Computer Based AASHTO Pavement Design Methodology

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Summary

A computer expert system has been developed for design of flexible pavements (FLEXPAVE). The design procedure follows the latest AASHTO Guide for Design of Pavement Structures. The system evaluates required thickness for initial pavement design and the subsequent overlays. The system is an educational and training tool as well as a design tool. The user is assisted in selecting design inputs by a rule-base expert system. The rules used to determine the recommended values are shown on the screen along with a brief explanation during the design process. Help screens and various worksheets help the user in selecting design inputs. A sensitivity analysis option allows the user to investigate the required precision for design inputs. The rules in the expert system are derived from the 1993 AASHTO manual and related literature.

Keywords: Pavement Design, Flexible Pavements, Pavement Sensitivity Analysis

1. Introduction

The American Association of State Highway and Transportation Officials (AASHTO) has been a leader in pavement design for nearly 40 years. In the 1950's and early 1960's, AASHTO performed the AASHO Road Test in Ottawa, Illinois. This test collected information, which was incorporated, into the AASHTO design equations for rigid and flexible pavements published in a design manual in 1961 [1]. With continuing research, AASHTO improved its design procedures, which were shown in the 1972, 1986, and 1993 design manuals. The 1986 and 1993 editions made major steps in moving from an empirical to a more theoretically based design of pavement structures. Unfortunately, designers found the improvements to the design process confusing and difficult to follow.

EXPAVE I and EXPAVE II were developed prior to this project to provide a tool for the design rigid pavements. This paper presents the development of the computer system, FLEXPAVE, which assists the user in flexible pavement design in accordance with the 1993 AASHTO guidelines. Unlike EXPAVE I and II that were intended as design tools, FLEXPAVE can be used as an educational tool in the field of pavement design. The goal is to introduce the user to the proper pavement design procedure.

The system is designed to accept design inputs and calculate the layer thickness and/or the overlay thickness for a flexible pavement in accordance with the 1993 AASHTO Guide for Design of Pavement Structures. A sensitivity analysis is included to allow the user to determine the degree of precision needed for a particular pavement input. Worksheets similar to the ones in the AASHTO manual are used to arrive at traffic data and Subgrade resilient modulus. The user may view the results in summary form, showing only the layer thickness, or in a detailed calculation form. The expert pavement designer based on the AASHTO Guide is supplied to the user through a knowledge base. The explanation for the selection of the input is shown to the user. This allows the user to learn from the experience.

Some of the inputs needed for the AASHTO pavement design are difficult to obtain or are difficult to select definitively. Two of these inputs are dealt with in FLEXPAVE, drainage coefficients and Subgrade resilience modulus. The AASHTO guide supplies a table to determine a range of drainage coefficients, but the variables used to classify are vague and subjective. Rules pertaining to the drainage coefficients were supplied from the previous work on EXPAVE [2].

AASHTO method uses measurements such as resilience modulus and elastic modulus to classify the asphalt layer, the base layer, the subbase layer, and subgrade soil. The methods needed to attain these measurements are not used throughout the pavement design community. FLEXPAVE has a number of correlation equations to help the user estimate these design inputs from values that are more common.

FLEXPAVE is not to replace the pavement designer but rather to assist in educating engineers. The computer system allows the user to be productive while learning. As the user becomes more experienced, his or her reliance on the knowledge base of the system will diminish. At that time, the system becomes merely a design tool to speed up pavement design.

2. AASHTO Flexible Pavement Design

The first major road test that included flexible pavement was the AASHO Road Test in Ottawa, Illinois, in the late 1950's and 1960's. In 1961, using the information learned from this test, an Interim Design Guide was written for pavements. Upon further research and review, revised editions were published in 1972, 1986, and 1993.

The AASHTO Design method uses serviceability as a user-defined definition of failure. Serviceability is defined as "… the ability of a pavement to serve the traffic for which it was designed" [1]. The AASHTO Road Test initially determined serviceability from the mean rating of a selected panel of people who judged each pavement with a zero to five rating (five being excellent pavement). These ratings were given at the time of construction and periodically through the life of the pavement. A statistical analysis was then made to relate these ratings to measurable physical properties of the road.

Present Serviceability Index (PSI) is the evaluated rating of the pavement at the time of development. Using PSI, the AASHTO Road Test developed an equation for flexible pavement design. It incorporated serviceability loss, traffic loads on the pavement, pavement materials, subgrade soil conditions, and different climates. This expert system was designed using the 1993 AASHTO manual. The design process is very similar to the 1972 version with the addition of environment, drainage and reliability variables. Methods of evaluating materials and conditions have also been modified. The variables for design are classified into four categories: design variables, performance criteria, material properties and structural characteristics.

3. FLEXPAVE

3.1 FLEXPAVE – Background

FLEXPAVE consists of a main program, FLEX, and the expert system, FRUL. FLEX was programmed with the Clarion programming language. Clarion is a database language that allows easy screen and report development while allowing for database operations. The user will primarily be in the FLEX program. The FRUL system will only be accessed by request from the user. FLEX allows the user to save the design inputs of a particular “job” including the ESAL and M_R worksheet information. The results of calculations, however, are not stored in the databases. Each time the user must recalculate the design for a particular job. This concept of allowing the user to store “jobs” provides a more conducive environment for learning and makes the program easier to use. By storing this information, the user is allowed to look at similar jobs done earlier. Also, jobs that may need design inputs, changed numerous times, would not require that the entire information be inputted for each session.

ESAL worksheets are made available in FLEXPAVE. A critical segment of the worksheet is the ESAL factors used. FLEXPAVE allows the user to enter his or her own ESAL tables in the section off the main menu. At the time of installation, two ESAL tables are included: Kentucky – Rural, used for rural areas; and Kentucky – Urban, used for urban locals. These tables were derived from information obtained in the 1986 Kentucky W-4 tables. The tables only gave ESAL factors for vehicles when the SN is equal to 5.0 and the terminal serviceability of 2.5. Since the W-4 tables showed the vehicle counts used to derive the ESAL factors, the author was able to use them along with Axle Load Equivalency Factors [ALEF] found in the 1993 AASHTO Guide for Design of Pavement Structures to derive the remaining ESAL factors. FLEX computerizes the AASHTO method. If the design inputs are known, the program will derive a layer thickness answer using equations directly from the AASHTO manual. The expert system, FRUL, is based on both the AASHTO manual and outside sources. Analysis and performance periods, reliability, standard deviations, and lane distribution rules come directly from the AASHTO manual. Information is provided from tables that give a range of acceptable values. For this thesis, the author has chosen to take the median of each of the stated ranges for use in the expert system.

The set of rules for the drainage coefficients uses confidence factors. For each rule, a certain condition is considered and that condition provides a confidence factor for each of a set of possible choices. The values can range from 0 to 10 with 0 being an absolute no and 10 being an absolute yes for that choice. The values of 1 to 9 provide the user with various degrees of certainty. The first value of 0 or 10 assigned to a choice will set it permanently to that value. However, if the confidence values stay within 1 to 9, the values will be averaged from all the rules that were used (EXSYS Professional Manual, B-8). The final confidence values for each choice are used to determine the values for the “Quality of Drainage” and the “Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation”. Finally, these values are used to determine the drainage coefficients for the design in question.

FRUL provides the user with assistance in selecting the layer coefficients for the asphalt, base, and subbase layers. From the equations derived and found in the AASHTO manual, a relationship between different test methods for strength, i.e. E and CBR, was concluded. It is important to understand that these conversions, either for layer strength or coefficients, are approximate values. Whenever more precise values are available that information should be used.

The AASHTO manual only provides a graph for the designer to derive the a_1 layer coefficient. To incorporate this information into FRUL, a set of values was taken from the graph and an equation derived for the curve using linear regression. The following is the equation used in the expert system for the asphalt layer coefficient:

$$a_1 = 0.169 (\ln Eac) - 1.763$$

For base and subbase, the AASHTO manual provides a set of nomographs for the different layer thickness measurements as well as the different materials used. Equations have been derived for each of the various combinations taking values from the nomographs in the AASHTO manual and applying linear regression. If resilience modulus of the subgrade is not known, FRUL allows the user to either select an approximate conversion from a CBR value or to use basic soil properties to derive an approximate M_R value.

FRUL uses the approximate conversion between CBR and M_R from the AASHTO manual as $M_R = 1500 * CBR$. This equation is a rough estimate, which should only be used when no other subgrade information is available.

It is important to note that the FLEX part of the system is static and will not change; however, the FRUL section is capable of growing and modifying as more information is accumulated from experts in the flexible pavement design field.

3.2 FLEXPAVE – Summary

The following is a brief summary of the FLEXPAVE software as illustrated in Figure 1.

1. Pavement Design

   a. Edit – The user is allowed to update design variables for the pavement job that is open. Four function keys are used for the edit mode: F1, F5, F6, and F10.

      F1 – Help Screens – Display a brief description of the design variable where the cursor is located

F5 – ESAL Worksheet – Allows the user to input traffic data (ADT) for different vehicle types along the projected growth rate. From this information and the ESAL factor table, which the user chooses, FLEXPAVE will derive the design ESAL using an ESAL worksheet. The "Detailed Calculations" selection will show the complete ESAL worksheet.

F6 – M_R Worksheet – Allows the user to calculate the effective roadbed soil resilient modulus. The user inputs the resilience modulus for each month or half month of the year. The complete M_R worksheet can be seen in the "Detailed Calculations".

F10 – Expert System – Accesses FLEXPAVE's knowledge base for assistance in deriving the design input under consideration. If there is information pertaining to the design input under consideration, the expert system will make a recommendation for the design input from the additional information requested from the user and the current design inputs shown on the design screen. If there is no information available, the user will be informed that no assistance is available.

b. Sensitivity – Provides the user with a Sensitivity Analysis for one of 16 different design inputs. During the analysis, all inputs shown on the design screen will remain constant except the variable being incremented. For each value of the design input under consideration, a pavement design will be displayed.

c. Calc – Allows the user to see a summary or detailed output of the calculations. The user may see a result summary, which only shows the layer thickness derived. Also, the user may select a "Detailed Calculation" option. The output of the detailed calculation can be sent to the screen or the printer.

2. ESAL Tables

Using this selection from the main menu, the user can add, delete, or edit ESAL factor tables. These tables are used in completing the ESAL worksheets to determine traffic design inputs.

3. Return To DOS

To leave the program and return to the DOS prompt, the user selects the RETURN TO DOS selection from the main menu.

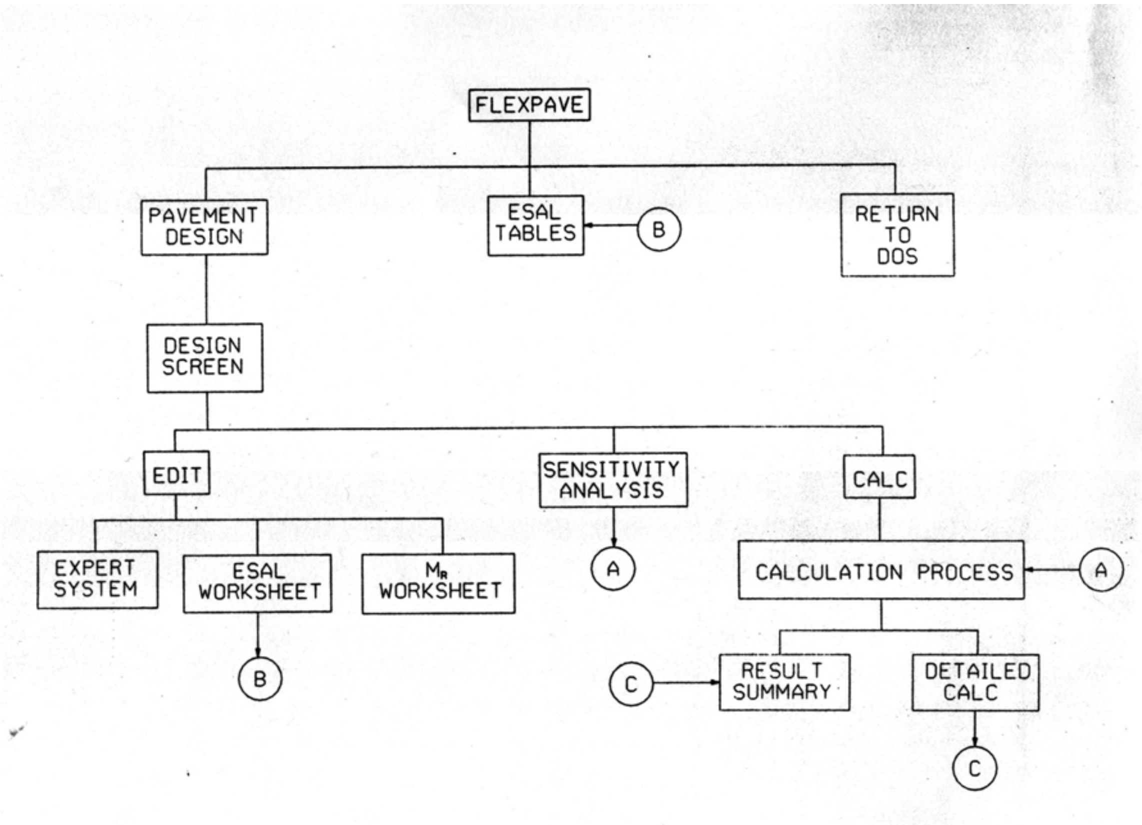

Figure 1 ***FLEXPAVE Flowchart***

4. Conclusions

FLEXPAVE has proven very useful as an enhanced computerized version of the latest AASHTO pavement design guide for flexible pavement. It is an effective educational tool as well as a powerful design tool. In the expert system, rules are shown to the user as they "fire". This helps each user to understand the reason why certain values are chosen. The step-by-step calculations can be seen so each intermediate step can be investigated rather just a final "black box" answer. The future plans are to update the operating system and incorporate the new upcoming AASHTO 2003 Pavement Design Guide Procedures.

5. References

[1] Yoder E.J., Witczak M.W., *Principles of Pavement Design*, Simon and Schuster, New York, 1975.

[2] Crowder T.R., *Ruled Based Modeling of AASHTO Rigid Pavement Design Methodology*, University of Louisville, 1990.