Teaching Methodology of Flexible Pavement Materials and Pavement Systems

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Abstract

Flexible pavement materials exhibit complex mechanical behavior, in the sense, that they not only show stress and temperature dependency but also are sensitive to moisture conditions. This complex behavior presents a great challenge to the faculty in bringing across the level of complexity and providing the concepts needed to understand them. The interaction of these materials within a pavement system is still not understood very well. Solving complex pavement systems has always been very challenging for researchers and practitioners. The authors present a methodical way of presenting this complex subject so that the student does not get lost in the details but also gets the perspective of the process of understanding complex material and the pavement system. First, it is necessary to explain whether the individual layers in the pavement system serve their purpose, and then explain the pavement system focusing on the interaction between layers. The concept of interaction does not change if the mechanical behaviors of the individual layers are modified. Then change the properties of individual layers to realistic values, briefly explaining the test methods and illustrating with actual laboratory data. Finally a backcalculation analysis and a field visit are conducted to observe the falling weight deflectometer tests.
Total: 207

Introduction

A flexible pavement system consist of various components, the materials include subgrade or natural soil at the bottom, then unbound granular base or subbase, followed by bound granular material and then the asphalt concrete layer at the top. The mechanical behavior is considerably different for all these materials. For example, asphalt concrete layer exhibits more temperature dependency than the unbound granular material, on the other hand, the unbound material are more susceptible to moisture changes than bound material. For all these materials, it is possible to explain theoretically the mechanical behavior and properties, but it is still very difficult to visualize its behavior (1,2). It is necessary to explain the response of the material under a given loading condition in the laboratory to appropriately understand the material behavior. Subsequently, the mechanical property that may be appropriate for the application under consideration should be calculated. The purpose of this paper is to present a course that presents this complex information in a very organized manner that is easy to understand and visualize.

Organization of Information

The organization of information in a class is extremely critical in understanding of pavement materials and pavement system. The detailed outline of the senior/graduate level course titled "Flexible Pavement Materials and Design" is shown in Table 1 on the following page. This section includes the methodical way of presenting the information so that all learning styles can be addressed.

Step I: Overview of the Materials and Its Contribution to the Pavement System and Pavement Distresses

Understanding the distresses in the pavements and discussing the cause of failures is a good starting point to get the students thinking about pavement materials and interaction between layers within a pavement system. For example: rutting in pavements can be caused due to surface course or subgrade being soft. To understand pavement materials it is important to explain the purpose of each of the material within the pavement system, and it always makes sense to start from the bottom. For example, subgrade is the natural soil and most probably cannot be altered. The purpose of other materials in the pavement system is to provide a most cost effective protection to the subgrade under the given loading and environmental conditions. The rock and aggregates is the most cost-effective load bearing materials available and would provide the best support structure for the traffic. Since all aggregates are not the same, the selection of aggregates is significantly influenced by the availability and its mechanical properties. The material closer to the pavement surface is expected to withstand higher stresses and should perform better than the aggregates closer to the subgrade. The aggregates closer to the surface alone cannot withstand traffic loads without a binding material. Therefore, the aggregates closer to the surface need binding material to interlock and sustain stresses due to loads and environmental conditions. Hence, asphalt concrete is used closer to the surface. When this concept is explained, different types of locally available materials should be shown to the students so that they get the feel of the material and where they could be used within the pavement system.

Step II: Mechanical Behavior of Pavement Materials

After the pavement materials were introduced, the mechanical behavior of the materials was explained. These include elastic versus viscoelastic versus plastic behavior, stress and temperature dependency (2). These were theoretically explained with illustrations of mechanical responses to simple input histories, like creep and recovery and dynamic loading at different temperatures. The change in the responses with environmental conditions was demonstrated to clearly indicate the effect of the pavement response to these environmental changes.

Step III: Measurement of Mechanical Properties of Pavement Materials

After the mechanical behavior of each material was presented, the mechanical properties significant to the performance of the pavement were explained.

Flexible Pavement Materials and Design		
Topic	**Sub-topic**	**Classes (75 minutes each)**
Syllabus/Introduction		1
Brief overview	Mechanical behavior of asphalt concrete	2
	Mechanical behavior of unbound material	1
Theoretical Overview	Theoretical behavior/example problems	2
Laboratory Measurements	Demonstration of laboratory data and analysis of raw data	2
Exam I		1
Elastic Layer System	Interaction between layers	2
	Computer software /example problems	3 or 4
Non-linear elastic and viscoelastic analysis	Non-linear elastic	2
	Viscoelastic	2
	Backcalculation	2
Exam II		1
Practical Application	Quality Control and quality assurance	2
	Invited Talk	1 or 2
Evaluation	In-class problems	1
	Case-studies	1
Exam III		1
Total		**28**

Table 1. Course Outline

This was done with an illustration of causes of typical pavement failures. The method of measuring mechanical properties is explained and if possible equipments used to measure them are shown to the students. To obtain an excellent grasp on the mechanical properties it is important to demonstrate the measurements necessary to calculate the properties. In several cases the raw data measured from the laboratory were presented to the students and they were asked to calculate the mechanical properties in small groups.

Figure 1. Superpave Gyratory Compactor

The biggest challenge was to explain the complex behavior of asphalt concrete. This material exhibits a great degree of temperature and stress dependency; hence it was difficult to make the students visualize the drastic change in mechanical properties. The asphalt concrete samples were compacted in the Superpave Gyratory Compactor (shown in figure 1) by teaching assistants. A demonstration experiment was conducted in which a static load of 500 lbs was applied on the sample for 100 seconds at four test temperatures; 4°F, 25ºF, 60ºF, and 100ºF, and vertical displacements were measured (shown in figure 2). The phenomenon of the change in displacement response under the same dynamic load at different temperatures and loading times demonstrated the time-temperature dependency. The students then calculated the creep compliance or the stiffness modulus of asphalt concrete from raw data of load and displacement measurements. The exposure to raw data was extremely helpful in visualizing the response of the material under various test conditions. This technique really blended very well with the theoretical information provided earlier in the course. In the case of subgrade and subbase materials, where raw data from the laboratory test was not available, raw data from published literature was used to illustrate the concept. Typical soil samples were shown to the students to compliment the raw data. To explain the mechanical properties of subgrade materials, the raw data from established literature was used to illustrate the concept.

Step IV: Practical Applications of Understanding Pavement Materials

After the mechanical properties were presented, the challenges faced by the materials engineer in selecting the materials were illustrated by videos that showed various materials being used during pavement construction. These also included various application techniques as well as issues faced during construction, like water on the surface, a gap between paver and the truck causing segregation, poor temperature control causing material to compact poorly.

Several personnel from the state department of transportation and local agencies were invited to share their experiences in the industry especially with selecting a quality material for a given application. This gave an excellent perspective to the students and provided practical applications and importance to the information they had studied during the class.

Step V: Assessment and Evaluation of Understanding of Pavement Materials

To assess and evaluate if the students had understood the mechanical responses and behavior of the material, various in-class problems were provided in small groups and then a quiz was given at the end of the topic (3).

The authors realized that the topic was vast and there was a lot of information to be presented, but to do justice to the topic and not lose focus, it was important to present the information in perspective to pavement performance so that it tied everything together and it did not seem like a lot of information.

Step VI: Flexible Pavement System

A flexible pavement system consists of various miniature systems of complex materials. Understanding the behavior of these materials within a pavement system is extremely challenging. The true mechanical behavior is very difficult to characterize and model. To explain the interaction between the components it was necessary to make simple assumptions to begin with and then proceed towards the actual material behavior.

Elastic Analysis

The elastic is the simplest mechanical behavior of a material and it is the easiest to explain the interaction of pavement layers with this theory. Even though none of the pavement layers are elastic, the concepts of interaction and compatibility are the same irrespective of the material behavior. The elastic analysis allows the computations to be simple and can be demonstrated without intensive calculations. First, the analysis was done by hand in class, using examples of a simple two-layer system (Pavement Design and Analysis textbook from Huang was used). The computer software was then used to explain three or more pavement layer systems. This also served as a good introduction to various Pavement analysis computer softwares.

Computer Softwares

Several analysis programs have been developed to analyze a pavement system; the analysis was conducted using more than one, to demonstrate the concepts. The analysis was done with a simple user-friendly window-based elastic layered analysis program like WESLEA and ROADENT to demonstrate concepts of interaction between layers within a pavement system. For example: the effect of various thickness or stiffness of different pavement layers on mechanical response at the surface and the interface was emphasized. In addition, the effect of mechanical response on the pavement distress was also presented. This helped the students to identify the contribution of each of these layers to pavement performance.

Step VII: Backcalculation

Once the concept of interaction between layers is explained within a pavement system, the backcalculation was introduced to the students. Backcalculation is a process of calculating the properties of pavement layers from a series of surface deflections using equipment called Falling Weight Deflectometer. It is a method widely used by the Departments of Transportations for overlay design. These processes expose the students to a brute force method of analyzing a pavement system and understand the response of the pavement system as a whole. The widely available computer software program like MODULUS was used for the analysis. This analysis reinforced the concepts of the response of the pavement system.

Figure 2. Materials Testing Machine and Environmental Chamber

The authors recognize that backcalculation is an approximate method of determining in-situ properties. The results need to be interpreted with caution before conclusions are made based on this process. However, in this class, the source of errors was only theoretically explained. After the backcalculation analysis is conducted, the students were introduced to mechanical properties and behavior of pavement materials.

The previous two sections of this course encourages students to apply techniques and tools for different engineering applications and addresses the following ABET assessment outcomes:
"The Civil Engineering Program at Rowan University will produce graduates who have the ability to use the techniques, skills, and modern engineering tools necessary for engineering practice."

Step VIII: Mechanical Properties - Non-Linear Elastic and Viscoelastic

After a brief overview of pavement materials is done, the elastic analysis was modified to account for the non-linear behavior of pavement materials. The non-linear layered analysis is computationally intensive, but computer programs like KELYAER have been widely used to conduct such analysis. The students did case studies using both elastic and non-linear elastic and the results were compared. For example, after a three-layer system was analyzed considering all material as elastic, the material properties were modified to represent actual material behavior. The asphalt concrete was considered as viscoelastic, the subbase and the subgrade were considered as non-linear elastic. The data representing material behavior was taken from the Pavement Design and Analysis textbook.

. . . important to emphasize the factors that influence pavement response and hence pavement performance.

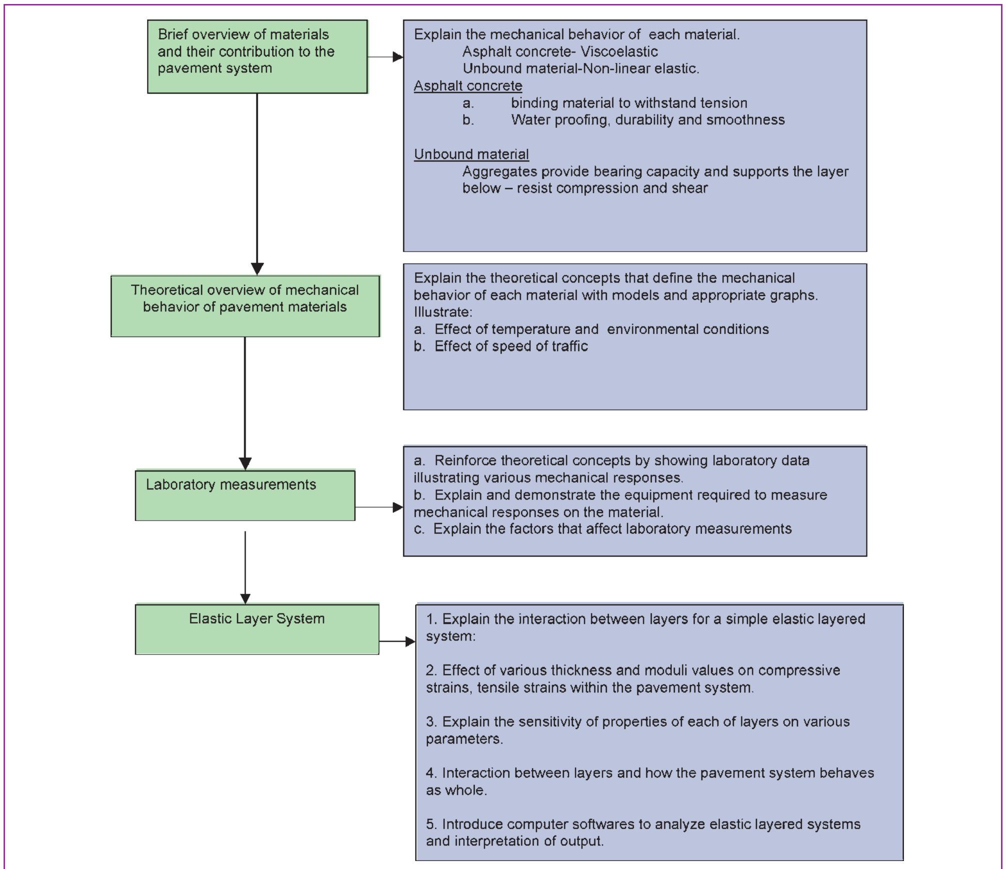

Figure 3. Flow Chart

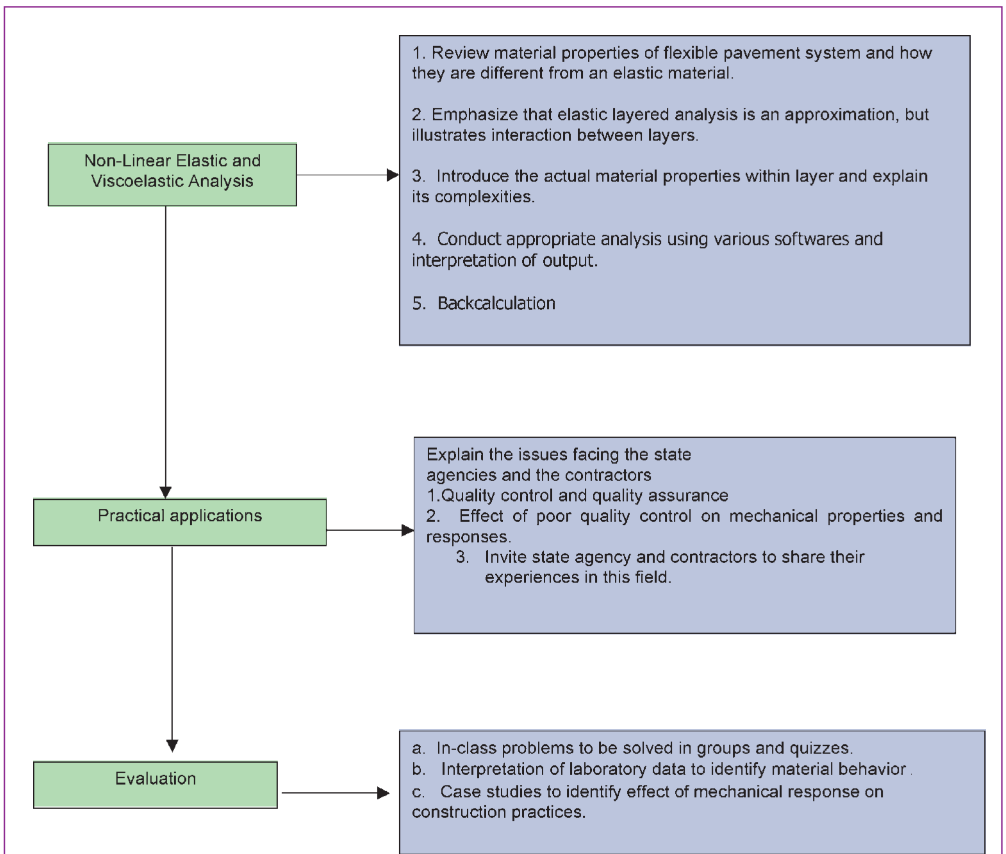

Figure 4. Flow Chart (Continued)

The data input and the analysis were conceptually explained before the softwares were used. The interpretation of the output and the implication of the difference in assuming an elastic material to a non-linear material were emphasized.

Step IX: Field Visit

A field visit was conducted on an interstate where pavement rehabilitation was needed, and the process of falling weight deflectometer and the factors that affect the surface deflections was demonstrated. This is important to emphasize the factors that influence pavement response and hence pavement performance. The outline is explained in the flowchart (figure 3 and 4).

The step IV and step IX emphasized practical issues during construction and evaluation of pavements. It addressed the following ABET outcome "The Civil Engineering Program at Rowan University will produce graduates who have the broad education necessary to appreciate contemporary issues and understand the impact of engineering solutions in a global/societal context".

Assessment of Course

The students understood the concepts based on the outline presented, especially, incorporating laboratory data and reiterating the importance of each material and its mechanical properties within the pavement system. The students provided positive feedback to this learning process and have shown to have more retention of the information when they were required to apply the concepts in senior and graduate level classes. One of the comments before the outline was used was "The class was unorganized and the delivery of information seemed haphazard and confused. It was difficult to establish a logical progression from step 1 to step 2 to step 3". The overall evaluations were 2.83/5.00. After the method was used the students gave a rating of 4.75/5.00 on organization and 4.90/5.00 overall. Thus, this technique seems to work.

Conclusions

The authors believe that the flexible pavement material is an extremely challenging topic to be understood. In fact several experienced people in the industry have serious misunderstanding about the topic. This outline has proven very useful in making this topic interesting and practical. This course follows the cognitive learning. This was extremely important considering the complexity of the topic. The outline presented has provided positive feedback from the students; they have enjoyed and retained the information longer when advanced classes were taught in subsequent semesters.

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