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16. Abstract <p>VESYS5 is a well developed mechanistic flexible pavement analysis computer program. However, it is a DOS program, and its inputs and outputs were very complicated. It is difficult for users to apply the program to analyze the performance of flexible pavements. Texas Transportation Institute (TTI) VESYS5W is a Windows version of VESYS5. TTI VESYS5W provides a user-friendly input and output interface and significantly improves the usability of the existing VESYS5 program. This report documents TTI VESYS5W release version 1.0. Also, a simple case is provided in the report.</p> <p>It is well known that the challenging task of predicting pavement performance is to determine the pavement material properties including modulus, rutting, and fatigue cracking, etc. One of the special features of the enhanced VESYS5 program is that the default values of material properties have been built into the program. These default values were recommended based on substantial literature review and laboratory testing. In addition, the laboratory test protocols have also been developed to determine these material properties. It should also be noted that the current TTI VESYS5W was calibrated by limited accelerated pavement test (APT) rutting data, further calibration on rutting and fatigue cracking models is needed, especially using the field experimental sections. Moreover, further study on the influence of climate on performance prediction is needed.</p>					
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**ASPHALT PAVEMENT PERFORMANCE ANALYSIS TOOL:
TTI VESYS5W**

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CHAPTER 1

INTRODUCTION

BACKGROUND OF TTI VESYS5W

VESYS5 is one of the latest published versions of VESYS. The VESYS series are based on the elastic model of layered homogeneous material in half infinite space with integration of empirical functions. Though VESYS5 is a well developed probabilistic and mechanistic flexible pavement analysis computer program, it is a DOS program that has complicated input and its output has a great amount of data which makes it impossible for users to see the analysis results directly. The Texas Transportation Institute (TTI) VESYS5W, Windows version of VESYS5, provides a user-friendly input and output interface and significantly improves the usability of the existing VESYS5 program. This report documents TTI VESYS5W release version 1.0.

TTI VESYS5W is designed to simplify user input and make user input more understandable based on thoroughly studying and examining the input of VESYS5. TTI VESYS5W also significantly changes the format of the output, offering users the ability to visualize the analysis results – a feature that cannot be found in any existing VESYS program. In TTI VESYS5W, the program simplifies the output data file and displays them in the format of chart, graph, and table.

TTI VESYS5W gives a new look to the VESYS program, and more importantly it develops a more convenient way to use VESYS and make VESYS a more useful analysis tool for pavement engineers and researchers to analyze asphalt pavement performance in terms of rutting, fatigue cracking, and present serviceability index (PSI).

NEW LOOK OF TTI VESYS5W

The Windows version of enhanced VESYS5 provides a user-friendly input and output interface and significantly improves the usability of the existing VESYS5 program. Figures [1a](#) and [1b](#) present the flowchart and the main input and output interface of the TTI VESYS5W, respectively. Input data are categorized into four types: General Information, Climate, Structure and Material Property, and Traffic. Output data include:

- a summary of input data,
- graphic output of performance data (total rutting, layer rutting, fatigue cracking, and PSI), and
- tabulated performance data.

REPORT ORGANIZATION

This report documents key input parameters of the upgraded Windows version of VESYS5. [Chapter 1](#) presents a brief introduction. [Chapter 2](#) discusses performance models used in the TTI VESYS5W program and associated laboratory test protocols. A case study is provided in [Chapter 3](#). Finally, [Chapter 4](#) summarizes the report.

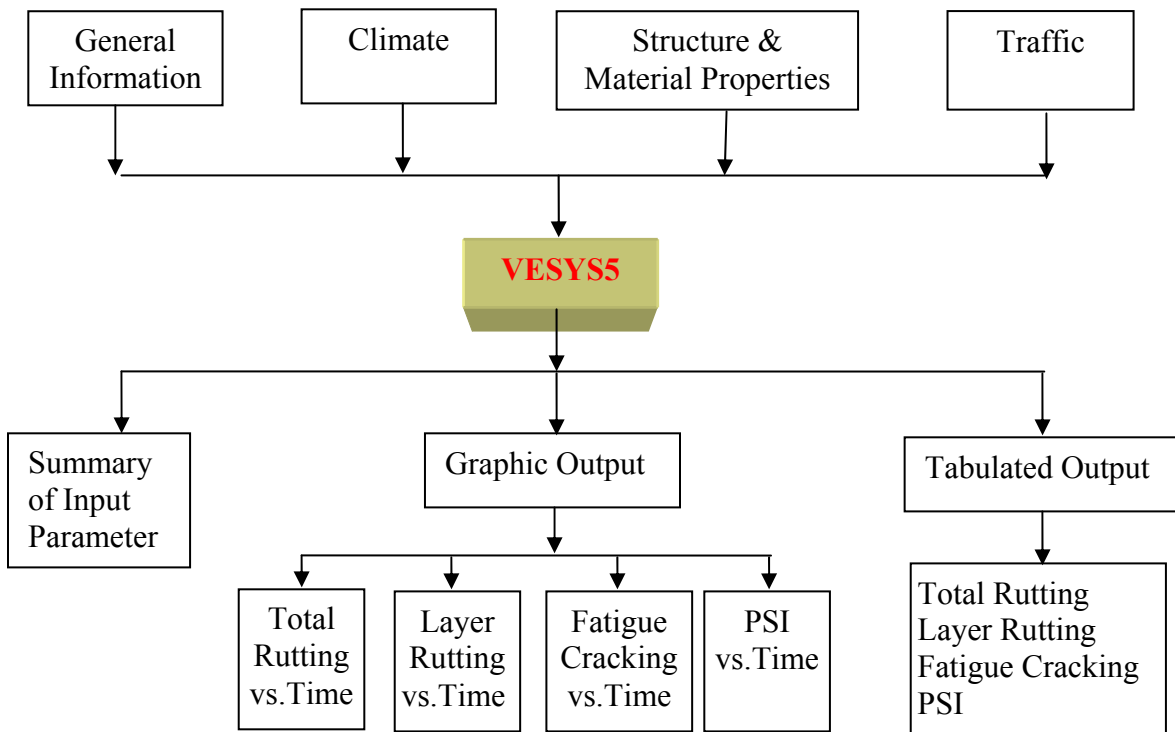


Figure 1a. Flowchart of Enhanced VESYS5.

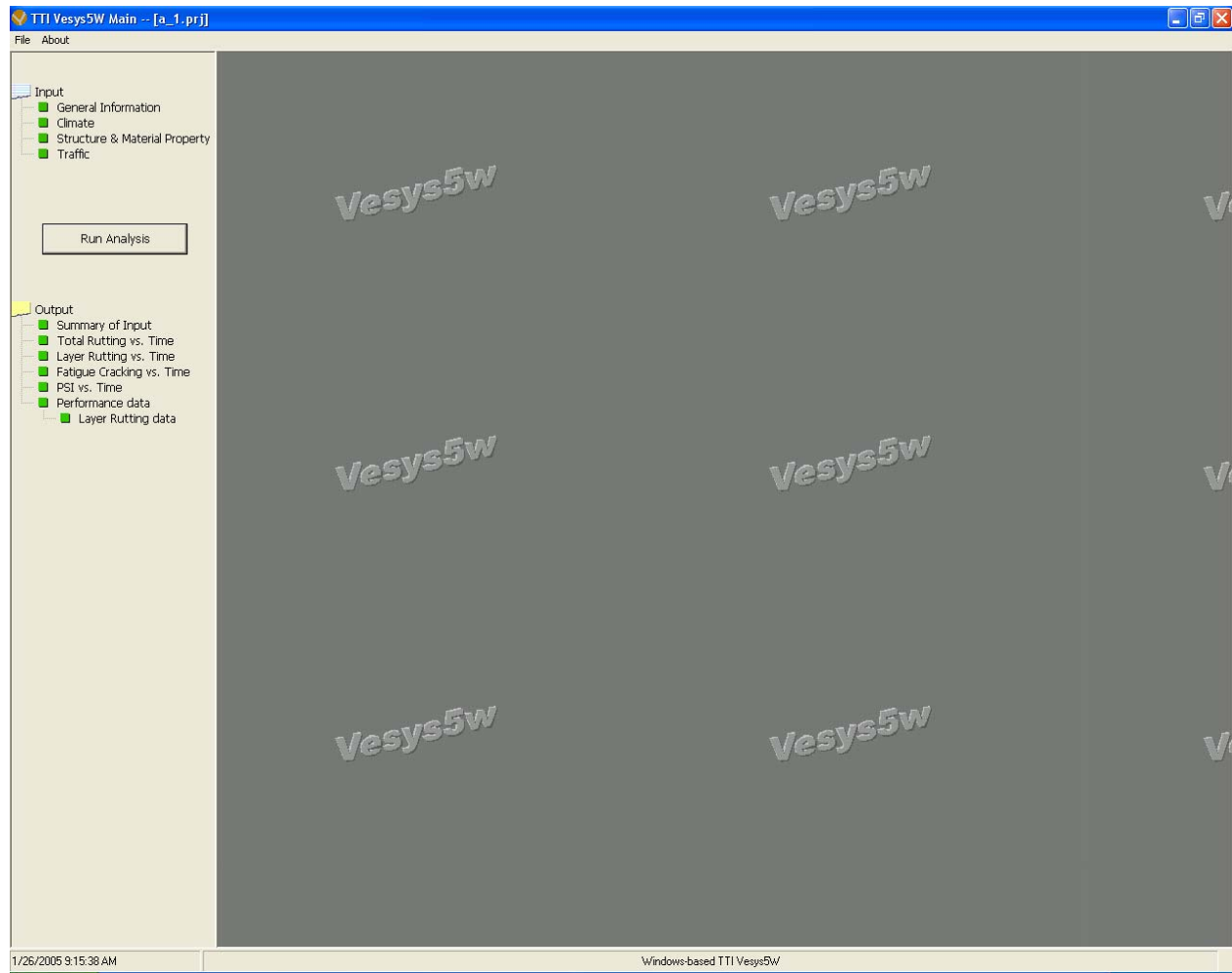


Figure 1b. Main Input and Output Interface of Enhanced VESYS5.

CHAPTER 2

TTI VESYS5W PERFORMANCE MODELS AND ASSOCIATED LABORATORY TEST PROTOCOLS

TTI VESYS5W PERFORMANCE MODELS

Two major distresses in asphalt pavement, rutting and fatigue cracking, are predicted in the TTI VESYS5W program. Rutting and fatigue cracking models are discussed next.

TTI VESYS5W Rutting Model

TTI VESYS5W predicts the rutting in each layer. The rutting in each layer is summarized to calculate the total rutting in the pavement structure. The layer rutting model estimates the permanent deformation in each finite layer as the product of the elastic compression in that layer and the layer material permanent deformation law associated with that layer. For infinite layer, the permanent deformation in the subgrade is defined differently because of the consideration of the effect of multi-axle load.

The total elastic strain within a pavement layer is simply the total compression within the layer, which in layer theory is given by the difference in deflections of the top and bottom surfaces of the layer. For each pavement layer, layer rutting can be written as:

$$R_D(N) = (W^+ - W^-) * \frac{\mu}{1 - \alpha} N^{(1-\alpha)} \quad (1)$$

For the semi-infinite subgrade layer, Eq. 1 reduces to:

$$R_{sub}(N) = W_{sub}^+ * \frac{e_t}{e_s} \frac{\mu}{1 - \alpha} N^{(1-\alpha)} \quad (2)$$

In which,

- $R_D(N)$ = permanent deformation (rutting) level after N load repetitions;
- W^+, W^- = elastic deflection amplitudes of the top and bottom surfaces of the layer, respectively;
- μ, α = laboratory permanent deformation parameters for each layer material;
- W_{sub}^+ = deflection at top of subgrade due to single axle load;

- e_t = strain at top of subgrade due to the axle group; and
 e_s = strain at top of subgrade due to single axle.

The equation shows that the permanent deformation of each layer mainly depends on the permanent deformation parameters of each layer: μ and α . These two parameters are determined by laboratory repeated load tests. The TTI VESYS5W program provides default values for regular mixes based on historical laboratory test results. Also, the test protocols on materials properties μ and α , have been developed under this project. These laboratory test protocols can be used to characterize the permanent deformation properties of new materials, if new materials are used in the pavement construction. The laboratory test protocols on μ and α are presented in the [next section](#).

TTI VESYS5W Fatigue Cracking Model

Another major distress in asphalt pavement is fatigue cracking. TTI VESYS5W predicts the development of fatigue cracking areas of asphalt pavement by using fatigue law of asphalt concrete mixture. Fatigue resistance of asphalt mixture has been studied for more than 50 years. Several fatigue laws of asphalt mixture, such as the Asphalt Institute (AI) model, the Shell model, the Strategic Highway Research Program (SHRP) model, and 2002 Mechanistic-Empirical Pavement Design Guide (MEPDG) model, have been developed in the literature. The general form of fatigue model is shown in [Equation 3](#). One of the main considerations when selecting fatigue law being built into the TTI VESYS5W was the compatibility with the framework of DOS VESYS5 program. After comparing the available models, the MEPDG model ([Equation 4](#)) was finally included in the TTI VESYS5W program. This model has been calibrated based on Long Term Pavement Performance (LTPP) data. No further calibration was conducted under this project, since there was no accelerated pavement fatigue data available in this report year. In addition, for new asphalt mixtures, fatigue properties can be characterized by the American Association of State Highway and Transportation Officials (AASHTO) T321 test procedure: Method for Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending.

$$N_f = k_1 \left(\frac{1}{\varepsilon_t} \right)^{k_2} \left(\frac{1}{E} \right)^{k_3} \quad (3)$$

Where

- N_f = fatigue life,
 ε_t = tensile strain under asphalt layer,
 E = modulus of asphalt concrete mixture, and
 k_1, k_2, k_3 = material parameters.

$$N_f = \frac{0.00432}{0.000398 + 0.003602 / (1 + e^{(11.02 - 3.49h_{ac})})} \left(\frac{1}{\varepsilon_t} \right)^{3.9492} \left(\frac{1}{E} \right)^{1.281} \quad (4)$$

Where

- h_{ac} = total thickness of asphalt layer(s),
 ε_t = tensile strain under asphalt layer, and
 E = modulus of asphalt concrete mixture.

LABORATORY TEST PROTOCOL ON PERMANENT DEFORMATION PARAMETERS μ AND α , FOR GRANULAR BASE/SUBBASE, AND SUBGRADE

Laboratory test protocol on TTI VESYS5W permanent deformation parameters μ and α , for granular base/subbase and subgrade, is presented in [Appendix A](#).

LABORATORY TEST PROTOCOL ON TTI VESYS5W PERMANENT DEFORMATION PARAMETERS μ AND α , FOR ASPHALT MATERIALS

Laboratory test protocol on TTI VESYS5W permanent deformation parameters μ and α , for asphalt materials, is presented in [Appendix B](#).

CHAPTER 3

A CASE STUDY ON THE ENHANCED VESYS5

This chapter provides a simple case study to demonstrate the input and output of the enhanced VESYS5 program.

The input and output of this case study are detailed in the following Figures.

- [Figure 2](#) shows the “General Information” screen and associated input parameters.
- [Figure 3](#) presents interface of “Climate” screen and input example.
- [Figure 4](#) shows input of “Structure and Material Properties.”
- [Figures 5 and 6](#) illustrate traffic information including “Axle Load” and “Repeated Load,” respectively.
- The output of this case study is shown in [Figures 7](#) (“Input Summary”), [8](#) (“Total Rutting vs. Time”), [9](#) (“Layer Rutting vs. Time”), [10](#) (“Fatigue Cracking vs. Time”), [11](#) (“PSI vs. Time”), [12](#) (tabulated “Performance Data”), and [13](#) (tabulated “Layer Rutting Data”).

Additionally, a user manual for this enhanced VESYS5 program (TTI VESYS5W) is attached in [Appendix C](#).

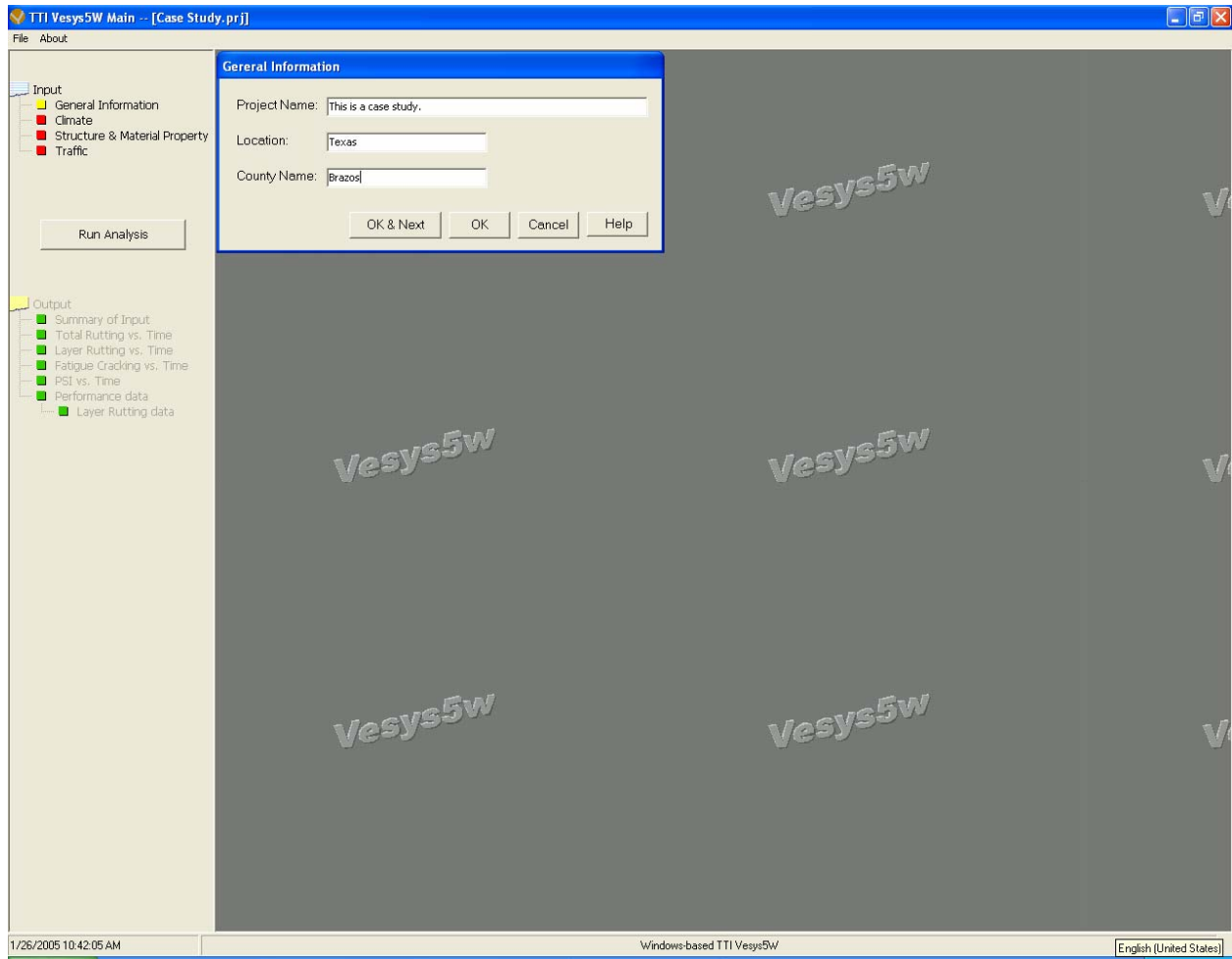


Figure 2. Input Example of General Information.

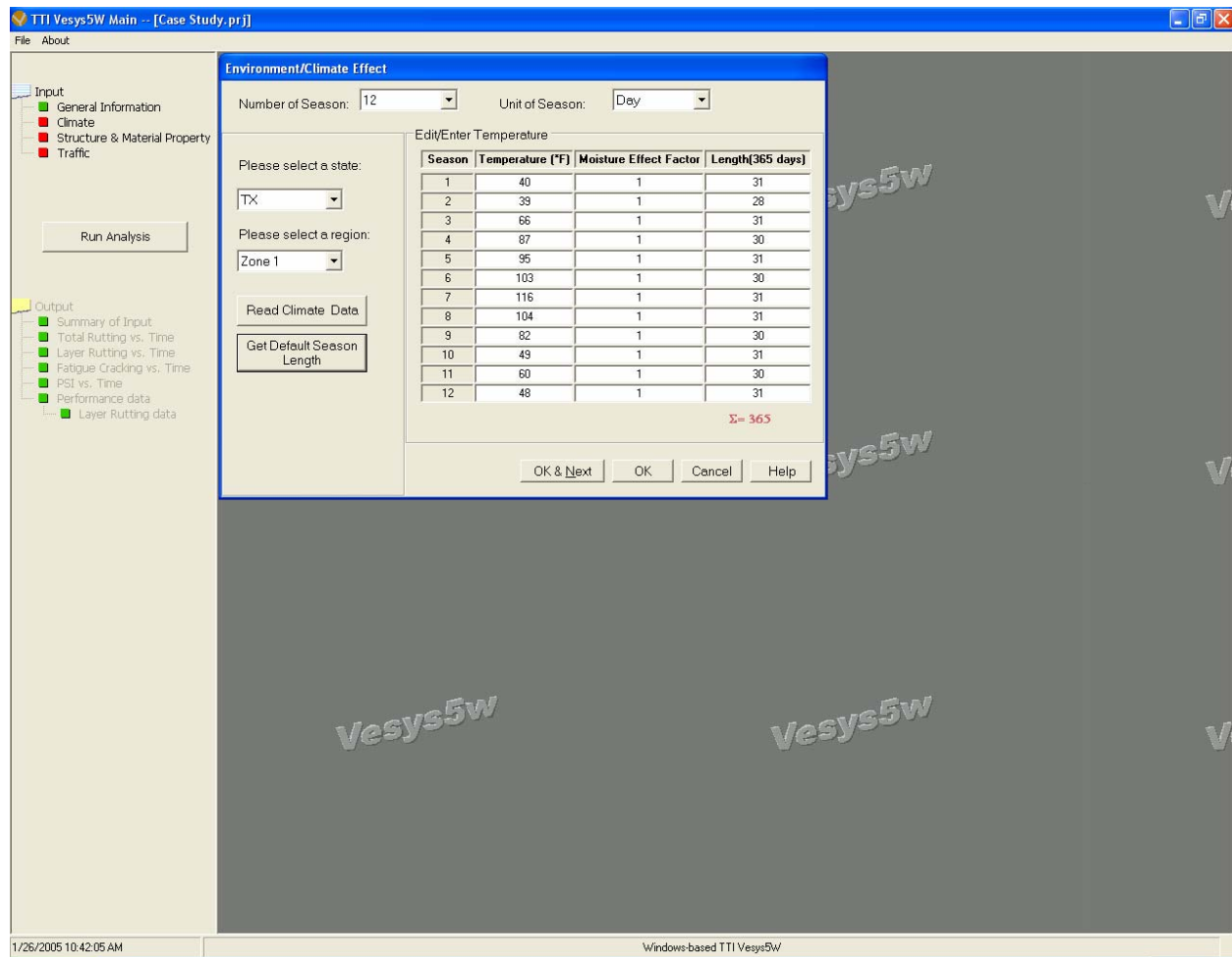


Figure 3. Input Example of Climate.

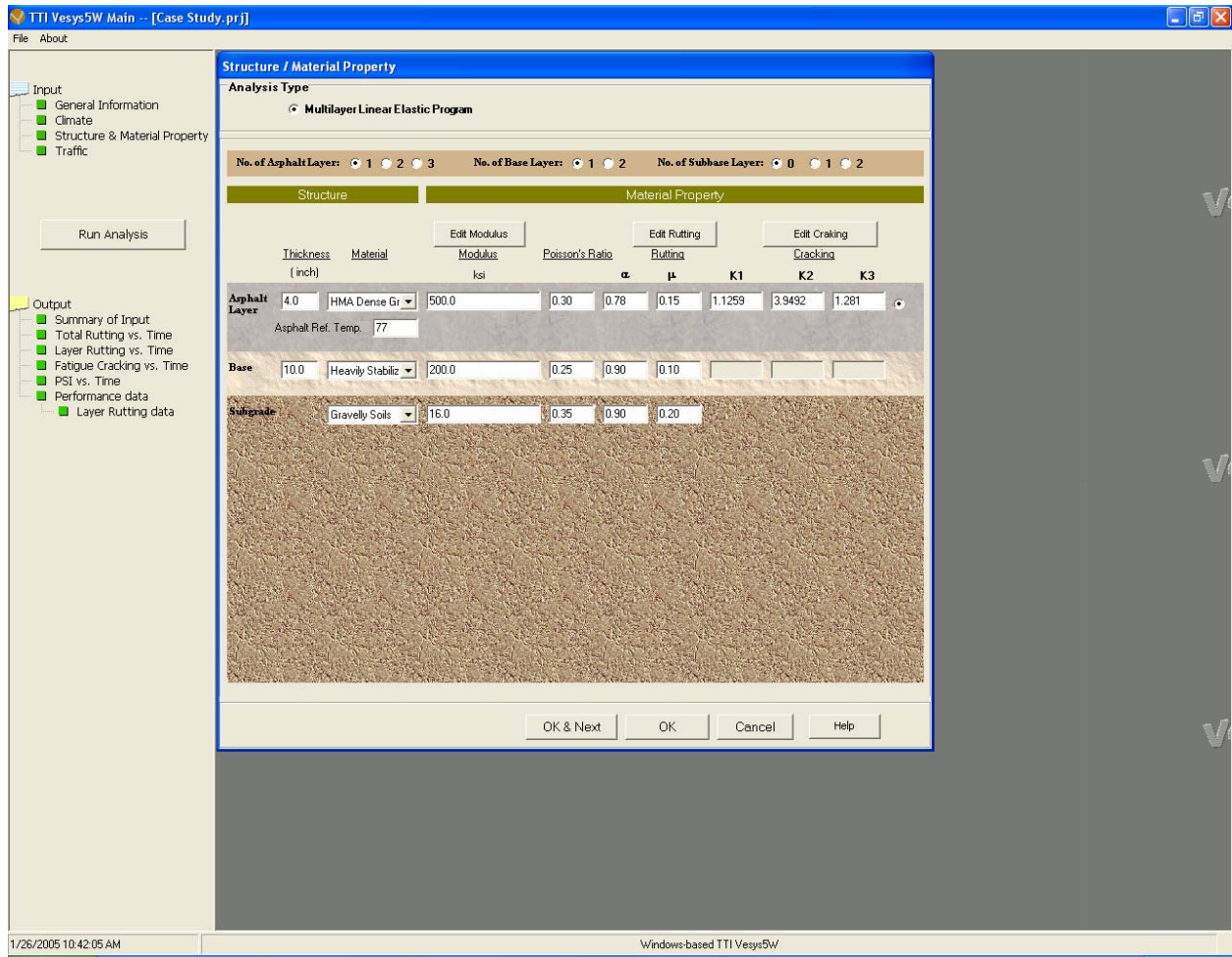


Figure 4. Input Example of Structure and Material Properties.

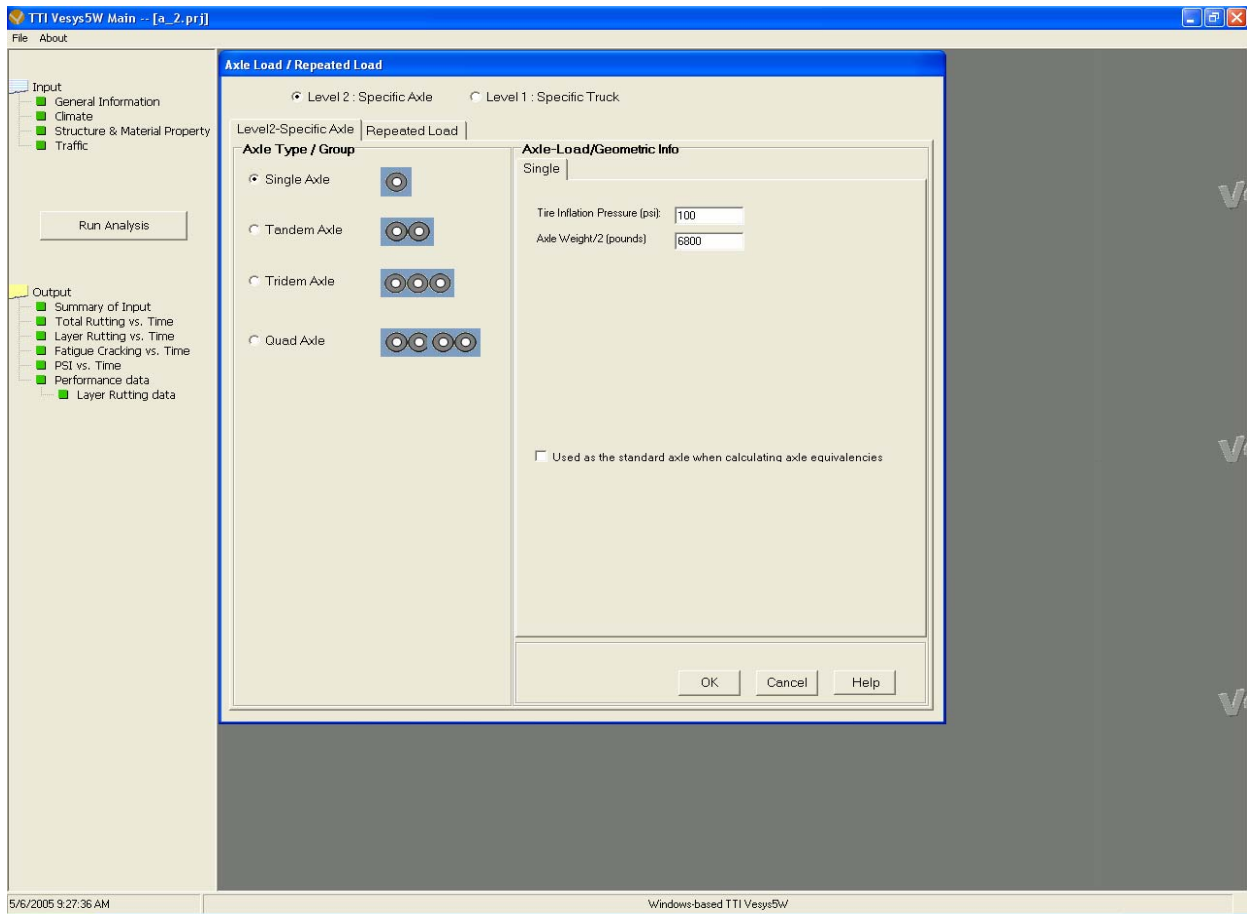


Figure 5. Input Example of Axle Load.

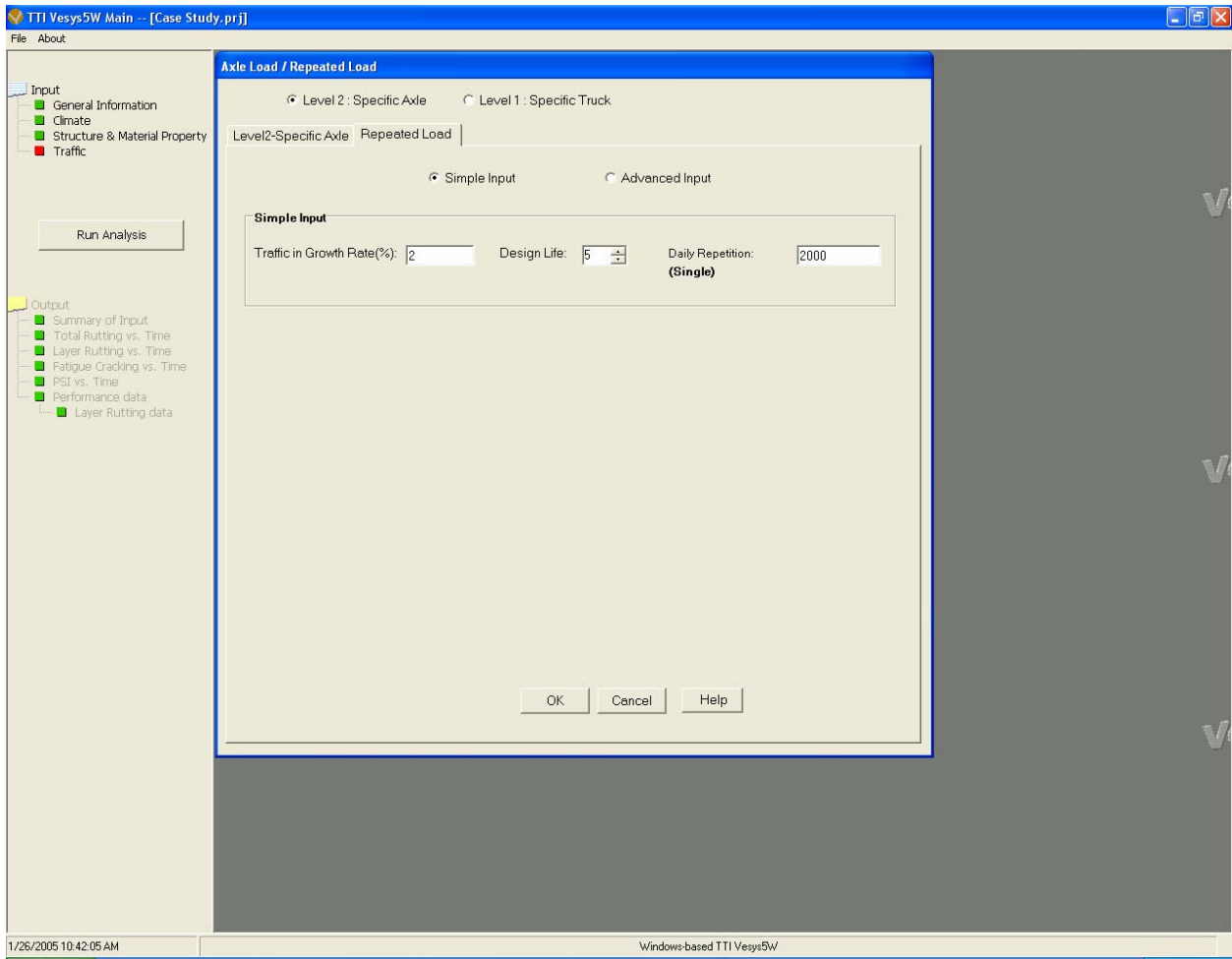


Figure 6. Input Example of Repeated Load.

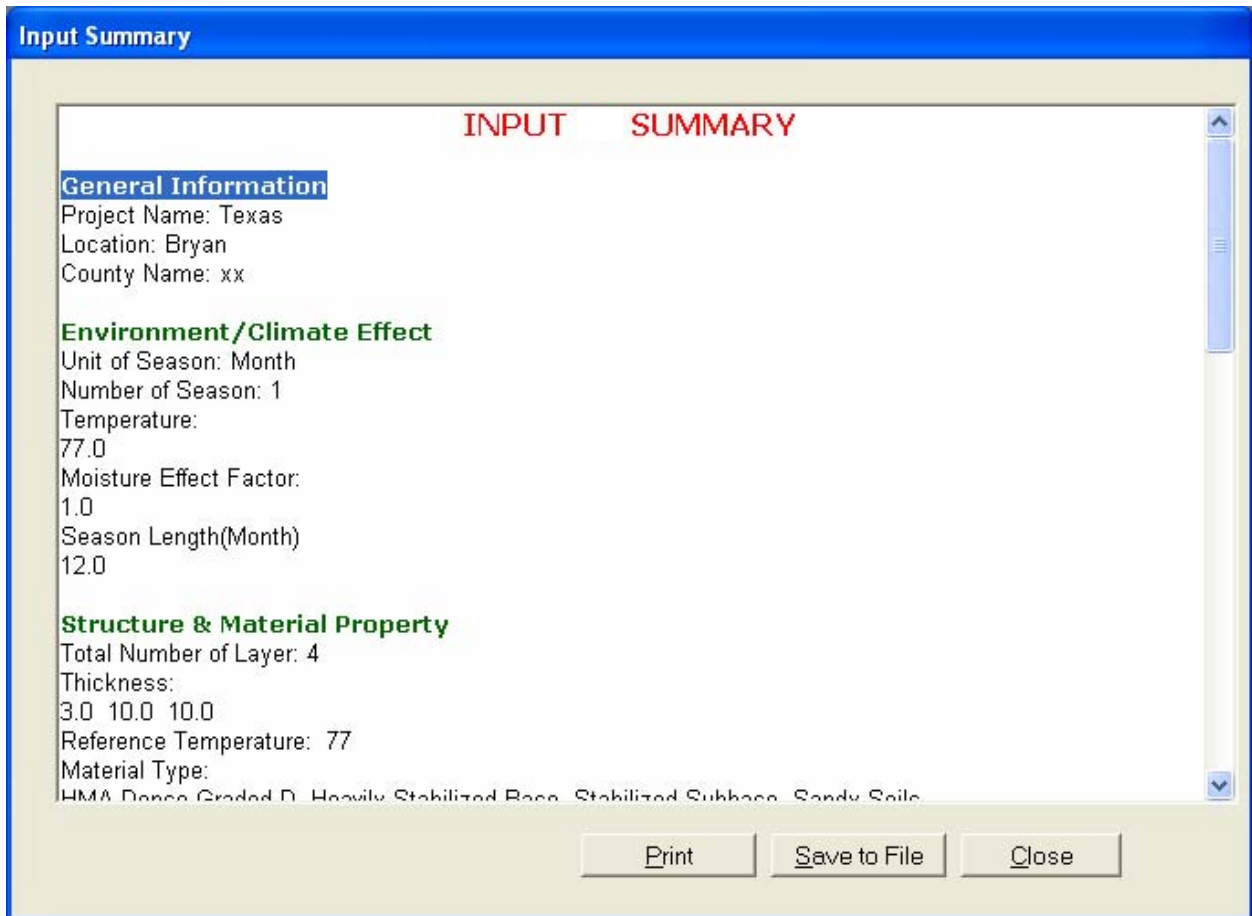


Figure 7. Output Example of “Input Summary.”

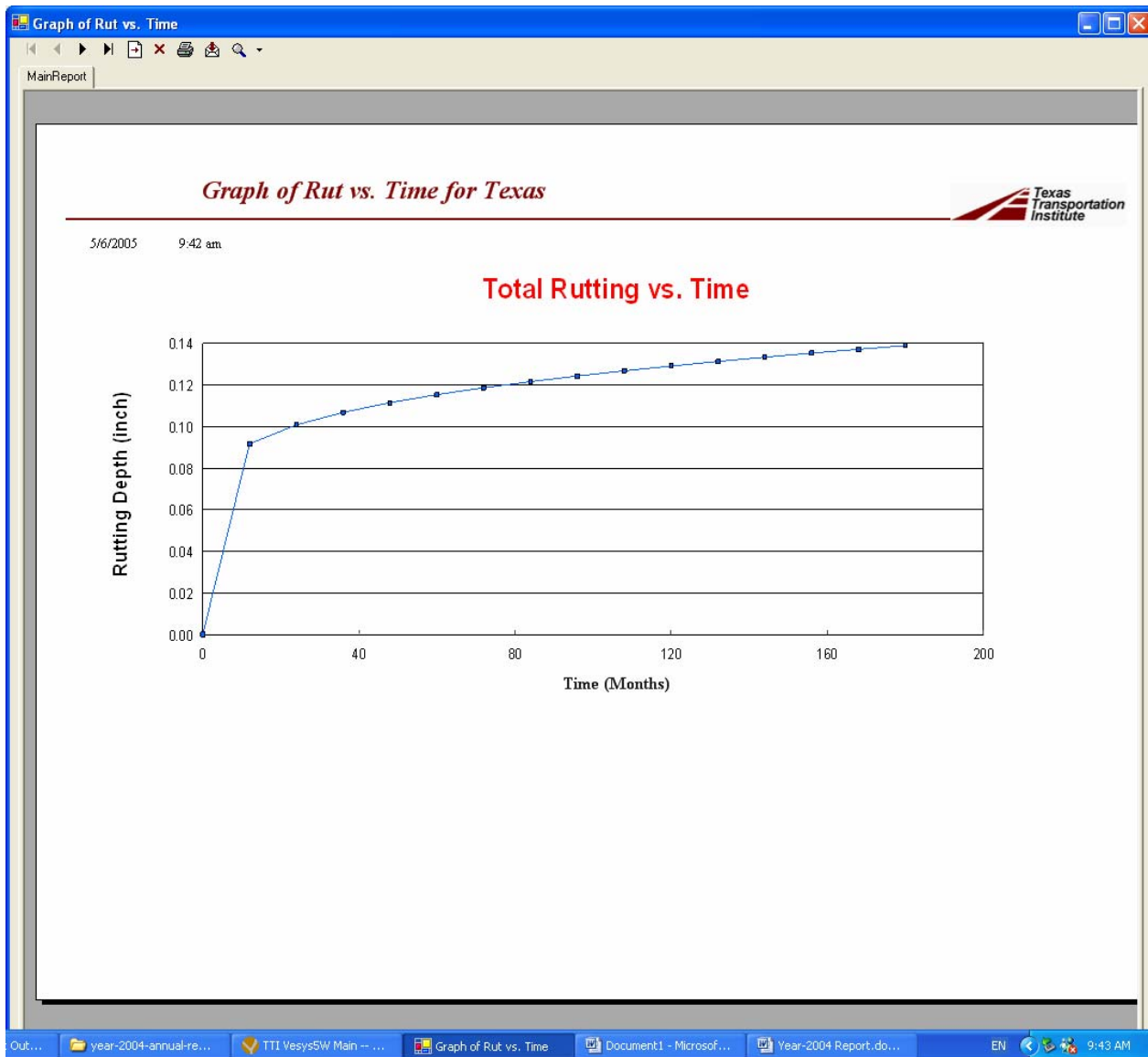


Figure 8. Output Example of “Total Rutting vs. Time.”

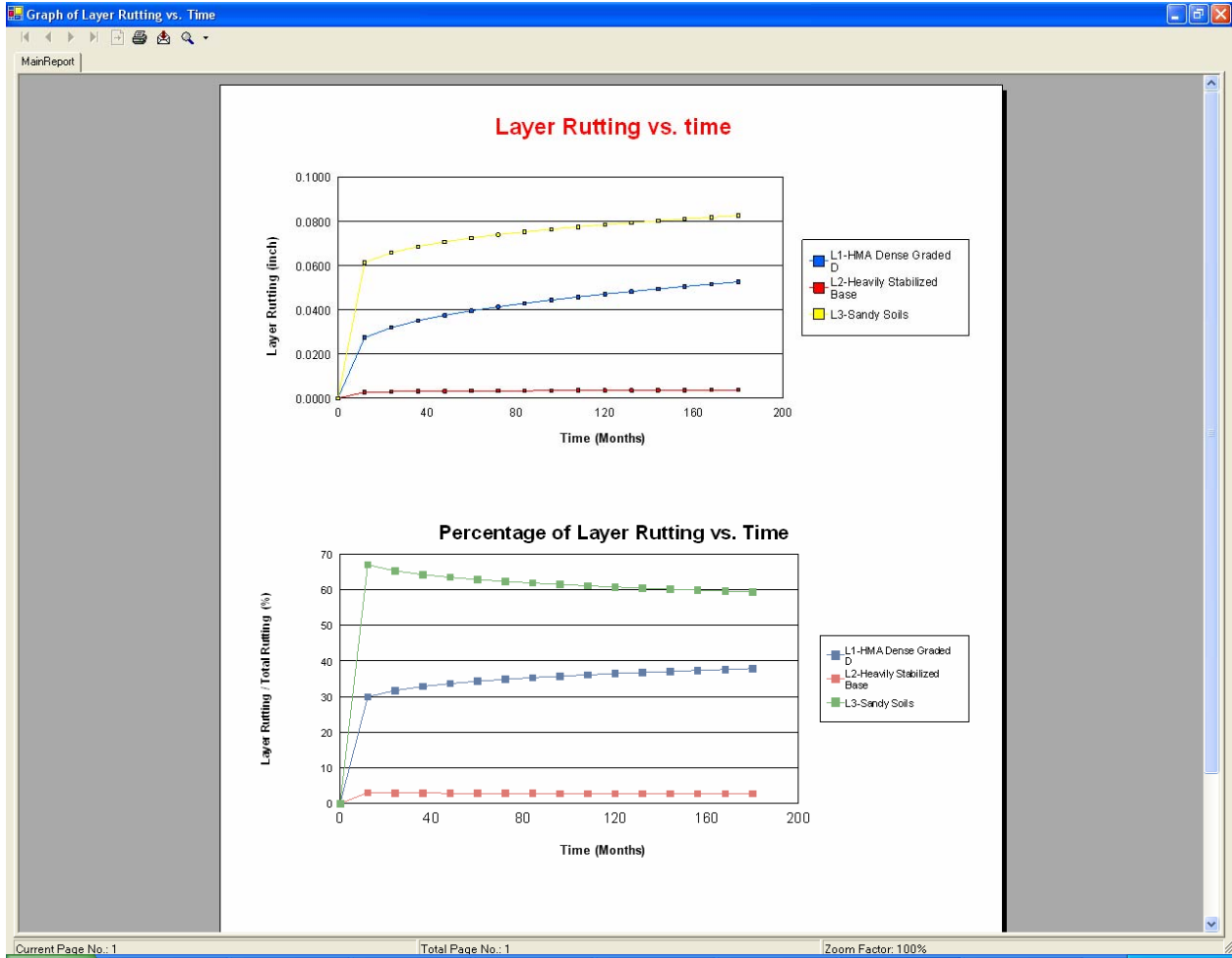


Figure 9. Output Example of “Layer Rutting vs. Time.”

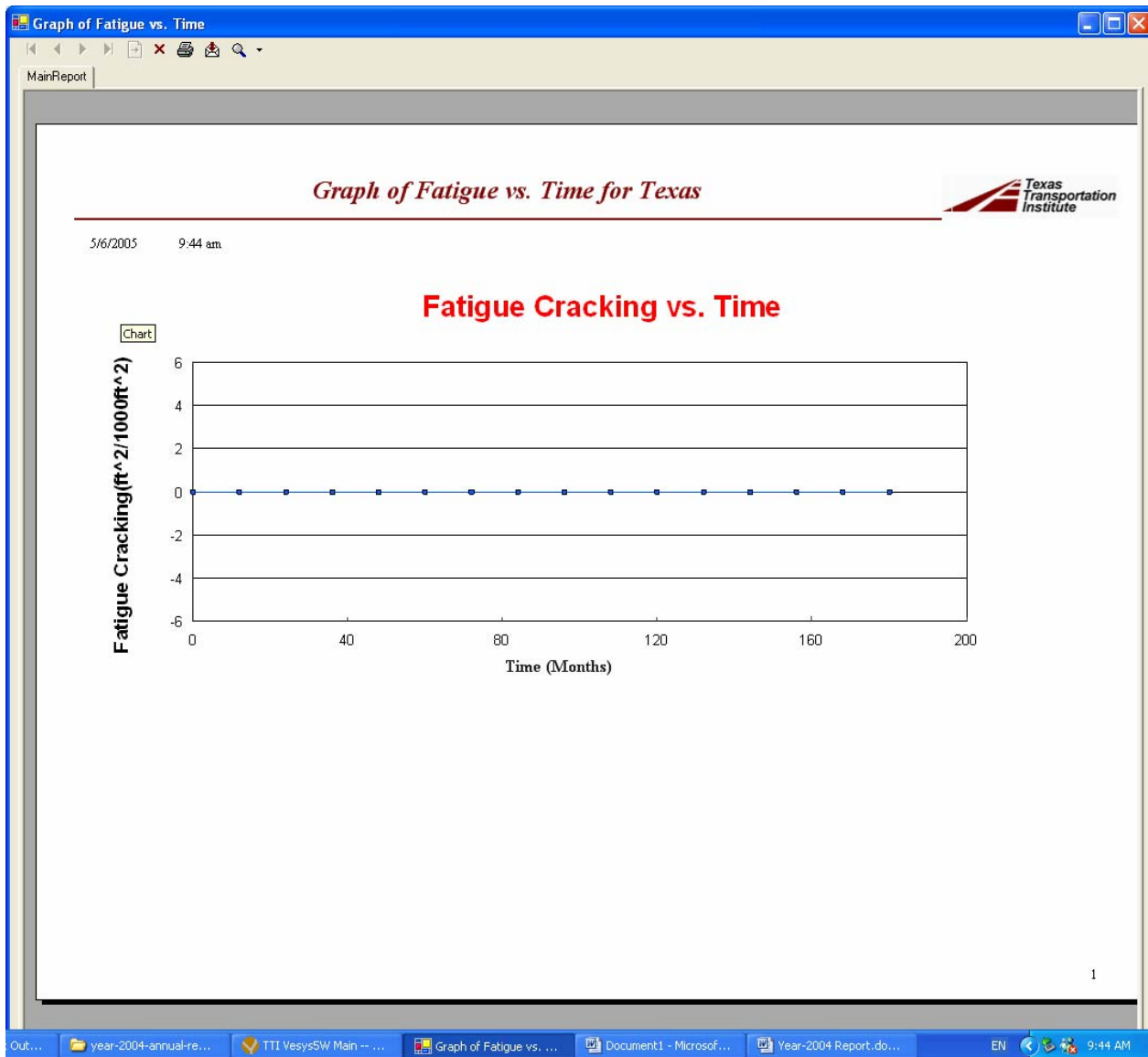


Figure 10. Output Example of “Fatigue Cracking vs. Time.”

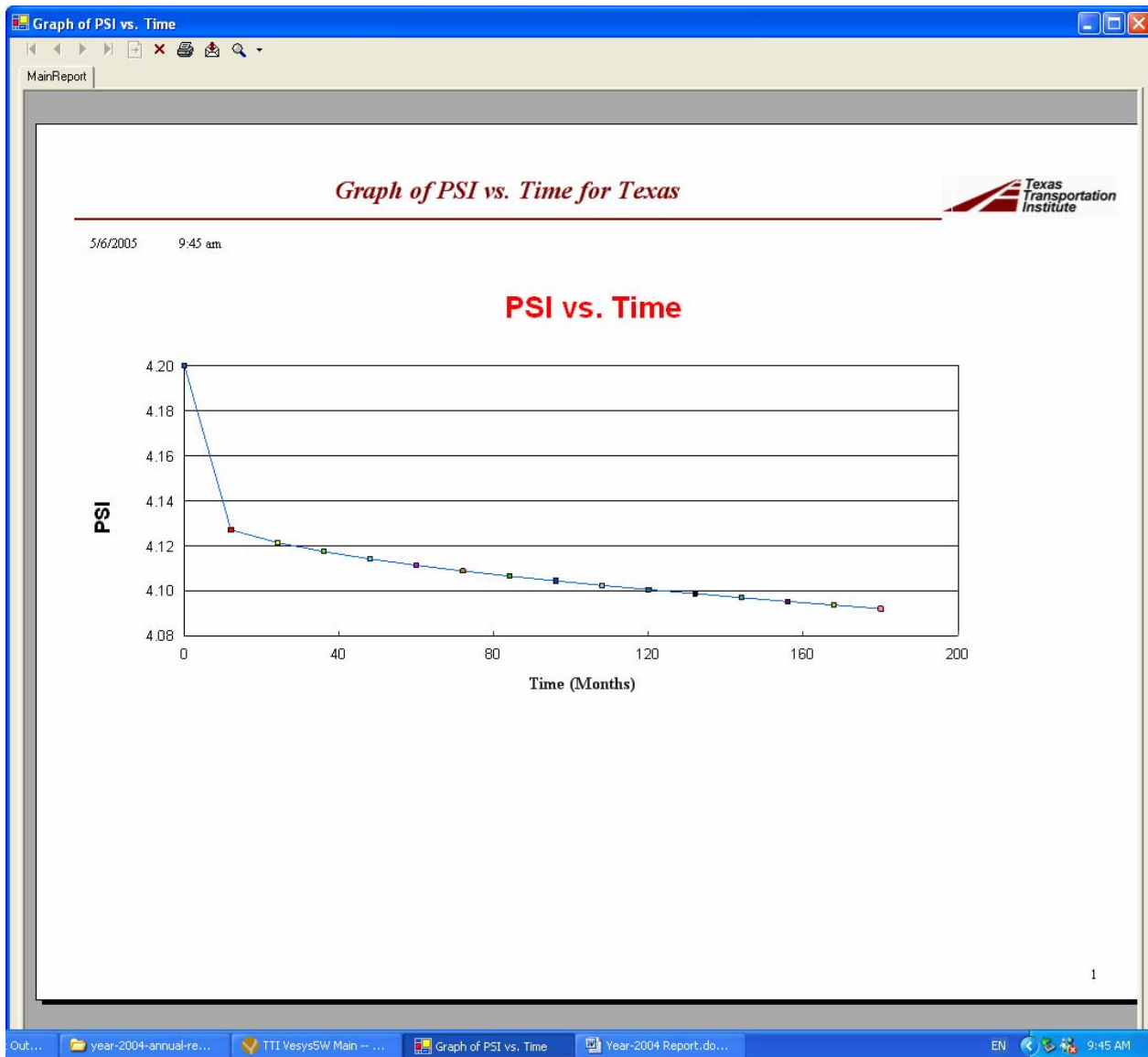


Figure 11. Output Example of “PSI vs. Time.”

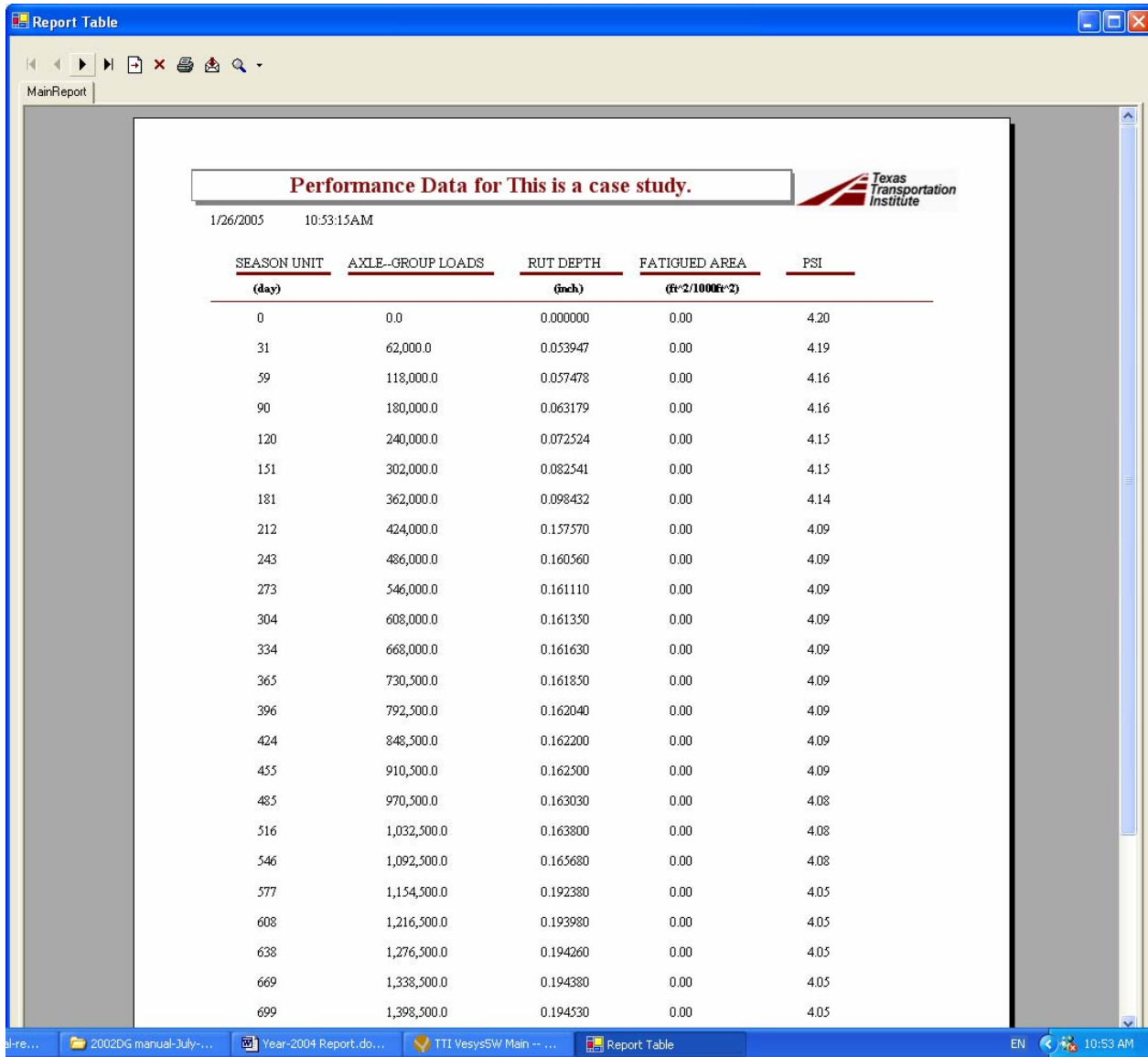


Figure 12. Output Example of Tabulated “Performance Data.”

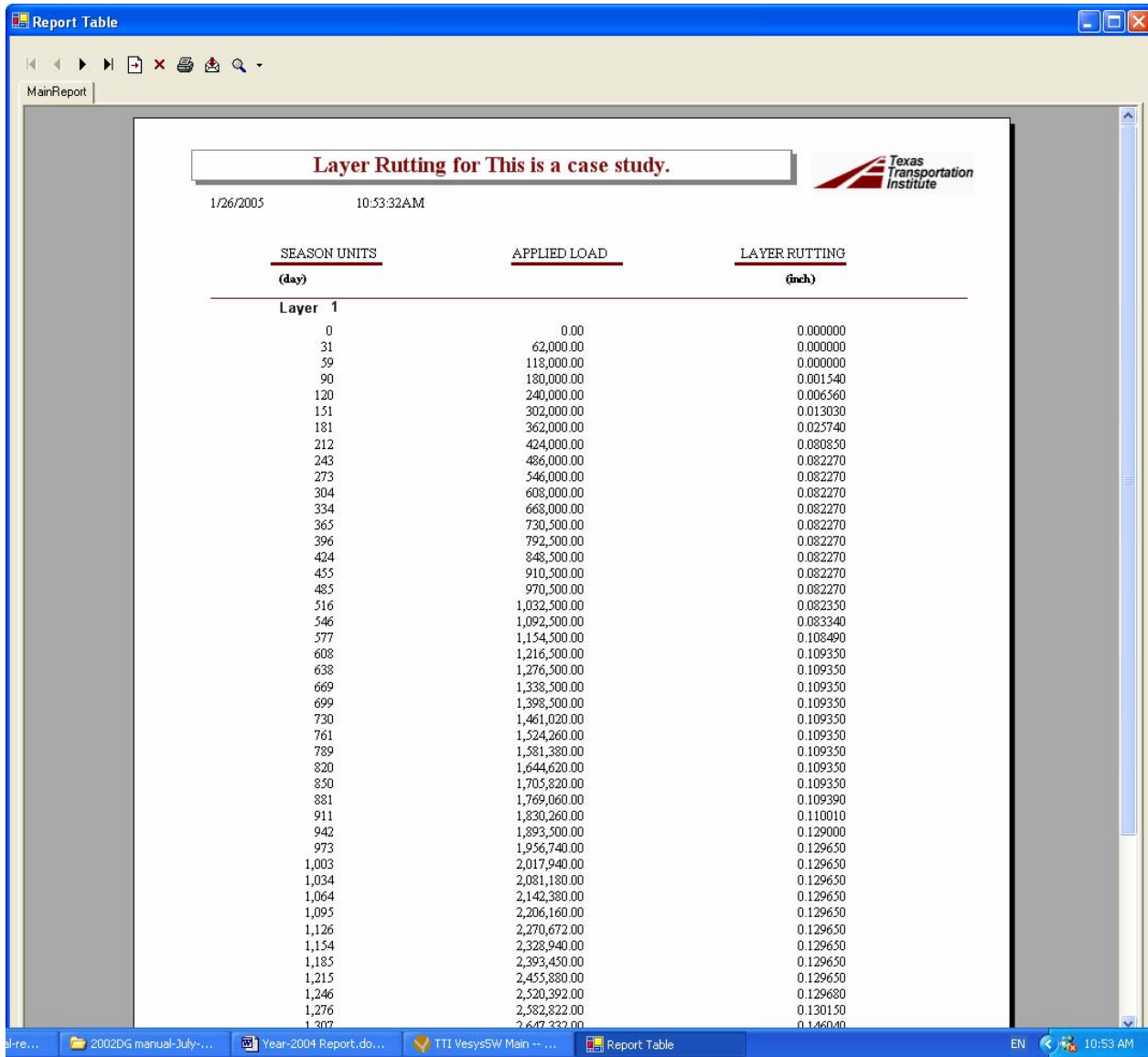


Figure 13. Output Example of Tabulated “Layer Rutting Data.”

CHAPTER 4

SUMMARY

VESYS5 is a well developed mechanistic flexible pavement analysis computer program. However, it is a DOS based program, and its input and output are very complicated. It is difficult for users to apply the program to analyze the performance of flexible pavements. TTI VESYS5W is a Windows version of VESYS5. TTI VESYS5W provides a user-friendly input and output interface and significantly improves the usability of the existing VESYS5 program. This report documents TTI VESYS5W release version 1.0. Also, a simple case is provided in the report.

It is well known that the most challenging task of developing pavement performance prediction program is to determine the material properties including modulus, rutting, and fatigue cracking, etc. One of the special features of the enhanced VESYS5 program is that the default values of material properties have been built into the program. These default values are based on substantial literature review and laboratory testing. In addition, the laboratory test protocols have also been recommended to determine these material properties. It should also be noted that current TTI VESYS5W was calibrated by limited APT rutting data; further calibration on rutting and fatigue cracking models is needed, especially using the field experimental sections. Furthermore, more research on the influence of climate on performance prediction is needed.

APPENDIX A:
RECOMMENDED PERMANENT DEFORMATION LABORATORY TEST
PROTOCOLS FOR UNBOUND GRANULAR BASE/SUBBASE
MATERIALS AND SUBGRADE SOILS

1. Scope

- 1.1. This test method describes the laboratory preparation and testing procedures for the determination of permanent deformation of unbound granular base/subbase materials and subgrade soils for pavement performance prediction. The stress conditions used in the test represent the ranges of stress states likely to be developed beneath flexible pavements subjected to moving wheel loads. This test procedure has been adapted from the standard test methods given in the VESYS user manual, National Cooperation Highway Research Program (NCHRP) 1-28A Digest Report, and AASHTO DESIGNATION: T294-92, TP46, and T292-91.
- 1.2. The methods described herein are applicable to laboratory-molded samples of unbound granular base/subbase materials and subgrade soils.
- 1.3. In this test procedure, stress states used for permanent deformation are based upon whether the specimen is located in the base/subbase or the subgrade. Specimen size for testing depends upon the maximum particle size of the material.
- 1.4. The values of permanent deformation determined from these procedures are the measures of permanent deformation properties and the resilient modulus of unbound granular base/subbase materials and subgrade soils with the consideration of their stress-dependency.
- 1.5. This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

- 2.1. AASHTO Standards:
 - T88 Particle Size Analysis of Soils
 - T89 Determining the Liquid Limit of Soils
 - T90 Determining the Plastic Limit and the Plasticity Index of Soils
 - T100 Specific Gravity of Soils

T180 Moisture-Density Relations of Soils Using a 454 kg (10 lb) Rammer and 457 mm (18 inch) Drop

T233 Density of Soil-in-Place by Block, Chunk or Core Sampling

T292-91 Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials

T296 Strength Parameters of Soils by Triaxial Compression

T265 Laboratory Determination of Moisture Content of Soils

3. Terminology

- 3.1. Unbound Granular Base and Subbase Materials – These include soil-aggregate mixtures and naturally occurring materials. No binding or stabilizing agent is used to prepare unbound granular base or subbase layers. These materials are classified as Type 1 and Type 2, as subsequently defined in Sections 3.3 and 3.4.
- 3.2. Subgrade – Subgrade soils may be naturally occurring or prepared and compacted before the placement of subbase and/or base layers. These materials are classified as Type 1, Type 2, and Type 3, as subsequently defined in Sections 3.3, 3.4, and 3.5.
- 3.3. Material Type 1 – Includes all unbound granular base and subbase materials and all untreated subgrade soils with maximum particle sizes greater than 9.5 mm (3/8 inch). All material greater than 25.4 mm (1.0 inch) shall be scalped off prior to testing. Materials classified as Type 1 shall be molded in either a 152 mm (6 inch) diameter mold or a 102 mm (4 inch) diameter mold. Materials classified as Type 1 shall be compacted by impact or vibratory compaction.
- 3.4. Material Type 2 – Includes all unbound granular base and subbase materials and all untreated subgrade soils that have a maximum particle size less than 9.5 mm (3/8 inch) and that meet the criteria of less than 10 percent passing the 75 mm (No. 200) sieve. Materials classified as Type 2 shall be molded in a 102 mm (4 inch) diameter mold and compacted by vibratory compaction.
- 3.5. Material Type 3 – Includes all untreated subgrade soils that have a maximum particle size less than 9.5 mm (3/8 inch) and that meet the criteria of more than 10 percent passing the 75 mm (No. 200) sieve. Materials classified as Type 3 shall be molded in a 102 mm (4 inch) diameter mold and compacted by impact compaction.

- 3.6. Permanent Deformation – Permanent deformation is determined by repeated load compression tests on specimens of the unbound materials. Permanent deformation is the uncovered deformation during the testing.
- 3.7. Loading Wave Form – Test specimens are loaded using a haversine-shaped load pulse with 0.1-second loading and 0.9-second rest period.
- 3.8. Maximum Applied Axial Load (P_{max}) – The load applied to the sample consisting of the contact load and cyclic load (confining pressure is not included):

$$P_{max} = P_{contact} + P_{cyclic}$$

- 3.9. Contact Load ($P_{contact}$) – Vertical load placed on the specimen to maintain a positive contact between the loading ram and the specimen top cap. The contact load includes the weight of the top cap and the static load applied by the ram of the loading system.
- 3.10. Cyclic Axial Load (P_{cyclic}) – Repetitive load applied to a test specimen:

$$P_{cyclic} = P_{max} - P_{contact}$$

- 3.11. Maximum Applied Axial Stress (S_{max}) – The axial stress applied to the sample consisting of the contact stress and the cyclic stress (the confining stress is not included):

$$S_{max} = P_{max} / A$$

where A = cross sectional area of the sample.

- 3.12. Cyclic Axial Stress – Cyclic (resilient) applied axial stress:

$$S_{cyclic} = P_{cyclic} / A$$

- 3.13. Contact Stress ($S_{contact}$) – Axial stress applied to a test specimen to maintain a positive contact between the specimen cap and the specimen:

$$S_{contact} = P_{contact} / A$$

The contact stress shall be maintained so as to apply a constant anisotropic confining stress ratio:

$$(S_{contact} + S_3) / S_3 = 1.2$$

where S_3 is the confining pressure.

- 3.14. S_3 is the applied confining pressure in the triaxial chamber (i.e., the minor principal stress σ_3).
- 3.15. e_r is the resilient (recoverable) axial deformation due to S_{cyclic} .
- 3.16. ϵ_r is the resilient (recoverable) axial strain due to S_{cyclic} .

$$\varepsilon_r = e_r / L$$

where L = distance between measurement points for resilient axial deformation, e_r .

3.17. e_p is the permanent (unrecoverable) axial deformation due to S_{cyclic} .

3.18. ε_p is the permanent (unrecoverable) axial strain due to S_{cyclic} :

$$\varepsilon_p = e_p / L$$

where L = distance between measurement points for permanent axial deformation, e_p .

3.19. Resilient Modulus (M_r) is defined as:

$$M_r = S_{cyclic} / \varepsilon_r$$

3.20. Load duration is the time interval the specimen is subjected to a cyclic stress pulse.

3.21. Cycle duration is the time interval between the successive applications of a cyclic stress (usually 1.0 sec.).

4. Summary of Method

4.1. A repeated axial stress of fixed magnitude, load duration, and cycle duration is applied to a cylindrical test specimen. The test is performed in a triaxial cell, and the specimen is subjected to a repeated (cyclic) stress and a constant confining stress provided by means of cell air pressure. Both total resilient (recoverable) and permanent axial deformation responses of the specimen are recorded and used to calculate the permanent deformation property and the resilient modulus.

5. Significance and Use

5.1. The resilient modulus test results provide a basic constitutive relationship between stiffness and stress state of pavement materials for use in the structural analysis of layered pavement systems. Furthermore, permanent deformation properties of pavement materials also can be determined from initially repeated load tests. The information is critical for pavement rutting performance prediction. The permanent deformation and resilient modulus tests simulate the conditions in a pavement with the application of moving wheel loadings.

6. Permanent Deformation Test Apparatus

6.1. Triaxial Pressure Chamber – The pressure chamber is used to contain the test specimen and the confining fluid during the test. A typical triaxial chamber suitable for use in resilient modulus testing of soils is shown in [Figure A1](#). The axial deformation is measured internally, directly on the specimen using normal gauges with rubber bands (shown in [Figure A2](#)), an optical extensometer, non-contact sensors, or clamps. For soft and very soft subgrade specimens (i.e., $S_u < 36$ kPa or 750 psf, where S_u is the undrained shear strength of the soil), rubber bands or clamps should not be used since they may damage the specimen. However, a pair of linear variable differential transformers (LVDTs) extending between the top and bottom platens can be used to measure axial deformation of these weak soils.

6.1.1. Air shall be used in the triaxial chamber as the confining fluid for all testing.

6.1.2. The chamber shall be made of suitable see-through material (such as polycarbonate).



Figure A1. Triaxial Cell and Test System.

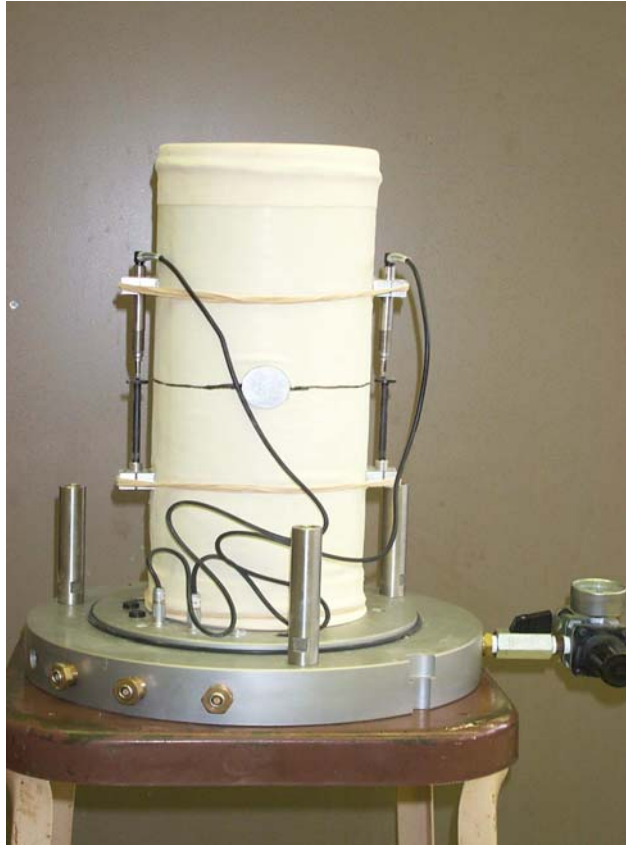


Figure A2. Sample with Instruments.

6.2. Loading Device – The loading device shall be a top loading, closed loop electro-hydraulic testing machine with a function generator that is capable of applying repeated cycles of a haversine-shaped load pulse. Each pulse shall have a 0.1-second duration followed by a rest period of 0.9-second duration for base/subbase materials and 0.2-second duration followed by a rest period of 0.8-second duration for subgrade materials. For non-plastic granular material, it is permissible, if desired, to reduce the rest period to 0.4-second to shorten testing time; the loading time may be increased to 0.15-second if required.

6.2.1. All conditioning and testing shall be conducted using a haversine-shaped load pulse. The electro-hydraulic system generated haversine waveform and the response waveform shall be displayed to allow the operator to adjust the gains to ensure they coincide during conditioning and testing.

6.3. Load and Specimen Response Measuring Equipment:

6.3.1. The axial load measuring device should be an electronic load cell which is preferred to be located inside the triaxial cell. The load cell should have the capacities presented in [Table A1](#).

Table A1. Load Cell Capacity.

Sample Diameter mm (in)	Max. Load Capacity kN (lb)	Required Accuracy N (lb)
102 (4.0)	8.9 (2000)	±17.8 (±4)
152 (6.0)	22.24 (5000)	±22.24 (±5)

Note 1 – During periods of permanent deformation and resilient modulus testing, the load cell shall be monitored and checked once every two weeks or after every fifty permanent deformation and resilient modulus tests with a calibrated proving ring to ensure that the load cell is operating properly. An alternative to using a proving ring is to inset an additional calibrated load cell and independently measure the load applied by the original cell. Additionally, the load cell shall be checked at any time there is a suspicion of a load cell problem. The testing shall not be conducted if the testing system is found to be out of calibration.

6.3.2. The chamber pressures shall be monitored with conventional pressure gauges, manometers, or pressure transducers accurate to 0.69 kPa (0.1 psi).

6.3.3. Axial Deformation: Axial deformation is to be measured with displacement transducers referenced to gauge points contacting the specimen with rubber bands as shown in [Figure A2](#). Deformation shall be measured over approximately the middle half part of the specimen. Axial deformations shall be measured at a minimum of two locations 180° apart (in plan view) and a pair of spring-loaded LVDTs are placed on the specimen at 0.25 point. Spring-loaded LVDTs shall be used to maintain a positive contact between the LVDTs and the surface on which the tips of the transducers rest.

Note 2 – [Table A2](#) summarizes the specifications for spring-loaded LVDTs.

Table A2. Specifications for Axial LVDTs.

Material	Specimen Size	Min. Range (inch)	Approximate Resilient Specimen Displacement (inch)
Aggregate base	6 inch diameter specimen	±0.25	0.001
	4 inch diameter specimen	±0.10	0.00065
Subgrade soil (sand and cohesive)	4 inch diameter specimen	±0.25	0.0014

Note: For soft subgrade soil, permanent and resilient displacement shall be measured over entire specimen height.

Note 3 – Misalignment or dirt on the shaft of the transducer can cause the shafts of the LVDTs to stick. The laboratory technician shall depress and release each LVDT back and forth a number of times prior to each test to assure that they move freely and are not sticking. A cleaner/lubricant specified by the manufacturer shall be applied to the transducer shafts on a regular basis.

6.3.4. Data Acquisition: An analog to digital data acquisition system is required. The overall system should include automatic data reduction to minimize production. Suitable signal excitation, conditioning, and recording equipment are required for simultaneous recording of axial load and deformations. The system should meet or exceed the following additional requirements:

- 25 μ s A/D conversion time;
- 12 bit resolution;
- single or multiple channel through put (gain=1), 30 kHz;
- software selectable gains;
- measurement accuracy of full scale (gain=1) of ± 0.02 percent; and
- non-linearity (LSBS) of ± 0.5 percent.

The signal shall be clean and free of noise. Filtering the output signal during or after data acquisition is discouraged. If a filter is used, it should have a frequency higher than 10 to 20 Hz. A supplemental study should be made to ensure correct

peak readings are obtained from filtered data compared to unfiltered data. A minimum of 200 data points from each LVDT shall be recorded per load cycle.

- 6.4. Specimen Preparation Equipment: A variety of equipment is required to prepare compacted specimens that are representative of field conditions. Use of different materials and different methods of compaction in the field requires the use of varying compaction techniques in the laboratory.
- 6.5. Miscellaneous Apparatus: This includes calipers, micrometer gauge, steel rule (calibrated to 0.5 mm [0.02 inch]), rubber membranes from 0.25 to 0.79 mm (0.02 to 0.031 inch) thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones (subgrade), 6.4 mm (0.25 inch) thick porous stones or bronze discs (base/subbase), scales, moisture content cans, and data sheets.
- 6.6. Periodic System Calibration: The entire system (transducers, signal conditioning, and recording devices) shall be calibrated every two weeks or after every fifty tests. Daily and other periodic checks of the system may also be preformed as necessary. No permanent deformation and resilient modulus testing will be conducted unless the entire system meets the established calibration requirements.

7. Preparation of Test Specimens

- 7.1. The following guidelines, based on the sieve analysis test results, shall be used to determine the test specimen size:
 - 7.1.1. Use 152 mm (6.0 inch) diameter and 305 mm (12 inch) high specimens for all materials with maximum particle sizes greater than 19 mm (0.75 inch). All material greater than 25.4 mm (1.0 inch) shall be scalped off prior to testing.
 - 7.1.2. Use 102 mm (4.0 inch) diameter and 204 mm (8.0 inch) high specimens for all materials with maximum particle sizes less than 19 mm (0.75 inch).
- 7.2. Laboratory Compacted Specimens: Reconstituted test specimens of all types shall be prepared to the specified or in-situ dry density (γ_d) and moisture content (w). Laboratory compacted specimens shall be prepared for all unbound granular base and subbase material, and for all subgrade soils.

- 7.2.1. Moisture Content: For in-situ materials, the moisture content of the laboratory compacted specimen shall be the in-situ moisture content for that layer obtained in the field using T238. If data are not available on in-situ moisture content, refer to Section 7.2.3.
- 7.2.1.1. The moisture content of the laboratory compacted specimen should not vary from the required value by more than ± 0.5 percent for all materials.
- 7.2.2. Compacted Density: The density of a compacted specimen shall be the in-place dry density obtained in the field for that layer using T239 or other suitable methods. If these data are not available on in-situ density, refer to Section 7.2.3.
- 7.2.2.1. The dry density of a laboratory compacted specimen should not vary more than ± 1.0 percent from the target dry density for that layer.
- 7.2.3. If either the in-situ moisture content or the in-place dry density is not available, then use the optimum moisture content and 95 percent of the maximum dry density by using T180 for the base/subbase and 95 percent of T99 for the subgrade.
- 7.2.3.1. The moisture content of the laboratory compacted specimen should not vary from the required value by more than ± 0.5 percent for all materials. The dry density of a laboratory compacted specimen should not vary more than ± 1.0 percent from the target dry density for that layer.
- 7.2.4. Sample Reconstitution – The target moisture content and density to be used in determining needed material qualities are given in Section 7.2. After this step is completed, specimen compaction can begin.
- 7.3. Compaction Methods and Equipment for Reconstituting Specimens:
- 7.3.1. Specimens of Type 1 materials shall be compacted by vibratory or impact compaction. The general method of vibratory compaction is given in T292-91. The general method of impact compaction is given in T292.
- 7.3.2. Specimens of Type 2 materials shall be compacted by vibratory compaction. The general method of vibratory compaction also is presented in T292-92.
- 7.3.3. Specimens of Type 3 materials shall be compacted by impact compaction. The general method of impact compaction is given in T292-91.

8. Test Procedure

Following this test procedure, a permanent deformation test is performed on all materials using a triaxial cell (confined).

8.1. Base/Subbase Materials: The procedure described in this section applies to all unbound granular base and subbase materials.

- 8.1.1. Assembly of the triaxial cell: If not already in place, place the specimen with end platens into position on the pedestal of the triaxial cell. Proper positioning of the specimen is extremely critical in applying a concentric load to the specimen. Couple the loading device to the specimen using a smooth steel ball. To center the specimen, slowly rotate the ball as the clearance between the load piston and the ball decreases and a small amount of load is applied to the specimen. Be sure the ball is concentric with the piston that applies the load (watch the gap around the ball). Shift the specimen laterally to achieve a concentric loading.
- 8.1.2. Check and adjust the axial displacement measurement system, load cell and data acquisition system, and make sure they are working properly.
- 8.1.3. If not already connected, connect the confining air pressure supply line to the triaxial chamber.
- 8.1.4. Open all valves on drainage lines leading to the inside of the specimen. This step is necessary to develop confining pressure on the specimen.
- 8.1.5. Apply the specified conditioning confining pressure of 103.5 kPa (15.0 psi) to the test specimen. A contact stress equal to 20 percent of the confining pressure shall be applied to the specimen so that the load piston stays in contact with the top platen at all times.
- 8.1.6. Preconditioning: Apply 100 repetitions of a load equivalent to a maximum axial stress of 41.4 kPa (6 psi) and a corresponding cyclic stress of 20.7 kPa (3 psi) using a haversine-shaped, 0.1-second load pulse followed by 0.9-second rest period.
- 8.1.7. [Table A3](#) presents the loading condition for permanent deformation test. For the first loading condition, apply the haversine loading (P_{cyclic}) equivalent to a maximum axial stress of 227.7 kPa (33 psi) and a corresponding cyclic stress of

207 kPa (30 psi) using a haversine-shaped, 0.1-second load pulse followed by 0.9-second rest period, and continue until 10,000 cycles (2.8 hours) or until the specimen fails and the vertical permanent strain reaches 5 percent during the testing, whichever comes first. The total number of cycles or the testing time will depend on the stress levels applied. After the first loading condition, the other two loading conditions will be proceeded on separated samples.

Table A3. Permanent Deformation Test Sequence for Granular Base and Subbase.

Test Condition	Confining Pressure		Contact Stress		Cyclic Stress	
	kPa	psi	kPa	psi	kPa	psi
Preconditioning	103.5	15.0	20.7	3.0	20.7	3.0
Condition-1	103.5	15.0	20.7	3.0	207.0	30.0
Condition-2	48.3	7.0	19.3	2.8	193.2	28.0
Condition-3	20.7	3.0	12.5	1.8	124.2	18.0

8.1.8. During the load applications, record the load applied, the axial deformation measured from two LVDTs through the data acquisition system. Signal-to-noise ratio should be at least 10. All data should be collected in real time and collected/processed so as to minimize phase errors due to sequential channel sampling. In order to save storage space during data acquisition for 10,000 cycles, it is recommended to use the data acquisition of the cycles shown in [Table A4](#).

Table A4. Suggested Data Collection for Triaxial Repeated Load Permanent Deformation Test.

Data Collection During Cycles	Data Collection During Cycles	Data Collection During Cycles	Data Collection During Cycles
1-15	450	1300	4000
20	500	1400	4500
30	550	1500	5000
40	600	1600	5500
60	650	1700	6000
80	700	1800	6500
100	750	1900	7000
130	800	2000	7500
160	850	2200	8000
200	900	2400	8500
250	950	2600	9000
300	1000	2800	9500
350	1100	3000	10000
400	1200	3500	

8.2. Subgrade Soils: This procedure is used for all laboratory compacted specimens of subgrade soils. Reconstructed specimens will usually be compacted directly on the pedestal of the triaxial cell.

8.2.1. Assembly of the triaxial cell: refer to section 8.1.1.

8.2.2. Set up the axial displacement measurement system, and verify it is working properly.

8.2.3. If not already connected, connect the confining air pressure supply line to the triaxial chamber.

8.2.4. Open all valves on drainage lines leading to the inside of the specimen. This step is necessary to develop confining pressure on the specimen.

8.2.5. Apply the specified conditioning confining pressure of 27.6 kPa (4.0 psi) to the test specimen. A contact stress equal to 20 percent of the confining

pressure shall be applied to the specimen so that the load piston stays in contact with the top platen at all times.

- 8.2.6. Preconditioning: Apply 100 repetitions of a load equivalent to a maximum axial stress of 12.4 kPa (1.8 psi) and a corresponding cyclic stress of 6.9 kPa (1 psi) using a haversine-shaped, 0.2-second load pulse followed by a 0.8-second rest period.
- 8.2.7. [Table A5](#) presents the loading condition for permanent deformation test. For the first loading condition, apply the haversine loading (P_{cyclic}) equivalent to a maximum axial stress of 60.7 kPa (8.8 psi) and a corresponding cyclic stress of 55.2 kPa (8 psi) using a haversine-shaped, 0.2-second load pulse followed by a 0.8-second rest period, and continue until 10,000 cycles (2.8 hours) or until the specimen fails and/or the vertical permanent strain reaches 5 percent during the testing, whichever comes first. The total number of cycles or the testing time will depend on the stress levels applied. After the first loading condition, the other two loading conditions will be proceeded on separated samples.
- 8.2.8. During the load applications, record the load applied, the axial deformation measured from two LVDTs through the data acquisition system. All data should be collected in real time and collected/processed so as to minimize phase errors due to sequential channel sampling. In order to save storage space during data acquisition for 10,000 cycles, it is recommended to use the data acquisition of the cycles shown in [Table A6](#).

Table A5. Permanent Deformation Test Sequence for Subgrade.

Test Condition	Confining Pressure		Contact Stress		Cyclic Stress	
	kPa	psi	kPa	psi	kPa	psi
Preconditioning	27.6	4.0	5.5	0.8	6.9	1.0
Condition-1	27.6	4.0	5.5	0.8	55.2	8.0
Condition-2	55.2	8.0	5.5	0.8	55.2	8.0
Condition-3	13.8	2.0	5.5	0.8	55.2	8.0

Table A6. Suggested Data Collection for Triaxial Repeated Load Permanent Deformation Test.

Data Collection During Cycles	Data Collection During Cycles	Data Collection During Cycles	Data Collection During Cycles
1-15	450	1300	4000
20	500	1400	4500
30	550	1500	5000
40	600	1600	5500
60	650	1700	6000
80	700	1800	6500
100	750	1900	7000
130	800	2000	7500
160	850	2200	8000
200	900	2400	8500
250	950	2600	9000
300	1000	2800	9500
350	1100	3000	10000
400	1200	3500	

9. Calculation of Permanent Strain

- 9.1. Calculate the average axial deformation for each specimen by averaging the readings from the two axial LVDTs. Convert the average deformation values to total axial strain, by dividing by the gauge length, L [152 mm (6 inch) for 152 mm diameter sample; 102 mm (4 inch) for 102 mm diameter sample].
- 9.2. Compute the cumulative axial permanent strain and resilient strain (ϵ_r) at 200th load repetition.
- 9.3. Plot the cumulative axial permanent strain versus the number of loading cycles in log space (shown in [Figure A3](#)). Determine the permanent deformation parameters, intercept (a) and slope (b), from the linear portion of the permanent strain curve (log-log scale), which is also demonstrated in [Figure A3](#).

9.4. Compute the rutting parameters, μ and α :

$$\mu = \frac{ab}{\varepsilon_r}$$
$$\alpha = 1 - b$$

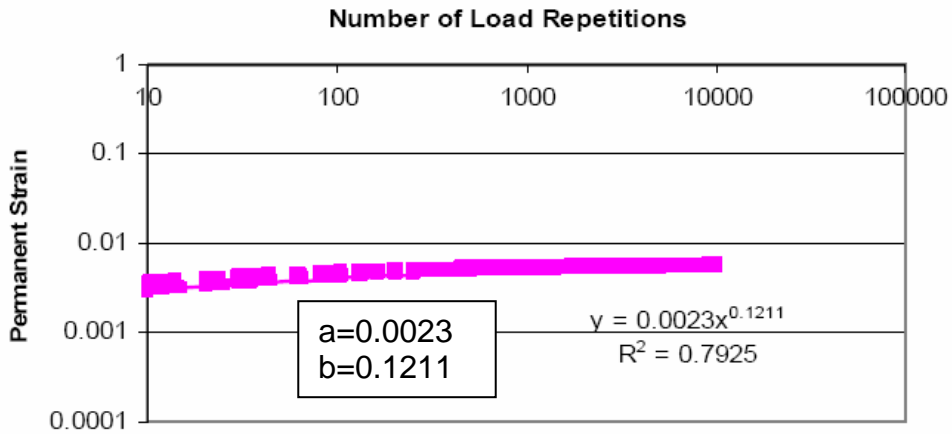


Figure A3. Permanent Strain vs. Number of Load Repetitions.

10. Report

- 10.1. Report all specimen basic information including specimen identification, dates of manufacturing and testing, specimen diameter and length, confining pressure, stress levels used, and axial permanent deformation parameters α , μ (or ε_r , a , and b).

APPENDIX B:
VESYS5W TEST PROTOCOL FOR ASPHALT MATERIALS

1. Test Samples

1.1 Size

Testing shall be performed on 100 mm (4 inch) diameter by 150 mm (6 inch) or more high test samples from laboratory or cores from field.

1.2 Aging

For laboratory compacted samples, mixture shall be aged in accordance with the short-term oven aging procedure in AASHTO PP2.

1.3 Gyratory Specimens

For laboratory compacted samples, prepare 150 mm (6 inch) high samples to the required air void content in accordance with AASHTO TP-4. Gyratory compactor is shown in [Figure B1](#).

1.4 End Preparation

The ends of all test samples shall be smooth and perpendicular to the axis of the specimen. Prepare the ends of the samples by milling with a single- or double-bladed saw. To ensure that the sawed samples have parallel ends, the sample ends shall have a cut surface waviness height within a tolerance of ± 0.05 mm (0.02 inch) across any diameter.

1.5 Air Void Content

Determine the air void content of the final test sample in accordance with AASHTO T269. Reject samples with air voids that differ by more than 0.5 percent from the target air voids.

1.6 Replicates

The number of test samples required depends on the number of axial strain measurements made per sample and the desired accuracy of the average permanent deformation. Normally, two replicates are OK for each sample with two LVDTs.

2. Test Sample Instrumentation

2.1 Attach mounting studs for the axial LVDTs to both sides of the sample with 180° intervals (in plan view) using epoxy cement (shown in [Figure B2](#)). Make sure the studs are aligned.



Figure B1. Superpave Gyrotory Compactor.

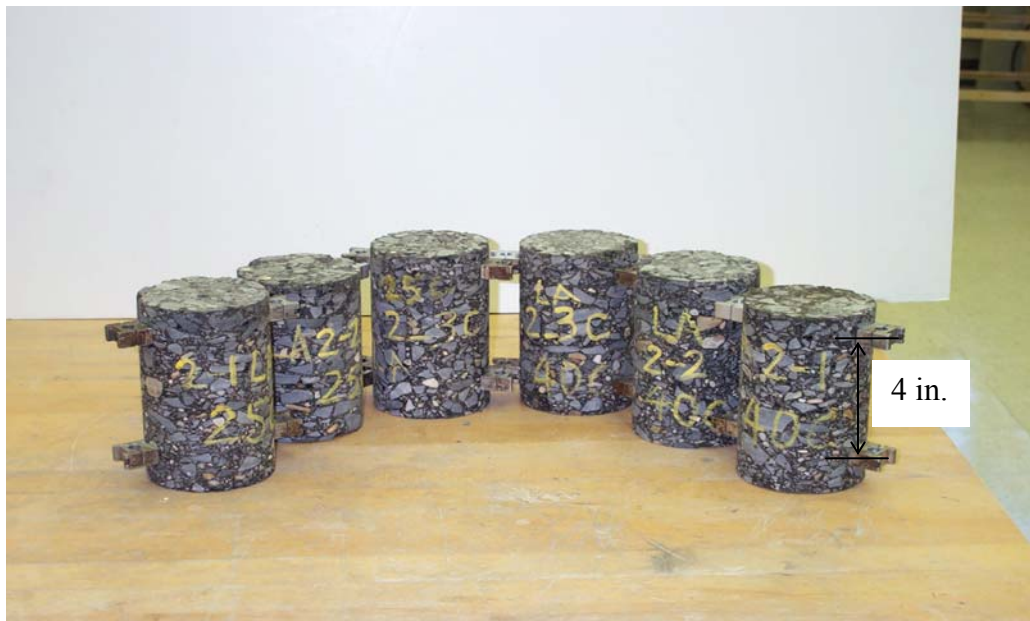


Figure B2. Samples with Studs.

2.2 The gauge length for measuring axial deformations shall be 100 mm (4 inch) \pm 1 mm (0.04 inch). The gauge length is normally measured between the stud centers.

3. Test Procedures

3.1 The recommended test protocol for ALPHA and GNU used in the VESYS program consists of testing the asphalt mix at two temperatures with specified stress level. [Table B1](#) shows the recommended test temperatures and associated stress level.

Table B1. Recommended Test Temperatures and Associated Stress Levels.

Test Temperature (°F)	Test Stress Level (psi)
77	30
104	20

3.2 Place the test sample in the environmental chamber and allow it to equilibrate to the specified testing temperature. A dummy specimen with a temperature sensor mounted at the center can be monitored to determine when the specimen reaches the specified test temperature. In the absence of the dummy specimen, [Table B2](#) provides a recommended temperature equilibrium time for samples starting from room temperature (77 °F).

Table B2. Recommended Equilibrium Times.

Test Temperature (°F)	Time (min.)
77	10
104	30

3.3 After temperature equilibrium is reached, place one of the friction-reducing end treatments on top of the platen at the bottom of the loading frame. Place the sample on top of the lower end treatment, and mount the axial LVDTs to the studs glued to the sample. Adjust the LVDT to near the end of its linear range to allow

- the full range to be available for the accumulation of compressive permanent deformation.
- 3.4 Place the upper friction reducing end treatment and platen on top of the sample. Center the specimen with the load actuator visually in order to avoid eccentric loading.
 - 3.5 Apply a contact load equal to 5 percent of the total load level that will be applied to the specimen, while checking the proper response of the LVDTs (i.e., check for proper direction for all LVDTs).
 - 3.6 Close the environmental chamber and allow sufficient time (normally 10 to 15 minutes) for the temperature to stabilize within the specimen and the chamber.
 - 3.7 After the sample reaches the testing temperature, apply the haversine load that yields the desired stress on the specimen. The procedure uses a loading cycle of 1.0 Hz frequency, and consists of applying 0.1-second haversine load followed by a 0.9-second rest period. The maximum applied load (P_{max}) is the maximum total load applied to the sample, including the contact and cyclic load: $P_{max} = P_{contact} + P_{cyclic}$.
 - 3.8 The contact load ($P_{contact}$) is the vertical load placed on the sample to maintain a positive contact between the loading strip and the sample: $P_{contact} = 0.05 \times P_{max}$.
 - 3.9 The cyclic load (P_{cyclic}) is the load applied to the test sample that is used to calculate the permanent deformation parameters: $P_{cyclic} = P_{max} - P_{contact}$.
 - 3.10 Apply the haversine-shaped loading (P_{cyclic}) and continue to 5000 cycles or until the sample fails and results in excessive tertiary deformation to the sample, whichever comes first.
 - 3.11 During the load applications, record the load applied and the axial deflection measured from all LVDTs through the data acquisition system. All data should be collected in real time so as to minimize phase errors due to sequential channel sampling. The data acquisition of the cycles shown in [Table B3](#) is recommended.

Table B3. Suggested Data Collection for VESYS5 Rutting Test.

Data Collected During Cycles	Data Collected During Cycles	Data Collected During Cycles
1 through 10	598 through 600	2723 through 2725
18 through 20	698 through 700	2998 through 3000
28 through 30	798 through 800	3248 through 3250
48 through 50	898 through 900	3498 through 3500
78 through 80	998 through 1000	3723 through 3725
98 through 100	1248 through 1250	3998 through 4000
148 through 150	1498 through 1500	4248 through 4250
198 through 200	1723 through 1725	4498 through 4500
298 through 300	1998 through 2000	4723 through 4725
398 through 400	2248 through 2250	4998 through 5000
498 through 500	2498 through 2500	

4. Calculations

- 4.1 Calculate the average axial deformation for each specimen by averaging the readings from the two axial LVDTs. Convert the average deformation values to total axial strain by dividing by the gauge length (100 mm [4 inch]).
- 4.2 Compute the cumulative axial permanent strain and resilient strain (ϵ_r) at 100th load repetition.
- 4.3 Plot the cumulative axial permanent strain versus number of loading cycles in log-log space (Figure B3). Determine the permanent deformation parameters, intercept (a) and slope (b), from the linear portion of the permanent strain curve.
- 4.4 Compute the rutting parameters α and μ

$$\mu = \frac{ab}{\epsilon_r}$$

$$\alpha = 1 - b$$

5. Report

Report all sample information including mix identification, manufacturing (or cored) and testing dates, sample diameter and length, volumetric properties, stress levels used, axial permanent deformation parameters α and μ (or ϵ_r , a , b).

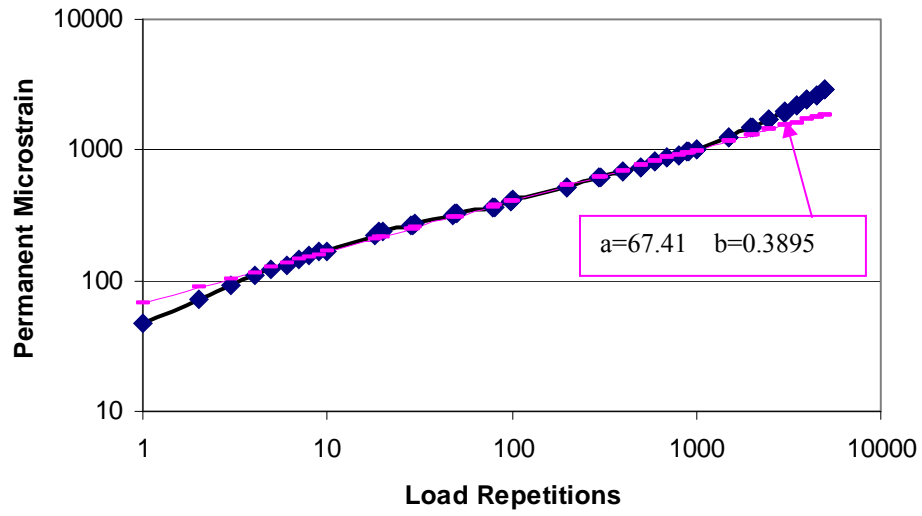


Figure B3. Plot of Regression Constants “a” and “b” from Log Permanent Strain – Log Number of Loading Cycles.

APPENDIX C:
TTI VESYS5W USER MANUAL

1. INSTALLATION

1.1 Operation System Requirements

The TTI VESYS5W runs best on the following operation systems:

- Microsoft Windows XP,
- Microsoft Windows 2000 (SP2 Recommended), and
- Microsoft Windows NT® 4.0 (SP 6a required).

1.2 Software Requirements

- Microsoft Internet Explorer 5.0 or later (Internet Explorer 6.0 is recommended);
- Microsoft .NET Framework must be installed in the target machine before installing the TTI VESYS5W. The TTI VESYS5W installation program will automatically check for the existence of the .NET Framework on the target machine. If Microsoft .NET Framework is not installed yet, please double click on dotnetfx.exe to install the Microsoft .NET Framework first.
- If an old version of TTI VESYS5W has been installed on the target machine, it must be uninstalled for the new program to be installed. Please go to Control Panel→Add/Remove Program to remove the old version program first.

1.3 Installation Instructions

- Launch setup.exe to start the installation.
- The installation program checks for the existence of the .NET Framework. If the .NET Framework couldn't be found, a message box with "This setup requires the .NET Framework. Please install the .NET Framework by running the file dotnetfx.exe, which can be found on the CD, and then run this setup again." is displayed. If the .NET Framework is already installed, a welcome screen should appear. Then follow the installation guidance.
- Run dotnetfx.exe, and follow the instructions to install .NET Framework.
- Run setup.exe again.
- On the Select Installation Folder screen, the user can choose the application folder in which to install the application. The user can decide to install the application for everyone using the computer if desired. The user must have administrative rights to be able to write to the All Users folder.

- A confirmation message will be displayed.
- Installation is complete.

2. OPERATIONS ON THE MAIN SCREEN

Figure C1 shows the main screen of TTI VESYS5W. Each item is discussed in the following sections.

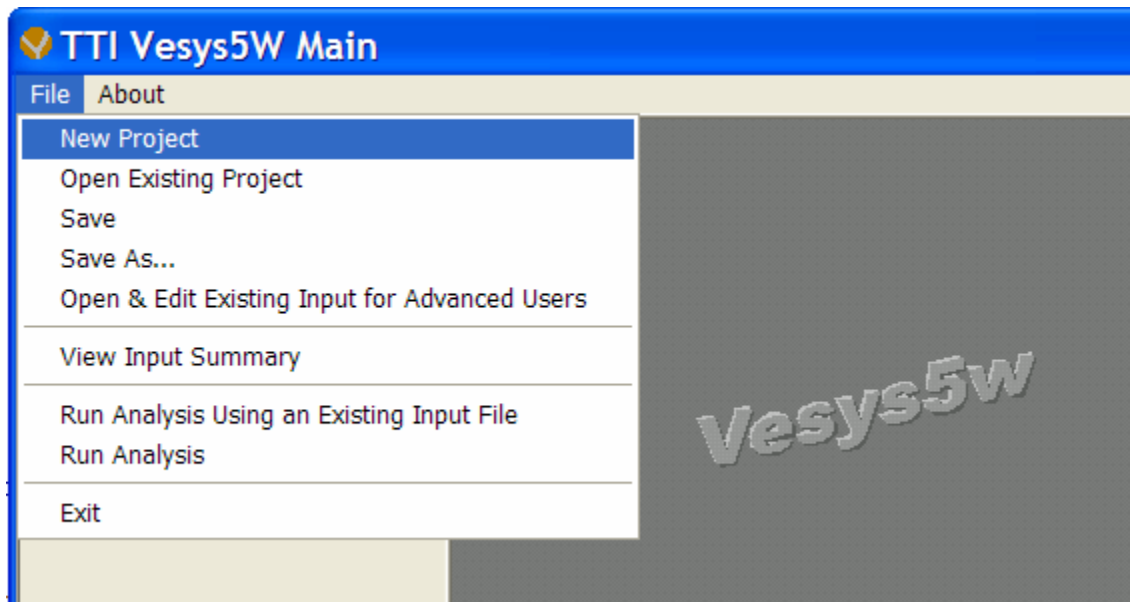


Figure C1. Main Screen of TTI VESYS5W.

2.1 Data Input/Output

There are three ways offered to create or edit input data: New Project, Open Existing Project, and Open Existing Input File for Advanced User.

- New Project

Users must start with this operation when creating the new input data for a particular project to run the analysis. The program will ask users to give a name for the file which stores input data for this project. The default location of input files is in the folder called “Project File” under the TTI VESYS5W directory. Users can also save project input files in any location in their computer. The project input file gives a

default extension “.prj.” This file stores all information users enter from the user interface.

- Open Existing Project

To view the input/output data or modify the input data of a project previously created, select “Open Existing Project” as shown in [Figure C2](#). The program will ask the name and location of the project file and load all information including output data files. If there is something wrong with the project input file, the program reports the error.

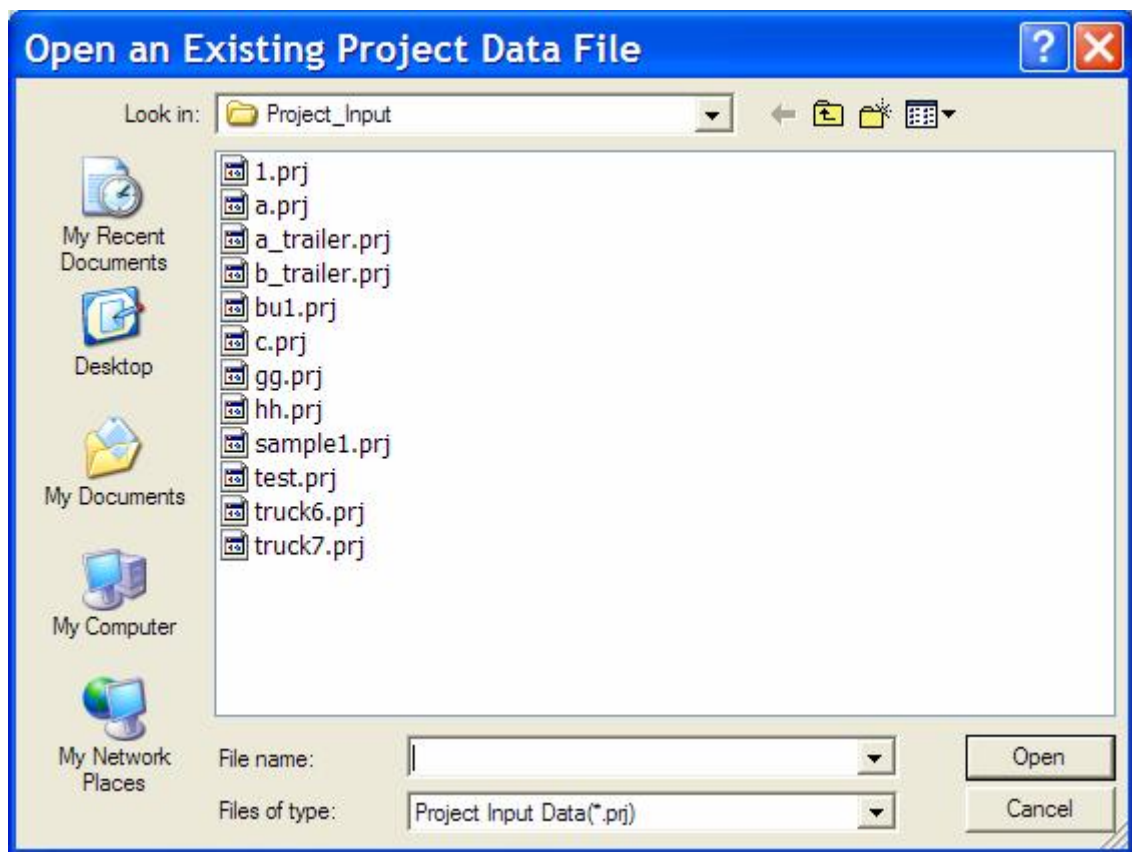


Figure C2. Open an Existing Project Data File Screen.

- Open Existing Input File for Advanced User

This operation is offered to users who are familiar with the input file of the DOS version VESYS5. Users can view or modify the data directly from the input text file

instead of through input screens. As shown in [Figure C3](#), this input file has a “.in” file extension.

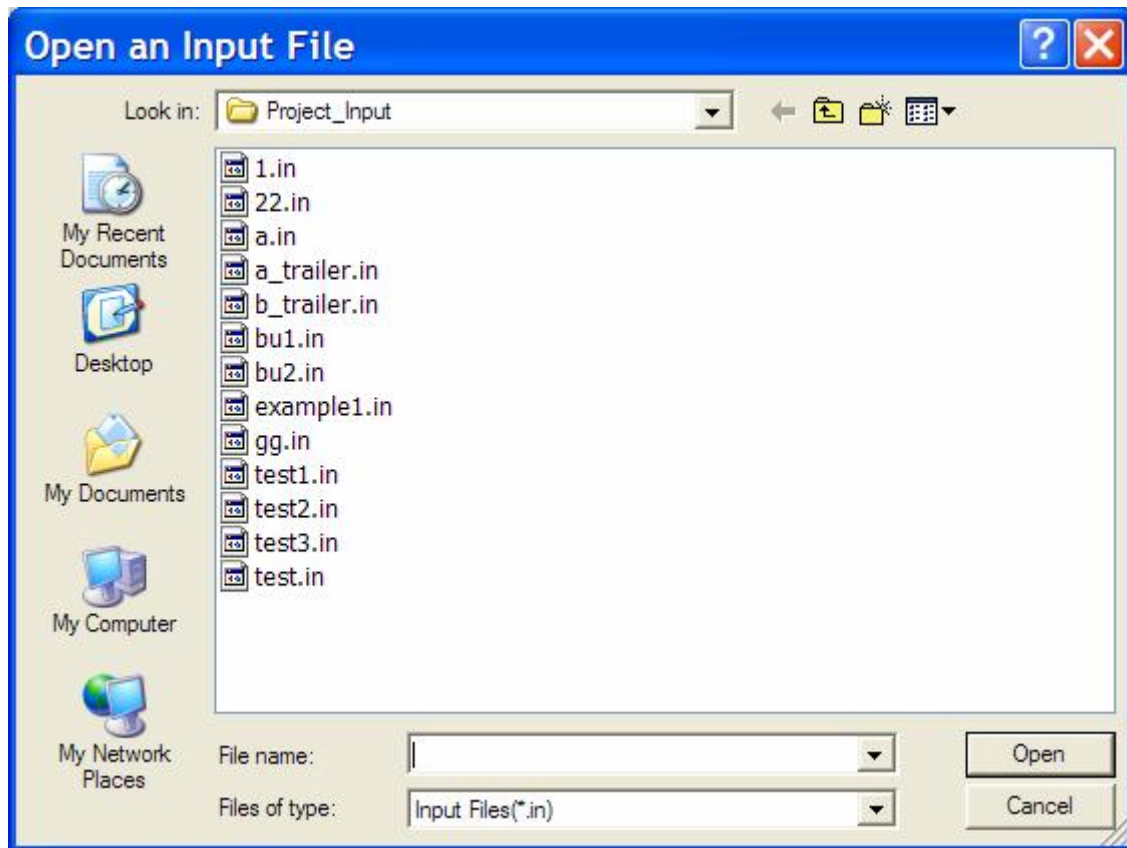


Figure C3. Open an Input File Screen.

2.2 Save

This “Save” operation will save the current project file, which allows users to save current work before running the VESYS Analysis.

2.3 Save As...

This “Save As...” operation will save the current project as a new project file. A File Save dialog, as shown in [Figure C4](#), will pop up to allow users to choose an alternate project file name.

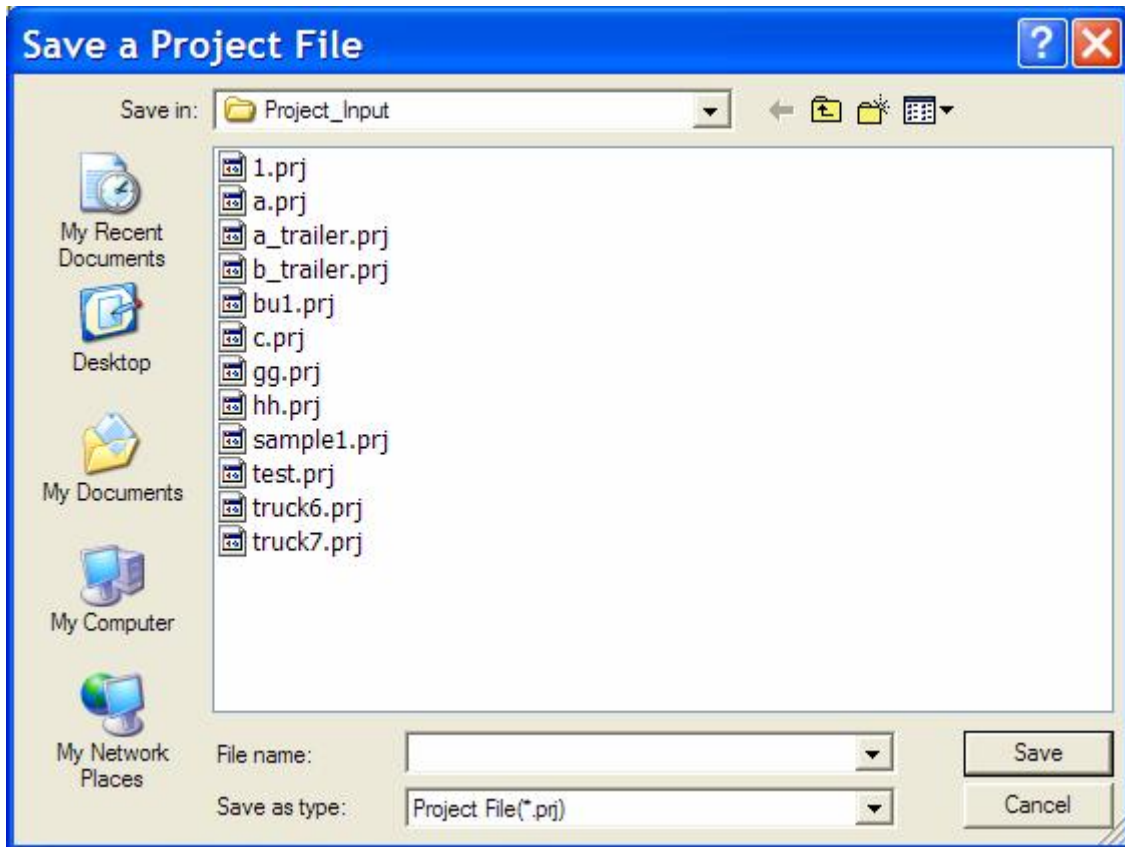


Figure C4. Save a Project File Screen.

2.4 View Summary

This “View Summary” operation provides the ability to view the data users enter from the user interface in text format. It allows users to print screen inputs or save all screen inputs into a text file for their reference as shown in [Figure C5](#).

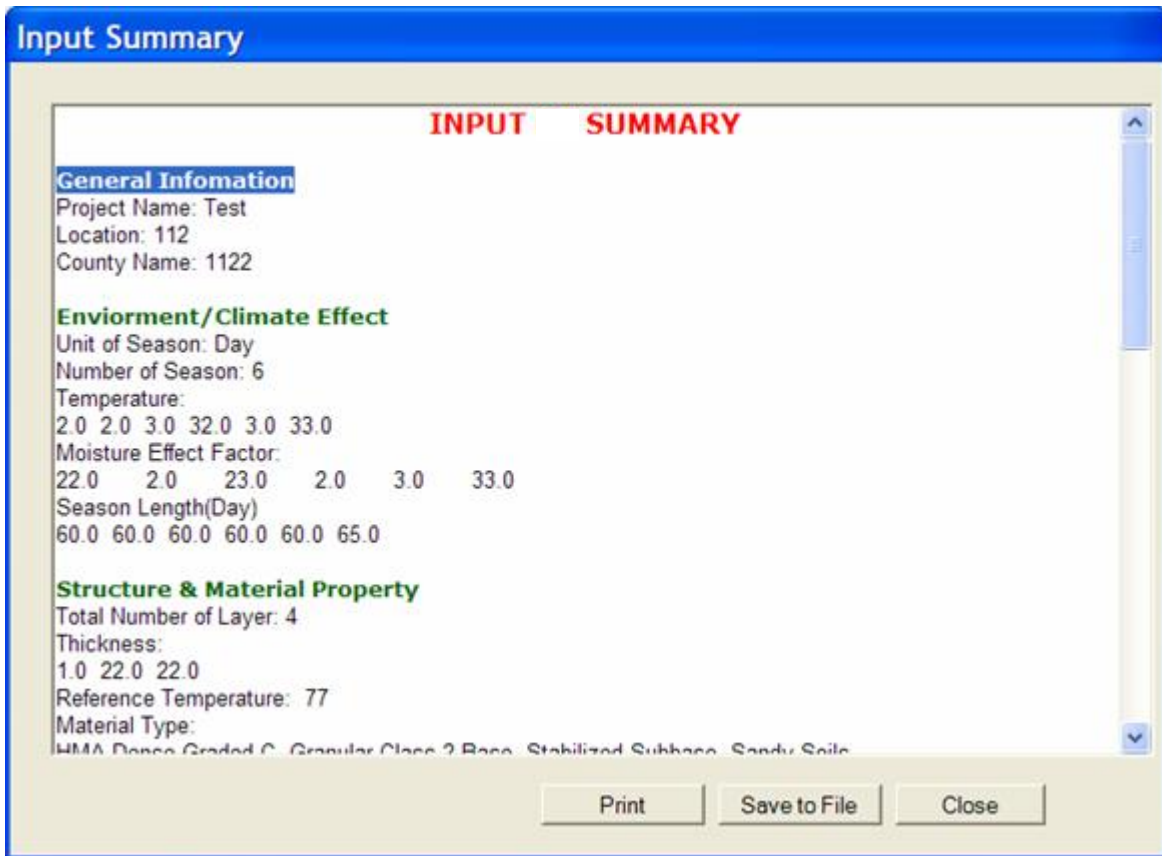


Figure C5. Input Summary Screen.

2.6 Run Analysis

- Run Analysis Using Existing Input File

If users already have an input file for the DOS version VESYS5 and want to create a VESYS5 input file outside the user interface, the “Run Analysis” operation allows users to open their input files and run the analysis. Users cannot only take advantage of TTI VESYS5W’s output feature and view the analysis result directly, but also save the output data in the original text format.

- Run Analysis

Users can click the “Run Analysis” button or select the “Run Analysis” menu item from the main menu. This function will call the VESYS5 DOS program with the input data from VESYS5W. VESYS5W will create an input file for VESYS5 to

perform the related analysis. It usually takes less than one minute for VESYS5 to finish the analysis. Users will see a waiting dialog with a progress bar showing on the middle of the screen. After the analysis is complete, the waiting dialog will disappear.

The program allows users to run analysis only when all required data are entered and all red lights on the input tree become green. The TTI VESYS5W will ask users whether or not to save the input and output data files. These text files refer to the DOS version VESYS5's input and output files.

If an error occurred during the analysis, such as "The output is incomplete, please check the input file," it may be caused by improper input data which the original VESYS5 cannot handle correctly. Check the input data and run the analysis again. If everything is OK and the analysis is complete, the output tree will be enabled and users will be able to see analysis reports including: Rutting vs. Time, Fatigue Cracking vs. Time, and PSI vs. Time and Performance Data.

3. DATA INPUT SCREENS

As presented in [Figure C6](#), there are four types of inputs clearly displayed in the tree structure. The red light on the input node indicates that the input is incomplete; it will become green when the input is complete and saved.

Users must enter the data in the following sequence: General Information → Climate → Structure & Material Property → Traffic.

When users click on Create New Input and give the name for the project input file, TTI VESYS5W will automatically pop up the General Information input screen and users can start to enter the data.

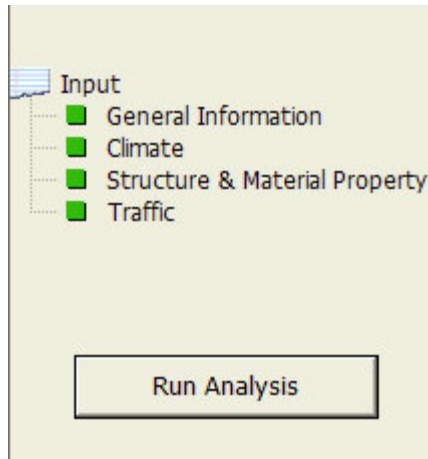


Figure C6. Major Input Screen of TTI VESYS5W.

3.1 General Information

The “General Information” fields are optional. The project name information will be displayed on the title of the output reports. The input screen is shown in [Figure C7](#).

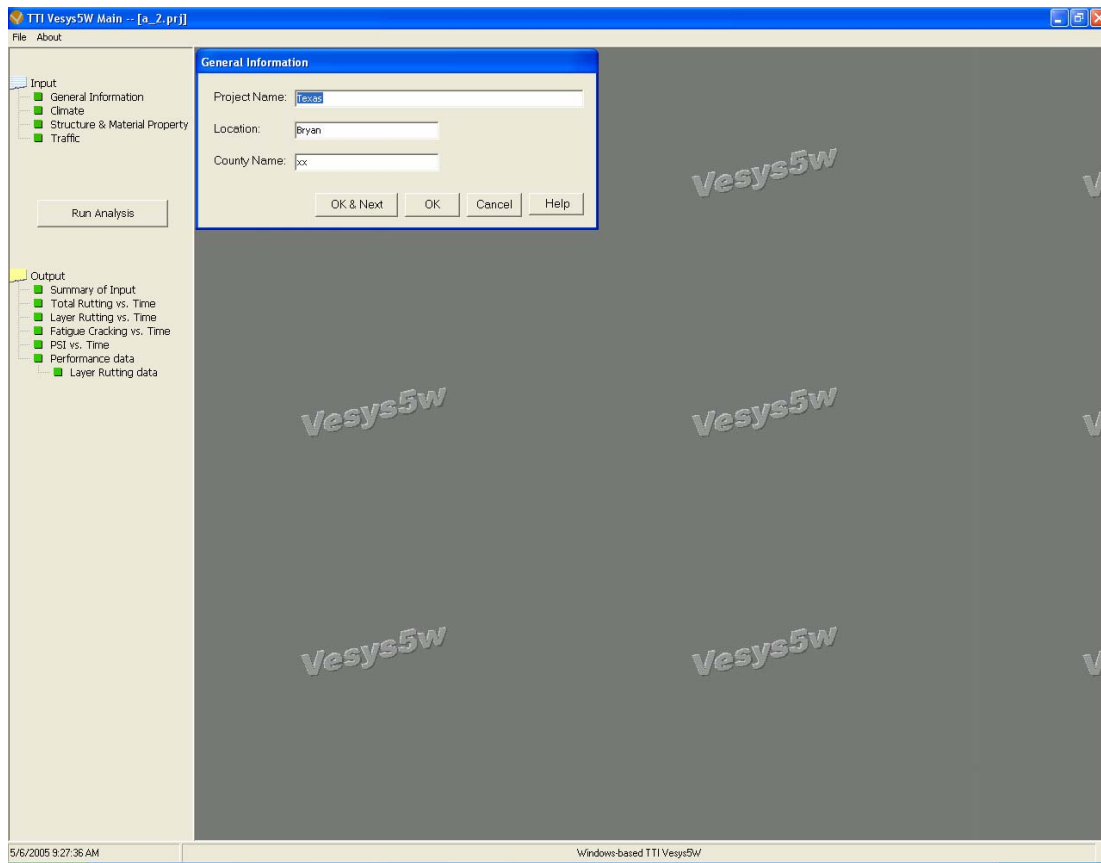


Figure C7. Input Parameters of General Information.

3.2 Climate

Climate data **MUST** be entered before “Structure & Material Property” and “Traffic” data. [Figure C8](#) shows required input data. However, only part of the data are mandatory in the VESYS5 program. Required data are number of seasons, unit of season, season length, and moisture effect factor. Both state and region selections are optional. Please note the importance of carefully selecting the number of seasons and the unit of season because this is important information for generating the program input and is directly related to the following “Structure & Material Property” and “Traffic” inputs.

Season	Temperature (°F)	Moisture Effect Factor	Length(365 days)
1	46	1	31
2	66	1	28
3	78	1	31
4	89	1	30
5	95	1	31
6	100	1	30
7	114	1	31
8	89	1	31
9	90	1	30
10	70	1	31
11	70	1	30
12	56	1	31

Figure C8. Input Parameters of Climate.

The number of seasons ranges from 1 to 12, with a default value of 12. There are two options for unit of season: day and month. Users can specify the length of each season, but the sum of the seasons per year should be 12 months or 365 days. The enhanced VESYS5 displays the calculation of total length, while users enter the season length. The moisture effect factor is set to consider the influence of moisture on base, subbase, and subgrade. The default moisture effect factor is 1 for all seasons, however users can modify it. Each season’s moisture effect factor affects the modulus of the base layer, subbase layer, and subgrade for that season. The

moduli values of base, subbase, and subgrade used in the pavement performance analysis are calculated by the moisture effect factor by multiplying the moduli entered in the following “Structure & Material Property” section.

The “Read Climate Data” button is active and allows users to select “State” and “Region” only if the number of seasons equals 12. After selecting the state and region, click the “Read Climate Data” button; the program reads the default temperature of that state and region and displays the data. Users can modify the temperature data. The “Get Default Season Length” button provides users a simple way to calculate the average length of season based on the number of seasons and unit.

3.3 Structure & Material Property Input

“Structure & Material Property” has been especially organized for users to easily input pavement structural and material information. As mentioned previously, users must finish entering and save climate data before starting “Structure & Material Property” input, since season temperature, moisture effect factor, and number of seasons will be used in calculating “Structure & Material Property” data. The following discusses input parameters.

- Analysis Type

Only multilayer linear elastic analysis is available in enhanced VESYS5.

- Defining Layers

The enhanced VESYS5 clearly defines pavement layers with a user-friendly Graphical User Interface (GUI). There are four types of layers: asphalt, base, subbase, and subgrade. Users can define the number of layers for each type of layer, except the subgrade layer, by clicking the radio button corresponding to each type. The default number of layers is 4, as illustrated in [Figure C9](#).

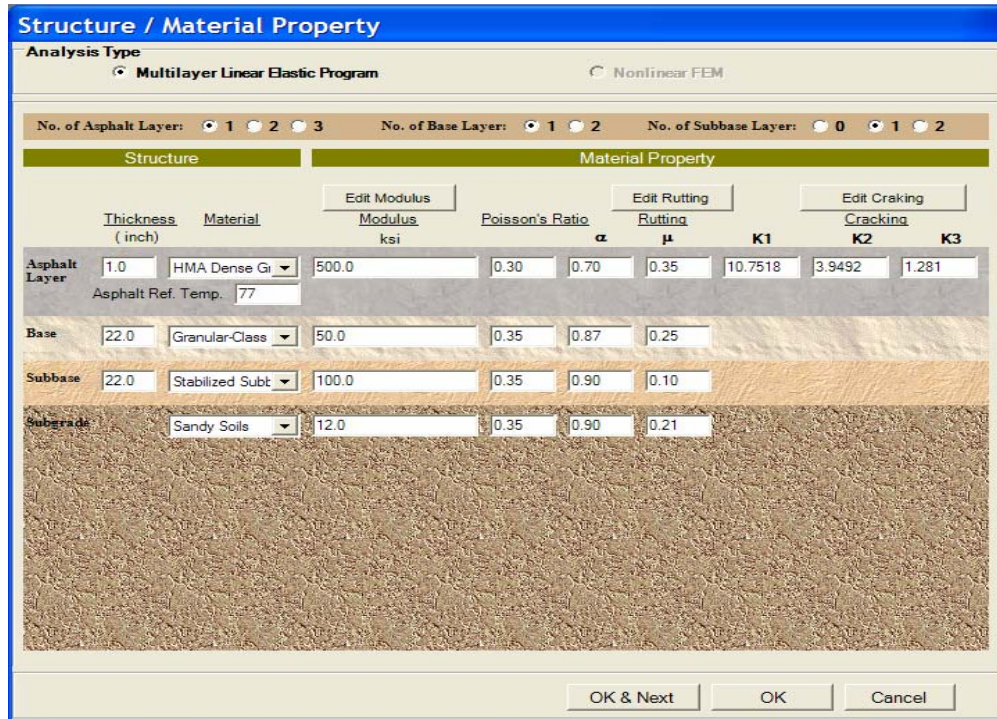


Figure C9. Overview of “Structure and Material Property.”

- Thickness

The enhanced VESYS5 defines the valid range of thickness. Thickness of asphalt layers is 0.5 – 20 inches, and thickness of other layers is 4 – 25 inches. The program checks the input value. If the input value is not valid, a red flashing icon appears near the thickness textbox (Figure C10). Pointing the cursor to the flashing icon displays valid range information.

Structure	Material Property							
Thickness (inch)	Material	Modulus (ksi)	Poisson's Ratio α	Rutting μ	Cracking			
					K1	K2	K3	
Asphalt Layer	HMA Dense Gr	500.0	0.30	0.70	0.35	1.0750	3.9492	1.281
Asphalt Re								
Base	Granular-Class	50.0	0.35	0.87	0.25			
Subbase	Stabilized Subt	100.0	0.35	0.90	0.10			
Subgrade	Sandy Soils	12.0	0.35	0.90	0.21			

Figure C10. Illustration of Thickness Check Function.

- Material

Material information for each layer helps users to define the material property. Users can select the material type for a specific layer from the layer's dropdown list (Figure C11). After selecting the material, users will see the material property data of that layer entered automatically. The enhanced VESYS5 defines and calculates the layer's material property based on the material type and layer thickness entered. Table C1 presents detailed default material type and associated properties for each layer.

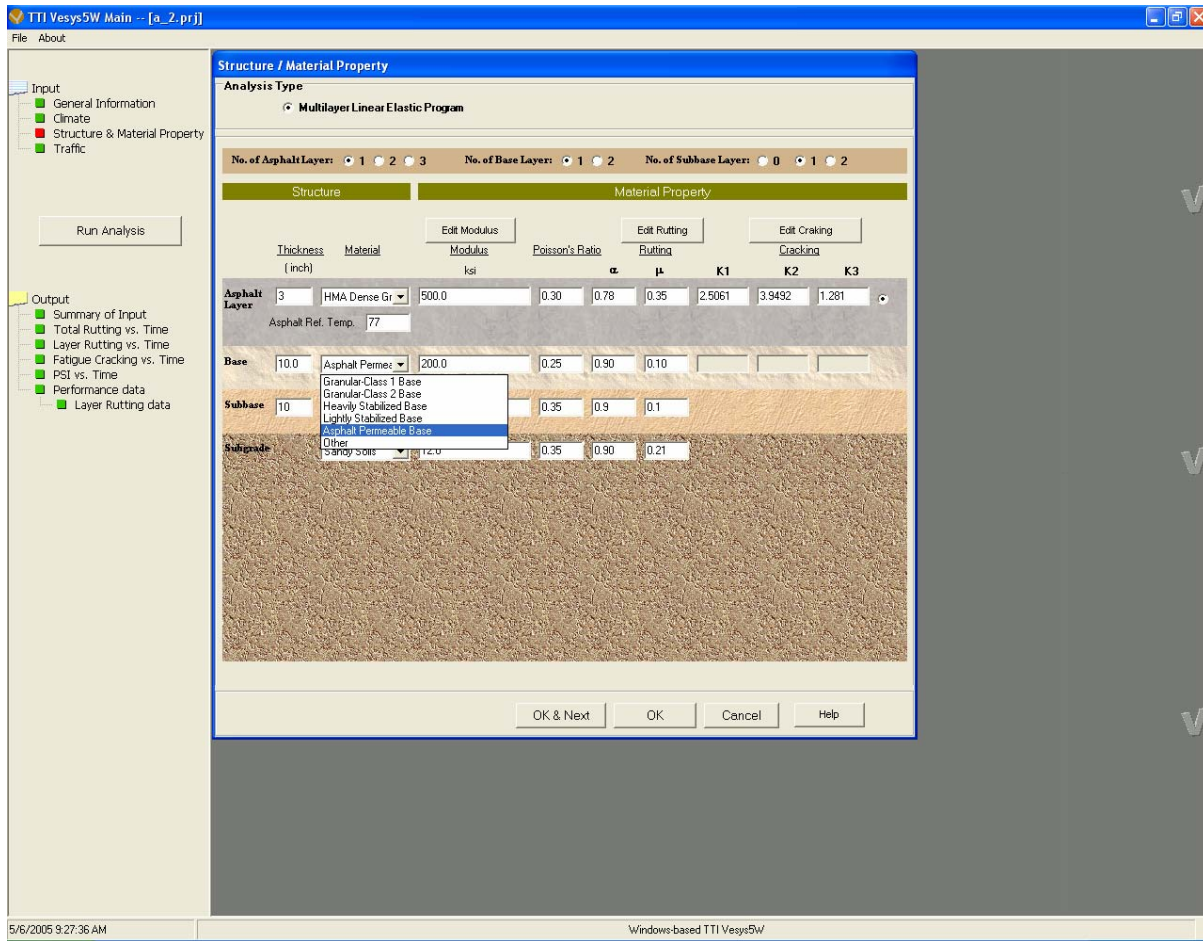


Figure C11. Illustration of Default Material Type.

- Modulus

Modulus of each pavement layer is a mandatory parameter for the enhanced VESYS5 program. The modulus value is used for calculating the pavement response under traffic load. ASTM D3497 “Standard Test Method for Dynamic Modulus of Asphalt Mixtures” can be used to determine the modulus of asphalt mixtures. The default modulus values of typical pavement materials are provided in the program and are presented in [Table C1](#). For asphalt materials, the default modulus value corresponds to the temperature of 77 °F. The default moduli value of base, subbase, and subgrade materials corresponds to the optimum moisture content. Users can modify the default modulus value of each layer.

Table C1. Default Material Properties Built in the Enhanced VESYS5.

Material Type		Modulus (ksi)	Poisson's Ratio	μ	α	K_1	K_2	K_3
Asphalt	HMA* Dense Graded A	300	0.3	0.35	0.78	**	3.9492	1.281
	HMA Dense Graded B	400	0.3	0.35	0.78			
	HMA Dense Graded C	500	0.3	0.35	0.78			
	HMA Dense Graded D	500	0.3	0.35	0.78			
	Rut Resistant HMA	900	0.3	0.30	0.89			
	Fatigue Resistant HMA	600	0.3	0.30	0.76			
	Modified HMA	1000	0.3	0.30	0.89			
	Other	1200	0.3	0.30	0.89			
Base/ Subbase	Granular-Class 1 Base	70	0.35	0.20	0.90			
	Granular-Class 2 Base	50	0.35	0.25	0.87			
	Heavily Stabilized Base	200	0.25	0.10	0.95			
	Lightly Stabilized Base	125	0.30	0.15	0.95			
	Asphalt Permeable Base	300	0.35	0.25	0.85			
	Other	100	0.30	0.10	0.90			
Soils	Gravelly Soils	16	0.35	0.20	0.90			
	Sandy Soils	12	0.35	0.21	0.90			
	High PI*** Clay	4	0.40	0.30	0.89			
	Low PI Clay	8	0.40	0.28	0.90			
	Other	8	0.40	0.30	0.90			

Note: * Hot Mix Asphalt (HMA)

$$**K_1 = \frac{0.00432}{0.000398 + \frac{0.003602}{1 + e^{(11.02 - 3.49 - h_{ac})}}}, h_{ac} \text{ is the thickness of asphalt layer(s)}$$

***Plasticity Index (PI)

The VESYS5 program requires the seasonal modulus value of each pavement layer. The enhanced VESYS5 automatically calculates the seasonal modulus of asphalt layer based on the reference modulus entered in the screen for that layer and each season's temperature defined in "Climate." The seasonal moduli of other layers are calculated based on the input value of modulus in the "Material & Structure" screen and moisture effect factor (Figure C8). Click the "Edit Modulus" button to open the modulus data screen (Figure C12). Users can view or modify the seasonal modulus of each layer from this screen. Please note the number of season displayed in the modulus data screen is the same as the number defined in the "Climate" screen (Figure C8). Users can continue to edit the modulus of a pavement layer by clicking the "Save" button on the current editing layer of the modified Modulus Data. Click "OK" to save the Modulus Data of the current layer and close this screen. Make sure to click the "Save" button to save the modulus data for each layer.

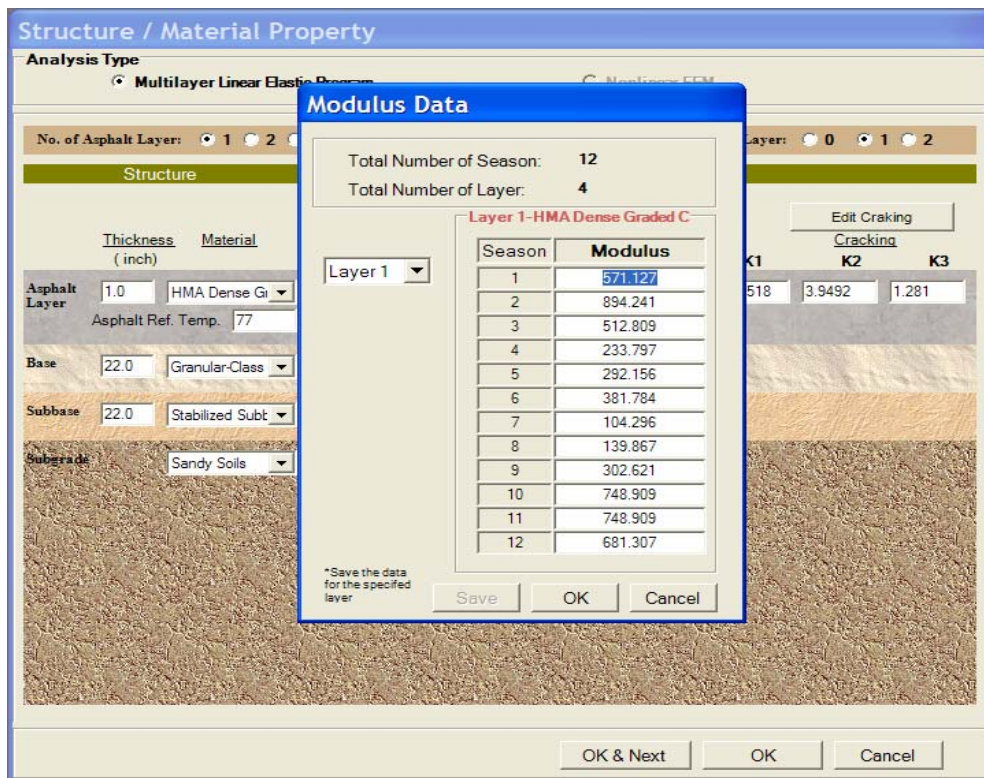


Figure C12. Editing Interface of Seasonal Modulus.

- Poisson's Ratio

The enhanced VESYS5 also requires Poisson's ratio. The default Poisson's ratio is given based on the layer's material type (Table C1). The valid range of Poisson's ratio is 0.1 – 0.44. The program automatically checks the input value.

- Permanent Deformation (Rutting) Property

The VESYS rutting model is used to predict the rutting development of asphalt pavement. The mandatory rutting parameters include ALPHA and GNU. ALPHA and GNU values are normally determined by repeated load tests. The program provides the default ALPHA and GNU values based on material types. Each season’s ALPHA/GNU values for asphalt layers are calculated based on the reference temperature, ALPHA/GNU input of each layer, and the season’s temperature from the climate screen. Clicking the “Edit Rutting” button allows users to open, view, or edit the ALPHA and GNU values of each season for specified layers (Figure C13). If the calculated rutting data are beyond the 0.1 – 0.95 range, the program limits the value to this range in order to make the original VESYS5 program execute smoothly.

The range of ALPHA defined by program is as follows:

- Asphalt Layer: 0.7 – 0.95. If the input value ranges from 0.1 to 0.95, users will get a warning but will still be allowed to save the data.
- Base and Subbase Layers: 0.7 – 0.9.
- Subgrade Layer: 0.5 – 1.

The range of GNU is 0 – 0.5. The program will validate the input ALPHA and GNU values. If the input is invalid, a red flashing icon appears to notify users.

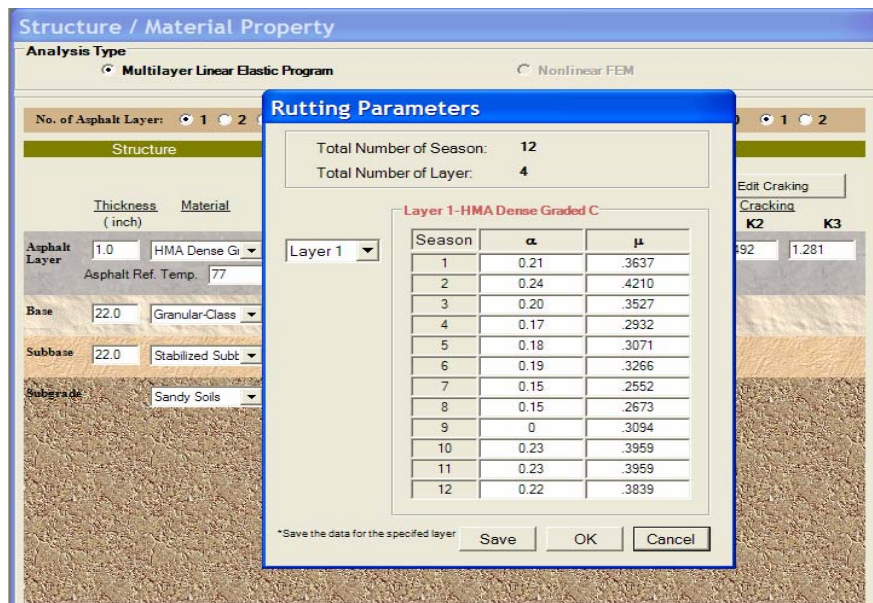


Figure C13. Illustration of Editing Alpha and Gnu.

- Fatigue Cracking Property

As discussed in Chapter 2, the enhanced VESYS5 uses the fatigue cracking equation in MEPDG as the default fatigue equation. The program automatically calculates the default K_1 based on the thickness of all asphalt layers. K_2 and K_3 are given and displayed after users pick up the last layer of asphalt layers. All three parameters can be modified. Clicking the “Edit Cracking” button allows users to view and edit each season’s K_1 , K_2 and K_3 data (Figure C14).

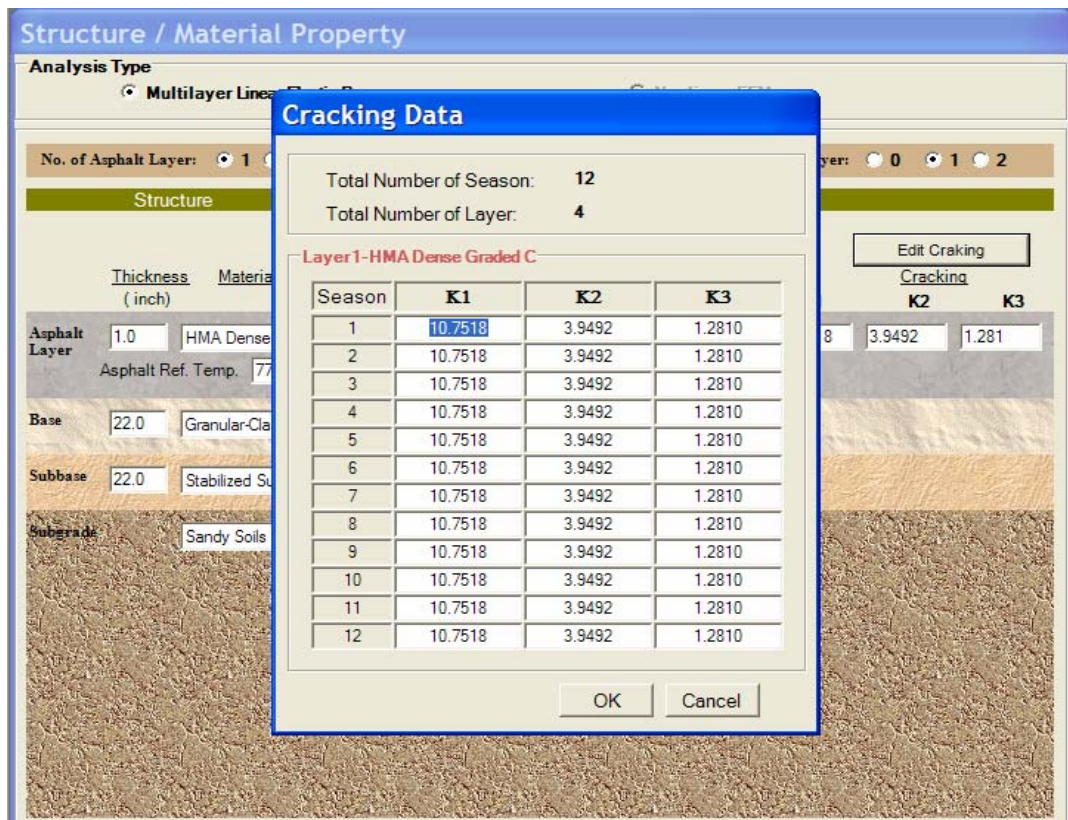


Figure C14. Illustration of Editing Fatigue Cracking Parameters: K_1 , K_2 , and K_3 .

3.4 Traffic Data

Traffic load information **MUST** be specified in order to run the enhanced VESYS5. Traffic Data input includes axle load and repeated load. Thus, it takes two steps to finish the traffic data input. First, select the axle type (or truck type). Second, specify the daily repetitions corresponding to the selected axle or truck. The following paragraphs discuss these two steps.

- Axle Load Data

The information describing axle load data (such as tire pressure and weight of axle/2) is needed in this input category. The enhanced VESYS5 classifies the potential axles as two levels (Level 2: specific axle and Level 1: specific truck). Users can select the applicable level based on the purpose of analysis.

- Level 2: Specific Axle

Level 2: Specific Axle is the default option when users open the traffic screen for the first time. Four types of axles are available: single, tandem, tridem, and quad axle(s). After users select an axle type, the right side of the screen displays the corresponding input information for the selected axle type (Figure C15).

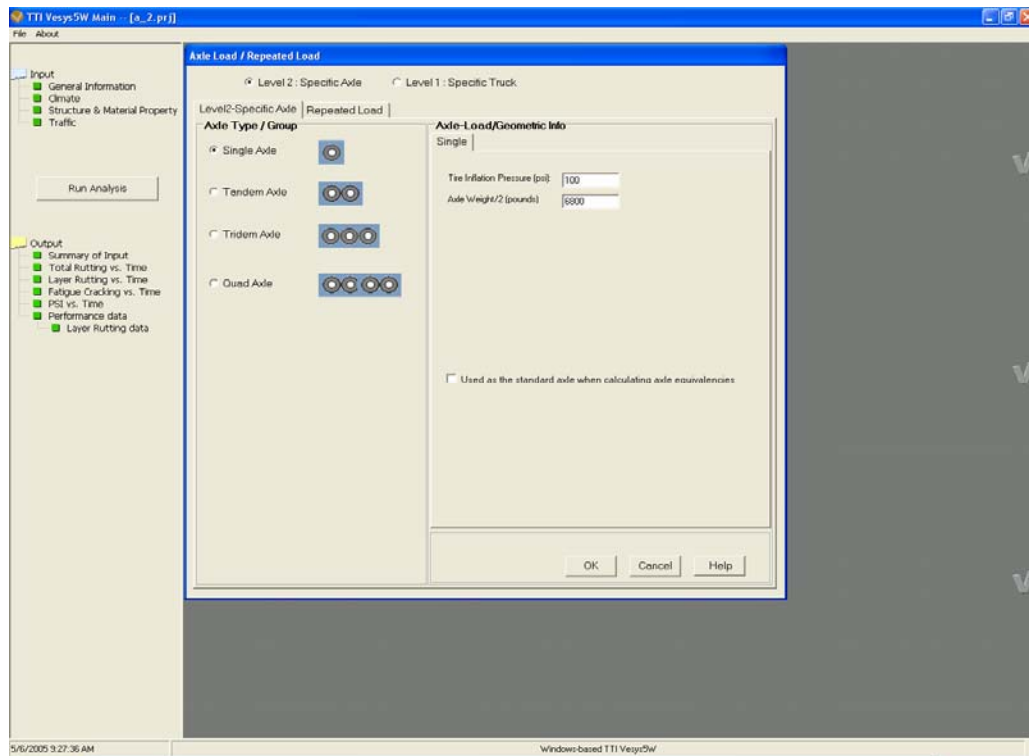


Figure C15. Input Screen of Traffic Input-Level 2: Specific Axle.

The parameters describing the axle load include “Tire Inflation Pressure” and “Axle Weight/2.” Except for single axle, the axle spacing must also be specified. “Inter-Axle Spacing” is the distance between the adjacent two axles. Please note that the “Axle Weight/2” is half the weight of the axle load. For example, for a 34 kip tandem load, Axle Weight/2 should be 8.5 kip ($34/2/2 = 8.5$ kip).

- Level 1: Specific Truck

In some cases, users may use multiple groups of multiple-axle loads for the pavement performance analysis. The enhanced VESYS5 defines the multiple-axle group as the different truck types (Figure C16). The enhanced VESYS5 defines 10 truck types plus trailer combinations. The picture of each type of truck shows users the definition of that truck clearly and visually. Select a type of truck, and enter the required axle load information for the selected truck on the right side of the screen. The basic information about axle loads is the same as described in the Level 2: Specific Axle section.

In addition, the trailer will appear if users choose trucks 4, 5, 6, or 7. Users can add the trailer to the current truck by selecting the check box. The trailer tab appears in the “Axle-Load/Geometric Info” section, and the information about the trailer axle is the same as described in the Level 2: Specific Axle section.

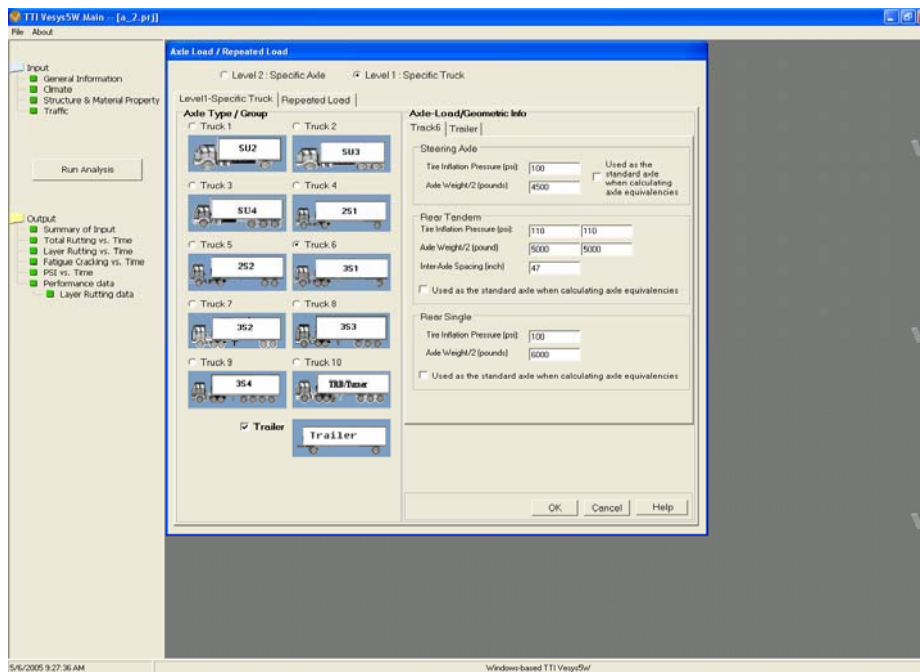


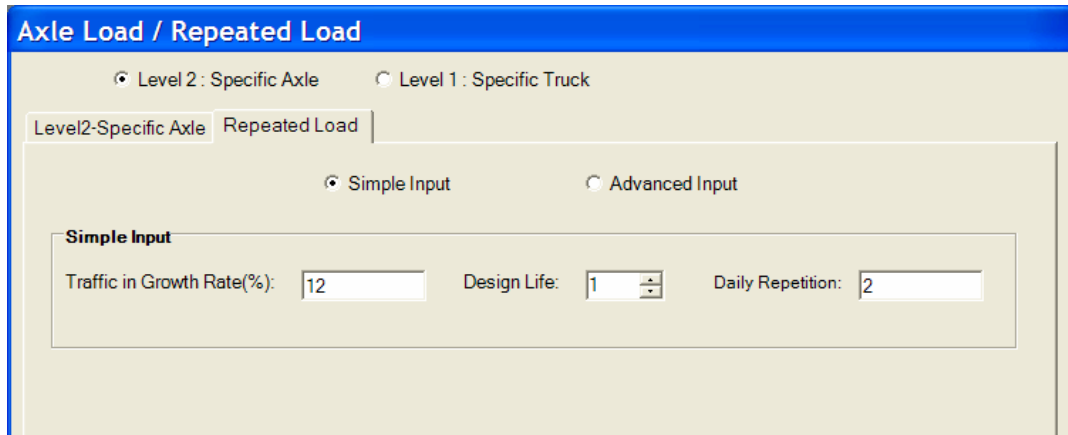
Figure C16. Input Screen of Traffic Input-Level 1: Specific Truck.

- Repeated Load

Users may enter the repeated load data information in two ways. The simple input is for general pavement performance analysis, and the advanced input is for Accelerated Pavement Test (APT) data analysis. The options are presented below.

- Simple Input

This method is the simple way to enter the repeated load information. Users only need to enter the growth rate, design life, and daily repetitions of the axle or truck previously specified (Figure C17). The program automatically calculates repeated data described above.



The screenshot shows a software window titled "Axle Load / Repeated Load". At the top, there are two radio buttons: "Level 2 : Specific Axle" (selected) and "Level 1 : Specific Truck". Below this, there are two tabs: "Level2-Specific Axle" (selected) and "Repeated Load". Under the "Level2-Specific Axle" tab, there are two radio buttons: "Simple Input" (selected) and "Advanced Input". The "Simple Input" section contains three input fields: "Traffic in Growth Rate(%)" with a value of 12, "Design Life:" with a value of 1 and a spinner control, and "Daily Repetition:" with a value of 2.

Figure C17. Repeated Load: Simple Input.

- Advanced Input

For the Advanced Input (Figure C18), users should specify the specific daily repetitions of the selected axle or truck within each season that has been defined in previous “Climate” zone. This function is especially designed for the APT performance prediction. It should be mentioned that the minimum daily repetitions of axles or trucks is 100.

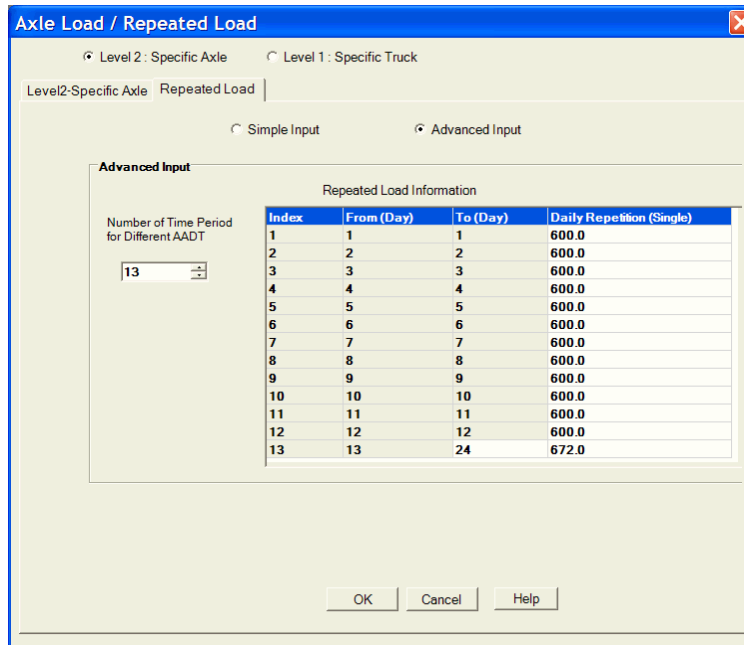


Figure C18. Repeated Load: Advanced Input.

4. TTI VESYS5W OUTPUT

TTI VESYS5W provides users with clear and straightforward outputs in the format of graphs and tables. As shown in [Figure C19](#), there are six types of output reports in the output tree:

- Summary of Input,
- Total Rutting vs. Time,
- Layer Rutting vs. Time,
- Fatigue Cracking vs. Time,
- PSI vs. Time, and
- Performance data including layer rutting data.

After users finish running the analysis from the TTI VESYS5W, click the name of report to open it.

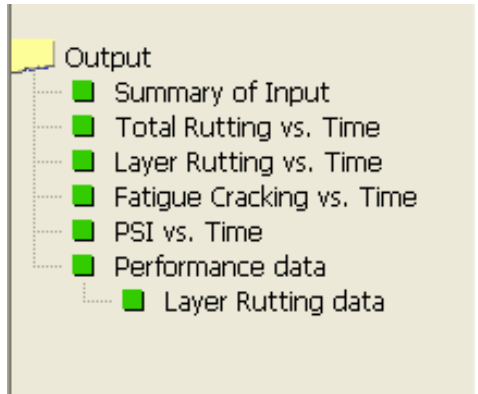


Figure C19. Screen of Output Tree.