An Algorithm for Determining Design Moduli from Seismic Methods

Center for Highway Materials Research
The University of Texas at El Paso

Conducted for
Texas Department of Transportation
and
Federal Highway Administration

November 2001

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Research Project 0-1780

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Acknowledgments

The authors would like to express their sincere appreciation to Mark McDaniel of the TxDOT Design Division, Joe Thompson of the Dallas District and John Rantz of Lubbock District for their ever-present support. We are also grateful to skillful programming by Mr. Ananth Srinivas Darsi.
# TABLE OF CONTENTS

CHAPTER ONE - INTRODUCTION ...........................................................................1
OVERVIEW ...........................................................................................................1
SYSTEM REQUIREMENTS ..................................................................................2
  Program files .................................................................................................2
  Project Files ..................................................................................................2

CHAPTER TWO - DETAIL DESCRIPTION OF ALGORITHMS ..............................5
LINEAR ELASTIC MODEL ....................................................................................5
EQUIVALENT-LINEAR MODEL ...........................................................................5
 PLASTICITY INDEX MODEL ................................................................................10
DESCRIPTION OF ALGORITHMS ........................................................................11
  Multi-Layer Linear System ............................................................................11
  Multi-Layer Equivalent-Linear System ..........................................................13
  Multi-Layer Nonlinear System Based on Plasticity Index ...............................15

CHAPTER THREE - USERS GUIDE ....................................................................17
MAIN MENU ........................................................................................................17
PROJECT INFORMATION MENU ........................................................................18
LAYER PROPERTY MENU ..................................................................................21
RESULTS MENU ................................................................................................22

REFERENCE ........................................................................................................22

APPENDIX A - INSTALLATION GUIDE .............................................................29

APPENDIX B - ONLINE HELP FILE .................................................................31
LIST OF FIGURES

FIGURE 2.3 INFLUENCE OF EFFECTIVE CONFINING PRESSURE ON MODULUS REDUCTION CURVE (FROM ISHBASHI, 1993) ................................................................. 11
FIGURE 2.5 – FLOW CHART OF IMPLEMENTATION OF EQUIVALENT-LINEAR MODEL .......................................................................................................................... 14

FIGURE 3.1 SNAPSHOT OF ELISMO’S MAIN MENU .......................................................................................................................... 18
FIGURE 3.2 SNAPSHOT OF ELISMO’S PROJECT DESCRIPTION FORM .......................................................... 18
FIGURE 3.3 SNAPSHOT OF ELISMO’S PAVEMENT TYPE FORM ......................................................................................... 20
FIGURE 3.4 SNAPSHOT OF ELISMO TRAFFIC DATA TAB ................................................................................................. 20
FIGURE 3.5 SNAPSHOT OF ELISMO LAYER PROPERTY MENU ......................................................................................... 21
FIGURE 3.6 SNAPSHOT OF ELISMO’S RESULTS SUMMARY MENU .......................................................... 22
FIGURE 3.7 SNAPSHOT OF ELISMO’S ESTIMATED PAVEMENT LIFE MENU ......................................................................................... 23
FIGURE 3.8 SNAPSHOT OF ELISMO’S FAILURE-MODE CONSTRAINTS MENU ......................................................................................... 23
FIGURE 3.9 SNAPSHOT OF ELISMO’S MODULUS PROFILE MENU ......................................................................................... 24
FIGURE 3.10 SNAPSHOT OF ELISMO’S MODULUS DATABASE MENU ......................................................................................... 24
FIGURE 3.11 SNAPSHOT OF THE REPORTING FEATURE IN ELISMO ......................................................................................... 25
CHAPTER ONE
INTRODUCTION

OVERVIEW
The main purpose of the Equivalent-Linear Seismic Modulus Design (ELiSMo) program is to use seismic moduli and well-substantiated nonlinear relationships to provide representative moduli for pavement design and analysis. The ELiSMo design program incorporates seismic moduli in a constitutive model recommended by a National Cooperative Highway Research Program (NCHRP) research project to determine the pavement responses in terms of the stress and strain developed within the pavement structures.

In addition to the representative moduli, the program provides several critical stresses and strains that are typically used in pavement analysis and design. Furthermore, the determined pavement responses are combined with the Asphalt Institute models that relate structural response to the magnitude of structural distress (such as rutting, cracking, etc.).

The success of this process, as a whole, is directly related to how well the input parameters, the structural models, and the transfer functions are balanced. To do so, having different levels of sophistication associated with different types of roads may be reasonable. For example, using simplified empirical models may be adequate for many tertiary roads in the network. Secondary roads can be simply designed using criteria developed based on FWD results and linear-elastic models. However, major highways should take advantage of thorough laboratory and field tests, with a reasonably sophisticated nonlinear elastic algorithm.

This report will contain the following:
1) System Requirements
2) Detail Description of Algorithms
3) Users Guide
SYSTEM REQUIREMENTS

The minimum system requirements to run the program are:

- IBM Compatible System,
- 64 Mb of RAM,
- Windows 95, 98, Me, NT4.0 and 2000,
- Pentium 200 or higher, and
- An EGA or VGA graphics card with 256kb of screen memory

It is recommended that an advanced computer be used in order to minimize program execution time.

Program files

This is the first version of the ELiSMo Design. The software needs to be installed in the C: \ under CHMRE\ELiSMo. This setup folder will contain the following files and folders.

- COUNTYS(Folder) Text files identifying all counties and Districts in Texas
- HIGHLIGHTS(Folder) JPEG files identifying highlights of the of the districts
- HELP(Folder) files containing topics for the HELP menu
- I780DES.EXE Processor module
- ELiSMo.EXE Application
- DBASE Files Database files required by ELiSMo to run properly consisting of DSP.DBF, INPUT1.DBF, INPUT2.DBF, MODL.DBF, MODULUS.DBF, PROPERTY1.DBF, PROPERTY2.DBF, PROPERTY18.DBF and REMLIFE.DBF
- JPEG Files Used in graphical interface of program including ac.jpg, animation1.jpg, animation2.jpg, free.jpg, front.jpg, over3.jpg, over4.jpg, spa2.jpg, strans.jpg and subg.jpg
- README.DOC Contains information about installing the program
- PALETTESNED.REG Registry file used for charting
- DISTRICTS.TXT Text file that contains nonlinear parameters for districts

These files will be created automatically in the folder C:\CHMRE\ELiSMo during the installation process. Other system files will be installed in the both the systems folders and the program directory folder. These supplemental files are crucial to the proper execution of the program.

Project Files

The project files are generated upon execution of the program. These files are stored in the user specified project folder. There are four types of files summarizing all the data used by the program. These files are used by ELiSMo to retrieve and display the results of the project, but they can also be accessed independently. The main files are in Dbase format with a .DBF extension. These files are as follows:

- PROPERTY1.DBF: contains the pavement properties and model parameters
- **MODULUS.DBF**: contains modulus results
- **REMLIFE.DBF**: contains life-cycle results

The next set of files is two files that contain the project description generated by the user. The two files with a .DSC extension are:
- **PROJ_DESC.DSC**: contains project identification information
- **PROJ_COM.DSC**: contains comments

The third set of files is a set of bitmap files that are used in generating the final report. The number of files varies depending whether the analysis is based on a three or four layer system.

The last file in the folder is used internally by the program and has a .DAT extension. This file is a duplicate of the PROPERTY1.DBF file.
CHAPTER TWO
DETAIL DESCRIPTION OF ALGORITHMS

This program was designed based on the classical layered elastic theory. The difference between this program and typical linear elastic programs is in the analysis of the structural response of the pavement system. Although the algorithm is not strictly a nonlinear algorithm, it accounts for the nonlinear behavior of the pavement materials under actual truck traffic. The algorithm integrated in this program is a compromise between the simple linear model and comprehensive nonlinear model. This algorithm takes advantage of the speed of the linear analysis while incorporating the nonlinear behavior of the pavement. The algorithm is referred to as an equivalent-linear analysis method. ELiSMo includes two other analysis methods. The methods are based on the layer-elastic theory (Linear Elastic model) and the nonlinear equation based on the plasticity index (Plasticity Index model). These models were incorporated into ELiSMo for practicality. It allows the user to make a more informed decision based on results of three analyses instead of relying on only one.

Each of the three algorithms is briefly discussed in this report. For more detail explanation to these algorithms refer to TXDOT Reports 1780-1, 1780-2 and 1780-3.

LINEAR ELASTIC MODEL

The simplest models for evaluating the behavior of pavements under load are linear elastic models. The constitutive model for a linear elastic material is rather simple since the modulus is considered as a constant value independent of the state of stress applied to the pavement. Therefore, the modulus of each layer does not change with the variation in other properties. Most algorithms used in pavement analysis and design takes advantage of this type of solution. KENLAYER (Huang, 1994), WESLEA (Van Cauweezen et al., 1989), and BISAR (De Jong et al., 1973) are three of the popular programs in this category. The advantage of these models is that they can rapidly yield results. Their main limitation is that the results are rather approximate if the loads are large enough for the material to exhibit a nonlinear behavior.

EQUIVALENT-LINEAR MODEL

An equivalent-linear model is a model that in an approximate fashion can consider the load-induced nonlinear behavior based on the static linear elastic layered theory. An iterative process is employed to consider the nonlinearity of the pavement materials. The constitutive model adopted in the equivalent linear model is:

\[
E = k_1 \sigma^{-1} \sigma_{eq}^{1/3}
\]

(2.1)
In this equation, \( k_1 \), \( k_2 \) and \( k_3 \) are statistically determined coefficients. In Equation 2.1, the modulus at a given point within the pavement structure is related to the state of stress. Since the state of stress can be known only if the material properties, including modulus, are known, an iterative process has to be used to implement this stress-modulus relationship. The advantage of the model presented in Equation 2.1 is that it is universally applicable to fine-grained and coarse-grained base and subgrade materials.

In Equation 2.1, the term \( k_1 \sigma_0^{k_2} \) corresponds to the initial tangent modulus, \( E_{\text{max}} \), which is related to the confining pressure. Normally parameter \( k_2 \) is positive. Therefore, the initial tangent modulus increases as the confining pressure increases. Parameter \( k_3 \) suggests that the modulus changes as the deviatoric stress changes. Because \( k_3 \) is usually negative, the modulus decreases with an increase in the deviatoric stress.

One of the major purposes of this study is to relate the seismic modulus with the load-induced nonlinear modulus. For this reason, parameter \( k_1 \) in Equation 2.1 will be replaced by a term that is a function of the seismic modulus and the stresses under seismic test.

Two different states of stress are considered: under seismic loads and under external loads, such as those imparted by a FWD or an actual truck. Figure 2.1a shows stresses for an infinitesimal material element during seismic tests. Only a very small external load is applied to generate various waves. Therefore, only stresses generated by geostatic pressure should be considered. If it is assumed that there are \( n \) layers of materials above the element shown in Figure 2.1a, each with a unit weight of \( \gamma_i \) and a thickness of \( h_i \), then:

\[
\sigma_i = \sum_{j=1}^{n} \gamma_j h_j \tag{2.2}
\]

where \( \sigma_i \) is the vertical stress. Similarly, \( \sigma_h \), the horizontal stress on the element, is related to \( \sigma_i \) by

\[
\sigma_h = k_3 \sigma_i \tag{2.3}
\]

where \( k_0 \) is the coefficient of lateral earth pressure at rest.

As shown in Figure 2.2a, additional stresses, \( \sigma_x \), \( \sigma_y \) and \( \sigma_z \) are induced under the application of an external load. A multi-layer elastic program can conveniently compute these additional stresses.

To implement the equivalent linear model, it is essential that these stresses be reformulated in terms of confining pressure and deviatoric stress. Figure 2.1b shows the transformed state of stress, which includes the initial confining pressure, \( \sigma_{\text{c,init}} \), and the initial deviatoric stress, \( \sigma_{\text{d,init}} \).

The initial confining pressure is the arithmetic mean value of the three original principal stresses. Since the two horizontal stresses can be considered equal:

\[
\sigma_{\text{c,init}} = \frac{1 + 2k_3}{3} \sigma_i \tag{2.4}
\]
(a) Actual state of stress

(b) Transformed state of stress

Figure 2.1 – State of Stress under Seismic Test

(a) Actual state of stress

(b) Transformed state of stress

Figure 2.2 – State of Stress under FWD Test
The initial deviatoric stress, which is the difference between $\sigma_i$ and $\sigma_{i,init}$, can be written as

$$\sigma_{d,init} = \frac{2 - 2k}{3} \sigma_i$$  \hspace{1cm} (2.5)

Figure 2.2b shows the transformed state of stress under load, such as those applied by an FWD. The state of stress consists of an ultimate confining pressure, $\sigma_{\text{conf},ult}$, and an ultimate deviatoric stress, $\sigma_{d,ult}$. The ultimate confining pressure contains two components, $\sigma_{\text{conf},ult}$ and $\Delta\sigma_c$. Parameter $\Delta\sigma_c$ is the arithmetic mean value of the three principal stresses $\sigma_x$, $\sigma_y$, and $\sigma_z$:

$$\Delta\sigma_c = \frac{\sigma_x + \sigma_y + \sigma_z}{3}$$  \hspace{1cm} (2.6)

Thus, the ultimate confining pressure is

$$\sigma_{\text{conf},ult} = \sigma_{\text{conf},ult} + \Delta\sigma_c$$  \hspace{1cm} (2.7)

or

$$\sigma_{\text{conf},ult} = \frac{1 + 2k}{3} \sigma_x + \frac{\sigma_y + \sigma_z}{3}$$  \hspace{1cm} (2.8)

The ultimate deviatoric stress also includes two parts, $\sigma_{d,init}$ and $\Delta\sigma_d$. The parameter $\Delta\sigma_d$ is the difference between $\sigma_d$ and $\Delta\sigma_c$:

$$\Delta\sigma_d = \sigma_d - \Delta\sigma_c$$  \hspace{1cm} (2.9)

$$\Delta\sigma_d = \frac{2\sigma_x - \sigma_y - \sigma_z}{3}$$  \hspace{1cm} (2.10)

Thus, the ultimate deviatoric stress is

$$\sigma_{d,ult} = \sigma_{d,init} + \Delta\sigma_d$$  \hspace{1cm} (2.11)

or

$$\sigma_{d,ult} = \frac{2 - 2k}{3} \sigma_x + \frac{2\sigma_y - \sigma_x - \sigma_z}{3}$$  \hspace{1cm} (2.12)

As indicated before, to obtain the seismic modulus, $E_{\text{seis}}$, very small external loads are applied. Therefore, the corresponding confining pressure and deviatoric stress are $\sigma_{i,init}$ and $\sigma_{d,init}$ respectively. Therefore, Equation 2.1 can be changed to

$$E_{\text{seis}} = k_i\sigma_{i,ult}^l\sigma_{d,ult}^t$$  \hspace{1cm} (2.13)
Thus,

\[ k_i = \frac{E_{\text{ref}}}{\sigma_{c,\text{ref}}^{x_i}} \sigma_{d,\text{ref}}^{y_i} \]  

(2.14)

In FWD tests or under actual truck loads, the modulus can become nonlinear depending on the amplitude of confining pressure \(\sigma_{c,\text{ref}}\) and deviatoric stress of \(\sigma_{d,\text{ref}}\). In that case:

\[ E = k_i \sigma_{c,\text{ref}}^{x_i} \sigma_{d,\text{ref}}^{y_i} \]  

(2.15)

Therefore, when combined with Equation 3.14, the nonlinear modulus can be related to the seismic modulus through

\[ E = E_{\text{ref}} \left( \frac{\sigma_{c,\text{ref}}^{x_i}}{\sigma_{c,\text{ref}}} \right)^{x_i} \left( \frac{\sigma_{d,\text{ref}}^{y_i}}{\sigma_{d,\text{ref}}} \right)^{y_i} \]  

(2.16)

Compared to Equation 2.1, parameter \(k_i\) is eliminated when the seismic modulus is considered as input. As indicated before, a large number of parameters impact the determination of \(k_i\) in the laboratory. Therefore, replacing \(k_i\) with a parameter measured in the field may reduce some of the uncertainties associated with the laboratory tests. Equation 2.16 can be used in an equivalent-linear model to obtain the modulus of a nonlinear material in this study.

One of the limitations of Equation 2.1 is that at very small or very large deviatoric stresses the modulus tends to be infinity and zero, respectively. Many years of research (see Kramer, 1996) have shown that below a certain strain level (or deviatoric stress) the modulus is constant and equal to the small-strain linear-elastic modulus of the material. Conversely, at higher strain levels (or higher deviatoric stresses), the modulus becomes more or less constant as well. Therefore, if the vertical strain is less than 0.01%, the modulus corresponding to a strain of 0.01% will be adopted. On the other hand, if the vertical strain is greater than 1%, the modulus corresponding to a strain of 1% will be adopted. The relationship among the modulus, stress, and strain is:

\[ E = \frac{\sigma_{c,\text{ref}}}{\varepsilon} \]  

(2.17)

Thus

\[ \sigma_{d,\text{unf}} = E \varepsilon \]  

(2.18)

Substituting the above equation in Equation 2.15

\[ E = k_i \sigma_{c,\text{ref}}^{x_i} (E \varepsilon)^{y_i} \]  

(2.19)

or
\[ E = k_i^{1-(\gamma-1)} \sigma_{\text{c,at}}^{1-(\gamma-1)} E_i^{1-(\gamma-1)} \]  

(2.20)

With respect to a strain of 1\%, the lower bound of the modulus is:

\[ E_{\text{low}} = k_i^{1-(\gamma-1)} \sigma_{\text{c,at}}^{1-(\gamma-1)} (0.01)^{1-(\gamma-1)} \]  

(2.21)

With respect to a strain of 0.01\%, the upper bound of the modulus is:

\[ E_{\text{up}} = k_i^{1-(\gamma-1)} \sigma_{\text{c,at}}^{1-(\gamma-1)} (0.001)^{1-(\gamma-1)} \]  

(2.22)

Since \( k_i \) is normally a negative value, the upper bound, \( E_{\text{up}} \), is larger than the lower bound, \( E_{\text{low}} \).

The two bounds shown in Equations 2.21 and 2.22 are checked after each iteration in the equivalent-linear model.

**PLASTICITY INDEX MODEL**

Ishibashi and Zhang (1993) combined the effects of the confining pressure and plasticity index on modulus behavior in the form

\[ \frac{E}{E_{\text{at}}} = K(y, PI) (\sigma'_c)^{m(y, PI) - m_0} \]  

(2.23)

where PI is the plasticity index of the base or subgrade material and \( y \) is the shear strain and

\[ K(y, PI) = 0.5 \left[ 1 + \tanh \left( \frac{0.000102 + n(PI)}{y} \right)^{0.102} \right] \]  

(2.24)

\[ m(y, PI) - m_0 = 0.272 \left[ 1 - \tanh \left( \frac{0.000556}{y} \right)^{0.1} \right] \exp(-0.0145PI^{1.5}) \]  

(2.25)

\[ n(PI) = \begin{cases} 0.0 & \text{for } PI = 0 \\ 3.37 \times 10^{-4} PI^{4.64} & \text{for } 0 < PI \leq 15 \\ 7.0 \times 10^{-3} PI^{0.976} & \text{for } 15 < PI \leq 70 \\ 2.7 \times 10^{-7} PI^{1.115} & \text{for } PI > 70 \end{cases} \]  

(2.26)

Influence of the confining pressure on modulus reduction, \( E/E_{\text{at}} \), is also illustrated in Figure 2.3. At higher confining pressures, the modulus reduction, \( E/E_{\text{at}} \), becomes closer to one, meaning that modulus is closer to seismic modulus.
Figure 2.3 Influence of Effective Confining Pressure on Modulus Reduction Curve (from Ishibashi, 1993)

DESCRIPTION OF ALGORITHMS

The following three algorithms were incorporated into ELiSMo:

- a multi-layer linear system, and
- a multi-layer equivalent-linear system, and
- a multi-layer nonlinear system based on the Plasticity Index.

Multi-Layer Linear System

Flexible pavements are layered systems with stiffer materials on top. Burmister (1943) first developed solutions for a two-layer system and then extended them to a three-layer system (Burmister, 1945). With the advent of computers, the theory can be applied to a multi-layer system with any number of layers (Uzun, 1994). A typical n-layer system subjected to a circular load is shown in Figure 2.3.

The basic assumptions to be satisfied are:

- Each layer is homogeneous, isotropic, and linear elastic.
- The material is weightless and extended to infinity in horizontal directions.
- Each layer has a finite thickness, except the bottom layer, which is extended to infinity.
- A uniform pressure is applied to the pavement surface over a circular area.

Continuity conditions at the layer interfaces, as indicated by the same vertical stress, shear stress, vertical displacement, and radial displacement, are satisfied. For a frictionless interface, the continuity of shear stress and radial displacement is replaced by zero shear stress at each side of the interface.

![Diagram of a multi-layer system](image)

**Figure 2.4 – A Typical n-layer System**

As in the classical theory of elasticity, a stress function $\phi$ that satisfies the governing differential equation

$$\nabla^4 \phi = 0 \quad (2.27)$$

is assumed for each layer. As shown in Figure 2.4, the system has an axially symmetrical stress distribution, thus
\[
\n\n(2.28)
\]

After solving the stress function \(\phi\) from the above fourth-order differential equation and applying boundary and continuity conditions, the layered system problem can be solved. After the stress function is found, the stresses can be determined by

\[
\sigma_n = \frac{\partial}{\partial z} \left( \nu \nabla^2 \phi - \frac{1}{r} \frac{\partial \phi}{\partial r} \right) \tag{2.29}
\]

\[
\sigma_r = \frac{\partial}{\partial r} \left( \nu \nabla^2 \phi - \frac{\partial^2 \phi}{\partial r^2} \right) \tag{2.30}
\]

\[
\sigma_\theta = \frac{\partial}{\partial \theta} \left( \nu \nabla^2 \phi - \frac{1}{r} \frac{\partial \phi}{\partial r} \right) \tag{2.31}
\]

Many computer programs, such as BISAR, WESLEA and KENLAYER, are available to obtain stresses and strains for linear elastic problems utilizing the solution of the multi-layered system. Throughout this study, the well-established computer program BISAR was used.

**Multi-Layer Equivalent-Linear System**

As indicated before, the equivalent-linear model is based on the static linear elastic layered theory. The constitutive model described in Equation 2.16 is adopted. An iterative process is employed to consider the nonlinear behavior of the pavement materials in an approximate fashion.

The implemented process is summarized in Figure 2.5. The nonlinear layers are divided into several sub-layers. The number of sub-layers depends on the accuracy required and the number of layers allowed by the program. One stress point is chosen for each nonlinear sub-layer. An initial modulus is assigned to each stress point. Basically, the seismic modulus is assigned to be the initial value since it will not have any effect on the final results. The stresses and strains are calculated for all stress points using a multi-layer elastic computer program. The confining pressure and deviatoric stress can then be calculated for each stress point using Equations 2.2 through 2.12. From Equation 2.16, a new modulus can be obtained. The assumed modulus and the newly calculated modulus at each stress point are compared. If the difference is larger than a pre-assigned tolerance, the process will be repeated using updated assumed moduli. To
Figure 2.5 - Flow Chart of Implementation of Equivalent-Linear Model
accelerate convergence, the updated assumed modulus for each nonlinear sub-layer equal to the average of the assumed and calculated moduli is used. The above procedure is repeated until the modulus difference is within the tolerance and, thus, convergence is reached. Finally, the required stresses and strains are computed using final moduli for all nonlinear sub-layers.

**Multi-Layer Nonlinear System Based on Plasticity Index**

The algorithm in this system adopts the model described in Equation 2.23. Similar to the Equivalent-Linear model, an iterative process is employed to consider the nonlinear behavior of the pavement materials.

As in the equivalent linear algorithm, the nonlinear layers are divided into several sub-layers. The number of sub-layers depends on the accuracy required and the number of layers allowed by the program. One stress point is chosen for each nonlinear sub-layer. An initial modulus is assigned to each stress point. Basically, the seismic modulus is assigned to be the initial value since it will not have any effect on the final results. The stresses and strains are calculated for all stress points using a multi-layer elastic computer program. The confining pressure can then be calculated for each stress point using Equations 2.2 through 2.12. From Equation 2.23, a new modulus can be obtained. The assumed modulus and the newly calculated modulus at each stress point are compared.

All three algorithms are incorporated in ElSmo. The program BISAR, based on its well-known functionality and flexibility of the number of layers it handles, was modified for all three of the algorithms.
CHAPTER THREE
USER'S GUIDE

The ELiSMo Designa Program is a window-based program developed with a user-friendly
interface. The menus of ELiSMo are easy to follow. This chapter will outline step by step the
use of this program through snapshots of the menus from ELiSMo. This user's guide will serve
as an additional guide to the user and is similar to the online help file that can be accessed from
the program. A printed copy of the help file is also available in Appendix B.

MAIN MENU

The first menu that appears when ELiSMo is executed is the main menu. Figure 3.1 shows the
form of ELiSMo’s main menu. This form contains the main selections that guide the user
through different aspects of the program. The first option under the main menu allows the user
to run the analysis portion of the program. If selected, the user is prompted with the option to
select a new project or work on an old project. Based on the project selection, a popup window
appears providing the user to select a project folder, which would contain the results of the
analysis. For a new project this option requires the user to select a new project folder. Once the
project is chosen a series of forms will appear and appropriate selection is required of the user.
These forms are explained later in this chapter. The analysis option was designed to act as a
wizard. The step-by-step flow of the forms allows the user to easily follow and use the program.

The other choices in the main menu shown in Figure 3.1 are the results and report options.
These are self-explanatory and their selections will lead directly to the results menu or report
menu respectively. These options are useful to directly access results or produce reports of
existing projects without having to run the analysis. Below the main menu two buttons are
provided to allow the user either to access the online help feature or to exit the program. A
helpful feature that is used throughout the program is the instant status or update that is located at
the bottom of the main windows. This feature activated as the cursor moves over any of the
program features and displays hints providing the user with additional help.
PROJECT INFORMATION MENU

Once the project folder is selected under the analysis option, the project information menu appears. Figure 3.2 shows an image of this form. This menu as shown in the figure contains four tabs. The first tab, detailed in the figure, is the project description. The project description window allows the user to provide descriptive information that identifies the project. This information is reproduced later in a report.

Figure 3.2 Snapshot of EiSMo’s Project Description Form
Once the project description information is provided, the user then proceeds to the next tab. The next tab contains information that defines the pavement type. This tab allows the user to select the type and quality of a three-layer or a four-layer system. Figure 3.3 shows the details of the pavement type tab. The first choice required by the user is the selection of one of the six pavement types available. Once the type is selected, a picture or a representation of the pavement section is produced with each layer labeled. This representation allows the user to further select the quality of the base and subgrade (subbase in the case of a four layer system). The options for the base and subgrade materials are based pavement layer types used in Texas. The type of base/subbase and subgrade selected by the user provides a priori information of the seismic modulus, thickness and poisons ratio selected. Another feature in this form is the quality of the pavement layer. These parameters are used in the constitutive model adopted by the program. A model preview button allows the user to view the models used in the equivalent linear analysis and the nonlinear model based on the plasticity index. The parameters used by these models are required as input to the program. There are two methods in which the parameters are provided. The first alternative is to use the default values provided. These values are based on the Texas district selected in the project description tab and are based on a previous study conducted by the Center for Highway Materials Research (CHMR) and sponsored by TxDOT under project TX-0-11336. Report 0-11336-2 (Nazarain et al., 1996) contains the model parameters used by this program. This information however is limited to few districts and missing data needs to be provided by the user. The database of values could be completed for all districts at a later date as TxDOT performs more field and lab tests. The other alternative available is to select the layer quality based on preset values. The quality selection for the base/subbase is divided into High/Average/Poor and for the subgrade the quality selection is divided into Sandy/High Plasticity Clay/Low Plasticity Clay. Once material quality selections are made, $k_3$, $k_4$ and PI values are set accordingly. These preset values are only recommendations provided by the researchers of this project to aid the user. These values can be modified on a project-by-project basis if the user knows the values of $k_3$, $k_4$ and PI.

The traffic information tab is the next tab in the menu the user needs to select and type in information about the traffic report. The traffic report information is used to project traffic at the end of the pavement design period. The values required to project the traffic are obtained from standard TxDOT traffic reports. To determine the traffic projection at any year the user inputs the desired construction year and the design period then select the button to calculate the projected ESALS. The algorithm used to project traffic is based on algorithm currently utilized by TxDOT. The projected traffic value can then be compared to the ESALS estimated based on the analysis. For this version of the program the user must provide traffic data in order to proceed with the program. However, as mentioned earlier this data is only used for comparison purposes and is not used in the analysis. If no traffic information is available at this time the user can use the default values.

Upon completion of the three tabs in this menu (Traffic Information, Pavement Type and Project Description), the user selects “Done” to proceed to the next step in the analysis process. Please note that if for any reason the information needed is not complete or left blank, a message appears informing the user to complete all required information before proceeding.
### Figure 3.3 Snapshot of ElISMo’s Pavement Type Form

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Pavement Type</th>
<th>Traffic Information</th>
<th>Done</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) ACP + FLEX BASE OVER SUBGRADE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) ACP + ASH STAB BASE OVER SUBGRADE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) ACP + ASH STAB BASE + FLEX BASE OVER SUBGRADE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) ACP + FLEXIBLE BASE + STAB SIGR OVER SUBGRADE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5) OVERLAY DESIGN (3 Layers)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) OVERLAY DESIGN (4 Layers)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Constitutive Model**
- Quality parameters K, A, E are based on the material's database.
- A user-defined factor can be used to adjust the values
- There are two types:
  - Elastic-Plastic: No Yield
  - Ductile: Yield

**Asphalt Base**

<table>
<thead>
<tr>
<th>Material Quality</th>
<th>K</th>
<th>A</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Concrete Base**

<table>
<thead>
<tr>
<th>Material Quality</th>
<th>K</th>
<th>A</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sands</th>
<th>RNC</th>
<th>LPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPC</td>
<td>High Plastic Clay</td>
<td></td>
</tr>
<tr>
<td>LPC</td>
<td>Low Plastic Clay</td>
<td></td>
</tr>
</tbody>
</table>

**Candy Sticks**

<table>
<thead>
<tr>
<th>Status</th>
<th>4 Layered Pavement</th>
</tr>
</thead>
</table>

### Figure 3.4 Snapshot of ElISMo Traffic Data Tab

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Pavement Type</th>
<th>Traffic Information</th>
<th>Done</th>
</tr>
</thead>
</table>

**Traffic Report**

<table>
<thead>
<tr>
<th>Traffic Period</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 AM - 9 AM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Average Daily Traffic**

<table>
<thead>
<tr>
<th>Start Year</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>1100</td>
<td></td>
</tr>
</tbody>
</table>

| Average Daily Traffic (End) | 5600 |
| Flex 18kg EISALS(1000)      | 1000 |

**Traffic Projection**

<table>
<thead>
<tr>
<th>Construction Year</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Period</td>
<td>25</td>
</tr>
<tr>
<td>Projected Cumulative EISALS(1000)</td>
<td>1017</td>
</tr>
</tbody>
</table>

**Calculate Projected EISALS**

<table>
<thead>
<tr>
<th>Status</th>
<th>4 Layered Pavement</th>
</tr>
</thead>
</table>

20
The next step in the analysis process is to view the layer property values that were selected based on the information provided by the user in the project description menu. This is information based on the selection of the pavement type and material quality. Figure 3.5 shows a sample of the layer property menu, which contains a table with pavement properties such as the modulus, thickness, Poisson’s ratio, coefficient of earth pressure, and unit weight. Even though these values set based on the pavement type and material quality, the user can modify any of the values. The other parameters in the table provide information about the linearity of the pavement layers. The “Linearity” parameter identifies whether the layer is linear or nonlinear, the “NO. OF SUB” parameter defines the number of sublayers each of the nonlinear layers will be divided into. The purpose of this parameter was discussed in the description of the equivalent linear algorithm. The default values for this parameter of each layer are set to eight. This is the maximum value that can be used in this program. Ke et al. (2000) has shown that three to four sublayers are adequate to identify the nonlinear behavior of the layer. The contour feature on the top of this menu is related to this parameter. When the contour option is checked, the value for the number of sublayer parameter would default to eight for each nonlinear layer. This allows the program to generate a contour map illustrating the nonlinear behavior of the layers after the analysis is completed. If the contour option is deselected, results of the nonlinear behavior will not be displayed. The option is deselected only to decrease the number of sublayers and speed up the analysis. This is an advance option and should be used by experienced users. The next three parameters in the table are related to the material quality and were the results of the selection in the previous menu. These parameters can be modified in this table if need be. Once the modification is made the user selects to continue to the next step of the analysis. The next step in the process is to run the analysis. The analysis run through the three algorithms discussed in this report. A message box pops up informing the user that the analysis is in progress. Once the analysis is completed the results menu appears.

Figure 3.5 Snapshot of EliSMo Layer Property Menu
RESULTS MENU

The results menu is the last menu of the analysis process. This menu displays all the results from the analysis. Figures 3.6 to 3.10 will show illustrations of the results menu. The results menu can also be accessed directly from the main menu. This results menu has two options, summary and detail versions. By default the first form that appears is a summary of the results. On the left hand side of the form, the estimated design ESALs based on Fatigue cracking and rutting of all three algorithms are presented in a table. Also shown, above the table, is the projected ESALs based on the traffic report. An option to select the detail results is available on the right hand side of the window. At the bottom of the form a table is provided, showing the equivalent linear modulus results at different lateral spacing for the different pavement section layers (nonlinear layers are divided into sublayers based on the number of subdivisions). The user can scroll down the table to view the results of all records.

Figure 3.6 Snapshot of ElsMo’s Results Summary Menu

To view a detailed version of the results, the user selects the "Detail" option and then “Show”. Figure 3.7 depicts the first tab of the detailed option. Figure 3.7 shows the Estimated ESALs based on fatigue cracking and rutting both graphically and numerically. By default the graph for fatigue cracking is shown, but the user can toggle between the two failure modes. The graph of either failure mode compares the results of the estimated design ESALs from all three algorithms using a bar graph to the projected ESALs using a line graph (based on the traffic report). The failure modes used by default are the Asphalt Institute models. However, the user can modify the failure mode by changing the constraints of the model. To change the models’ constraints the user selects the model constraints tab. Figure 3.8 shows picture of the model constraints tab where the coefficients of both failure modes can be changed. This tab allows the user to easily change the coefficients of the model based on values from other institutes. Once the constraints are change the user must select the view graph button to update the values in the graph and switch back to the estimated pavement life tab.

22
The last two tabs in the detailed results menu contain information about the modulus. Figure 3.9 shows a sample of the modulus profile tab. The pavement moduli are illustrated in a form of a contour plot to help the user appreciate and identify the nonlinearity of pavement section. A plot for each layer is shown and is set up proportional to the layer thickness. The results shown in the contour plots are based solely on the equivalent linear analysis. To view the numerical results of the equivalent linear analysis the modulus database tab needs to be selected. Figure 3.10 shows a snapshot of that form.
The last feature in this program is the reporting feature. This feature is accessed directly from the main menu by selecting report and then run. The report menu contains all the information from the project description to the results of the analysis. Figure 3.11 below shows a sample of the report menu. This report menu allows the user to save the report under any name and or print the report provided that a printer is installed. The report menu can also be used to access other saved reports.

Figure 3.11 Snapshot of the Reporting Feature in EliSMo
REFERENCE


27
EQUIVALENT LINEAR SEISMIC MODULUS DESIGN PROGRAM

ELiSMo version1.0

INSTALLATION GUIDE

This guide assumes that the user has basic knowledge about computers. This knowledge includes use of Windows 95/98/2000 or NT 4.0 operating systems.

NOTE: It is strongly recommended that the user become familiarized with all the steps listed in each section of this guide, before actually carrying them out.

MINIMUM RECOMMENDED HARDWARE REQUIREMENTS

- IBM or compatible LAPTOP or DESKTOP with:
  - Pentium processor (200 MHz or higher)
  - 64 MB of RAM (128 MB recommended)
  - 2 GB Hard Disk (10MB of free space recommended)
  - VGA monitor or higher resolution
  - CD-ROM drive
  - Keyboard
  - Mouse or compatible pointing device
  - Windows 95/98/2000 or Windows NT 4.0 or higher operating system
  - Printer (optional, recommended)

INSTALLATION PROCESS AND STARTUP

NOTE: When installing under the Windows NT 4.0 or Windows 2000 environment, all software programs must be installed from an account with Administrator privileges; otherwise, they will not be able to run after installation.

Place the ELiSMo installation CD into the computer’s CD-ROM. Follow the instructions on the screen. If the CD drives auto-run is off, browse the CD, go to ELiSMo directory and double click on SETUP.EXE.

The suggested destination directory is:
<instDrive>\c:

The setup will automatically detect the working operating system and will install the required files into the corresponding directory location. It is recommended that you close any virus protection programs, which may cause problems during the installation. The setup program can be stopped at any time.

To uninstall the software, follow the typical steps to Add/Remove programs under the Control Panel.
APPENDIX B
ONLINE HELP FILE

The “Online Help” form is used to access information that assist in knowing how this program works. This form contains six features:

a. Overview  
b. Quick Start  
c. Input  
d. Process  
e. Results  
f. About

Each of these options provides help on how this program works. The Online Help feature works simply by clicking on any of the topics. Once clicked, a detailed explanation pops up on the right hand side of the form.

This help file can be accessed from any window in the program by clicking on the [HELP] button.
Overview

ELiSMo design is a user-friendly program based on the equivalent linear analysis that considers the nonlinear behavior of flexible pavements. The program calculates the critical strains within the pavement due to a standard dual tandem load. This information is used to estimate design parameters such as fatigue life and rut depth through empirical equations.

This program is based on the following constitutive model for both Granular and Cohesive materials:

\[ M_e = K_1 \sigma_1^{1.2} \sigma_2^{1.3} \]

where \( k_1 \) parameter is based on the Seismic Pavement Analyzer (SPA) and initial stress conditions. Parameters \( k_2 \) and \( k_3 \) are determined from laboratory tests and or published values. \( T_i \) is the stress due to the confining pressure and \( T_o \) is the stress due to the deviatomic stress.

Detail explanation about the modeling and analysis are given in TxDOT Reports 1780-1, 1780-2 and 1780-3.

Quickstart

This program runs on a multiple windows operating systems. The program installs in the C directory under C:\CHMR\ELiSMo. To execute the program either type C:\CHMR\ELiSMo\ELiSMo.EXE under the run command or click ELiSMo under CHMR which is located under Programs of the Start menu.

The flow of the program is setup to allow the user ease of use with minimal expertise.

There are three main selections in the main menu of this program:
- Analysis: This selection is used to select and generate a Project Folder.
- Results: This selection allows the user to view the results directly of an existing project.
- Report: This selection allows the user to generate a report for an existing project that contains project description and results of analysis. This report feature is set up to print the project result in a preset report format.

Two other feature are available in the main menu:
- Online Help: This feature accesses the online help menu
- Exit ELiSMo: This feature exits the program

Project Folder

Project Folder is used by ELiSMo to store all the files produced and created which contain results. After selecting either of New Project or Old Project, a set of steps follow that guides the user through the rest of the process.

New Project: This selection generates a new project folder.
Old Project: This selection allows the user to modify an existing project for re-analysis.

NOTE: The data files produce by ELiSMo are either in text format or DbaseIV format (.dbf). These files can be viewed in Microsoft Excel.

Input

Four types of inputs are required by ELiSMo.

*Project Description* - Project description requires inputs that identifies the project identification such as:
- Problem ID,
- Highway,
- Control,
- Section,
- Job,
- District,
- County,
- Comments and
- Date.

It also requires the user to select the county and district to identify the project location.

*Pavement Type* - Pavement type has six predetermined pavement layouts for three or four layer flexible pavements. These options were identified as per Texas pavement needs and are currently the options used by TxDOT flexible pavement design programs.

Once the pavement section is selected the next step is to select the material type for each of the base and subgrade. In the case of a four layer the subbase material type is selected. This selection specifies predetermined layer quality that is used in the equivalent linear analysis. This version ELiSMo considers the Asphalt-Concrete (A) layer as linear and as such the AC layer quality is not identified.

*Traffic Information* - This set of inputs is directly related to the traffic report by TxDOT. The parameters used are:
- 20/30 Traffic Period,
- Start year,
- Average daily traffic @ Start,
- Average daily traffic @ End,
- Flex18Kip, Construction year and
- Design period

These values are used to estimate the projected design ESALS which the pavement can handle at the end of the design period. The design ESALS used to assess the life of the pavement by comparing the value to the fatigue life and rut depth results from the analysis.
Process

The program starts with a Main Form where you can make the selection to create a new project or re-run an already developed project or view results of an existing project and generate a report.

Analysis

- New Project: Upon selection to create a new project you are given an option to create a new project or re-create a new project in an already existing folder.

- Existing Project: This prompts for an existing project.

After a project folder is selected the user is prompted to input the project description, pavement type and material properties. The user then proceeds to the next menu to view the a priori information in the layer property menu. These values are displayed in a table format and can be modified based on the user's discretion. If the values are satisfactory to the user the user at this point selects to continue and run the analysis. Once the analysis is complete, the program automatically pulls up the results menu. The results menu displays the results of the analysis. The program also provides the user the option to automatically generate a report.

Results: Generates a printable summary of the project with the inputs and outputs.

Report: Generates a printable summary of the project with the inputs and outputs.

Note: Traffic information is based on the traffic reports generated for TXDOT

Results

The results portion if this program is either accessed from the main menu or automatically viewed after the analysis process is completed. The result menu shows a summary of the design life based on fatigue cracking and rutting and also provides the modulus profile database results based on the equivalent linear analysis. A detailed version of the results can also be accessed which shows more comprehensively the results of the analysis both graphically and numerically.

About

“Pavement Design Based On Seismic Moduli”
ELiSMo Design Program version 1.0

For Windows 9x, Windows 2000 and Windows NT 4.0 or Higher

Developed at CHMR by
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This product is licensed to the Texas Department of Transportation.

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