

WINPRES

USER MANUAL

Version 1.0

by

Robert Lytton
Professor
Texas A&M University

Charles Aubeny
Associate Professor
Texas A&M University

Gyeong Taek Hong
Research Assistant
Texas Transportation Institute
Texas A&M University

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1. INTRODUCTION

This manual is a guide to using WinPRES, which is the developed Windows® version of the program PRES. The [Appendix](#) of this manual includes some examples to show the user how to input data and how to get output answers.

A simple model was developed to estimate the vertical movement at any point in a pavement in order to correlate the vertical movement to the roughness measurements made in different wheel paths of the pavement sections. Another model was developed to predict the pavement roughness in terms of serviceability index (SI) and international roughness index (IRI) by correlating regression constants obtained from the roughness analysis to the vertical movement estimated from the vertical movement model.

The vertical movement model and the roughness model developed were then assembled in the program PRES written in the Fortran language. The input data are entered to the program through a Windows graphical user interface developed using a Visual Basic tool. PRES is a model to estimate the development of pavement roughness on expansive soil subgrades, including the effects of the depth of a vertical moisture barrier and the thickness of inert and stabilized soil, if desired.

2. MAIN DIALOG WINDOW

When you launch WinPRES, the main dialog box ([Fig. 1](#)) appears, which has a logo and toolbar menu. These menus are displayed across the top of the screen as: File, Run, and Help.

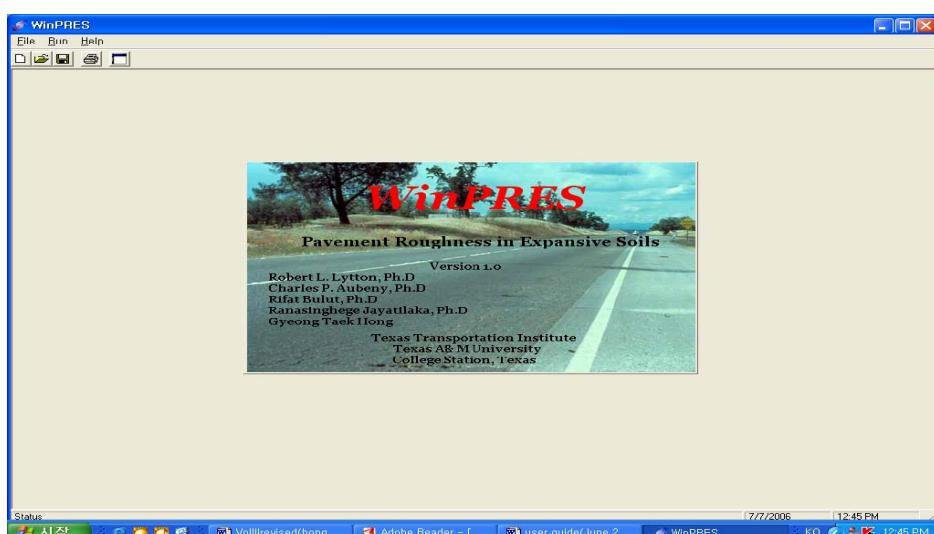


Figure 1. Main Dialog Box.

2.1 The File Menu

The File menu is universally used to start a new project, open an existing project, save, save as, print, and exit (Fig. 2).

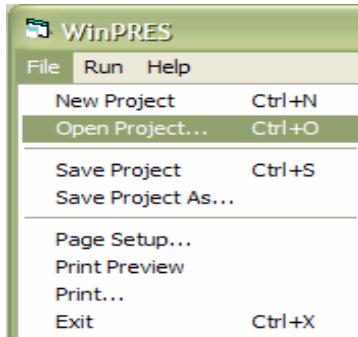


Figure 2. File Menu.

2.2 The Run Menu

The Run menu runs PRES.exe, which is the executable file written in the Fortran language (Fig. 3).

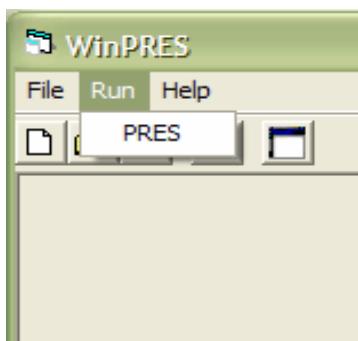


Figure 3. Run Menu.

2.3 The Help Menu

The Help menu (Fig. 4) is used only to look at the About WinPRES dialog box (Fig. 5). The program information is presented in this box.

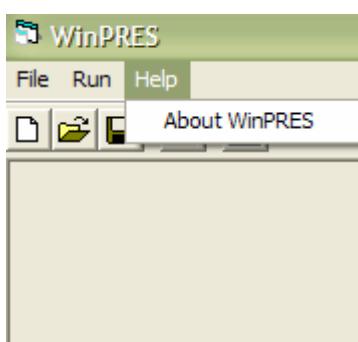


Figure 4. Help Menu.

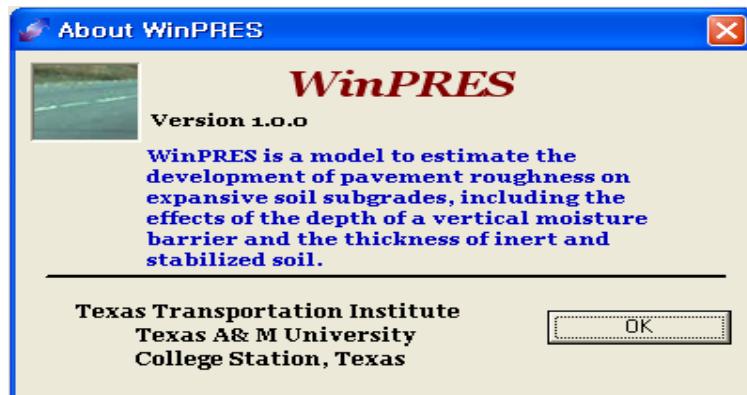


Figure 5. About WinPRES.

3. INPUT DIALOG BOX

The INPUT dialog box has nine tabs: Project Information, Units and Pavement Types, Environmental and Geometric Conditions, Soil Properties, Barrier and Wheel Path, Structural Properties of Pavement, Traffic and Reliability, Roughness, and Diffusivity (Fig. 6).

To gain experience in using this program, the user is encouraged to modify one of the existing example problems.

3.1 Project Information

This screen is used to specify or modify the project name, date, number, and engineer (Fig. 6).

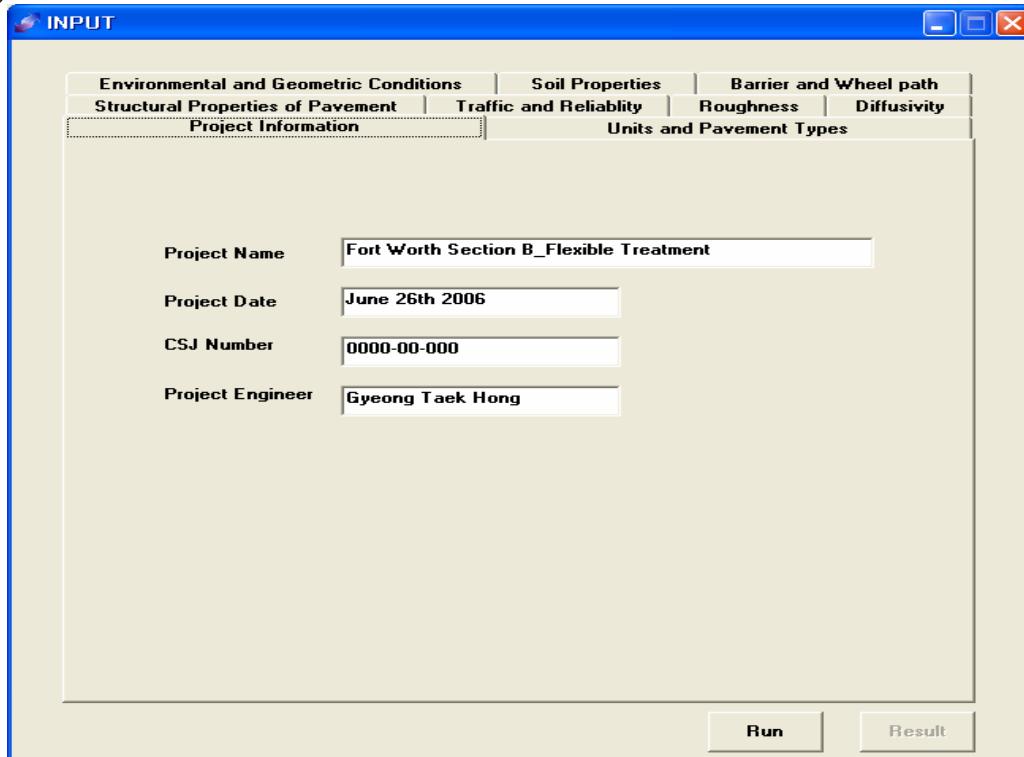


Figure 6. INPUT Dialog Box.

3.2 Units and Pavement Types

This screen allows the selection of the units of measurement and pavement types (Fig. 7).

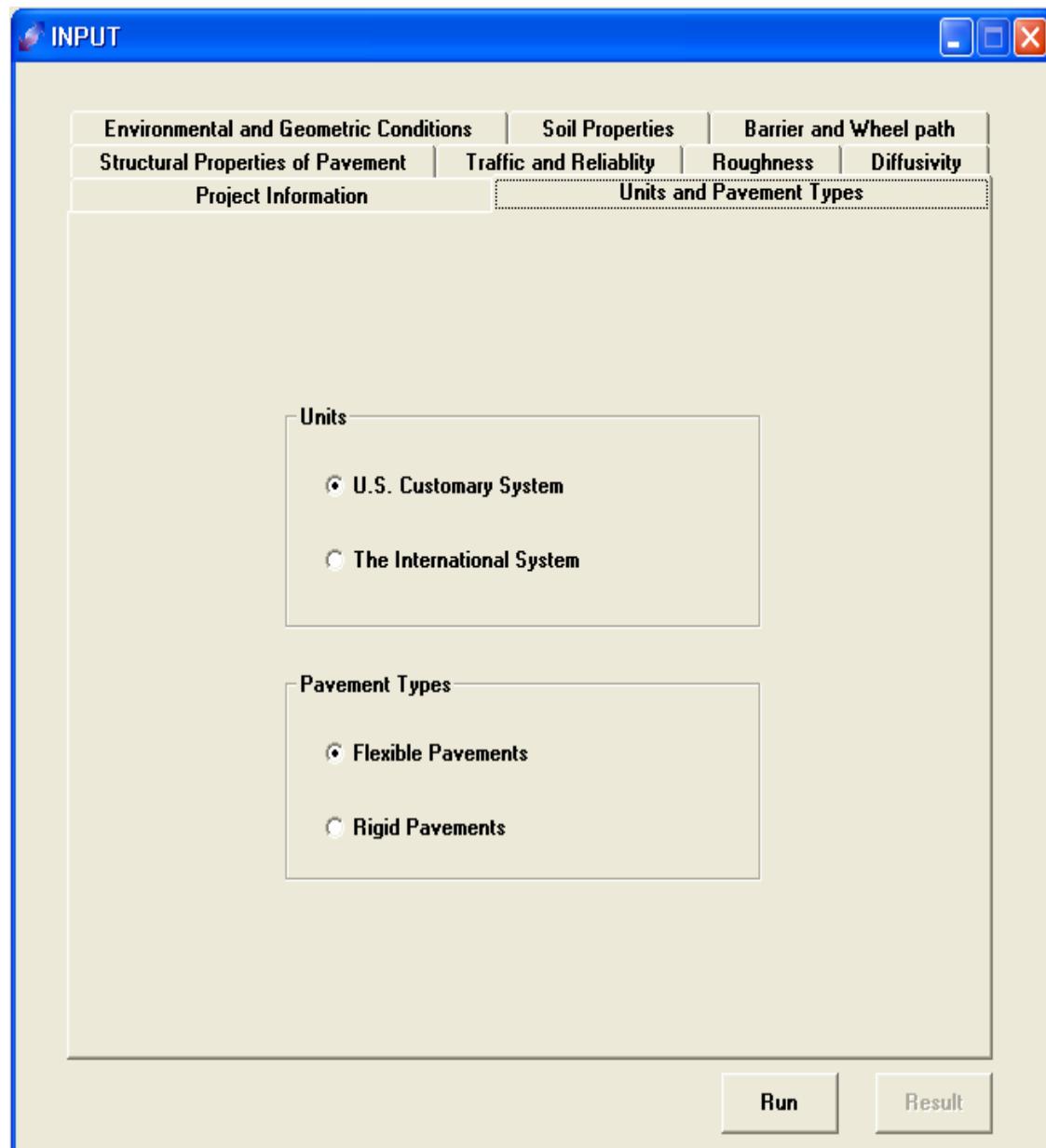


Figure 7. Units and Pavement Types.

3.3 Environmental and Geometric Conditions

This screen is used to enter the environmental and geometric conditions for a project (Fig. 8).

INPUT

Structural Properties of Pavement	Traffic and Reliability	Roughness	Diffusivity
Project Information	Units and Pavement Types		
Environmental and Geometric Conditions		Soil Properties	Barrier and Wheel path

Climatic Data

Thornthwaite Moisture Index

Drainage Condition

Lateral Slope

Cut Flat Fill

Longitudinal Drainage

Hill Slope Valley

Field Conditions

Depth of Root Zone : (ft)

Depth of the Moisture Active Zone (Z_m) : (ft)

Determine The Equilibrium Suction

Measured Suction at Z_m (pF)
 Calculate Suction based on TMI

Run **Result**

Figure 8. Environmental and Geometric Conditions.

Step 1 – Enter the Thornthwaite Moisture Index (TMI) based on the values shown on the map of Texas (Fig. 9) by clicking the button **Thornthwaite Moisture Index for Texas** (Fig. 8).

Thornthwaite Moisture Index is used to characterize the climate in the test sites. The TMI can be calculated by a water balance procedure that involves: (1) determination of monthly potential evapotranspiration; (2) allocation of available water to storage, deficit, and runoff on a monthly basis; and (3) summation of monthly runoff moisture depth, deficit moisture depth, and evapotranspiration to obtain annual values. Then the TMI is given by:

$$TMI = \frac{100R - 60DEF}{E_p} \quad (1)$$

where

- R = runoff moisture depth
- DEF = deficit moisture depth
- E_p = evapotranspiration.

Step 2 – Select the roadway drainage condition for both the lateral slope and longitudinal drainage ([Fig. 8](#)).

Generally, the minimum and maximum suction at the surface of the site are considered as the suction at the field capacity (wettest soil in the field), 2.0 pF and wilting point, 4.5 pF, respectively.

The suction at the field capacity should be adjusted with lateral slope and longitudinal drainage conditions of the pavement. The lateral slope conditions used are cut, flat, and fill as shown in [Fig. 8](#). The longitudinal drainage conditions used are hill, slope, and valley. The minimum suction at the surface for different drainage and slope conditions are given in [Table 1](#).

Table 1. Minimum Suction (pF) for Different Slope and Drainage Conditions.

Longitudinal Drainage	Lateral Slope		
	Cut	Flat	Fill
Hill	2.3	2.5	2.6
Slope	2.0	2.2	2.3
Valley	2.0	2.2	2.3

Note : For Thornthwaite Moisture Index (TMI) greater than +10.0, the values in the table are used. For $-20.0 \leq TMI < 10.0$, 0.2 is added to the values in the table. For TMI less than -20.0, 0.4 is added to the values in the table.

Step 3 – Enter values for the depth of root zone and depth of the moisture active zone (Z_m). The equilibrium suction, U_e , can be determined by selecting the option Measured Suction at Z_m or Calculate Suction based on TMI, which is an approximated suction value based on the regression equation ([Eq. 2](#)) for the relation between field data and TMI.

$$U_e = 3.5633 \exp(-0.0051TMI) \quad (2)$$

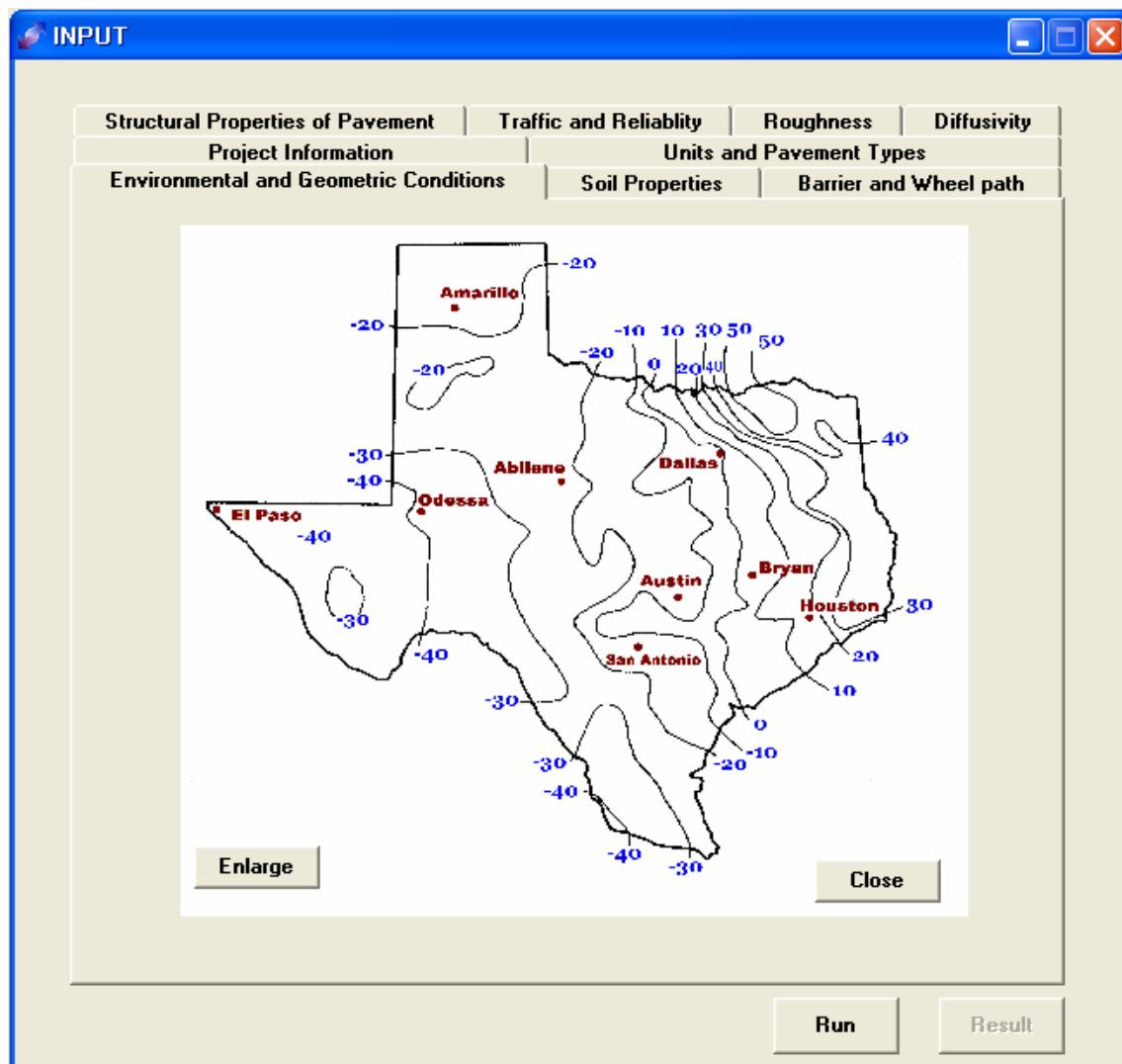


Figure 9. Thornthwaite Moisture Index Map of Texas.

Depth of root zone is needed at the site that has some trees near the edge of pavement. Maximum suction at the site should be wilting point 4.5 pF up to depth of root zone. The value of equilibrium suction at the site can be measured or considered as a calculated suction based on TMI, which is an approximated suction value based on the regression equation for the relation between field data and TMI. Depth of moisture active zone (Z_m), the deepest depth for possible moisture flow, is assumed as a point where equilibrium suction begins.

3.4 Soil Properties

This screen is used to specify the individual soil layer data acquired from testing field samples (Fig. 10). Type of soil layer, thickness, dry unit weight, liquid limit (LL), plasticity index (PI), % passing less than #200 sieve, and % passing less than $2\mu\text{m}$ are required. Lime or cement as a stabilizing material should be added when adding a stabilized soil layer.

Inert soil can be described as a soil borrowed and brought in from an offsite location that has much less expansive properties than the existing subgrade. Typically this would mean a soil with a PI of less than 15. The input values of the stabilized soil are the values of the untreated soil. The algorithm within the design program will alter the LL and PI based upon the percent of stabilizing agent (lime or cement) that is used.

Layer	Soil Type	Thickness (ft)	Dry Unit Weight(pcf)	LL(%)	PI(%)	% Passing #200 Sieve	% Less than 2 Microns
1	stabilized	3	120	60	36	85	30
2	inert	1	130	25	10	10	1
3	natural	1	100	55	30	80	25
4	natural	4	100	65	38	85	30
5	natural	0.5	115	30	15	35	10
6	natural	1.5	100	53	32	80	25
7	natural	4	100	45	15	99	37

Figure 10. Soil Properties.

Step 1 – Specify or modify the soil properties of each layer by entering the test data in each text box. Move into the previous or next layer by using these buttons **Previous** **Next** and add or delete a layer by using these buttons **Add** **Delete**.

Step 2 – If stabilizing a layer, select the options for lime or cement as an additional stabilizing material and enter the percent by weight of the material for stabilization of a subgrade soil.

Step 3 – Review the input data displayed in the bottom half of the screen and correct if needed.

3.5 Barrier and Wheel Path

This screen is used to specify the depth of vertical moisture barrier if used and a vehicle wheel path of most concern (Fig. 11).

The Texas Department of Transportation has been using vertical moisture barrier for several years in pavement sections where repeated maintenance work due to expansive clay activity has been reported. A typical value of 8.0 ft can be used for the pavement in the state of Texas.

Depth of vertical moisture barrier recommended does not exceed the depth of moisture active zone, if used. Width of pavement and the distance from the center of pavement to the wheel path of most concern are required.

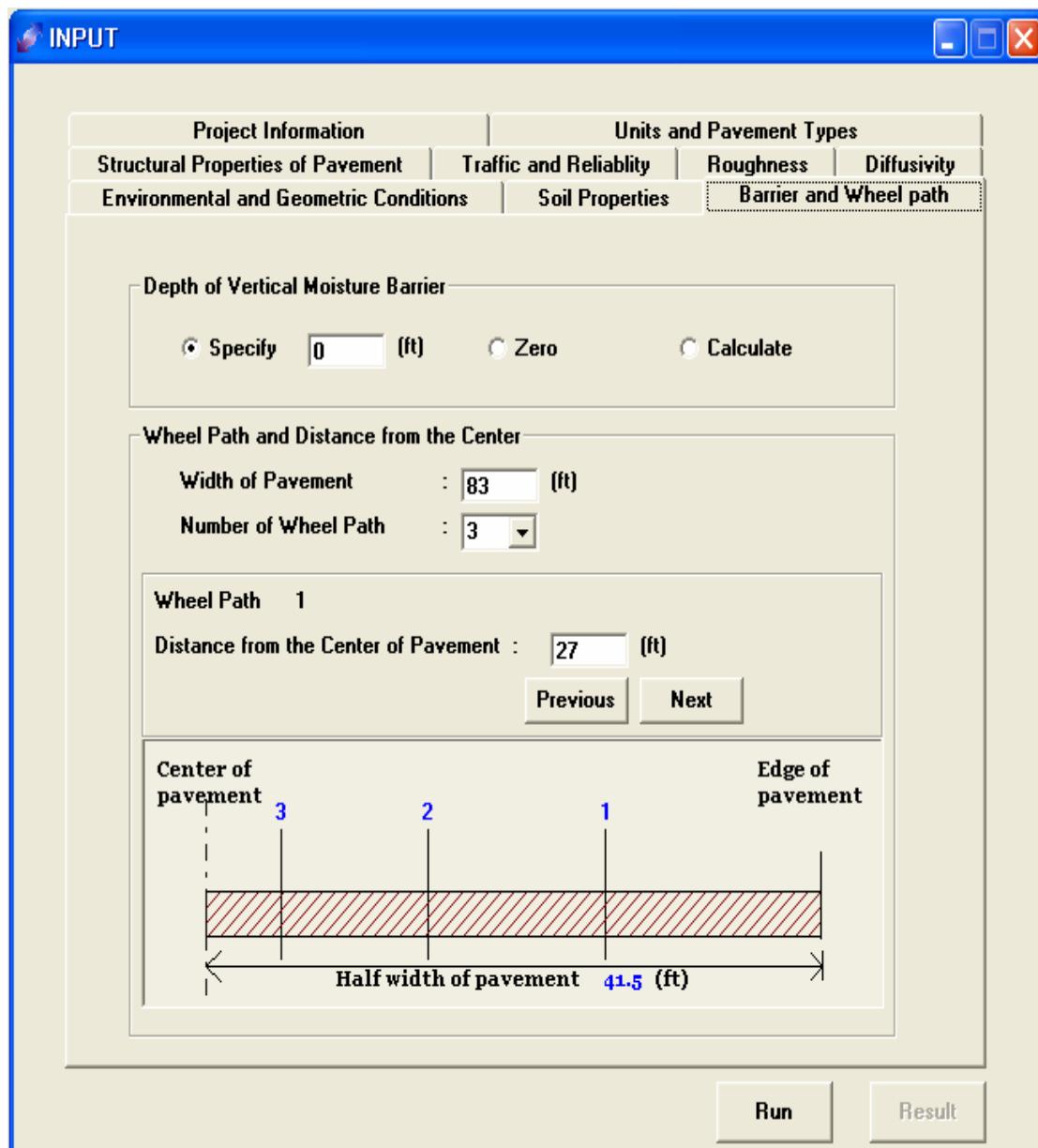


Figure 11. Barrier and Wheel Path.

Step 1 – Select one of the options, Specify, Zero, or Calculate for the depth of vertical moisture barrier. Enter a number in the text box (Fig. 11) when selecting the

option Specify. Input the terminal roughness information on the Roughness tab when selecting the option Calculate.

Step 2 – Enter the width of pavement and determine the number of wheel paths by using the input box . Input the distance from the roadway centerline for each wheel path. Check each distance input from the diagram, which automatically plots the wheel paths.

3.6 Structural Properties of Pavement

The screens shown in [Figs. 12-17](#) require the input of pavement specific data.

3.6.1 Flexible Pavements

The structural number (SN) and falling weight deflectometer (FWD) modulus of subgrade soil (from the drop weight closest to the 9k load) are needed.

Step 1 – Select the options Specify or Input Thickness of the Surface, Base, and Subbase to input the structural number of pavement ([Fig. 12](#)).

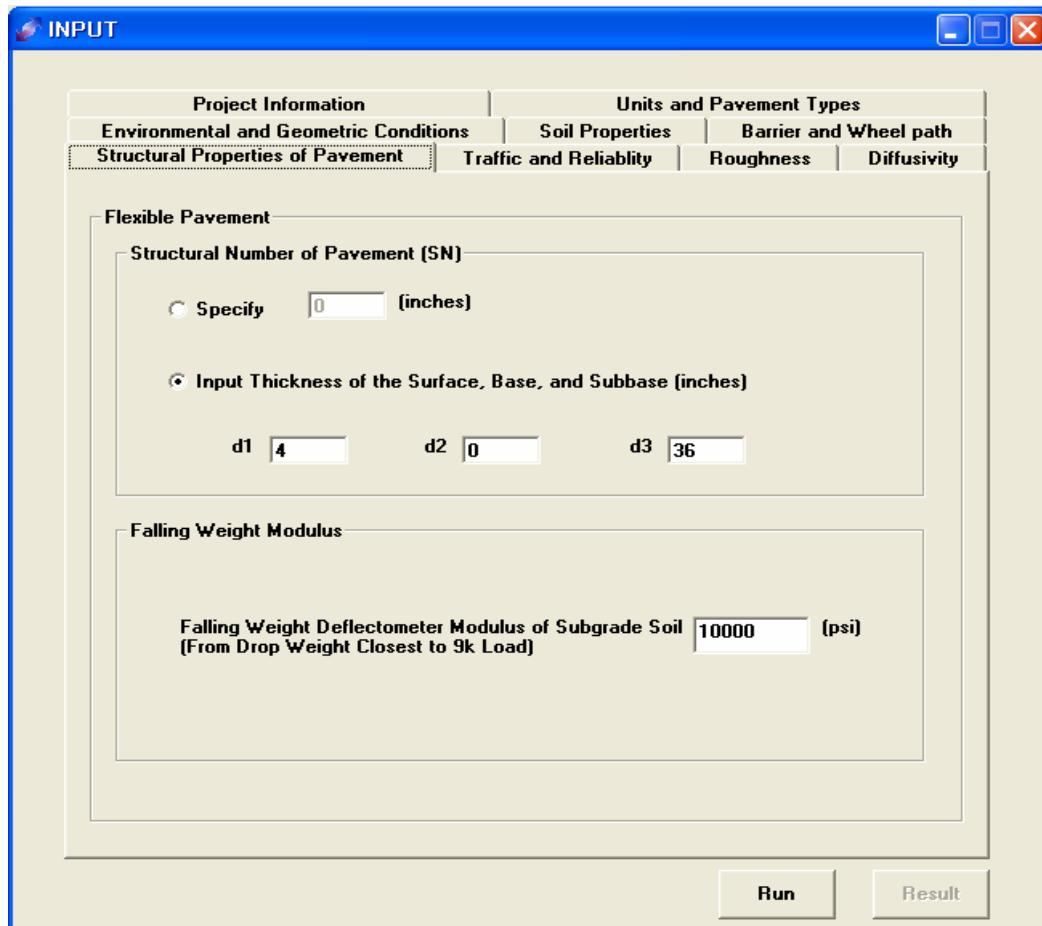


Figure 12. Structural Properties of Flexible Pavements.

Structural number of flexible pavement is computed by:

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3 \quad (3)$$

where

a_1, a_2, a_3 = layer coefficients for the surface, base, and subbase, respectively

D_1, D_2, D_3 = the thickness of the surface, base, and subbase, respectively.

Step 2 – Enter the FWD modulus of subgrade soil (from the drop weight closest to the 9k load) ([Fig 12](#)).

3.6.2 Rigid Pavements

For the case of rigid pavements, there are six input parameters: the slab thickness, 28-day compressive strength of concrete, mean modulus of rupture of concrete, falling weight deflectometer modulus of subgrade soil (from the drop weight closest to the 9k load), drainage coefficient, and load transfer coefficient ([Fig. 13](#)).

Environmental and Geometric Conditions		Soil Properties		Barrier and Wheel path	
Project Information		Units and Pavement Types			
Structural Properties of Pavement		Traffic and Reliability		Roughness	Diffusivity
Rigid Pavement					
Slab Thickness	:	15	[inches]		
28-day Compressive Strength of Concrete	:	4000	(psi)		
Mean Modulus of Rupture of Concrete	:	620	(psi)		
Falling Weight Deflectometer Modulus of Subgrade Soil (From Drop Weight Closest to 9k Load)	:	6500	(psi)		
Drainage Coefficient					
1	Recommended Values				
Corresponding to Drainage Conditions					
Load Transfer Coefficient					
2.9	Recommended Values				
Corresponding to Various Pavement Types and Design Conditions					
Terminal Serviceability Index					
<input type="radio"/> IH	3.0	<input checked="" type="radio"/> US and State	2.8	<input type="radio"/> FM	2.4
			Run	Result	

Figure 13. Structural Properties of Rigid Pavements.

Step 1 – Enter the slab thickness, 28-day compressive strength of concrete, mean modulus of rupture of concrete, and falling weight deflectometer modulus of subgrade soil (from the drop weight closest to the 9k load).

The property of roadbed soil to be used for rigid pavement design is the modulus of subgrade reaction k , rather than the resilient modulus M_R (Huang 1993). If the slab is placed directly on the subgrade without a subbase, the American Association of State Highway and Transportation Officials (AASHTO) suggested the use of the following theoretical relationship based on an analysis of the plate bearing test:

$$k = \frac{M_R}{19.4} \quad (k \text{ is in pci and } M_R \text{ is in psi}) \quad (4)$$

Step 2 – Enter the drainage coefficient by selecting the recommended values (Fig. 14) by clicking **Recommended Values** or determining the value corresponding to drainage conditions (Fig. 15) by clicking **Corresponding to Drainage Conditions**.

Rating	Water Removed within	Recommended Values
<input type="radio"/> Excellent	2 hours	1.25
<input type="radio"/> Good	1 days	1.15
<input checked="" type="radio"/> Fair	1 week	1.00
<input type="radio"/> Poor	1 month	0.90
<input type="radio"/> Very Poor	never drain	0.70

Close

Figure 14. Recommended Values for Drainage Coefficient in Rigid Pavements.

Lateral Drainage	Longitudinal Slope		
	Hill	Slope	Valley
Positive	1.15	1.25	1.00
Flat	1.00	1.10	0.90
Negative	0.90	0.80	0.70

Close

Figure 15. Drainage Coefficient Corresponding to Drainage Conditions.

Step 3 – Enter the load transfer coefficient by selecting the recommended values (Fig. 16) by clicking **Recommended Values** or determining the value corresponding to various pavement types and design conditions (Fig. 17) by clicking **Corresponding to Various Pavement Types and Design Conditions**.

The load transfer coefficient, J , is a factor used in rigid pavement design to account for the ability of a concrete pavement structure to transfer a load across joints and cracks.

Rating	Recommended Values
<input type="radio"/> Excellent	2.3
<input type="radio"/> Good	2.9
<input checked="" type="radio"/> Fair	3.2
<input type="radio"/> Poor	3.8
<input type="radio"/> Very Poor	4.4

Close

Figure 16. Recommended Values for Load Transfer Coefficient in Rigid Pavement.

Design Condition	Type of Concrete Pavement		
	<input type="radio"/> Jointed Plain	<input checked="" type="radio"/> Jointed Reinforced	<input type="radio"/> Continuously Reinforced
Load Transfer Devices			
<input checked="" type="radio"/> Yes	3.2	3.2	N/A
<input type="radio"/> No	4.4	4.4	3.9
Asphalt Shoulders			
<input type="radio"/> Yes	3.2	3.2	3.0
<input checked="" type="radio"/> No	4.1	4.1	N/A
Tied PCC Shoulders			
<input checked="" type="radio"/> Yes	2.8	2.8	2.6
<input type="radio"/> No	3.9	3.9	N/A

Close

Figure 17. Load Transfer Coefficient Corresponding to Various Pavement Types and Design Conditions in Rigid Pavements.

Step 4 – Select the roadway type option, IH, US and State, or FM, as a terminal serviceability index (Fig. 13).

3.7 Traffic and Reliability

Traffic analysis and reliability data are used to calculate serviceability index and international roughness index loss for a traffic analysis period.

Step 1 – Enter the traffic analysis period (C), average daily traffic in one direction $T_k=0$ (r_0) (current level) and average daily traffic in one direction $T_k=C$ (r_c) (final level), and 18 kip single axles $T_k=C$ (N_c) for each wheel path (Fig. 18).

The 18 kip single-axle load applications (W_{18}) can be calculated from the following traffic equation used by the Texas Department of Transportation.

$$W_{18} = \frac{N_c}{C(r_0 + r_c)} \left[2r_0 t_k + \left(\frac{r_c - r_0}{C} \right) t_k^2 \right] \quad (5)$$

The screenshot shows a software window titled "INPUT". The window has a tab bar at the top with several tabs: "Environmental and Geometric Conditions", "Soil Properties", "Barrier and Wheel path", "Project Information", "Units and Pavement Types", "Structural Properties of Pavement", "Traffic and Reliability" (which is currently selected), "Roughness", and "Diffusivity".

The "Traffic and Reliability" section contains the following data:

Traffic Analysis	
Wheel Path	1
Traffic Analysis Period, C	: <input type="text" value="30"/> (yr)
ADT(Average Daily Traffic) in One Direction T=0	: <input type="text" value="13712"/>
ADT(Average Daily Traffic) in One Direction T=C	: <input type="text" value="21744"/>
18 kip Single Axles T=C	: <input type="text" value="8415520"/>

Below this are two buttons: "Previous" and "Next".

The "Reliability" section contains the following data:

Reliability	
Reliability for Traffic (AASHTO model)	: <input type="text" value="95"/> (%)
Reliability for Expansive Soil Roughness Constants	: <input type="text" value="95"/> (%)

At the bottom of the window are two buttons: "Run" and "Result".

Figure 18. Traffic Analysis and Reliability.

Step 2 – Enter the reliability for traffic and expansive soil roughness constants.

The following explanation of reliability was taken from the textbook Pavement Analysis and Design by Y. H. Huang (Prentice Hall) 2nd Edition, pp 507-508:

“Reliability is a means of incorporating some degree of certainty into the design process to ensure that the various design alternatives will last the analysis period.

The level of reliability to be used for design should increase as the volume of traffic, and public expectation of availability increase.” **Table 2** presents the recommended level of reliability for various functional classes.

Table 2. Suggested Levels of Reliability for Various Functional Classifications.

Functional Classification	Recommended Level of Reliability	
	Traffic (After AASHTO, 1986)	Expansive Soil
for prediction	50%	50%
for design		
Interstate and other freeways	85 – 99.9 %	80 – 99.9 %
Principal arterials	80 – 99.0 %	75 – 95.0 %
Collectors	80 – 95.0 %	75 – 95.0 %
Local	50 – 80.0 %	50 – 80.0 %

The 50 percent reliability level that is used for prediction uses the formula in predicting the expected value of the riding quality or roughness, without taking into account the variability of the input data.

3.8 Roughness

The initial serviceability index or international roughness index and years roughness calculation required for each wheel path are required in this screen (**Fig. 19**).

The serviceability index and the international roughness index are widely used to estimate the roughness of pavement. The serviceability performance concept in the design of pavements emerged from the AASHTO road test. In the AASHTO road test, the serviceability of pavements was rated subjectively by a panel made up of individuals selected to represent many important groups of highway users. The mean of the individual ratings was defined as the present serviceability rating (PSI), and it was a number between zero and five. The international roughness index emerged from the International Road Roughness Experiment (IRRE) held in Brasilia, Brazil, in 1982. The IRI is based on the roadmeter measure and has units of slope such as m/km or in/mile. The IRI is influenced by

wavelengths ranging from 1.2 m to 30 m and is linearly proportional to roughness. The relationship developed between IRI and SI is as follows:

$$IRI = 8.4193 \exp(-0.4664SI) \quad (6)$$

Equivalent pavement roughness measures estimated with respect to serviceability based on Equation (6) are given in [Table 3](#).

Table 3. Equivalent Pavement Roughness Measures

International Roughness Index		Serviceability Index
(m/km)	(in/mile)	
0.95	60	4.68
1.03	65	4.51
1.10	70	4.35
1.18	75	4.21
1.26	80	4.07
1.34	85	3.94
1.42	90	3.82
1.50	95	3.70
1.58	100	3.59
1.66	105	3.48
1.74	110	3.39
1.82	115	3.29
1.89	120	3.20
1.97	125	3.11
2.05	130	3.03
2.13	135	2.95
2.21	140	2.87
2.29	145	2.79
2.37	150	2.72
2.45	155	2.65

Terminal roughness information is required if the user wants to calculate the depth of vertical moisture barrier required.

Step 1– Enter the initial serviceability index or international roughness index and years roughness calculation required for each wheel path ([Fig. 19](#)).

Step 2– Terminal roughness information ([Fig. 19](#)) is required if the user has previously selected the option  Calculate the Depth of Vertical Moisture Barrier Required on the dialog box ([Fig. 11](#)).

INPUT

Project Information		Units and Pavement Types	
Environmental and Geometric Conditions		Soil Properties	Barrier and Wheel path
Structural Properties of Pavement	Traffic and Reliability	Roughness	Diffusivity
Initial Roughness			
Wheel Path 1 Initial Serviceability Index : <input type="text" value="4.2"/> Initial International Roughness Index : <input type="text" value="75.2"/> (in/mi)			
Years Roughness Calculation Required : <input type="text" value="30"/> (yr)			
Terminal Roughness (For Calculating the Depth of Vertical Barrier Required)			
Wheel Path 1 Terminal Serviceability Index : <input type="text" value="2.5"/> Terminal International Roughness Index : <input type="text" value="165"/> (in/mi)			
Years to Reach Terminal SI or IRI : <input type="text" value="30"/> (yr)			
<input type="button" value="Previous"/>		<input type="button" value="Next"/>	
<input type="button" value="Run"/>		<input type="button" value="Result"/>	

Figure 19. Initial and Terminal Roughness.

3.9 Diffusivity

The moisture diffusion coefficient, α , is the most critical parameter controlling the depth of the moisture active zone and the suction envelope of the extreme case for wet and dry condition in the field. Laboratory measurements of α on intact clay samples will normally be far less than that representative of field conditions. The moisture diffusion coefficient, α , can be determined by selecting the option Calculate based on the empirical equation or Lab Value with Soil Mass Multiplier (Fig. 20).

INPUT

Project Information		Units and Pavement Types		
Environmental and Geometric Conditions		Soil Properties	Barrier and Wheel path	
Structural Properties of Pavement	Traffic and Reliability	Roughness	Diffusivity	
Diffusivity				
Soil Layer 1 <input type="radio"/> Calculate $\alpha = 0.0029 - 0.000162(S) - 0.0122(\gamma_h)$ <input checked="" type="radio"/> Lab Value <input type="text" value="0.000084"/> (cm ² /sec) Soil Mass Multiplier <input type="text" value="40"/>				
<input type="button" value="Previous"/> <input type="button" value="Next"/>				
<input type="button" value="Run"/> <input type="button" value="Result"/>				

Figure 20. Diffusivity.

3.9.1 Estimation of Empirical Diffusivity α

The program can automatically estimate the diffusion coefficient α according to the empirical relationship:

$$\alpha = 0.0029 - 0.000162 S - 0.0122 \gamma_h \quad (7)$$

where γ_h is the suction compression index (also estimated by program), and S is the slope of the suction-water content curve:

$$S = -20.3 - 0.155 (\text{LL}) - 0.117 (\text{PI}) + 0.068 (\%-\#200) \quad (8)$$

where:

LL = the liquid limit in percent

PI = the plasticity index in percent

$\% - \# 200$ = the percent of soil passing the #200 sieve.

The above estimation of α is a default option; however, a site-specific determination is definitely desirable when sufficient data are available. Two approaches for a site-specific determination are discussed below.

3.9.2 Laboratory Measurement with Crack Correction

The unsaturated soil diffusivity test performed in the laboratory represents conditions of an intact soil mass. While intact conditions can occur under certain conditions such as the absence of root penetration or desiccation cracking, more commonly some degree of cracking can be expected within the soil mass. Such cracking will substantially increase the apparent diffusivity, α_{field} , of the soil mass to well above that indicated from a laboratory test. In addition, the existence of fractures will generate heterogeneity in the soil mass such that α_{field} depends on sampling location; hence, α_{field} must be expressed in probabilistic terms.

[Figure 21](#) shows the relationship of the ratio $\alpha_{\text{field}}/\alpha_{\text{lab}}$ expressed in terms of probability of non-exceedance for crack depths ranging from 1 to 16 ft. This figure shows that for crack depths up to 16 ft, α_{field} can exceed α_{lab} by a multiplier of greater than 100.

[Figure 22](#) shows the general nature of desiccation crack patterns in a soil mass. Crack patterns near the ground surface are usually closely spaced. However, the spacing of deep cracks is much wider than the shallower cracks, with crack spacing being approximately equal to crack depth. Estimating crack depth through direct observation is generally difficult. However, there are several indirect indicators of crack depth that are reasonably reliable. The first is the occurrence of any root fiber. Tree roots cannot penetrate an intact clay mass; i.e., root penetration occurs along cracks in clay soils. In addition, the roots induce desiccation within a vicinity of about 2 ft; therefore, cracking will extend to about 2 ft deeper than the deepest root fiber.

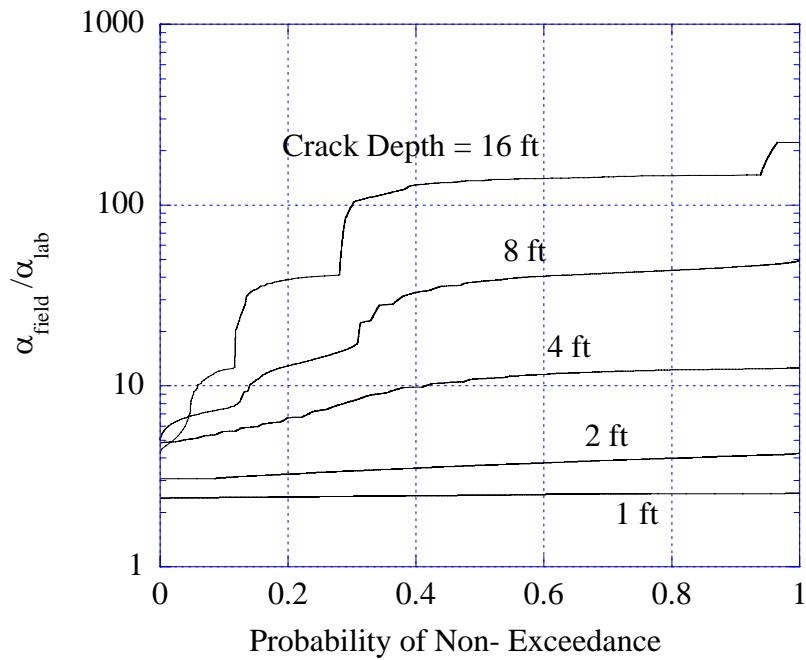


Figure 21. Adjustment of Laboratory Measurements of Diffusivity for Effects of Cracking.

Crack Spacing & Depth:

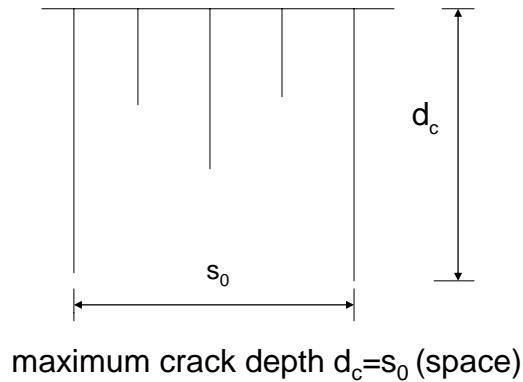


Figure 22. Desiccation Crack Pattern in a Soil Mass.

Example 1

A diffusivity measured in a laboratory diffusion test indicates $\alpha_{lab} = 8.0 \times 10^{-5} \text{ cm}^2/\text{sec}$. Root fibers in the borehole from which the soil sample was taken were observed to a depth of 6 ft. Estimate the field diffusivity α_{field} corresponding to a 50% level of non-exceedance.

Since roots were observed to a depth of 6 ft, a maximum crack depth of 8 ft should be assumed. From Fig. 21, for a 50% level of non-exceedance and a crack depth of 8 ft, $\alpha_{field}/\alpha_{field}=40$. Hence:

$$\alpha_{field} = 40 \times 8.0 \times 10^{-5} \text{ cm}^2/\text{sec} = 3.2 \times 10^{-3} \text{ cm}^2/\text{sec} \quad (9)$$

A second indicator of tree root depth is a suction profile at or near the wilting point of vegetation, about 4.5 pF. Figure 23 shows the characteristic suction profile of a deep root zone. Corrections for crack depths estimated through this method are computed in an identical manner as that shown in the above example.

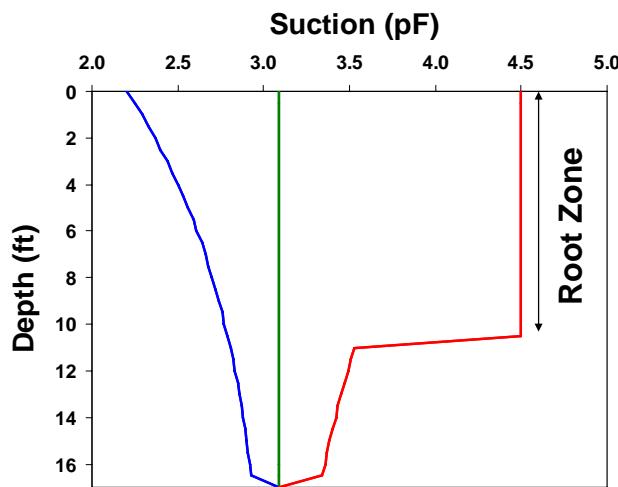


Figure 23. Characteristic Suction Profile for a Deep Root Zone.

3.9.3 Diffusivity from the Depth of Moisture Active Zone

Estimates of the depth of the moisture active zone y_{ma} can also provide a basis for estimating field diffusivity α_{field} using the relationship:

$$\alpha_{field} = 0.6 n (y_{ma})^2 \quad (10)$$

where n is the frequency of seasonal suction variation, usually 1cycle/yr.

Example 2

An examination of a suction profile indicates that an equilibrium suction is reached at a depth of 12 ft. Estimate the field diffusivity α_{field} . In this case, the depth of the moisture active zone $y_{\text{ma}} = 12$ ft. Based on the [Equation \(10\)](#), assuming a seasonal frequency $n = 1$ yr leads to:

$$\alpha_{\text{field}} = 0.6 \text{ (1 cycle/yr)} (12 \text{ ft})^2 = 86.4 \text{ ft}^2/\text{yr}$$

Conversion to units of cm^2/sec leads to $\alpha_{\text{field}} = 2.6 \times 10^{-3} \text{ cm}^2/\text{sec}$.

4. PROGRAM EXECUTION

To execute the program, click the button  on the Input dialog box, click the

 icon on the toolbar ([Fig. 1](#)), or click the Run option ([Fig. 3](#)) on the menu bar.

Several error message boxes ([Fig. 24](#)) will appear if a mistake has been made with the input data.

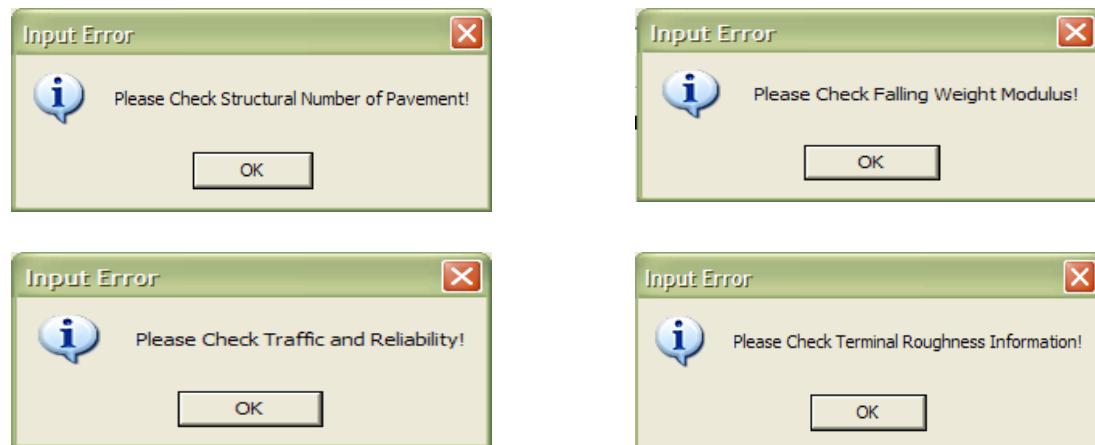


Figure 24. Several Error Message Boxes.

When all input data are correct, a dark execute window will appear as in [Fig. 25](#) when the program is running. It will take a few minutes to complete it. To show results, click the button .

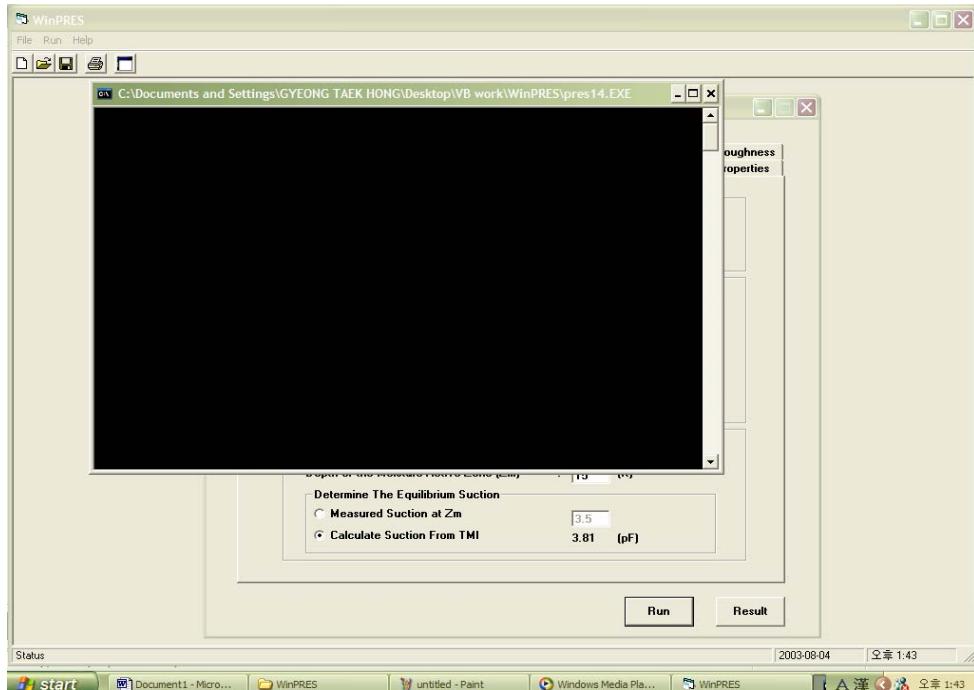


Figure 25. Execute Window.

5. OUTPUT DIALOG WINDOW

The Output Dialog window displays five small window boxes related to the results: Calculated Vertical Movement, Output, Suction Profile versus Depth, Serviceability Index versus Time, and International Roughness Index versus Time ([Fig. 26](#)).

After running the program, a message box may appear that informs the designer that the expansive clay roughness will increase too rapidly ([Fig. 27](#)). In this case, the roughness with time will not be calculated. To determine this information for a less extreme condition in controlling rate of increase of roughness due to expansive clays, use a vertical moisture barrier, a lower reliability for expansive clay roughness or removal and replacement of subgrade with either inert or stabilized soil. In order to decrease rate of increase of roughness due to traffic, increase structural number (SN) or modulus of subgrade soil or decrease reliability for traffic.



Figure 26. Output Dialog Window.

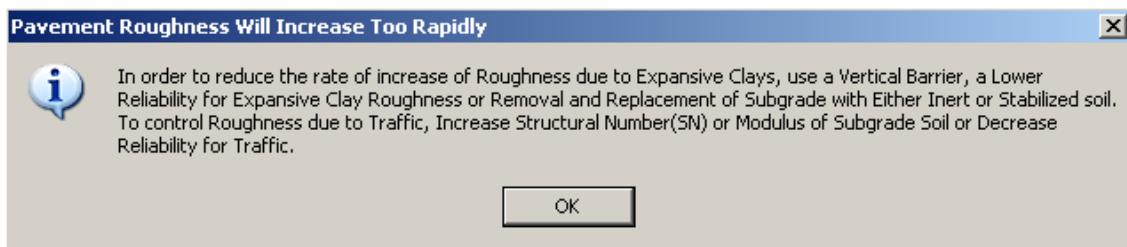


Figure 27. Information Message Box for the Roughness.

After executing the program, the five output files such as suction.txt, SI.txt, IRI.txt, summary.txt, and outputfull.txt will appear in the folder that has an executable file winpres.exe. The suction.txt file includes the suction profile with depth. The SI.txt and IRI.txt files have serviceability index and international roughness index versus time, respectively. The summary.txt file includes the vertical movement at the edge of pavement and in the wheel path of interest. The outputfull.txt file has all input and output data.

5.1 Calculated Vertical Movement

This window shows the summary of results calculated for total one-dimensional vertical movement at the edge of pavement by summing the swelling and shrinkage and for two-dimensional vertical movement at the wheel path (Fig. 28).

Calculated Vertical Movement	
FLEXIBLE PAVEMENTS	
BARRIER DEPTH	= 0.00 ft
DEPTH OF ACTIVE ZONE	= 7.60 ft
VERTICAL SWELLING	= 0.31 in
VERTICAL SHRINKAGE	= 0.60 in
TOTAL 1-D MOVEMENT	= 0.90 in
2D VERTICAL MOVEMENT	
DIST. FROM CENTER(ft) MOVEMENT(inches)	
27.00	0.38
15.00	0.34
5.00	0.34

Figure 28. Calculated Vertical Movement.

5.2 Output

The user can view the full results of the data by moving the right scrollbar up or down (Fig. 29).

Output	
COMPLETE OUTPUT FILE	
PROJECT NAME	: Fort Worth Section B_Flexible Treatment
PROJECT DATE	: June 26th 2006
CSJ NUMBER	: 0000-00-000
PROJECT ENGINEER	: Gyeong Taek Hong
***** INPUT DATA *****	
PAVEMENT TYPES	: FLEXIBLE PAVEMENTS
SOIL PROPERTIES	

Figure 29. Complete Output.

5.3 Suction Profile versus Depth

This window shows graphically the suction values of the wetting envelope, equilibrium, and drying envelope conditions with depth. The graph shows the soil type such as inert, stabilized, and natural soil in each layer and the depth of a vertical moisture barrier if used (Fig. 30).

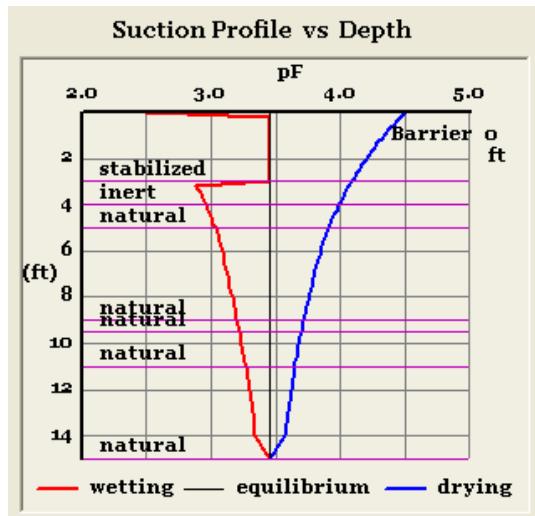


Figure 30. Suction Profile versus Depth.

5.4 Roughness with Time

The two graphs, serviceability index and international roughness index versus time in each wheel path can be displayed by clicking these buttons **Path 1** **Path 2** **Path 3** (Fig. 31).

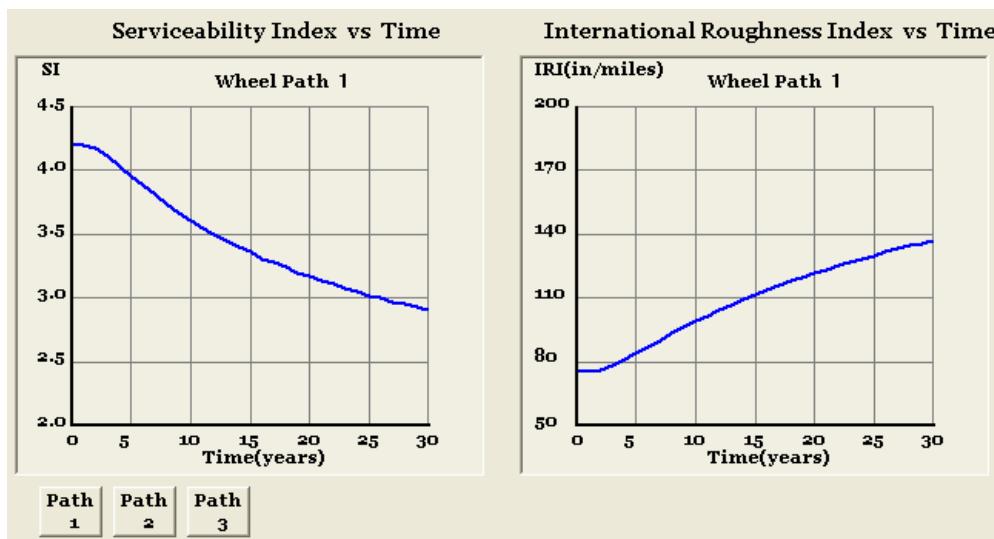


Figure 31. Roughness with Time.

To demonstrate various applications of the computer program WinPRES and to serve as exercises as well as output interpretation, four examples based on case studies are given in the EXAMPLES.

EXAMPLES

Input File Name: Fort Worth SectionA Flexible No Treat

COMPLETE OUTPUT FILE

```
PROJECT NAME :Fort Worth Section A Flexible No Treat
PROJECT DATE :June 26th 2006
CSJ NUMBER :0000-00-000
PROJECT ENGINEER :Gyeong Taek Hong

***** INPUT DATA *****

PAVEMENT TYPES : FLEXIBLE PAVEMENTS

SOIL PROPERTIES

    LAYER #    1
SOIL TYPE      = NATURAL SOIL
THICKNESS (ft) =      3.00
LIQUID LIMIT (%) =     60.00
PLASTICITY INDEX (%) =   28.00
PERCENT PASSING # 200 (%) = 80.00
LESS THAN 2 MICRONS (%) = 25.00
DRY UNIT WEIGHT (lb/ft3) = 100.00

    LAYER #    2
SOIL TYPE      = NATURAL SOIL
THICKNESS (ft) =      4.20
LIQUID LIMIT (%) =     60.00
PLASTICITY INDEX (%) =   25.00
PERCENT PASSING # 200 (%) = 80.00
LESS THAN 2 MICRONS (%) = 23.00
DRY UNIT WEIGHT (lb/ft3) = 100.00

    LAYER #    3
SOIL TYPE      = NATURAL SOIL
THICKNESS (ft) =      1.30
LIQUID LIMIT (%) =     30.00
PLASTICITY INDEX (%) =   15.00
PERCENT PASSING # 200 (%) = 35.00
LESS THAN 2 MICRONS (%) = 10.00
DRY UNIT WEIGHT (lb/ft3) = 115.00

    LAYER #    4
SOIL TYPE      = NATURAL SOIL
THICKNESS (ft) =      0.50
LIQUID LIMIT (%) =     20.00
PLASTICITY INDEX (%) =   10.00
PERCENT PASSING # 200 (%) = 25.00
LESS THAN 2 MICRONS (%) = 10.00
DRY UNIT WEIGHT (lb/ft3) = 130.00

    LAYER #    5
SOIL TYPE      = NATURAL SOIL
THICKNESS (ft) =      3.50
LIQUID LIMIT (%) =     65.00
PLASTICITY INDEX (%) =   35.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 30.00
DRY UNIT WEIGHT (lb/ft3) = 100.00

    LAYER #    6
SOIL TYPE      = NATURAL SOIL
THICKNESS (ft) =      2.50
LIQUID LIMIT (%) =     65.00
PLASTICITY INDEX (%) =   35.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 35.00
DRY UNIT WEIGHT (lb/ft3) = 100.00
```

ELEMENT DATA

LAYER NO.	LAYER THICK.(ft)	NO. OF ELEMENTS
1	3.00	16
2	4.20	20
3	1.30	7
4	0.50	3
5	3.50	18
6	2.50	6

ENVIRONMENTAL AND GEOMETRIC CONDITION

MEAN THORNTHWAITE MOISTURE INDEX	=	-10.00
ROOT DEPTH,ZR (ft)	=	0.00
DEPTH OF MOISTURE ACTIVE ZONE,ZM (ft)	=	15.00
WIDTH OF PAVEMENT (ft)	=	83.00
LONGITUDINAL SLOPE	=	SLOPE
LATERAL DRAINAGE	=	FILL

WHEEL PATH DATA

NO.	DISTANCE FROM THE CENTER OF PAVEMENT (ft)
1	27.00

INITIAL ROUGHNESS

WHEEL PATH NO.	SI	IRI (in/mi)
1	4.20	75.20

DEPTH OF VERTICAL BARRIER (ft)	=	0.00
--------------------------------	---	------

STRUCTURAL PROPERTIES OF PAVEMENT

STRUCTURAL NUMBER (ft)	=	0.26
FALLING WEIGHT DEFLECTOMETER MODULUS OF SUBGRADE SOIL (FROM DROP WEIGHT CLOSEST TO 9K LOAD) (psi)	=	10000.00

TRAFFIC DATA

WHEEL PATH NO.	1
TRAFFIC ANALYSIS PERIOD (Years)	= 30.0
ADT IN ONE DIRECTION WHEN T=0	= 13712.0
ADT IN ONE DIRECTION WHEN T=C	= 21744.0
18 kip SINGLE AXLES WHEN T=C	= 8415520.0

RELIABILITY

FOR TRAFFIC	= 95.0
FOR ROUGHNESS CONSTANTS Bs AND Bi	= 95.0

***** RESULTS *****

SUCTION COMPRESSION INDEX (SCI)

LAYER NO.	ZONE	SCI	alpha(cm^2/s)
1	4	0.0313	0.00346400
2	4	0.0288	0.00356000
3	2	0.0257	0.00412000
4	1	0.0180	0.00412000
5	3	0.0529	0.00236000
6	3	0.0576	0.00080000

SUCTION PROFILE(h), VOL. WATER CONTENT(m), AND VERTICAL MOVEMENT

DEPTH(ft)	h(EQ.)	h(WET)	h(DRY)	m(WET)	m(DRY)	SWELL(IN)	SHRINK(IN)	TOTAL(IN)
0.00	2.58	2.50	4.50	0.5943	0.2286	0.0636	1.0690	1.1326
0.19	2.58	2.50	4.44	0.5939	0.2392	0.0596	1.0254	1.0850
0.38	2.58	2.50	4.39	0.5934	0.2495	0.0557	0.9832	1.0389
0.56	2.58	2.51	4.33	0.5930	0.2595	0.0519	0.9422	0.9941
0.75	2.58	2.51	4.28	0.5926	0.2691	0.0482	0.9024	0.9507
0.94	2.58	2.51	4.23	0.5922	0.2785	0.0447	0.8639	0.9086
1.13	2.58	2.51	4.18	0.5919	0.2876	0.0412	0.8265	0.8677
1.31	2.58	2.52	4.13	0.5915	0.2964	0.0379	0.7903	0.8282
1.50	2.58	2.52	4.08	0.5911	0.3050	0.0346	0.7551	0.7898
1.69	2.58	2.52	4.04	0.5908	0.3133	0.0315	0.7210	0.7525
1.88	2.58	2.52	3.99	0.5904	0.3213	0.0285	0.6880	0.7164
2.06	2.58	2.52	3.95	0.5901	0.3291	0.0255	0.6559	0.6814
2.25	2.58	2.52	3.91	0.5898	0.3367	0.0227	0.6248	0.6475
2.44	2.58	2.53	3.87	0.5895	0.3440	0.0199	0.5946	0.6145

2.63	2.58	2.53	3.83	0.5892	0.3511	0.0172	0.5654	0.5826
2.81	2.58	2.53	3.79	0.5889	0.3580	0.0146	0.5370	0.5517
3.00	2.58	2.53	3.76	0.5886	0.3647	0.0121	0.5095	0.5216
3.21	2.58	2.53	3.72	0.6109	0.3855	0.0096	0.4820	0.4916
3.42	2.58	2.53	3.68	0.6106	0.3927	0.0072	0.4553	0.4625
3.63	2.58	2.54	3.64	0.6103	0.3996	0.0048	0.4296	0.4344
3.84	2.58	2.54	3.61	0.6101	0.4064	0.0026	0.4047	0.4073
4.05	2.58	2.54	3.57	0.6098	0.4129	0.0006	0.3806	0.3812
4.26	2.58	2.54	3.54	0.6095	0.4192	0.0000	0.3567	0.3567
4.47	2.58	2.54	3.51	0.6093	0.4253	0.0000	0.3328	0.3328
4.68	2.58	2.54	3.48	0.6090	0.4312	0.0000	0.3091	0.3091
4.89	2.58	2.54	3.45	0.6088	0.4368	0.0000	0.2857	0.2857
5.10	2.58	2.55	3.42	0.6086	0.4423	0.0000	0.2631	0.2631
5.31	2.58	2.55	3.39	0.6083	0.4477	0.0000	0.2413	0.2413
5.52	2.58	2.55	3.36	0.6081	0.4528	0.0000	0.2204	0.2204
5.73	2.58	2.55	3.34	0.6079	0.4578	0.0000	0.2003	0.2003
5.94	2.58	2.55	3.31	0.6077	0.4626	0.0000	0.1812	0.1812
6.15	2.58	2.55	3.29	0.6075	0.4672	0.0000	0.1629	0.1629
6.36	2.58	2.55	3.26	0.6073	0.4717	0.0000	0.1456	0.1456
6.57	2.58	2.55	3.24	0.6072	0.4760	0.0000	0.1293	0.1293
6.78	2.58	2.55	3.22	0.6070	0.4802	0.0000	0.1139	0.1139
6.99	2.58	2.55	3.20	0.6068	0.4843	0.0000	0.0994	0.0994
7.20	2.58	2.56	3.18	0.6067	0.4882	0.0000	0.0860	0.0860
7.39	2.58	2.56	3.16	0.3915	0.3171	0.0000	0.0756	0.0756
7.57	2.58	2.56	3.14	0.3914	0.3191	0.0000	0.0658	0.0658
7.76	2.58	2.56	3.13	0.3913	0.3210	0.0000	0.0567	0.0567
7.94	2.58	2.56	3.11	0.3912	0.3228	0.0000	0.0482	0.0482
8.13	2.58	2.56	3.10	0.3912	0.3246	0.0000	0.0404	0.0404
8.31	2.58	2.56	3.09	0.3911	0.3264	0.0000	0.0333	0.0333
8.50	2.58	2.56	3.07	0.3910	0.3281	0.0000	0.0268	0.0268
8.67	2.58	2.56	3.06	0.4039	0.3414	0.0000	0.0229	0.0229
8.83	2.58	2.56	3.05	0.4038	0.3429	0.0000	0.0193	0.0193
9.00	2.58	2.56	3.04	0.4038	0.3443	0.0000	0.0161	0.0161
9.19	2.58	2.56	3.02	0.6069	0.5204	0.0000	0.0097	0.0097
9.39	2.58	2.56	3.00	0.6067	0.5235	0.0000	0.0048	0.0048
9.58	2.58	2.56	2.99	0.6066	0.5265	0.0000	0.0016	0.0016
9.78	2.58	2.56	2.97	0.6065	0.5294	0.0000	0.0000	0.0000
9.97	2.58	2.56	2.96	0.6064	0.5322	0.0000	0.0000	0.0000
10.17	2.58	2.56	2.94	0.6063	0.5349	0.0000	0.0000	0.0000
10.36	2.58	2.57	2.93	0.6061	0.5375	0.0000	0.0000	0.0000
10.56	2.58	2.57	2.91	0.6060	0.5400	0.0000	0.0000	0.0000
10.75	2.58	2.57	2.90	0.6059	0.5424	0.0000	0.0000	0.0000
10.94	2.58	2.57	2.89	0.6058	0.5447	0.0000	0.0000	0.0000
11.14	2.58	2.57	2.88	0.6058	0.5469	0.0000	0.0000	0.0000
11.33	2.58	2.57	2.87	0.6057	0.5491	0.0000	0.0000	0.0000
11.53	2.58	2.57	2.86	0.6056	0.5511	0.0000	0.0000	0.0000
11.72	2.58	2.57	2.85	0.6055	0.5531	0.0000	0.0000	0.0000
11.92	2.58	2.57	2.84	0.6054	0.5550	0.0000	0.0000	0.0000
12.11	2.58	2.57	2.83	0.6053	0.5568	0.0000	0.0000	0.0000
12.31	2.58	2.57	2.82	0.6053	0.5586	0.0000	0.0000	0.0000
12.50	2.58	2.57	2.81	0.6052	0.5603	0.0000	0.0000	0.0000
12.92	2.58	2.57	2.78	0.6095	0.5705	0.0000	0.0000	0.0000
13.33	2.58	2.57	2.75	0.6093	0.5755	0.0000	0.0000	0.0000
13.75	2.58	2.57	2.73	0.6091	0.5798	0.0000	0.0000	0.0000
14.17	2.58	2.57	2.71	0.6090	0.5835	0.0000	0.0000	0.0000
14.58	2.58	2.58	2.69	0.6089	0.5867	0.0000	0.0000	0.0000
15.00	2.58	2.58	2.58	0.6080	0.6080	0.0000	0.0000	0.0000

TOTAL POTENTIAL VERTICAL SWELLING = 0.005 ft
 TOTAL POTENTIAL VERTICAL SHRINKAGE = 0.089 ft
 TOTAL 1-D VERTICAL MOVEMENT = 0.094 ft

THE DEPTH OF MOVEMENT ACTIVE ZONE FOR WETTEST = 4.05 ft
 THE DEPTH OF MOVEMENT ACTIVE ZONE FOR DRYIEST = 9.78 ft

DEPTH OF VERTICAL BARRIER = 0.00ft

DEPTH OF AVAILABLE MOISTURE dam (ft) = 2.00
 PARAMETERS FOR VERTICAL MOVEMENT
 XI-1 = 0.4650
 XI-2 = 0.7373
 XI-3 = 4.4968

EQUATION FOR 2D VERTICAL MOVEMENT
 $VM = 13.38 * EXP((0.7373 * d/D) ** 4.4968) \text{ mm}$

VERTICAL MOVEMENT
DISTANCE FROM CENTER ,d, (ft) VERTICAL MOVEMENT,VM,(inches)
27.00 0.55

Pavement Roughness will increase too rapidly.

<Controlling Roughness due to Expansive Clay>

Use a Vertical Barrier, a Lower Reliability for Expansive

Clay Roughness or Removal and Replacement of Subgrade

with Either Inert or Stabilized soil .

<Controlling Roughness due to Traffic>

Increase Structural Number(SN) or Modulus of Subgrade Soil

Input File Name: Fort Worth SectionB Flexible No Treat

COMPLETE OUTPUT FILE

PROJECT NAME :Fort Worth Section B_Flexible No Treatment
PROJECT DATE :June 26th 2006
CSJ NUMBER :0000-00-000
PROJECT ENGINEER :Gyeong Taek Hong

***** INPUT DATA *****

PAVEMENT TYPES : FLEXIBLE PAVEMENTS

SOIL PROPERTIES

LAYER # 1
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 3.50
LIQUID LIMIT (%) = 60.00
PLASTICITY INDEX (%) = 36.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 30.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 2
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 1.50
LIQUID LIMIT (%) = 55.00
PLASTICITY INDEX (%) = 30.00
PERCENT PASSING # 200 (%) = 80.00
LESS THAN 2 MICRONS (%) = 25.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 3
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 4.00
LIQUID LIMIT (%) = 65.00
PLASTICITY INDEX (%) = 38.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 30.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 4
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 0.50
LIQUID LIMIT (%) = 30.00
PLASTICITY INDEX (%) = 15.00
PERCENT PASSING # 200 (%) = 35.00
LESS THAN 2 MICRONS (%) = 10.00
DRY UNIT WEIGHT (lb/ft³) = 115.00

LAYER # 5
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 1.50
LIQUID LIMIT (%) = 53.00
PLASTICITY INDEX (%) = 32.00
PERCENT PASSING # 200 (%) = 80.00
LESS THAN 2 MICRONS (%) = 25.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 6
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 4.00
LIQUID LIMIT (%) = 45.00
PLASTICITY INDEX (%) = 15.00
PERCENT PASSING # 200 (%) = 99.00
LESS THAN 2 MICRONS (%) = 37.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

ELEMENT DATA

LAYER NO. LAYER THICK.(ft) NO. OF ELEMENTS

1	3.50	18
2	1.50	8
3	4.00	20
4	0.50	3
5	1.50	8
6	4.00	6

ENVIRONMENTAL AND GEOMETRIC CONDITION

MEAN THORNTHWAITE MOISTURE INDEX	= -10.00
ROOT DEPTH,ZR (ft)	= 0.00
DEPTH OF MOISTURE ACTIVE ZONE,ZM (ft)	= 15.00
WIDTH OF PAVEMENT (ft)	= 83.00
LONGITUDINAL SLOP	= SLOPE
LATERAL DRAINAGE	= FILL

WHEEL PATH DATA

NO.	DISTANCE FROM THE CENTER OF PAVEMENT (ft)
1	27.00

INITIAL ROUGHNESS

WHEEL PATH NO.	SI	IRI (in/mi)
1	4.20	75.20

DEPTH OF VERTICAL BARRIER (ft) = 0.00

STRUCTURAL PROPERTIES OF PAVEMENT

STRUCTURAL NUMBER (ft)	= 0.26
FALLING WEIGHT DEFLECTOMETER MODULUS	
OF SUBGRADE SOIL (FROM DROP WEIGHT	
CLOSEST TO 9K LOAD) (psi)	= 10000.00

TRAFFIC DATA

WHEEL PATH NO.	1
TRAFFIC ANALYSIS PERIOD (Years)	= 30.0
ADT IN ONE DIRECTION WHEN T=0	= 13712.0
ADT IN ONE DIRECTION WHEN T=C	= 21744.0
18 kip SINGLE AXLES WHEN T=C	= 8415520.0

RELIABILITY

FOR TRAFFIC	= 95.0
FOR ROUGHNESS CONSTANTS Bs AND Bi	= 95.0

***** RESULTS *****

LAYER NO.	ZONE	SCI	alpha(cm^2/s)
1	3	0.0706	0.00336000
2	3	0.0469	0.00336000
3	3	0.0565	0.00330400
4	2	0.0257	0.00344000
5	2	0.0547	0.00386400
6	4	0.0262	0.00304400

DEPTH(ft)	h(EQ.)	h(WET)	h(DRY)	m(WET)	m(DRY)	SWELL(IN)	SHRINK(IN)	TOTAL(IN)
0.00	3.45	2.50	4.50	0.5594	0.2169	2.4568	1.2744	3.7311
0.19	3.45	2.53	4.47	0.5543	0.2226	2.2916	1.2207	3.5123
0.39	3.45	2.56	4.43	0.5493	0.2282	2.1333	1.1685	3.3018
0.58	3.45	2.59	4.40	0.5444	0.2335	1.9816	1.1164	3.0980
0.78	3.45	2.62	4.37	0.5397	0.2387	1.8361	1.0644	2.9005
0.97	3.45	2.64	4.34	0.5352	0.2437	1.6966	1.0126	2.7092
1.17	3.45	2.67	4.32	0.5308	0.2486	1.5627	0.9612	2.5239
1.36	3.45	2.69	4.29	0.5265	0.2533	1.4343	0.9101	2.3444
1.56	3.45	2.72	4.26	0.5224	0.2579	1.3111	0.8595	2.1706
1.75	3.45	2.74	4.24	0.5184	0.2623	1.1928	0.8094	2.0022
1.94	3.45	2.76	4.21	0.5145	0.2665	1.0792	0.7599	1.8391
2.14	3.45	2.78	4.19	0.5108	0.2707	0.9702	0.7110	1.6812
2.33	3.45	2.81	4.16	0.5072	0.2747	0.8654	0.6627	1.5282
2.53	3.45	2.83	4.14	0.5037	0.2786	0.7648	0.6152	1.3800
2.72	3.45	2.85	4.12	0.5003	0.2823	0.6681	0.5683	1.2365

2.92	3.45	2.86	4.10	0.4970	0.2860	0.5752	0.5222	1.0975
3.11	3.45	2.88	4.08	0.4938	0.2895	0.4859	0.4769	0.9629
3.31	3.45	2.90	4.06	0.4907	0.2929	0.4001	0.4324	0.8325
3.50	3.45	2.92	4.04	0.4877	0.2962	0.3206	0.3886	0.7092
3.69	3.45	2.94	4.02	0.4615	0.2838	0.2749	0.3605	0.6354
3.88	3.45	2.95	4.00	0.4589	0.2866	0.2335	0.3329	0.5664
4.06	3.45	2.97	3.98	0.4564	0.2894	0.1963	0.3058	0.5021
4.25	3.45	2.98	3.97	0.4540	0.2921	0.1629	0.2792	0.4421
4.44	3.45	3.00	3.95	0.4516	0.2947	0.1332	0.2532	0.3864
4.63	3.45	3.01	3.94	0.4493	0.2972	0.1071	0.2277	0.3348
4.81	3.45	3.02	3.92	0.4471	0.2997	0.0843	0.2033	0.2877
5.00	3.45	3.04	3.91	0.4450	0.3020	0.0648	0.1806	0.2454
5.20	3.45	3.05	3.89	0.4940	0.3407	0.0445	0.1546	0.1991
5.40	3.45	3.06	3.88	0.4916	0.3434	0.0282	0.1308	0.1590
5.60	3.45	3.08	3.86	0.4893	0.3459	0.0158	0.1091	0.1248
5.80	3.45	3.09	3.85	0.4871	0.3484	0.0070	0.0894	0.0964
6.00	3.45	3.10	3.84	0.4849	0.3508	0.0018	0.0718	0.0736
6.20	3.45	3.11	3.82	0.4828	0.3531	0.0000	0.0562	0.0562
6.40	3.45	3.12	3.81	0.4808	0.3554	0.0000	0.0426	0.0426
6.60	3.45	3.13	3.80	0.4788	0.3575	0.0000	0.0309	0.0309
6.80	3.45	3.14	3.79	0.4769	0.3596	0.0000	0.0212	0.0212
7.00	3.45	3.15	3.78	0.4751	0.3617	0.0000	0.0133	0.0133
7.20	3.45	3.16	3.77	0.4733	0.3636	0.0000	0.0073	0.0073
7.40	3.45	3.17	3.76	0.4716	0.3655	0.0000	0.0031	0.0031
7.60	3.45	3.18	3.75	0.4699	0.3674	0.0000	0.0007	0.0007
7.80	3.45	3.19	3.74	0.4683	0.3691	0.0000	0.0000	0.0000
8.00	3.45	3.20	3.73	0.4668	0.3708	0.0000	0.0000	0.0000
8.20	3.45	3.21	3.72	0.4653	0.3725	0.0000	0.0000	0.0000
8.40	3.45	3.22	3.71	0.4638	0.3741	0.0000	0.0000	0.0000
8.60	3.45	3.22	3.70	0.4624	0.3757	0.0000	0.0000	0.0000
8.80	3.45	3.23	3.69	0.4610	0.3772	0.0000	0.0000	0.0000
9.00	3.45	3.24	3.68	0.4597	0.3786	0.0000	0.0000	0.0000
9.17	3.45	3.24	3.68	0.3069	0.2535	0.0000	0.0000	0.0000
9.33	3.45	3.25	3.67	0.3062	0.2542	0.0000	0.0000	0.0000
9.50	3.45	3.25	3.67	0.3055	0.2550	0.0000	0.0000	0.0000
9.69	3.45	3.26	3.66	0.3866	0.3246	0.0000	0.0000	0.0000
9.88	3.45	3.27	3.65	0.3858	0.3255	0.0000	0.0000	0.0000
10.06	3.45	3.27	3.65	0.3850	0.3264	0.0000	0.0000	0.0000
10.25	3.45	3.28	3.64	0.3842	0.3273	0.0000	0.0000	0.0000
10.44	3.45	3.28	3.64	0.3834	0.3282	0.0000	0.0000	0.0000
10.63	3.45	3.29	3.63	0.3826	0.3290	0.0000	0.0000	0.0000
10.81	3.45	3.29	3.63	0.3819	0.3298	0.0000	0.0000	0.0000
11.00	3.45	3.30	3.62	0.3812	0.3306	0.0000	0.0000	0.0000
11.67	3.45	3.31	3.60	0.4769	0.4208	0.0000	0.0000	0.0000
12.33	3.45	3.33	3.59	0.4740	0.4240	0.0000	0.0000	0.0000
13.00	3.45	3.34	3.57	0.4714	0.4269	0.0000	0.0000	0.0000
13.67	3.45	3.35	3.56	0.4691	0.4295	0.0000	0.0000	0.0000
14.33	3.45	3.36	3.55	0.4670	0.4317	0.0000	0.0000	0.0000
15.00	3.45	3.45	3.45	0.4652	0.4338	0.0000	0.0000	0.0000

TOTAL POTENTIAL VERTICAL SWELLING = 0.205 ft
 TOTAL POTENTIAL VERTICAL SHRINKAGE = 0.106 ft
 TOTAL 1-D VERTICAL MOVEMENT = 0.311 ft

THE DEPTH OF MOVEMENT ACTIVE ZONE FOR WETTEST = 6.00 ft
 THE DEPTH OF MOVEMENT ACTIVE ZONE FOR DRYIEST = 7.60 ft

DEPTH OF VERTICAL BARRIER = 0.00ft

DEPTH OF AVAILABLE MOISTURE dam (ft) = 1.90

PARAMETERS FOR VERTICAL MOVEMENT

XI-1 = 0.3809
 XI-2 = 0.9424
 XI-3 = 2.8429

EQUATION FOR 2D VERTICAL MOVEMENT
 $VM = 36.10 * EXP((0.9424 * d/D) ** 2.8429) \text{ mm}$

VERTICAL MOVEMENT
 DISTANCE FROM CENTER ,d, (ft) VERTICAL MOVEMENT,VM,(inches)
 27.00 1.82

Pavement Roughness will increase too rapidly.

<Controlling Roughness due to Expansive Clay>

Use a Vertical Barrier, a Lower Reliability for Expansive Clay Roughness or Removal and Replacement of Subgrade with Either Inert or Stabilized soil .

<Controlling Roughness due to Traffic>

Increase Structural Number(SN) or Modulus of Subgrade Soil or Decrease Reliability for Traffic.

Input File Name: Fort Worth SectionB Flexible Treat

COMPLETE OUTPUT FILE

PROJECT NAME :Fort Worth Section B_Flexible Treatment
PROJECT DATE :June 26th 2006
CSJ NUMBER :0000-00-000
PROJECT ENGINEER :Gyeong Taek Hong

***** INPUT DATA *****

PAVEMENT TYPES : FLEXIBLE PAVEMENTS

SOIL PROPERTIES

LAYER # 1
SOIL TYPE = STABILIZED SOIL
THICKNESS (ft) = 3.00
LIQUID LIMIT (%) = 60.00
PLASTICITY INDEX (%) = 36.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 30.00
DRY UNIT WEIGHT (lb/ft³) = 120.00
PERCENT OF LIME (%) = 6.00

LAYER # 2
SOIL TYPE = INERT SOIL
THICKNESS (ft) = 1.00
LIQUID LIMIT (%) = 25.00
PLASTICITY INDEX (%) = 10.00
PERCENT PASSING # 200 (%) = 10.00
LESS THAN 2 MICRONS (%) = 1.00
DRY UNIT WEIGHT (lb/ft³) = 130.00

LAYER # 3
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 1.00
LIQUID LIMIT (%) = 55.00
PLASTICITY INDEX (%) = 30.00
PERCENT PASSING # 200 (%) = 80.00
LESS THAN 2 MICRONS (%) = 25.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 4
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 4.00
LIQUID LIMIT (%) = 65.00
PLASTICITY INDEX (%) = 38.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 30.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 5
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 0.50
LIQUID LIMIT (%) = 30.00
PLASTICITY INDEX (%) = 15.00
PERCENT PASSING # 200 (%) = 35.00
LESS THAN 2 MICRONS (%) = 10.00
DRY UNIT WEIGHT (lb/ft³) = 115.00

LAYER # 6
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 1.50
LIQUID LIMIT (%) = 53.00
PLASTICITY INDEX (%) = 32.00
PERCENT PASSING # 200 (%) = 80.00
LESS THAN 2 MICRONS (%) = 25.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 7
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 4.00

LIQUID LIMIT (%)	=	45.00
PLASTICITY INDEX (%)	=	15.00
PERCENT PASSING # 200 (%)	=	99.00
LESS THAN 2 MICRONS (%)	=	37.00
DRY UNIT WEIGHT (lb/ft ³)	=	100.00

ELEMENT DATA

LAYER NO.	LAYER THICK.(ft)	NO. OF ELEMENTS
1	3.00	16
2	1.00	6
3	1.00	6
4	4.00	20
5	0.50	3
6	1.50	8
7	4.00	6

ENVIRONMENTAL AND GEOMETRIC CONDITION

MEAN THORNTONTHWAITE MOISTURE INDEX	=	-10.00
ROOT DEPTH,ZR (ft)	=	0.00
DEPTH OF MOISTURE ACTIVE ZONE,ZM (ft)	=	15.00
WIDTH OF PAVEMENT (ft)	=	83.00
LONGITUDINAL SLOP	=	SLOPE
LATERAL DRAINAGE	=	FILL

WHEEL PATH DATA

NO.	DISTANCE FROM THE CENTER OF PAVEMENT (ft)
1	27.00
2	15.00
3	5.00

INITIAL ROUGHNESS

WHEEL PATH NO.	SI	IRI (in/mi)
1	4.20	75.20
2	4.20	75.20
3	4.20	75.20

DEPTH OF VERTICAL BARRIER (ft) = 0.00

STRUCTURAL PROPERTIES OF PAVEMENT

STRUCTURAL NUMBER (ft)	=	0.48
FALLING WEIGHT DEFLECTOMETER MODULUS OF SUBGRADE SOIL (FROM DROP WEIGHT CLOSEST TO 9K LOAD) (psi)	=	10000.00

TRAFFIC DATA

WHEEL PATH NO.	1
TRAFFIC ANALYSIS PERIOD (Years)	= 30.0
ADT IN ONE DIRECTION WHEN T=0	= 13712.0
ADT IN ONE DIRECTION WHEN T=C	= 21744.0
18 kip SINGLE AXLES WHEN T=C	= 8415520.0

WHEEL PATH NO.	2
TRAFFIC ANALYSIS PERIOD (Years)	= 30.0
ADT IN ONE DIRECTION WHEN T=0	= 13712.0
ADT IN ONE DIRECTION WHEN T=C	= 21744.0
18 kip SINGLE AXLES WHEN T=C	= 8415520.0

WHEEL PATH NO.	3
TRAFFIC ANALYSIS PERIOD (Years)	= 30.0
ADT IN ONE DIRECTION WHEN T=0	= 13712.0
ADT IN ONE DIRECTION WHEN T=C	= 21744.0
18 kip SINGLE AXLES WHEN T=C	= 8415520.0

RELIABILITY FOR TRAFFIC	= 95.0
FOR ROUGHNESS CONSTANTS Bs AND Bi	= 95.0

***** RESULTS *****

SUCTION COMPRESSION INDEX (SCI)

LAYER NO.	ZONE	SCI	alpha(cm^2/s)
1	3	0.0212	0.00336000
2	2	0.0120	0.00336000
3	3	0.0469	0.00336000
4	3	0.0565	0.00330400
5	2	0.0257	0.00344000
6	2	0.0547	0.00386400
7	4	0.0262	0.00304400

SUCTION PROFILE(h), VOL. WATER CONTENT(m), AND VERTICAL MOVEMENT

DEPTH(ft)	h(EQ.)	h(WET)	h(DRY)	m(WET)	m(DRY)	SWELL(IN)	SHRINK(IN)	TOTAL(IN)
0.00	3.45	2.50	4.50	0.1259	0.0540	0.3064	0.5979	0.9043
0.19	3.45	3.45	4.47	0.0917	0.0551	0.2610	0.5816	0.8426
0.38	3.45	3.45	4.44	0.0917	0.0562	0.2610	0.5657	0.8267
0.56	3.45	3.45	4.41	0.0917	0.0573	0.2610	0.5499	0.8108
0.75	3.45	3.45	4.38	0.0917	0.0584	0.2610	0.5341	0.7950
0.94	3.45	3.45	4.35	0.0917	0.0594	0.2610	0.5183	0.7793
1.13	3.45	3.45	4.32	0.0917	0.0604	0.2610	0.5027	0.7636
1.31	3.45	3.45	4.29	0.0917	0.0613	0.2610	0.4871	0.7481
1.50	3.45	3.45	4.27	0.0917	0.0623	0.2610	0.4717	0.7327
1.69	3.45	3.45	4.24	0.0917	0.0632	0.2610	0.4564	0.7174
1.88	3.45	3.45	4.22	0.0917	0.0641	0.2610	0.4413	0.7023
2.06	3.45	3.45	4.20	0.0917	0.0649	0.2610	0.4264	0.6874
2.25	3.45	3.45	4.17	0.0917	0.0657	0.2610	0.4117	0.6726
2.44	3.45	3.45	4.15	0.0917	0.0665	0.2610	0.3971	0.6581
2.63	3.45	3.45	4.13	0.0917	0.0673	0.2610	0.3828	0.6437
2.81	3.45	3.45	4.11	0.0917	0.0680	0.2610	0.3686	0.6296
3.00	3.45	3.45	4.09	0.0917	0.0688	0.2610	0.3547	0.6157
3.17	3.45	2.89	4.07	0.1188	0.0734	0.2610	0.3478	0.6087
3.33	3.45	2.90	4.05	0.1179	0.0741	0.2493	0.3409	0.5902
3.50	3.45	2.92	4.04	0.1173	0.0747	0.2380	0.3342	0.5722
3.67	3.45	2.93	4.02	0.1167	0.0753	0.2273	0.3276	0.5548
3.83	3.45	2.95	4.01	0.1162	0.0759	0.2172	0.3211	0.5383
4.00	3.45	2.96	3.99	0.1157	0.0765	0.2078	0.3146	0.5225
4.17	3.45	2.97	3.98	0.4550	0.2909	0.1769	0.2909	0.4678
4.33	3.45	2.99	3.96	0.4529	0.2933	0.1490	0.2675	0.4165
4.50	3.45	3.00	3.95	0.4508	0.2955	0.1240	0.2446	0.3686
4.67	3.45	3.01	3.93	0.4488	0.2978	0.1016	0.2221	0.3237
4.83	3.45	3.02	3.92	0.4469	0.2999	0.0820	0.2007	0.2827
5.00	3.45	3.04	3.91	0.4450	0.3020	0.0648	0.1806	0.2454
5.20	3.45	3.05	3.89	0.4940	0.3407	0.0445	0.1546	0.1991
5.40	3.45	3.06	3.88	0.4916	0.3434	0.0282	0.1308	0.1590
5.60	3.45	3.08	3.86	0.4893	0.3459	0.0158	0.1091	0.1248
5.80	3.45	3.09	3.85	0.4871	0.3484	0.0070	0.0894	0.0964
6.00	3.45	3.10	3.84	0.4849	0.3508	0.0018	0.0718	0.0736
6.20	3.45	3.11	3.82	0.4828	0.3531	0.0000	0.0562	0.0562
6.40	3.45	3.12	3.81	0.4808	0.3554	0.0000	0.0426	0.0426
6.60	3.45	3.13	3.80	0.4788	0.3575	0.0000	0.0309	0.0309
6.80	3.45	3.14	3.79	0.4769	0.3596	0.0000	0.0212	0.0212
7.00	3.45	3.15	3.78	0.4751	0.3617	0.0000	0.0133	0.0133
7.20	3.45	3.16	3.77	0.4733	0.3636	0.0000	0.0073	0.0073
7.40	3.45	3.17	3.76	0.4716	0.3655	0.0000	0.0031	0.0031
7.60	3.45	3.18	3.75	0.4699	0.3674	0.0000	0.0007	0.0007
7.80	3.45	3.19	3.74	0.4683	0.3691	0.0000	0.0000	0.0000
8.00	3.45	3.20	3.73	0.4668	0.3708	0.0000	0.0000	0.0000
8.20	3.45	3.21	3.72	0.4653	0.3725	0.0000	0.0000	0.0000
8.40	3.45	3.22	3.71	0.4638	0.3741	0.0000	0.0000	0.0000
8.60	3.45	3.22	3.70	0.4624	0.3757	0.0000	0.0000	0.0000
8.80	3.45	3.23	3.69	0.4610	0.3772	0.0000	0.0000	0.0000
9.00	3.45	3.24	3.68	0.4597	0.3786	0.0000	0.0000	0.0000
9.17	3.45	3.24	3.68	0.3069	0.2535	0.0000	0.0000	0.0000
9.33	3.45	3.25	3.67	0.3062	0.2542	0.0000	0.0000	0.0000
9.50	3.45	3.25	3.67	0.3055	0.2550	0.0000	0.0000	0.0000
9.69	3.45	3.26	3.66	0.3866	0.3246	0.0000	0.0000	0.0000
9.88	3.45	3.27	3.65	0.3858	0.3255	0.0000	0.0000	0.0000
10.06	3.45	3.27	3.65	0.3850	0.3264	0.0000	0.0000	0.0000
10.25	3.45	3.28	3.64	0.3842	0.3273	0.0000	0.0000	0.0000
10.44	3.45	3.28	3.64	0.3834	0.3282	0.0000	0.0000	0.0000
10.63	3.45	3.29	3.63	0.3826	0.3290	0.0000	0.0000	0.0000
10.81	3.45	3.29	3.63	0.3819	0.3298	0.0000	0.0000	0.0000
11.00	3.45	3.30	3.62	0.3812	0.3306	0.0000	0.0000	0.0000
11.67	3.45	3.31	3.60	0.4769	0.4208	0.0000	0.0000	0.0000
12.33	3.45	3.33	3.59	0.4740	0.4240	0.0000	0.0000	0.0000
13.00	3.45	3.34	3.57	0.4714	0.4269	0.0000	0.0000	0.0000
13.67	3.45	3.35	3.56	0.4691	0.4295	0.0000	0.0000	0.0000

14.33	3.45	3.36	3.55	0.4670	0.4317	0.0000	0.0000	0.0000
15.00	3.45	3.45	3.45	0.4652	0.4338	0.0000	0.0000	0.0000

TOTAL POTENTIAL VERTICAL SWELLING = 0.026 ft
 TOTAL POTENTIAL VERTICAL SHRINKAGE = 0.050 ft
 TOTAL 1-D VERTICAL MOVEMENT = 0.075 ft

THE DEPTH OF MOVEMENT ACTIVE ZONE FOR WETTEST = 6.00 ft
 THE DEPTH OF MOVEMENT ACTIVE ZONE FOR DRYTEST = 7.60 ft

DEPTH OF VERTICAL BARRIER = 0.00ft

DEPTH OF AVAILABLE MOISTURE dam (ft) = 1.03
 PARAMETERS FOR VERTICAL MOVEMENT
 XI-1 = 0.3759
 XI-2 = 0.8210
 XI-3 = 3.5141

EQUATION FOR 2D VERTICAL MOVEMENT

$VM = 8.64 * \exp((0.8210 * d/D) ** 3.5141) \text{ mm}$

VERTICAL MOVEMENT
 DISTANCE FROM CENTER ,d, (ft) VERTICAL MOVEMENT,VM,(inches)
 27.00 0.38
 15.00 0.34
 5.00 0.34

WHEEL PATH NO. 1

DISTANCE FROM CENTER OF THE PAVEMENT (ft) = 27.00

ROUGHNESS CONSTANTS
 THE COEFFICIENT ,AS = 476.5531
 THE COEFFICIENT ,BS = 24.8608
 THE COEFFICIENT ,Rhos = 236.8177
 THE COEFFICIENT ,Ai = 940.2037
 THE COEFFICIENT ,Bi = 49.2369
 THE COEFFICIENT ,Rhoi = 465.4063

ESTIMATED ROUGHNESS WITH TIME

YEAR	PSI	IRI(in/mi)	dPSI(SOILS)	dPSI(TRAFFIC)	DIRI(SOILS)	DIRI(TRAFFIC)
0	4.20	75.20	0.00	0.00	0.00	0.00
1	4.20	75.28	0.00	0.00	0.08	0.00
2	4.17	76.19	0.03	0.00	0.91	0.08
3	4.12	78.08	0.07	0.01	2.50	0.38
4	4.05	80.58	0.12	0.03	4.42	0.96
5	3.97	83.39	0.17	0.05	6.40	1.79
6	3.90	86.31	0.22	0.08	8.30	2.82
7	3.83	89.26	0.26	0.12	10.07	3.99
8	3.76	92.17	0.29	0.15	11.69	5.28
9	3.70	95.00	0.32	0.19	13.17	6.63
10	3.64	97.75	0.34	0.23	14.50	8.04
11	3.58	100.39	0.36	0.26	15.71	9.48
12	3.53	102.94	0.38	0.30	16.81	10.94
13	3.48	105.39	0.39	0.33	17.79	12.40
14	3.43	107.74	0.40	0.37	18.69	13.85
15	3.39	110.00	0.41	0.40	19.49	15.30
16	3.34	112.16	0.42	0.44	20.23	16.74
17	3.30	114.25	0.43	0.47	20.89	18.15
18	3.27	116.25	0.43	0.50	21.50	19.55
19	3.23	118.17	0.44	0.53	22.05	20.93
20	3.20	120.03	0.44	0.56	22.55	22.28
21	3.17	121.81	0.45	0.59	23.01	23.60
22	3.14	123.53	0.45	0.62	23.42	24.91
23	3.11	125.19	0.45	0.64	23.81	26.19
24	3.08	126.80	0.45	0.67	24.15	27.44
25	3.05	128.35	0.45	0.69	24.47	28.67
26	3.03	129.84	0.45	0.72	24.76	29.88
27	3.00	131.29	0.45	0.74	25.03	31.06
28	2.98	132.69	0.45	0.77	25.28	32.22
29	2.96	134.05	0.45	0.79	25.50	33.35
30	2.94	135.37	0.45	0.81	25.70	34.46

WHEEL PATH NO. 2

DISTANCE FROM CENTER OF THE PAVEMENT (ft) = 15.00

ROUGHNESS CONSTANTS

THE COEFFICIENT ,As	= 476.5531
THE COEFFICIENT ,Bs	= 24.8608
THE COEFFICIENT ,Rhos	= 258.8540
THE COEFFICIENT ,Ai	= 940.2037
THE COEFFICIENT ,Bi	= 49.2369
THE COEFFICIENT ,Rhoi	= 509.0492

ESTIMATED ROUGHNESS WITH TIME

YEAR	PSI	IRI(in/mi)	dPSI(SOILS)	dPSI(TRAFFIC)	DIRI(SOILS)	DIRI(TRAFFIC)
0	4.20	75.20	0.00	0.00	0.00	0.00
1	4.20	75.25	0.00	0.00	0.05	0.00
2	4.18	75.96	0.02	0.00	0.68	0.08
3	4.13	77.52	0.06	0.01	1.94	0.38
4	4.07	79.68	0.10	0.03	3.52	0.96
5	4.00	82.16	0.14	0.05	5.17	1.79
6	3.94	84.80	0.18	0.08	6.78	2.82
7	3.87	87.49	0.21	0.12	8.30	3.99
8	3.81	90.18	0.24	0.15	9.70	5.28
9	3.74	92.82	0.27	0.19	10.99	6.63
10	3.69	95.40	0.29	0.23	12.16	8.04
11	3.63	97.90	0.31	0.26	13.22	9.48
12	3.58	100.32	0.32	0.30	14.18	10.94
13	3.53	102.66	0.33	0.33	15.06	12.40
14	3.49	104.91	0.34	0.37	15.85	13.85
15	3.44	107.08	0.35	0.40	16.57	15.30
16	3.40	109.17	0.36	0.44	17.23	16.74
17	3.36	111.18	0.37	0.47	17.83	18.15
18	3.33	113.13	0.37	0.50	18.38	19.55
19	3.29	115.00	0.38	0.53	18.87	20.93
20	3.26	116.81	0.38	0.56	19.33	22.28
21	3.22	118.55	0.39	0.59	19.74	23.60
22	3.19	120.23	0.39	0.62	20.13	24.91
23	3.16	121.86	0.39	0.64	20.47	26.19
24	3.14	123.44	0.39	0.67	20.79	27.44
25	3.11	124.96	0.39	0.69	21.09	28.67
26	3.08	126.43	0.40	0.72	21.36	29.88
27	3.06	127.86	0.40	0.74	21.60	31.06
28	3.04	129.25	0.40	0.77	21.83	32.22
29	3.01	130.59	0.40	0.79	22.04	33.35
30	2.99	131.90	0.40	0.81	22.23	34.46

WHEEL PATH NO. 3

DISTANCE FROM CENTER OF THE PAVEMENT (ft) = 5.00

ROUGHNESS CONSTANTS

THE COEFFICIENT ,As	= 476.5531
THE COEFFICIENT ,Bs	= 24.8608
THE COEFFICIENT ,Rhos	= 261.8163
THE COEFFICIENT ,Ai	= 940.2037
THE COEFFICIENT ,Bi	= 49.2369
THE COEFFICIENT ,Rhoi	= 514.9161

ESTIMATED ROUGHNESS WITH TIME

YEAR	PSI	IRI(in/mi)	dPSI(SOILS)	dPSI(TRAFFIC)	DIRI(SOILS)	DIRI(TRAFFIC)
0	4.20	75.20	0.00	0.00	0.00	0.00
1	4.20	75.25	0.00	0.00	0.05	0.00
2	4.18	75.93	0.02	0.00	0.65	0.08
3	4.13	77.46	0.06	0.01	1.88	0.38
4	4.07	79.57	0.10	0.03	3.41	0.96
5	4.01	82.01	0.14	0.05	5.02	1.79
6	3.94	84.62	0.18	0.08	6.60	2.82
7	3.88	87.28	0.21	0.12	8.09	3.99
8	3.81	89.94	0.24	0.15	9.46	5.28
9	3.75	92.55	0.26	0.19	10.72	6.63
10	3.69	95.11	0.28	0.23	11.87	8.04
11	3.64	97.59	0.30	0.26	12.91	9.48
12	3.59	99.99	0.31	0.30	13.86	10.94
13	3.54	102.31	0.33	0.33	14.72	12.40
14	3.49	104.55	0.34	0.37	15.50	13.85
15	3.45	106.71	0.35	0.40	16.21	15.30
16	3.41	108.79	0.35	0.44	16.86	16.74

17	3.37	110.80	0.36	0.47	17.45	18.15
18	3.33	112.73	0.37	0.50	17.98	19.55
19	3.30	114.60	0.37	0.53	18.47	20.93
20	3.26	116.40	0.38	0.56	18.92	22.28
21	3.23	118.14	0.38	0.59	19.33	23.60
22	3.20	119.82	0.38	0.62	19.71	24.91
23	3.17	121.44	0.38	0.64	20.05	26.19
24	3.14	123.01	0.39	0.67	20.37	27.44
25	3.12	124.53	0.39	0.69	20.66	28.67
26	3.09	126.00	0.39	0.72	20.93	29.88
27	3.07	127.43	0.39	0.74	21.17	31.06
28	3.04	128.81	0.39	0.77	21.39	32.22
29	3.02	130.15	0.39	0.79	21.60	33.35
30	3.00	131.45	0.39	0.81	21.79	34.46

Input File Name: Fort Worth SectionB Rigid Treat

COMPLETE OUTPUT FILE

PROJECT NAME :Fort Worth Section B_Rigid Treatment
PROJECT DATE :June 26th 2006
CSJ NUMBER :0000-00-000
PROJECT ENGINEER :Gyeong Taek Hong

***** INPUT DATA *****

PAVEMENT TYPES : RIGID PAVEMENTS

SOIL PROPERTIES

LAYER # 1
SOIL TYPE = STABILIZED SOIL
THICKNESS (ft) = 1.00
LIQUID LIMIT (%) = 60.00
PLASTICITY INDEX (%) = 36.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 30.00
DRY UNIT WEIGHT (lb/ft³) = 120.00
PERCENT OF LIME (%) = 6.00

LAYER # 2
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 3.00
LIQUID LIMIT (%) = 60.00
PLASTICITY INDEX (%) = 36.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 30.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 3
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 1.50
LIQUID LIMIT (%) = 55.00
PLASTICITY INDEX (%) = 30.00
PERCENT PASSING # 200 (%) = 80.00
LESS THAN 2 MICRONS (%) = 25.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 4
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 4.00
LIQUID LIMIT (%) = 65.00
PLASTICITY INDEX (%) = 38.00
PERCENT PASSING # 200 (%) = 85.00
LESS THAN 2 MICRONS (%) = 30.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 5
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 0.50
LIQUID LIMIT (%) = 30.00
PLASTICITY INDEX (%) = 15.00
PERCENT PASSING # 200 (%) = 35.00
LESS THAN 2 MICRONS (%) = 10.00
DRY UNIT WEIGHT (lb/ft³) = 115.00

LAYER # 6
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 1.50
LIQUID LIMIT (%) = 53.00
PLASTICITY INDEX (%) = 32.00
PERCENT PASSING # 200 (%) = 80.00
LESS THAN 2 MICRONS (%) = 25.00
DRY UNIT WEIGHT (lb/ft³) = 100.00

LAYER # 7
SOIL TYPE = NATURAL SOIL
THICKNESS (ft) = 4.00

LIQUID LIMIT (%)	=	45.00
PLASTICITY INDEX (%)	=	15.00
PERCENT PASSING # 200 (%)	=	99.00
LESS THAN 2 MICRONS (%)	=	37.00
DRY UNIT WEIGHT (lb/ft ³)	=	100.00

ELEMENT DATA

LAYER NO.	LAYER THICK.(ft)	NO. OF ELEMENTS
1	1.00	6
2	3.00	16
3	1.50	8
4	4.00	20
5	0.50	3
6	1.50	8
7	4.00	6

ENVIRONMENTAL AND GEOMETRIC CONDITION

MEAN THORNTONTHWAITE MOISTURE INDEX	=	-10.00
ROOT DEPTH,ZR (ft)	=	0.00
DEPTH OF MOISTURE ACTIVE ZONE,ZM (ft)	=	15.00
WIDTH OF PAVEMENT (ft)	=	83.00
LONGITUDINAL SLOP	=	SLOPE
LATERAL DRAINAGE	=	FILL

WHEEL PATH DATA

NO.	DISTANCE FROM THE CENTER OF PAVEMENT (ft)
1	27.00

INITIAL ROUGHNESS

WHEEL PATH NO.	SI	IRI (in/mi)
1	4.50	65.40

DEPTH OF VERTICAL BARRIER (ft) = 0.00

STRUCTURAL PROPERTIES OF PAVEMENT

CONCRETE PAVEMENT LAYER THICKNESS (ft)	=	1.00
FALLING WEIGHT DEFLECTOMETER MODULUS OF SUBGRADE SOIL FOR LOAD NEAR 9000lb	=	5820.00

DESIGN VARIABLES FOR RIGID PAVEMENT

28-DAY COMPRESSIVE STRENGTH OF CONCRETE (psi)	=	4000.00
ELASTIC MODULUS OF CONCRETE (psi)	=	3604996.53
MEAN MODULUS OF RUPTURE OF CONCRETE (psi)	=	620.00
DRAINAGE COEFFICIENT	=	1.00
LOAD TRANSFER COEFFICIENT	=	2.90
TERMINAL SERVICEABILITY INDEX FOR THE CONCRETE PAVEMENT	=	2.80

TRAFFIC DATA

WHEEL PATH NO.	1
TRAFFIC ANALYSIS PERIOD (Years)	= 30.0
ADT IN ONE DIRECTION WHEN T=0	= 13712.0
ADT IN ONE DIRECTION WHEN T=C	= 21744.0
18 kip SINGLE AXLES WHEN T=C	= 8415520.0

RELIABILITY

FOR TRAFFIC	= 95.0
FOR ROUGHNESS CONSTANTS BS AND Bi	= 95.0

***** RESULTS *****

SUCTION COMPRESSION INDEX (SCI)			
LAYER NO.	ZONE	SCI	alpha(cm ² /s)
1	3	0.0212	0.00252000
2	3	0.0706	0.00252000
3	3	0.0469	0.00336000
4	3	0.0565	0.00330400

5	2	0.0257	0.00344000
6	2	0.0547	0.00386400
7	4	0.0262	0.00304400

SUCTION PROFILE(h), VOL. WATER CONTENT(m), AND VERTICAL MOVEMENT

DEPTH(ft)	h(EQ.)	h(WET)	h(DRY)	m(WET)	m(DRY)	SWELL(IN)	SHRINK(IN)	TOTAL(IN)
0.00	3.45	2.50	4.50	0.1259	0.0540	1.4931	1.0560	2.5491
0.17	3.45	3.45	4.47	0.0917	0.0551	1.4527	1.0415	2.4942
0.33	3.45	3.45	4.43	0.0917	0.0563	1.4527	1.0274	2.4801
0.50	3.45	3.45	4.40	0.0917	0.0574	1.4527	1.0134	2.4660
0.67	3.45	3.45	4.37	0.0917	0.0585	1.4527	0.9993	2.4520
0.83	3.45	3.45	4.34	0.0917	0.0595	1.4527	0.9853	2.4380
1.00	3.45	3.45	4.32	0.0917	0.0605	1.4527	0.9714	2.4241
1.19	3.45	2.69	4.29	0.5263	0.2535	1.4527	0.9222	2.3748
1.38	3.45	2.72	4.26	0.5217	0.2586	1.3341	0.8734	2.2075
1.56	3.45	2.75	4.23	0.5173	0.2635	1.2208	0.8252	2.0460
1.75	3.45	2.77	4.20	0.5130	0.2682	1.1125	0.7776	1.8901
1.94	3.45	2.79	4.17	0.5089	0.2727	1.0090	0.7307	1.7397
2.13	3.45	2.82	4.15	0.5050	0.2771	0.9100	0.6845	1.5945
2.31	3.45	2.84	4.12	0.5012	0.2813	0.8154	0.6390	1.4544
2.50	3.45	2.86	4.10	0.4975	0.2854	0.7248	0.5944	1.3192
2.69	3.45	2.88	4.08	0.4939	0.2893	0.6382	0.5506	1.1888
2.88	3.45	2.90	4.06	0.4905	0.2931	0.5553	0.5076	1.0629
3.06	3.45	2.92	4.03	0.4872	0.2968	0.4759	0.4655	0.9414
3.25	3.45	2.94	4.01	0.4840	0.3003	0.3999	0.4242	0.8242
3.44	3.45	2.96	3.99	0.4809	0.3037	0.3287	0.3839	0.7126
3.63	3.45	2.98	3.97	0.4779	0.3070	0.2646	0.3444	0.6091
3.81	3.45	2.99	3.96	0.4751	0.3102	0.2073	0.3059	0.5132
4.00	3.45	3.01	3.94	0.4723	0.3132	0.1565	0.2683	0.4247
4.19	3.45	3.02	3.92	0.4472	0.2996	0.1268	0.2433	0.3701
4.38	3.45	3.04	3.91	0.4450	0.3020	0.1006	0.2188	0.3195
4.56	3.45	3.05	3.89	0.4430	0.3043	0.0779	0.1949	0.2728
4.75	3.45	3.06	3.88	0.4409	0.3065	0.0583	0.1717	0.2300
4.94	3.45	3.07	3.87	0.4390	0.3087	0.0417	0.1502	0.1920
5.13	3.45	3.08	3.85	0.4371	0.3108	0.0281	0.1303	0.1584
5.31	3.45	3.10	3.84	0.4352	0.3128	0.0173	0.1120	0.1293
5.50	3.45	3.11	3.83	0.4335	0.3148	0.0091	0.0953	0.1044
5.70	3.45	3.12	3.82	0.4817	0.3544	0.0028	0.0770	0.0798
5.90	3.45	3.13	3.81	0.4797	0.3566	0.0000	0.0607	0.0607
6.10	3.45	3.14	3.79	0.4777	0.3587	0.0000	0.0464	0.0464
6.30	3.45	3.15	3.78	0.4759	0.3608	0.0000	0.0341	0.0341
6.50	3.45	3.16	3.77	0.4741	0.3627	0.0000	0.0237	0.0237
6.70	3.45	3.17	3.76	0.4723	0.3647	0.0000	0.0153	0.0153
6.90	3.45	3.18	3.75	0.4707	0.3665	0.0000	0.0087	0.0087
7.10	3.45	3.19	3.74	0.4690	0.3683	0.0000	0.0040	0.0040
7.30	3.45	3.20	3.73	0.4675	0.3701	0.0000	0.0011	0.0011
7.50	3.45	3.20	3.72	0.4659	0.3718	0.0000	0.0000	0.0000
7.70	3.45	3.21	3.71	0.4645	0.3734	0.0000	0.0000	0.0000
7.90	3.45	3.22	3.70	0.4630	0.3750	0.0000	0.0000	0.0000
8.10	3.45	3.23	3.70	0.4617	0.3765	0.0000	0.0000	0.0000
8.30	3.45	3.23	3.69	0.4603	0.3780	0.0000	0.0000	0.0000
8.50	3.45	3.24	3.68	0.4590	0.3794	0.0000	0.0000	0.0000
8.70	3.45	3.25	3.67	0.4578	0.3808	0.0000	0.0000	0.0000
8.90	3.45	3.26	3.67	0.4566	0.3821	0.0000	0.0000	0.0000
9.10	3.45	3.26	3.66	0.4554	0.3834	0.0000	0.0000	0.0000
9.30	3.45	3.27	3.65	0.4543	0.3846	0.0000	0.0000	0.0000
9.50	3.45	3.27	3.64	0.4532	0.3858	0.0000	0.0000	0.0000
9.67	3.45	3.28	3.64	0.3026	0.2582	0.0000	0.0000	0.0000
9.83	3.45	3.28	3.63	0.3020	0.2589	0.0000	0.0000	0.0000
10.00	3.45	3.29	3.63	0.3015	0.2595	0.0000	0.0000	0.0000
10.19	3.45	3.29	3.62	0.3816	0.3301	0.0000	0.0000	0.0000
10.38	3.45	3.30	3.62	0.3809	0.3309	0.0000	0.0000	0.0000
10.56	3.45	3.30	3.61	0.3802	0.3317	0.0000	0.0000	0.0000
10.75	3.45	3.31	3.61	0.3796	0.3324	0.0000	0.0000	0.0000
10.94	3.45	3.31	3.60	0.3789	0.3331	0.0000	0.0000	0.0000
11.13	3.45	3.31	3.60	0.3783	0.3338	0.0000	0.0000	0.0000
11.31	3.45	3.32	3.60	0.3777	0.3345	0.0000	0.0000	0.0000
11.50	3.45	3.32	3.59	0.3771	0.3351	0.0000	0.0000	0.0000
12.17	3.45	3.34	3.58	0.4724	0.4258	0.0000	0.0000	0.0000
12.83	3.45	3.35	3.56	0.4700	0.4285	0.0000	0.0000	0.0000
13.50	3.45	3.36	3.55	0.4678	0.4309	0.0000	0.0000	0.0000
14.17	3.45	3.37	3.54	0.4659	0.4330	0.0000	0.0000	0.0000
14.83	3.45	3.38	3.53	0.4642	0.4349	0.0000	0.0000	0.0000
15.50	3.45	3.45	3.45	0.4503	0.4503	0.0000	0.0000	0.0000

TOTAL POTENTIAL VERTICAL SWELLING = 0.124 ft
 TOTAL POTENTIAL VERTICAL SHRINKAGE = 0.088 ft

TOTAL 1-D VERTICAL MOVEMENT = 0.212 ft

THE DEPTH OF MOVEMENT ACTIVE ZONE FOR WETTEST = 5.70 ft
THE DEPTH OF MOVEMENT ACTIVE ZONE FOR DRYEST = 7.30 ft

DEPTH OF VERTICAL BARRIER = 0.00ft

DEPTH OF AVAILABLE MOISTURE dam (ft) = 1.48

PARAMETERS FOR VERTICAL MOVEMENT

XI-1 = 0.3710

XI-2 = 0.8917

XI-3 = 3.2025

EQUATION FOR 2D VERTICAL MOVEMENT

VM = 24.02 * EXP((-0.8917 * d/D) ** 3.2025) mm

VERTICAL MOVEMENT

DISTANCE FROM CENTER ,d, (ft)	VERTICAL MOVEMENT,VM,(inches)
27.00	1.13

WHEEL PATH NO. 1

DISTANCE FROM CENTER OF THE PAVEMENT (ft) = 27.00

ROUGHNESS CONSTANTS

THE COEFFICIENT ,AS = 903.9343

THE COEFFICIENT ,BS = 24.8608

THE COEFFICIENT ,Rhos = 192.5963

THE COEFFICIENT ,Ai = 1877.2769

THE COEFFICIENT ,Bi = 49.2369

THE COEFFICIENT ,Rhoi = 468.4679

ESTIMATED ROUGHNESS WITH TIME

YEAR	PSI	IRI(in/mi)	dPSI(SOILS)	dPSI(TRAFFIC)	dIRI(SOILS)	dIRI(TRAFFIC)
0	4.50	65.40	0.00	0.00	0.00	0.00
1	4.49	65.48	0.01	0.00	0.08	0.00
2	4.44	66.42	0.06	0.00	1.02	0.00
3	4.35	68.39	0.15	0.00	2.97	0.02
4	4.25	70.99	0.24	0.00	5.50	0.08
5	4.15	73.91	0.34	0.01	8.30	0.21
6	4.06	76.96	0.43	0.01	11.16	0.40
7	3.97	80.04	0.51	0.02	13.97	0.67
8	3.88	83.08	0.58	0.04	16.66	1.02
9	3.81	86.05	0.64	0.05	19.22	1.42
10	3.74	88.92	0.70	0.07	21.63	1.89
11	3.67	91.69	0.75	0.09	23.88	2.41
12	3.61	94.36	0.79	0.10	25.99	2.97
13	3.55	96.92	0.83	0.12	27.95	3.58
14	3.50	99.39	0.86	0.14	29.78	4.21
15	3.45	101.75	0.89	0.16	31.48	4.88
16	3.40	104.03	0.92	0.19	33.06	5.57
17	3.35	106.21	0.94	0.21	34.54	6.27
18	3.31	108.31	0.96	0.23	35.92	7.00
19	3.27	110.33	0.98	0.25	37.20	7.73
20	3.24	112.28	0.99	0.27	38.40	8.48
21	3.20	114.15	1.00	0.29	39.52	9.23
22	3.17	115.96	1.02	0.32	40.56	10.00
23	3.14	117.70	1.03	0.34	41.54	10.76
24	3.11	119.38	1.04	0.36	42.46	11.53
25	3.08	121.01	1.04	0.38	43.31	12.30
26	3.05	122.58	1.05	0.40	44.12	13.07
27	3.02	124.10	1.06	0.42	44.87	13.83
28	3.00	125.58	1.06	0.44	45.58	14.60
29	2.98	127.01	1.07	0.46	46.24	15.37
30	2.95	128.39	1.07	0.48	46.86	16.13

FLODEF

USER MANUAL

Version 1.0

by

Robert Lytton
Professor
Texas A&M University

Charles Aubeny
Associate Professor
Texas A&M University

Xiaoyan Long
Research Assistant
Texas Transportation Institute
Texas A&M University

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1. INTRODUCTION

FLODEF is a sequentially coupled unsaturated flow and deformation finite element method (FEM) analysis program. Originally developed by Dr. Robert Lytton and Dr. Derek Gay in 1993, the program computes the transient unsaturated moisture flow and movement in an expansive clay domain. Unsaturated moisture flow is analyzed through Mitchell's model by converting the nonlinear partial differential equation given in the modified Darcy's law into an ordinary partial differential equation.

The program has provided a friendly graphic user interface (GUI). The input part is composed of four sections: **site information**, **pavement section geometry**, **layer properties**, and **vegetation**. For the post-processing part, the user can have the options of viewing surface deformation plots, contour plots, time history plots, and vertical profile plots to check the analysis results.

2. PROGRAM INSTALLATION

It is recommended that the user's computer screen resolution be set to 1024 by 768 pixels. If the current computer monitor setting is not compatible with this requirement, adjust the setting by pressing the mouse's right button at the window screen to enter the “Properties” option, “Settings” tab, then change the screen resolution to 1024 by 768 pixels and select the “Apply” button.

To install the program, the user just inserts the attached CD in the computer drive and clicks the file “**Flodef_setup.exe**”. Then the program **winflow** can be automatically installed in any user-defined destination path.

3. INPUT

For the purpose of executing the program, the user needs to fill in the data for **Site Information** , **Pavement Section Geometry** , **Layer Properties**  and **Vegetation**  screens. The user can click the associated icon or menu toolbar to enter each input screen.

3.1 Site Information

The program provides choices of seasonal weather data at nine different locations in Texas (west Texas, central Texas, and east Texas): **El Paso, Snyder, Wichita Falls, Converse, Seguin, Dallas, Ennis, Houston, and Port Arthur**. If the actual field site is not located near any of these nine cities, select the region for analysis based on the TMI value and geological location ([Fig. 1](#)).

Initial moisture conditions at the beginning of analysis fall into three categories: **wet condition** (winter season), **equilibrium condition** (spring/fall season), and **dry condition** (summer season). Select the season most appropriate for the roadway during its expected lifespan.

Based on the user's requirement, the analysis period of 5 years, 10 years, 15 years, or 20 years can be selected. The program has the capability to compute the effects of vertical embedded moisture barrier, horizontal moisture barrier, median condition and drainage condition. The information of special geological formation such as a tinted limestone layer can be input in the "Special Soil Layer" box. The existences of one format of geological formation in different locations are accounted for more than one type of special subgrade layers.

The default equilibrium suctions for these nine locations are automatically calculated in the computer program. If the site has specific equilibrium suction value which doesn't match with the default value, the user can input the measured equilibrium suction value in the input screen to overwrite the default value.

Click the "Map" button on this screen to view a Texas map with indicated TMI values ([Fig. 2](#)).

FLODEF - [Site Information]

File Input Analysis View Help

Project Name: PRES

Project Engineer:

Region: El Paso (selected)

Initial Condition: Wet (selected)

Duration (years): 5 (selected)

Vertical Moisture Barriers: No (selected)

Special Soil Layer?: No? (selected)

Horizontal Moisture Barriers?: No? (selected)

Drainage Condition?: Good? (selected)

Median Condition: Paved Median (selected)

Ponded Water Depth in Ditch: 0 ft

Input equilibrium suction measurement: 3.5 pF

Map

Figure 1. Site Information Screen.

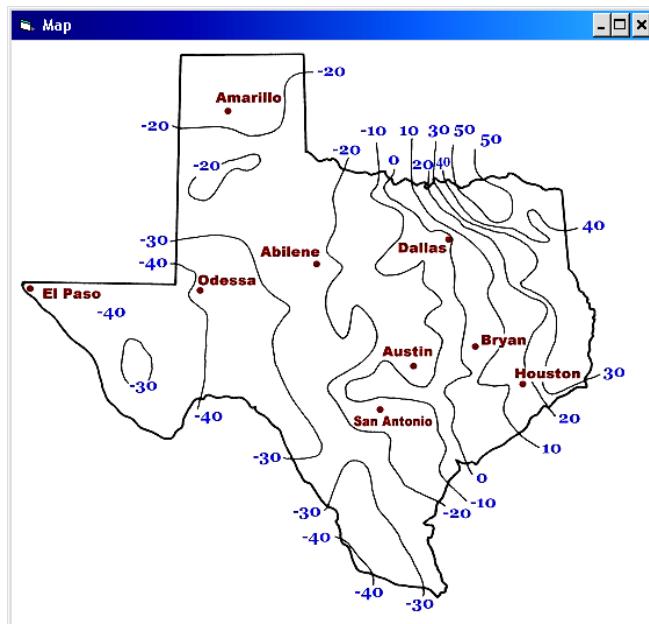


Figure 2. Texas Map with TMI Value Indicated.

3.2 Pavement Section Geometry

This section requires the user to input the roadway geometry dimensions (surface, base, subbase, and subgrade layer thicknesses plus pavement cross section information). Normally, the moisture active zone depth z_m is around 20 ft. If the sum of individual

subgrade layers is not less than 20 ft, the mesh analysis depth is set to 20 ft by the program. Where the total depth of the subgrade layers is less than 20 ft, for instance, in the situation that bedrock is encountered at shallow depth, the mesh depth is equal to the bedrock depth.

If the number of total subgrade layers is less than four, the user must split the deepest individual subgrade layer into two layers with duplicate data. The depth of the two layers does not have to be exactly equal but can be rounded to the nearest foot to make the sum of the two equal the total. (Example: The Drill Log only shows three subgrade layers. Subgrade layer 2 is 9 ft thick. Split this into subgrade layers 2 and 3 with depths of 5 ft, and 4 ft, respectively, and make the previous subgrade layer 3, subgrade layer 4.)

The unit for thicknesses of the surface, base, subbase courses is inches, while the depth of each subgrade layer is counted in ft. The side slopes S_1 , S_2 , R_3 , S_4 , R_5 , R_6 and S_7 are unitless and given by common slope designations used in construction, such as 2 to 1 or 10 to 1. It should be emphasized that none of the parameters (S_2 , S_4 , S_7 , Z_4 , Z_5 , Z_6 , Z_7 , X_3 , X_4 , X_5 and X_6) can receive an input value of zero. The minimum value that can be input is 0.01.

[Figure 3](#) below shows an illustration of the physical meanings of these parameters.

The manual provides examples of several types of mesh dimension combinations from the **Fort Worth Loop 820**, **Atlanta US 271**, and **Austin Loop 1** field conditions used in the initial research:

1) If the shoulder slope S_1 is not equal to zero (**Atlanta US 271 type**), then the input pavement dimension parameters should agree with the following two requirements: a) the sum of the surface and base course thickness equals the elevation difference of two sides of the shoulder ($(Z_1+Z_2)/12.0=(-1)*X_4/S_1$, where Z_1 , Z_2 have units in inches, and X_4 has units in ft); b) the total sum of surface, base course and subbase course thickness plus the subgrade layer 1 depth equals the value of elevation difference from the surface course to the ditch bottom ($(Z_1+Z_2+Z_3)/12+Z_4=(-1)*X_4/S_1+ (-1)*X_5/S_2$, where Z_1 , Z_2 have units in inches, and X_4 , X_5 have units in ft). The slope is negative when it goes clockwise and positive when rotating counterclockwise.

2) If the shoulder slope S_1 is equal to zero and the elevation difference from the surface course to the ditch bottom is very small (around 1 ft) (**Fort Worth study Section B type**), then the input pavement dimension parameters should conform to the following restriction: adjust the input value of surface course thickness Z_1 , and make Z_1 equal to the elevation difference from the surface course to the ditch bottom ($Z_1/12.0=(-1)*X_5/S_2$, where Z_1 has units in inches, X_5 has units in ft). If the shoulder slope S_1 is equal to zero and the elevation difference from the surface course to the ditch bottom is not small (greater than 1 ft)

(Fort Worth study Section A type, Austin Loop 360 type), then the input pavement dimension parameters should be input as follows: the total sum of surface course thickness Z_1 , base course thickness Z_2 , subbase course thickness Z_3 , and subgrade layer 1 thickness Z_4 should equal the elevation difference from the surface course to the ditch bottom ($((Z_1+Z_2+Z_3/12.0)+Z_4=(-1)*X_5/S_2$, where Z_1, Z_2, Z_3 have units in inches and Z_4 has units in ft).

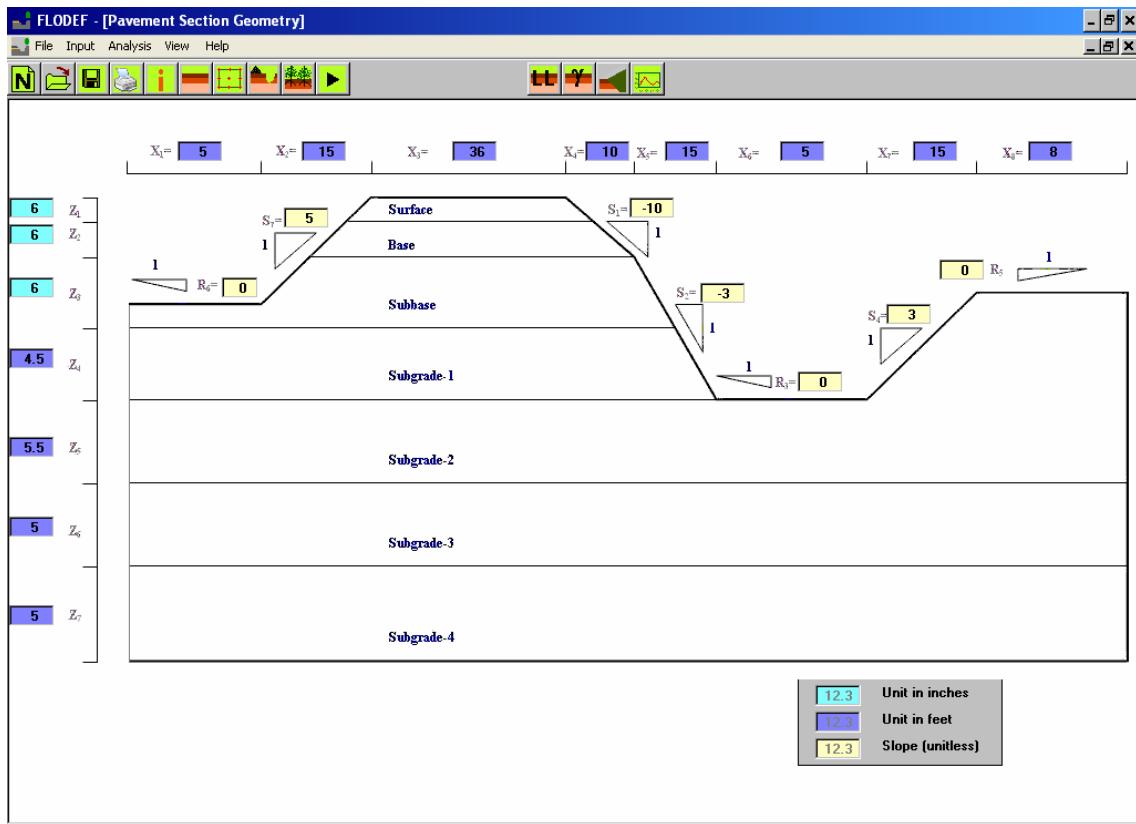


Figure 3. Pavement Section Geometry Screen.

3.3 Mesh View

After the user inputs the pavement section dimension values, the user should click the “Mesh View” icon  to review the mesh automatically generated by the program. The element types in the mesh are 8 nodes quadratic element and 6 nodes bilinear triangle element. The user can click the element to view the global node numbers for each element in the upper right window.

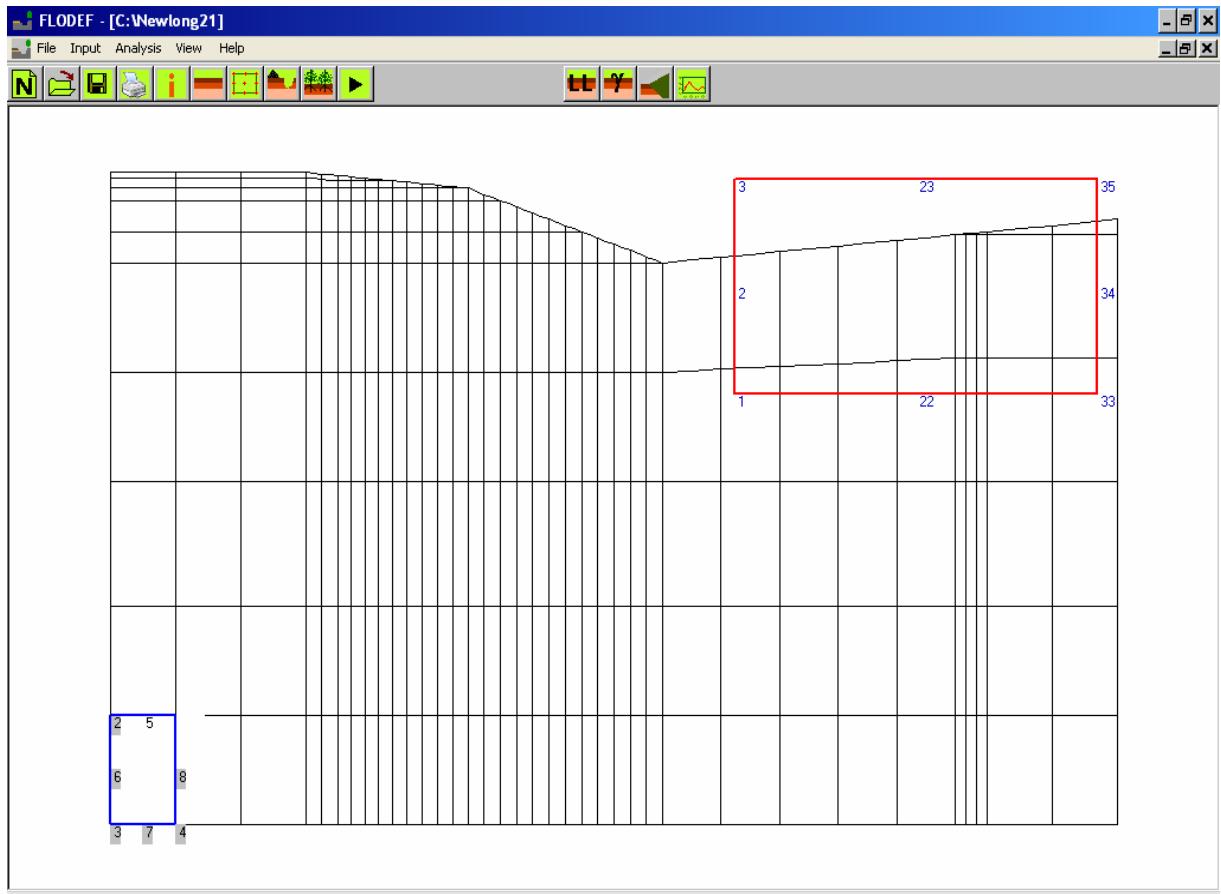


Figure 4. Automatic Mesh View Screen.

The user needs to input the pavement dimensions which satisfy the listed requirements in the manual. If the input data do not satisfy the requirements, when the “Mesh View” button is clicked, the program will give an error message and ask for a new input of pavement dimensions which conform to the described restrictions above.

3.4 Layer Properties

In this screen, the surface course type (asphalt/concrete), base course type (untreated granular/lime stabilized/cement stabilized/asphalt-treated), subbase course type (untreated granular/lime stabilized/cement stabilized/asphalt-treated), and subgrade layers properties data (LL, PI, percent of passing -200# sieve, percent of minus 2 micron clay content, Poisson’s ratio ν , dry unit weight γ_d) information is entered .

The subgrade layers are labeled in four layers (layer 1, 2, 3, 4) from top to bottom. Subgrade layers can be natural soil, inert soil, or soil stabilized with lime or cement. The default lime or cement percent by weight is 6%.

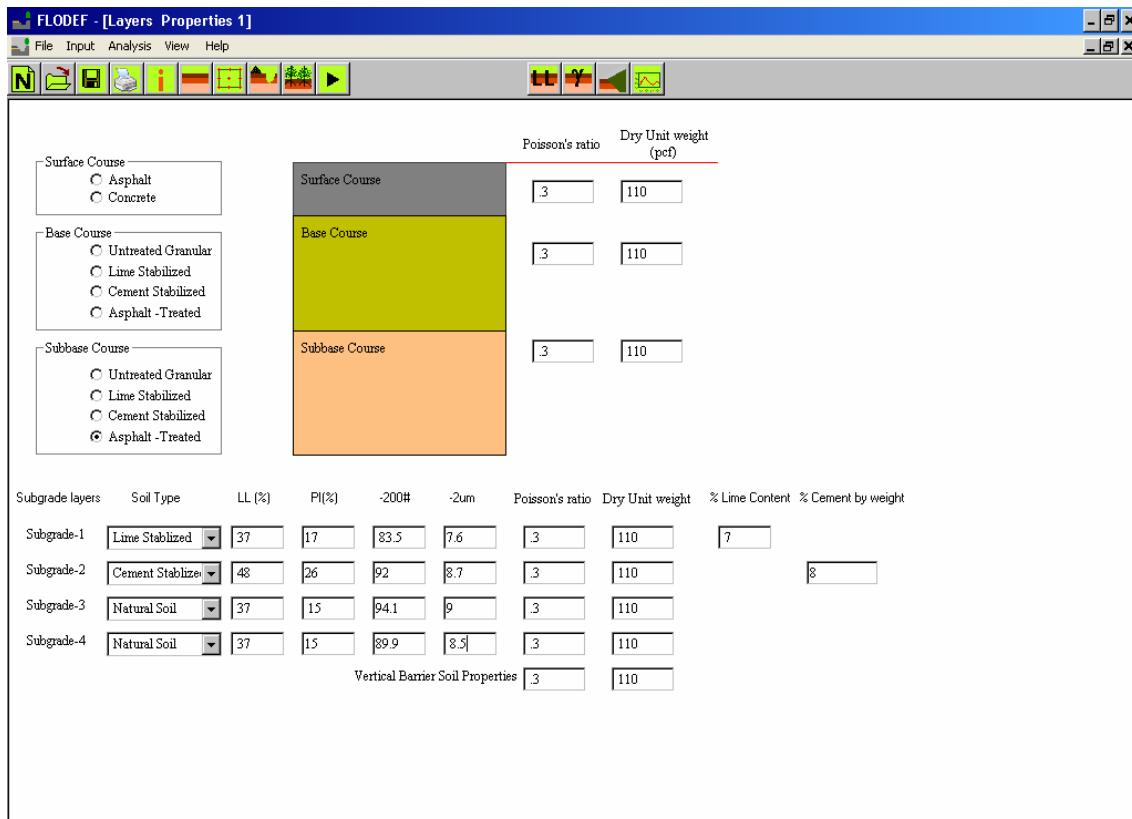


Figure 5. Layer Properties Screen.

3.5 Vegetation

The vegetation information (tree root zone depth/grass, if any) can be entered in this

screen by clicking the icon or “Input” option, “Vegetation” sub option.

If the field site has an existing tree, the user needs to click the “Tree” button and adjust the actual tree influence extent by slowly sliding the left line with the left mouse button and the right line with the right mouse button along the pavement cross section surface. It should be emphasized that the right line should not go beyond the right range of the pavement cross section when sliding and adjusting the vegetation location extent. The surface grass extent grass button can be input in the same way described above.

In this screen, the root transpiration rate and root zone depth are also required for the tree and grass information.

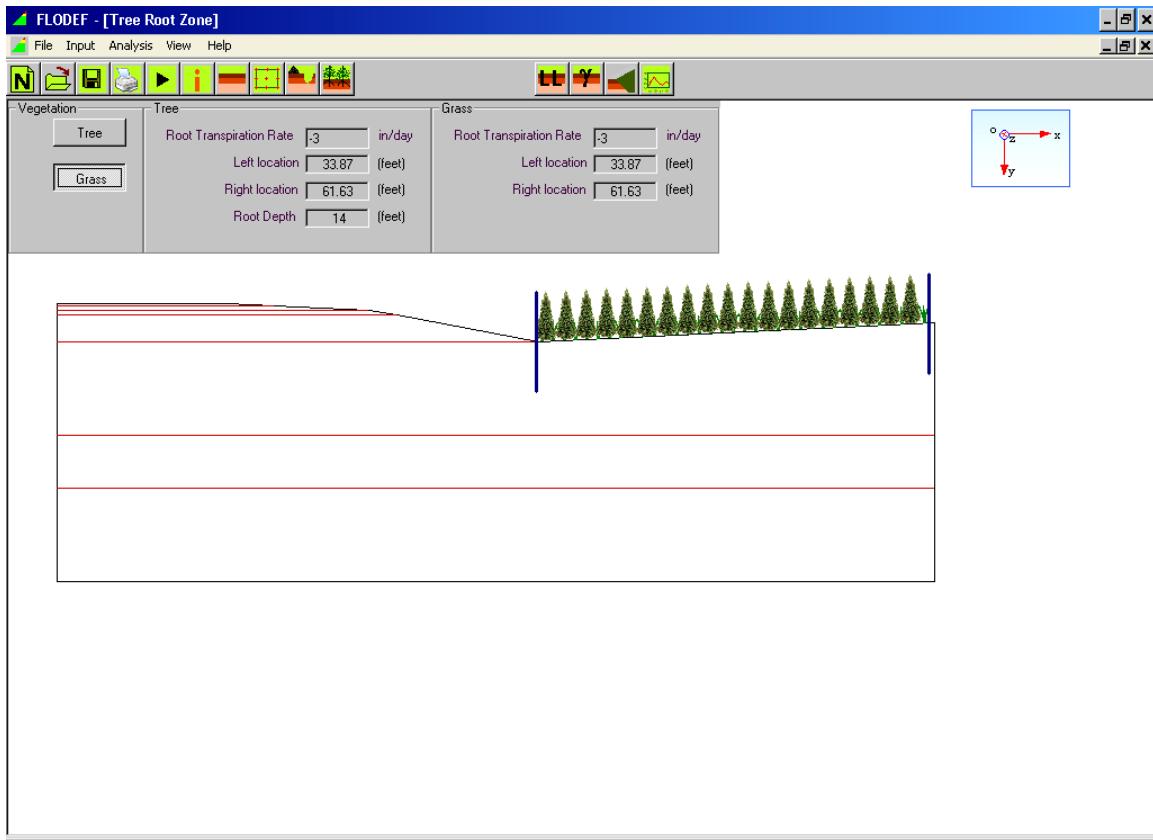


Figure 6. Vegetation Information Screen.

The default transpiration rate of 3mm/day is built into the program. It is an accurate value for most cases. Unless a very special situation occurs in which the user may contact the District Landscape Architect, Vegetation Management Specialist, or the Maintenance Division for the actual transpiration rate, the user can just adopt the default value for the analysis.

For the two-dimensional moisture diffusion and volume change analysis, the moisture diffusion coefficient, α , is an important material parameter. The program can automatically estimate the diffusion coefficient, α , according to the empirical relationship:

$$\alpha = 0.0029 - 0.000162 S - 0.0122 \gamma_h$$

where γ_h is the suction compression index (also estimated by program), and S is the slope of the suction-water content curve:

$$S = -20.3 - 0.155 (\text{LL}) - 0.117 (\text{PI}) + 0.068 (\%-\#200)$$

The above estimation of α is a default option; however, a site-specific determination is definitely desirable when sufficient data are available. Two approaches for a site-specific determination are discussed below.

(1) *Laboratory Measurement with Crack Correction*

The unsaturated soil diffusivity test performed in the laboratory represents conditions of an intact soil mass. While intact conditions can occur under certain conditions such as the absence of root penetration or desiccation cracking, more commonly some degree of cracking can be expected within the soil mass. Such cracking will substantially increase the apparent diffusivity, α_{field} , of the soil mass to well above that indicated from a laboratory test. In addition, the existence of fractures will generate heterogeneity in the soil mass such that α_{field} depends on sampling location; hence, α_{field} must be expressed in probabilistic terms. [Figure 7](#) shows the relationship of the ratio $\alpha_{\text{field}}/\alpha_{\text{lab}}$ expressed in terms of probability of non-exceedance for crack depths ranging from 1 to 16 ft. This figure shows that for crack depths up to 16 ft, α_{field} can exceed α_{lab} by a factor of greater than 100.

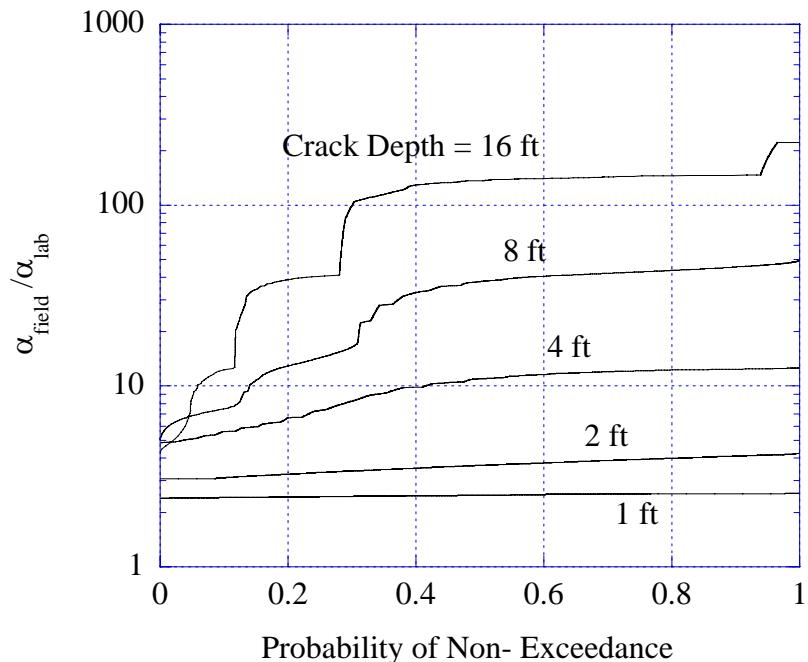


Figure 7. Adjustment of Laboratory Measurements of Diffusivity for Effects of Cracking.

[Figure 8](#) shows the general nature of desiccation crack patterns in a soil mass. Crack patterns near the ground surface are usually closely spaced. However, the spacing of deep cracks is much wider than the shallower cracks, with crack spacing being approximately equal to crack depth. Estimating crack depth through direct observation is generally difficult. However, there are several indirect indicators of crack depth that are reasonably reliable. The first is the occurrence of any root fiber. Tree roots cannot penetrate an intact clay mass; i.e., root penetration occurs along cracks in clay soils. In addition, the roots induce desiccation within a vicinity of about 2 ft; therefore, cracking will extend to about 2 ft deeper than the deepest root fiber.

Crack Spacing & Depth:

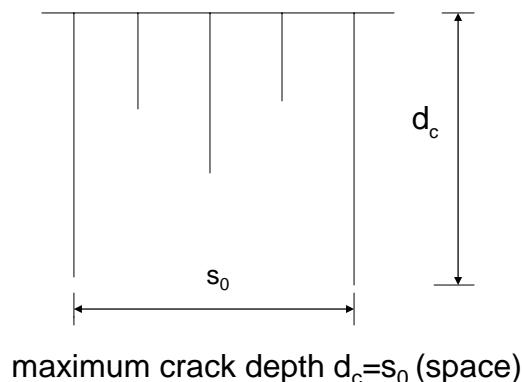


Figure 8. Typical Desiccation Crack Pattern in a Soil Mass.

Example

A diffusivity measured in a laboratory diffusion test indicates $\alpha_{lab} = 8.0 \times 10^{-5} \text{ cm}^2/\text{sec}$. Root fibers in the borehole from which the soil sample was taken were observed to a depth of 6 ft. Estimate the field diffusivity α_{field} corresponding to a 50% level of non-exceedance.

Since roots were observed to a depth of 6 ft, a maximum crack depth of 8 ft should be assumed. From [Fig. 7](#), for a 50% level of non-exceedance and a crack depth of 8 ft, $\alpha_{field}/\alpha_{lab}=40$. Hence:

$$\alpha_{field} = 40 \times 8.0 \times 10^{-5} \text{ cm}^2/\text{sec} = 3.2 \times 10^{-3} \text{ cm}^2/\text{sec}$$

A second indicator of tree root depth is a suction profile at or near the wilting point of vegetation, about 4.5 pF. [Figure 9](#) shows the characteristic suction profile of a deep root zone. Corrections for crack depths estimated through this method are computed in an identical manner as that shown in the above example.

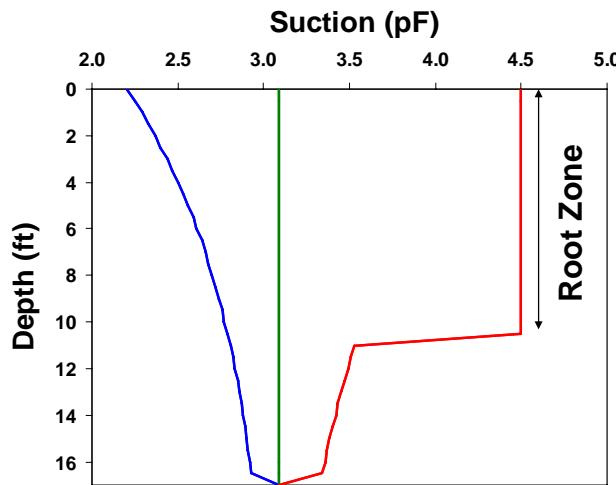


Figure 9. Characteristic Suction Profile for a Deep Root Zone.

(2) Diffusivity from the Depth of Moisture Active Zone

Estimates of the depth of the moisture active zone y_{ma} can also provide a basis for estimating field diffusivity α_{field} using the relationship:

$$\alpha_{field} = 0.6 n (y_{ma})^2$$

where n is the frequency of seasonal suction variation, usually 1 cycle/yr.

Example

An examination of a suction profile indicates that an equilibrium suction is reached at a depth of 12 ft. Estimate the field diffusivity α_{field} .

In this case, the depth of the moisture active zone $y_{ma} = 12$ ft. Assuming a seasonal frequency $n = 1$ yr leads to:

$$\alpha_{field} = 0.6 (1 \text{ cycle/yr}) (12 \text{ ft})^2 = 86.4 \text{ ft}^2/\text{yr}$$

Conversion to units of cm^2/sec leads to $\alpha_{field} = 2.6 \times 10^{-3} \text{ cm}^2/\text{sec}$.

4. RUN

After inputting all the required data information, click the “Run” icon  on the toolbar or “Analysis” option in the menu at the top of the screen to execute the program and perform an analysis.

The usual run time for a 5-year analysis on a PC (CPU around 1GHz) is about 20 minutes; 10 years, 40 minutes; 15 years, 60 minutes; and 20 years, 80 minutes. The running screen appears below in Fig. 10.

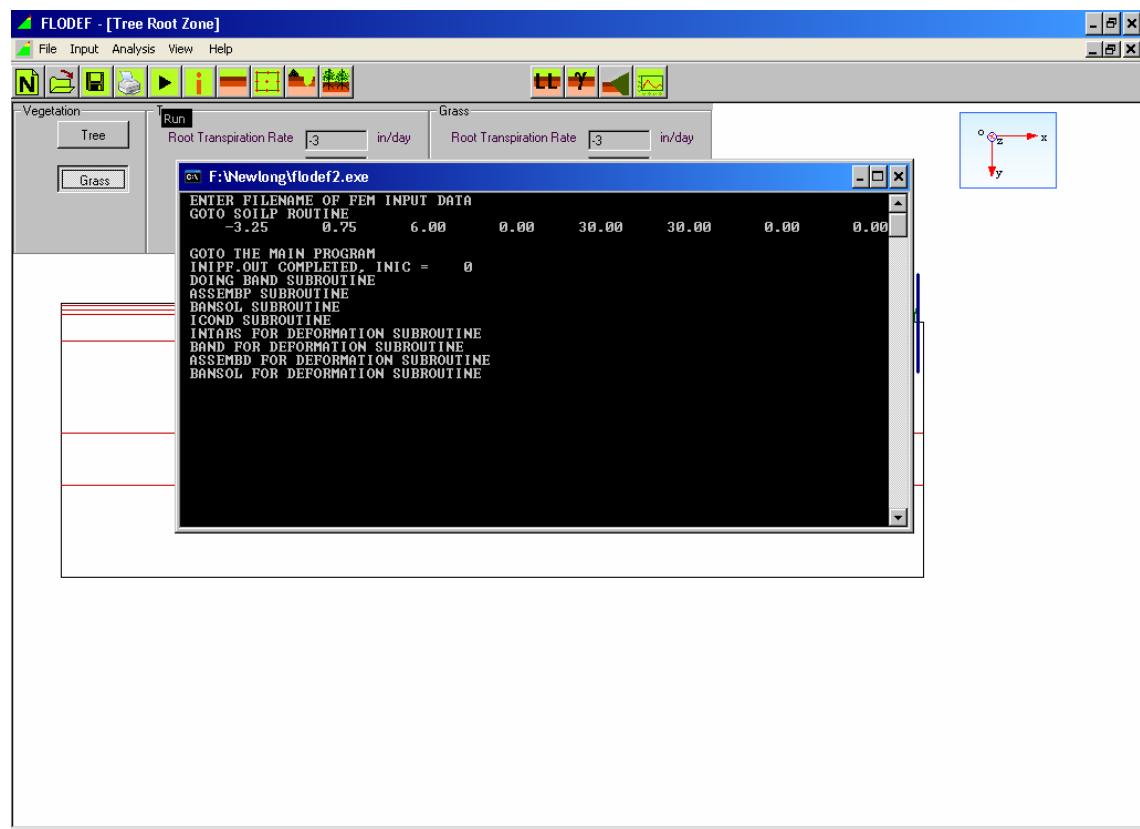


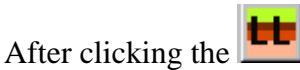
Figure 10. Running Screen.

5. OUTPUT

The program provides output options of vertical profile plot (suction/vertical displacements/horizontal displacements), contour plot (suction/vertical displacements/horizontal displacements), surface deformation plot and time history plot (suction/vertical displacements/horizontal displacements) to review the analysis results.

5.1 Vertical Profile Plots

The user can view the vertical profiles (**Suction/Vertical Displacements/ Horizontal Displacements**) of 30 equally divided segments along the pavement cross section.



After clicking the icon or “View” option, “Vertical Profiles” sub option on the menu bar, the following screen (Fig. 11) will appear.

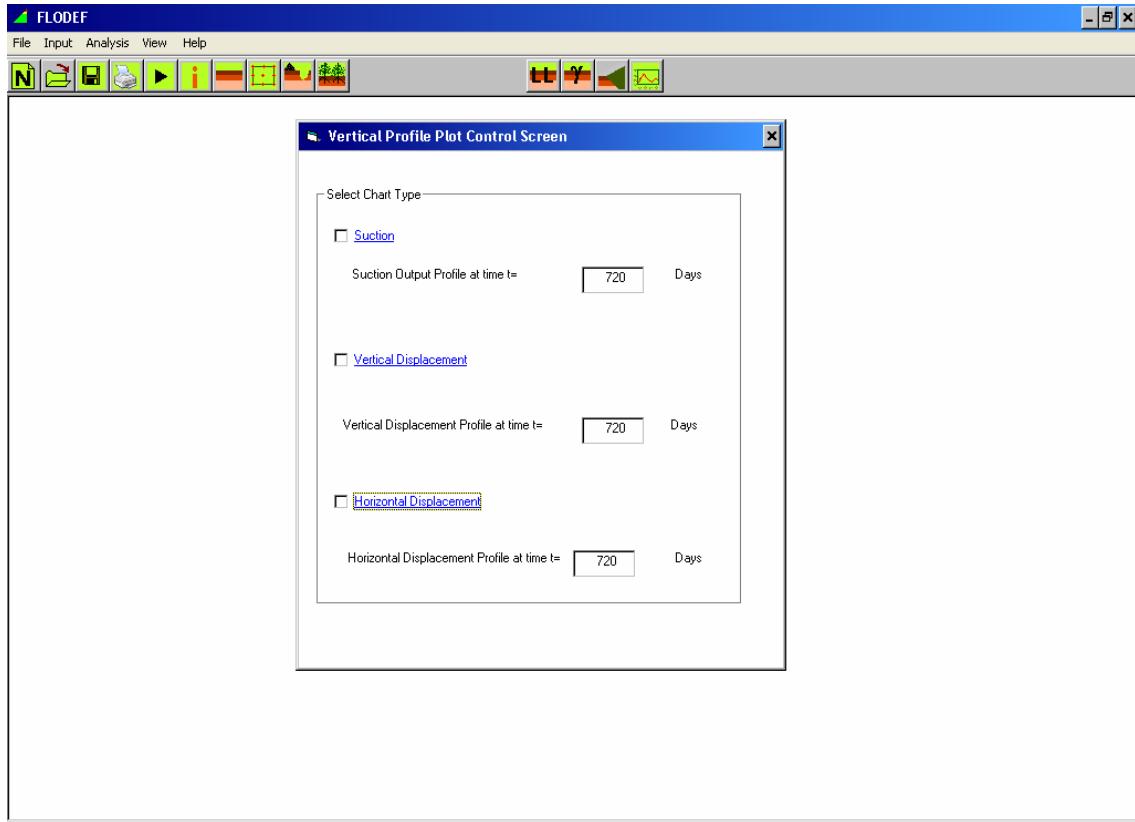


Figure 11. Vertical Profile Screens (1).

The user can view the associated vertical profile plots by inputting the desired output time in the textboxes and clicking the underlined label (suction/vertical displacement/horizontal displacement). If the cursor is moved along the vertical profile curve (black color), the associated suction (Fig. 12)/vertical displacement (Fig. 13)/horizontal displacement (Fig. 14) value and elevation y coordinate for this location will appear in the left upper screen (text in blue color). The blue dotted lines in Fig. 12/Fig. 13/Fig. 14 stand for the 30 equally divided segments in the pavement cross section, while the black solid lines are the suction curves (Fig. 12)/ vertical displacement curves (Fig. 13)/horizontal displacement curves (Fig. 14) for these segments.

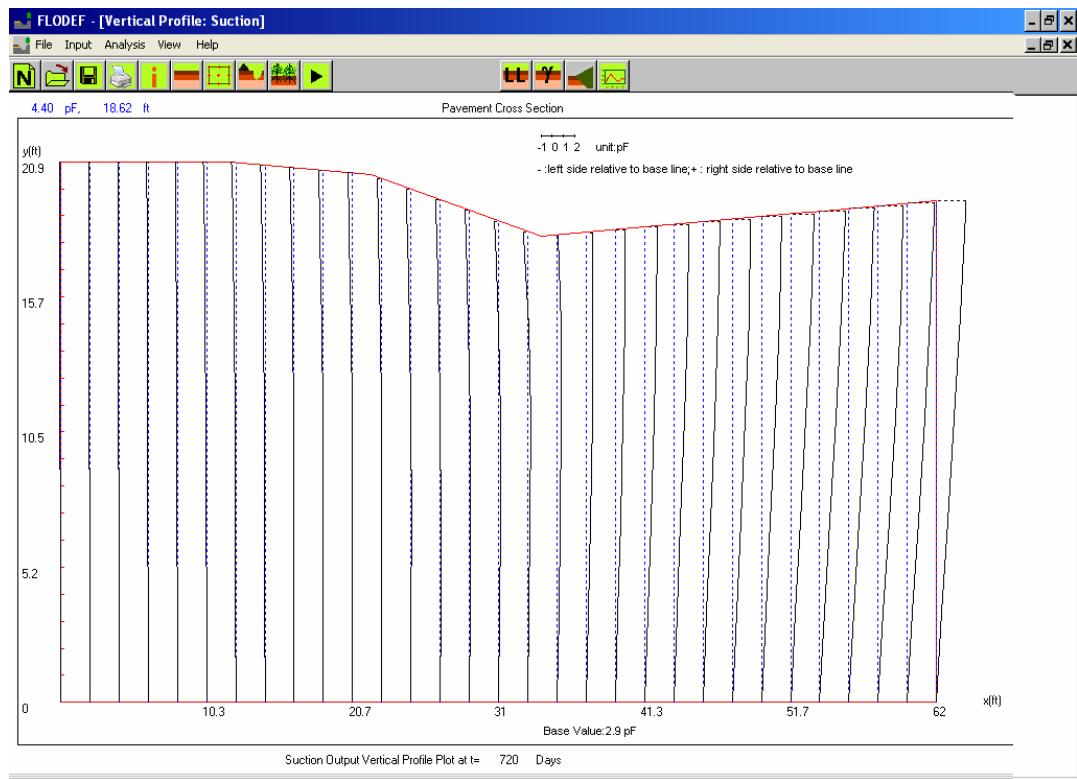


Figure 12. Vertical Profile Screens (2).

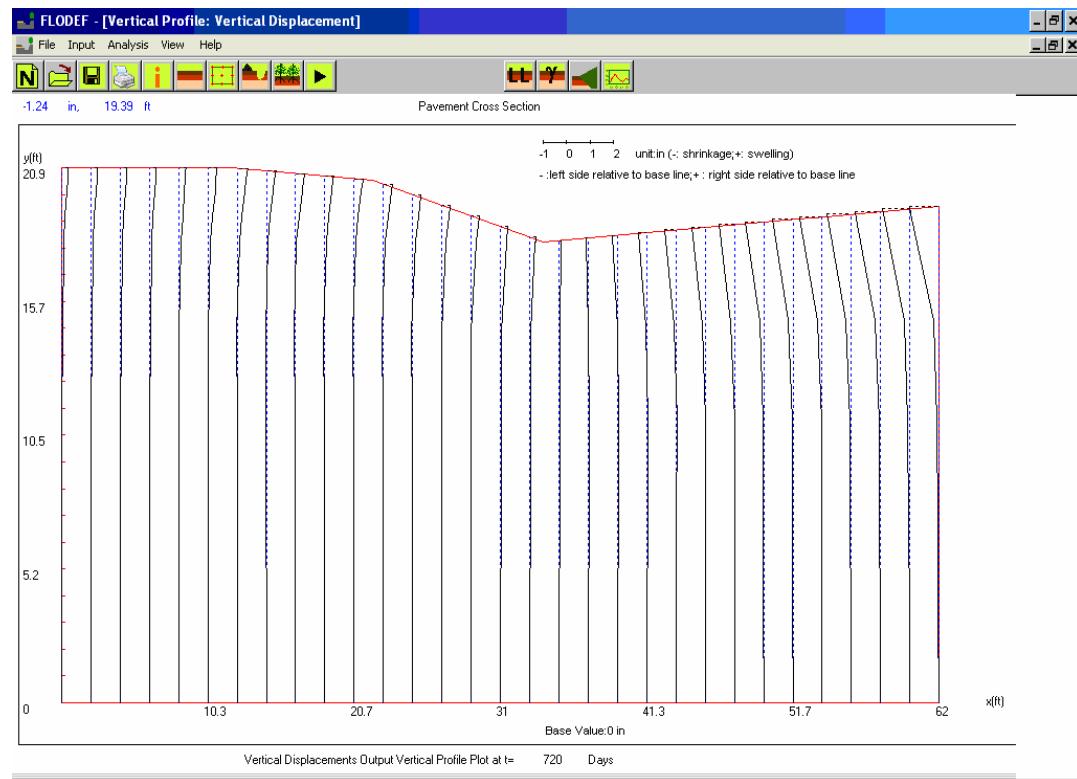


Figure 13. Vertical Profile Screens (3).

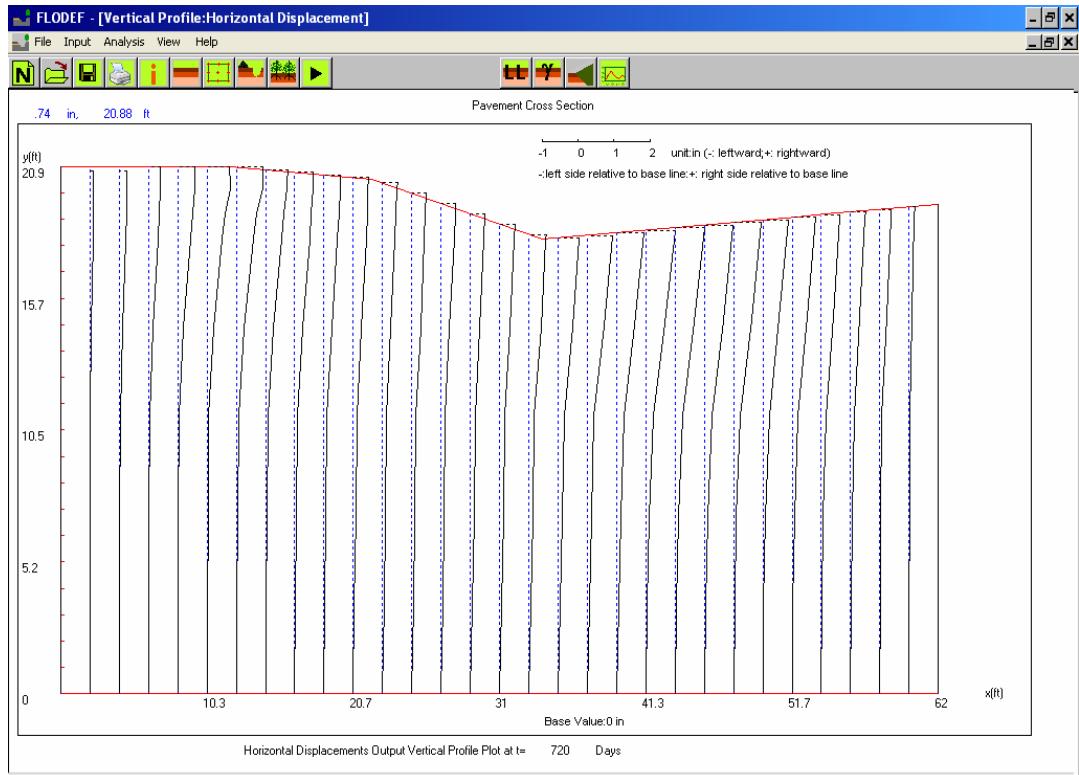


Figure 14. Vertical Profile Screens (4).

5.2 Contour Plots

After clicking the icon or “View” option, “Contours” sub option on the menu bar, the following screen ([Fig. 15](#)) will be shown.

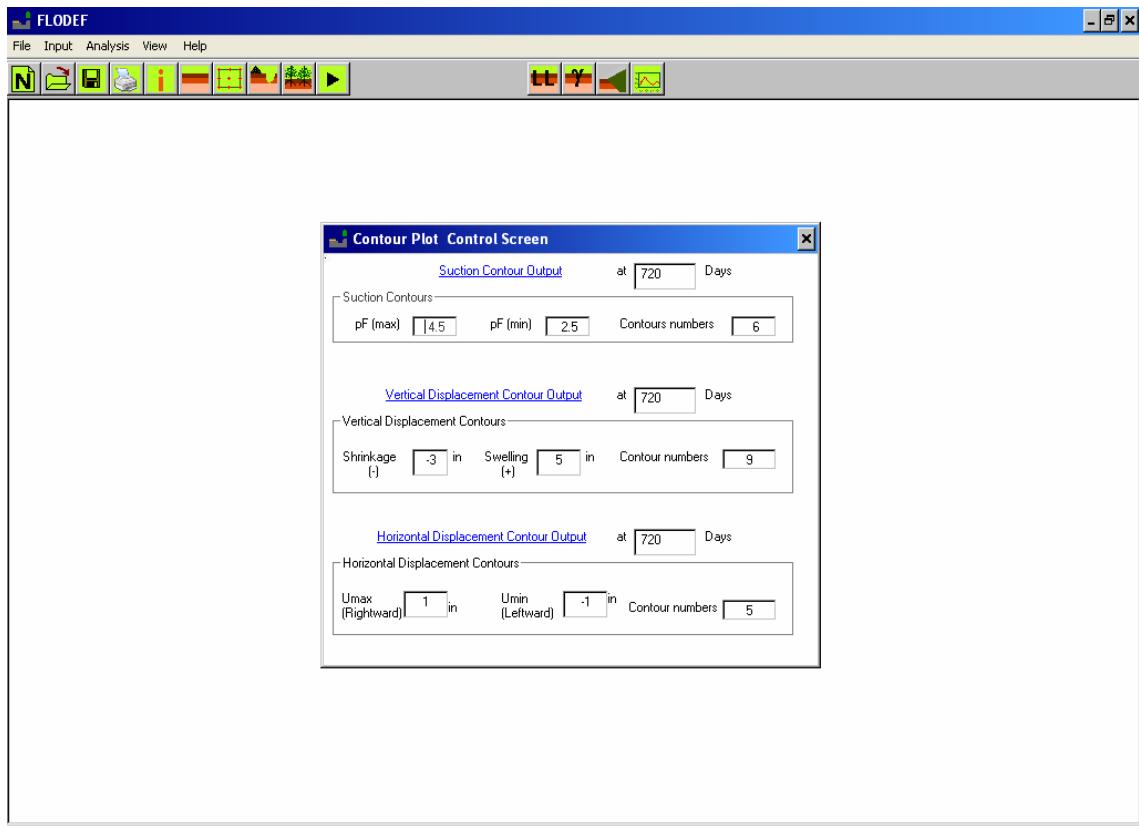


Figure 15. Vertical Plot Screens (1).

By clicking the underlined blue “Suction Contour Output”/“Vertical Displacement Contour Output”/“Horizontal Displacement Contour Output” labels, the user can view the suction contours (Fig. 16)/ vertical displacement contours (Fig. 17)/horizontal displacement contours (Fig. 18) after the desired output time, maximum/minimum display values and number of desired contours are input to the associated textboxes. The maximum value of the number of specified contours is 12 in this program.

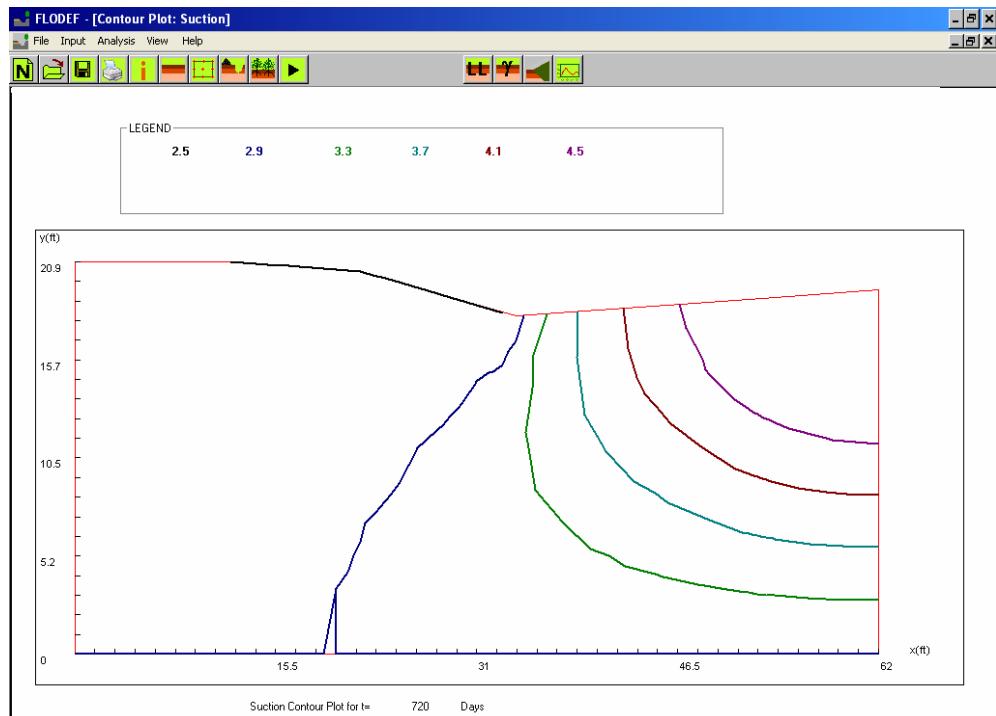


Figure 16. Contour Plot Screens (2).



Figure 17. Contour Plot Screens (3).

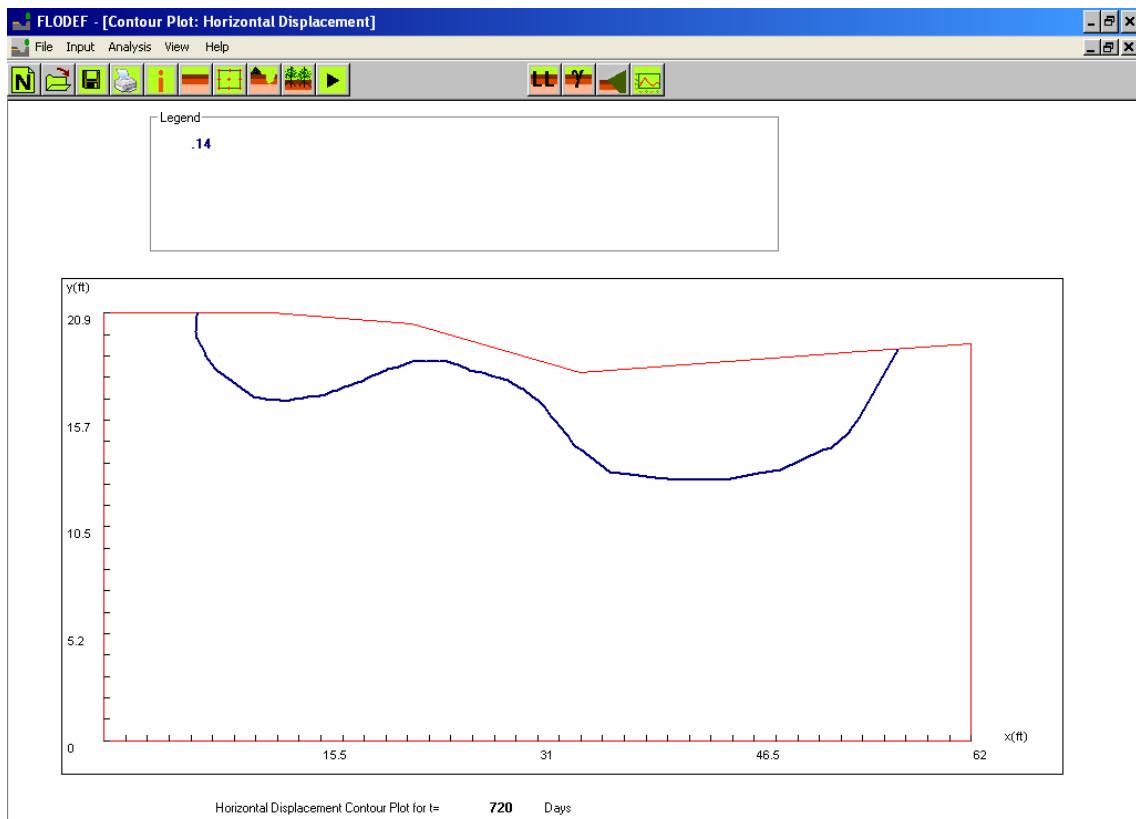


Figure 18. Contour Plot Screens (4).

It should be pointed out that for some combinations of maximum/minimum display values and number of specified contours, the program can not show any contour curve for these desired contour values.

The user can distinguish the contour lines by the associated colors. In the legend, each text is shown with a different color. For example, in Fig. 16, the text “4.1” in the legend has a red font color, so the red suction contour curve stands for suction value “4.1”. The unit for vertical displacement and horizontal displacement is inches. For vertical displacement, positive values “(+)” denote swelling and for horizontal displacement, “positive (+)” values denote rightward horizontal movement.

5.3 Surface Deformation Plot



After clicking the  icon or “View” option, “Surface Deformation Plots” sub option on the menu bar, the following screen ([Fig. 19](#)) will appear below for specifying the desired output time, t .

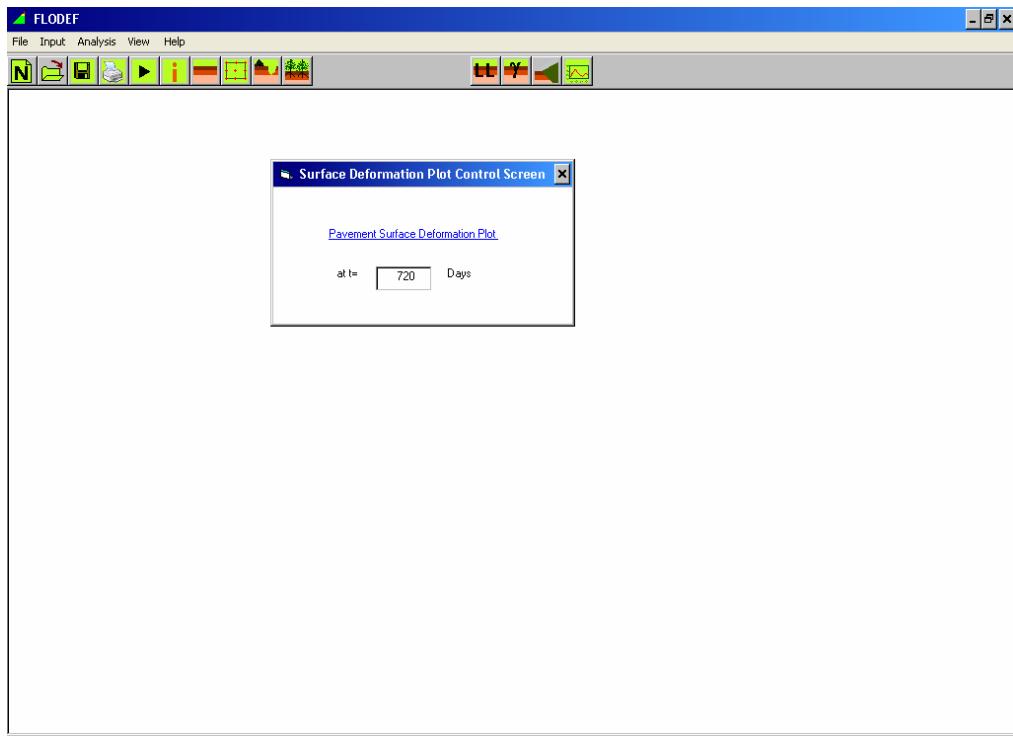


Figure 19. Surface Deformation Plot Screen (1).

By clicking the blue underlined “Pavement Surface Deformation Plot” label, the user can see the screen shown in Fig. 20.

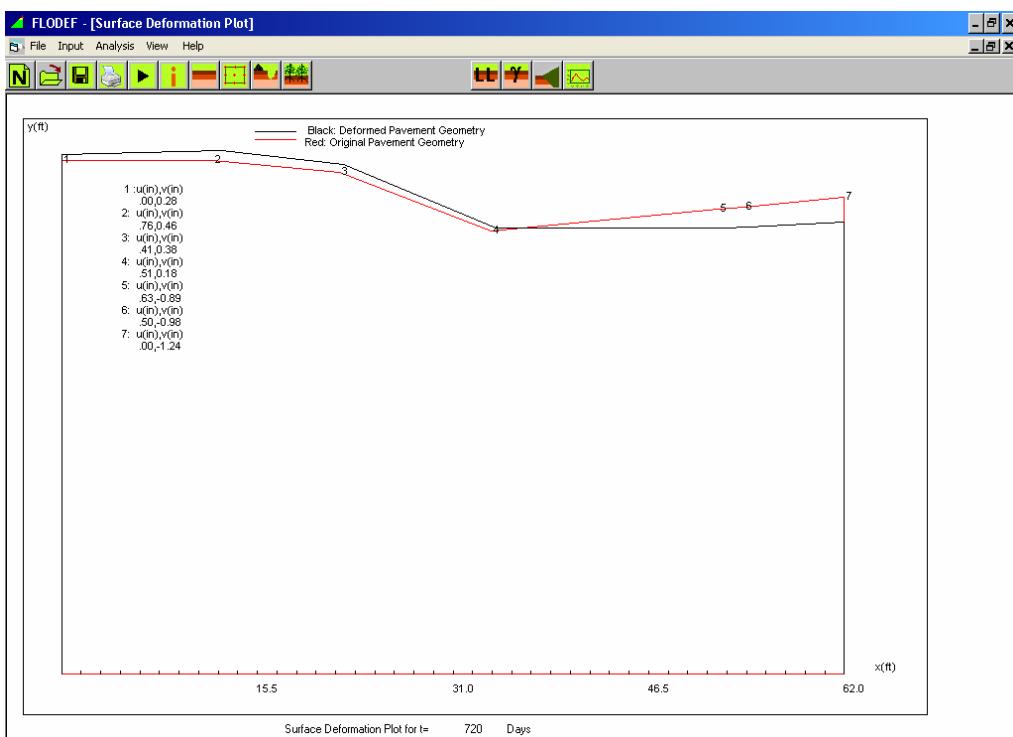


Figure 20. Surface Deformation Plot Screen (2).

5.4 Time History Plots

Figure 21 provides the options for the program to view different time history plots [suction (Fig. 22)/ vertical displacement (Fig. 23)/ horizontal displacement (Fig. 24)] for any

desired location in the pavement cross section. The viewer can either click the  icon or click on “View → Time History Plots → Suction/Vertical Displacement/Horizontal Displacement” sub option on the menu bar to review the time history plots (Figs. 21-24) for 5,10,15, and 20 years analysis periods.

The “Time History Output Charts Control Screen” (Fig. 21) will appear only if the

user clicks the  icon.

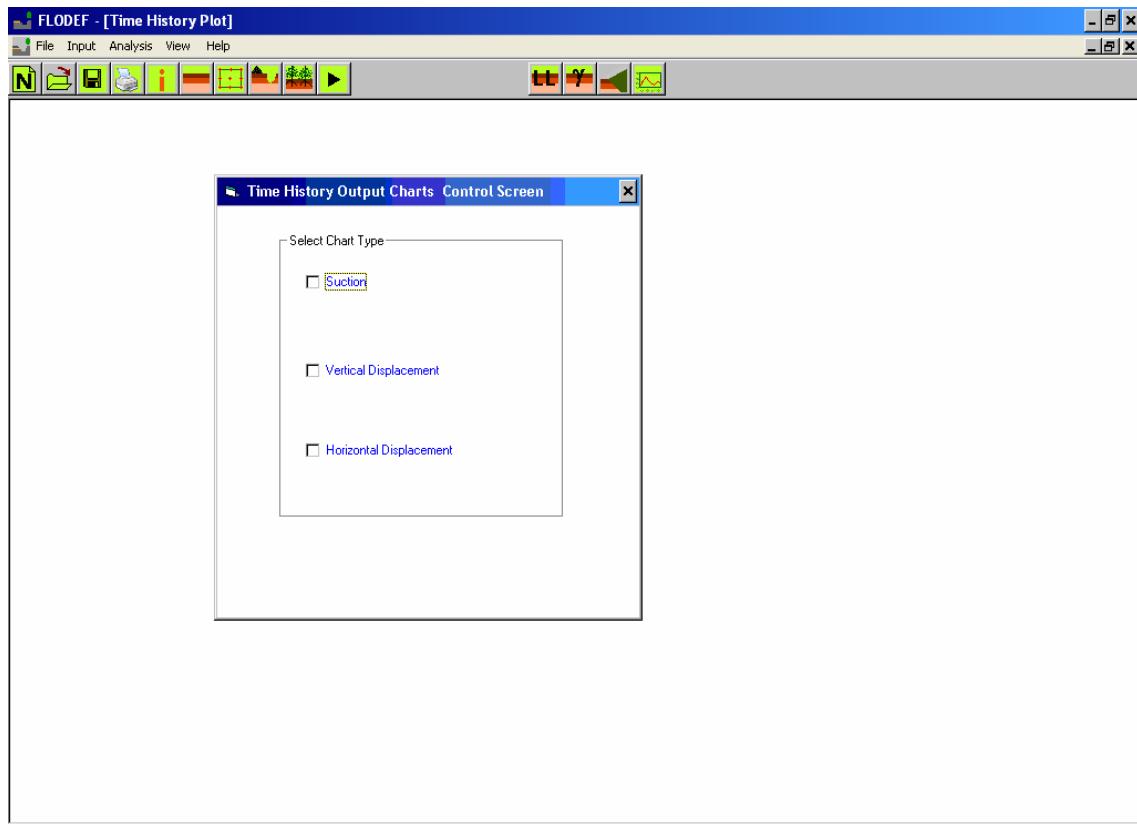


Figure 21. Time History Plot Screens (1).

By clicking the blue labels for “Suction,” “Vertical Displacement,” “Horizontal Displacement,” the user can view Figs. 22, 23, and 24.

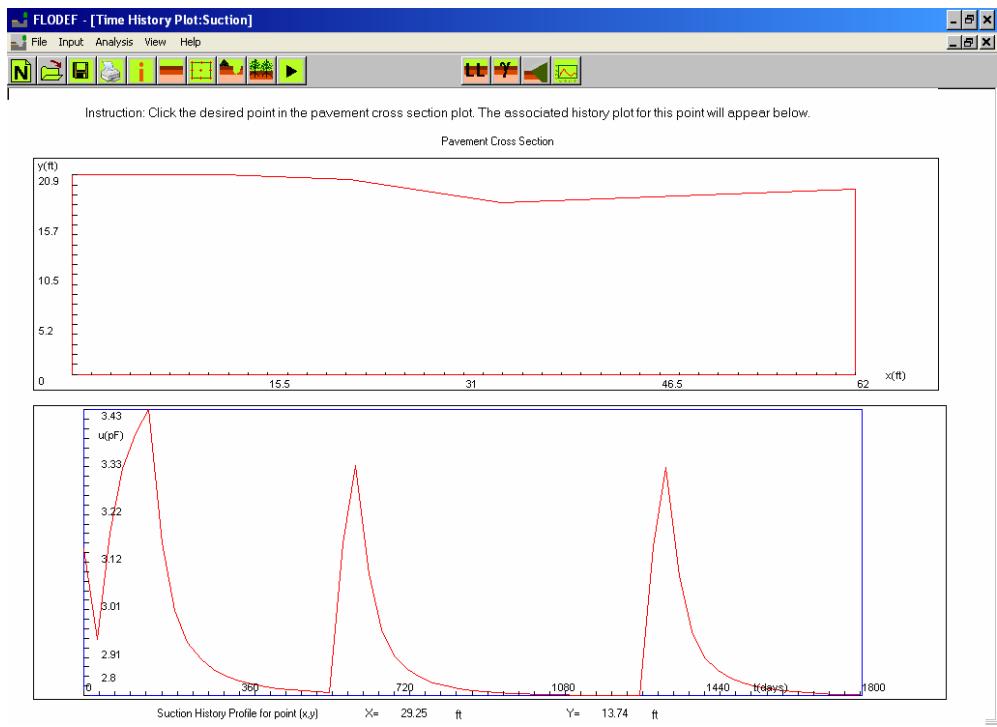


Figure 22. Time History Plot Screens (2).

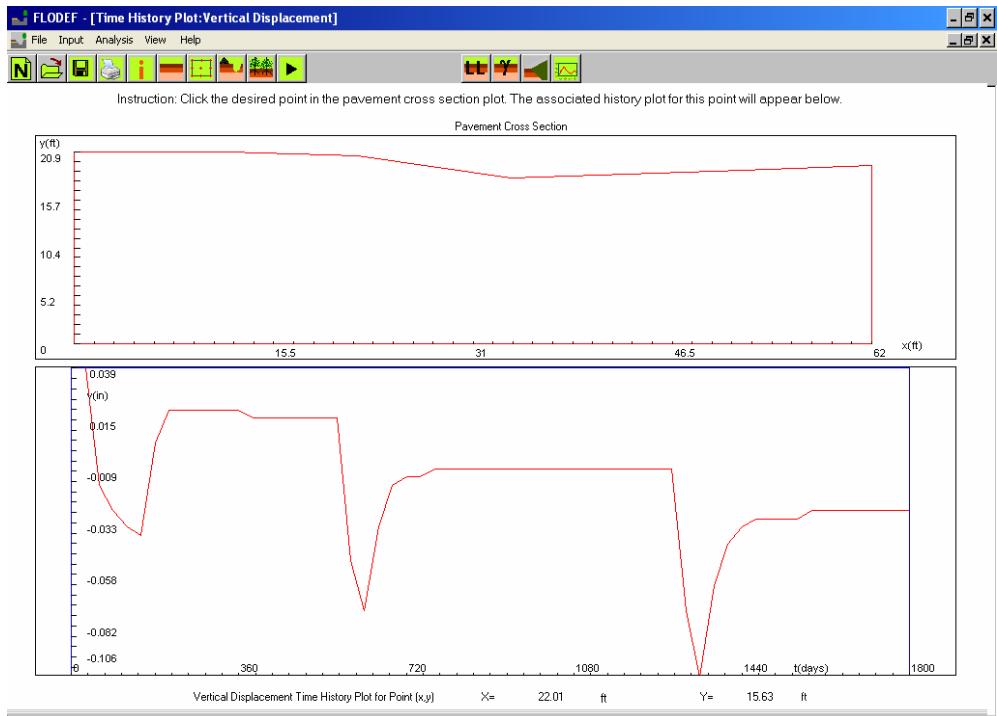


Figure 23. Time History Plot Screens (3).

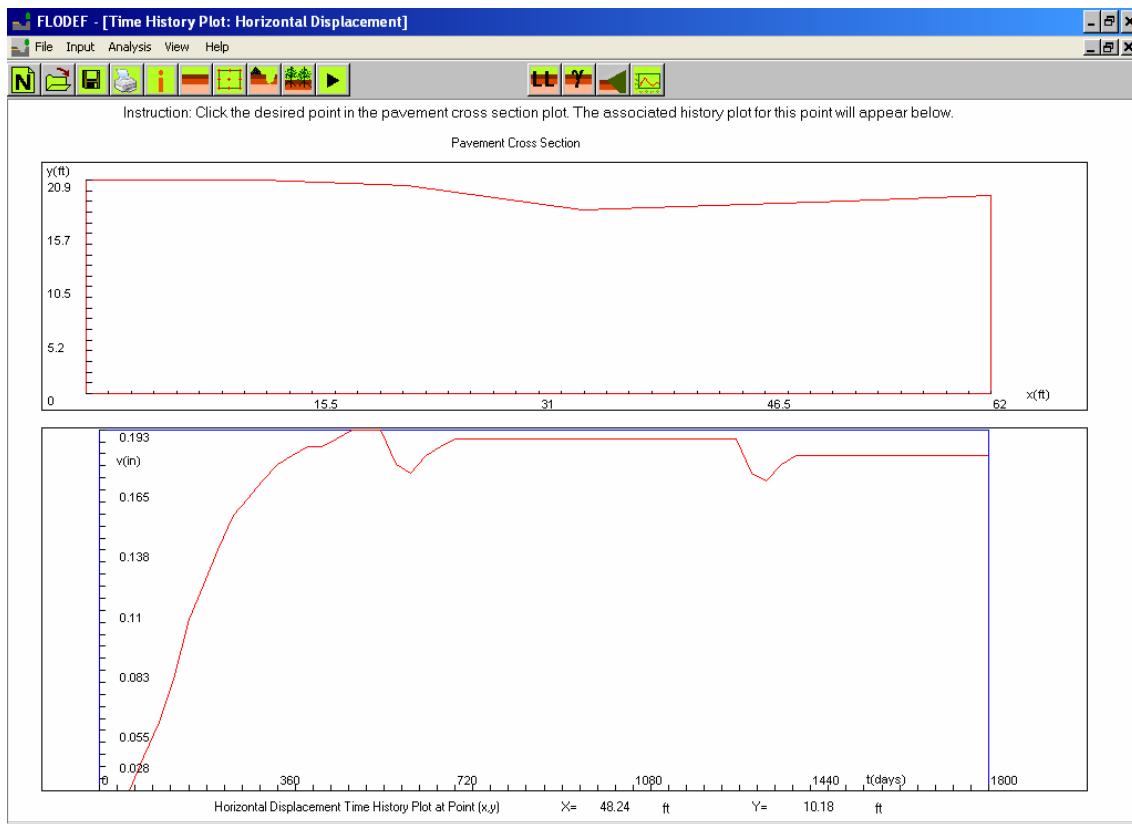


Figure 24. Time History Plot Screens (4).

6. SUPPLEMENT

The user can create a new file, open an existing file, save a file, or save a file as a different name by clicking the “File” option, “New”/ “Open”/ “Save”/ “Save As” sub options

on the menu bar or clicking the associated icons / / .

The program also provides “Print” functions for the user to get hard copies of all the input forms and output plots. In printer preferences, the “layout” setting should be “Landscape” on the orientation tab.

APPENDIX

An example of the Atlanta US 271 site case study is given below to demonstrate the input and output steps for the FLODEF program more in detail.

Case Description

In the Atlanta US 271 site, there are trees and grasses existing from the ditch line out to the right-of-way line. For the two-dimensional finite element analysis in FLODEF, the tree root zone depth is assumed to be 14 ft according to the borehole data. The root transpiration rate and grass transpiration rate are estimated to be 0.12 in/day. The site cross section is shown in [Fig. 25](#).

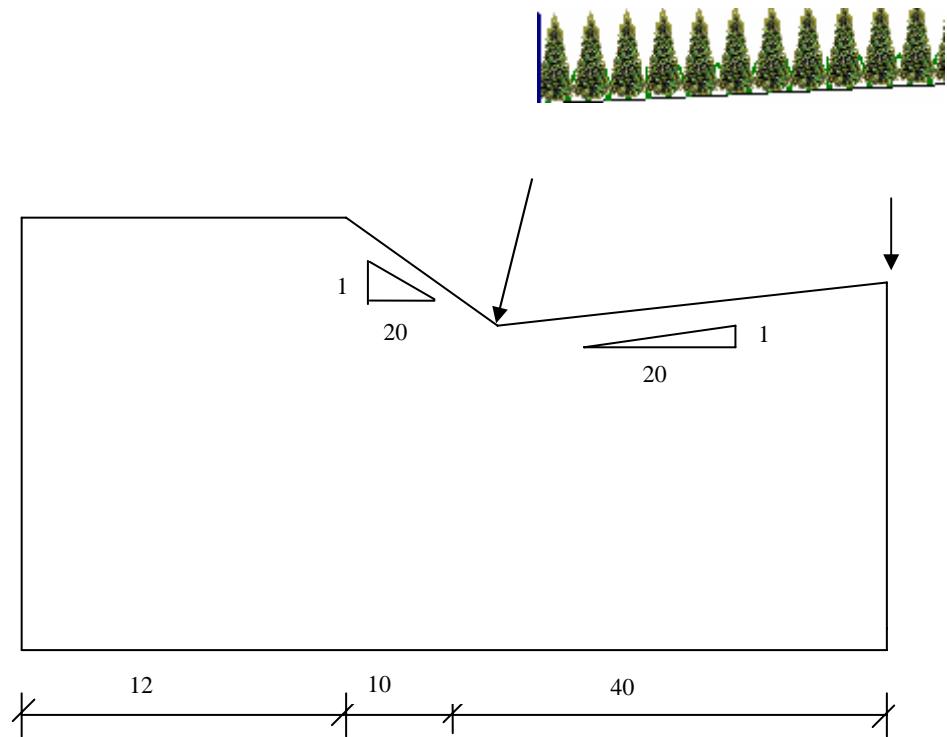


Figure 25. Atlanta Site Cross Section Sketch.

Four subgrade layers are employed for the mesh generation and finite element method analysis purposes with the thicknesses for the layers from top to bottom being: 2 ft, 7 ft, 4 ft, and 2 ft. The pavement structure has an asphalt surface (flexible pavement), and untreated granular base and subbase courses. The soil properties of the subgrade layers are illustrated in [Table 1](#).

Table 1. Soil Properties for Subgrade Layers in the Atlanta US 271 Site Example.

Location (From top to bottom)	Soil Type	LL (%)	PI (%)	-200#	-2μm
Subgrade layer 1	Natural	37	17	83.5	7.6
Subgrade layer 2	Natural	48	26	92	8.7
Subgrade layer 3	Natural	37	15	94.1	9
Subgrade layer 4	Natural	37	15	89.9	8.5

Illustration: Input Screens

Based on the information of the pavement cross section geometries, soil layer

properties, and vegetation condition, the user will click the icons      and  to enter “Site Information,” “Pavement Section Geometry,” “Mesh View,” “Layer Properties,” and “Vegetation” input data. [Figure 26](#) through [Figure 30](#) show the associated user inputs for this example.

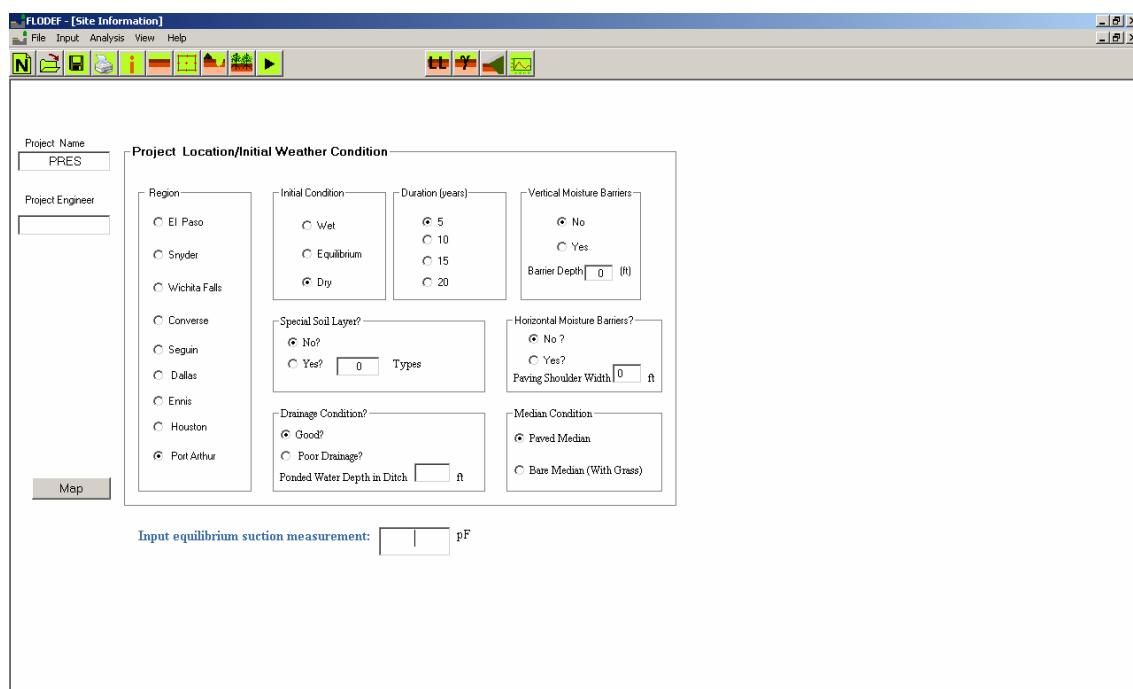


Figure 26. Input Screen 1: Site Information.

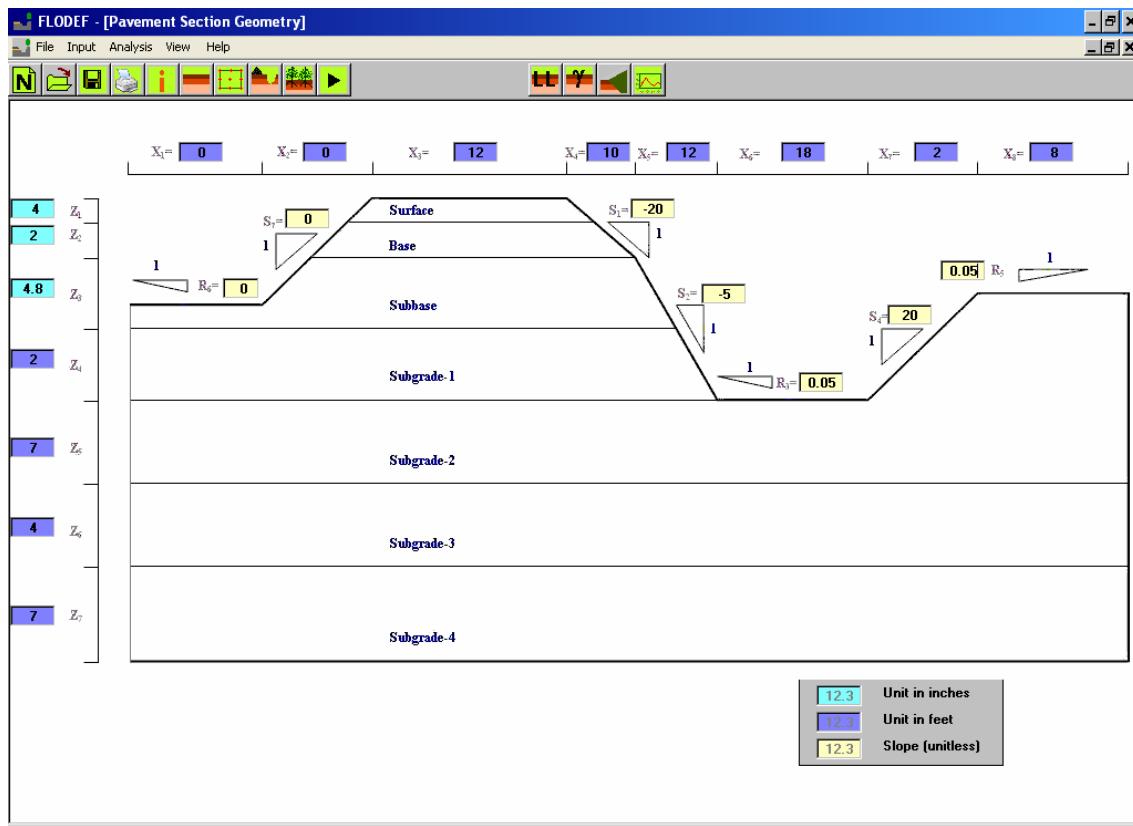


Figure 27. Input Screen 2: Pavement Section Geometry.

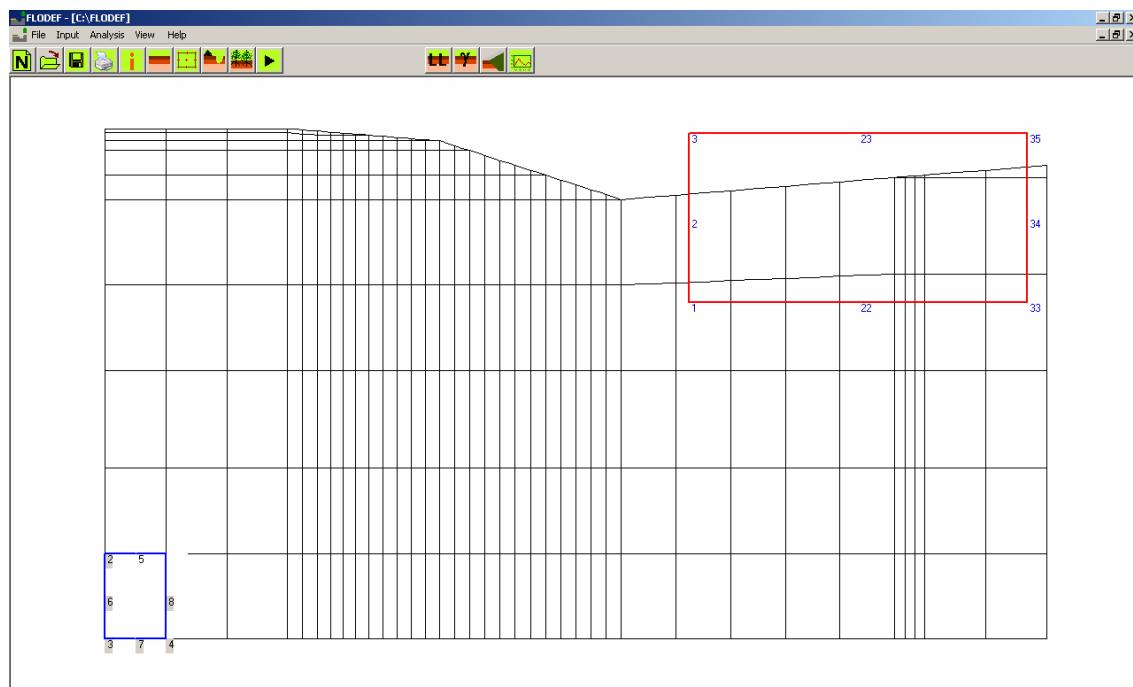


Figure 28. Input Screen 3: Automatic Mesh View.

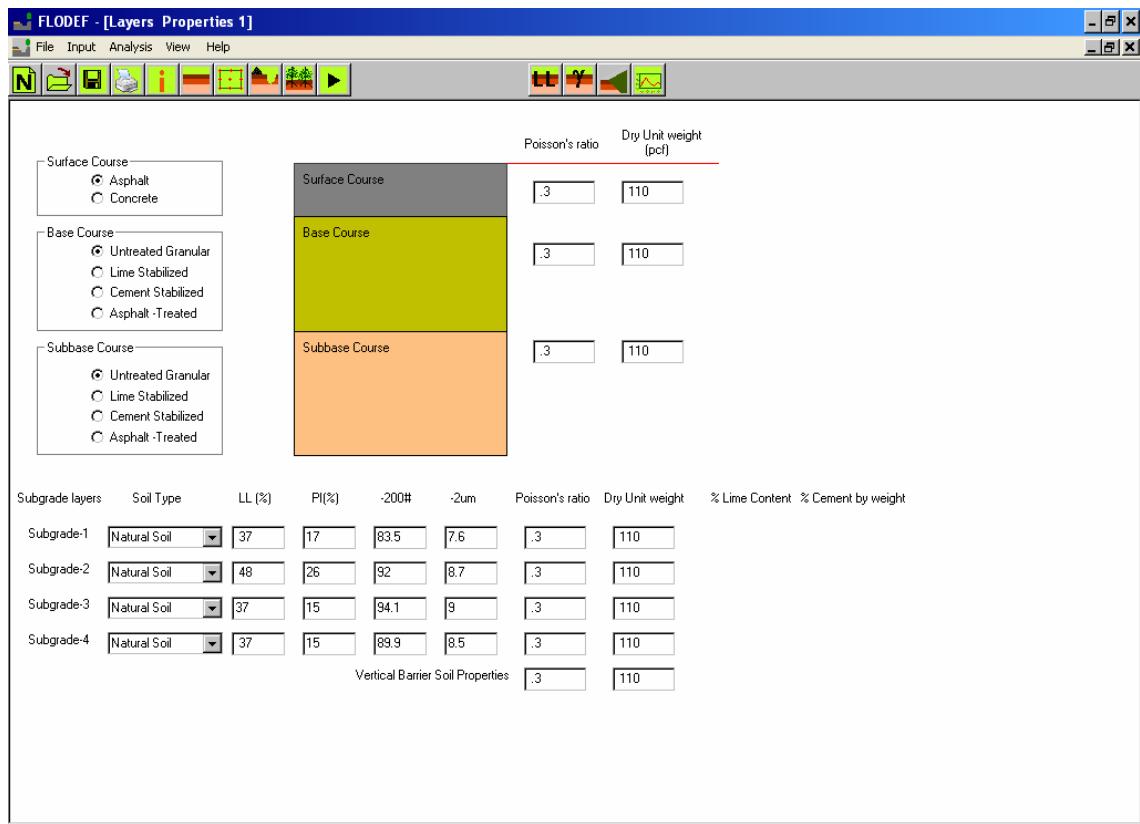


Figure 29. Input Screen 4: Layer Properties.

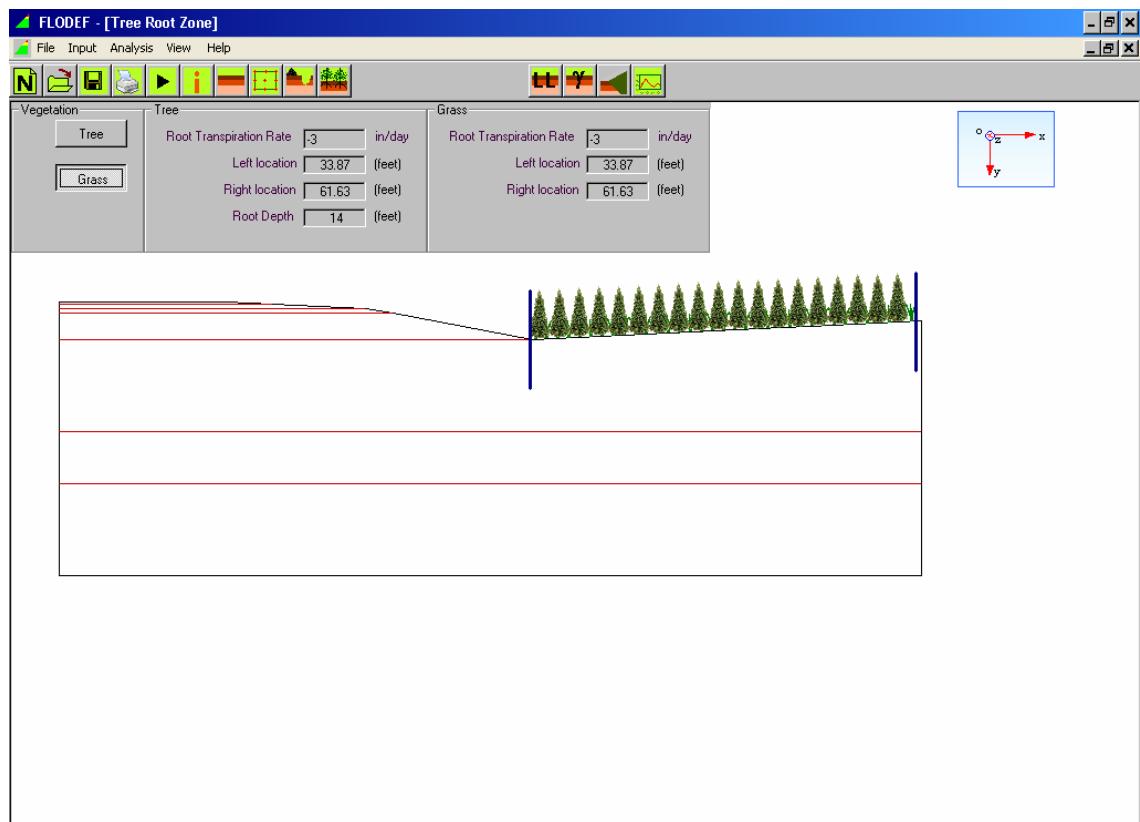


Figure 30. Input Screens: Vegetation.

After the user clicks the “Run”  icon with the fulfillment of the input screen parts, the program generates a file “input.dat” used for the internally built Fortran program. The format of this file is shown below:

File name: Input.Dat

```
*****
S1-info
Location: PRES
Engineer:
Special Soil Layer Configuration?(1:yes;0:no)
0      0
Region, Ini Condition, Duration, Vertical barrier, Horizontal barrier, Paved Shoulder Width, Barrier depth, Median Condition
9      3      4      0      0      0      0      0
Tree (no:0;yes:1), Grass(no:0;yes:1)
1      1
Drainage Condition?(0:good;1:poor)
0      0
S2-section
Z1,Z2,Z3,Z4,Z5,Z6,Z7
2 4 4.8 2 7 4 7
x1, x2, X3,X4,X5,X6,X7,X8
12 10 12 18 2 8 0 0
S1,S2,S3,S4,S5,S6,S7
-20 -5 0.05 20 0.05 0 0
S3-property-pavement
Layer Poisson's-Ratio Dry-unit-weight
1      1      0.3      110
2      1      0.3      110
3      1      0.3      110
S4-property-subgrade
No. ID LL(%) PI(%) -200# -2um Poisson's-Ratio Dry-unit-weight %Lime-or-Cement
1      1      37      17      83.5      7.6      0.3      110      0
2      1      48      26      92       8.7      0.3      110      0
3      1      37      15      94.1      9       0.3      110      0
4      1      37      15      89.9      8.5      0.3      110      0
S5-tree
-4
33.6279726261762      61.790504704876      14
S6-grass
-3
33.8666381522669      61.6313943541488
```

Illustration: Output Plot Screens

After FLODEF has executed, the program generates output files for the suction and displacement (vertical/horizontal) calculations. If the analysis period is 5 years, the output files will be PF1.DAT~PF6.DAT, DY1.DAT~DF6.DAT. For the case of a 20 year analysis period, the output files then will be PF1.DAT~PF24.DAT, DY1.DAT~DY24.DAT. The user can review all the output files in the directory where the program is installed.

For this example, the associated output plot screens for Vertical Profile Plots/ Contour Plots/Surface Deformation Plot/Time History Plots are demonstrated in [Fig. 31](#) through [Fig. 34](#) for an arbitrary selected output time of 720 days. The users can change the output time according to their review needs.

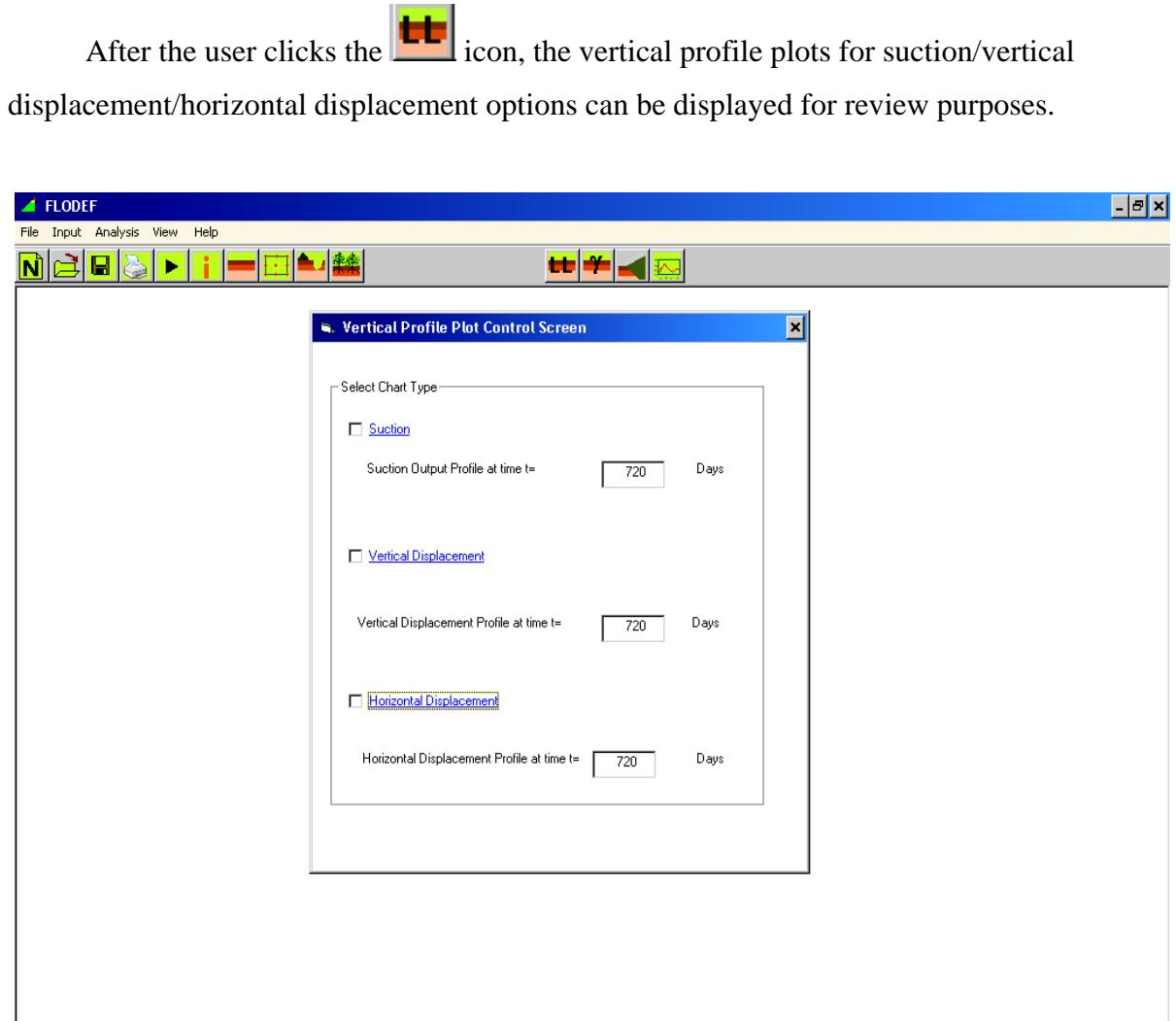


Figure 31. Output Plots Screens: Vertical Profile Plots Selection.

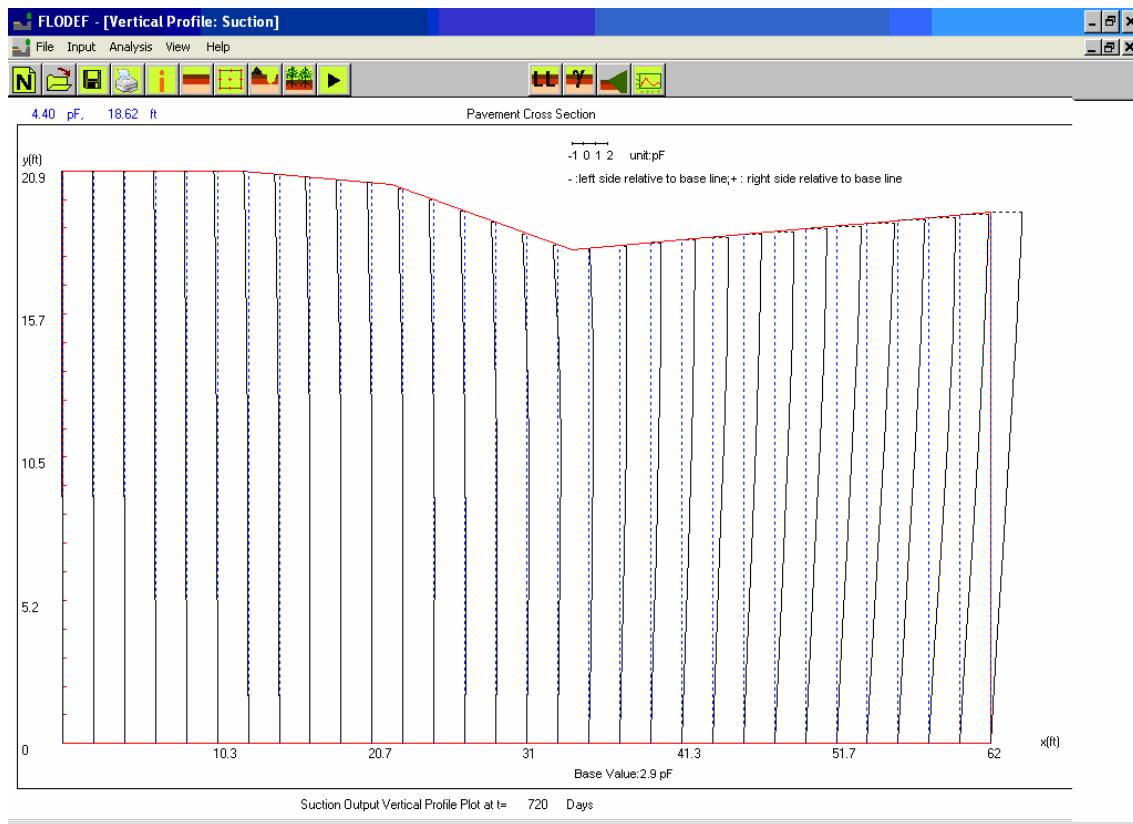


Figure 32. Output Plots Screens: Vertical Profile Plots-Suction.

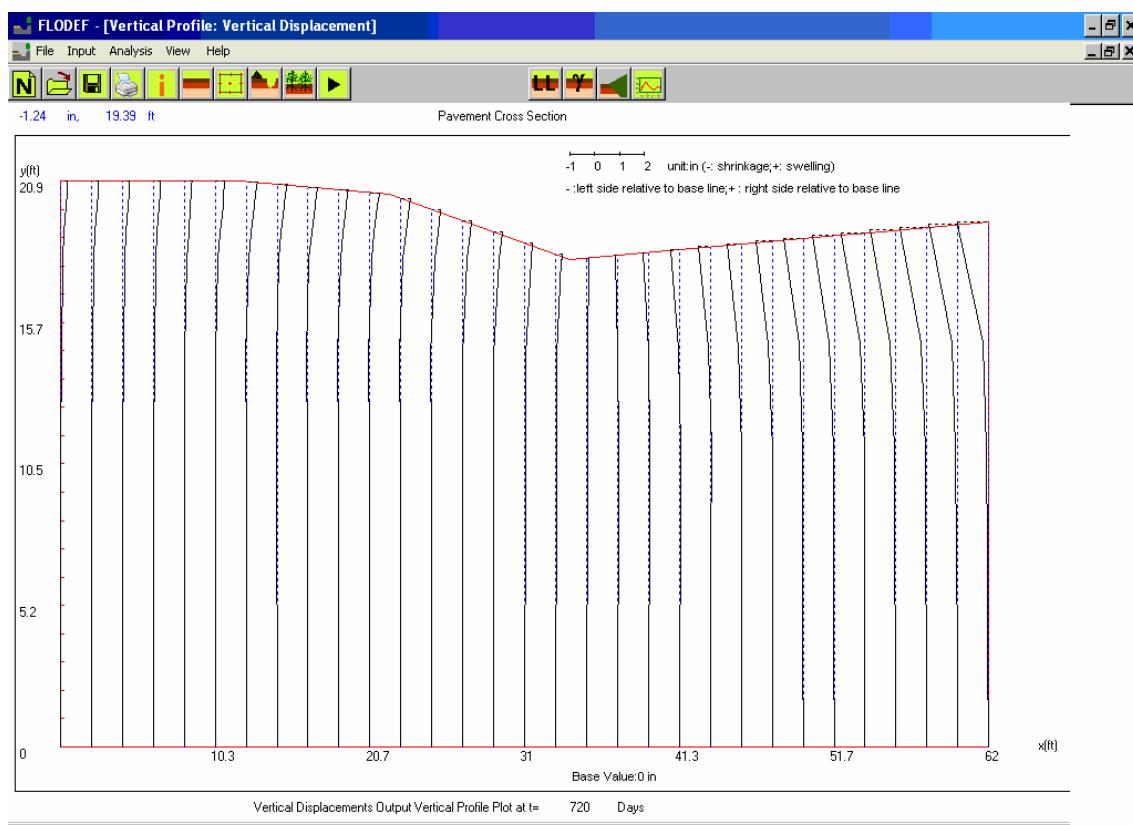


Figure 33. Output Plots Screens: Vertical Profile Plots-Vertical Displacement.

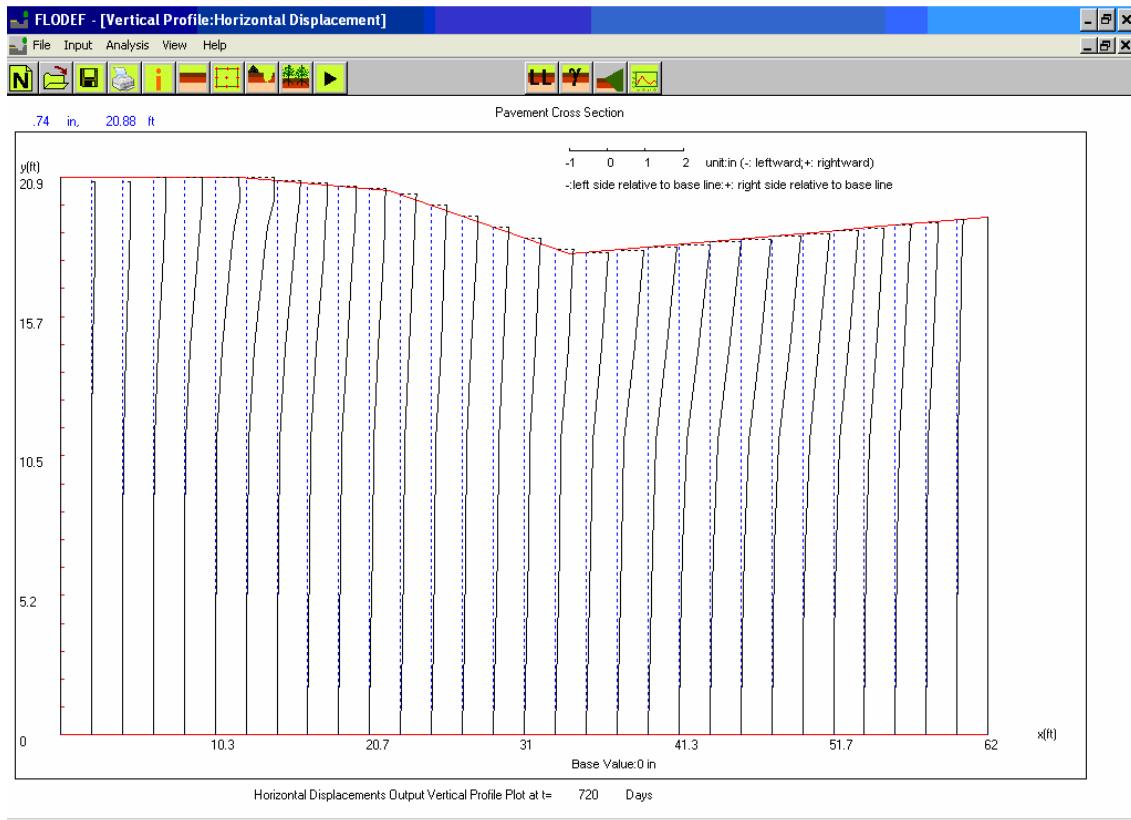


Figure 34. Output Plots Screens: Vertical Profile Plots-Horizontal Displacement.

The contour plots screens can be accessed after the user clicks the  icon, as shown in [Fig. 35](#) through [Fig. 38](#). The unit for vertical and horizontal displacement is inches.

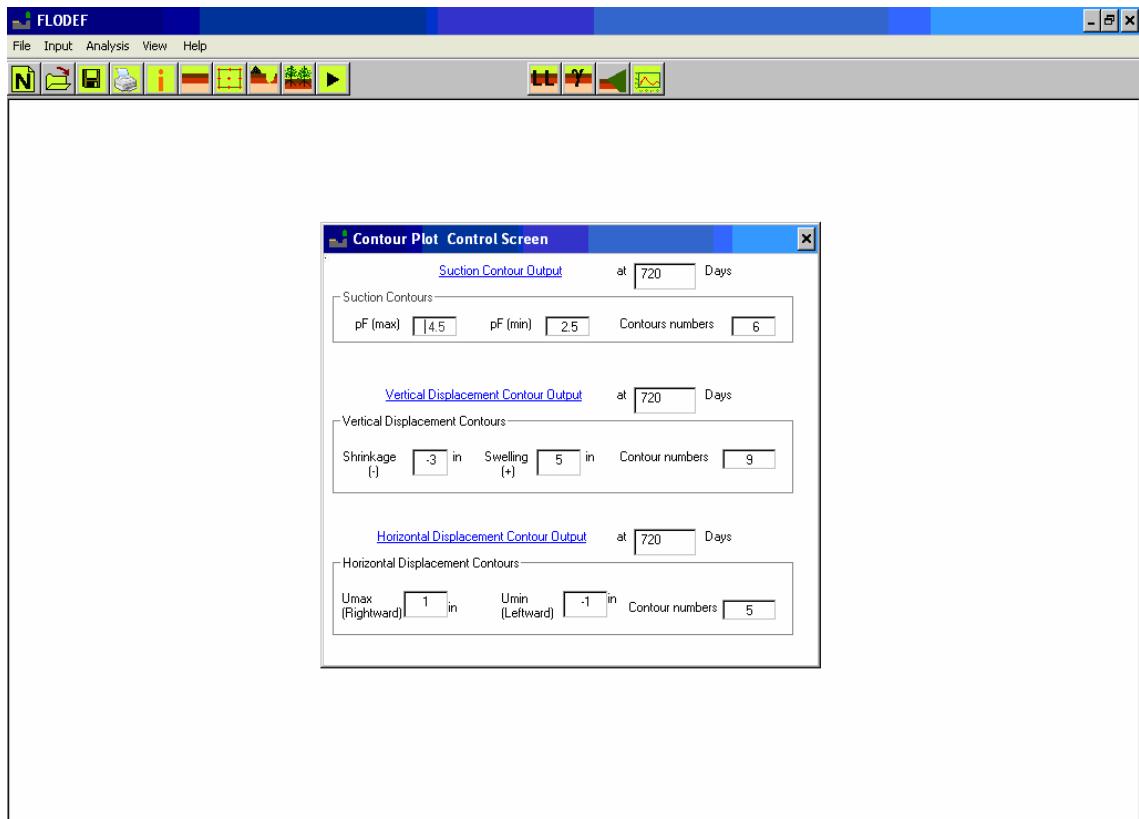


Figure 35. Output Plots Screens: Contour Plot Selection.

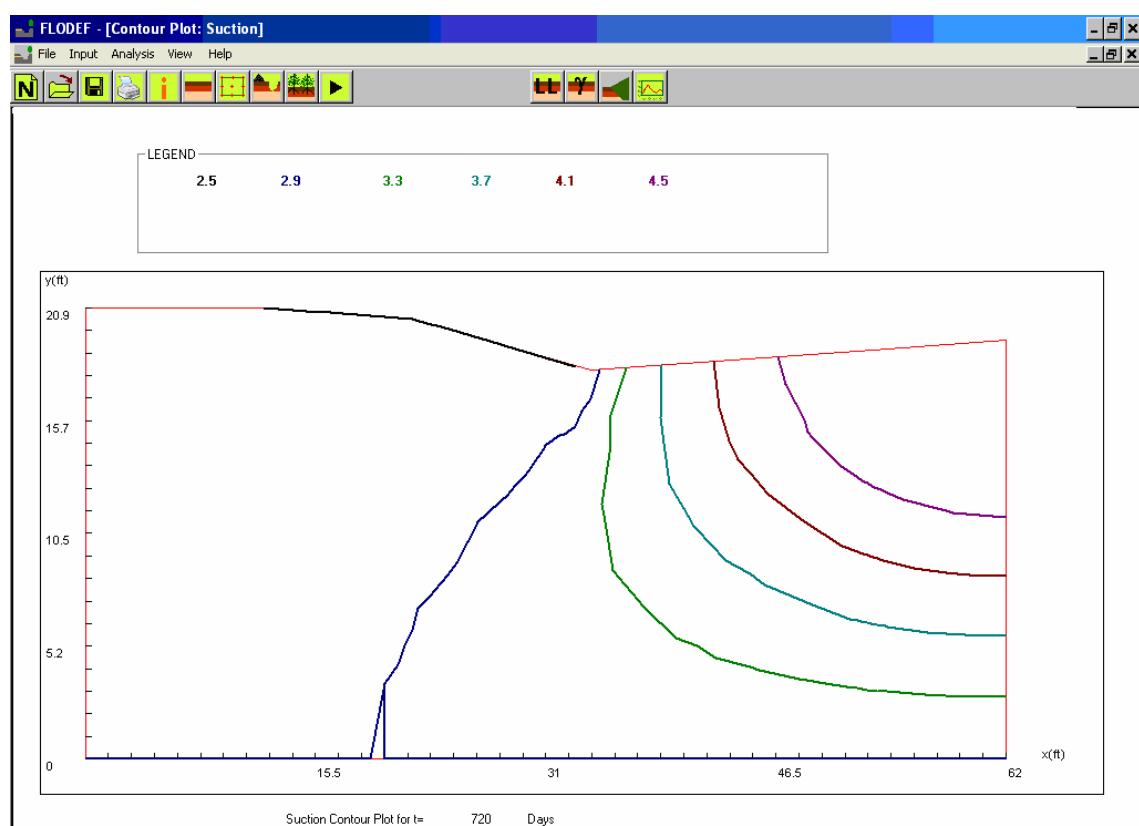


Figure 36. Output Plots Screens: Contour Plots Screens-Suction.



Figure 37. Output Plots Screens: Contour Plots Screens-Vertical Displacement.

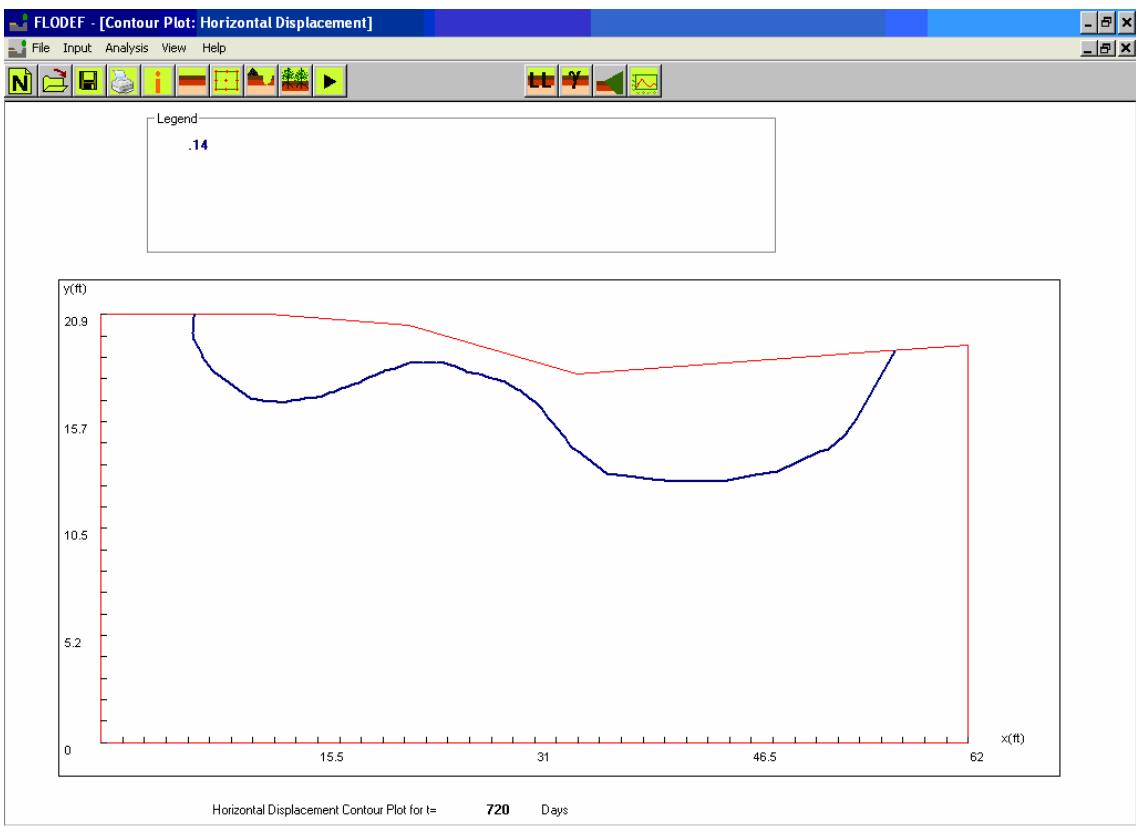


Figure 38. Output Plots Screens: Contour Plots Screens-Horizontal Displacement.

The surface deformation plot (Fig. 39 and Fig. 40) is displayed with the click of the



icon.

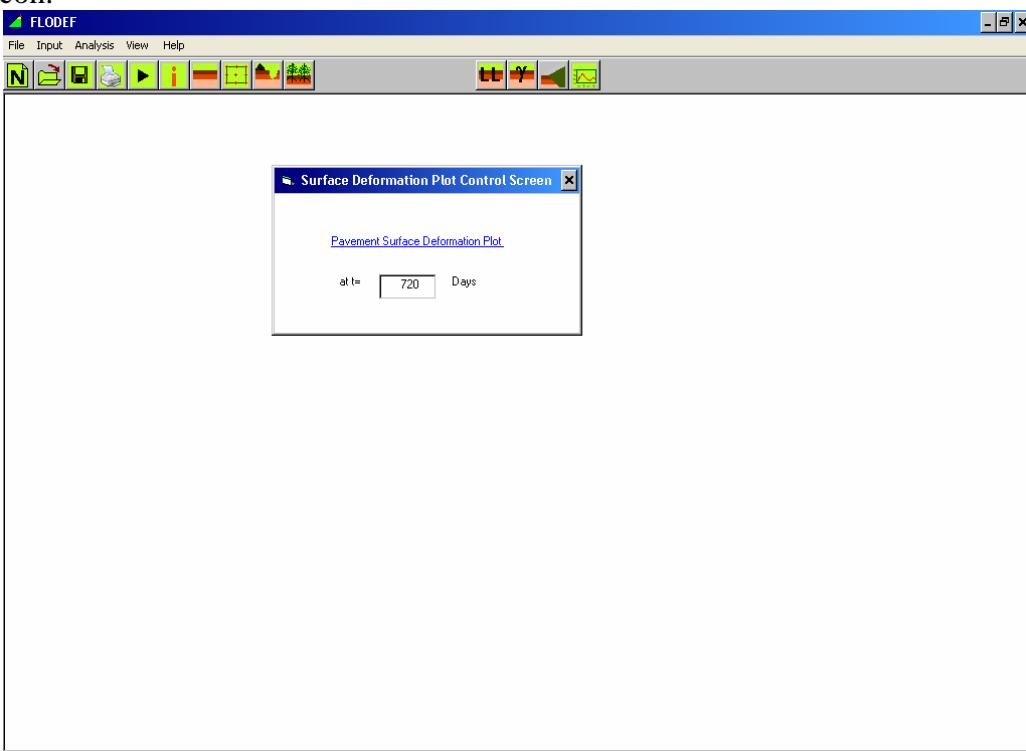


Figure 39. Output Plots Screens: Surface Deformation Plot Screen (1).

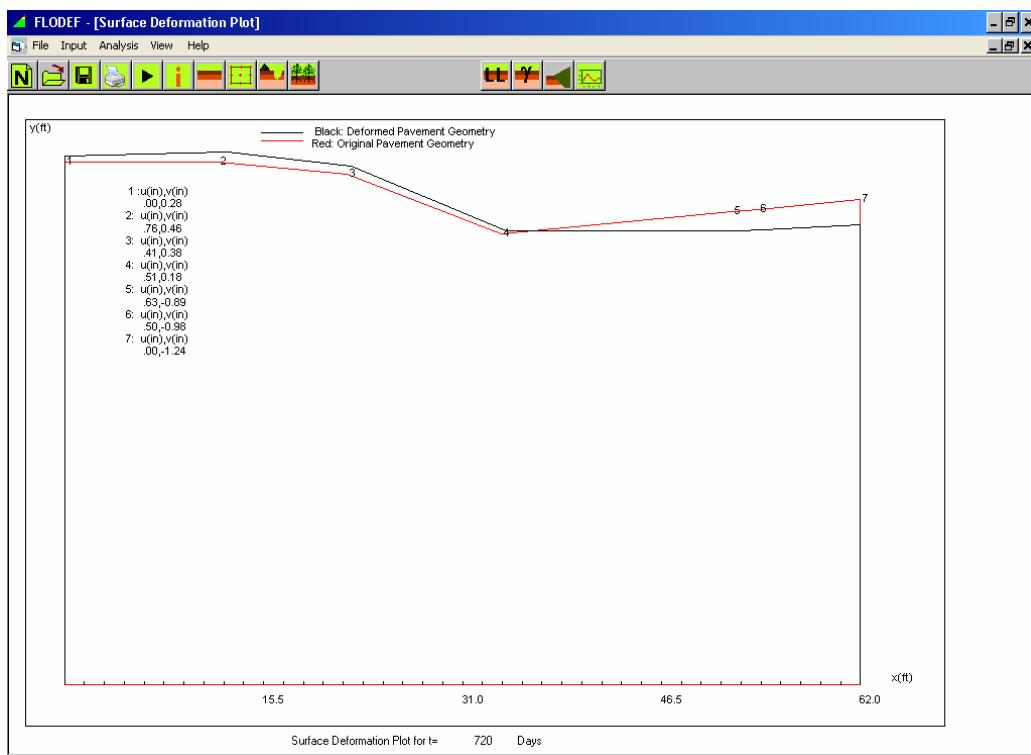


Figure 40. Output Plots Screens: Surface Deformation Plot Screen (2).



By clicking the icon, the user can view the time history plots for suction/vertical displacement/horizontal displacement, which are shown in Fig. 41 through Fig. 44.

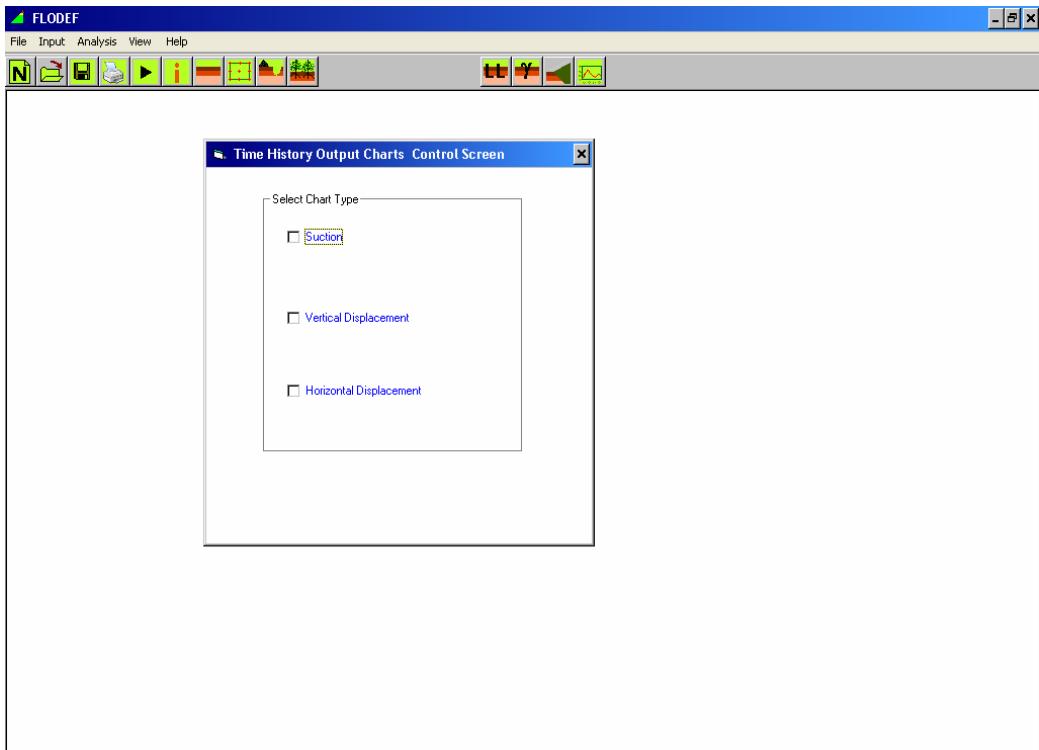


Figure 41. Output Plots Screens: Time History Plot Selection.

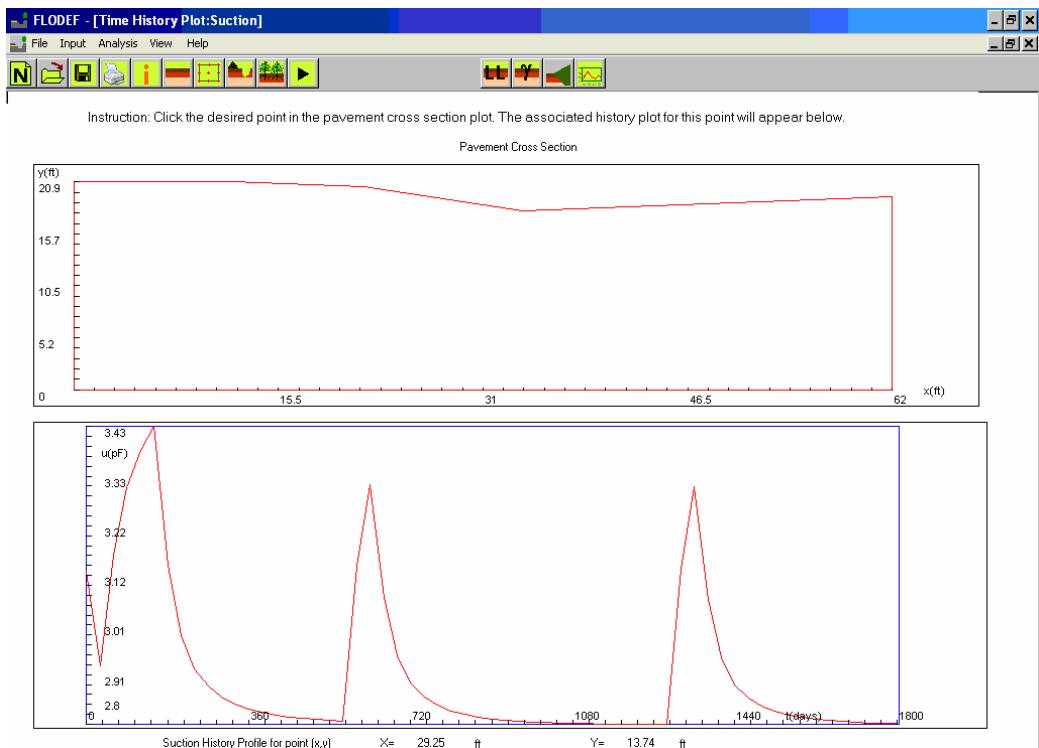


Figure 42. Output Plots Screens: Time History Plot-Suction.

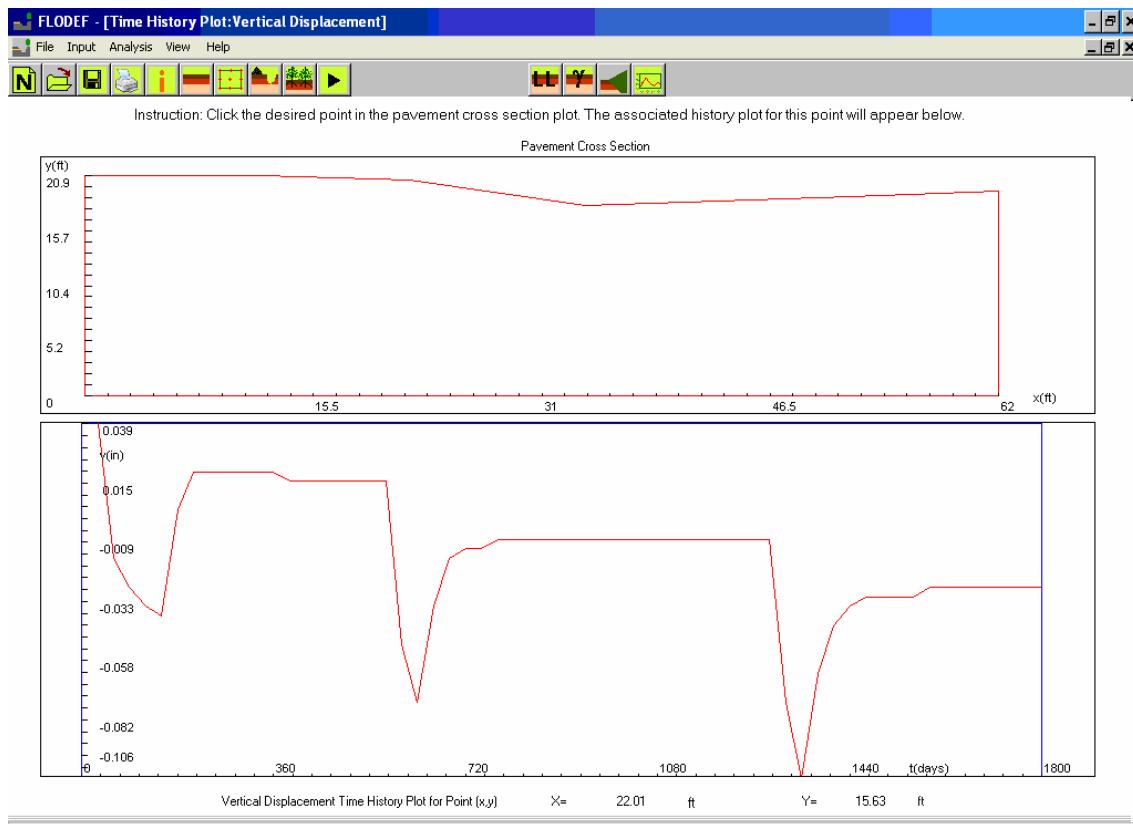


Figure 43. Output Plots Screens: Time History Plot-Vertical Displacement.

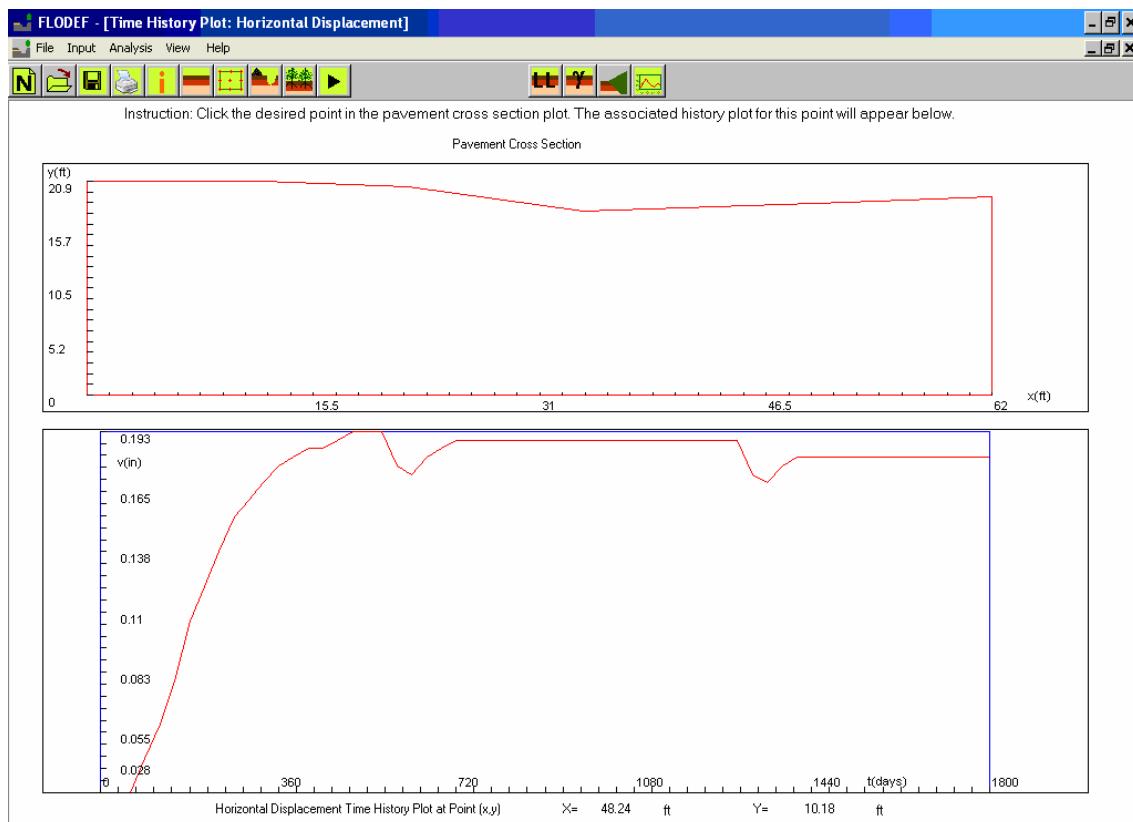


Figure 44. Output Plots Screens: Time History Plot-Horizontal Displacement.