

# **Non-Destructive Evaluation of Iowa Pavements Phase 2:**

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## **Development of a Fully Automated Software System for Rapid Analysis/ Processing of the Falling Weight Deflectometer Data**

**Final Report  
February 2009**

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<b>16. Abstract</b> <p>The Office of Special Investigations at Iowa Department of Transportation (DOT) collects FWD data on regular basis to evaluate pavement structural conditions. The primary objective of this study was to develop a fully-automated software system for rapid processing of the FWD data along with a user manual. The software system automatically reads the FWD raw data collected by the JILS-20 type FWD machine that Iowa DOT owns, processes and analyzes the collected data with the rapid prediction algorithms developed during the phase I study. This system smoothly integrates the FWD data analysis algorithms and the computer program being used to collect the pavement deflection data. This system can be used to assess pavement condition, estimate remaining pavement life, and eventually help assess pavement rehabilitation strategies by the Iowa DOT pavement management team. This report describes the developed software in detail and can also be used as a user-manual for conducting simulation studies and detailed analyses.</p>			
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# **NON-DESTRUCTIVE EVALUATION OF IOWA PAVEMENTS, PHASE 2: DEVELOPMENT OF A FULLY AUTOMATED SOFTWARE SYSTEM FOR RAPID ANALYSIS/PROCESSING OF THE FALLING WEIGHT DEFLECTOMETER DATA**

**Final Report  
February 2009**

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## **EXECUTIVE SUMMARY**

This study is a follow-up to the IA DOT Project (CTRE Project 04-177), Nondestructive Evaluation of Iowa Pavements - Phase 1. The objective of this Phase II study is the development of a fully-automated software system for rapid processing of the FWD data accompanied by a user manual. The software system can automatically read the FWD raw data collected by the Iowa DOT's JILS-20 type FWD machine, process and analyze the collected data with the rapid prediction algorithms developed during the phase I study. This report, which can also be used as a user-manual for the software, contains examples or case studies for all three pavement types (flexible, rigid, and composite) illustrating the step-by-step procedure in using the software.

Some of specific features of the fully-automated software system described in this report are summarized below:

- A comprehensive pavement structural analysis toolbox incorporating all three common pavement types (flexible, rigid, and composite)
- Capability of automatically reading the FWD raw data collected by the JILS-20 type FWD machine that Iowa DOT owns
- Integration of all the Artificial Neural Network (ANN) models developed as part of Phase I research into a comprehensive unified framework
- Rapid backcalculation of pavement layer moduli and prediction of critical pavement responses from FWD data (100,000 deflection basins analyzed in less than a second)
- Useful for both project-level and network-level pavement structural evaluation
- Visualization of results through automatic plotting capability
- Commonly used Import/Export options for transporting data
- Automatic generation of output statistics



## INTRODUCTION

Evaluating structural condition of existing, in-service pavements is a part of the routine maintenance and rehabilitation activities undertaken by the most Departments of Transportation (DOTs). In the field, the pavement deflection profiles (or basins) gathered from the nondestructive Falling Weight Deflectometer (FWD) test data are typically used to evaluate pavement structural condition. FWD testing is often preferred over destructive testing methods because it is faster than destructive tests and does not entail the removal of pavement materials. This kind of evaluation requires the use of backcalculation type structural analysis to determine pavement layer stiffnesses and as a result estimate pavement remaining life. Although the Office of Special Investigations at Iowa DOT has collected the FWD data on regular basis, the pavement layer moduli backcalculation techniques used so far have been cumbersome and time consuming. Thus, there was a need for more efficient and faster methods.

During the first phase of the Iowa (DOT) Project (CTRE Project 04-177), “Nondestructive Evaluation of Iowa Pavements-Phase I”, advanced yet easy-to-use backcalculation models were developed using the ANN methodology (Ceylan et al, 2007). ANNs are very adaptable and support the real-time applications of the developed models. These ANN models are capable of predicting pavement layer stiffnesses as well as pavement critical responses (forward modeling) from FWD test results. For the three pavement types, over 300 models in total were developed for varying input parameters. The primary pavement types considered were flexible (conventional and full-depth), rigid, and composite.

Predicted flexible pavement parameters were,  $E_{AC}$ -modulus of hot-mix asphalt (HMA) or asphalt concrete (AC),  $K_b$ -base modulus parameter,  $E_{Ri}$ -subgrade resilient modulus,  $\epsilon_{AC}$ -tensile strain at the bottom of asphalt layer,  $\epsilon_{SG}$ -compressive strain at the top of subgrade, and  $\sigma_D$ -subgrade deviator stress.

For rigid pavements,  $E_{PCC}$ -modulus of portland cement concrete (PCC),  $k_s$ -coefficient of subgrade reaction,  $\sigma_{PCC}$ -tensile stress at the bottom of the PCC layer, and radius of relative stiffness (RRS) were predicted.

In the case of composite pavements (CPs), where an AC surface is overlaid on top of an existing PCC pavement,  $E_{AC}$ ,  $E_{PCC}$ ,  $k_s$ ,  $\sigma_{PCC}$  (tensile stress at the bottom of the PCC), and  $\epsilon_{AC}$  were predicted.

The developed methodology was successfully verified using results from long-term pavement performance (LTPP) FWD test results, as well as Iowa DOT FWD field data. All successfully developed ANN models were incorporated into a Microsoft Excel spreadsheet-based backcalculation software toolbox with a user-friendly interface. The phase I study also concluded that the developed nondestructive pavement evaluation methodology for analyzing the FWD deflection data would be adopted by Iowa DOT pavement and material engineers and technicians, who do not employ any preferable FWD backcalculation analysis technique.

## **OBJECTIVES**

This phase II follow-up study of IA DOT Project (CTRE Project 04-177) focused on the development of a fully-automated software system for rapid processing of the FWD data. The software system can automatically read the FWD raw data collected by the JILS-20 type FWD machine that Iowa DOT owns, process and analyze the collected data with the algorithms being developed during the phase I study. This system smoothly integrates the FWD data analysis algorithms and the computer program being used to collect the pavement deflection data. With the implementation of the developed software system the FWD data can be filtered, processed and analyzed on-the-fly.

## **PROGRAM USER MANUAL**

The password-protected, Excel-based software toolbox was developed using Microsoft Visual Basic programming language and Excel macros. In case of troubleshooting, the user is requested to change the macro security (Tools → Macro → Security) to the “medium” or “low” level to allow macros to run. The Excel spreadsheets provide the user interaction for data editing and pasting, displaying results, charts, and tables, and for displaying statistical information. The Excel sheets include a main menu, analysis menu (for each pavement type), plotting menu, and summary menu.

### **Program Main Menus**

The program starts by displaying the main menu (Figure 1). As a first step, users are expected to select the pavement type (conventional, full-depth flexible, composite or rigid pavements) by clicking on it to activate the selected pavement analysis Excel sheet/interface. There are six Excel pavement analysis sheets, including the conventional flexible pavement analysis module with 9-kip and variable FWD load, the full-depth flexible pavements analysis module with 9-kip and variable FWD load, and the composite and rigid pavement analysis module with 9-kip FWD loading. The software toolbox is programmed to give warning messages if the user clicks anywhere else.

While working with the toolbox, all other Excel features are accessible, including open, close, copy, paste, save, save as, print, and print settings. When the user quits the toolbox, all the charts and results for the analysis, except the last data entered, will be deleted. To retain the results, they should be copied into another spreadsheet.

The ANN information buttons in Figure 2 provide the user general information about the ANN models employed. Six Excel Spreadsheets as shown in Figure 3 appear upon clicking “ANN info show” button. Each of Excel sheets as shown in Figure 4 contain the ANN model information such as the ranges of the data used in the development of ANN models. These Excel sheets can be hid again by clicking on “ANN info hide”.

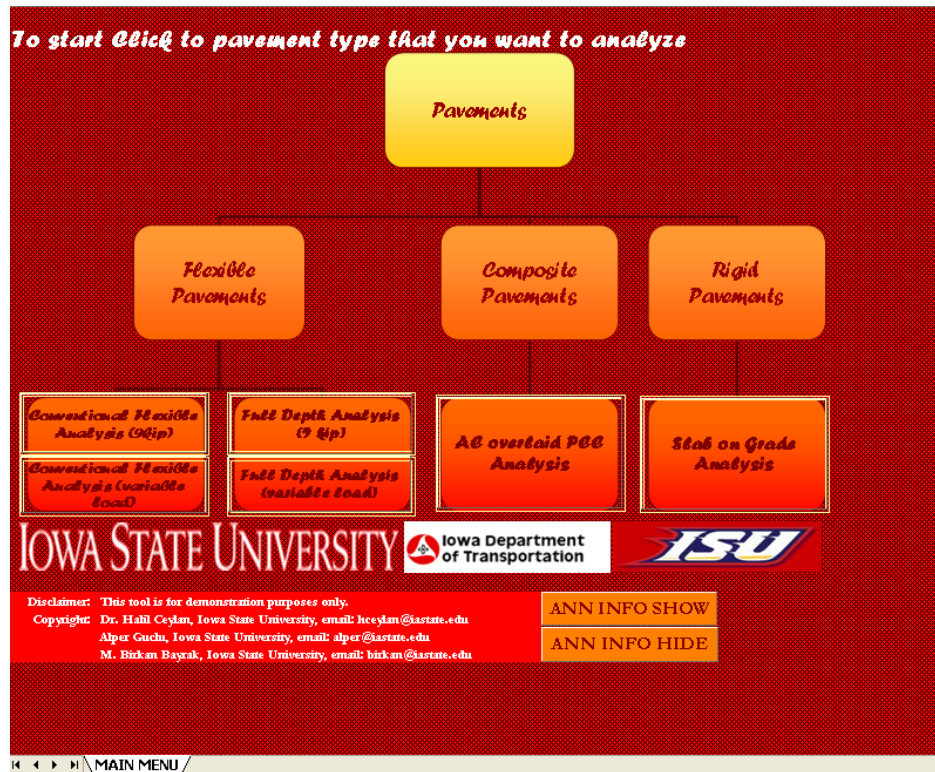


Figure 1. FWD analysis program main menu

Disclaimer: This tool is for demonstration purposes only. Copyright: Dr. Habil Ceylan, Iowa State University, email: hceylan@iastate.edu Alper Gucu, Iowa State University, email: alper@iastate.edu M. Birkan Bayrak, Iowa State University, email: birkan@iastate.edu	ANN INFO SHOW ANN INFO HIDE
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	--------------------------------

Figure 2. ANN Information button in main menu



**Figure 4. Sample Excel sheet showing ANN model information**



## Flexible Pavement Analysis, Plotting, and Summary Menus

Pavement analysis menu consists of three main sections: inputs, analysis tool, and outputs. The user can provide the software with the information required for analysis in the inputs section of the pavement analysis menu. The analysis tool allows the user to process the data and analyze with several functions. The results of analysis are provided in the outputs section of the pavement analysis menu. Typical layouts of the conventional and full depth flexible pavement analysis menus are shown in Figure 5.

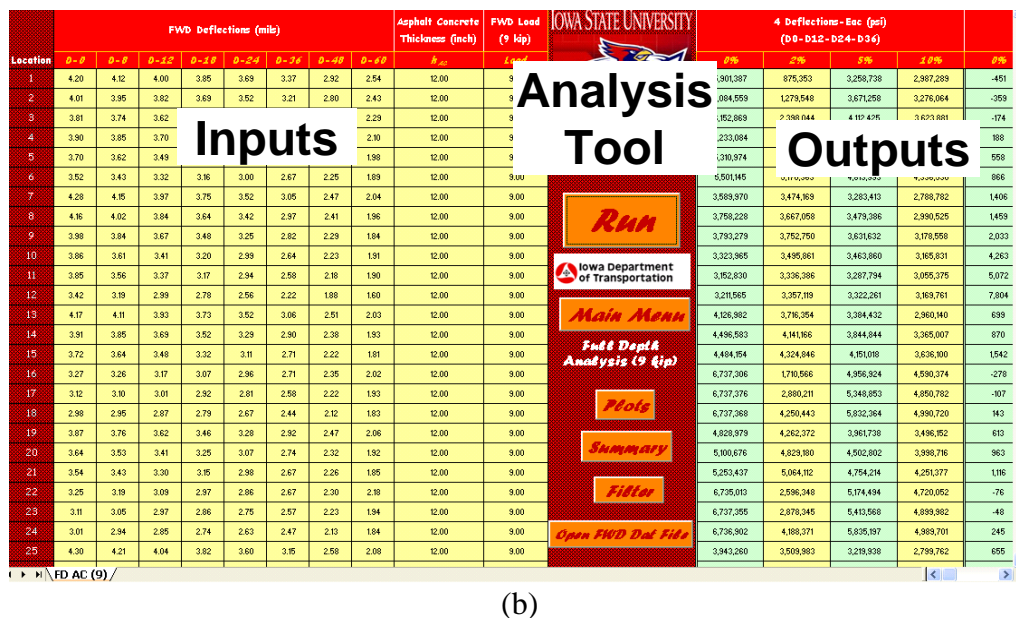
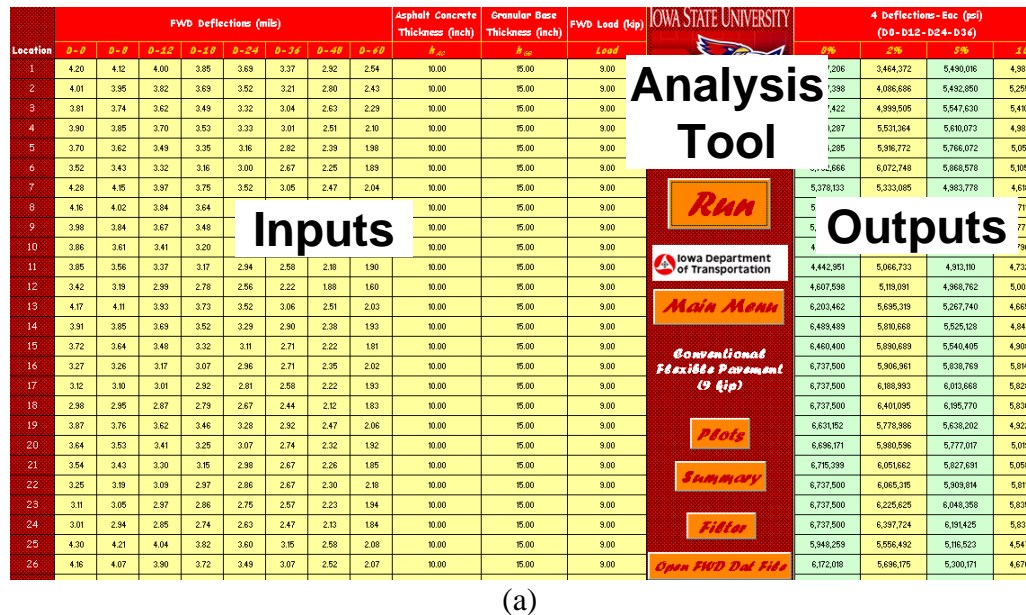
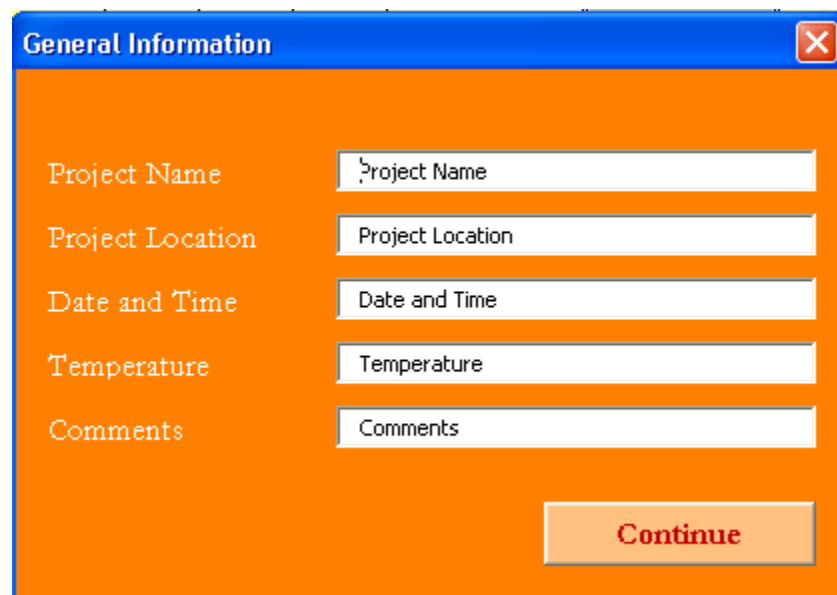


Figure 5. Flexible pavement analyses menus: (a) conventional, (b) full depth

After selecting one of the pavement types from the main menu, a general information window appears. Its purpose is to get information that represents a project site at the beginning of each analysis (see Figure 6.). The user is required to fill in the information to continue with pavement analysis.

General information inputs will be displayed with each graph at the end of the analysis to identify the project information.

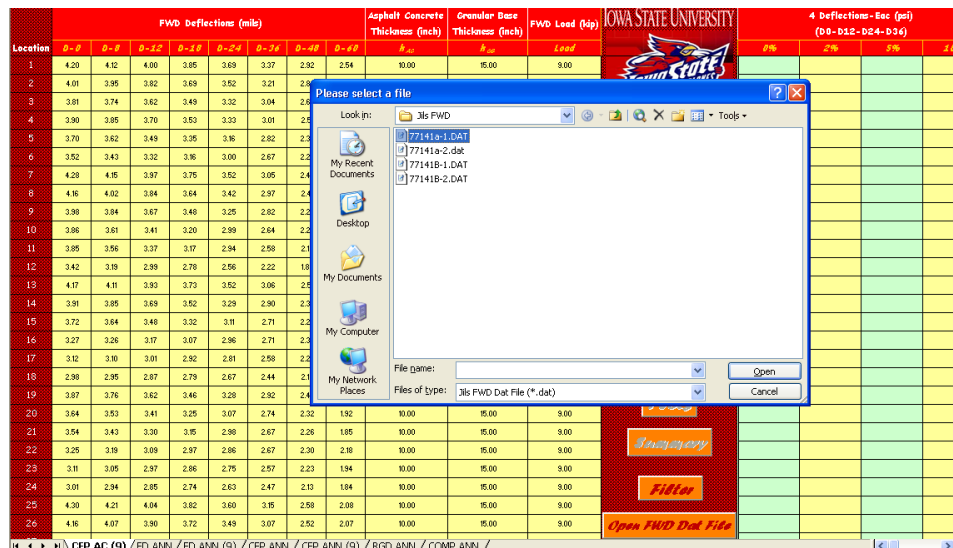
A screenshot of a software window titled "General Information" with a blue title bar and a red close button. The window has an orange background. It contains five input fields, each with a label to its left: "Project Name", "Project Location", "Date and Time", "Temperature", and "Comments". Each label and its corresponding input field are highlighted with a light orange background. At the bottom right of the window is a button labeled "Continue" in red text.

**Figure 6. General information window**

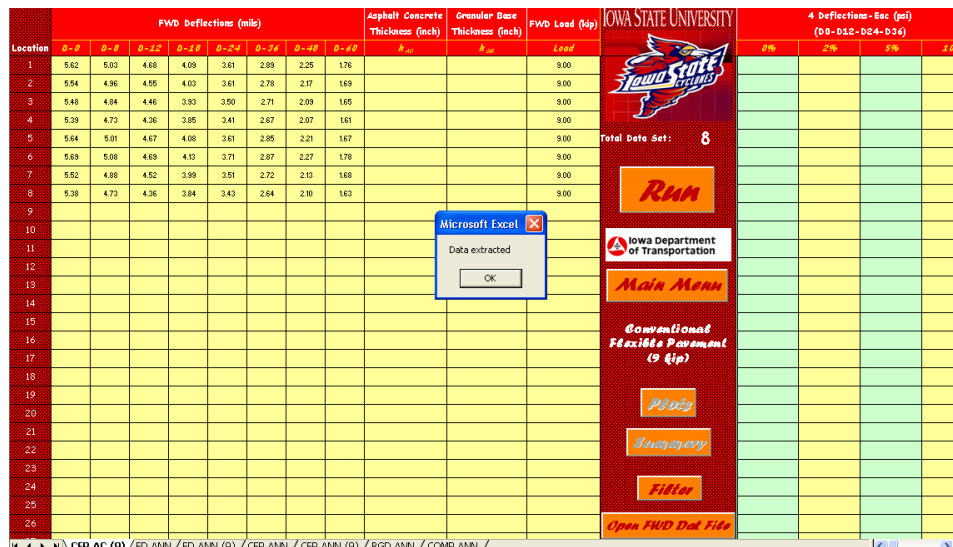
At the next step, the user is expected to enter the FWD deflection data and other required inputs. These include pavement layer information (layer thicknesses), and FWD load (for variable FWD load analysis). Depending on the pavement type, the number of layers can be changed. The input requirements for conducting conventional flexible pavement analyses include FWD deflection data, asphalt concrete thickness, granular base thickness, and FWD load. The input requirements for conducting full depth asphalt pavement analyses are same as those for conventional flexible pavement analyses except that granular base thickness is not required. If any of the required parameter is missing, the program will display an error message which reads “No Data” in the results section.

The default units used in the program are US customary units. FWD deflection data ( $D_0$  till  $D_{60}$ ) should be entered in mils ( $10^{-3}$  inches), layer thickness in inches, and FWD load should be in kips. The program will not run correctly if the inputs are entered in different units or if they are out of range. The user is requested to refer to the report for the appropriate ranges of these parameters. Reported results are pavement layer modulus values, strains, and stresses. Modulus and stress values are reported in psi and strains are reported in micro-strains ( $\times 10^6$ ).

User can enter the FWD deflection database manually or obtain those directly from the JILS-20 type FWD raw data files clicking “Open FWD data file”. The “Open FWD data file” command allows the user to load the FWD raw data files and extract the FWD deflections required as inputs to the automated analysis software as shown in Figure 7. The software allows two types of flexible pavement analysis based on FWD loading amplitude; 9-kip-constant FWD load analysis and variable FWD load analysis. As shown in Figure 8(a), the raw FWD deflection data corresponding to the raw FWD loads are extracted and inputted into the program under variable FWD load analysis. The 9-kip-constant FWD load analysis in Figure 8(b) uses the FWD deflection data normalized to 9 kip-constant FWD load



(a)



(b)

**Figure 7. Screen shot of FWD data extraction through open FWD data file button: (a) choosing raw FWD file, (b) FWD data extracted**

Location	FWD Deflections (mil)								Asphalt Concrete Thickness (inch)	Granular Base Thickness (inch)	FWD Load (kip)
	0-0	0-8	0-12	0-18	0-24	0-36	0-48	0-60	$h_{AC}$	$h_{GB}$	Load
1	3.69	3.42	3.21	2.85	2.57	2.07	1.66	1.32			5.88
2	5.55	5.07	4.73	4.23	3.77	3.01	2.41	1.89			8.59
3	7.37	6.60	6.23	5.58	4.99	3.96	3.16	2.46			11.67
4	8.90	7.95	7.49	6.73	6.00	4.75	4.34	2.98			14.33
5	3.27	3.41	3.21	2.85	2.57	2.06	1.64	1.27			5.93
6	5.95	5.10	4.77	4.28	3.84	3.03	2.42	1.88			8.64
7	7.21	6.65	6.23	5.60	5.02	3.96	3.19	2.44			11.55
8	7.73	7.97	7.48	6.71	6.00	4.80	3.82	3.00			14.28

(a)

Location	FWD Deflections (mil)								Asphalt Concrete Thickness (inch)	Granular Base Thickness (inch)	FWD Load (kip)
	0-0	0-8	0-12	0-18	0-24	0-36	0-48	0-60	$h_{AC}$	$h_{GB}$	Load
1	5.65	5.23	4.91	4.36	3.93	3.17	2.54	2.02			9.00
2	5.81	5.31	4.96	4.43	3.95	3.15	2.53	1.98			9.00
3	5.68	5.09	4.80	4.30	3.85	3.05	2.44	1.90			9.00
4	5.59	4.99	4.70	4.23	3.77	2.98	2.73	1.87			9.00
5	4.96	5.18	4.87	4.33	3.90	3.13	2.49	1.93			9.00
6	6.20	5.31	4.97	4.46	4.00	3.16	2.52	1.96			9.00
7	5.62	5.18	4.85	4.36	3.91	3.09	2.49	1.90			9.00
8	4.87	5.02	4.71	4.23	3.78	3.03	2.41	1.89			9.00

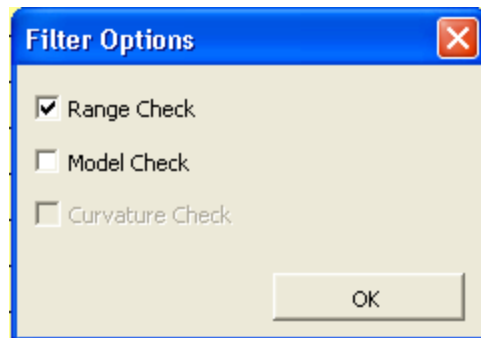
(b)

**Figure 8. Extracted FWD data: (a) variable FWD load analysis, (b) 9-kip-constant FWD load analysis**

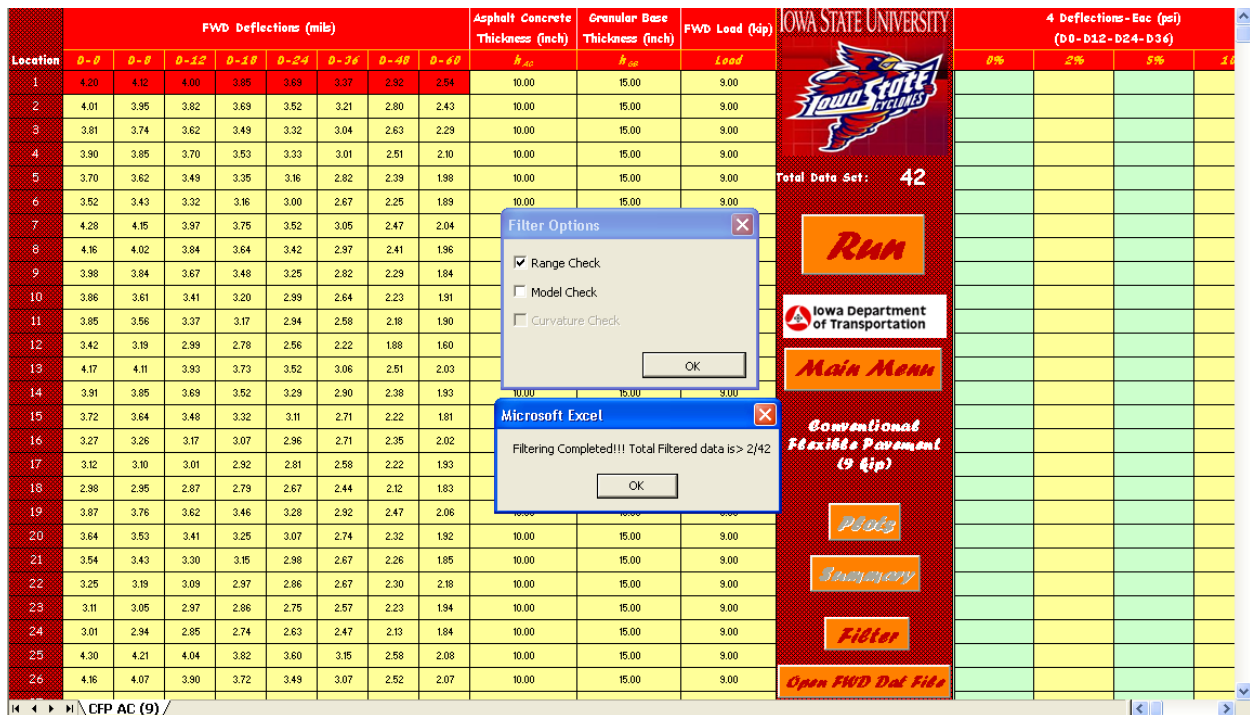
Once the FWD deflection data is entered, the user has the option to check the data for anomalies using the data preprocessing unit (Filter command button) for filtering the data. It is optional to use the filtering window. Figure 9. shows the available options for filtering. The two options are:

- Range Check: Deflection basin should form a bowl shape and, therefore, deflections should be in decreasing order. Data that falls outside this range are red colored.
- Model Check: ANN models are normalized according to the model ranges and, therefore, any input outside the range used in ANN training will form a poor quality input. As a result, the model check will determine the outliers and color them in red.

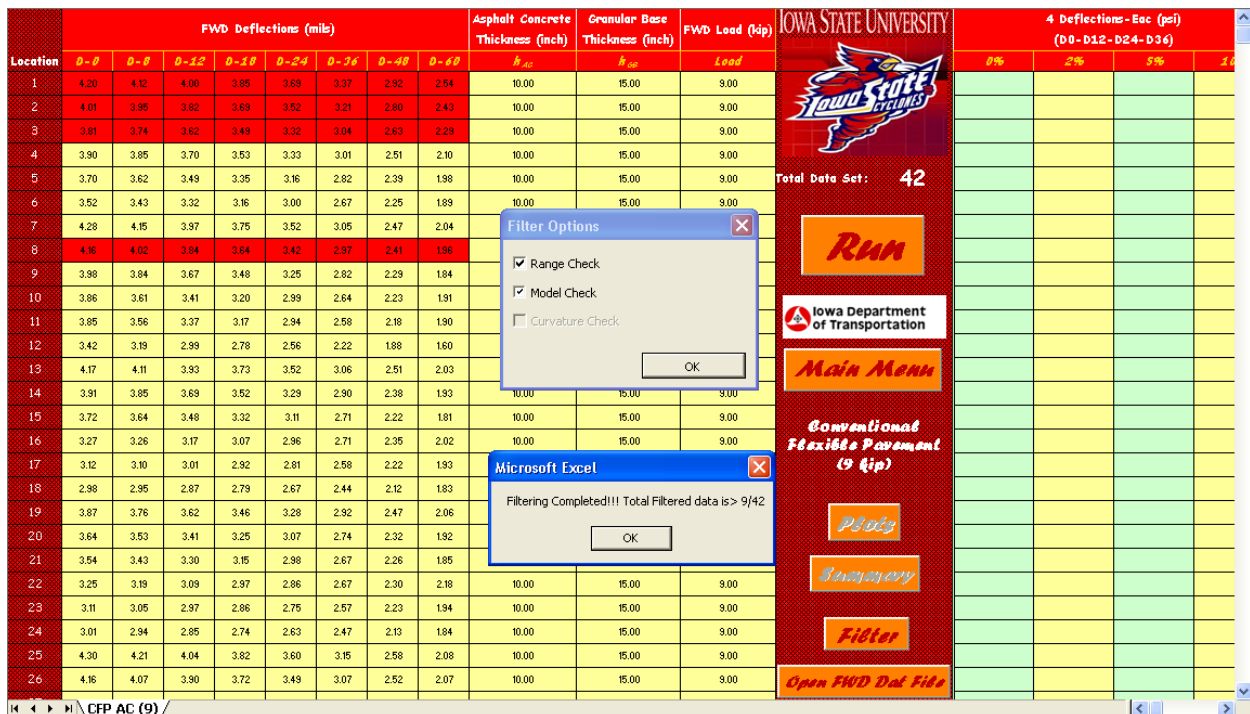
The filtering is applied by changing the color of the input parameter to red (see Figure 10). The analysis results from filtered data are also shown with red color in charts (see Figure 11). Therefore, results for these parameters are also calculated. With this approach, engineers will have a better understanding of the sources of errors.



**Figure 9. Filter options menu**

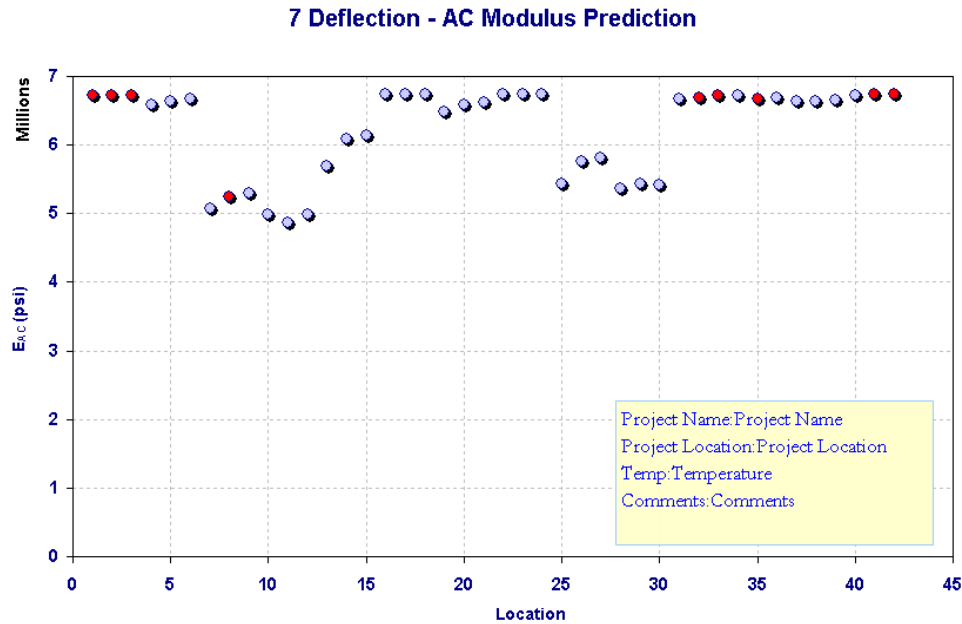


(a)



(b)

Figure 10. Filtering the FWD data: (a) range check, (b) range and model check



**Figure 11. Sample pavement analysis results identifying analysis results from FWD data that falls outside filtering range**

After preprocessing the data, clicking the “Run” button will activate a neural network-based analysis of pavements. The program will analyze model by model for the pavement properties. The ANN models employed for flexible pavement analysis are 4, 6, 7, and 8 deflection models with 0%,  $\pm 2\%$ ,  $\pm 5\%$  and  $\pm 10\%$  noise. Each model has a different number of input parameters depending on the number of deflections. The purpose of introducing noisy patterns in the development of each model was to provide more robust networks that can tolerate the noisy or inaccurate deflection patterns collected from the FWD deflection basins. The detail descriptions of each model are provided in phase I project report (Ceylan et al, 2007).

For each model, the analysis results will be displayed on the right side of the screen. The user should scroll right to see all results. Also, disabled menu commands of plots and the summary will be activated. The conventional flexible pavement analysis results are  $E_{AC}$ -modulus of AC,  $K_b$ -base modulus parameter,  $E_{Ri}$ -subgrade resilient modulus,  $\epsilon_{AC}$ -tensile strain at the bottom of asphalt layer,  $\epsilon_{SG}$ -compressive strain at the top of subgrade, and  $\sigma_D$ -subgrade deviator stress. The full depth flexible pavement analysis results are  $E_{AC}$ -modulus of AC,  $E_{Ri}$ -subgrade resilient modulus,  $\epsilon_{AC}$ -tensile strain at the bottom of asphalt layer,  $\epsilon_{SG}$ -compressive strain at the top of subgrade, and  $\sigma_D$ -subgrade deviator stress.

Figure 12 illustrates the sample analysis results of a conventional and a full depth flexible pavement. Failure to supply all the input parameters will be reflected in the results column of that model. The program will automatically write “No Data.” For example, if  $D_{48}$  is missing in the input data, then all six- and eight-deflection model columns will display the error message of “No Data.”

At the end of each column, statistical information regarding that model is presented (see Figure



13.). The collection of these statistics is summarized in summary sheets.

[illegible]

(a)

[illegible]

(b)

**Figure 12. Sample Excel sheet outputs of flexible pavement analysis: (a) conventional, (b) full-depth**



Location	UNIVERSITY	4 Deflections-Eac (psi) (D0-D12-D24-D36)				4 Deflections-Eri (psi) (D0-D12-D24-D36)				4 Deflections-K (psi) (D0-D12-D24-D36)				
		8%	2%	5%	10%	8%	2%	5%	10%	8%	2%	5%	10%	
28		5,837,793	2,869,659	4,072,610	3,666,773	-129	1,274	1,615	3,193	1,894	2,082	3,781	5,259	5,413,138
29		5,898,991	4,355,569	4,496,663	3,987,184	124	1,122	1,823	3,185	1,943	2,757	4,863	6,922	5,459,896
30		5,838,379	5,193,935	4,830,372	4,281,029	445	1,153	1,998	3,184	2,447	4,985	5,803	7,101	5,446,531
31		6,730,921	6,060,596	5,852,932	5,085,998	1,064	3,071	3,858	5,752	12,173	12,716	11,988	8,784	6,695,800
32		6,731,745	6,137,374	5,879,580	5,120,352	1,398	4,120	4,800	6,346	12,765	12,974	12,192	8,680	6,709,121
33		6,736,795	6,226,403	5,953,644	5,226,999	1,477	4,771	5,436	7,085	13,064	13,094	12,358	9,484	6,728,656
34		6,626,582	6,041,129	5,754,582	5,037,018	1,514	3,545	4,677	6,393	12,555	12,863	11,967	8,321	6,725,546
35		6,588,483	6,043,129	5,684,056	5,057,589	1,936	4,518	5,554	7,068	12,962	12,764	11,656	8,610	6,697,665
36		6,609,326	6,056,991	5,637,900	5,107,871	2,411	5,733	6,503	7,962	13,028	12,793	11,448	9,264	6,707,172
37		6,724,977	2,283,807	5,489,244	4,041,840	-388	1,494	1,438	2,753	1,878	2,053	4,524	2,755	6,670,524
38		6,720,859	2,564,135	5,458,264	4,274,015	-318	1,267	1,576	2,882	1,889	2,532	4,853	3,874	6,661,258
39		6,724,788	3,190,814	5,458,016	4,527,168	-248	1,140	1,692	2,975	1,973	4,004	6,086	5,519	6,674,341
40		6,737,485	4,670,367	5,529,023	5,460,092	-186	1,262	2,387	3,638	3,414	8,986	8,244	9,993	6,734,366
41		6,737,497	5,154,658	5,584,627	5,639,863	-156	1,645	2,712	3,593	9,134	12,053	10,878	10,268	6,736,521
42		6,737,498	5,859,215	5,758,910	5,690,307	77	2,633	2,843	4,510	11,343	12,973	11,860	10,035	6,736,924
43														
44	AVERAGE	6,358,385	5,339,434	5,508,288	5,080,658	945	2,640	3,233	4,835	8,261	9,739	9,495	8,424	6,264,431
45	STDEV	623,113	1,059,948	435,888	528,246	1,331	1,582	1,538	1,561	4,518	3,653	2,734	1,931	633,722
46	CV	10%	20%	8%	11%	141%	60%	48%	32%	55%	38%	29%	23%	10%
47														
48														
49														
50														
51														
52														

**Figure 13. Sample Excel sheet output statistics of pavement analysis**

The plot button will be enabled after the backcalculation analysis is complete. The plot option window appears after clicking on the plot button (see Figure 14). With this window, the user can select the models to display on charts. Selected models will be plotted in the form of backcalculated parameter versus FWD test location. Provided that the data is from a specified section, the first data will be represented as the starting point, and each subsequent data is assumed to correspond to FWD test locations along the path of the pavement system. Filtered data from the preprocessor will be displayed in red, whereas all others will be in blue. The upper right corner will display a textbox containing general information about the project. Figure 15 and Figure 16 illustrate color-coded conventional and the full depth flexible pavement analysis results, respectively, from 4-deflection ANN model with 0 % noise.

**Plots Option**

CFP | **FD** | RGD | CP

☒ 9 kjp    ☐ 5-21 kjp

**4 Deflection Models**

<input type="checkbox"/> Eac (Virgin)	<input type="checkbox"/> Eac (2%)	<input type="checkbox"/> Eac (5%)	<input type="checkbox"/> Eac (10%)
<input type="checkbox"/> K (Virgin)	<input type="checkbox"/> K (2%)	<input type="checkbox"/> K (5%)	<input type="checkbox"/> K (10%)
<input type="checkbox"/> Eri (Virgin)	<input type="checkbox"/> Eri (2%)	<input type="checkbox"/> Eri (5%)	<input type="checkbox"/> Eri (10%)
<input type="checkbox"/> Strain AC	<input type="checkbox"/> Strain SG	<input type="checkbox"/> Deviator Stress	

**6 Deflection Models**

<input type="checkbox"/> Eac (Virgin)	<input type="checkbox"/> Eac (2%)	<input type="checkbox"/> Eac (5%)	<input type="checkbox"/> Eac (10%)
<input type="checkbox"/> K (Virgin)	<input type="checkbox"/> K (2%)	<input type="checkbox"/> K (5%)	<input type="checkbox"/> K (10%)
<input type="checkbox"/> Eri (Virgin)	<input type="checkbox"/> Eri (2%)	<input type="checkbox"/> Eri (5%)	<input type="checkbox"/> Eri (10%)
<input type="checkbox"/> Strain AC	<input type="checkbox"/> Strain SG	<input type="checkbox"/> Deviator Stress	

**7 Deflection Models**

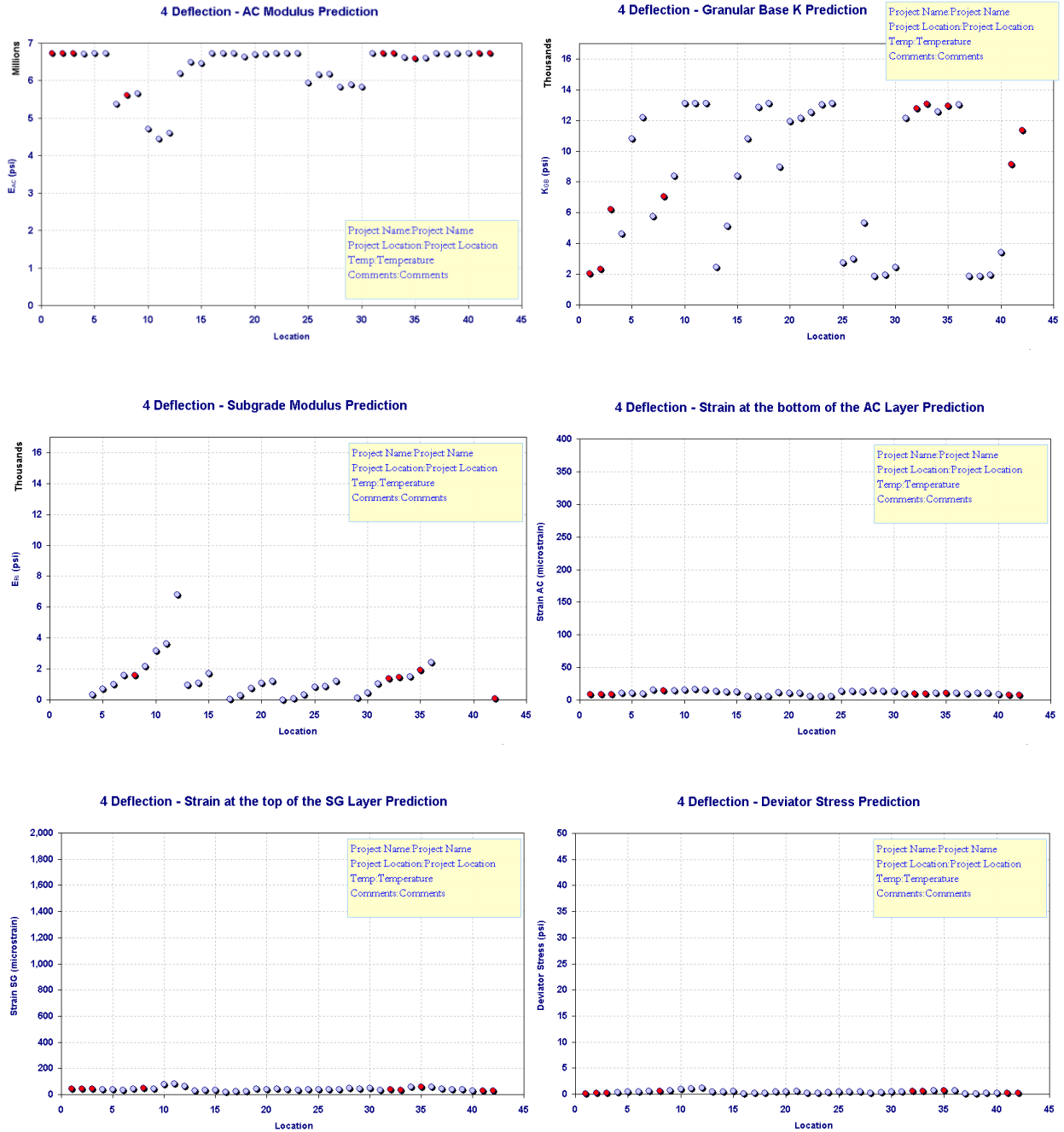
<input type="checkbox"/> Eac (Virgin)	<input type="checkbox"/> Eac (2%)	<input type="checkbox"/> Eac (5%)	<input type="checkbox"/> Eac (10%)
<input type="checkbox"/> K (Virgin)	<input type="checkbox"/> K (2%)	<input type="checkbox"/> K (5%)	<input type="checkbox"/> K (10%)
<input type="checkbox"/> Eri (Virgin)	<input type="checkbox"/> Eri (2%)	<input type="checkbox"/> Eri (5%)	<input type="checkbox"/> Eri (10%)
<input type="checkbox"/> Strain AC	<input type="checkbox"/> Strain SG	<input type="checkbox"/> Deviator Stress	

**8 Deflection Models**

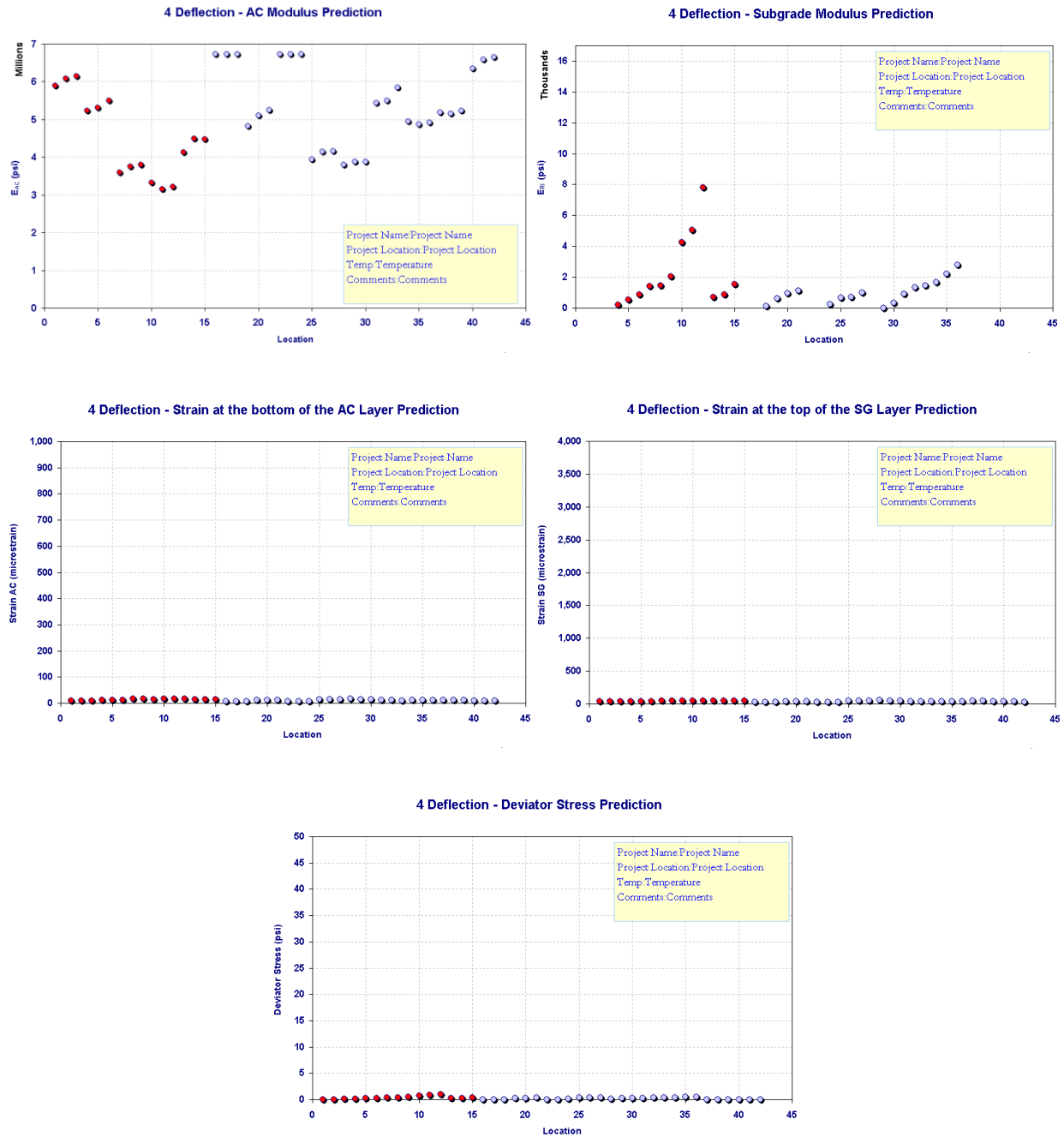
<input type="checkbox"/> Eac (Virgin)	<input type="checkbox"/> Eac (2%)	<input type="checkbox"/> Eac (5%)	<input type="checkbox"/> Eac (10%)
<input type="checkbox"/> K (Virgin)	<input type="checkbox"/> K (2%)	<input type="checkbox"/> K (5%)	<input type="checkbox"/> K (10%)
<input type="checkbox"/> Eri (Virgin)	<input type="checkbox"/> Eri (2%)	<input type="checkbox"/> Eri (5%)	<input type="checkbox"/> Eri (10%)
<input type="checkbox"/> Strain AC	<input type="checkbox"/> Strain SG	<input type="checkbox"/> Deviator Stress	

**Figure 14. Plot option window**



**Figure 15. Sample Excel plots for conventional pavement analysis results**



**Figure 16. Sample Excel plots for full-depth asphalt pavement analysis results**

The Summary button within the pavement analysis Excel spreadsheet is disabled until the “Run” button is clicked. It summarizes the statistical output information for each model. It opens up a new Excel sheet with tables of each output and summary statistics for every model (see Figure 17). The reported statistical information include:

- Average (or mean value): The average value along the section.

- Standard deviation: A common measure of the dispersion. It shows how widely the data is spread from the mean value.
- Coefficient of variation (CV): CV is a measure of the dispersion of probability distribution. It is the ratio of the standard deviation to the mean. It allows the user to compare the CV of populations that have different mean values. It is reported as a percentage.

Statistics							Details						
Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise	Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise
E <sub>ac</sub>	6350303	623,113	10%	CFP9-4	4	0	E <sub>u</sub>	945	1,571	141%	CFP9-4	4	0
	3,339,444	1,039,944	20%	CFP9-4	4	2		2,640	1,572	60%	CFP9-4	4	2
	3,304,208	451,888	8%	CFP9-4	4	5		2,233	1,578	44%	CFP9-4	4	5
	3,000,658	324,246	11%	CFP9-4	4	10		4,833	1,561	32%	CFP9-4	4	10
	6,264,689	631,722	10%	CFP9-6	6	0		1,610	1,183	73%	CFP9-6	6	0
	3,916,786	691,872	12%	CFP9-6	6	2		1,933	1,033	54%	CFP9-6	6	2
	3,398,188	677,394	12%	CFP9-6	6	5		2,478	1,044	42%	CFP9-6	6	5
	3,200,456	391,609	12%	CFP9-6	6	10		2,840	1,002	35%	CFP9-6	6	10
	6,239,816	646,972	10%	CFP9-7	7	0		1,576	1,191	76%	CFP9-7	7	0
	3,837,898	674,897	12%	CFP9-7	7	2		2,049	893	44%	CFP9-7	7	2
	3,485,323	329,022	10%	CFP9-7	7	5		2,711	1,150	42%	CFP9-7	7	5
	3,503,588	632,164	11%	CFP9-7	7	10		3,122	1,134	36%	CFP9-7	7	10
	6,229,968	637,000	11%	CFP9-8	8	0		1,517	1,174	77%	CFP9-8	8	0
	3,896,143	686,003	12%	CFP9-8	8	2		1,581	1,063	67%	CFP9-8	8	2
	3,349,946	729,373	13%	CFP9-8	8	5		3,184	1,472	46%	CFP9-8	8	5
	3,409,378	372,266	11%	CFP9-8	8	10		3,107	1,042	34%	CFP9-8	8	10
Note: E <sub>ac</sub> predictions are limited to ranges between 100,000 and 6,000,000 psi.							Note: E <sub>u</sub> predictions are limited to ranges between 1,000 and 15,000 psi.						
Statistics							Details						
Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise	Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise
K <sub>ac</sub>	8,261	4,318	53%	CFP9-4	4	0	E <sub>u</sub>	11	3	28%	CFP9-4	4	0
	9,759	3,633	38%	CFP9-4	4	2		11	3	27%	CFP9-6	6	0
	9,493	2,714	29%	CFP9-4	4	5		12	3	24%	CFP9-7	7	0
	8,424	1,931	23%	CFP9-4	4	10		12	3	24%	CFP9-8	8	0
	3,789	4,883	84%	CFP9-6	6	0		42	13	30%	CFP9-4	4	0
	6,920	4,624	67%	CFP9-6	6	2		27	19	71%	CFP9-6	6	0
	6,424	4,013	63%	CFP9-6	6	5		30	14	39%	CFP9-7	7	0
	6,882	2,693	39%	CFP9-6	6	10		24	19	69%	CFP9-8	8	0
	6,366	4,779	75%	CFP9-7	7	0		0	0	34%	CFP9-4	4	0
	7,136	4,710	66%	CFP9-7	7	2		0	0	33%	CFP9-6	6	0
	6,687	4,234	63%	CFP9-7	7	5		0	0	33%	CFP9-7	7	0
	7,084	3,444	47%	CFP9-7	7	10		0	0	30%	CFP9-8	8	0
	6,204	3,001	41%	CFP9-8	8	0							
	8,178	4,596	56%	CFP9-8	8	2							
	6,592	4,508	68%	CFP9-8	8	5							
	7,207	3,069	43%	CFP9-8	8	10							
Note: E <sub>ac</sub> predictions are limited to ranges between 100,000 and 6,000,000 psi.							Note: E <sub>u</sub> predictions are limited to ranges between 1,000 and 15,000 psi.						
Statistics							Details						
Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise	Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise
E <sub>ac</sub>	5,800,860	1,875,020	22%	FD9-4	4	0	E <sub>u</sub>	304	1,659	55%	FD9-4	4	0
	3,383,283	1,451,508	43%	FD9-4	4	2		2,634	2,634	99%	FD9-4	4	2
	4,028,044	300,626	7%	FD9-4	4	5		1,940	1,069	55%	FD9-4	4	5
	3,626,624	826,701	23%	FD9-4	4	10		2,620	1,036	40%	FD9-4	4	10
	4,708,771	1,807,020	24%	FD9-6	6	0		1,285	1,285	100%	FD9-6	6	0
	4,328,532	1,022,308	24%	FD9-6	6	2		1,570	1,111	69%	FD9-6	6	2
	4,323,429	1,038,462	25%	FD9-6	6	5		1,657	878	47%	FD9-6	6	5
	3,853,023	961,670	24%	FD9-6	6	10		1,526	762	41%	FD9-6	6	10
	4,328,769	1,188,248	24%	FD9-7	7	0		1,573	1,330	85%	FD9-7	7	0
	4,383,070	1,085,478	25%	FD9-7	7	2		1,643	1,114	68%	FD9-7	7	2
	4,087,853	1,162,804	27%	FD9-7	7	5		2,078	888	43%	FD9-7	7	5
	3,496,727	963,330	27%	FD9-7	7	10		2,368	436	19%	FD9-7	7	10
	4,638,604	1,167,948	24%	FD9-8	8	0		1,546	1,304	85%	FD9-8	8	0
	4,388,880	1,062,732	24%	FD9-8	8	2		1,460	1,168	80%	FD9-8	8	2
	4,094,680	953,680	24%	FD9-8	8	5		1,746	1,045	60%	FD9-8	8	5
	3,942,581	950,901	24%	FD9-8	8	10		2,081	794	38%	FD9-8	8	10
Note: E <sub>ac</sub> predictions are limited to ranges between 100,000 and 6,000,000 psi.							Note: E <sub>u</sub> predictions are limited to ranges between 1,000 and 15,000 psi.						
Statistics							Details						
Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise	Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise
E <sub>ac</sub>	12	3	25%	FD9-4	4	0	E <sub>u</sub>	12	3	25%	FD9-4	4	0
	12	3	25%	FD9-6	6	0		12	3	25%	FD9-6	6	0
	12	3	25%	FD9-7	7	0		12	3	25%	FD9-7	7	0
E <sub>u</sub>	42	8	19%	FD9-4	4	0	E <sub>u</sub>	42	8	19%	FD9-4	4	0
	42	8	19%	FD9-6	6	0		42	8	19%	FD9-6	6	0
	42	8	19%	FD9-7	7	0		42	8	19%	FD9-7	7	0
σ <sub>p</sub>	0	0	0%	FD9-4	4	0	σ <sub>p</sub>	0	0	0%	FD9-4	4	0
	0	0	0%	FD9-6	6	0		0	0	0%	FD9-6	6	0
	0	0	0%	FD9-7	7	0		0	0	0%	FD9-7	7	0
Note: Strain AC predictions are limited to ranges between 0 and 1000 microstrain.							Note: Strain AC predictions are limited to ranges between 0 and 1000 microstrain.						
Note: Strain SG predictions are limited to ranges between 0 and 4000 microstrain.							Note: Strain SG predictions are limited to ranges between 0 and 4000 microstrain.						
Note: Deviator Stress predictions are limited to ranges between 0 and 25 psi.							Note: Deviator Stress predictions are limited to ranges between 0 and 25 psi.						

Figure 17. Output statistics summary sheet for flexible pavement: (a) conventional, (b) full-depth

## Rigid Pavement Analysis, Plotting, and Summary Menus

Similar to flexible pavement analysis menu, the rigid pavement analysis menu consists of three main sections: inputs, analysis tool, and outputs as shown in Figure 18. Required input parameters for rigid pavement analysis are deflection data, pavement layer information (layer thicknesses, degree of bonding, and estimated moduli ratio), and FWD load. To simplify the ANN-based backcalculation methodology, PCC layer and base layer thicknesses are combined into one thickness value (effective PCC thickness) through the concept of equivalent thickness (Ceylan et al, 2007). While conducting the analysis, the effective PCC thickness can be automatically calculated from pavement layer information and used in the backcalculation analysis.

The analysis tool functionalities in the rigid pavement analysis menu are identical to those in flexible pavement analysis menu except two additional functions-“equation” and “show normalization.” The “Equation” button, once clicked, is meant to provide the equations sheet as shown in Figure 19. This equation sheet summarizes the equations used for calculation of effective PCC thickness for fully bonded PCC layers, unbonded PCC layers and partially bonded PCC layers. The “show normalization” button is enabled only after the backcalculation analysis is complete. The raw FWD deflection data corresponding to the raw FWD loads are normalized to the 9-kip constant FWD load during backcalculation analysis. As shown in Figure 20, the normalized FWD data can be shown or hid in rigid pavement analysis menu by clicking “show normalization” or “hide normalization.” Preprocessing the data for rigid pavement analysis such as obtaining and filtering the FWD data is same as that for flexible pavement analysis.

Section	INPUTS										Status on Grade Analysis	Coefficient of Subgrade Reaction (psi/in)			
	RWD/FWD Deflections (mil)					RWD/FWD Load (kip)	Effective Thickness (calculated) (in)	PCC Thickness (in)	Base Thickness (in)	Degree of Bonding (%)	Estimated Moduli Ratio				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2.23	2.17	2.10	2.04	1.92	0.80	0.80	0.80	0.20	0.20	0.20	1.115	1.097	1.101	1.110
2	2.49	2.42	2.35	2.42	2.29	2.87	1.31	0.80	0.20	0.20	0.20	237	234	240	245
3	3.24	3.01	3.04	2.94	2.75	2.80	2.10	0.80	0.20	0.20	0.20	281	280	281	285
4	2.34	2.20	2.20	2.15	2.05	1.84	1.70	0.40	0.20	0.20	0.20	166	167	166	164
5	2.79	2.71	2.61	2.59	2.37	2.54	1.51	1.77	0.20	0.20	0.20	241	242	249	234
6	3.49	3.40	3.20	3.10	2.95	2.71	2.24	2.87	0.20	0.20	0.20	235	236	239	225
7	2.70	2.74	2.64	2.59	2.40	2.20	1.92	0.80	0.20	0.20	0.20	167	167	172	161
8	3.40	3.44	3.30	3.20	3.00	2.80	2.47	2.18	0.20	0.20	0.20	187	187	193	184
9	4.58	4.07	3.94	3.74	3.62	3.20	3.37	2.82	0.20	0.20	0.20	170	169	177	165
10	2.18	2.03	2.04	2.03	1.81	2.29	2.28	1.94	0.40	0.20	0.20	189	189	189	184
11	3.82	3.47	3.34	3.22	3.00	2.79	2.46	2.39	0.20	0.20	0.20	172	171	173	164
12	4.10	4.04	3.91	3.77	3.61	3.24	3.17	2.74	0.20	0.20	0.20	176	177	178	172
13	2.44	2.39	2.31	2.41	2.30	2.10	1.91	0.80	0.20	0.20	0.20	165	164	171	161
14	3.32	3.27	3.16	3.03	2.81	2.41	2.29	2.25	0.20	0.20	0.20	181	181	180	180
15	4.17	3.97	3.93	3.69	3.83	3.23	2.14	2.83	0.20	0.20	0.20	174	172	179	167
16	2.13	2.06	2.00	2.00	1.82	1.99	1.92	1.89	0.40	0.20	0.20	214	215	221	208
17	3.40	3.44	3.30	3.17	2.91	2.71	2.29	2.80	0.20	0.20	0.20	189	191	194	180
18	4.03	3.96	3.79	3.67	3.44	3.04	2.34	2.33	0.20	0.20	0.20	220	219	227	210
19	2.86	2.81	2.42	2.31	2.20	2.01	1.88	1.74	0.20	0.20	0.20	185	182	191	187
20	3.22	3.10	3.02	2.90	2.70	2.83	2.24	2.20	0.20	0.20	0.20	197	194	203	190
21	3.11	3.19	3.09	3.07	3.00	3.04	2.49	2.31	0.20	0.20	0.20	181	181	187	181
22	2.84	2.80	2.40	2.33	2.23	2.06	1.91	1.76	0.20	0.20	0.20	164	164	165	169
23	3.21	3.16	3.07	2.98	2.82	2.87	2.24	1.99	0.20	0.20	0.20	171	171	177	171
24	3.19	3.16	3.04	2.99	2.74	3.07	2.41	2.34	0.20	0.20	0.20	184	183	193	182
25	2.80	2.76	2.76	2.64	2.80	2.26	2.30	2.30	0.20	0.20	0.20	192	192	192	188
26	3.09	3.02	2.81	2.76	2.70	2.87	2.40	2.40	0.20	0.20	0.20	181	181	181	181
27	4.20	4.09	4.09	3.97	3.66	3.29	2.30	2.30	0.20	0.20	0.20	216	216	216	216
28	2.17	2.03	2.03	2.03	1.84	2.04	2.04	2.00	0.20	0.20	0.20	216	216	216	216
29	3.84	3.82	3.41	3.28	3.16	2.81	2.81	2.40	0.20	0.20	0.20	192	192	192	192
30	4.20	4.20	4.21	4.03	3.91	3.87	3.23	2.40	0.20	0.20	0.20	145	145	152	145
31	1.71	1.71	1.63	1.56	1.40	0.80	0.80	0.80	0.40	0.20	0.20	1.115	1.115	1.114	1.110
32	2.32	2.24	2.16	2.08	1.97	1.81	0.80	0.20	0.20	0.20	0.20	160	162	164	167
33	2.73	2.63	2.52	2.43	2.31	2.14	2.03	1.93	0.20	0.20	0.20	216	216	216	216
34	2.37	2.30	2.22	2.11	2.01	1.82	1.80	0.80	0.20	0.20	0.20	216	216	216	216
35	2.41	2.33	2.24	2.14	2.04	1.84	1.84	1.84	0.20	0.20	0.20	216	216	216	216

Figure 18. Rigid pavement analysis menu

Effective thickness for fully bonded PCC layers as:

$$h_{e-f} = \left\{ h_1^3 + \frac{E_2}{E_1} h_2^3 + 12 \left[ \left( x_{na} - \frac{h_1}{2} \right)^2 h_1 + \frac{E_2}{E_1} \left( h_1 - x_{na} + \frac{h_2}{2} \right)^2 h_2 \right] \right\}^{1/3}$$

$$x_{na} = \frac{E_1 h_1 \frac{h_1}{2} + E_2 h_2 \left( h_1 + \frac{h_2}{2} \right)}{E_1 h_1 + E_2 h_2}$$



Effective thickness for unbonded PCC layers as:

$$h_{e-u} = \left( h_1^3 + \frac{E_2}{E_1} h_2^3 \right)^{1/3}$$

Effective thickness for partially bonded PCC layers as:

$$h_{e-p} = (1-x)h_{e-u} + (x)h_{e-f}$$

$$x = \frac{h_{e-p} - h_{e-u}}{h_{e-f} - h_{e-u}}$$



- $h_{e-f}$  = Effective thickness of the fully bonded PCC layers
- $h_{e-u}$  = Effective thickness of the unbonded PCC layers
- $h_{e-p}$  = Effective thickness of the partially bonded PCC layers
- $E_1$  or  $E_2$  = Elastic modulus for layer 1 or 2
- $h_1$  or  $h_2$  = Thickness for layer 1 or 2
- $x_{na}$  = Neutral axis distance from top of layer
- $x$  = degree of bonding which ranges between 0 and 1

$k$  - coefficient of subgrade reaction and Epcc equations in terms of  $l$  - radius of relative stiffness

$$k = \left( \frac{P}{8D_e \ell_r^3} \right) \left\{ 1 + \left( \frac{1}{2\pi} \right) \left[ \ln \left( \frac{a}{2\ell_r} \right) - 0.673 \right] \left( \frac{a}{\ell_r} \right)^2 \right\}$$

$$E_{pcc} = \left( \frac{12\ell_r^3 k(1-\mu^2)}{h_{pcc}^3} \right)$$

◀ ▶ ⌂ Equations /

Figure 19. Screen shot of Equations sheet

Location	INPUTS																Stab o Ana
	HVD/FVD Deflections (mils)								HVD/FVD Load (kips)	Effective Thickness (calculated) (inch)	PCC Thickness (inch)	Base Thickness (inch)	Degree of Bonding (%)	Estimated Moduli Ratio			
	D-6	D-8	D-12	D-18	D-24	D-36	D-48	D-60	Load	A <sub>ave</sub>	A <sub>PCC</sub>	A <sub>base</sub>	B	(E <sub>base</sub> /E <sub>PCC</sub> )	(E <sub>base</sub> /E <sub>PCC</sub> )		
1	2.23	2.17	2.10	2.01	1.92	0.00	0.00	0.00	9.34	10.24	10.20	4.00	0	0.20	Total Data S Main Eqn St Norm P Sh Fi Open Fr		
2	2.69	2.62	2.53	2.42	2.29	2.07	1.81	0.00	12.18	10.24	10.20	4.00	0	0.20			
3	3.26	3.18	3.06	2.94	2.78	2.50	2.18	1.90	14.67	10.24	10.20	4.00	0	0.20			
4	2.34	2.28	2.20	2.12	2.03	1.84	1.70	0.49	9.22	10.24	10.20	4.00	0	0.20			
5	2.79	2.71	2.61	2.50	2.37	2.14	1.88	1.77	11.94	10.24	10.20	4.00	0	0.20			
6	3.49	3.40	3.28	3.13	2.95	2.71	2.34	2.07	14.81	10.24	10.20	4.00	0	0.20			
7	2.79	2.74	2.64	2.55	2.42	2.20	1.92	0.00	9.26	10.24	10.20	4.00	0	0.20			
8	3.48	3.44	3.33	3.20	3.05	2.80	2.47	2.15	11.88	10.24	10.20	4.00	0	0.20			
9	4.14	4.07	3.94	3.81	3.62	3.30	2.87	2.52	14.71	10.24	10.20	4.00	0	0.20			
10	2.88	2.83	2.74	2.63	2.51	2.29	2.20	1.96	9.43	10.24	10.20	4.00	0	0.20			
11	3.52	3.47	3.36	3.22	3.08	2.79	2.46	2.39	12.26	10.24	10.20	4.00	0	0.20			
12	4.12	4.04	3.91	3.77	3.58	3.26	2.87	2.74	14.78	10.24	10.20	4.00	0	0.20			
13	2.64	2.59	2.51	2.41	2.30	2.12	1.88	0.59	9.36	10.24	10.20	4.00	0	0.20			
14	3.32	3.27	3.16	3.03	2.88	2.61	2.29	2.25	12.10	10.24	10.20	4.00	0	0.20			
15	4.07	3.97	3.83	3.69	3.53	3.23	2.84	2.53	14.52	10.24	10.20	4.00	0	0.20			
16	2.61	2.56	2.48	2.36	2.23	1.99	1.72	1.49	9.43	10.24	10.20	4.00	0	0.20			
17	3.49	3.41	3.30	3.17	3.01	2.71	2.35	2.09	12.18	10.24	10.20	4.00	0	0.20			
18	4.03	3.95	3.79	3.67	3.44	3.06	2.64	2.33	14.94	10.24	10.20	4.00	0	0.20			
19	2.56	2.51	2.42	2.31	2.20	2.01	1.95	1.74	9.57	10.24	10.20	4.00	0	0.20			
20	3.22	3.13	3.02	2.92	2.78	2.53	2.24	2.20	12.43	10.24	10.20	4.00	0	0.20			
21	3.81	3.75	3.59	3.47	3.30	3.04	2.65	2.31	15.22	10.24	10.20	4.00	0	0.20			
22	2.54	2.50	2.43	2.33	2.23	2.06	1.82	1.76	9.27	10.24	10.20	4.00	0	0.20			
23	3.21	3.16	3.07	2.95	2.82	2.57	2.24	1.99	12.26	10.24	10.20	4.00	0	0.20			
24	3.85	3.76	3.64	3.50	3.34	3.07	2.68	2.36	14.97	10.24	10.20	4.00	0	0.20			
25	2.92	2.86	2.76	2.66	2.52	2.26	2.18	1.90	9.29	10.24	10.20	4.00	0	0.20			
26	3.69	3.62	3.51	3.36	3.18	2.87	2.49	2.34	12.18	10.24	10.20	4.00	0	0.20			
27	4.30	4.20	4.05	3.87	3.66	3.29	2.86	2.39	14.78	10.24	10.20	4.00	0	0.20			
Rigid Pavement Analysis																	

(a)

Location	INPUTS																								Stab o Ana
	HVD/FVD Deflections (mils)								HVD/FVD Load (kips)	9 kip Normalization								Effective Thickness (calculated) (inch)	PCC Thickness (inch)	Base Thickness (inch)	Degree of Bonding (%)	Estimated Moduli Ratio			
	D-6	D-8	D-12	D-18	D-24	D-36	D-48	D-60	Load	D-6	D-8	D-12	D-18	D-24	D-36	D-48	D-60	Load	h <sub>eff</sub>	h <sub>PCC</sub>	h <sub>base</sub>	f <sub>b</sub>	MR <sub>avg</sub>	MR <sub>min</sub>	
1	2.23	2.17	2.10	2.01	1.92	0.00	0.00	0.00	9.34	2.15	2.09	2.02	1.94	1.85	0.00	0.00	0.00	9.00	10.24	10.20	4.00	0	0.20		
2	2.69	2.62	2.53	2.42	2.29	2.07	1.81	0.00	12.18	1.99	1.94	1.87	1.79	1.69	1.53	1.34	0.00	9.00	10.24	10.20	4.00	0	0.20		
3	3.26	3.18	3.06	2.94	2.78	2.50	2.18	1.90	14.67	2.00	1.95	1.88	1.80	1.71	1.53	1.34	1.17	9.00	10.24	10.20	4.00	0	0.20		
4	2.34	2.28	2.20	2.12	2.03	1.84	1.70	0.49	9.22	2.28	2.23	2.15	2.07	1.98	1.80	1.66	0.48	9.00	10.24	10.20	4.00	0	0.20		
5	2.79	2.71	2.61	2.50	2.37	2.14	1.88	1.77	11.94	2.30	2.24	2.17	2.08	1.99	1.81	1.62	1.33	9.00	10.24	10.20	4.00	0	0.20	Total	
6	3.49	3.40	3.28	3.13	2.95	2.71	2.34	2.07	14.81	2.32	2.27	2.19	2.10	1.99	1.85	1.62	1.26	9.00	10.24	10.20	4.00	0	0.20		
7	2.79	2.74	2.64	2.55	2.42	2.20	1.92	0.00	9.26	2.71	2.66	2.57	2.48	2.35	2.14	1.87	0.00	9.00	10.24	10.20	4.00	0	0.20		
8	3.48	3.44	3.33	3.20	3.05	2.80	2.47	2.15	11.88	2.64	2.61	2.52	2.42	2.31	2.12	1.87	1.63	9.00	10.24	10.20	4.00	0	0.20		
9	4.14	4.07	3.94	3.81	3.62	3.30	2.87	2.52	14.71	2.53	2.49	2.41	2.33	2.21	2.02	1.76	1.54	9.00	10.24	10.20	4.00	0	0.20		
10	2.88	2.83	2.74	2.63	2.51	2.29	2.20	1.96	9.43	2.75	2.70	2.62	2.51	2.40	2.19	2.10	1.87	9.00	10.24	10.20	4.00	0	0.20		
11	3.52	3.47	3.36	3.22	3.08	2.79	2.46	2.39	12.26	2.58	2.55	2.47	2.36	2.26	2.05	1.81	1.75	9.00	10.24	10.20	4.00	0	0.20		
12	4.12	4.04	3.91	3.77	3.58	3.26	2.87	2.74	14.78	2.51	2.46	2.38	2.30	2.18	1.99	1.76	1.67	9.00	10.24	10.20	4.00	0	0.20		
13	2.64	2.59	2.51	2.41	2.30	2.12	1.88	0.59	9.36	2.54	2.49	2.41	2.32	2.21	2.04	1.81	0.57	9.00	10.24	10.20	4.00	0	0.20		
14	3.32	3.27	3.16	3.03	2.88	2.61	2.29	2.25	12.10	2.47	2.43	2.35	2.25	2.14	1.94	1.70	1.67	9.00	10.24	10.20	4.00	0	0.20		
15	4.07	3.97	3.83	3.69	3.53	3.23	2.84	2.53	14.52	2.52	2.46	2.37	2.29	2.19	2.00	1.76	1.57	9.00	10.24	10.20	4.00	0	0.20		
16	2.61	2.56	2.48	2.36	2.23	1.99	1.72	1.49	9.43	2.49	2.44	2.37	2.25	2.13	1.90	1.64	1.42	9.00	10.24	10.20	4.00	0	0.20		
17	3.49	3.41	3.30	3.17	3.01	2.71	2.35	2.09	12.18	2.58	2.52	2.44	2.34	2.22	2.00	1.74	1.54	9.00	10.24	10.20	4.00	0	0.20		
18	4.03	3.95	3.79	3.67	3.44	3.06	2.64	2.33	14.94	2.43	2.38	2.28	2.21	2.07	1.84	1.59	1.40	9.00	10.24	10.20	4.00	0	0.20		
19	2.56	2.51	2.42	2.31	2.20	2.01	1.95	1.74	9.57	2.41	2.36	2.28	2.17	2.07	1.89	1.63	1.64	9.00	10.24	10.20	4.00	0	0.20		
20	3.22	3.13	3.02	2.92	2.78	2.53	2.24	2.20	12.43	2.33	2.27	2.19	2.11	2.01	1.83	1.62	1.59	9.00	10.24	10.20	4.00	0	0.20	Dye	
21	3.81	3.75	3.59	3.47	3.30	3.04	2.65	2.31	15.22	2.25	2.22	2.12	2.05	1.95	1.80	1.57	1.37	9.00	10.24	10.20	4.00	0	0.20		
22	2.54	2.50	2.43	2.33	2.23	2.06	1.82	1.76	9.27	2.47	2.43	2.36	2.26	2.17	2.00	1.77	1.71	9.00	10.24	10.20	4.00	0	0.20		
23	3.21	3.16	3.07	2.95	2.82	2.57	2.24	1.99	12.26	2.36	2.32	2.25	2.17	2.07	1.89	1.64	1.46	9.00	10.24	10.20	4.00	0	0.20		
24	3.85	3.76	3.64	3.50	3.34	3.07	2.68	2.36	14.97	2.31	2.26	2.19	2.10	2.01	1.85	1.61	1.42	9.00	10.24	10.20	4.00	0	0.20		
25	2.92	2.86	2.76	2.66	2.52	2.26	2.18	1.90	9.29	2.83	2.77	2.67	2.58	2.44	2.19	2.11	1.84	9.00	10.24	10.20	4.00	0	0.20		
26	3.69	3.62	3.51	3.36	3.18	2.87	2.49	2.34	12.18	2.73	2.67	2.59	2.48	2.35	2.12	1.84	1.73	9.00	10.24	10.20	4.00	0	0.20		
27	4.30	4.20	4.05	3.87	3.66	3.29	2.86	2.39	14.78	2.62	2.56	2.47	2.36	2.23	2.00	1.74	1.46	9.00	10.24	10.20	4.00	0	0.20		
Rigid Pavement Analysis																									

(b)

Figure 20. Screen shot of inputs in rigid pavement analysis menu: (a) hide normalization, (b) show normalization



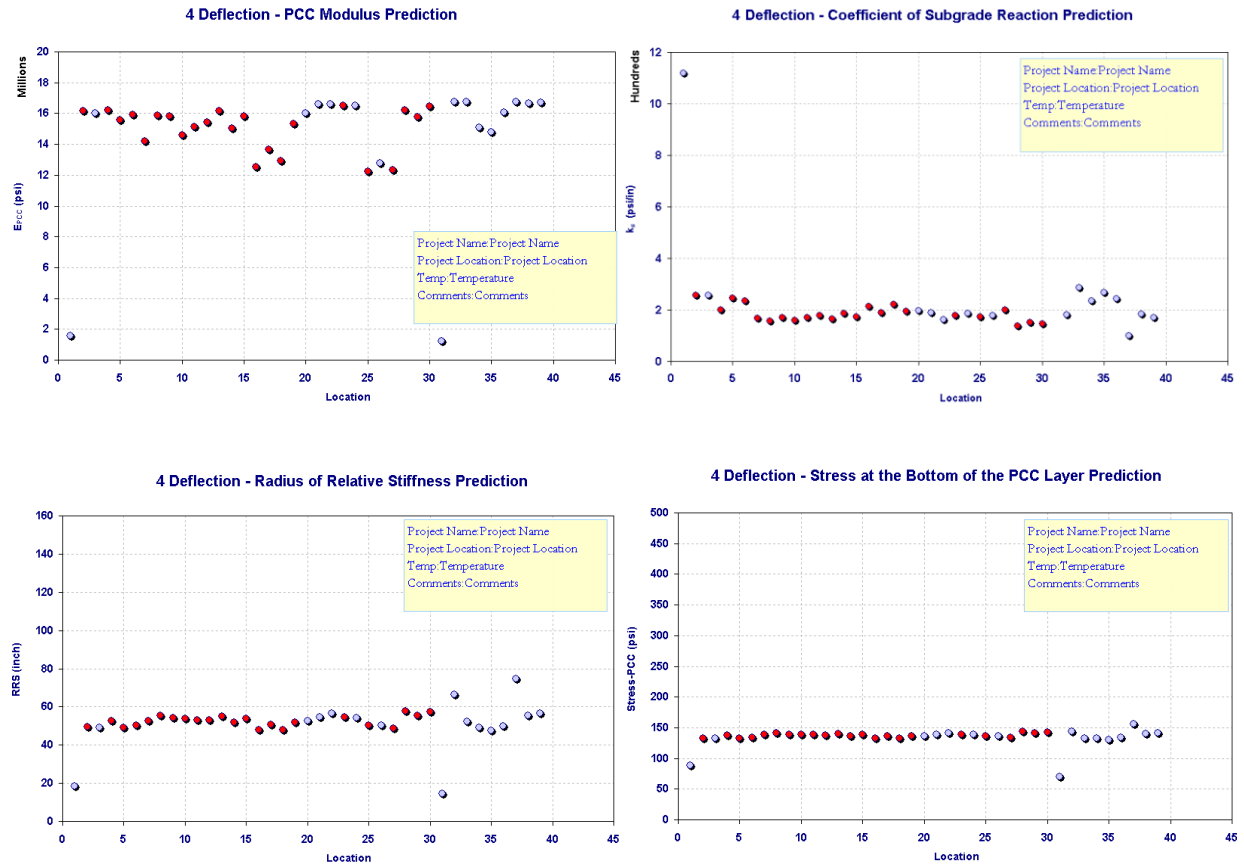
Similar to flexible pavement analysis, the program can analyze model by model by clicking the “Run” button after preprocessing the data. The ANN models employed for rigid pavement analysis are 4-, 6-, 7-, and 8-deflection models with 0%,  $\pm 2\%$ ,  $\pm 5\%$  and  $\pm 10\%$  noise. Each model has a different number of input parameters depending on the number of deflections. The purpose of introducing noisy patterns in the development of each model was to provide more robust networks that can tolerate the noisy or inaccurate deflection patterns collected from the FWD deflection basins. Detailed descriptions of each model are provided in phase I project report (Ceylan et al, 2007).

For each model, the analysis results will be displayed on the right side of the screen. The user should scroll right to see all results. Also, disabled menu commands of Plots and Summary will be activated after the analysis is complete. The rigid pavement analysis results are  $E_{PCC}$ -modulus of PCC,  $k_s$ -coefficient of subgrade reaction,  $\sigma_{PCC}$ -tensile stress at the bottom of the PCC layer, and radius of relative stiffness (RRS)

Figure 21 illustrates the sample analysis results from a rigid pavement run. Figure 22 illustrates color-coded rigid pavement analysis results of 4-deflection ANN model with 0 % noise which are generated from the plotting function. Figure 23 illustrates sample Excel sheet with the output tables and their statistics for every model generated by clicking “summary” button.

8 Deflection Model (D9-D8-D12-D18-D24-D36-D48-D60)									
Model	Coefficient of Subgrade Reaction (psi/in)				PCC Modulus (psi)				Radius of Relative Stiffness (inches)
	$k_s$	$k_s$	$k_s$	$k_s$	$E_{PCC}$	$E_{PCC}$	$E_{PCC}$	$E_{PCC}$	RRS
1	1,111	1,111	1,111	1,111	5,232,348	5,838,745	5,444,897	5,834,362	17
2	456	733	733	733	6,579,181	3,742,382	3,812,425	3,345,425	32
3	237	224	224	224	15,379,354	15,379,354	15,482,355	14,382,381	32
4	236	415	422	428	8,575,381	5,887,817	5,582,854	5,197,453	33
5	283	183	181	179	15,277,438	15,277,447	15,244,456	15,142,557	35
6	247	283	283	283	15,353,851	15,379,283	15,355,236	14,284,538	33
7	383	541	552	558	5,835,582	2,837,554	2,814,918	2,617,846	33
8	158	145	145	141	15,179,141	15,183,417	14,815,882	13,738,333	37
9	165	153	158	155	15,846,334	15,818,455	14,872,518	13,854,478	35
10	116	186	187	187	15,748,479	15,315,435	15,188,858	14,855,318	35
11	141	128	127	125	15,788,483	15,218,323	15,118,568	14,535,188	38
12	143	137	135	135	15,158,457	15,158,543	15,787,558	14,552,222	33
13	264	358	375	363	7,577,883	5,252,358	5,847,884	4,472,837	33
14	152	155	155	155	15,248,425	15,248,425	15,814,185	14,862,242	38
15	153	152	151	147	15,218,853	15,246,858	15,824,233	13,884,153	37
16	288	183	183	188	13,221,851	14,225,175	13,345,868	13,882,823	38
17	175	155	163	163	14,388,789	15,197,383	14,731,422	13,555,862	38
18	284	191	191	198	14,274,852	14,716,115	14,443,736	13,418,684	31
19	134	122	123	121	15,748,388	15,487,813	15,538,555	15,355,388	35
20	154	138	138	137	15,741,343	15,483,458	15,481,412	15,118,281	34
21	185	178	177	177	15,445,423	15,881,886	15,235,183	14,482,185	35
22	155	124	124	123	15,742,822	15,383,857	15,381,388	15,144,518	33
23	172	165	164	162	15,688,211	15,374,572	15,158,353	14,884,125	36
24	177	178	168	167	15,648,544	15,818,787	15,385,858	14,175,833	36
25	127	145	137	135	15,823,151	15,188,483	15,218,555	14,844,833	34
26	155	143	141	137	15,384,846	15,237,461	14,864,478	13,731,193	36
27	151	184	184	182	15,818,685	15,327,785	15,883,683	15,437,583	38
28	113	183	184	183	15,738,758	15,319,333	15,872,837	15,851,517	35
29	125	114	114	114	15,723,223	15,254,531	15,885,551	14,781,781	33
30	127	113	128	113	15,728,383	15,216,558	15,738,734	14,513,881	32
31	1,111	1,118	1,117	1,387	721,218	1,883,738	3,125,862	4,313,333	15
32	788	1,847	1,842	1,813	4,628,741	3,155,283	3,481,362	3,534,554	26
33	187	165	165	165	15,748,432	15,743,283	15,743,283	15,534,888	38
34	337	876	938	937	5,853,853	3,375,916	2,955,582	3,165,726	32
35	243	223	227	223	15,183,183	15,748,427	14,387,515	14,158,433	34
36	218	284	283	284	15,887,321	15,881,788	15,544,473	14,522,742	34
37	188	187	118	187	15,743,423	15,138,113	15,231,282	15,474,333	31
38	155	123	124	122	15,748,184	15,532,218	15,744,753	15,137,184	36
39	141	123	123	128	15,745,483	15,151,535	15,151,535	15,117,148	34
40									
41	248	273	274	274	19,522,435	12,333,813	12,638,386	11,847,338	31
42	237	288	282	275	6,828,394	5,242,763	5,888,283	4,568,373	34
43	35X	183X	183X	182X	36X	48X	48X	38X	27X

Figure 21. Sample Excel sheet of rigid pavement analysis outputs



**Figure 22. Sample Excel sheet rigid pavement analysis charts**

Statistic				Detail		
Prediction	Average (pr/in)	Std Dev (pr/in)	CV	Model	Deflection	Noise
k <sub>s</sub>	235	211	89%	RGD-4	4	0
	233	208	89%	RGD-4	4	2
	240	207	86%	RGD-4	4	5
	229	210	92%	RGD-4	4	10
	248	241	97%	RGD-6	6	0
	272	262	104%	RGD-6	6	2
	269	263	105%	RGD-6	6	5
	271	261	104%	RGD-6	6	10
	253	235	93%	RGD-7	7	0
	246	314	106%	RGD-7	7	2
	247	316	107%	RGD-7	7	5
	246	309	105%	RGD-7	7	10
	248	237	95%	RGD-8	8	0
	273	260	103%	RGD-8	8	2
	274	262	103%	RGD-8	8	5
	271	275	102%	RGD-8	8	10
Note: k <sub>s</sub> predictions are limited to range between 50 and 1,000 pr/in.				Back		
				Eecc predictions are limited to range between 1,000,000 and 15,000,000 pr.		
Statistic				Detail		
Prediction	Average (in)	Std Dev (in)	CV	Model	Deflection	Noise
RRS	50	10	19%	RGD-4	4	0
	51	14	26%	RGD-6	6	0
	51	15	29%	RGD-7	7	0
	51	14	27%	RGD-8	8	0
Note: RRS predictions are limited to range between 15 and 141 in.						
Statistic				Detail		
Prediction	Average	Std Dev	CV	Model	Deflection	Noise
σPCC	130	14	10%	RGD-4	4	
	135	18	13%	RGD-6	6	
	134	17	13%	RGD-7	7	
	135	16	12%	RGD-8	8	
Note: PCC Stress predictions are limited to range between 20 and 400 pr.						

Figure 23. Output statistics summary sheet for rigid pavement analysis

## Composite Pavement Analysis, Plotting, and Summary Menus

The AC overlaid PCC-type composite pavement analysis menu also consists of three main sections: inputs, analysis tool, and outputs as shown in Figure 24. Required input parameters for composite pavement analysis are deflection data, pavement layer information (layer thicknesses, PCC modulus predictions, and coefficient of subgrade reaction predictions), and FWD load. The analysis tool functionalities in composite analysis menu are identical to those in flexible pavement analysis menu. This means preprocessing of the data for composite pavement analysis is same as that for flexible pavement analysis.

Similar to flexible and rigid pavement analysis, the program analyzes the data model by model by clicking the “Run” button after preprocessing the data. The ANN models employed for composite pavement analysis are 4-, 6-, 7-, and 8- deflection models with 0%, ±2%, ±5% and ±10% noise. Each model has a different number of input parameters depending on the number of deflections and a different level of noise to provide more robust networks. Detailed descriptions of each model are provided in phase I project report (Ceylan et al, 2007).

For each model, the analysis results will be displayed on the right side of the screen. The user should scroll right to see all results. Also, disabled menu commands of plots and the summary

will be activated. The composite pavement analysis results are  $E_{AC}$ -modulus of AC,  $E_{PCC}$ -modulus of PCC,  $k_s$ -coefficient of subgrade reaction,  $\epsilon_{AC}$ -tensile strain at the bottom of asphalt layer, and  $\sigma_{PCC}$ -tensile stress at the bottom of the PCC layer.

Figure 25 illustrates sample analysis results for a composite pavement section. Figure 26 illustrates color-coded composite pavement analysis results of 4-deflection model with 0 % noise which are generated from the plotting function. Figure 27 illustrates sample Excel sheet with tables of each output and their statistics for every generated model by clicking “summary” button.

Location	FWD Deflections (mil)								Asphalt Concrete Thickness	Portland Cement Concrete	E <sub>pcc</sub> Prediction (psi)	k Prediction (psi/in)	Eas 4 Deflections - (psi) (D1-D24-D36)				(D4-D36)
	D-0	D-8	D-12	D-16	D-24	D-36	D-48	D-60	A <sub>ac</sub>	A <sub>pcc</sub>	E <sub>ac</sub>		D4	D8	D12	D36	
1	2.50	2.19	2.08	1.99	1.93	0.00	0.00	0.00	10.00	10.00			3,362,500	3,353,907	3,236,242	1,667,776	
2	3.01	2.61	2.46	2.36	2.24	2.05	2.05	0.00	10.00	10.00			1,094,829	1,218,712	1,685,600	2,091,545	
3	3.65	3.15	2.98	2.86	2.71	2.44			10.00								17
4	2.88	2.63	2.45	2.31	2.16	1.89			10.00								17
5	3.82	3.31	3.09	2.91	2.74	2.38			10.00								18
6	4.57	3.94	3.69	3.49	3.25	2.85	2.35	2.20	10.00	10.00							18
7	3.41	3.07	2.88	2.72	2.54	2.17	2.00	0.00	10.00	10.00							
8	4.31	3.87	3.65	3.43	3.19	2.72	2.23	2.12	10.00	10.00							
9	5.16	4.59	4.35	4.08	3.77	3.22	2.61	2.28	10.00	10.00							
10	3.42	2.84	2.63	2.43	2.23	1.95	1.82	0.00	10.00	10.00							
11	4.30	3.55	3.28	3.03	2.80	2.41	2.02	0.00	10.00	10.00							
12	5.22	4.30	3.98	3.68	3.39	2.92	2.47	2.27	10.00	10.00							
13	3.62	3.10	2.91	2.78	2.62	2.35	1.99	0.00	10.00	10.00							
14	4.55	3.87	3.65	3.49	3.28	2.92	2.50	2.43	10.00	10.00							
15	5.40	4.60	4.33	4.13	3.88	3.46	2.96	2.54	10.00	10.00							
16	4.38	4.00	3.79	3.57	3.33	2.89	2.38	2.25	10.00	10.00							
17	5.37	4.88	4.60	4.35	4.04	3.48	2.85	2.53	10.00	10.00							
18	6.40	5.80	5.48	5.16	4.79	4.12	3.39	2.76	10.00	10.00							
19	3.28	2.88	2.71	2.55	2.35	2.01	1.83	0.00	10.00	10.00							
20	4.22	3.67	3.46	3.25	3.03	2.57	2.06	2.01	10.00	10.00							
21	5.08	4.40	4.13	3.89	3.60	3.05	2.46	2.13	10.00	10.00							
22	3.59	3.32	3.13	2.97	2.79	2.45	2.13	0.00	10.00	10.00							
23	4.51	4.12	3.88	3.69	3.45	3.03	2.50	2.31	10.00	10.00							
24	5.42	4.93	4.67	4.42	4.12	3.59	2.89	2.49	10.00	10.00							
25	3.50	3.11	2.91	2.73	2.51	2.12	1.96	0.00	10.00	10.00							
26	4.57	3.98	3.76	3.51	3.23	2.72	2.19	2.06	10.00	10.00							
27	5.50	4.78	4.50	4.20	3.87	3.27	2.61	2.28	10.00	10.00							
28	4.60	4.18	3.92	3.65	3.38	2.85	2.47	0.00	10.00	10.00							

# Analysis Inputs

Run

Main Menu

AC overlaid PCC Analysis

Plot

Summary

Filter

Open FWD Data File

# Analysis Tool

Iowa Department of Transportation

AC overlaid PCC Analysis

Plot

Summary

Filter

Open FWD Data File

# Analysis Outputs

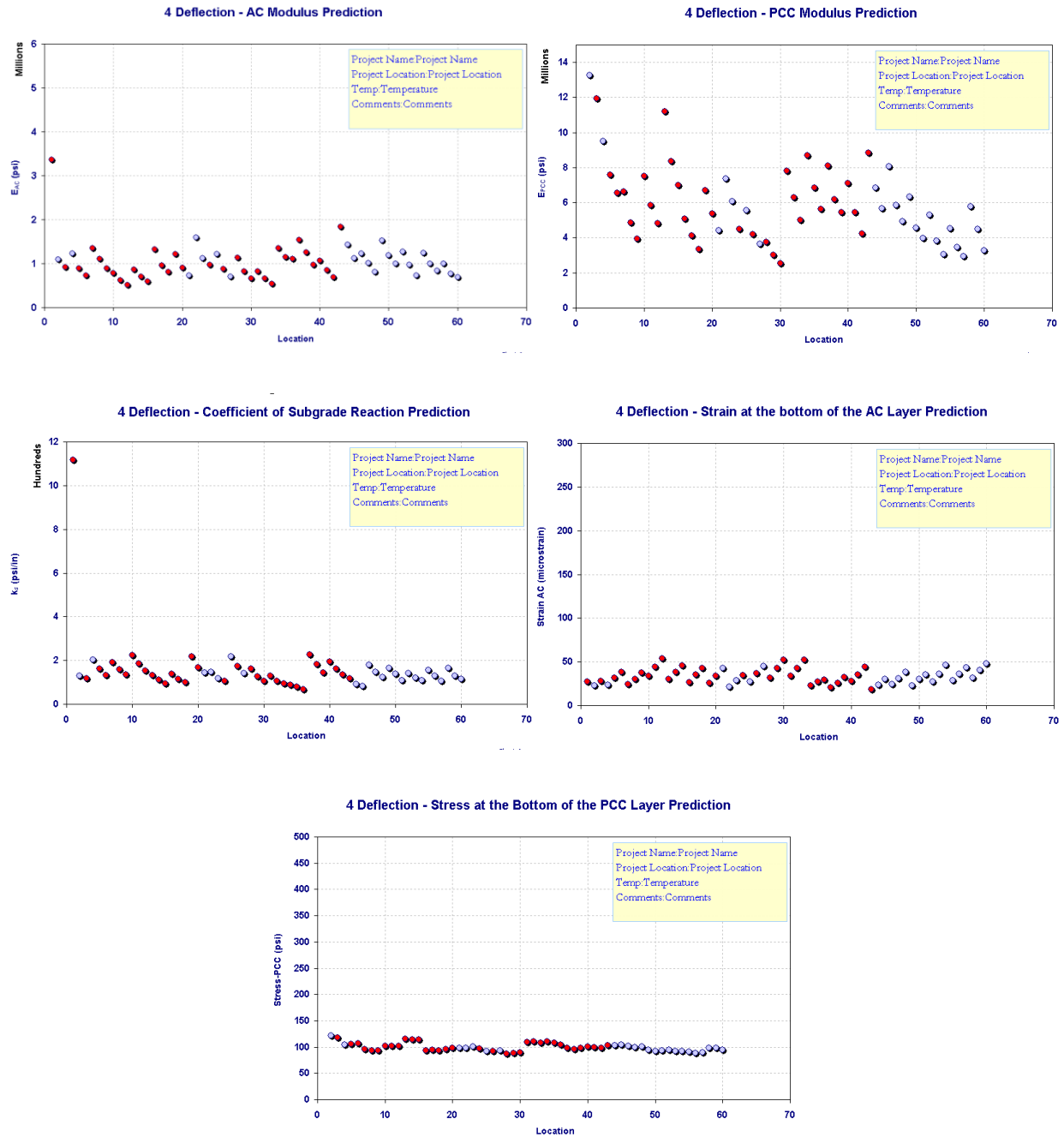
1,362,596	1,449,438	1,692,212	1,892,741
1,105,947	1,174,549	1,406,344	1,668,527
896,930	913,876	1,121,740	1,396,119
788,556	785,320	787,003	1,231,608
610,524	630,006	612,282	950,001
510,503	520,648	468,596	772,525
868,732	884,403	1,017,604	1,687,890
699,090	704,099	916,814	1,299,901
599,797	592,823	617,571	1,041,449
1,320,304	1,445,332	1,691,049	1,775,995
954,928	1,000,727	1,221,770	1,521,681
804,095	807,461	998,277	1,386,211
1,209,993	1,246,118	1,454,823	1,733,714
909,064	943,089	1,105,775	1,478,793
725,749	732,568	813,302	1,182,898
1,589,074	1,733,017	1,866,006	1,931,907
1,118,251	1,195,768	1,477,969	1,734,275
966,616	1,015,771	1,252,962	1,567,502
1,213,689	1,285,979	1,470,533	1,712,143
877,848	895,850	1,084,585	1,382,285
704,097	700,976	751,639	1,114,770
1,130,058	1,200,019	1,409,063	1,622,218

Figure 24. Composite pavement analysis menu

Location	Eac 4 Deflections- (psi) D12-D24-D36				Epc 4 Deflections- (psi) D0-D12-D24-D36				ks 4 Deflections- (psi/in) D0-D12-D24-D36			
	6%	2%	5%	10%	6%	2%	5%	10%	6%	2%	5%	10%
4	1,234,639	1,265,899	1,519,102	1,836,437	9,499,322	9,147,167	7,792,633	7,546,496	202	203	216	222
5	891,216	913,423	1,029,944	1,530,668	7,592,611	7,316,779	6,347,208	6,670,237	161	163	166	172
6	736,423	737,415	837,433	1,267,516	6,556,046	6,322,297	5,875,011	5,209,243	132	137	139	143
7	1,352,596	1,449,436	1,693,213	1,819,741	6,640,353	6,161,698	5,603,228	5,720,321	192	190	195	192
8	1,105,947	1,174,549	1,406,344	1,668,527	4,863,962	4,565,452	4,171,684	4,222,728	158	156	157	156
9	896,930	913,876	1,121,740	1,398,118	3,955,277	3,847,150	3,549,299	3,210,390	136	135	136	133
10	788,556	785,320	787,003	1,231,608	7,535,960	7,621,437	6,794,030	6,905,758	224	222	229	238
11	618,524	630,006	612,382	950,001	5,874,340	5,792,261	5,562,333	4,893,209	186	183	186	185
12	510,503	520,648	468,596	772,525	4,839,293	4,876,478	4,723,546	4,086,396	153	151	150	152
13	868,732	884,403	1,017,604	1,687,890	11,212,355	10,343,529	8,756,121	7,517,044	133	136	158	161
14	699,010	704,099	816,814	1,299,901	8,355,041	8,233,398	7,226,994	6,521,882	111	112	126	129
15	589,797	582,823	617,571	1,041,449	7,013,359	7,006,064	6,377,420	4,795,449	94	92	99	105
16	1,320,104	1,445,332	1,691,148	1,775,915	5,101,984	4,773,213	4,430,351	4,192,110	138	139	141	132
17	954,938	1,000,727	1,221,770	1,521,681	4,133,066	4,026,434	3,722,162	2,998,709	116	120	121	110
18	804,055	807,461	998,277	1,366,211	3,347,803	3,386,332	3,077,044	2,592,748	100	104	103	93
19	1,209,993	1,246,118	1,454,823	1,733,784	6,703,043	6,368,631	5,743,087	5,955,298	218	217	222	222
20	909,064	943,089	1,105,775	1,478,793	5,374,990	5,096,446	4,533,829	4,456,015	169	167	169	169
21	725,749	732,568	813,302	1,192,898	4,423,493	4,315,517	3,873,046	3,591,367	144	143	144	145
22	1,589,074	1,733,017	1,866,006	1,931,907	7,366,460	6,922,938	6,353,703	6,471,687	148	150	156	152
23	1,118,251	1,195,768	1,477,969	1,734,275	6,075,579	5,604,080	5,148,606	4,333,281	119	123	129	118
24	966,616	1,015,771	1,262,962	1,567,502	4,488,521	4,417,099	4,034,015	3,103,407	106	111	111	99
25	1,213,689	1,265,179	1,470,533	1,712,143	5,548,079	5,269,105	4,743,724	4,858,034	218	216	219	215
26	877,848	895,150	1,054,565	1,382,285	4,208,145	4,031,352	3,700,352	3,838,214	173	170	174	168
27	704,097	700,976	751,639	1,114,770	3,654,947	3,629,093	3,277,411	3,212,183	141	139	141	138
28	1,130,058	1,200,019	1,409,063	1,622,218	3,775,932	3,456,469	3,376,836	3,671,105	163	159	162	157
29	822,980	828,926	974,988	1,250,888	3,011,004	2,960,112	2,794,933	2,649,789	126	125	127	119
30	662,059	614,149	788,781	1,077,938	2,555,561	2,404,246	2,358,640	1,696,826	106	108	111	99
31	830,329	848,417	1,013,213	1,507,917	7,812,279	7,512,331	6,454,643	6,659,213	129	134	143	144

Composite Pavement Analysis /

Figure 25. Sample Excel sheet outputs of composite pavement analysis



**Figure 26. Sample Excel sheet charts of composite pavement analysis**

Statistic							Details			
Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Moire				
E <sub>ac</sub>	1,038,278	414,020	40%	CPDR-4	4	0				
	1,033,033	444,615	43%	CPDR-4	4	2				
	1,257,428	455,117	36%	CPDR-4	4	5				
	1,522,526	253,506	18%	CPDR-4	4	10				
	1,113,712	551,508	50%	CPDR-6	6	0				
	1,408,863	371,373	63%	CPDR-6	6	2				
	1,882,929	655,874	55%	CPDR-6	6	5				
	1,354,267	402,321	30%	CPDR-6	6	10				
	1,258,102	648,010	52%	CPDR-7	7	0				
	1,471,259	945,294	64%	CPDR-7	7	2				
	1,375,167	624,481	48%	CPDR-7	7	5				
	1,435,359	351,232	24%	CPDR-7	7	10				
	1,103,669	514,652	46%	CPDR-8	8	0				
	1,400,777	652,400	61%	CPDR-8	8	2				
	1,460,520	731,657	50%	CPDR-8	8	5				
	1,550,617	405,559	26%	CPDR-8	8	10				
Note: E <sub>ac</sub> predictions are limited to ranges between 1,000,000 and 3,000,000 psi.							Back			
Note: E <sub>pcc</sub> predictions are limited to ranges between 1,000,000 and 12,000,000 psi.										
Statistic							Details			
Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Moire				
E <sub>pcc</sub>	5,700,655	2,337,869	40%	CPDR-4	4	0				
	5,541,571	2,069,289	37%	CPDR-4	4	2				
	4,977,317	1,755,488	35%	CPDR-4	4	5				
	4,604,157	1,703,022	37%	CPDR-4	4	10				
	4,111,025	3,345,759	81%	CPDR-6	6	0				
	4,532,794	3,613,534	79%	CPDR-6	6	2				
	4,554,526	3,258,023	72%	CPDR-6	6	5				
	4,052,316	3,034,113	75%	CPDR-6	6	10				
	4,010,109	3,608,751	90%	CPDR-7	7	0				
	4,438,551	3,744,457	84%	CPDR-7	7	2				
	4,608,601	3,733,943	80%	CPDR-7	7	5				
	4,105,721	3,067,744	74%	CPDR-7	7	10				
	4,175,616	2,940,627	69%	CPDR-8	8	0				
	4,105,327	3,155,405	76%	CPDR-8	8	2				
	3,938,022	2,645,639	74%	CPDR-8	8	5				
	4,212,302	2,533,110	67%	CPDR-8	8	10				
Note: E <sub>pcc</sub> predictions are limited to ranges between 1,000,000 and 12,000,000 psi.										
Statistic							Details			
Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Moire				
k <sub>s</sub>	158	132	84%	CPDR-4	4	0				
	156	128	82%	CPDR-4	4	2				
	161	125	78%	CPDR-4	4	5				
	159	123	78%	CPDR-4	4	10				
	205	176	86%	CPDR-6	6	0				
	239	216	90%	CPDR-6	6	2				
	255	229	90%	CPDR-6	6	5				
	256	224	87%	CPDR-6	6	10				
	245	215	88%	CPDR-7	7	0				
	312	307	98%	CPDR-7	7	2				
	322	316	98%	CPDR-7	7	5				
	331	319	96%	CPDR-7	7	10				
	170	170	100%	CPDR-8	8	0				
	235	212	90%	CPDR-8	8	2				
	252	233	93%	CPDR-8	8	5				
	250	229	92%	CPDR-8	8	10				
Note: k <sub>s</sub> predictions are limited to ranges between 50 and 1,000 psi.										
Statistic							Details			
Prediction	Average	Std Dev	CV	Model	Deflection	Moire				
E <sub>ac</sub>	34	9	26%	CPDR-4	4					
	34	8	23%	CPDR-6	6					
	33	8	24%	CPDR-7	7					
	33	8	25%	CPDR-8	8					
	37	10	28%	CPDR-4	4					
	38	10	26%	CPDR-6	6					
	34	10	30%	CPDR-7	7					
	30	25	83%	CPDR-8	8					
Note: E <sub>ac</sub> predictions are limited to ranges between 5 and 200 microstrain.										
σ <sub>pcc</sub>										
Note: σ <sub>pcc</sub> predictions are limited to ranges between 10 and 320 psi.										

Figure 27. Output statistics summary sheet for composite pavement analysis

## SUMMARY

In summary, the following are some of the significant features of the fully-automated ANN-based, user-friendly pavement structural analysis software system:

- A comprehensive pavement structural analysis tool incorporating all three common pavement types (flexible, rigid, and composite)
- Capability of automatically reading the FWD raw data collected by the JILS-20 type FWD machine that Iowa DOT owns
- Integration of all the ANN models developed as part of Phase I research into a comprehensive unified framework
- Rapid backcalculation of pavement layer moduli and prediction of critical pavement responses from FWD data (100,000 deflection basins analyzed in less than a second)
- Useful for both project-level and network-level pavement structural evaluation
- Visualization of results through automatic plotting capability
- Commonly used Import/Export options for transporting data
- Automatic generation of output statistics

## REFERENCES

Ceylan, H., Guclu, A., R., Bayrak , B., and Gopalakrishnan, K. 2007. *Nondestructive Evaluation of Iowa Pavements-Phase I*. CTRE Project 04-177, Center for Transportation Research and Education, Iowa State University, Ames, Iowa.