M.E.'s ME Report

Newsletter on mechanistic-empirical pavement design implementation at the Michigan DOT August 2012

Beginning with this issue, I am going to highlight specific ME inputs. This edition features articles on two new, and critical, inputs compared with traditional design procedures: Axle Load Spectra and HMA Dynamic Modulus. Axle Load Spectra replaces Equivalent Single Axle Load as the truck traffic input. The HMA Dynamic Modulus is an input that characterizes the asphalt mixture's response to loading. I would like to thank Dr. M. Emin Kutay from Michigan State University for agreeing to write the HMA Dynamic Modulus summary.

Mike Eacker

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Axle Load Spectra

After the completion of the AASHO Road Test in Ottawa, Illinois in 1960, the first interim design procedure was released in 1961. It introduced the idea of characterizing all truck traffic into one single value called the equivalent single axle load (ESAL). An ESAL is the relative damage an 18 kip single axle does to the pavement. ESALs have since been the traffic input in the AASHTO design method.

With the mechanistic-empirical (ME) design method, ESALs are no longer used. Instead, the Axle Load Spectra is used along with various other inputs. The Axle Load Spectra is a set of tables (spreadsheets) containing the percentage of trucks falling into weight categories, or "bins." Figure 3 (see page 4) shows just a portion of a single axle spectra. The rows are divided to contain each month of the year for each of the FHWA vehicle classifications that pertain to busses and trucks (4 through 13). The columns are divided into weight bins depending on the axle type as follows:

- Single Axles – 3,000 to 41,000 lb at 1,000 lb intervals.
- Tandem Axles – 6,000 to 82,000 lb at 2,000 lb intervals.
- Tridem and Quad Axles – 12,000 to 102,000 lb at 3,000 lb intervals.

The cells contain the percentage of axles in each vehicle classification that is in each weight category for each month. Each design in ME requires the Axle Load Spectra for single, tandem, tridem, and quad axles.

An advantage to using Axle Load Spectra is that this data is already being collected by weigh-in-motion (WIM) devices. The data from a WIM can easily be converted into the correct format for inclusion into the ME software. If a segment of roadway being designed is not represented by a nearby WIM, the necessary spectra can be represented by regional or statewide averages from other

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Dynamic Modulus (|E*|) Mastercurve

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One of the key inputs in the DARWin-ME for asphalt pavements is the dynamic modulus (|E*|) mastercurve. The |E*| defines the stress-strain relationship of asphalt mixtures when they are loaded in a cyclic mode. Figure 1 shows a typical response of a cylindrical asphalt specimen when subjected to a haversine loading. As shown, the measured strain also has a haversine shape, with a delay in the peak as compared to the peak of the stress. This time delay is used to calculate the so-called phase angle of the material. For perfectly elastic materials, the phase angle is zero; for perfectly viscous materials (e.g., fluids), the phase angle is 90 degrees. It should be noted that the behavior seen in Figure 1 is linear viscoelastic and only observed if the loading level does not result in strain levels larger than 100-120 microstrain. At higher load levels, plastic deformation occurs at high temperatures (40-70ºC) and microcracking initiates at intermediate temperatures (10-30ºC).

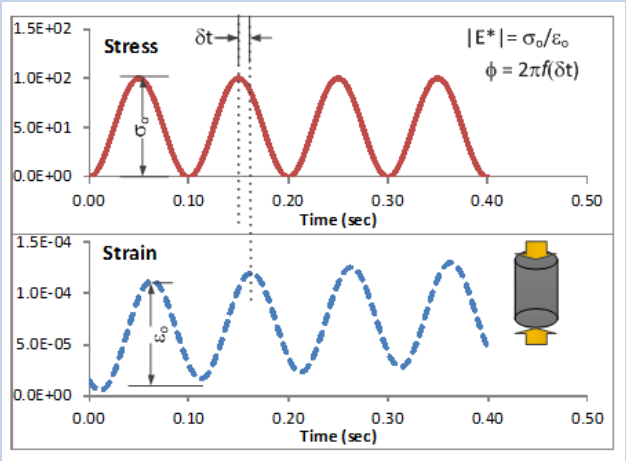

Figure 1. Illustration of cyclic loading of an asphalt specimen and corresponding strain response

Asphalt mixtures have different |E*| values at different temperatures and loading frequencies. The |E*| increases with increasing frequency, decreases with increasing temperature. In order to be able to combine the effects of frequency and temperature on |E*|, a so-called 'mastercurve' is generated. Once |E*| values are measured at different temperatures (T) and loading frequencies (*f*), the |E*| mastercurve is obtained using the time-temperature superposition (TTS) principle (Kim 2009). Based on the TTS principle, a single |E*| master curve can be obtained by simply shifting the data obtained at different temperatures along the loading frequency as shown in Figure 2. The resulting parameter in x-axis is called the reduced frequency (f_R), which is defined as follows:

$$f_R = f \; a(T)$$

where *f* is the frequency of the load and *a(T)* is the shift factor coefficient, which is a function of temperature (T). In the |E*| mastercurve graph, reduction in reduced frequency is equivalent to increase in temperature, i.e., the left side of Figure 2 shows the |E*| values at high temperatures (and low frequencies) and the right side in Figure 2 shows the |E*| at low temperatures (and high frequencies).

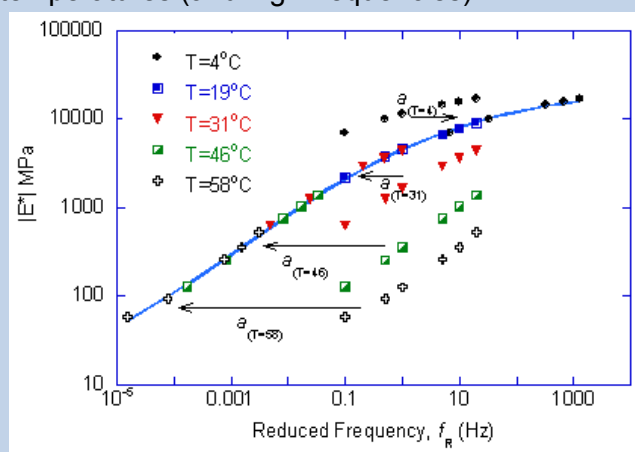

Figure 2. Illustration of shifting |E*| data at different temperatures to obtain the |E*| master curve

In DARWin-ME, the rutting and fatigue cracking models use the |E*| mastercurve as an input (AASHTO 2008). Better rutting performance is expected in mixtures with relatively high |E*| values at low reduced frequencies (i.e., high temperatures). On the other hand, better fatigue cracking is expected in mixtures with relatively low |E*| values at high reduced frequencies.

References

AASHTO, "Mechanistic-Empirical Pavement Design Guide: A Manual of Practice: Interim Edition," American Association of State Highway and Transportation Officials 2008.

Kim, Y. R., Modeling of Asphalt Concrete, 1st ed., McGraw Hill, ASCE press, 2009.

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|E*| defines the stress-strain relationship of asphalt mixtures when they are loaded in a cyclic mode.

Michigan E* Mastercurve Inputs

So, how is the designer to know what the appropriate E* inputs are for an HMA layer being used in DARWin-ME? Michigan State University (MSU) is conducting E* testing on mixes sampled from MDOT projects. This testing is being done as part of the research project "Preparation for Implementation of the Mechanistic-Empirical Pavement Design Guide in Michigan." To date, 59 samples of 46 different mix types have been collected and delivered to MSU for testing. Mix designations that use different PG binders in different regions are considered different mix types. Similarly, mixes not using the standard binder as called for in the HMA Mixture Selection Guidelines are considered a different mix type.

The E* input is a table of values as seen in Table 1. MSU is working on software that will allow the designer to pick a specific mix designation/binder combination and generate the necessary ME inputs. These inputs can then be imported into DARWin-ME. The plan is to have default inputs for standard mix/binder combinations for the various regions embedded in the DARWin-ME database. The designer could pick the mix type for their region and have the inputs for that HMA layer automatically filled in. This would include E*, as well as other required HMA inputs. Other mix/binder combinations not included in the database could have inputs generated by the software being developed. So, the designer would only to have to know the appropriate mix designation for the layer (top, leveling, base) being input and for the expected traffic level for that location.

The plan is to have default inputs for standard mix/binder combinations for the various regions embedded in the DARWin-ME database. The designer could pick the mix type for their region and have the inputs for that HMA layer automatically filled in.

	Frequency, Hz			
Temp., °F	0.1	1	10	25
10	1,624,000	1,920,000	2,140,000	2,264,000
40	1,458,000	1,725,000	1,940,000	2,073,000
70	1,253,000	1,443,000	1,672,000	1,867,000
100	864,000	972,000	1,355,000	1,595,000
130	335,000	506,000	868,000	1,016,000

Table 1. Example E* Table. Values are in psi and are not actual test data - shown for illustrative purposes only.

It is important to point out that E* can be estimated in the software by inputting the aggregate gradation, mix volumetrics, and binder to be used. However, the ME performance models are sensitive to the E* input. Therefore, the use of test results is deemed to be the optimum choice.

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WIMs or through correlation with a WIM from a site with similar traffic characteristics. The inclusion of monthly information allows for the calculation of pavement response (stresses and strains) as material properties change throughout the year due to climatic variation.

Month	Class	Total	3000	4000	5000	6000	7000		38000	39000	40000	41000
January	4	100	1.8	0.96	2.91	3.99	6.8		0.01	0.01	0.01	0
January	5	100	10.05	13.21	16.42	10.61	9.22		0.01	0	0	0
January	6	100	2.47	1.78	3.45	3.95	6.7		0.01	0.01	0.01	0
January	7	100	2.14	0.55	2.42	2.7	3.21		0.01	0.01	0.01	0
January	8	100	11.65	5.37	7.84	6.99	7.99		0	0.01	0	0
January	9	100	1.74	1.37	2.84	3.53	4.93		0	0	0	0
January	10	100	3.64	1.24	2.36	3.38	5.18		0	0.01	0.04	0
January	11	100	3.55	2.91	5.19	5.27	6.32		0.02	0.01	0.02	0
January	12	100	6.68	2.29	4.87	5.86	5.97		0.01	0	0	0
January	13	100	8.88	2.67	3.81	5.23	6.03	.....	0.01	0.01	0	0
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December	4	100	1.8	0.96	2.91	3.99	6.8		0.01	0.01	0.01	0
December	5	100	10.05	13.21	16.42	10.59	9.23		0.01	0	0	0
December	6	100	2.47	1.78	3.45	3.95	6.7		0.01	0.01	0.01	0
December	7	100	2.14	0.55	2.42	2.71	3.21		0.01	0.01	0.01	0
December	8	100	11.65	5.36	7.82	6.99	7.99		0	0.01	0	0
December	9	100	1.74	1.37	2.84	3.53	4.93		0	0	0	0
December	10	100	3.64	1.24	2.36	3.38	5.18		0	0.01	0.04	0
December	11	100	3.55	2.91	5.19	5.27	6.32		0.02	0.01	0.02	0
December	12	100	6.69	2.31	4.88	5.87	5.98		0.01	0	0	0
December	13	100	8.88	2.67	3.81	5.23	6.03	.....	0.01	0.01	0	0

Figure 3. Portion of an axle load spectra for single axles

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ME vs. AASHTO 1993

For many years, MDOT has used AASHTO's *1993 Guide for Design of Pavement Structures* and the 1986 version prior to that. So, how does ME differ from the AASHTO 1993? Table 2 contains a list of the major differences between the two design procedures.

	AASHTO 1993	Mechanistic-Empirical
Basis	Empirical observation from the 1958-59 AASHO Road Test	Theories of mechanics
Original Calibration	AASHO Road Test – Ottawa, Illinois	SHRP test sections from around the country
Traffic Characterization	Equivalent Single Axle Load	Axle load spectra
Materials Inputs	Very few	Many
Climatic Effects	Limited – can change inputs based on season	Integral – weather data from 600+ US weather stations included
Performance Parameter	Present Serviceability Index	Various distresses, IRI
Output	Thickness	Performance prediction (distress prediction)

Table 2. Comparison of AASHTO 1993 and ME design procedures

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ME Design Output

The output in ME design is predicted pavement performance, in the form of pavement distresses, compared with AASHTO 1993, which has pavement thickness as the output. The pavement cross section is instead a major input into ME. The distresses that ME predicts over the pavement design life for new/reconstructed pavements are as follows:

HMA Pavements

- International Roughness Index (ride quality), in./mile
- Longitudinal top-down cracking, ft./mile
- Longitudinal bottom-up cracking (alligator cracking), % surface area
- Transverse cracking (thermal cracking), ft./mile
- Total rutting (rutting in the HMA, base, and subgrade layers), inches
- HMA rutting, inches

Jointed Plain Concrete Pavements (JPCP)

- International Roughness Index (ride quality), in./mile
- Transverse cracking, % of slabs cracked
- Faulting (average fault at transverse joints), inches

Continuously Reinforced Concrete Pavements (CRCP)

- International Roughness Index (ride quality), in./mile
- Punchouts, #/mile

These same distresses are predicted for overlays using the above pavement types, with a few additions. Reflective Cracking is also available for all HMA overlays, % slabs cracked is available for HMA overlays of JPCP, and punchouts is available for HMA overlays of CRCP.

Reliability, like AASHTO 1993, is an input in ME design. However, instead of having one reliability value for the entire design, a desired reliability level can be assigned to each distress predicted. This allows for the possibility of assigning different reliability levels to each distress.

Each distress is assigned a maximum value that is not to be exceeded at the end of the design life. This value is called the distress threshold. If any of the predicted distresses exceed the threshold value at the end of the design life (at the reliability level assigned), then the design has failed. The designer will need to change one or more inputs to reduce any failing distresses so that a passing design can be achieved.

Appropriate threshold values and reliability levels are being investigated. Final values for fix types will be chosen prior to implementation with the help of the ME Oversight Committee.

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ME Oversight Committee Formed

The ME design method is bringing about a lot of changes in how we will create a pavement design—the quantity and specialty of inputs, thickness no longer the output, traffic data changes, etc. This makes it much more critical that this be an MDOT-wide effort than with previous design methods. Therefore, a committee has been formed to help make decisions on ME implementation issues. Examples of issues the committee will work on are input values, input levels, threshold values, reliability levels, equipment needs for testing, recommendations for research projects, criteria for when a design is final, and any business changes for the design process.

The committee will include MDOT supervisors from the following general areas: concrete materials, HMA materials, aggregate materials, pavement testing, traffic data collection, and pavement management. The committee will also include region soils engineers and have representation from the two paving industries.

Three subcommittees have also been identified: concrete, HMA, and traffic. These subcommittees will work on recommending input values and levels, threshold values, equipment for testing, etc. The recommendations will go to the ME Oversight Committee for review. The ME Oversight Committee will make final recommendations to MDOT management. Membership on these subcommittees will consist of MDOT personnel with expertise in concrete, HMA or traffic data collection, as appropriate, and at least one region soils engineer. The paving industries will also be represented on their respective material's subcommittee.

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ME Web Page Delayed

In the May newsletter, it was mentioned that Construction Field Services Division was working on an ME-related Web page. The creation of that Web page has been delayed until sometime after October as MDOT transitions to a new Web page publishing application. Initially, the Web page will have links to completed MDOT reports, ME newsletters, presentations, and other ME-related resources. Eventually, the Web page will have user manuals, training materials, typical input values, etc. The Web address will appear in a future newsletter after the Web page has been created.

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For questions about information in this newsletter, further details on mechanistic-empirical pavement design implementation in Michigan, or to submit an idea for an article in a future newsletter, please contact:

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