INTEGRATION OF STRUCTURAL AND HMA MIXTURE DESIGN: WHY HASN’T THIS BEEN DONE?

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Introduction
The HMA mixture design process more common in the U.S. today is to have the contractor responsible for the HMA mixture design, while the agency maintains responsibility for the structural design and confirming the mixture design. Researchers and consultants have recommended for decades that hot mix asphalt (HMA) mixture and structural design be integrated into one system.\(^1\)\(^2\)\(^3\)\(^4\) Unfortunately, these two operations remain as independent functions—even when both are the responsibility of the agency or same organization on a day-to-day basis. The major reason for this independence is that most agencies use the 1993 AASHTO Design Guide for structural design and the Superpave-Gyratory volumetric method for mixture design.\(^5\)\(^6\) These design procedures are based on and use different material properties and design criteria.

Presently, there is a move to use structural design procedures that are based on mechanistic-empirical (M-E) principles.\(^5\)\(^6\) Figure 1 is a conceptual schematic of the three-stage design process for M-E based design methods. These M-E based procedures use both volumetric and fundamental material properties, such as air voids, asphalt content, modulus, strength, etc. to characterize HMA. As such, M-E based design methods have the capability to tie mixture design to structural design, as well as to performance-related specifications. Tying structural design to mixture design seems simple, but if it was simple and straight-forward, it would have already been done. Various issues need to be considered to integrate the design methods, especially in the low bid system that is common to the U.S.

TRB sponsored a session in 2004 that was specifically directed towards integrating HMA mixture and structural design procedures. Little interest or aggressive action was generated from that session towards integrating the design methods. As AASHTO has voted affirmative in 2008 towards an interim M-E based structural design method (titled Mechanistic-Empirical Pavement Design Guide [MEPDG]), the interest and potential success of integrating structural and mixture design methods is much higher today than in

\(^1\) Some of the AAPT symposiums were focused on using structural design parameters for HMA mixture design: 1983, Specifications for Pavement Performance; 1985, Asphalt Mix Design; 1988, Effect of Mix Properties on Structural Design: A Review.
In addition, Advanced Asphalt Technology (AAT) has developed a new mixture design process under NCHRP Project 9-33 that ties structural to mixture design.\(^2\)

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\(^2\) The draft final report and design manual have been submitted for review under NCHRP Project 9-33. A workshop on the design procedure is scheduled for February 27, 2009 in Irvine, California.
When an M-E based method becomes standard practice, structural and mixture design can be based on the same criteria and mixture properties. Figure 2 is a simplified flow chart showing the steps involved in developing an integrated structural and HMA mixture design system, while figure 3 shows a simplified flow chart of an integrated system. This paper presents those implements that delayed or impeded the adoption of an integrated design system and how to minimize their effect into the low bid system. Although the impediments will vary from agency to agency, the paper discusses some of the more common ones—many of which are not technical issues.

**Impediments to Implementing an Integrated Design System**

1. **Institutional and Communication Barriers (Turf Protection)**
   
   As noted in the introduction to the paper, structural and HMA mixture designs are usually performed within different departments or by completely different organizations for some agencies. Institutional or communication barriers that exist at any level and for whatever reason will result in frustration and potential problems for the agency, contractor, and material suppliers.

   Departments, as well as other organizations involved in construction, need to know what data are needed and how those data will be used and interpreted to establish the input values for structural design and establishing criteria for mixture design. To minimize misinterpretation of data between departments within an agency, between the agency and industry, and reduce any “turf protection,” a committee should be established—similar to the process used by some agencies in revising construction specifications to ensure industry support. This committee should consist of individuals from each department and organization that is responsible for or provides data to establish inputs to the structural and mixture designs to establish universal support across all departments within an agency for the integration plan.

2. **Reluctance or Resistance to Change from Standard Practice—Insufficient Confidence in New Methods**
   
   Most agencies find it difficult or become nervous when adopting changes to the way they are accustomed to doing business on a day-to-day basis. For example, the 1993 AASHTO Design Guide requires the use of repeated load resilient modulus tests for characterizing paving materials and foundation soils. Resilient modulus test procedures have been available for multiple decades. Few agencies, however, require resilient modulus tests for design—correlations are used, which have been accepted without extensive data. Adoption of an M-E based structural and mixture design method will be no different, in terms of resistance to change. The question is; Why?

   A major reason for this resistance to change is that the new method is not understood so the user has little confidence in that method and is worried about those embarrassing premature failures. To minimize the resistance to using M-E based methods, training and education initiatives need to be at the forefront of the integration effort. Demonstration projects should also be planned over time, because they allow all parties of the design and construction teams to become familiar with and understand the process. More
importantly, the asphalt industry (contractors, consultants, and material suppliers) should be invited to attend seminars and open-houses for these demonstration projects.

Figure 2. Simplified flowchart of the minimum steps needed to integrate structural and HMA mixture design procedures.
3. Increased Complexity of Design Methods, As Compared to Traditional Procedures

One of the definite advantages of the 1993 AASHTO Design Guide is its simplicity and ease of use as a thickness design tool. There is no question that the level of effort and costs to complete a new pavement design or rehabilitation design using the M-E based methods will be greater. The M-E based methods require many more inputs and material properties for pavement and mixture designs. Another impediment is that there is no manual solution to a specific design project. Agencies are used to being able to complete manual solutions with the 1993 AASHTO Design Guide, which can be made in a short time period. This restricts an agency’s quick check of a design through the existing AASHTO structural design software.
These impediments will be difficult to overcome based on the current programs and design methodology. The committee and champion of the M-E based design method within an organization should clearly acknowledge these facts but also acknowledge the benefits with implementing and integrating the design system. Training programs to reduce the time needed for determining the input values and software execution will reduce but not eliminate the frustration with these two impediments.

4. Additional Costs and Time for Pavement and Mixture Designs

One of the more significant impediments to using M-E based design software and implementing an integrated design system is the amount of run time for analyzing flexible pavements and HMA overlays. Most 10-year designs require at least 20 minutes of computational time and over 45 minutes for 20-year designs.

In addition, some M-E based methods do not compute the required layer thickness for specific site conditions. M-E based methods compute the magnitudes of various performance indicators. A series of software runs is usually needed to optimize multiple design features. To make these computations, more laboratory testing (test specimens and different tests) will be needed. Initially, agency personnel will have minimal experience and knowledge in many areas required by M-E based methods. This issue of more costs and time will definitely hamper and impede the support or an integrated design system.

A method that agencies can use to minimize the number of design iterations and reduce the frustration with having to rerun many problems is to produce a catalog of trial structural designs and rehabilitation strategies that satisfy the failure criteria adopted by the agency. This catalog of designs should be based on an agency’s previous experience, the performance of their traditional designs, policy decisions, and M-E based software.

Some agencies will have insufficient funds to purchase the field and laboratory equipment needed for materials testing to determine the input values for structural design. Obtaining the equipment needs to occur over time, especially in de-centralized agencies. Significant training and education efforts will be required for performing the tests and operating the software. Thus, implementation of an integrated design system needs to be planned over a period of time.

The field and laboratory equipment purchases should be planned so that training can occur simultaneously between the different departments and industry. Those agencies that allow contractors and consultants to complete the structural and mixture designs will also need to communicate and coordinate with the asphalt industry. The training and educational plans should be developed between the agency and industry groups and document the benefits of the integrated system.

3 NHI Course 1310118 on the Simple Performance Test is being developed and will be available in 2009. Training and certification programs need to be available for all test methods that are used for structural and HMA mixture designs.
5. **Mixture Properties Unfamiliar or Not Understood by Agency and Contractor Personnel; Unknowns Create Uncertainty or Reluctance to Support Integration**

Under the low bid system, the materials for pavement construction and HMA mixture design are usually not known when the structural designs are completed, with the exception for the design-build concept. Agency and contractor personnel have little historical experience on the mixture inputs for the structural design procedure, and how to establish mixture design criteria for those properties. With the use of any new design process, agency and industry personnel will need time to understand the mixture properties and their effects on the mixture and structural design process. In other words, agency and contractor personnel need to know how changes in a volumetric property or mix component that are controlled by the contractor affect the fundamental properties used for structural design.

HMA material and mixture property libraries will need to be established within agencies to support use of the structural design method, which are consistent with those used in the mixture design method and QA program. A feedback plan or data storage capability needs to be included so that an agency can update and/or confirm the properties being used for structural design and identify any changes in those properties over time.

6. **Certification of Personnel and Equipment**

Most of the test procedures being used to measure the HMA properties that are needed for structural design are not included in the AASHTO or ARML certification program. Personnel need to become proficient in the new test methods that will be used in the integrated system for structural and mixture design. The certification issue becomes critically important for those agencies where the contractor is responsible for the mixture design and the agency confirms that design, as well as for QA programs. This impediment can be overcome with time.

7. **Controversy on Which Transfer Function is the “Best” for Predicting Pavement Distress**

There is no perfect model for predicting pavement distress over time. All prediction models have errors. More importantly, multiple transfer functions are typically available for use in predicting the same distress. When any new design method is put forth, there is debate within the research community regarding the model errors and applicability of the model—model A versus model B. Debate and discussion on the model limitations and errors is good, but to the practicing engineer this debate can reduce confidence in all of the prediction models—increasing the reluctance of agencies adopting any of the design methods.

8. **Unreasonable Predictions From Experience Create Misconceptions and Reduce Confidence in Design Process**

As note above, all predictive models have error and limitations. The transfer functions embedded in M-E based software are no exception. An important impediment is unreasonable predictions with the software as compared to an individual or agency’s experience. Unreasonable predictions create frustration and reduce the confidence in the design process.
It is impossible and cost prohibitive to include all possible materials and design scenarios used across the U.S. within the calibration and validation process of any M-E based design system. Agencies and organizations should plan to sponsor a local or regional calibration effort to reduce the error terms, as a part of the implementation plan for the integrated design system. The calibration and validation of the prediction models is an essential step in giving the design analysis credibility. The calibration and validation of the M-E based prediction models is considered by many to be the most important activities to establish confidence in the design procedure and facilitate its implementation, acceptance, and adoption. Furthermore, it is believed that the transfer functions (or prediction models) and design analysis procedure will not be accepted for routine use by the highway community if the validation results do not demonstrate reasonable correspondence between the field-observed and predicted distress levels.

The *M-E DPM* database developed under NCHRP 9-30 was created for this specific purpose. This database can be used to assist agencies in their local/regional calibration efforts and is a feature that agencies can use to store their calibration data for future use. In addition, an agency’s pavement management database should not be overlooked for assisting in the local calibration effort. The effectiveness and use of the pavement management database will depend on the detail included and maintained within that database. As part of the regional calibration and validation process, agencies should plan to develop libraries of inputs to support the M-E based design method and implementation efforts. Those libraries that will likely provide the greatest benefit and use include traffic, HMA materials, unbound aggregate base materials and soils, and construction quality assurance data.

9. **Climatic Effect on Test Conditions for Structural and Mixture Design**

Historically, the mixture design process or method has used one single test temperature for measuring specific mixture properties for selecting the target asphalt content for an HMA mixture that will be used in any climate or environment. For example, the Marshall and Hveem mixture design methods. The use of one test temperature will be insufficient within the integration process for all climates.

10. **Applicability to Quality Assurance Programs and Test Plans and Forensic Investigations**

Stated simply, there can be a bias between the structural, mixture, and functional mixture tests and those tests used in quality assurance (QA) programs. Calibration must eliminate this potential bias for project success. For example, a good modulus for one project might be an inferior value for another project under different conditions. Figure 4 shows some of the calibration steps in the systems approach to ensure that the flexible pavement will meet the design expectations—reducing fracture, distortion, disintegration, and surface condition over the design period.

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*FHWA is sponsoring a project for using agency PMS data to assist in the calibration and validation of the transfer functions in an M-E based structural and mixture design system.*
Site Features
- Climate
- Traffic
- Foundation

Select Strategy: Trial cross-sections for pavement structural design or rehabilitation.

Complete structural design using mixture specifications; Select structural properties to minimize distress
[M-E Design Guide]

Material selection and certification: Source approval; NCHRP 9-33

Material Specifications:
- Aggregate
- Binder
- Additives, etc.

Volumetric Mixture Design;
Superpave Gyratory Compactor
[NCHRP 9-33]

Confirmation – Adjustment of volumetric mixture design, verify structural properties used in design.

Perform torture test(s) (APA, Hamburg, etc.) or dynamic modulus, fracture, permanent deformation tests, etc.; NCHRP 9-19

Prepare specimens over range of volumetric conditions.

Finalize Mix Design, NCHRP 9-33

Use E*, creep compliance, & other properties of HMA mixtures for setting construction specifications.

Acceptance Plan & Specifications

Performance Related Specifications
[NCHRP 9-22]

Calibrate NDT- QA tests

Quality Control Plan

Extract properties from materials library (HMA and other materials).

Feedback from monitoring pavement performance, NCHRP 9-30 database

Confirmation of structural design assumptions & performance expectations

Feedback from monitoring pavement performance, NCHRP 9-30 database

Feedback from monitoring pavement performance, NCHRP 9-30 database

Figure 4. Flowchart for the systems approach for designing, specifying quality HMA mixtures and flexible pavements using an integrated design approach.
Calibration of field and laboratory equipment is important to reduce the error and variability in test results. However, calibration of the system (and operator) is equally important but overlooked or confused with equipment calibration in many mixture and structural design projects. Various researchers have found that proper calibration of the tests will be a critical element to the successful implementation and integration of mixture and structural designs.

**More Design Time and Costs—Is It Worth It?**

As noted above, the level of effort and equipment needed to complete an integrated design will be greater, because M-E based procedures require many more inputs to consider different design features. Both volumetric and fundamental properties of each HMA layer are needed to predict the performance and distress of trial pavement sections and materials. M-E based procedures, however, have more versatility and features than the 1993 AASHTO Design Guide that is in use today. These added features require more design and testing time. But, how much more time and costs and more importantly are the benefits worth the increased effort? Each agency will need to determine if the benefits are worth the added costs and efforts. The opinion of these two authors is that the added design time and costs are beneficial.

The test equipment needed to measure the mixture properties shown in figure 4 is more complicated and sophisticated than typically used in an agency’s laboratory. The test equipment and interpretation of the test results require extensive training for both agency and industry personnel. Without question, there is a significant shortage of laboratory test equipment and personnel within most agencies, at least in the beginning. Thus, commercial resources will be needed for design services. Agencies may need to consider the potential use of universities and resource centers to establish initial mixture libraries that can be used for structural design purposes.

**TRB Subcommittee Action in Support of the Design Integration Process**

The following lists some of the potential steps or actions that Committees AFD60 and AFK50 should take to ensure that the design integration process becomes a reality.

1. Support or sponsor user group meetings regarding the new methods. MEPDG user group meetings have been initiated, and need to be continued. These user group meetings provide a basis to document and discuss the increased costs and complexity of an integrated design system in comparison to the benefits and advantages over the current state-of-practice.

2. FHWA is currently sponsoring three Expert Task Groups (ETGs); binder, mix, and models ETG. The mixture ETG should be expanded to include M-E based mixture design compatibility with M-E based structural design—focused on using those transfer functions for both HMA mixture and structural design.

3. Identify and publish demonstration projects where an integrated design process has been used for structural design, HMA mixture design, and to control/accept the HMA pavement. In addition, host regional open-house meetings where the
structural design, mixture design, and quality assurance programs were integrated. Because of travel restrictions for agency personnel, the use of video conferences should also be considered. The focus of these demonstration projects or open-houses (video conferences) should be on increasing the confidence and reducing the reluctance to adopt the integrated design system (refer to figure 4).

4. Sponsor additional TRB sessions on the use and application of an integrated design system, in comparison to the use of current state-of-practice—comparison of comparable designs. More importantly, the key papers within these sessions should be presented or distributed at the regional user group meetings and used as examples in training courses to “get the message out” to more of the practicing engineers.

5. Regarding the professional debate between different transfer functions for the same distress, provide a summary of the limitations and errors between the different methods but more importantly include the benefits and precision and accuracy in comparison to the existing design method. The errors and accuracy of the M-E based methods are being defined, but the errors and accuracy of the current state-of-practice has not been well defined or published.

6. Provide a simple and concise document or white paper that provides guidance for agencies to implement an integrated structural design—HMA mixture design—quality assurance plan. This white paper should also include plans to establish certification of the new test procedures to be used on a day-to-day basis for design.

7. Identify training courses for the new integrated method and publish information on demonstration projects where an integrated design process has been used for structural design, HMA mixture design, quality assurance, and to establish specification criteria for the HMA mixtures. Training courses for the M-E based methods exist, but courses for integrating the methods, developing the design criteria and specification limits for structural properties need to be developed. TRB should advocate those NHI courses that are applicable to the integration process, publish demonstration projects, and support the use of User Group meetings at the regional level, as noted above.

8. Provide information and literature or references on how to create material and mixture libraries from the HMA mixture design process in support of the structural design process. Use of the AASHTO construction materials database can be used to store and evaluate mixture and construction data for future use in structural design. In addition, provide support or sponsor user group meetings regarding the new methods.

9. An NHI course is in the process of being developed for the simple performance test (NHI Course 130118). Provide references and information on the methods used to establish the test conditions.
Summary

Implementation of the M-E based structural design procedures and using those properties for mixture design will not be a simple activity. Integration of structural and mixture design to result in a system design will take time and effort. This paper has attempted to identify some of the more common impediments to this integration process. Figures 3 and 4 presented a preliminary vision of an integrated design system in a low-bid process.

As agencies begin to consider adopting and using M-E based methods, they should consider and compare the errors and limitations of their current design system to that of the new system. In addition, M-E based design methods and software is a much more powerful design system that can be used to optimize all design features—it is not just a thickness design procedure. Agencies should be encouraged to begin the implementation process as soon as possible and not underestimate the costs and efforts that will be required.

References


