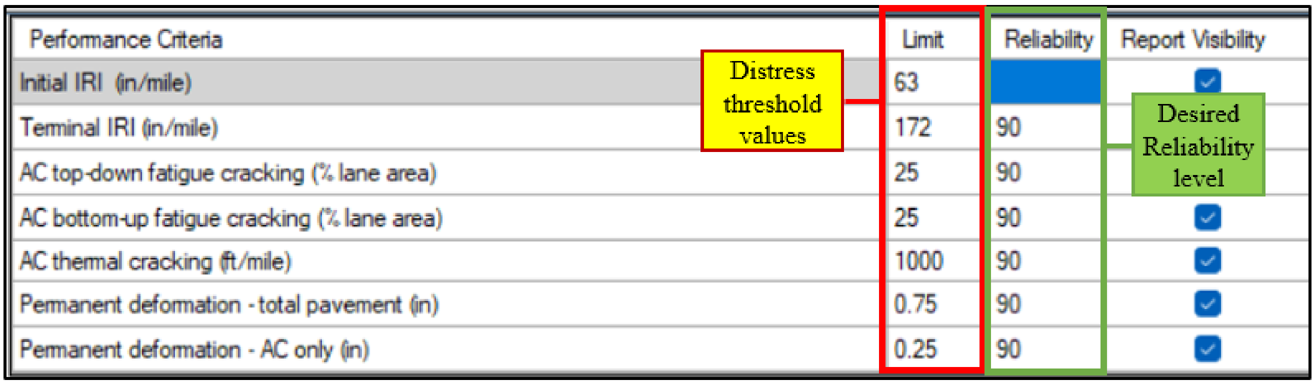


Figure 25. AASHTOWare Pavement ME Performance Criteria dialog box

4.3 Input Traffic Data

The traffic data is a key input for a pavement structure being designed using AASHTOWare Pavement M-E. The user can access the traffic interface as shown in Figure 26 by (1) double-clicking on the Traffic node located in the Explorer tab under the Projects folder; or (2) clicking on the tire symbol that appears in the Pavement Structure pane. The populated Traffic input tab will appear at the Pavement ME tabs zone (Figure 27), where the user can enter traffic inputs based on the available traffic data. It should be mentioned that the Pavement ME tabs zone uses a hierarchical approach with three levels (1, 2, and 3) to define the traffic data inputs. The user can either use the software's default values or the project's agency values when there is a lack of traffic data available for the trial design. The average annual daily truck traffic (AADTT) inputs and the growth rate input are the most fundamental traffic inputs that are required for all hierarchical input levels. The AADTT input area is associated with the two-direction base year truck's volume and speed and described as follows:

1. **Two-way AADTT**: the average annual daily truck traffic (AADTT) during the base year in both directions. AADTT is required for pavement design/analysis of all hierarchical input levels.
2. **Number of lanes**: the proposed number of lanes in the design direction that are used to estimate the traffic in the design lane.
3. **Percent trucks in design direction:** the percentage of trucks that are expected to be in the design direction. The design direction is the direction that is expected to carry the most load or typically the direction with a fewer number of lanes.
4. **Percent trucks in design lane:** the percentage of trucks in the design direction or that are expected to use the design lane.

5. **Operational speed (mph):** the expected traveling speed in the design lane, which consequently impacts the loading frequency of asphalt layers.

Figure 28 presents a screenshot of the AADTT input area.

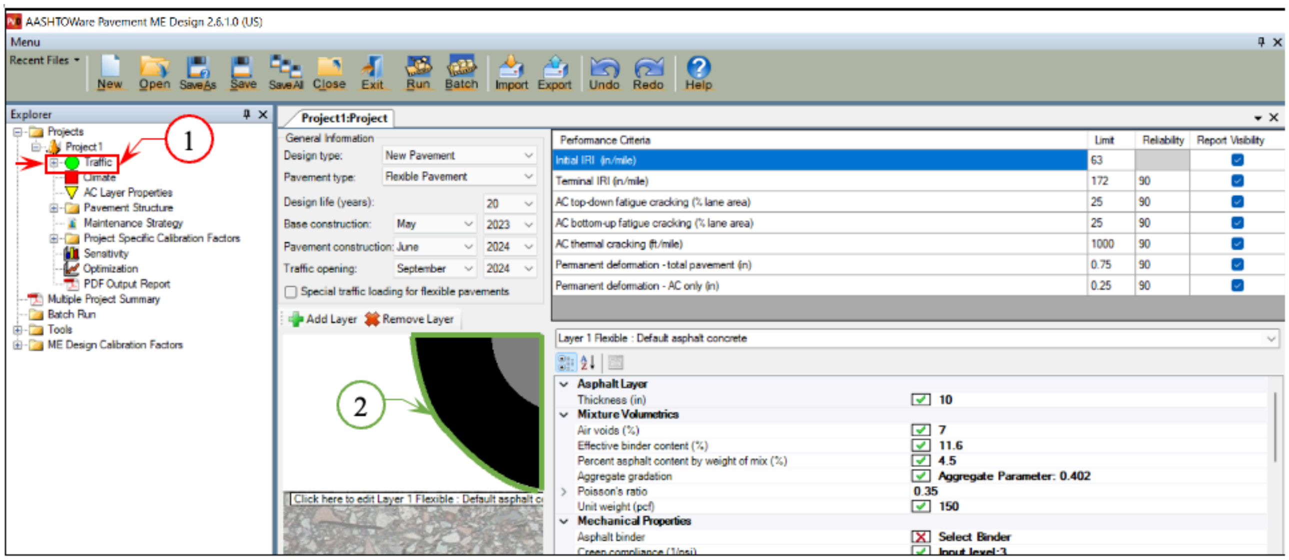


Figure 26. Accessing the Traffic input tab

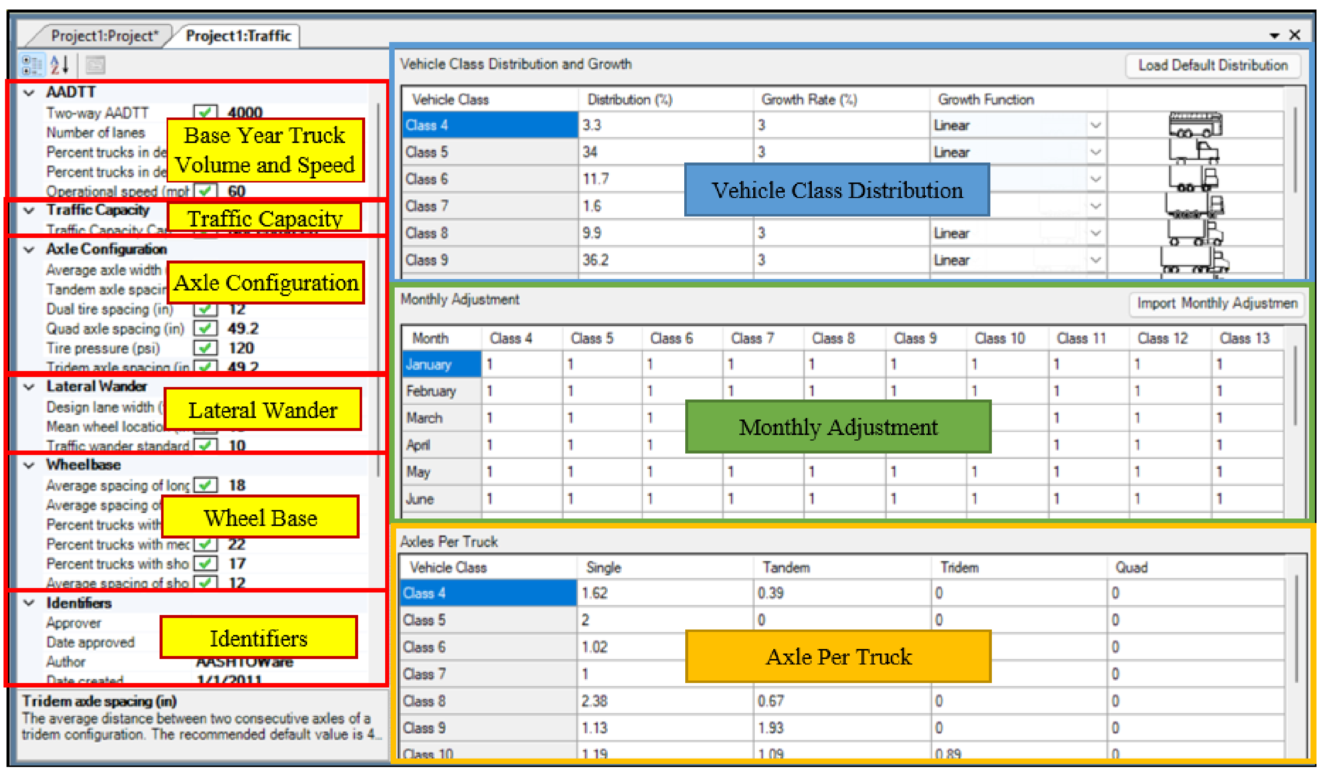


Figure 27. AASHTOWare Pavement ME performance traffic input section

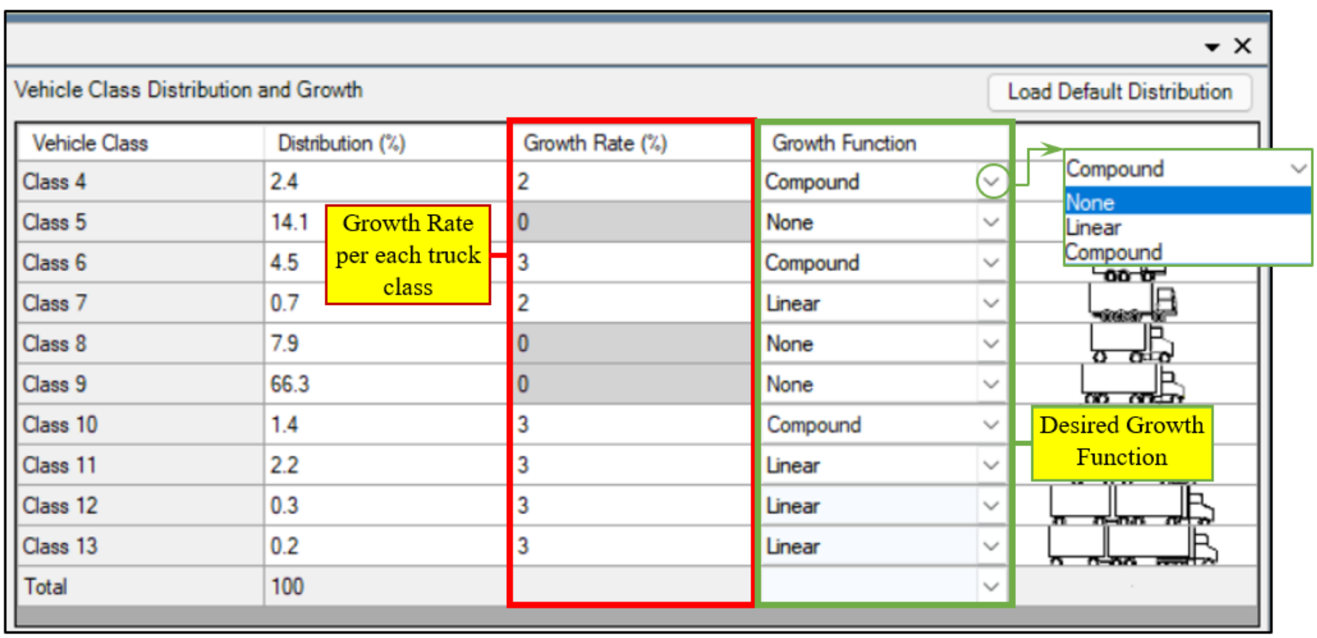
AADTT	
Two-way AADTT	4000
Number of lanes	2
Percent trucks in design direction	50
Percent trucks in design lane	95
Operational speed (mph)	60

Figure 28. Screenshot of the AADTT input area

The growth factors for trucks are important inputs that are used to estimate the increase of trucks over time. The AASHTOWare Pavement M-E Software allows the user to select different growth rates and growth functions for each truck class (Class 4 to Class 13). There are three options for the growth function:

1. **None** means that the truck volume of that class would remain constant during the design life.
2. **Linear** is used when the truck volume increases by a constant percentage from the base year at a defined rate per truck class.
3. **Compound** is used if a truck volume is expected to increase by a constant percentage from the previous year traffic across each truck class.

Figure 29 shows the growth rate and growth function columns located in the Vehicle Class Distribution area. The Growth Rate (%) can be edited by double-clicking on the appropriate box and typing the desired growth rate value. The Growth Function can be changed from the drop-down arrow located at the right side of the Growth Function column.



Vehicle Class	Distribution (%)	Growth Rate (%)	Growth Function
Class 4	2.4	2	Compound
Class 5	14.1	0	None
Class 6	4.5	3	Compound
Class 7	0.7	2	Linear
Class 8	7.9	0	None
Class 9	66.3	0	None
Class 10	1.4	3	Compound
Class 11	2.2	3	Linear
Class 12	0.3	3	Linear
Class 13	0.2	3	Linear
Total	100		

Figure 29. Screenshot of Vehicle Class Distribution input area

4.4 Input Climate Data

The environmental conditions have a significant effect on the predicted pavement performance as the temperature and moisture contents of unbounded layers are directly affected by the climatic characteristics such as precipitation, temperature, freeze-thaw cycles, and water table depth. Moreover, the environmental factors affect the stiffness of asphalt concrete (AC) layers.

The AASHTOWare Pavement M-E Software requires temperature, precipitation, wind speed, percent sunshine, and relative humidity data to predict the temperature and moisture profiles within the pavement structure during the design life, and these may be obtained from the weather stations located near the project location. The user can easily define and select one or more weather stations that are close to the project. The climate section on the AASHTOWare Pavement M-E Software can be accessed as shown in Figure 30 by (1) double-clicking on the Climate node located in the Explorer tab under the Projects folder; or (2) clicking on the white area within the image of a tire on pavement.

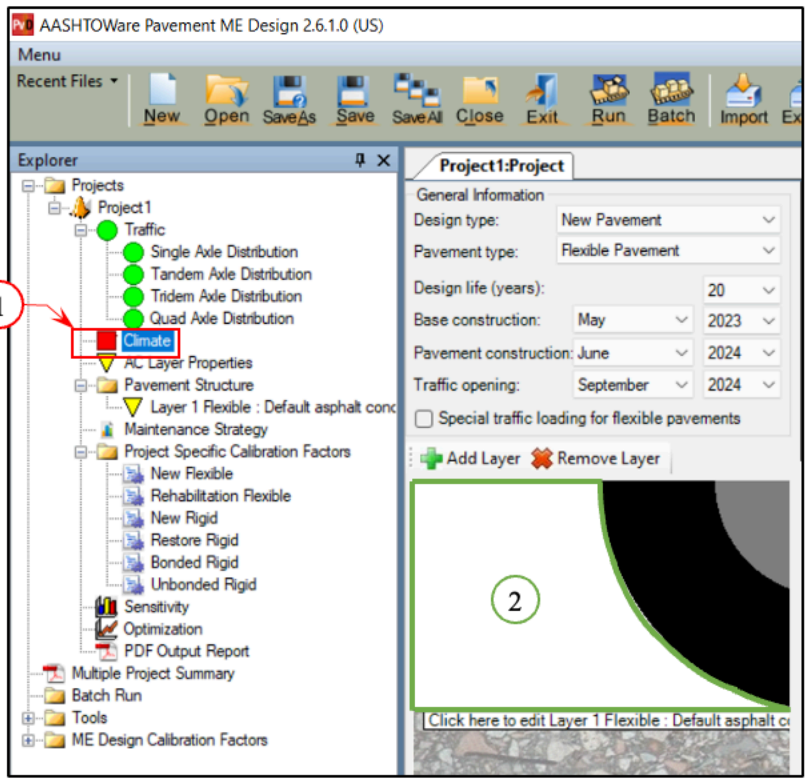


Figure 30. Accessing the Climate input tab

The software will open the climate input tab at the Pavement ME tabs zone as shown in Figure 31. The user can navigate around the Google map by rolling the wheel of the mouse to zoom in and out; the user can also pan by holding down the left button and moving the mouse. This can also be done by using the "+" button to zoom in and the "-" button to zoom out. Also, another way to navigate the map would be by typing the closest location to the project in the search bar and pressing "Enter" as shown in Figure 32 and Figure 33. If the user double-clicks on a location on the map (the closest location to the project), a yellow pushpin will pop up. The nearest available climate grid point locations in the climate data set will be displayed. This is where the user can show more weather stations by clicking on the show more markers button. After clicking the button, more available weather station grid point locations will be displayed as presented in Figure 30. The displayed climate grid points will either be blue or red icons. The blue icon indicates that the weather station data is stored in the AASHTOWare Pavement M-E Software program folder, and the red icon means that the climate data is not included at the program folder. Therefore, the user must download it to use that weather station; this will be explained in the following pages. If the user moves the cursor over any weather station, the latitude, longitude, and elevation data for that weather station will appear as shown in Figure 34.

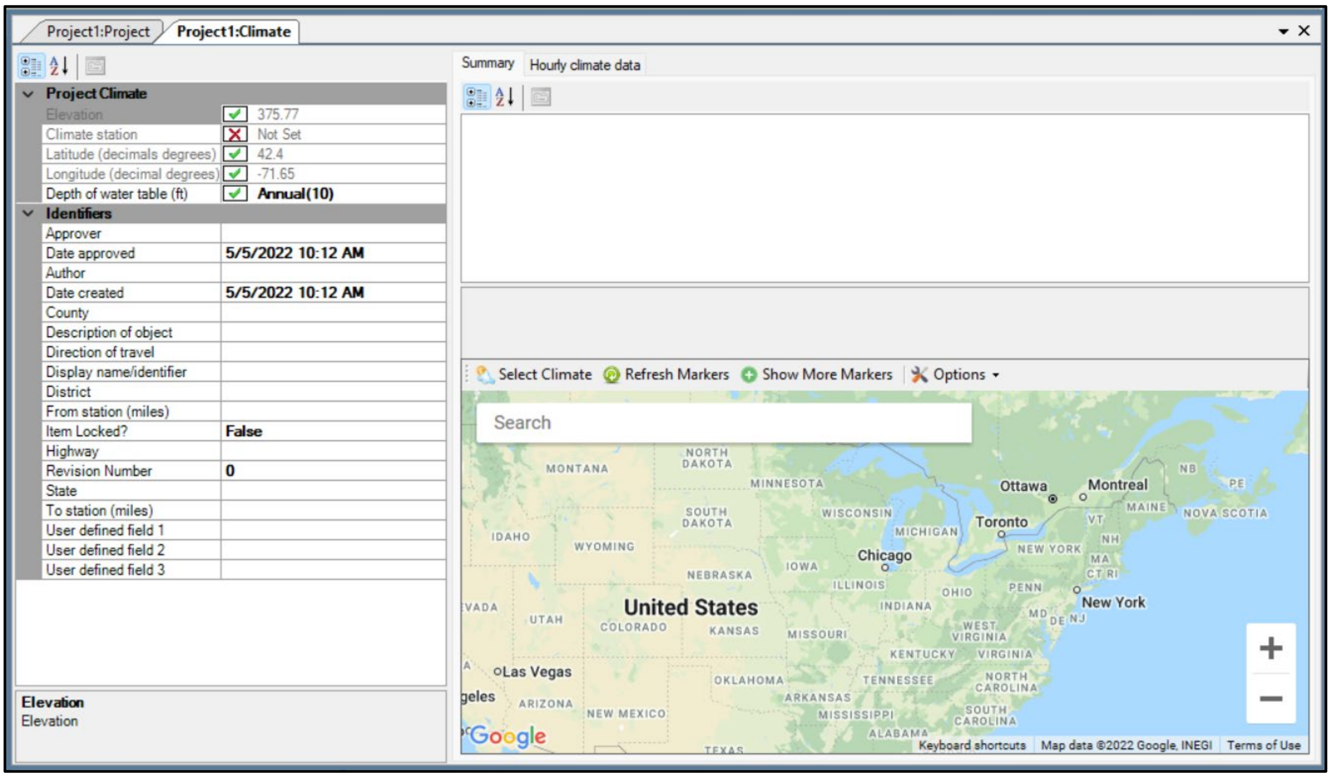


Figure 31. AASHTOWare Pavement ME performance climate input area

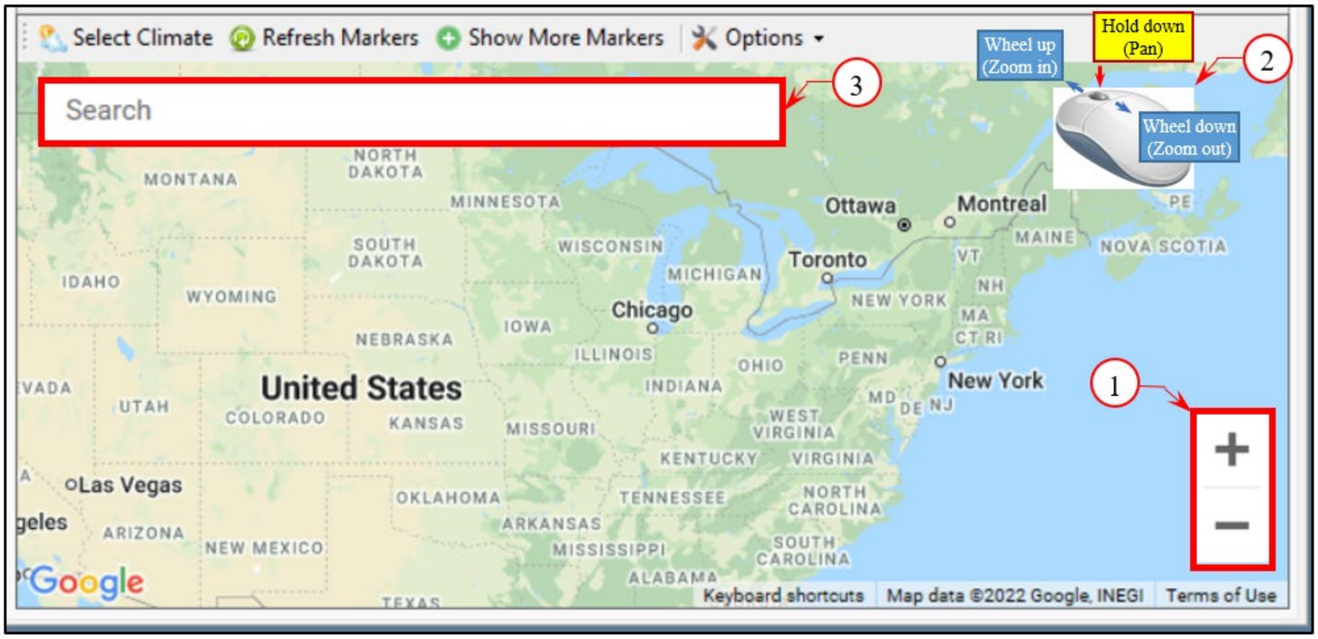


Figure 32. Different methods for selecting climate location

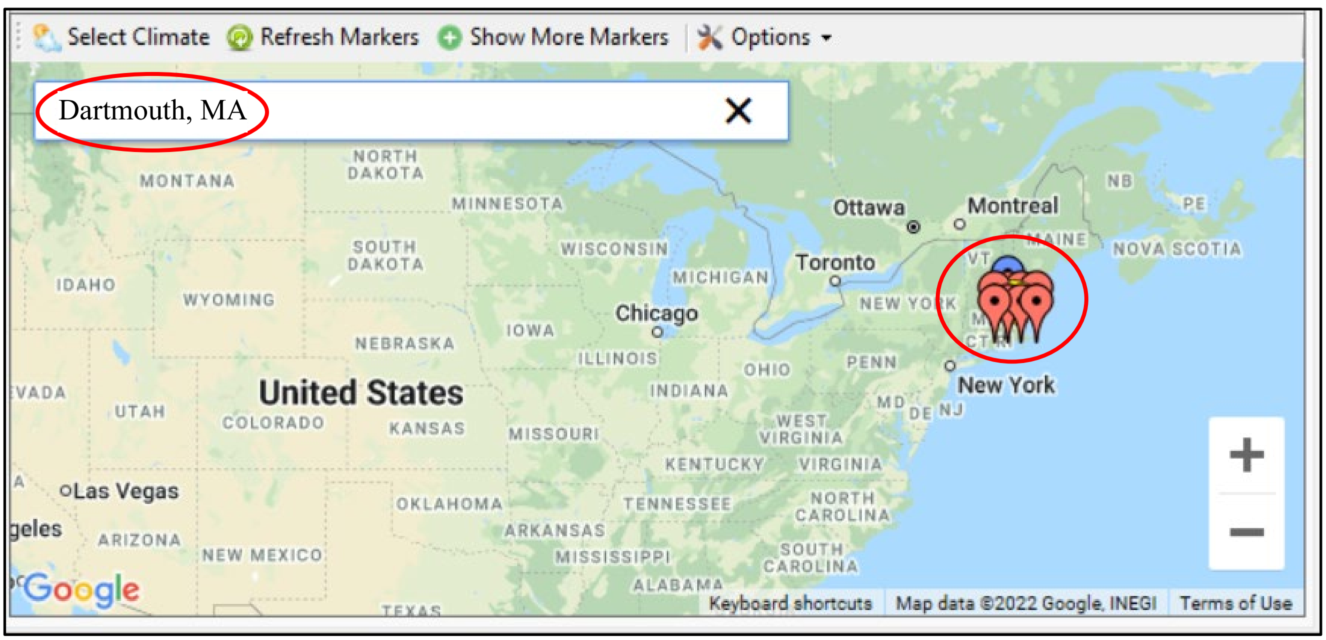


Figure 33. Select climate location using the search bar

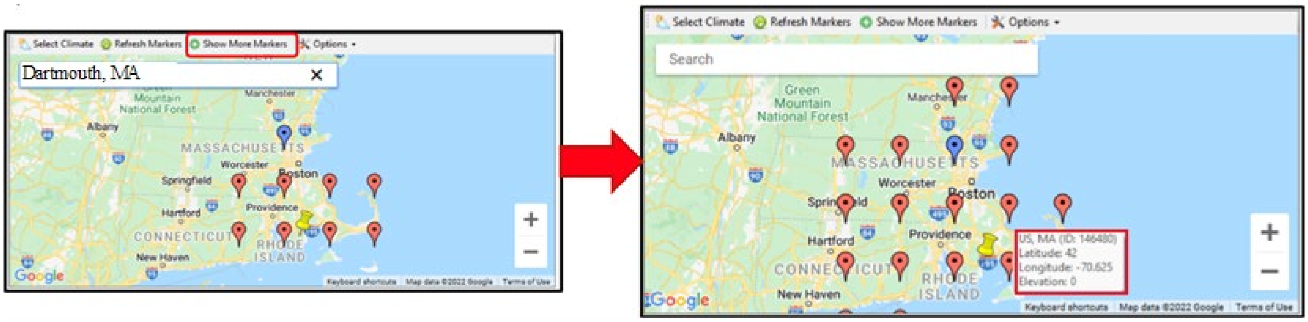


Figure 34. Select the desired location directly on the map

The following procedure depicts the steps for downloading a weather station climate file (red markers):

1. Click on the weather station marker, then a new window will pop up with the LTPP InfoPave website as shown in Figure 35. The LTPP InfoPave website will display a map and various search features. If the InfoPave website does not_display a map, then the user's default internet browser is not compatible with LTTP InfoPave. In order to complete this step, open LTTP InfoPave on a different browser such as Google Chrome. The website can be found by searching "MERRA Climate Data for MEPDG Inputs" or by using this link: https://infopave.fhwa.dot.gov/Tools/MEPDGInputsFromMERRA. The subsequent steps will be the same once the browser is switched.

2. At the search bar, enter the latitude and longitude for the desired weather station. This can be easily obtained by hovering over the weather station icon in the AASHTOWare Pavement ME Google map (Figure 34); then click the search button as shown in Figure 36.

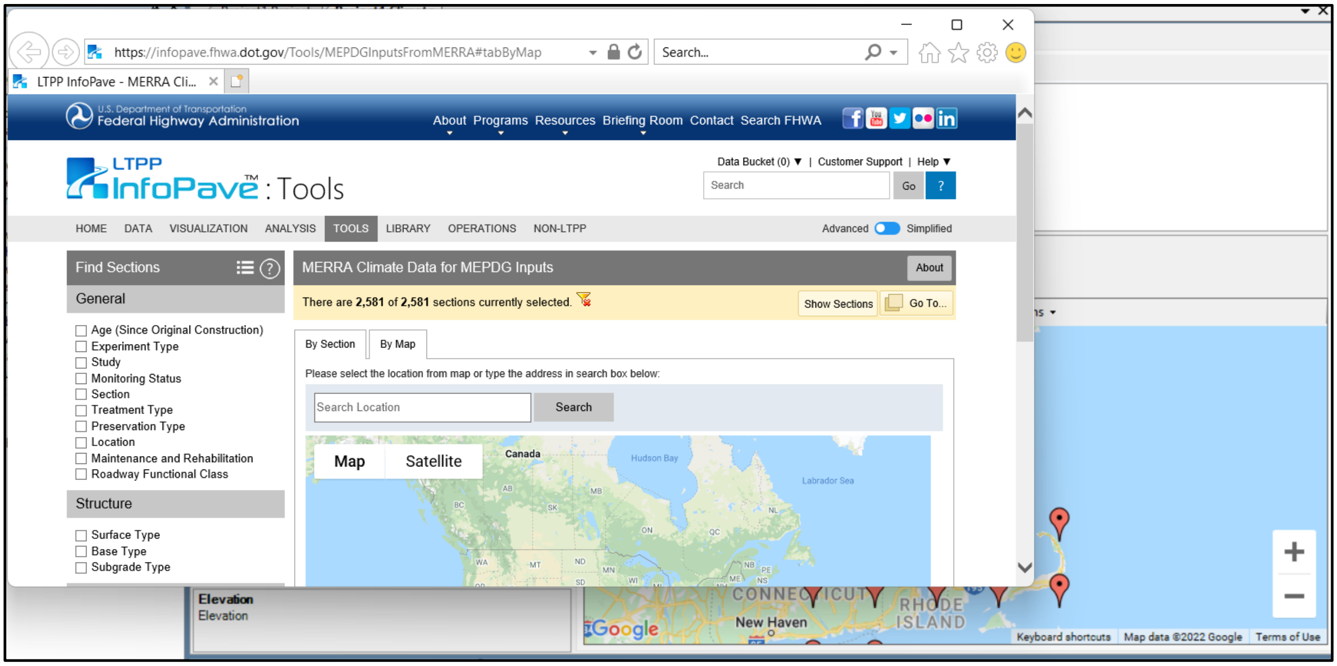


Figure 35. Clicking on a red weather station marker to access the LTPP InfoPave website

3. The selected weather station will appear. Scroll down, then select "US Customary" units; then click on "Download MERRA Climate Data File (.hcd)"; finally click the download button in the popped-up window as shown in Figure 37.

4. Select "Save as" as shown in Figure 38 and make sure that the file will be saved under the correct file path "This PC\C:\ProgramData\AASHTOWare\ME Design\HCD" as shown in Figure 39; then press "Save"; then "Open folder"; then extract the climate zipped folder ".zip" into in the main folder (HCD folder) as shown in Figures 40 and 41. If the "Save as" dialog box does not appear, change browsers and use Internet Explorer.

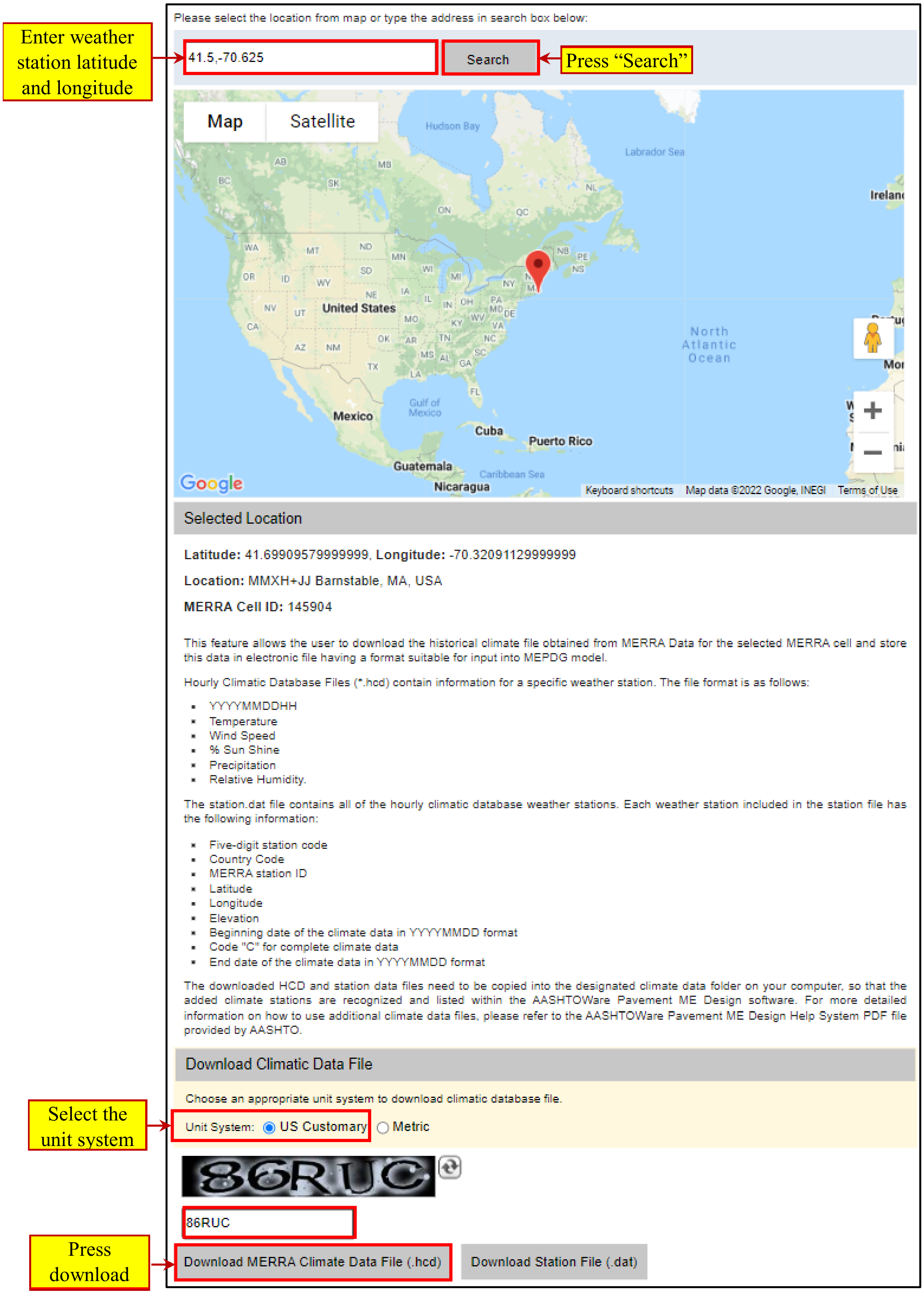


Figure 36. Downloading a climate data file for a specific location

Figure 37. Click Download to save the requested climate data file to the computer

Figure 38. Saving the requested climate data file at a desired path

Figure 39. Example Path for the climate data file

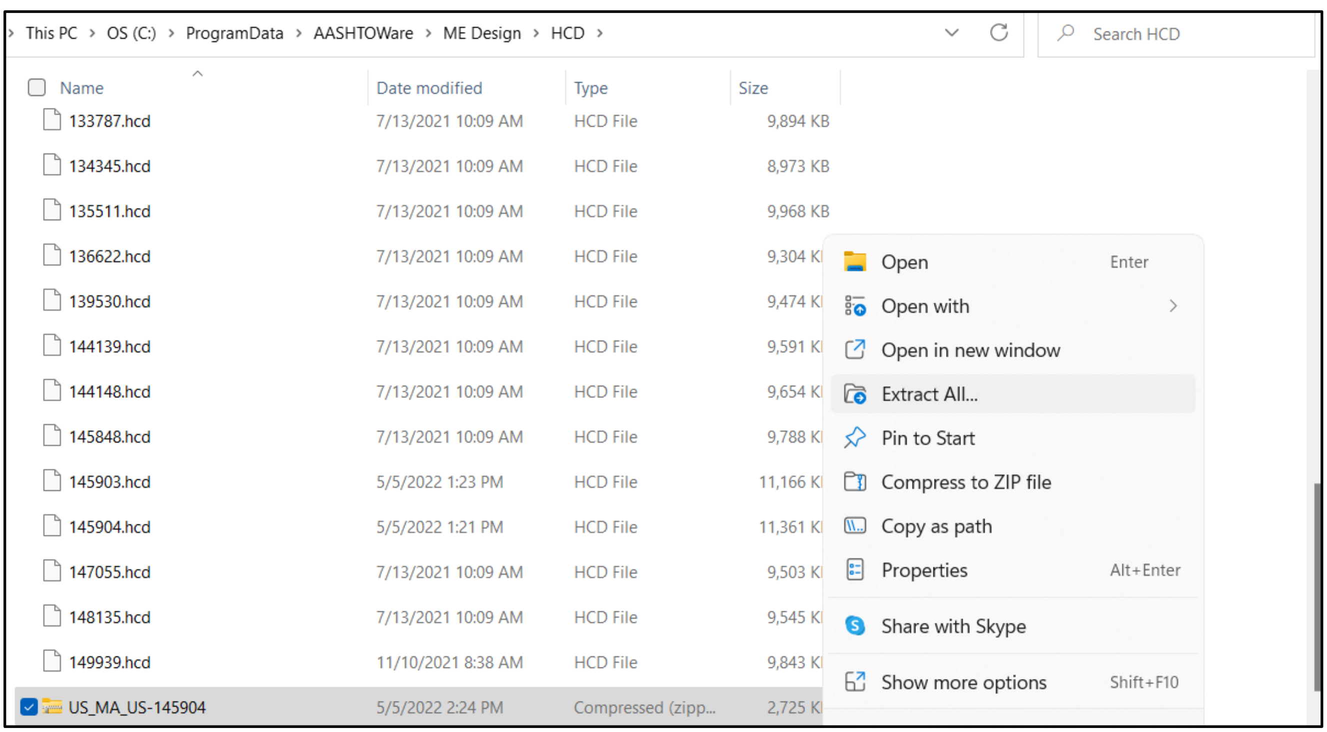


Figure 40. Extracting the climate data folder as a ".zip" file

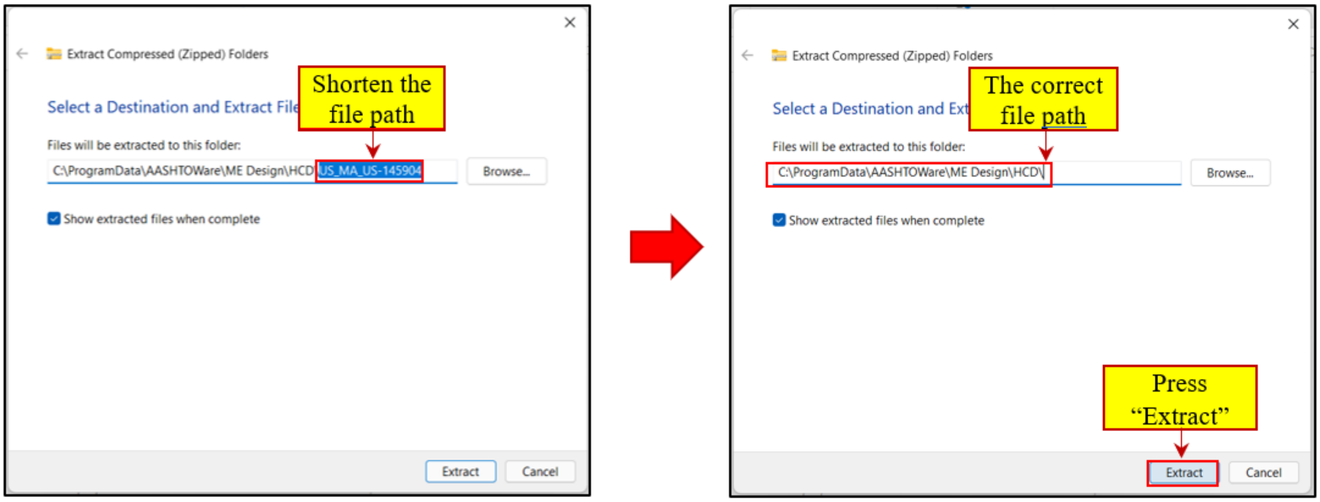


Figure 41. Selecting the correct path of the extracted climate data file

5. This process can be repeated for each climate data file needed to be included in the AASHTOWare Pavement ME Design Software.

6. If the user goes to the AASHTOWare Pavement ME Design climate input tab and clicks on the Refresh Markers button, the red icons for weather stations that have been downloaded will no longer be red and will change to blue icons as shown in Figure 42. This means that the weather stations' data have successfully downloaded, and the software has been able to retrieve it. If the red icons for the downloaded stations have not turned blue, the user most likely downloaded the weather data files into the wrong folder. In this scenario the user must check to see if the data was saved to the correct location.

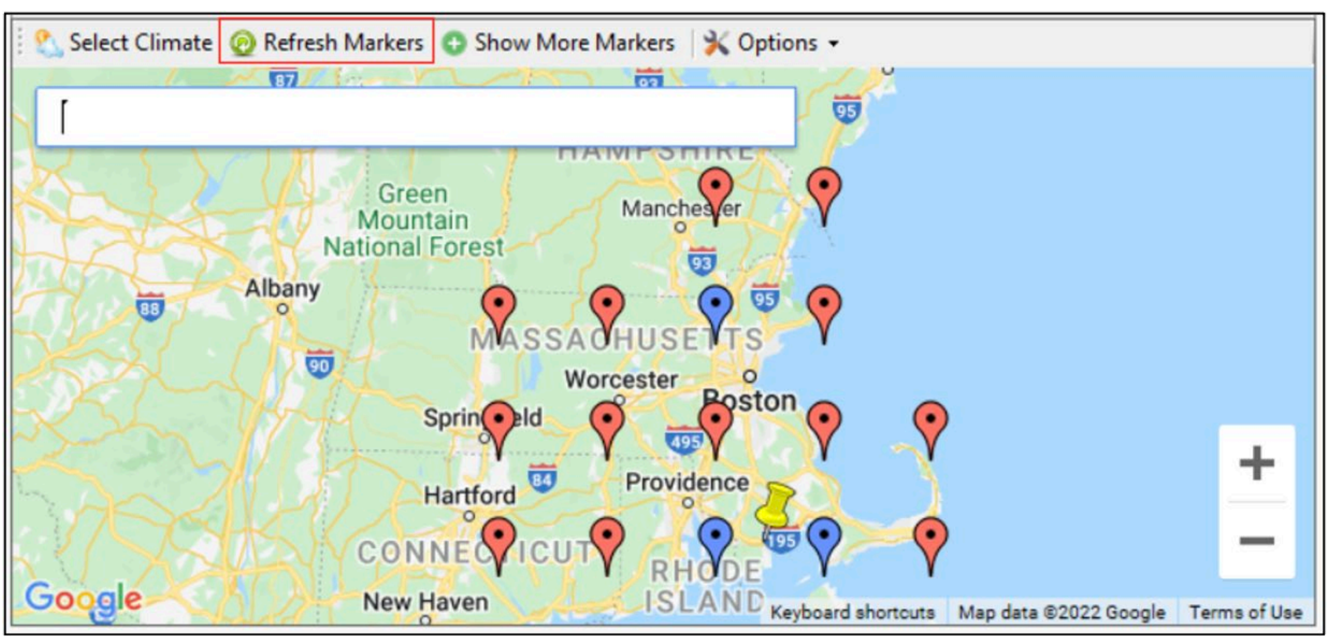


Figure 42. Click on Refresh Markers to update the available weather stations

7. Now, the user can select the climate station. There are two options for choosing a weather station: (a) select a single weather station that is the closest to the project location; or (b) create a virtual weather station by selecting up to six stations around the project location. Selecting a single weather station is not recommended because any missing data or error will not allow the software to run the analysis. The best practice is to choose multiple weather stations that have similar elevations as the project site, thereby creating a virtual weather station.

8. To create a virtual weather station, click on the desired blue icons; then their color will change to green as presented at Figure 43; then click on the "Select Climate" button, which will turn the yellow push pin into a white flag. The climate input node indicator (red square) located in the Explorer Pane will be converted into a green circle, indicating the climate data was successfully loaded for the project as shown in Figure 44.

9. The depth of the water table (at the project location) from the top surface of the subgrade can be adjusted to either the annual or seasonal average value, if necessary (Figure 45).

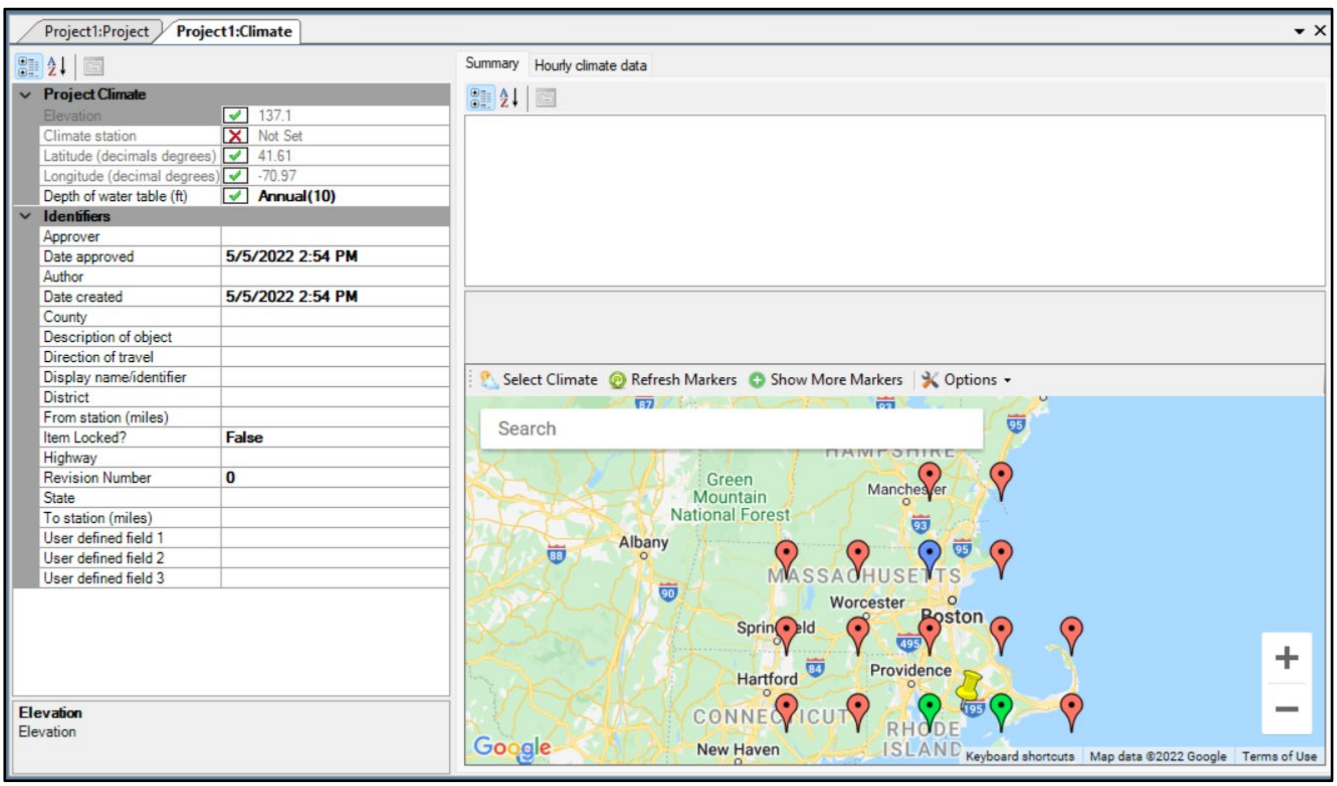


Figure 43. Click the blue markers necessary to create the virtual weather station

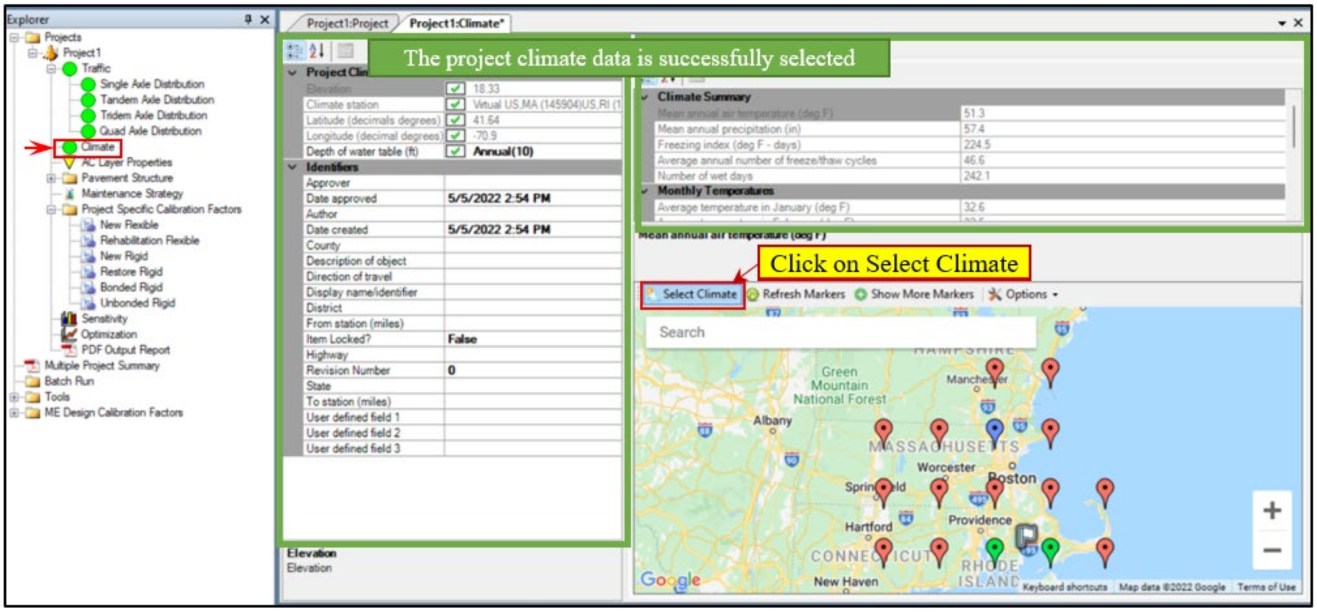


Figure 44. Click the Select Climate button to create a virtual weather station

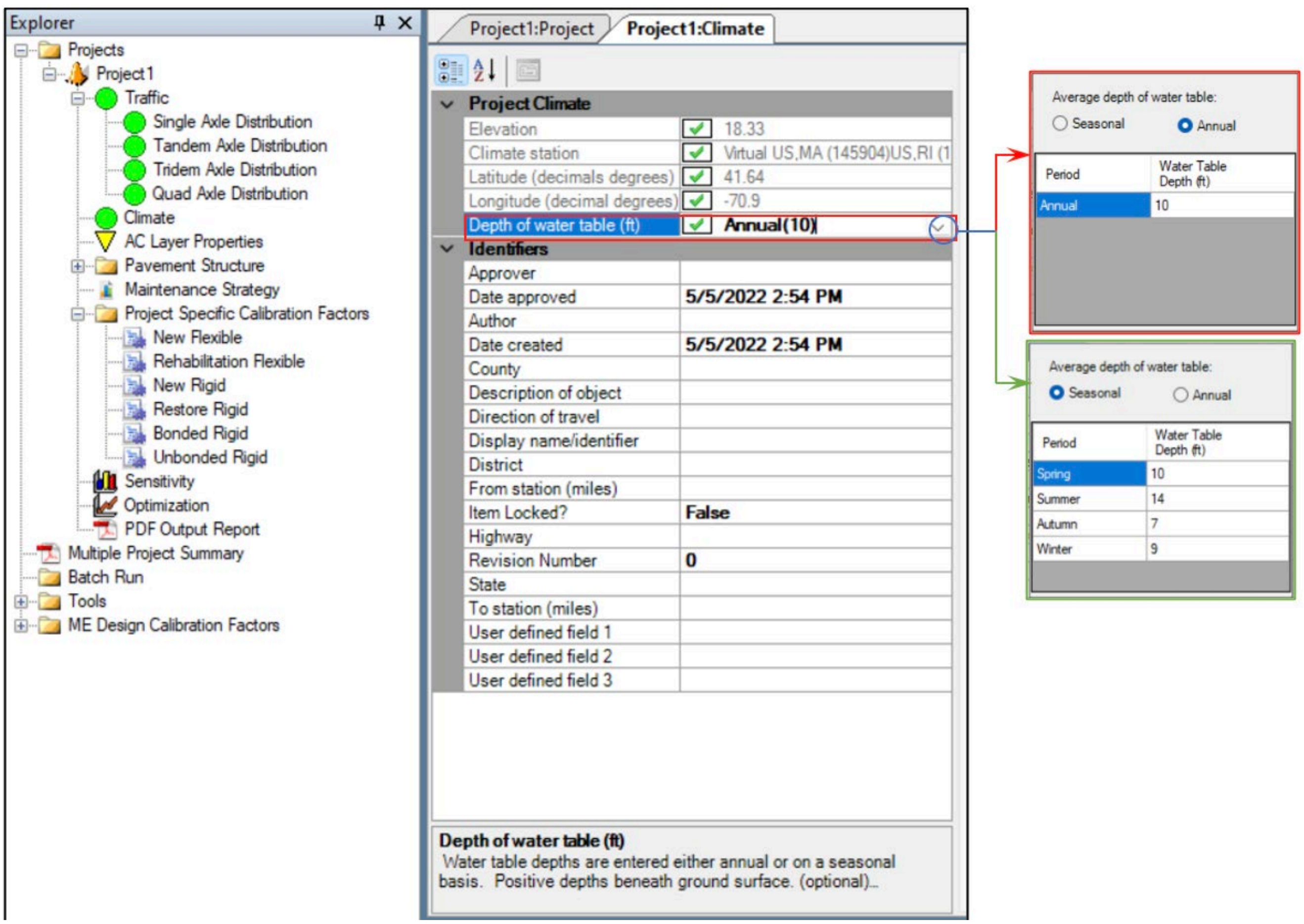


Figure 45. Enter the desired annual or seasonal water table depth below the subgrade surface

4.5 Define New Flexible Pavement Structure and Materials

In the AASHTOWare Pavement ME Design Software, the user can begin developing a trial design by changing "Design Type" and "Pavement Type" from the "General Information" area at the main Project tab (Figures 13 and 24). The software will automatically generate an initial pavement structure that will appear in the "Pavement Structure" pane. Figure 46 presents the pavement structure generated by selecting "New Pavement" and "Flexible Pavement" from the "Design Type" and "Pavement Type" drop-down menus.

<u>*4.5.1 Pavement Layers (Add/Remove/Change Properties)*</u>

The user can change the properties of the inserted default layer in addition to adding or removing pavement layers (AC, base, subbase, and subgrade layers). This can be done by clicking on the "Add Layer" button or using the "Remove Layer" button as presented in Figure 46.

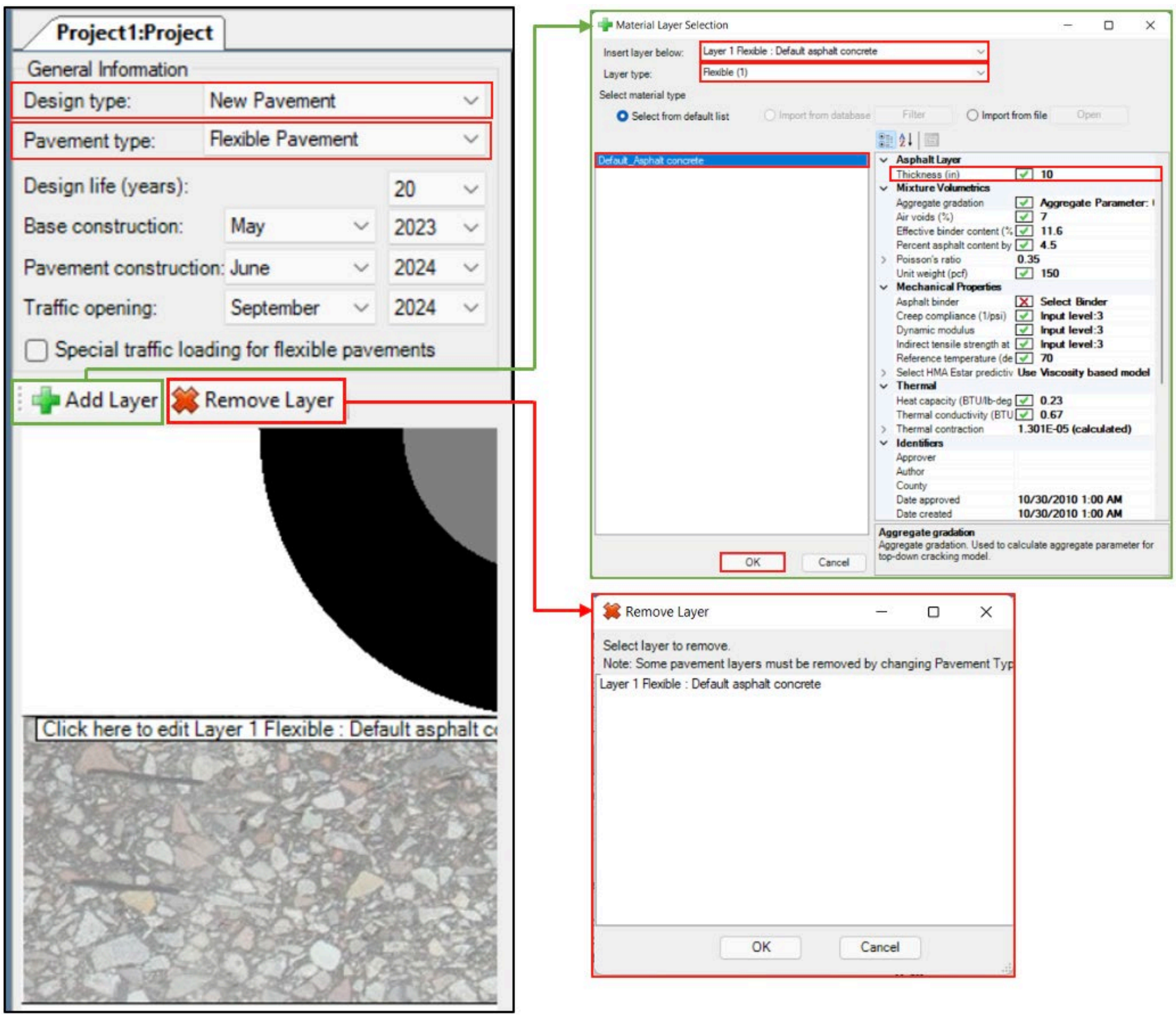


Figure 46. Generated pavement structure for a New Pavement design type and Flexible Pavement type

When the user clicks on the “Add Layer” button, a new window called “Material Layer Selection” will pop up. There the user will be able to change the position of the new layer below any of the existing layers, the layer type, and the material (from the list on the left). This allows the initial material layer inputs such as the AC layer thickness to be specified. To confirm this the user must press the “OK” button.

The user can also enter or edit the properties of any pavement layer from the Property Page located within the property grid zone (Figure 17). There the layer properties can be accessed through one of three ways (Figure 47):

1. Double-clicking on the layer node located in the Explorer Pane under the “Pavement Structure” folder.
2. Clicking on the pavement material layer on the virtual pavement cross section presented at the “Pavement Structure” zone.
3. Using the drop-down arrow located at the right side of the Property Control area.

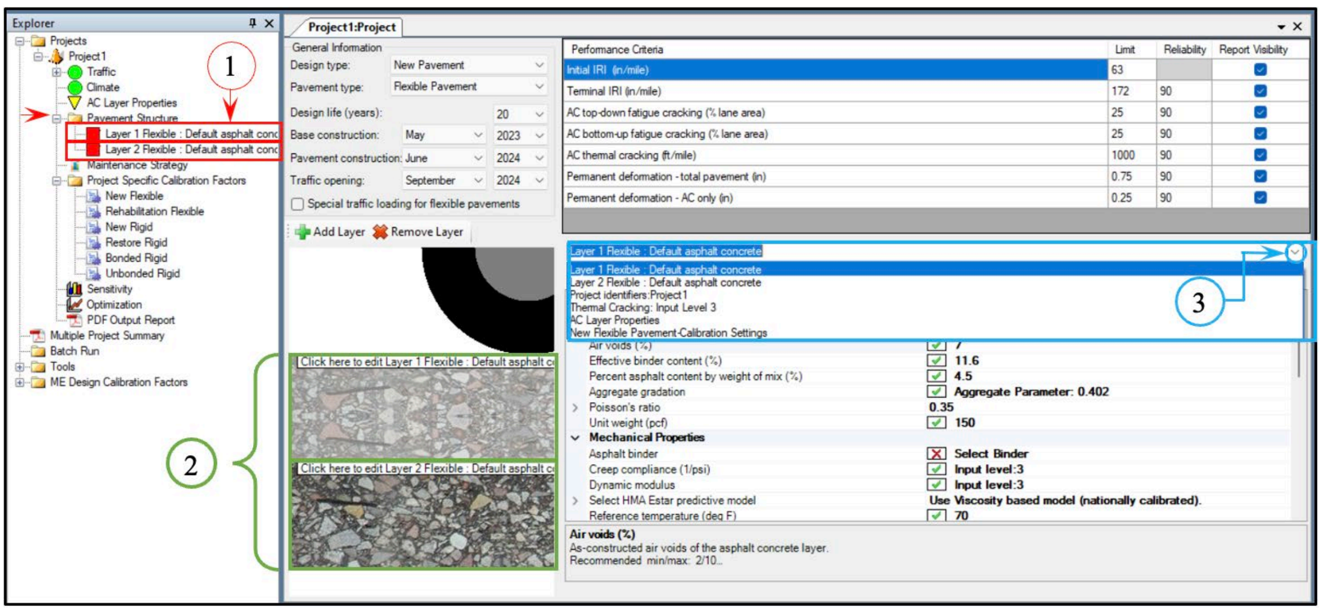


Figure 47. Accessing the properties of a pavement layer

4.5.1.1 Hierarchical Input Levels (Levels 1–3)

One of the main advantages of the AASHTOWare Pavement ME Design Software is the flexibility while inserting data for the trial design by using hierarchical input levels for traffic loading, environmental conditions, and material characterization. The AASHTOWare Pavement ME Design Software provides a hierarchy of three levels for characterizing the material properties based on the importance of the project, the availability of materials, and quality of materials. These levels are as follows:

- **Level 1**: Inputs include engineering properties of materials. These properties are typically obtained from direct testing or measurements such as the dynamic modulus for asphalt concrete or the resilient modulus for unbound materials. Level 1 has the highest level of accuracy and is typically recommended for projects having unusual characteristics for their sites such as odd materials, unusual climates, or extreme traffic conditions.

- **Level 2**: Inputs are estimated through empirical correlations or regression equations (such as predictive models) to be able to predict dynamic moduli values for asphalt concrete at the different frequencies and temperatures or resilient moduli estimated from California bearing ratio (CBR). Level 2 provides an intermediate level of accuracy and can be used for routine projects or when there is a lack of resources and/or testing equipment.
- **Level 3**: Inputs are default values selected from global or regional default values (such as soil classification) to determine the range of resilient moduli. Level 3 has the lowest level of accuracy and is appropriate for minor projects such as low traffic roads.

Users can use different levels of inputs based on the available data while the AASHTOWare Pavement ME Design Software provides a combination between different levels. For example, the software may use a combination of the asphalt dynamic modulus for Level 1, the R-values of unbound materials and subgrade for Level 2, and the subgrade resilient modulus for Level 3.

The following subsections explain the steps used to define material properties for a new flexible pavement structure that includes AC, base, subbase, and subgrade layers.

4.5.2 Asphalt Binder and Mixture Properties for a New Asphalt Concrete Layer

For a new flexible pavement design, the AASHTOWare Pavement ME Design Software allows the user to insert up to three new asphalt concrete layers. Typically, these layers are surface, intermediate, and base. Therefore, if the proposed pavement structure contains more than three AC layers, the asphalt layers with similar HMA mixtures may be combined into a single layer. The user is required to input the volumetric and mechanical properties for each AC layer. The volumetric properties include air voids (%), effective binder content (%), aggregate gradation, and mix unit weight. Mechanical properties such as the dynamic modulus, creep compliance, indirect tensile strength of AC mixtures, the complex shear modulus (G*) and phase angle (δ) at multiple test temperatures and a frequency of 10 rad/sec, or viscosity versus temperature properties of rolling thin film oven (RTFO) aged asphalt binders. These inputs can be entered into the software based on the available data and the importance of the project following the hierarchy of levels where the user can combine between different levels. Figure 48 shows the property page for a new asphalt surface layer that consists of five sections: Asphalt Layer, Mixture Volumetrics, Mechanical Properties, Thermal Properties, and Identifiers.

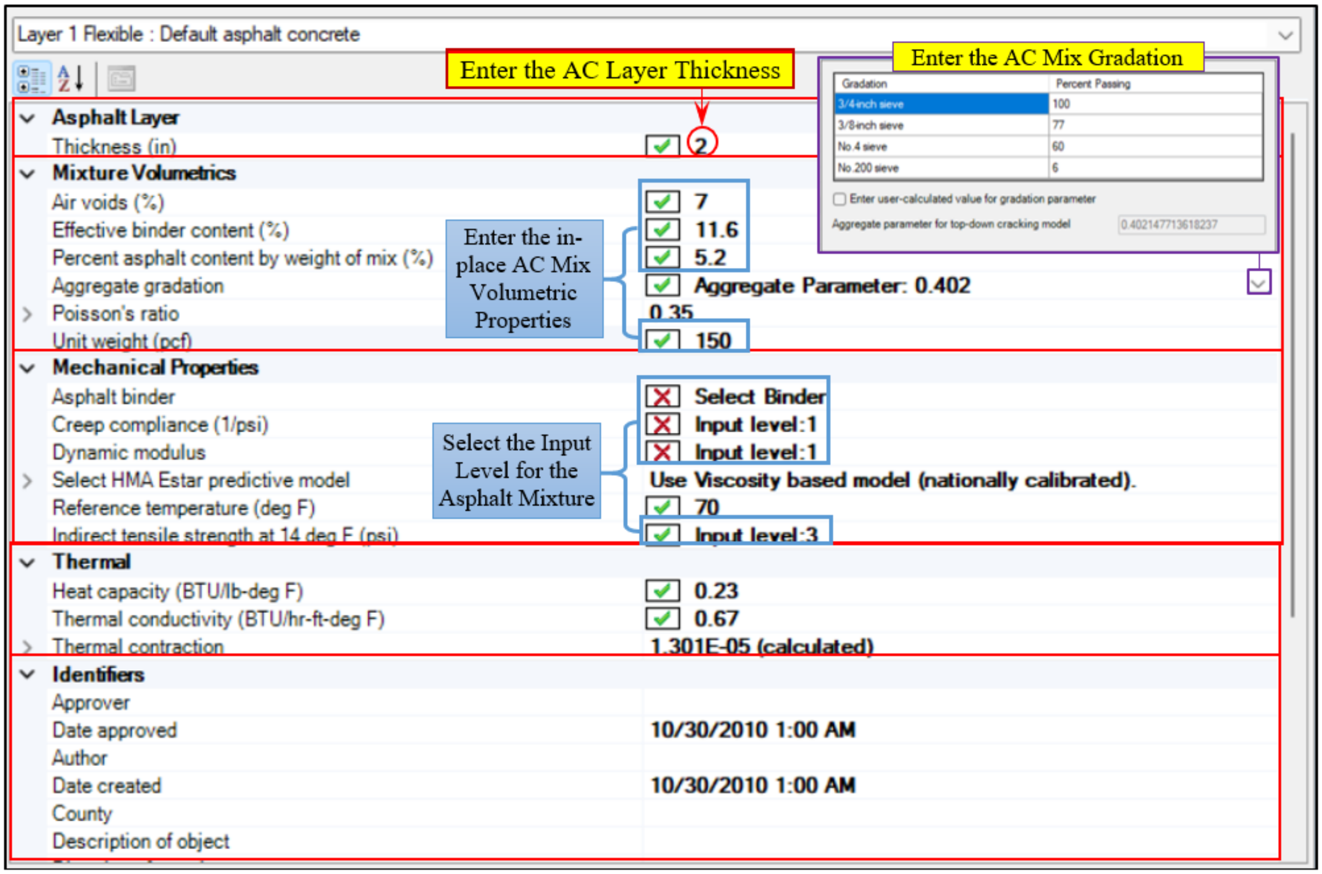


Figure 48. Property page for entering the properties of a new flexible pavement asphalt surface layer

4.5.2.1 Dynamic Modulus (|E|)*

Dynamic modulus (|E*|) is the primary stiffness property for an asphalt mixture and is used to characterize the elastic modulus for a linear viscoelastic material. AASHTOWare PMED uses |E*| to characterize the stiffnesses of asphalt pavement layers throughout the different seasons and under different truck loading configurations. AASHTOWare PMED Level 1 requires a laboratory-measured |E*|, whereas Levels 2 and 3 use the mixture aggregate gradation to predict the |E*| at the temperatures and loading frequencies required by AASHTOWare PMED. The user can select the |E*| input level by using the drop-down arrow located at the right side of the "Dynamic modulus" option as shown in Figure 49.

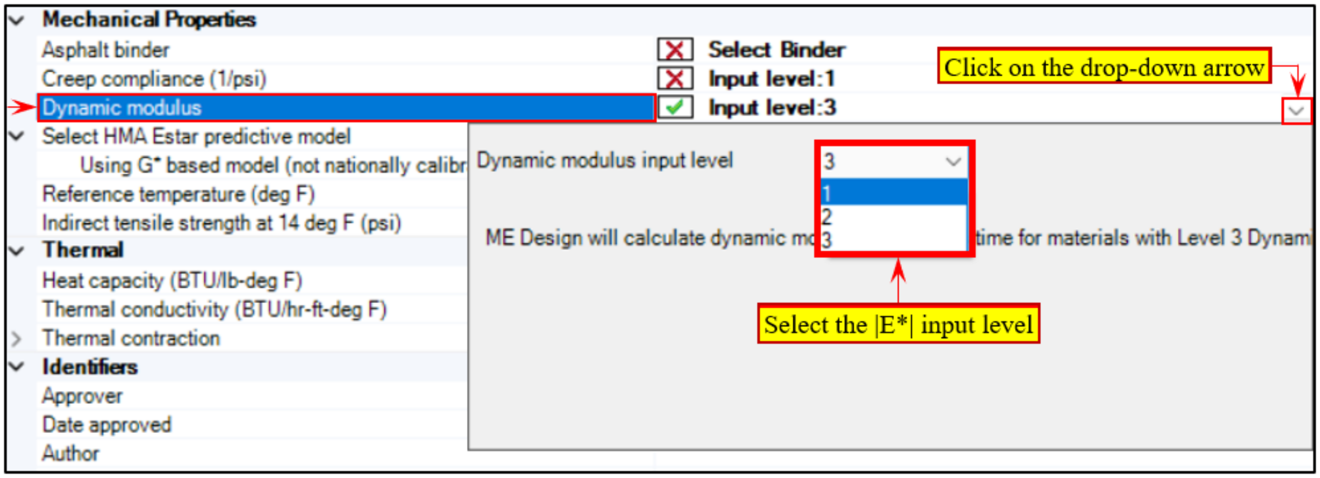


Figure 49. Selecting the |E*| input level

If the |E*| input is selected at Level 1, the user will be required to enter the |E*| values of the AC mixture by selecting the number of test temperatures and frequencies; then the user must enter the temperature values (°F) in the first column, frequency values (Hz) in the first row, and measured |E*| values (psi) corresponding to each testing temperature and frequency as presented in Figure 50. The |E*| table can be copied from any Excel file and pasted into the software dynamic modulus table.

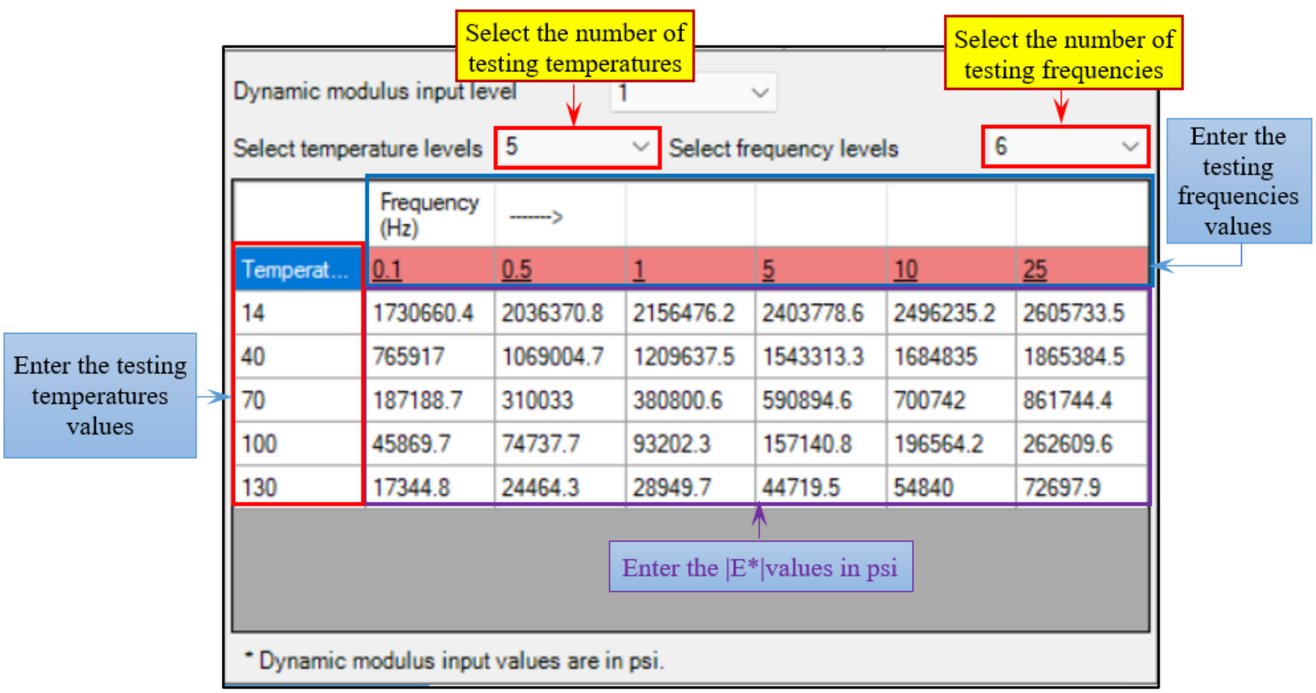


Figure 50. Dynamic modulus of asphalt concrete mixture input Level 1 screen

The |E*| input screens for Levels 2 and 3 are presented in Figure 51. For Levels 2 and 3, the AASHTOWare PMED provides the user with two options for predicting the |E*| values: one is the viscosity based model (NCHRP 1-37A), and the other is the G* (dynamic shear modulus of the asphalt) based model (NCHRP 1-40D). The user can select the |E*| prediction model through the "Select HMA Estar predictive model" option that is located under "Dynamic modulus." If the user selects "True," the software will use the G* based model that adjusts viscosity by frequency to determine the |E*|. However, by selecting "False," the software will use the viscosity based model without adjusting viscosity by frequency. Figure 52 shows the "Select HMA Estar predictive model" input screen. The "Reference temperature (°F)" allows the user to define a reference temperature in degrees Fahrenheit. This is used for deriving the |E*| master curve. The suggested value is 70°F; this is the software's default value.

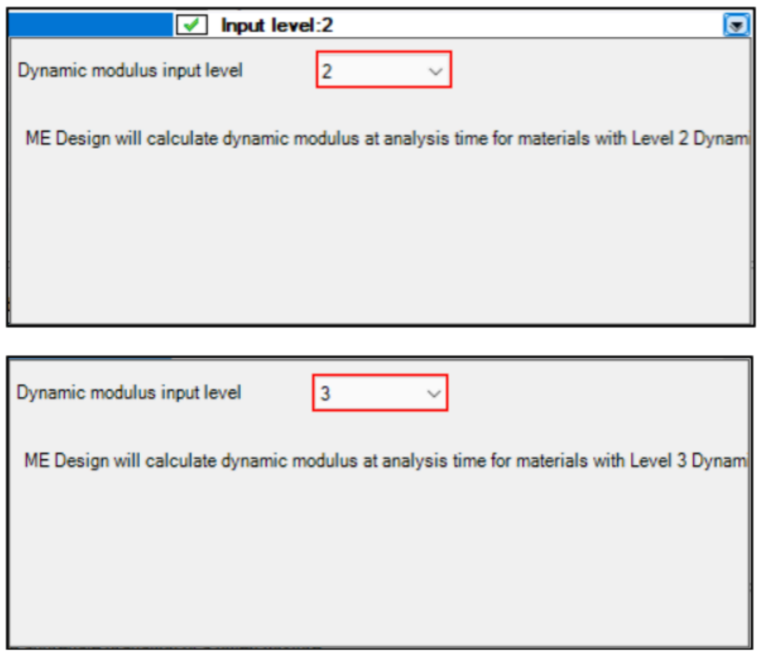


Figure 51. Dynamic modulus input Level 2 and 3 screens

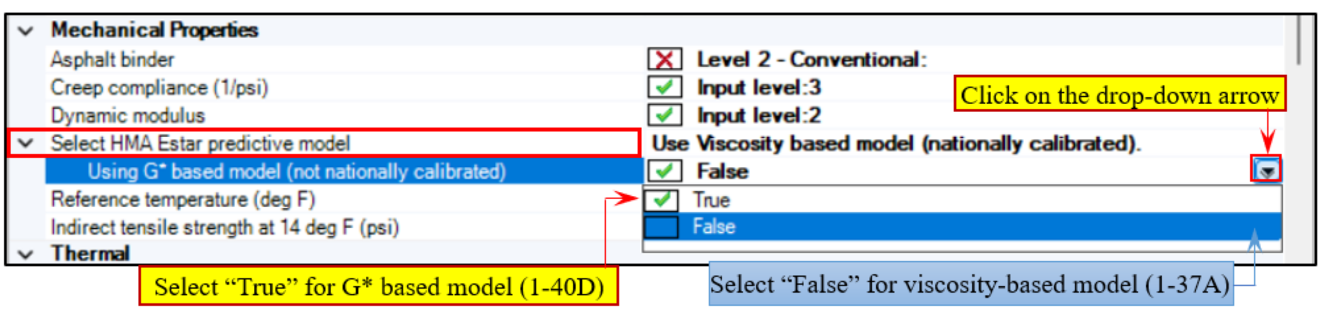


Figure 52. Selecting the |E*| predictive model for Levels 2 and 3

4.5.2.2 Asphalt Binder

The asphalt binder input screen automatically varies depending on the |E*| input level that is selected by the user. The asphalt binder properties' input screens are similar when Levels 1 and 2 are selected for the |E*|, but the Level 3 |E*| input screen for AC is different. Input Levels 1 and 2 require either the conventional grading test data consisting of viscosity and penetration values at different temperatures or Superpave test data for the measured complex shear moduli (G*) and phase angles (δ) of the asphalt binder at multiple temperatures (Figure 53). Because most DOTs use the Superpave performance grading system and do not use penetration or viscosity graded binders, the user may select "Superpave Performance Grade" option for Level 1. Input Level 3 requires the asphalt binder grade as shown in Figure 54.

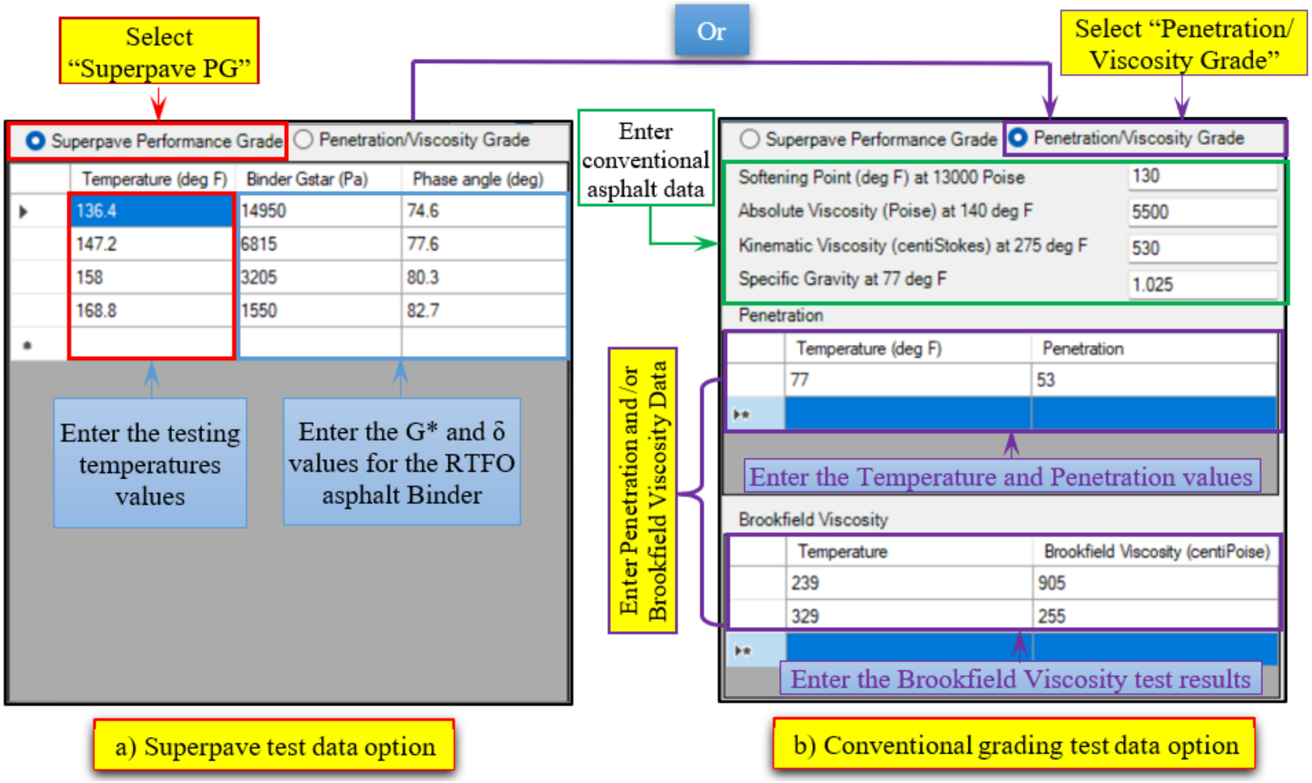


Figure 53. Levels 1 and 2 asphalt binder input screens

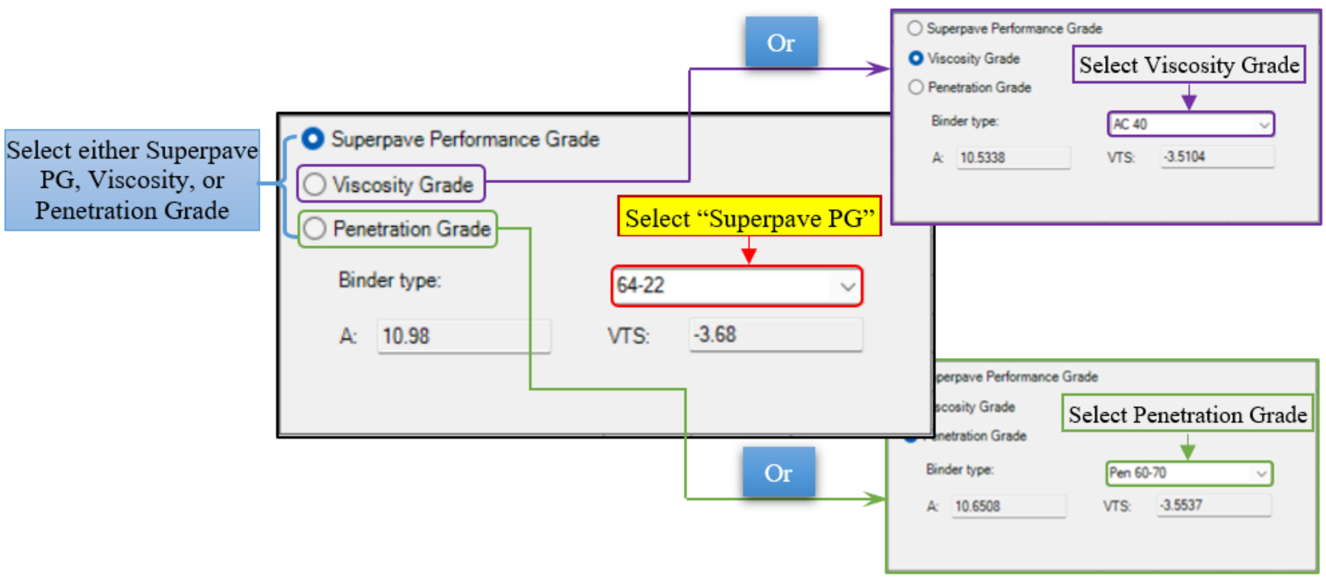


Figure 54. Level 3 asphalt binder input screens

4.5.2.3 Indirect Tensile Strength at 14°F (psi)

The AASHTOWare Pavement ME Design Software uses the indirect tensile (IDT) strength of the asphalt mixture at a temperature of 14°F (−10°C) to measure the cracking susceptibility of the asphalt mixture. Levels 1 and 2 require a laboratory-measured value, whereas Level 3 automatically calculates a typical value based on statistical relationships with other AC inputs. Figures 55 through 57 show IDT strength input screens for Levels 1 through 3, respectively.

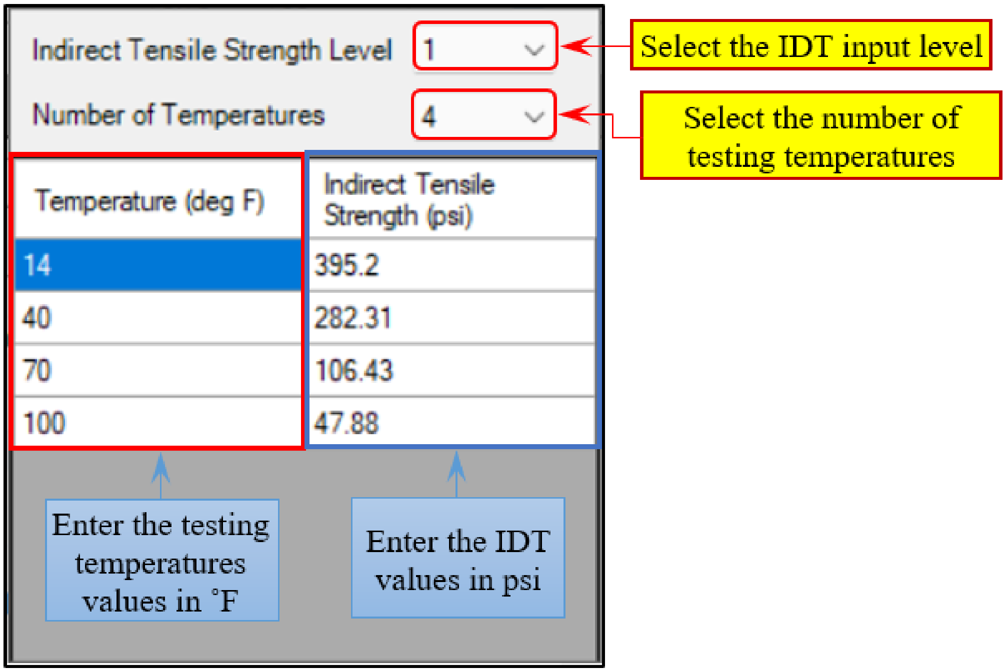


Figure 55. Indirect tensile strength input screen for Level 1

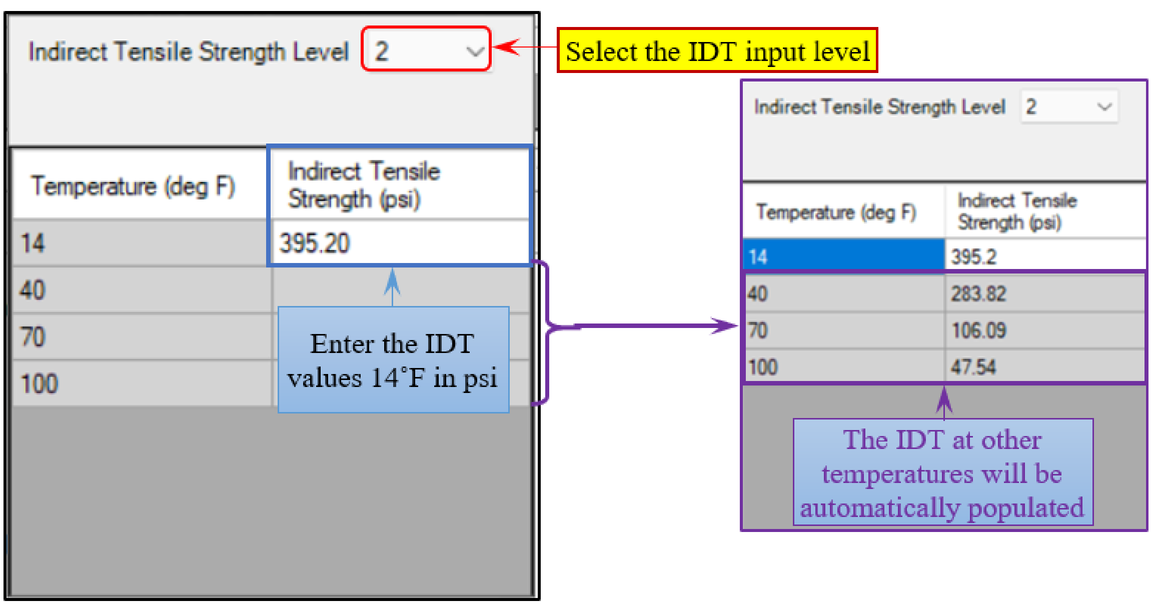
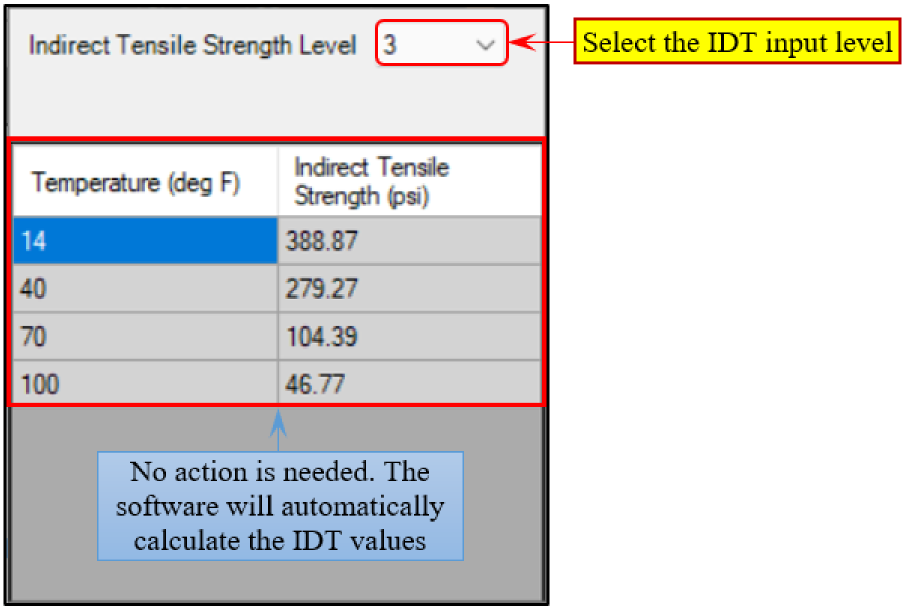


Figure 56. Indirect tensile strength input screen for Level 2

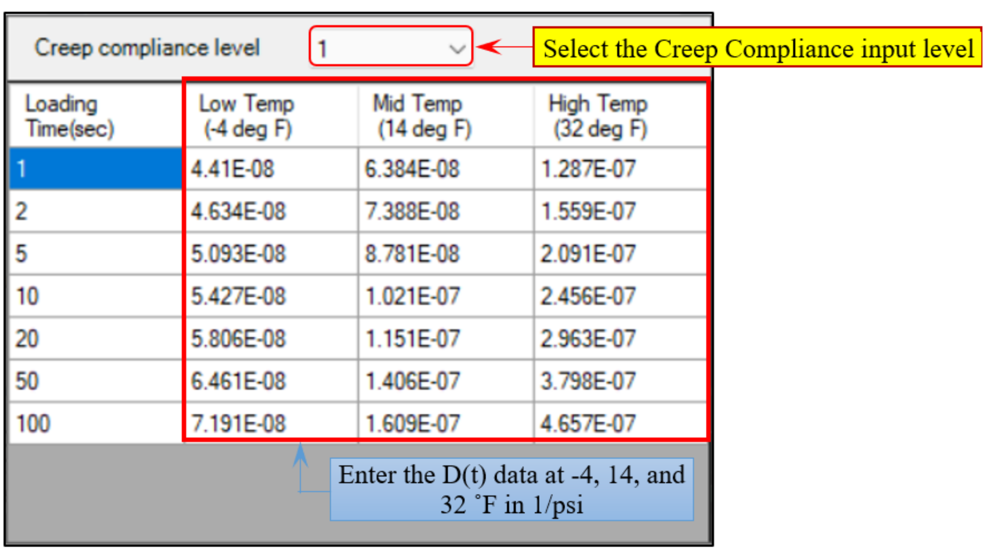


Temperature (deg F)	Indirect Tensile Strength (psi)
14	388.87
40	279.27
70	104.39
100	46.77

Figure 57. Indirect tensile strength input screen for Level 3

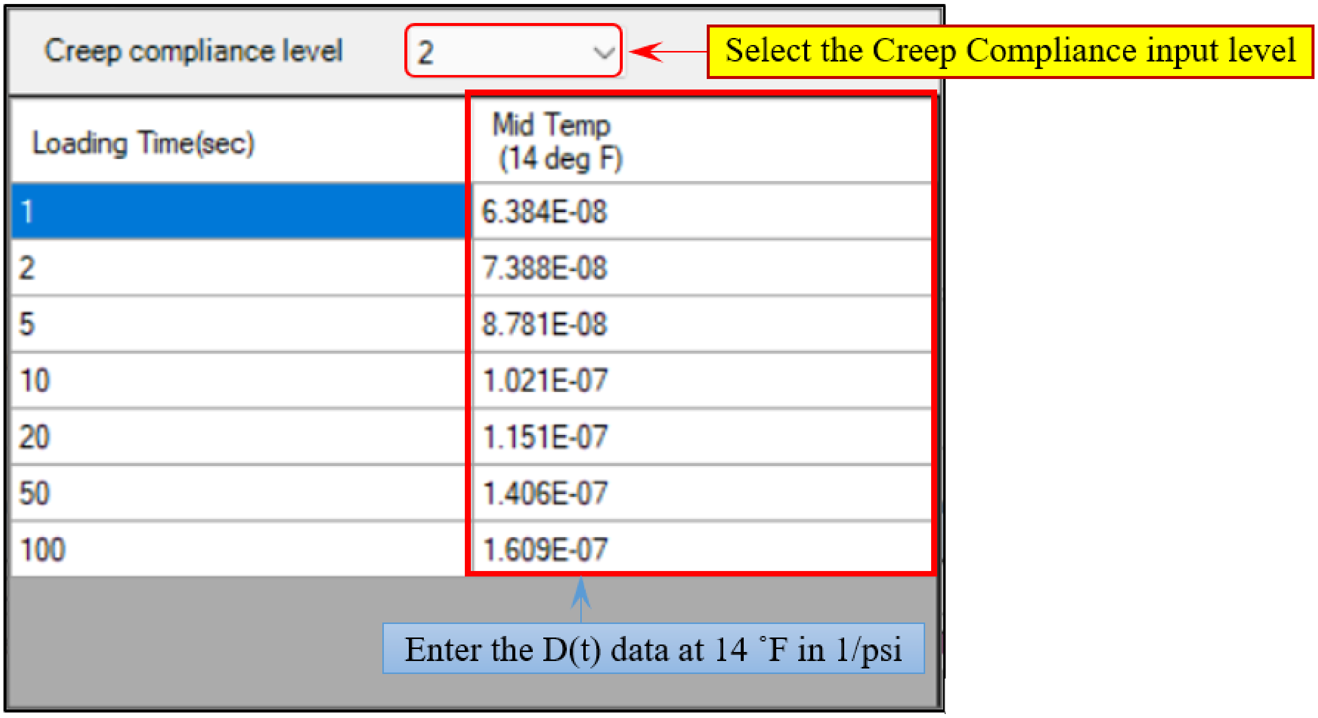
4.5.2.4 Creep Compliance

Creep compliance (1/psi) is the time-dependent strain per unit stress of the asphalt mixture. The AASHTOWare Pavement ME Design Software uses the creep compliance (D(t)) test data for thermal cracking analysis. The software will construct the creep compliance master curve based on data measured at −4°F (−20°C), 14°F (−10°C), and 32°F (0°C). The user can use one of the three hierarchical levels to define the creep compliance data. Level 1 requires laboratory tested creep compliance data at temperatures −4, 14, and 32°F. Level 2 requires the creep compliance test data only at 14°F. Finally for Level 3, the software automatically produces creep compliance data using statistical relationships from other AC inputs. Figures 58 through 60 show creep compliance input screens for Levels 1 through 3, respectively.



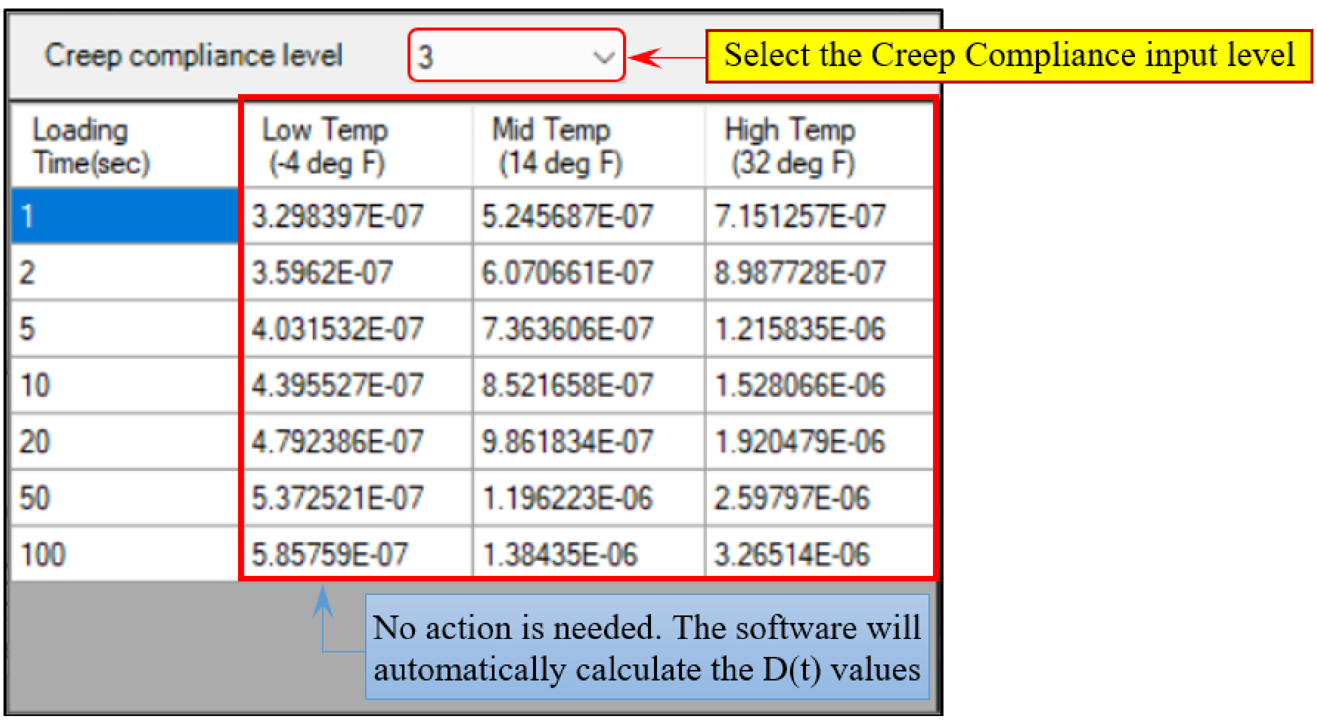
Loading Time(sec)	Low Temp (-4 deg F)	Mid Temp (14 deg F)	High Temp (32 deg F)
1	4.41E-08	6.384E-08	1.287E-07
2	4.634E-08	7.388E-08	1.559E-07
5	5.093E-08	8.781E-08	2.091E-07
10	5.427E-08	1.021E-07	2.456E-07
20	5.806E-08	1.151E-07	2.963E-07
50	6.461E-08	1.406E-07	3.798E-07
100	7.191E-08	1.609E-07	4.657E-07

Figure 58. Creep compliance input screen for Level 1



Loading Time(sec)	Mid Temp (14 deg F)
1	6.384E-08
2	7.388E-08
5	8.781E-08
10	1.021E-07
20	1.151E-07
50	1.406E-07
100	1.609E-07

Figure 59. Creep compliance input screen for Level 2



Loading Time(sec)	Low Temp (-4 deg F)	Mid Temp (14 deg F)	High Temp (32 deg F)
1	3.298397E-07	5.245687E-07	7.151257E-07
2	3.5962E-07	6.070661E-07	8.987728E-07
5	4.031532E-07	7.363606E-07	1.215835E-06
10	4.395527E-07	8.521658E-07	1.528066E-06
20	4.792386E-07	9.861834E-07	1.920479E-06
50	5.372521E-07	1.196223E-06	2.59797E-06
100	5.85759E-07	1.38435E-06	3.26514E-06

Figure 60. Creep compliance input screen for Level 3

4.5.3 Aggregate Base/Subbase Layers

The base and subbase layers can be inserted into the AASHTOWare Pavement ME Design Software using the "Add Layer" button then selecting "Non-stabilized Base" from "Layer type" as seen in Figure 61. The properties of base and subbase layers can be entered/edited from the property grid located within the property page pane, which can be accessed by using one of the three ways described in Section 4.5.1 and presented in Figure 62. The user is required to define the physical and engineering properties for non-stabilized base/subbase materials. These properties include dry density, moisture content, hydraulic conductivity, specific gravity, soil water characteristic curve (SWCC) parameters, classification properties, and the resilient modulus. These inputs can be entered into the software based on the available data and the importance of the project following the input hierarchy levels. Figure 63 shows the property page for a non-stabilized base/subbase material layer. This property page is made up of four sections: Unbound, Modulus, Sieve, and Identifiers.

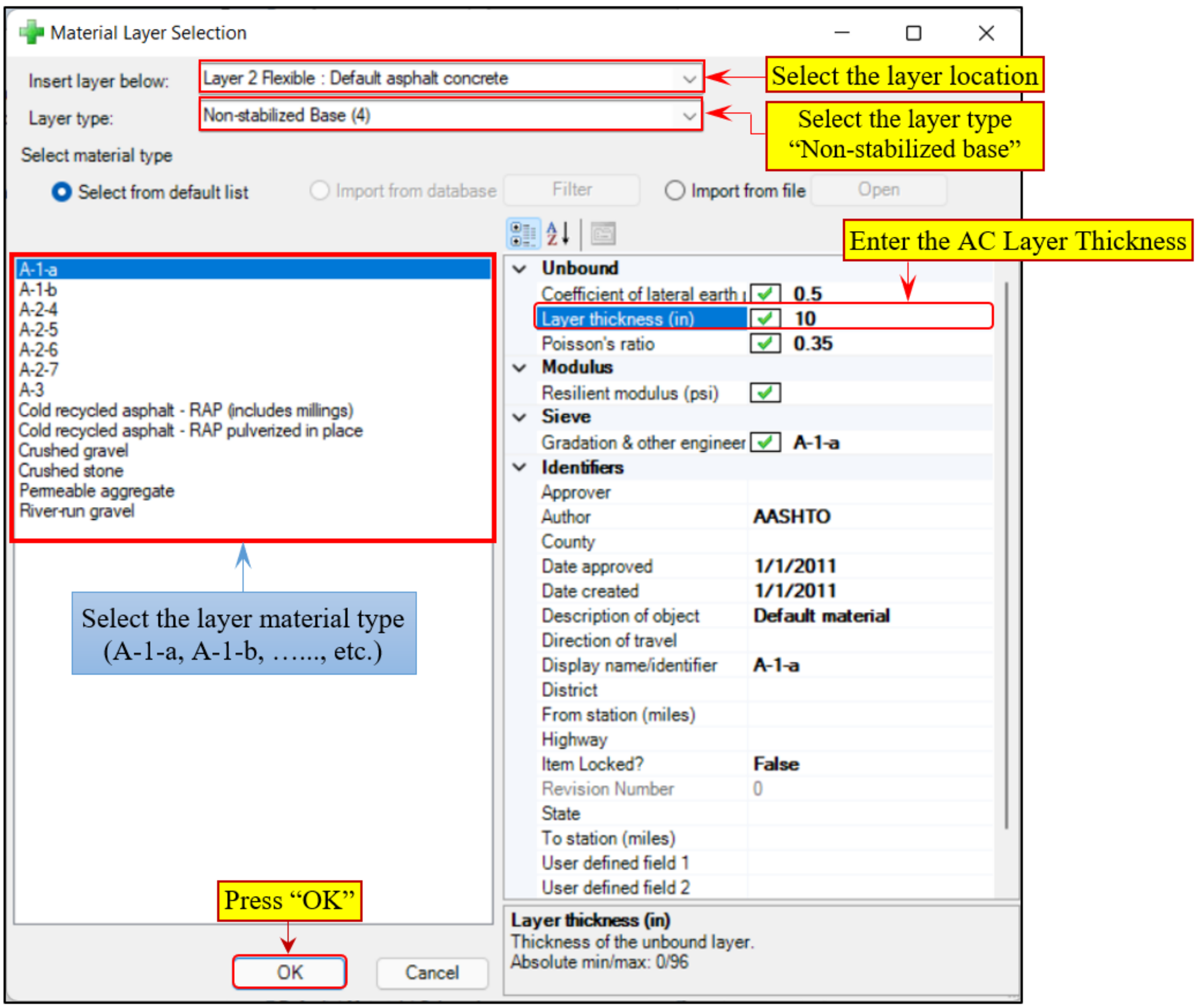


Figure 61. Input screen for adding base/subbase layer

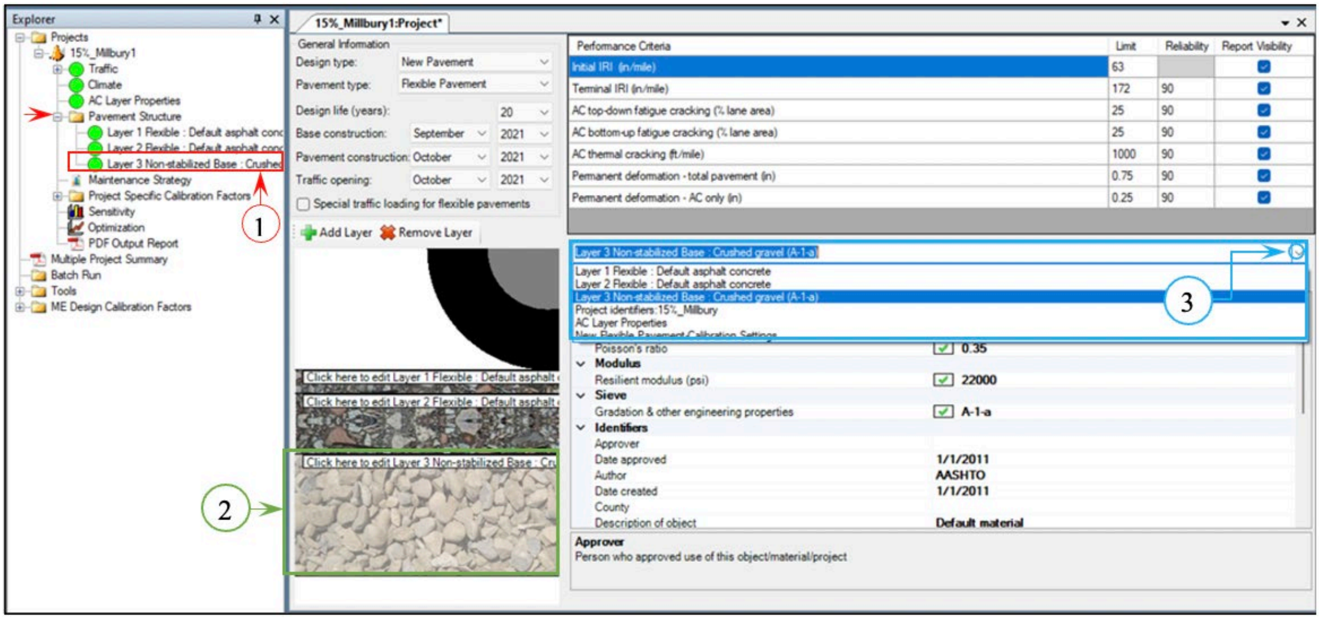


Figure 62. Accessing the properties of base/subbase layer

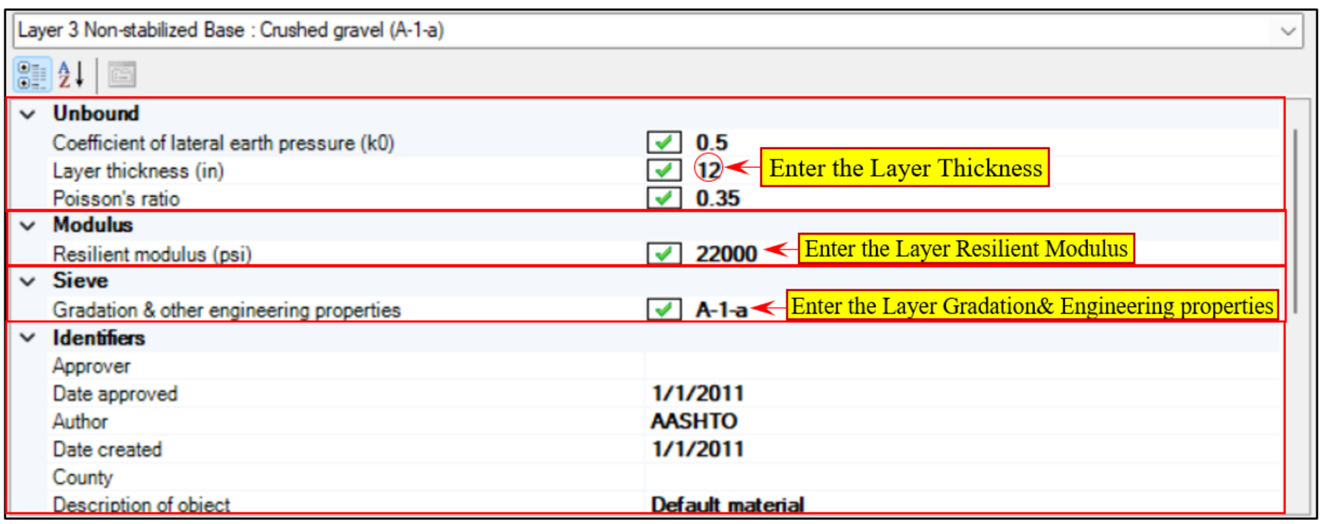


Figure 63. Property page for entering the properties of base/subbase layer

4.5.3.1 Thickness

Thickness is a primary input for unbound layers, which affects the pavement performance over the analysis period. The user cannot enter a base/subbase layer thickness unless there is another layer beneath that layer as presented in Figure 64. The software defines the thickness of the last unbound layer as "Semi-infinite."

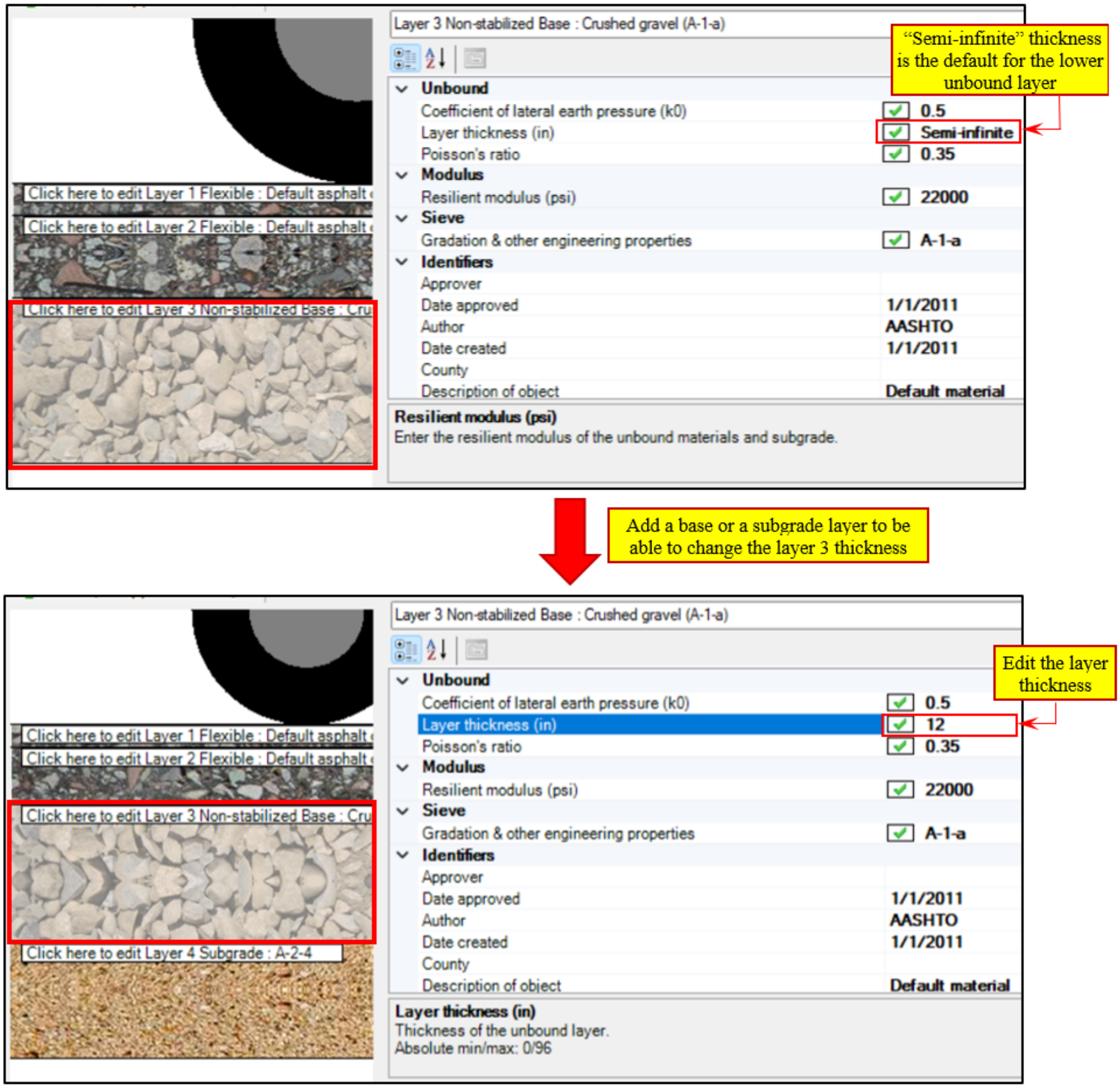


Figure 64. Property page for entering the properties of a base/subbase layer

4.5.3.2 Resilient Modulus (psi)

Resilient modulus (psi) is a primary input for unbound layers, which affects the predicted distresses over the analysis period. AASHTOWare Pavement ME Design Software displays a default value (Level 3) for the resilient modulus (M_r) of the base/subbase layer based on the material type selected when adding an unbound layer; then the user can access the modulus M_r input screen using the drop-down arrow located at the right side of the "Resilient modulus (psi)" option to edit the M_r default value or input level.

Moreover, the user can define how the AASHTOWare Pavement ME Design Software accounts for seasonal variations (freezing, thawing, and moisture) in the M_r calculations through the "Analysis Types" options in different input levels. The user can either select Level 2 or 3 to define the M_r. Level 3 allows the user to override the software default M_r value as presented in Figure 65. Level 2 selection allows the user to either enter the M_r or enter another strength property such a: California bearing ratio (CBR), R-value, Layer coefficient (ai), and so forth. This will automatically convert the provided strength property to the M_r by the conversion models imbedded in the software. Figure 66 presents the M_r input screen for Level 2. For Level 2, the second radio button under Analysis Types ("Monthly Representative Values") allows the user to define the M_r or strength property for each month of a year to account for seasonal variations without the software internal adjustments.

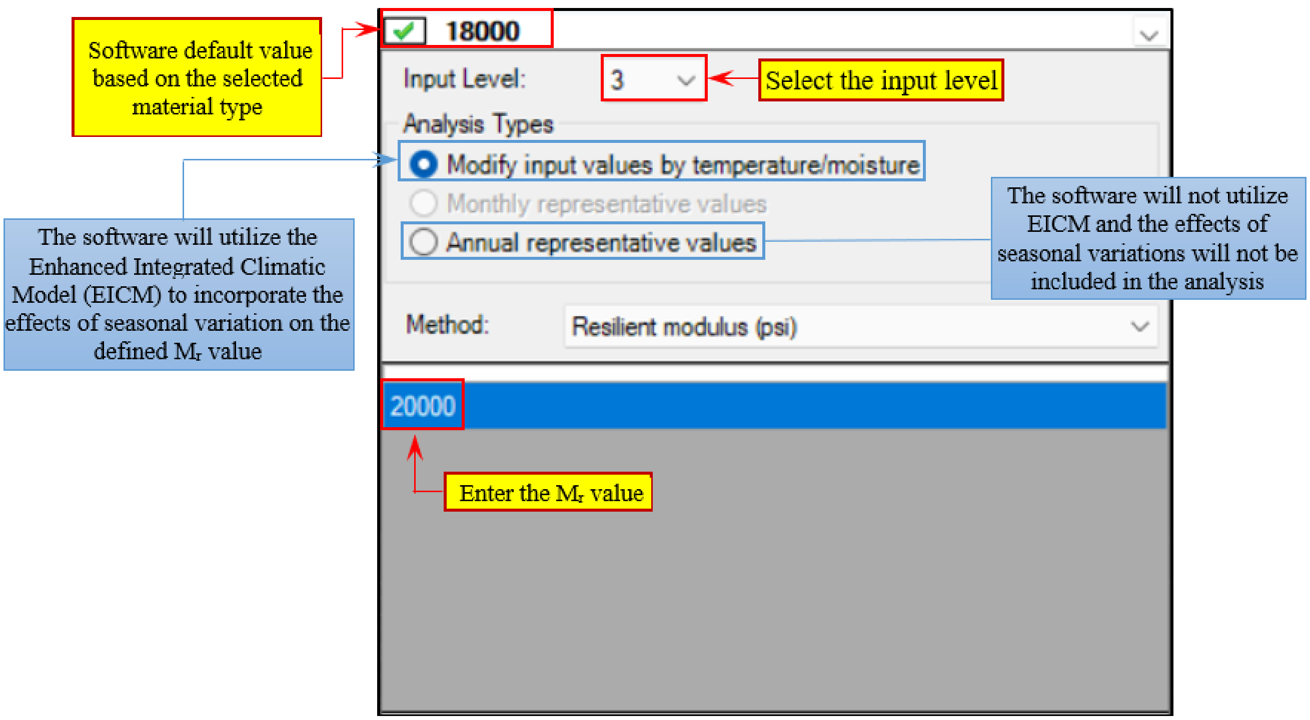


Figure 65. Resilient modulus Level 3 input screen

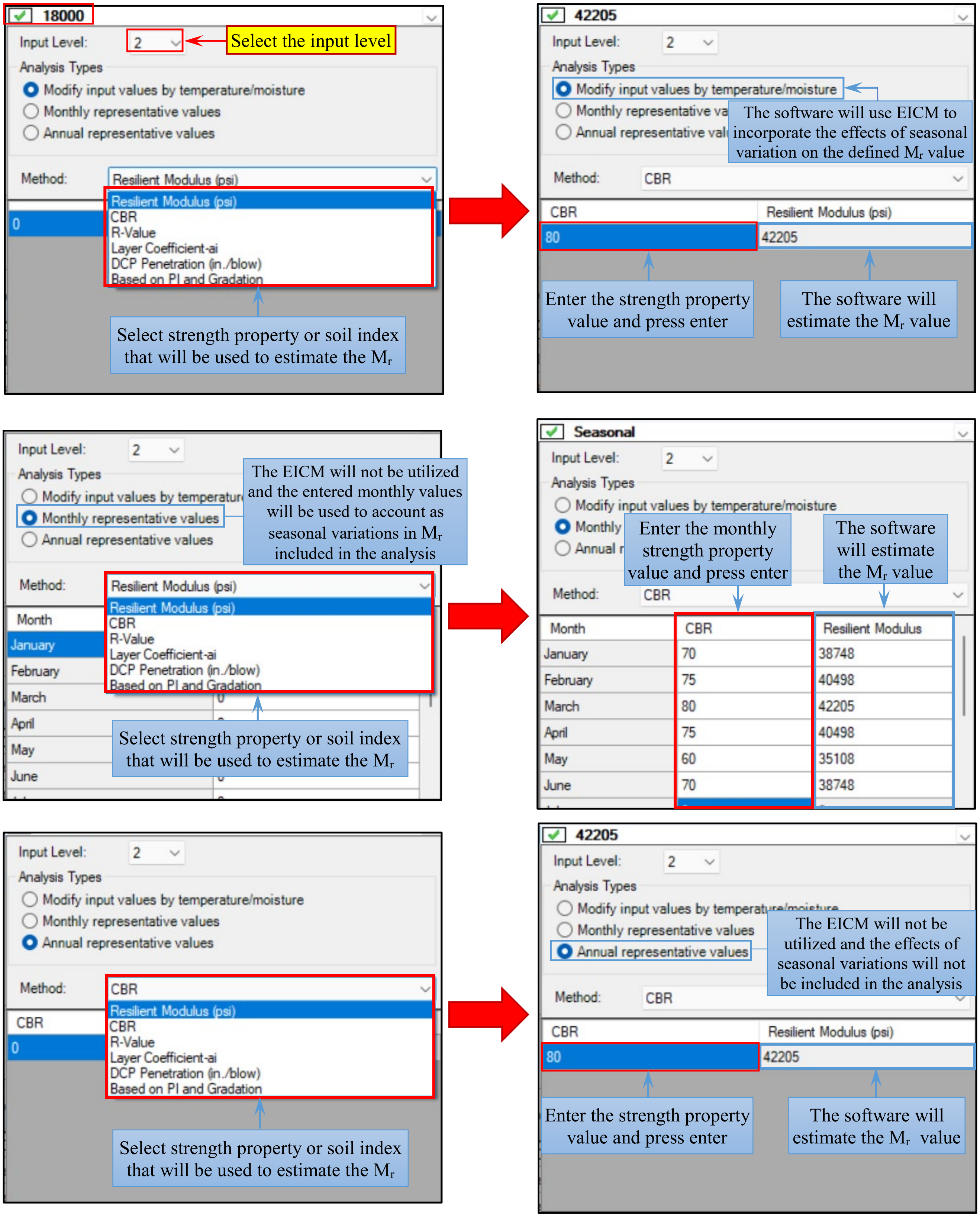


Figure 66. Resilient modulus Level 2 input screens

4.5.3.3 Gradation and Other Engineering Properties

Gradation and other engineering properties allow the user to edit the software's default values of gradation, Atterberg limits, specific gravity, water content, maximum dry density, saturated hydraulic conductivity, and the SWCC parameters of the base/subbase materials. The user can access the input screen by clicking on the drop-down arrow located at the right side of the "Gradation and other engineering properties" option as shown in Figure 67. The software estimates the layer coefficients that appear beside the unchecked boxes based on the inputs for Gradation, Liquid Limit, Plasticity Index, and whether the layer is compacted. Thus, changing the default inputs will result in the recalculation of the layer coefficients. The user is allowed to modify the internally computed values by checking boxes beside these coefficients and entering the required values.

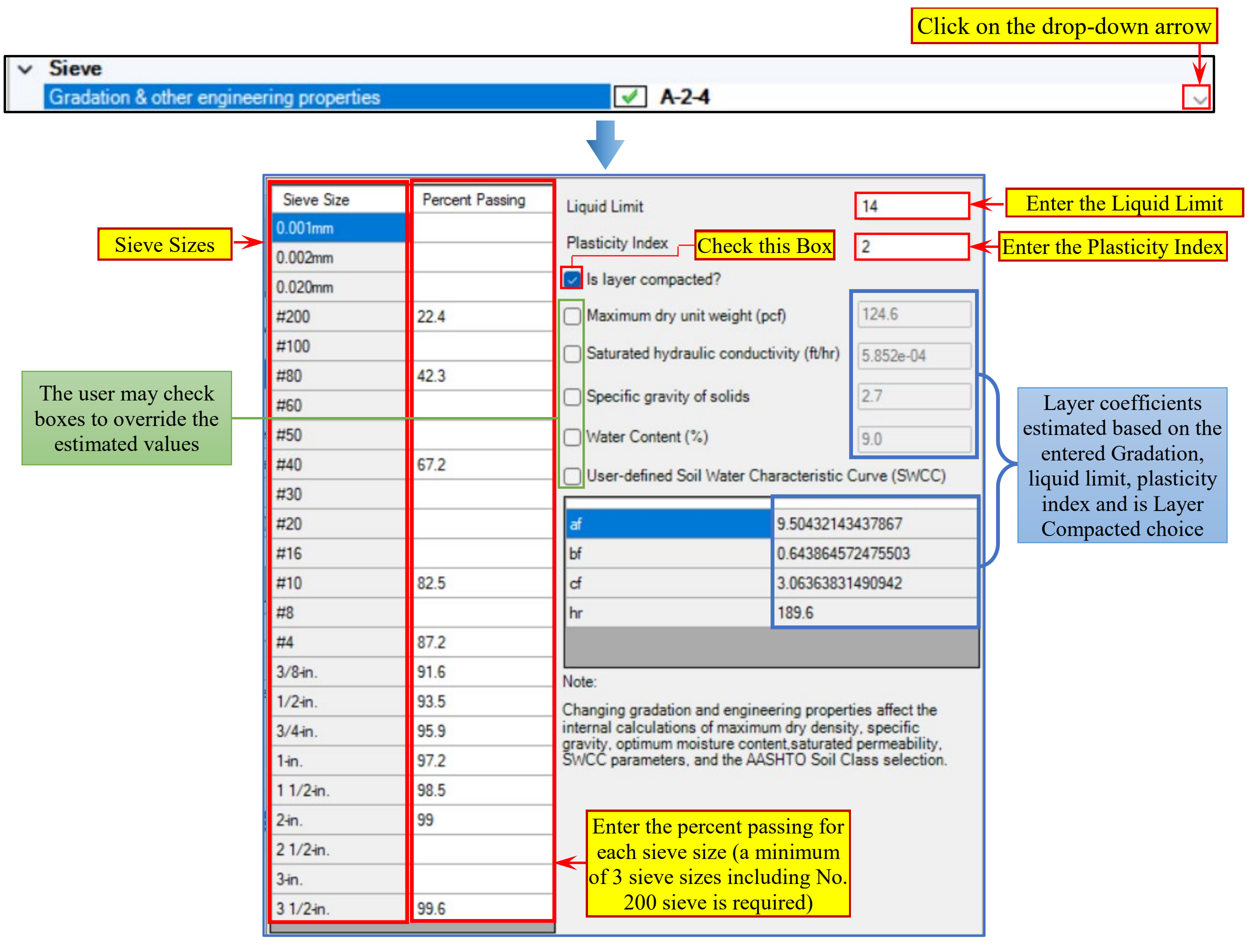


Figure 67. Gradation and other engineering properties input screen

4.5.4 Subgrade Layer

The subgrade layer can be inserted into the AASHTOWare Pavement ME Design Software using the "Add Layer" button by selecting "Subgrade" from "Layer type" as presented at Figure 68. In the AASHTOWare Pavement ME Design Software, subgrade materials include soil classes A-1 through A-7-6 in accordance with the AASHTO soil classification system. The subgrade material inputs are the same as those of the base/subbase layer where the software requires the same physical and engineering properties including M_r, gradation, Atterberg limits, specific gravity, water content, maximum dry density, saturated hydraulic conductivity, and the SWCC parameters of the subgrade materials.

4.5.5 AC Layer Properties

In the AASHTOWare Pavement ME Design Software, the "AC Layer Properties" tab is used to identify other AC layer inputs related to pavement analysis and design such as the amount of solar energy absorbed by the pavement surface, friction at the interface of adjacent layers, endurance limit and whether the user wants to incorporate the endurance limit in the design analysis, and whether or not the user wants to use rutting calibration factors in the trial design analysis. The user can access the "AC Layer Properties" input screen using one of these two ways that are presented in Figure 68:

1. Double-clicking on the layer node located in the Explorer Pane under the project folder.
2. Using the drop-down arrow located at the right side of the Property Control area.

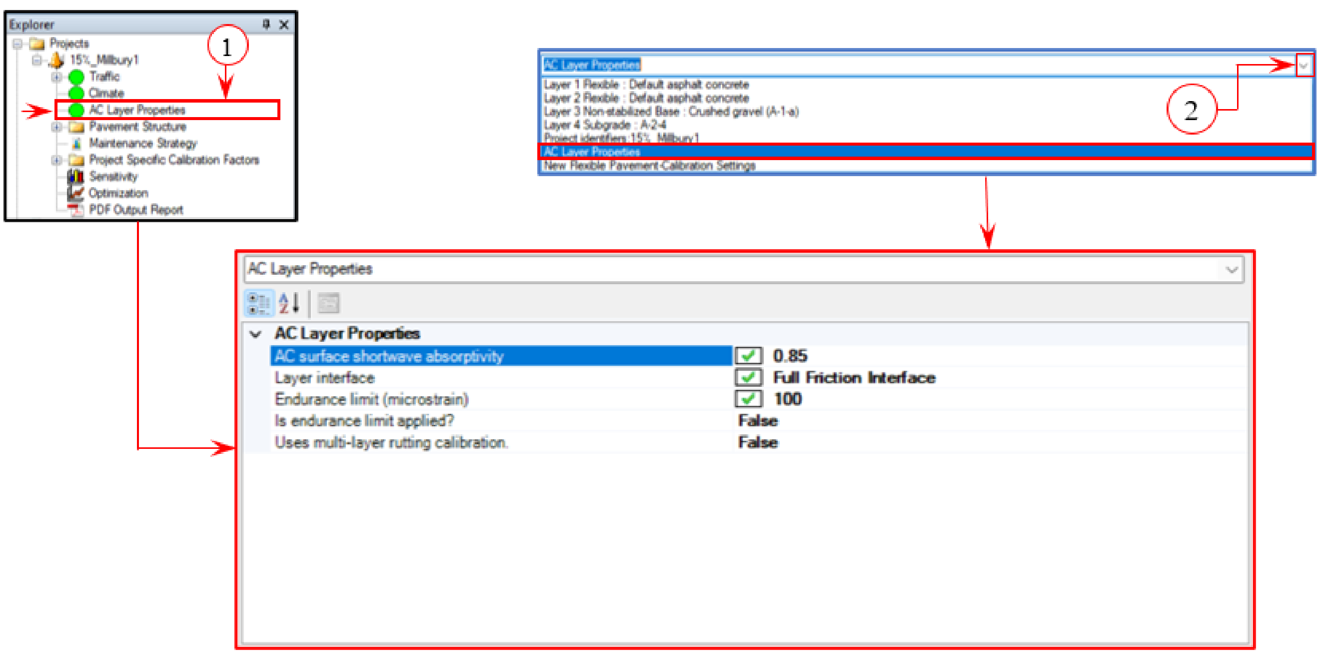


Figure 68. Accessing the AC Layer Properties input screen

The AC Layer Properties will be populated in the Property Page zone which consists of:

1. AC surface shortwave absorptivity: represents the percentage of the solar energy absorbed by the asphalt pavement surface. AASHTOWare Pavement ME Design provides 0.85 as the default value. The user can use this value for the analysis.

2. Layer interface: allows the user to identify the friction at the interface of adjacent layers in the created pavement structure. The user can access the layer interface table by clicking on the drop-down arrow located on the right side of the "Layer interface" option as presented in Figure 69. A value of "1" indicates that a full friction is expected with the layer below layer, whereas a value "0" represents that no bond is expected. A value between "0" and "1" represents the expected bond with the layer below. It is recommended to assume full bond among all pavement layers by using the Pavement ME Design default value of 1 for the interface friction column.

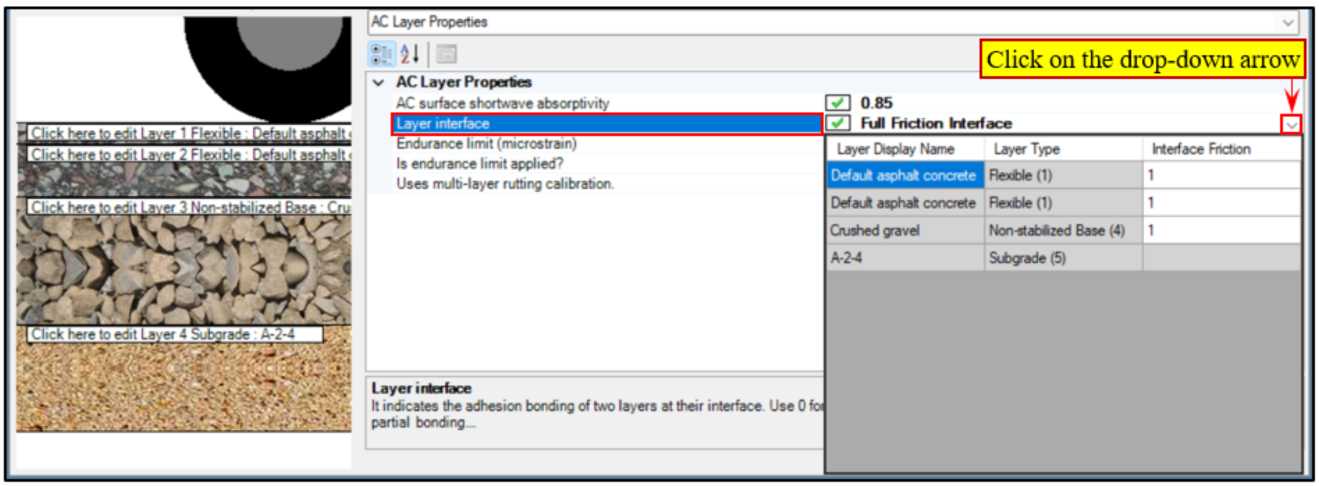


Figure 69. Accessing the Layer interface input screen

3. Endurance limit (microstrain): defined as the tensile strain at which no fatigue cracking occurs within the AC layer. Consequently, if the calculated strains at the bottom of an AC layer is below the endurance limit value, the layer will not fail in fatigue cracking. In AASHTOWare Pavement ME Design, the recommended endurance limit value is between 50 and 100 microstrain. However, the user can determine the endurance limit for a specific asphalt concrete mixture using AASHTO T321, "Standard Method of Test for Determining the Fatigue Life of Compacted Asphalt Mixtures Subjected to Repeated Flexural Bending."

4. Is the endurance limit applied? This option allows the user to decide whether the entered endurance limit will be considered in the design analysis. Selecting "True" considers the endurance limit in the design analysis where the software will exclude all tensile strains below the endurance limit from damage computation. Selecting "False" does not consider the endurance limit. It is recommended to apply the endurance limit option only when the user already calculated the laboratory fatigue coefficients, k_{f1}, k_{f2}, k_{f3}, and the endurance

limit of a specific AC mixture that will be used in the lower AC layer of the pavement structure. Thus, do not apply the endurance limit control (select "False") when using the software global fatigue cracking model coefficients.

5. Uses multilayer rutting calibration: This option allows you to determine how the rutting calibration coefficients will be applied in the design analysis. Selecting "False" will apply one set of the rutting calibration coefficients for all AC layers, whereas selecting "True" will allow the user to enter different rutting calibration coefficients for each AC layer. Up to three different sets can be applied.

4.5.6 Calibration Factors

The AASHTOWare Pavement ME Design Software allows the user to replace the prediction models default coefficients (known as a global calibration coefficients) that were derived using long-term pavement performance (LTPP) test sections with laboratory determined and local calibration coefficients that were determined based on the local conditions for materials, traffic, and climate of a transportation agency to improve the distresses prediction accuracy. The user can either modify the calibration coefficients only for the current project or permanently modify the software default calibration coefficients for the entire application where current and future design trials will use the new calibration coefficients.

To access the input screen of calibration factors for an open project, the user can use one of the two listed methods that are presented in Figure 70:

1. Double-clicking on the layer node located in the Explorer Pane under the "Project Specific Calibration Factors" folder for that project.
2. Using the drop-down arrow located at the right side of the Property Control area.

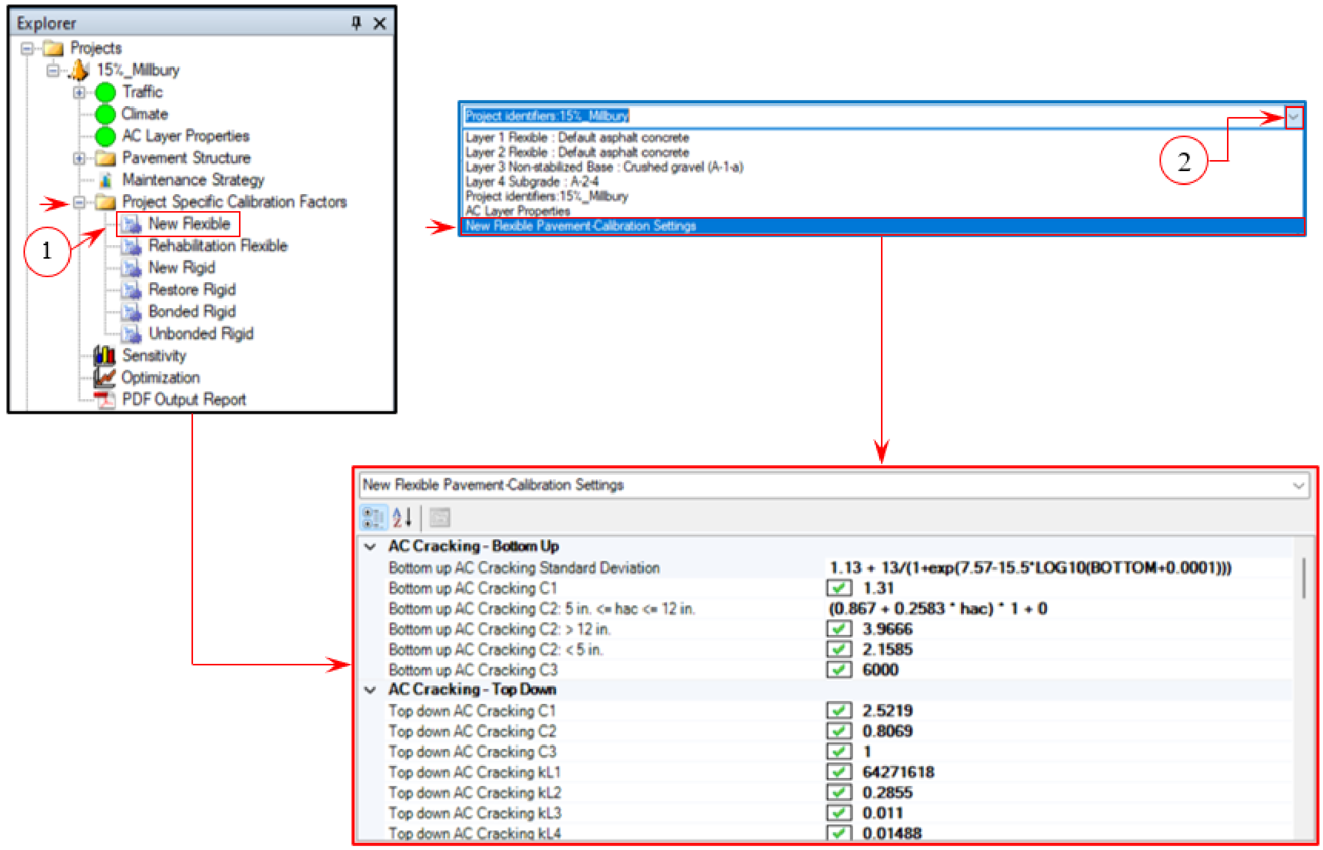


Figure 70. Accessing the New Flexible Pavement Calibration factors input screen for an open project

To access the default design calibration settings screen for the entire application and to modify the calibration factors of all current opened projects and/or future design trials, double-click on the appropriate layer node located in the Explorer Pane under the “ME Design Calibration Factors” folder (Figure 71). The populated calibration factors input tab will appear in the Pavement ME Tabs zone (Figure 72), where the user can modify the default calibration factors.

After entering the calibration coefficients, if the user clicks on “Save Changes to Calibration” button, all future trial designs that are created after pressing the “Save Changes to Calibration” button will utilize the new calibration factors. Do not forget to press “Update Open Projects” button to replace the software default global calibration factors with the modified ones for currently open projects. Moreover, the user can restore the software default calibration factors again by opening the input tab screen (Figure 72) and by clicking on “Restore Calibration Defaults.”

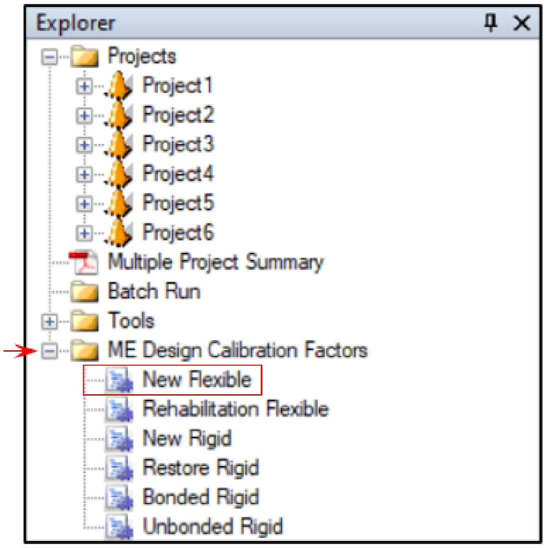


Figure 71. Accessing the New Flexible Pavement Calibration Factors input screen for the entire software

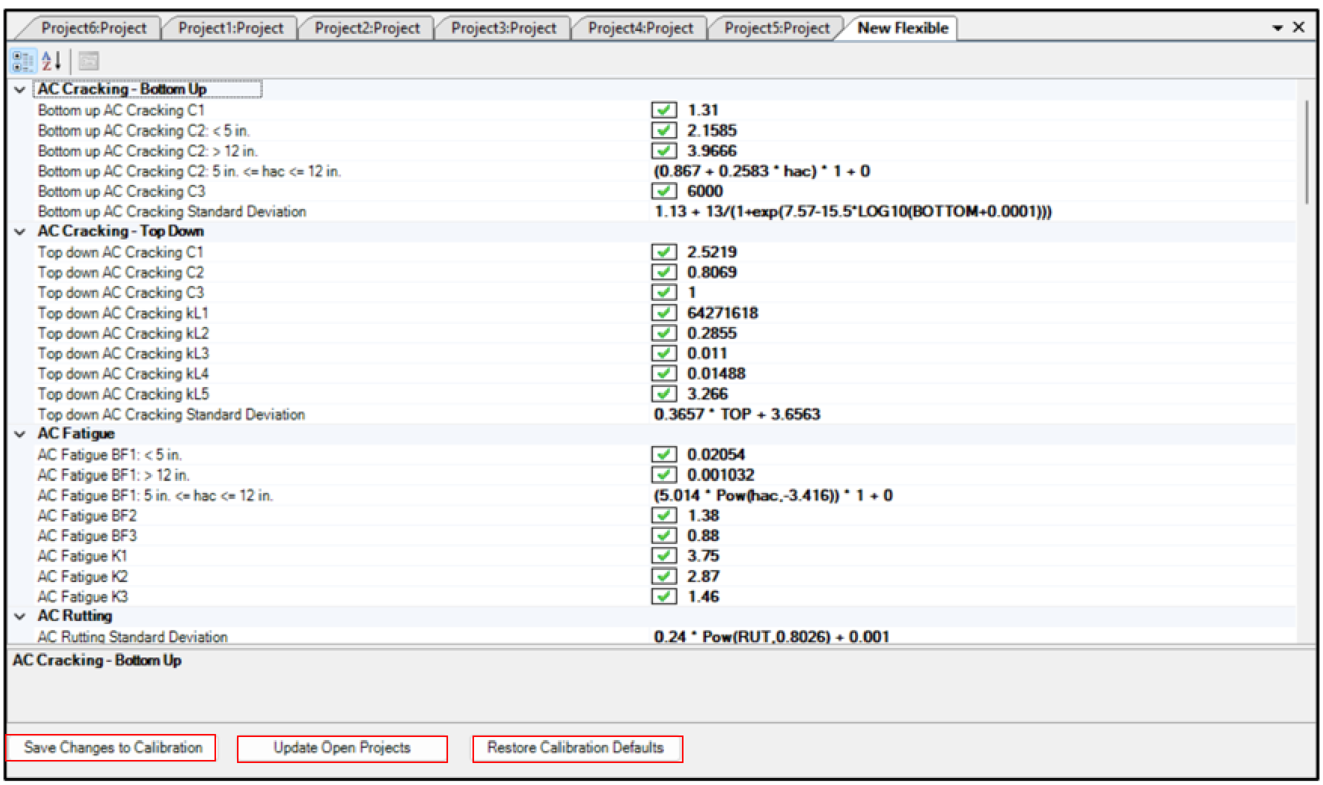


Figure 72. New Flexible Pavement Calibration Factors control tab for modifying or restoring the software global calibration factors

4.6 Run Analysis

Prior to running the AASHTOWare Pavement ME Design Software, it is recommended to review all input parameters for accuracy due to the large number of inputs the user has entered for each trial design (traffic, climate, pavement structure, material properties, and design/construction features). The user should verify that input node indicators on the Explorer Pane are either green circles or yellow triangles; any red X's (error indicators) displayed on the "Error List" due to missing or invalid data must be addressed, otherwise the analysis cannot be performed. The user must create a folder on their hard drive to save the trial design and the generated output files before running the analysis.

To run the analysis on a current active project, the user can either click the "Run" button located on the Menu bar, or right click on the project folder name located on the Explorer Pane and select "Run Analysis" from the drop-down list as shown in Figure 73.

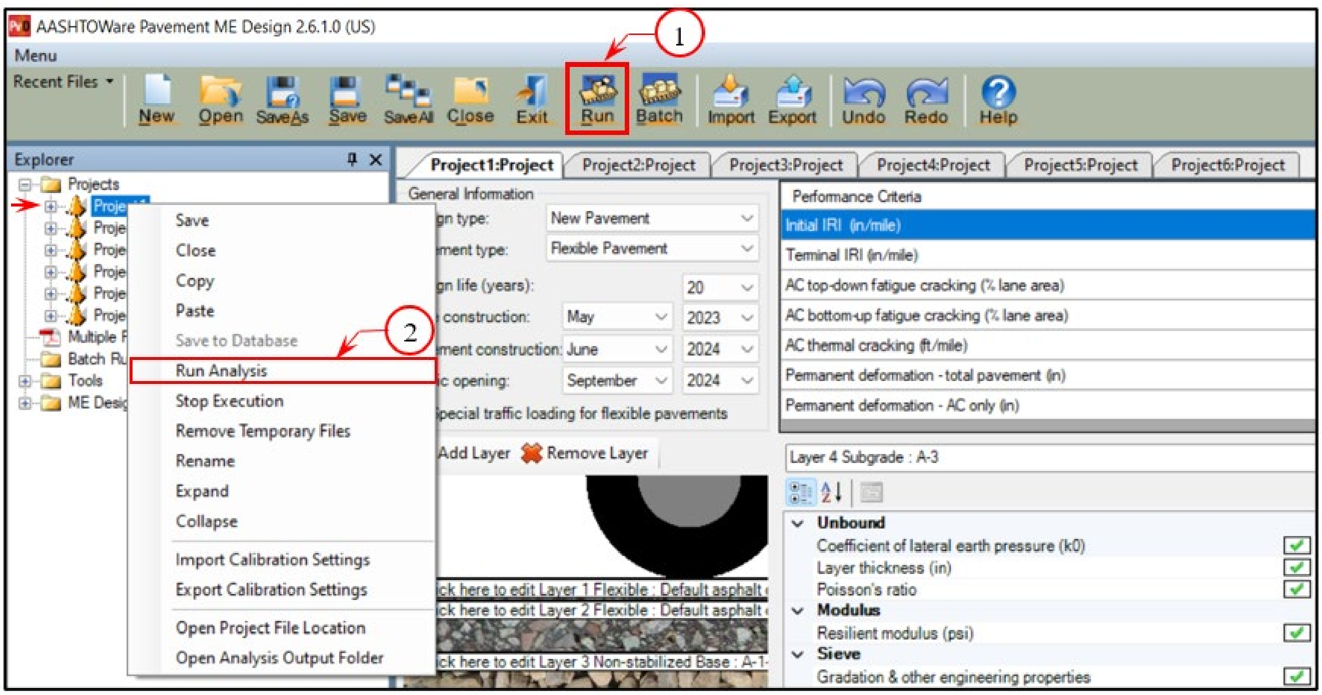


Figure 73. Performing analysis on a single trial design

Although the user can simultaneously perform analyses for different created projects by repeating the "Run Analysis" command, it is recommended to utilize the "Batch Run" option if more than one project is desired to be analyzed in one click to save time. The user can perform the "Batch Run" option by (1) Right-clicking the "Batch Run" folder located on the Explorer Pane and selecting "Load Projects" from the drop-down list to browse the folder(s) and then selecting the desired projects to load into the Batch Run folder before the analysis can begin (Figure 74); or (2) clicking the "Batch" button located on the Menu bar, or right-clicking the "Batch Run" folder name located on the Explorer Pane and selecting "Run Batch Projects" from the drop-down list (Figure 74) to start running the analyses. The user can check the status of the ongoing analysis of either a single project or several projects from the Progress

Pane. The Progress Pane shows the status of each stage using the three software symbols (a green circle, a yellow triangle, or a red square) as shown in Figure 74. The user can terminate the ongoing analyses by clicking on the "Stop All Analysis" Button.

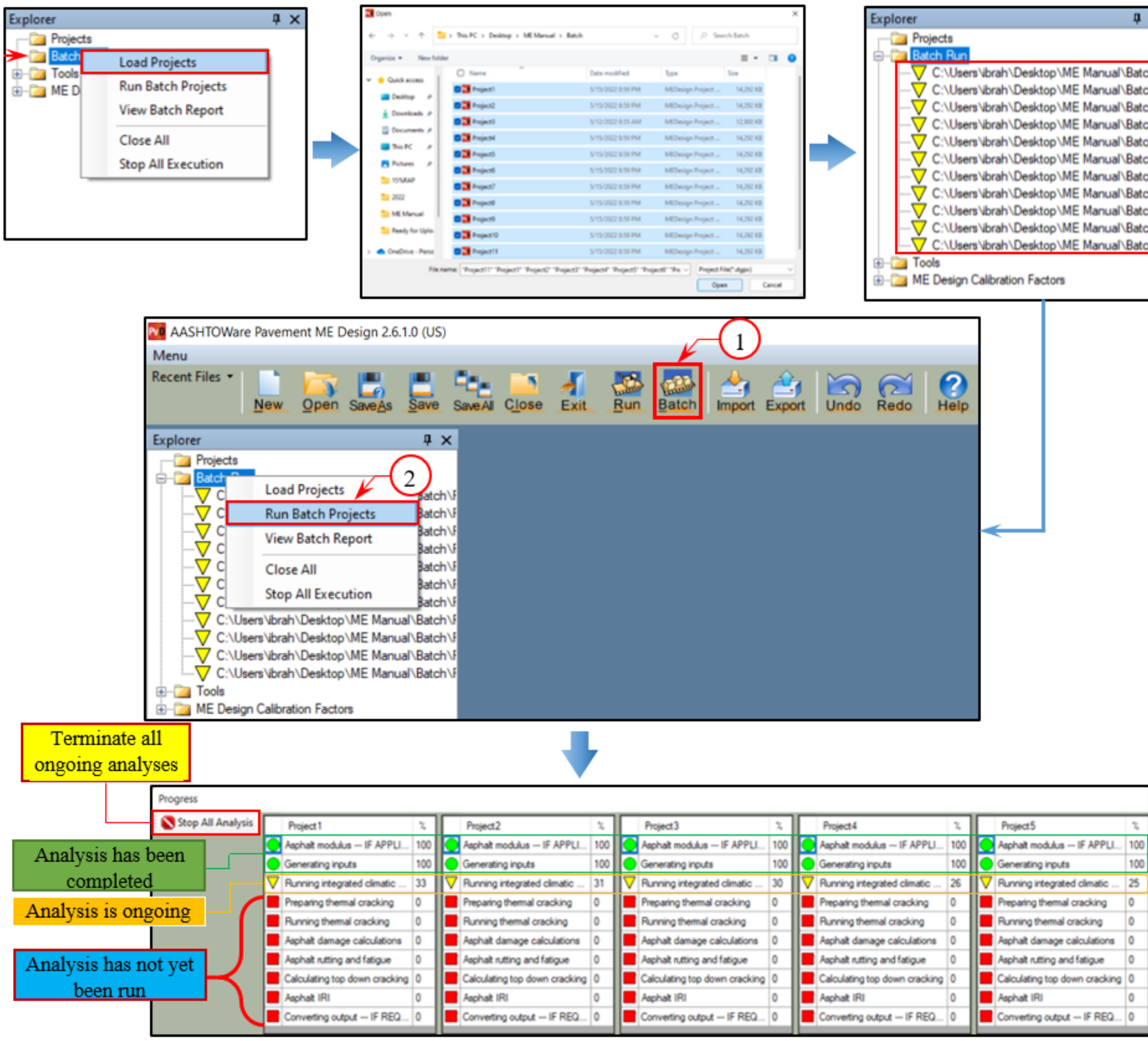


Figure 74. Performing an analysis on multiple trial designs using the Batch Run option

As the analysis of each project is completed, the yellow triangle next to the project filename in the Batch Run folder will turn into a green circle (Figure 75).

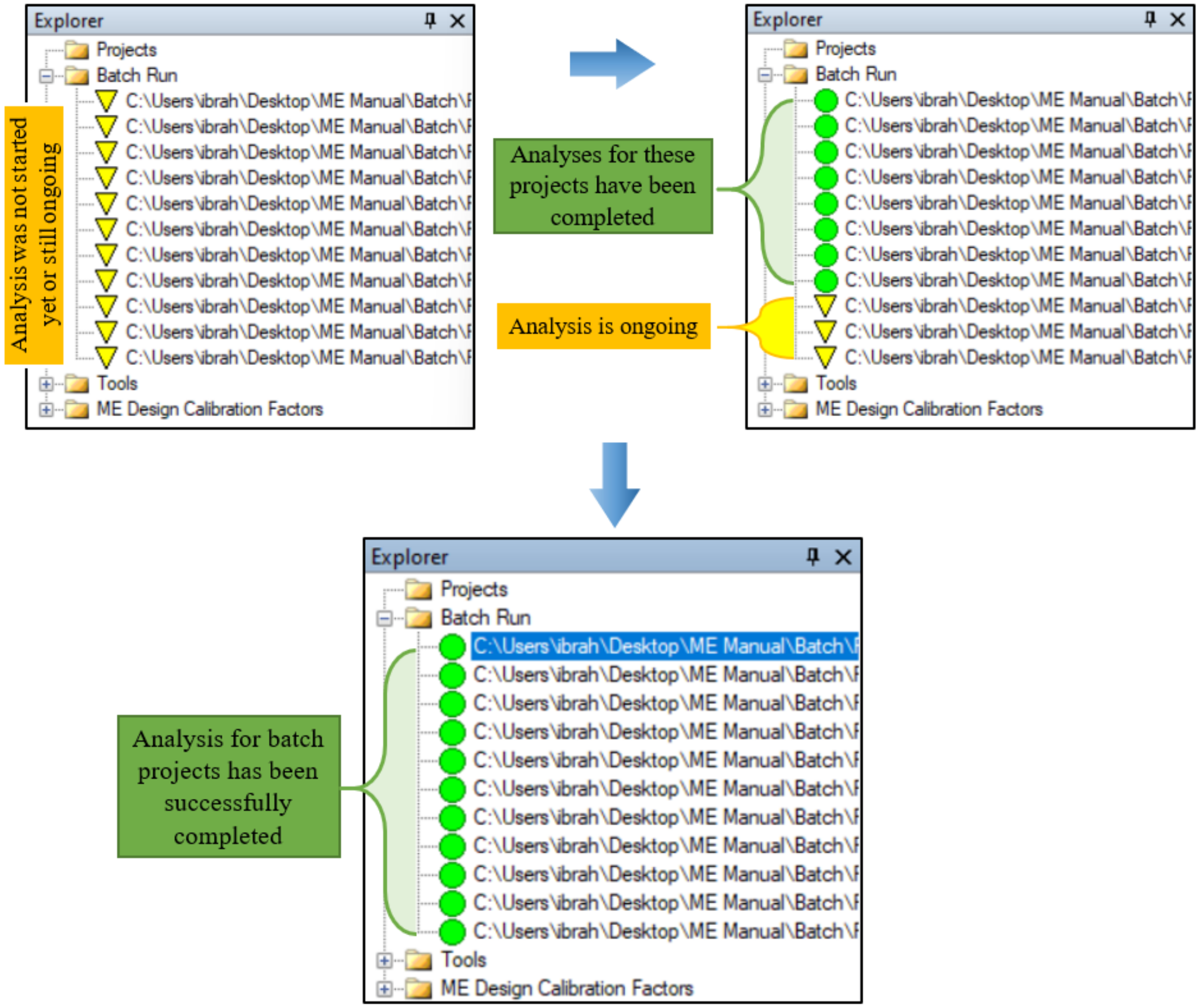


Figure 75. Analysis progress in Explorer pane for batch projects

4.7 Reports

When the AASHTOWare Pavement ME Design Software has completed the design analysis of a single project, a PDF output report containing input information and predicted performances will be generated and automatically opened for review. If the user closes the PDF report, the output report can be accessed again by double-clicking on "PDF Output Report node" located in the Explorer Pane (Figure 76) or can be found inside the folder where the project files were saved.

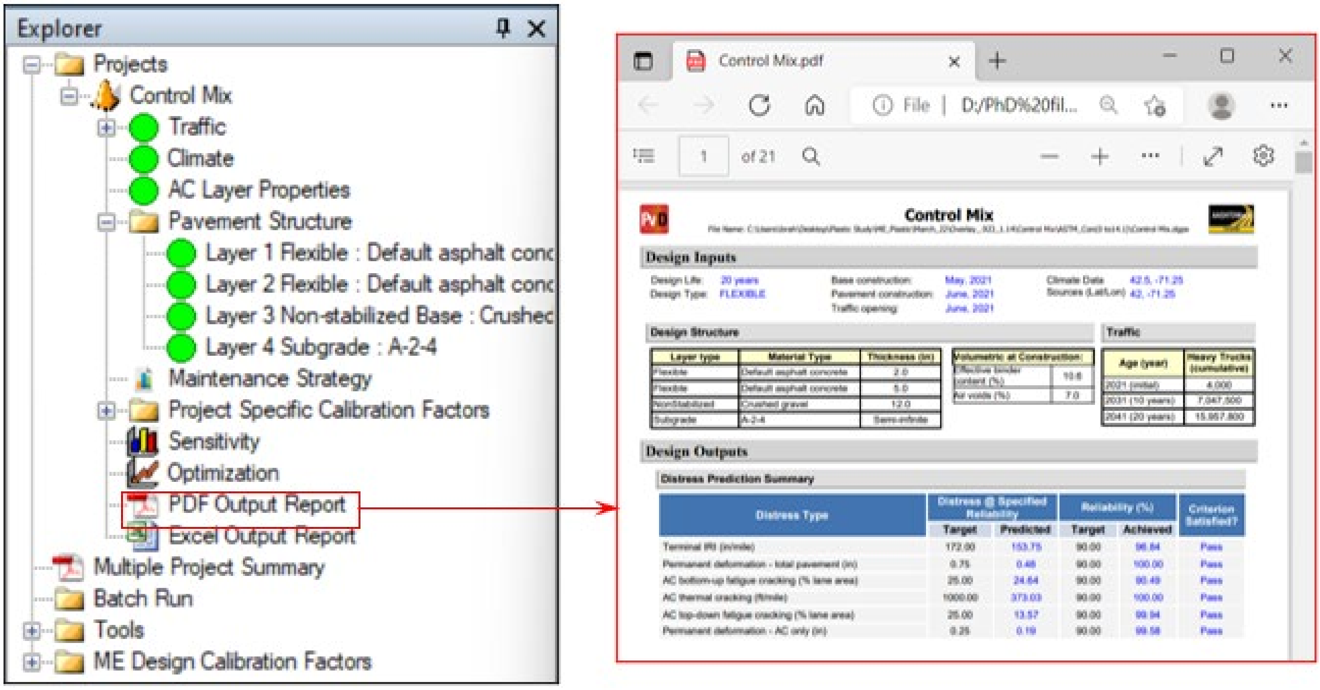


Figure 76. Opening the output PDF file for a single trial design

For projects that have been executed using the Run Batch option, the user can obtain a summary report for all projects by right clicking on the Batch Run folder located in the Explorer Pane and select "View Batch Report" from the drop-down list as presented in Figure 77. The generated batch report will contain the first two pages of the PDF output report from each project.

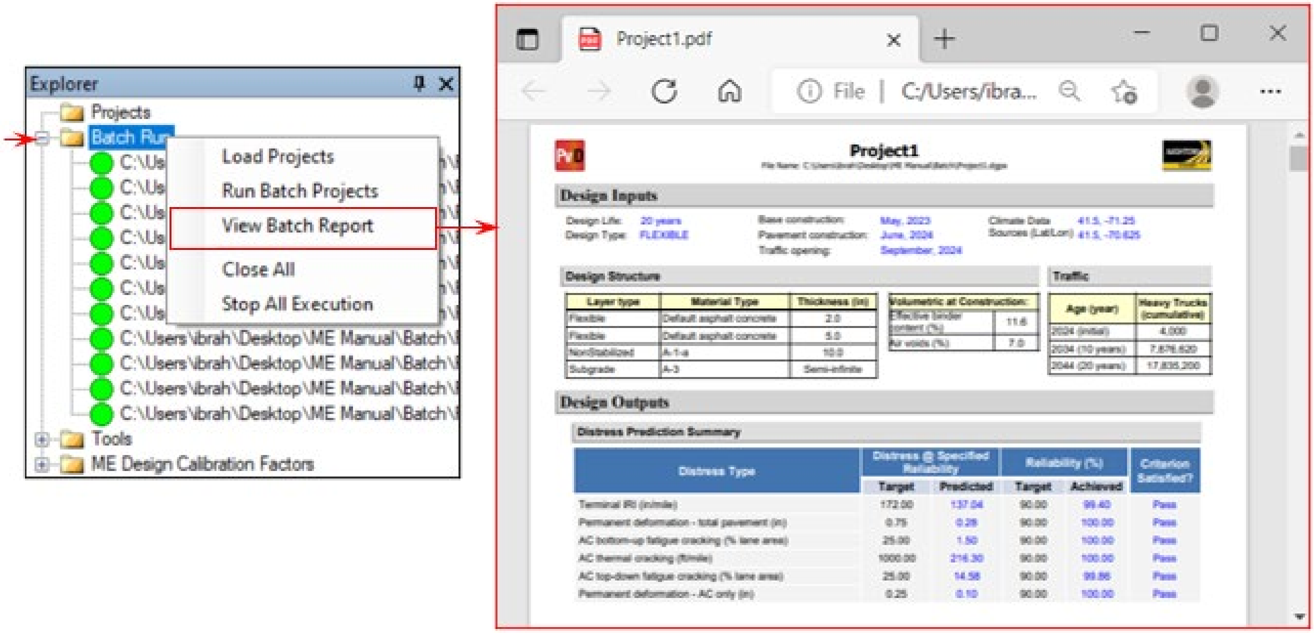


Figure 77. Opening the PDF output summary for batch projects

The AASHTOWare Pavement ME Design Software can generate project output files in Microsoft Excel format if the user applies that option by setting the “Generate Excel reports?” option to “True.” The user can access that tab by double-clicking on the “Options” node under the “Tools” folder located in the Explorer pane as presented in Figure 78.

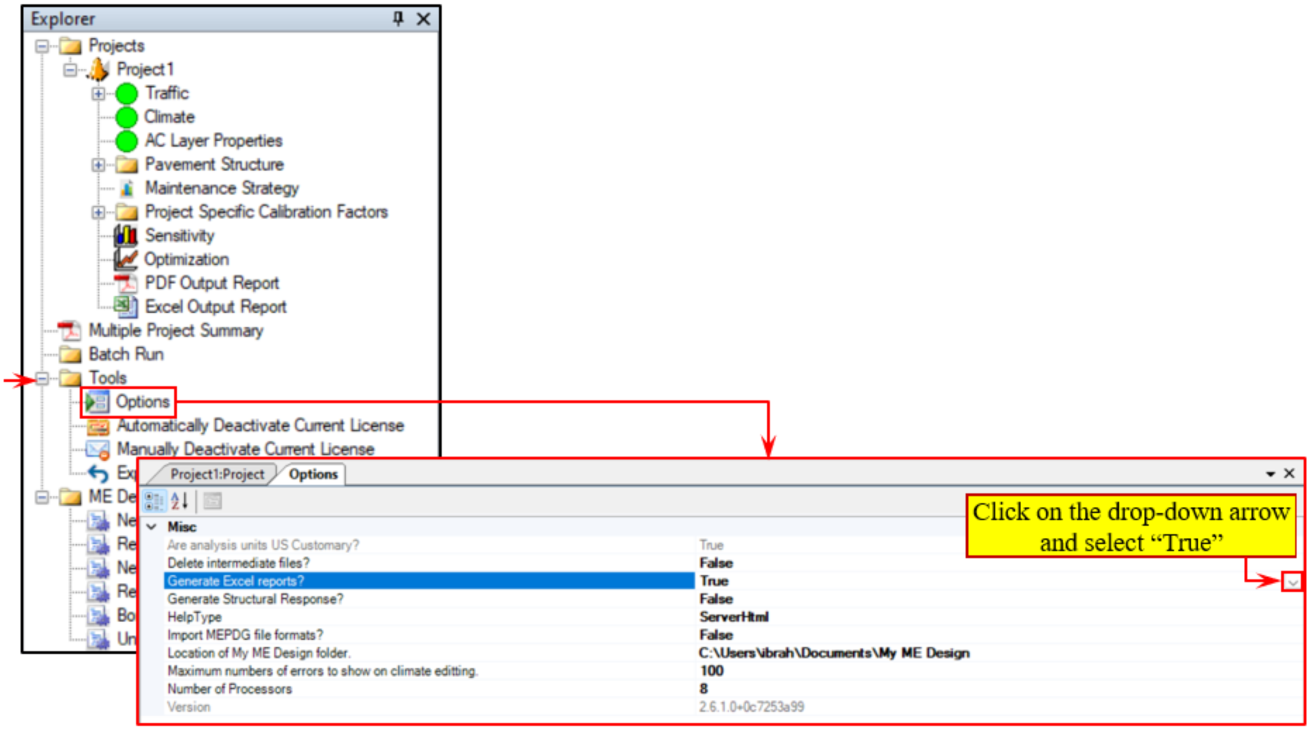
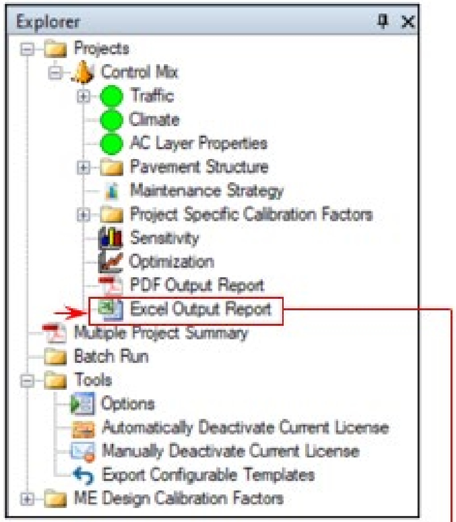


Figure 78. Activating "Generate Excel Reports?" on completion of analysis runs

The Excel report can be opened by double-clicking on the "Excel Output Report" node located in the Explorer pane (Figure 79), or the Excel report can be found in the project folder where the project files were stored.



Predicted Distress

Month	Pavement Age (years)	Heavy Trucks (cum.)	Thermal Crack Depth (in)	Crack Spacing (ft)	Mean Predicted Distress								Predicted Distress @ Reliability							
					IRI (in/mi)	Permanent deformation - total pavement (in)	Permanent deformation - AC only (in)	AC total fatigue cracking: bottom up + reflective (% lane area)	AC total transverse cracking: thermal + reflective (ft/mile)	AC bottom-up fatigue cracking (% lane area)	AC top-down fatigue cracking (% lane area)	AC thermal cracking (ft/mile)	IRI (in/mi)	Permanent deformation - total pavement (in)	Permanent deformation - AC only (in)	AC total fatigue cracking: bottom up + reflective (% lane area)	AC total transverse cracking: thermal + reflective	Bottom-Up Cracking (%)	AC top-down fatigue cracking (% lane area)	AC thermal cracking (ft/mile)
6/2021	0.08	51,744	0	500	69.5	0.162	0.03	0.000	0.000	0.000	0	0	94.4	0.220	0.05	0	0	1.4481571	4.685737	216.3
7/2021	0.17	103,488	0	500	71.3	0.208	0.06	0.000	0.000	0.000	0	0	97.0	0.274	0.09	0	0	1.4482148	4.685737	216.3
8/2021	0.25	155,231	0	500	71.8	0.219	0.06	0.000	0.000	0.000	0	0	97.7	0.288	0.09	0	0	1.4483453	4.685737	216.3
9/2021	0.33	206,975	0	500	72.0	0.222	0.06	0.000	0.000	0.000	0	0	97.9	0.292	0.09	0	0	1.4484183	4.685737	216.3
10/2021	0.42	258,719	0	500	72.1	0.224	0.06	0.000	0.000	0.000	0	0	98.0	0.294	0.09	0	0	1.4484373	4.685737	216.3
11/2021	0.50	310,463	0	500	72.1	0.225	0.06	0.000	0.000	0.000	0	0	98.1	0.295	0.09	0	0	1.4484433	4.685737	216.3
12/2021	0.58	362,206	1.28E-06	500	72.2	0.226	0.06	0.000	0.000	0.000	0	0	98.2	0.296	0.09	0	0	1.4484463	4.685737	216.3
1/2022	0.67	413,950	0.000693	500	72.3	0.227	0.06	0.000	0.000	0.000	0	0	98.3	0.297	0.09	0	0	1.4484513	4.685737	216.3
2/2022	0.75	465,694	0.000716	500	72.3	0.228	0.06	0.000	0.000	0.000	0	0	98.4	0.298	0.09	0	0	1.4484523	4.685737	216.3
3/2022	0.83	517,438	0.000737	500	72.4	0.229	0.06	0.000	0.000	0.000	0	0	98.5	0.299	0.09	0	0	1.4484633	4.685737	216.3
4/2022	0.92	569,181	0.000737	500	72.5	0.230	0.06	0.000	0.000	0.000	0	0	98.7	0.301	0.09	0	0	1.4485163	4.685737	216.3
5/2022	1.00	620,925	0.000737	500	72.8	0.235	0.06	0.000	0.000	0.001	0	0	99.0	0.307	0.09	0	0	1.4488423	4.685737	216.3
6/2022	1.08	674,221	0.000737	500	72.9	0.239	0.06	0.000	0.000	0.001	0	0	99.3	0.311	0.09	0	0	1.4492334	4.685737	216.3
7/2022	1.17	727,517	0.000737	500	73.2	0.244	0.06	0.000	0.000	0.002	0	0	99.6	0.317	0.10	0	0	1.4498736	4.685737	216.3
8/2022	1.25	780,813	0.000737	500	73.4	0.247	0.06	0.000	0.000	0.003	0	0	99.8	0.320	0.10	0	0	1.4506941	4.685737	216.3
9/2022	1.33	834,109	0.000737	500	73.4	0.248	0.06	0.000	0.000	0.003	0	0	100.0	0.321	0.10	0	0	1.4510444	4.685737	216.3
10/2022	1.42	887,405	0.000737	500	73.5	0.248	0.06	0.000	0.000	0.003	0	0	100.1	0.322	0.10	0	0	1.4511345	4.685737	216.3
11/2022	1.50	940,701	0.000737	500	73.6	0.249	0.06	0.000	0.000	0.003	0	0	100.2	0.322	0.10	0	0	1.4511545	4.685737	216.3
12/2022	1.58	993,997	0.000737	500	73.7	0.249	0.06	0.000	0.000	0.003	0	0	100.3	0.323	0.10	0	0	1.4511745	4.685737	216.3
1/2023	1.67	#######	0.00141	500	73.7	0.249	0.06	0.000	0.000	0.003	0	0	100.4	0.323	0.10	0	0	1.4511946	4.685737	216.3
2/2023	1.75	#######	0.0119	500	73.8	0.249	0.06	0.000	0.000	0.003	0	0.67	100.4	0.323	0.10	0	0	1.4511946	4.685737	216.66

... HMA 1 Shift Curve Inputs | HMA 1 Viscosity Curve Inputs | HMA 2 Master Curve Inputs | HMA 2 Shift Curve Inputs | HMA 2 Viscosity Curve Inputs | Distress Data | Sublayer Modulus ...

Figure 79. Opening the Excel Output Report on completion of a trial design

If the predicted distresses do not meet the targeted criteria, the user can adjust trial design inputs such as pavement structure and material characteristics then rerun the program until achieving the target distress values.