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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(CTRE Project 04-177 Phase 2)

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16. Abstract

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.

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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, ε_{AC}-tensile strain at the bottom of asphalt layer, ε_{SG}-compressive strain at the top of subgrade, and σ_D-subgrade deviator stress.

For rigid pavements, E_{PCC}-modulus of portland cement concrete (PCC), k_s-coefficient of subgrade reaction, σ_{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}, ks, σ_{PCC} (tensile stress at the bottom of the PCC), and ε_{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".

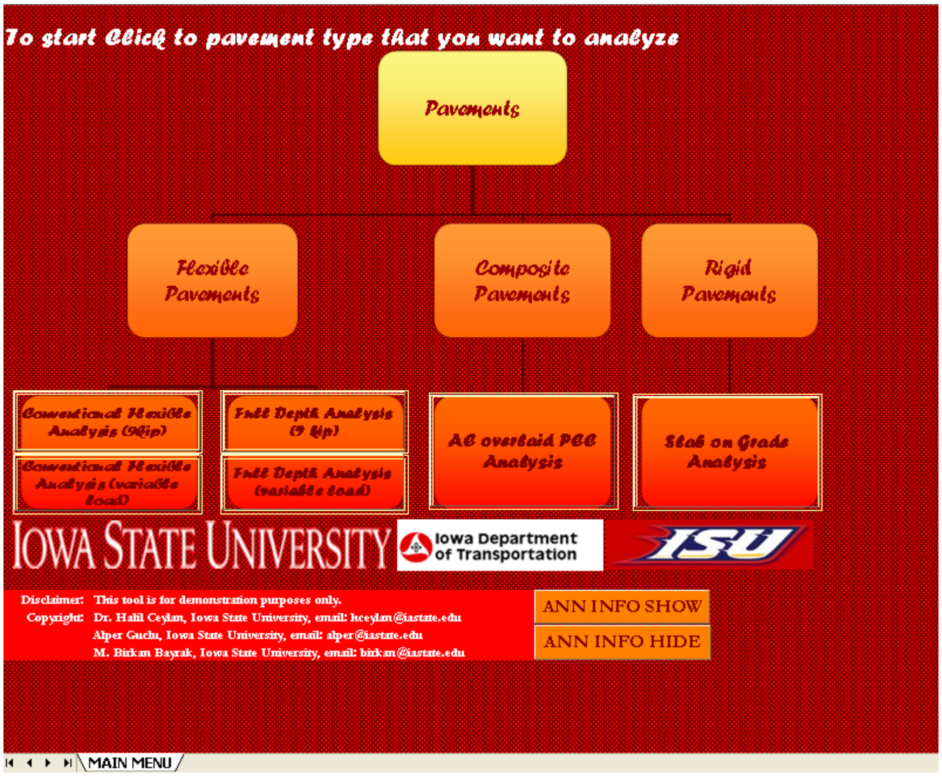


Figure 1. FWD analysis program main menu

Figure 2. ANN Information button in main menu

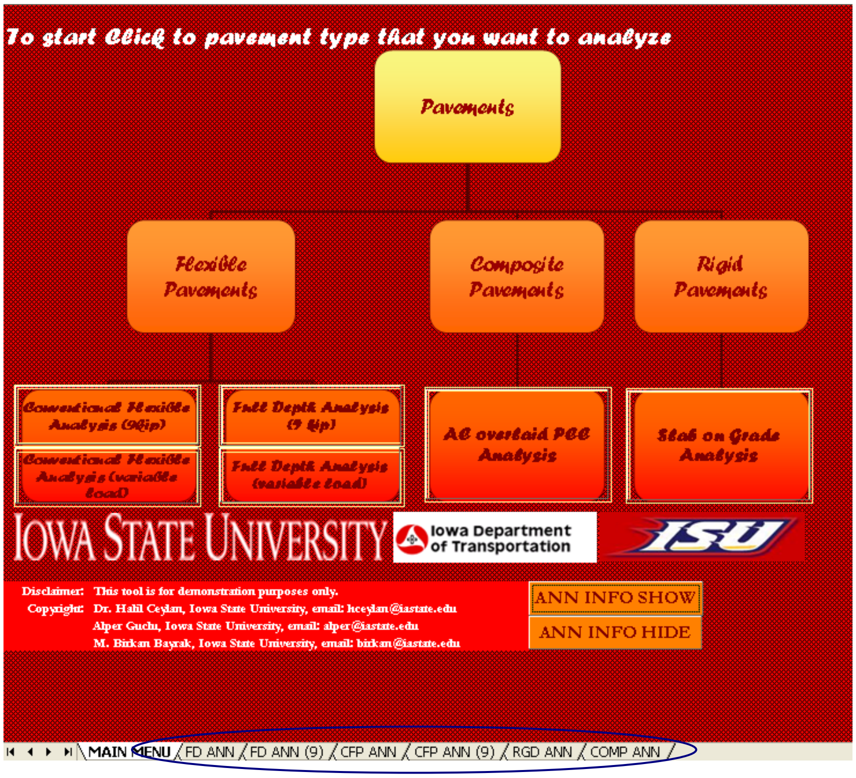


Figure 3. Screenshot of main menu on choosing ANN info show option

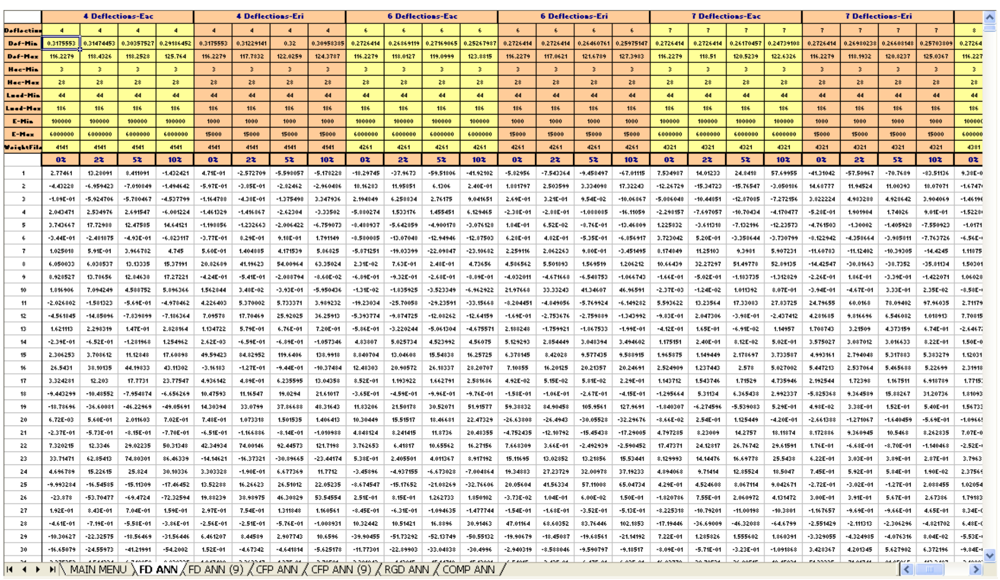
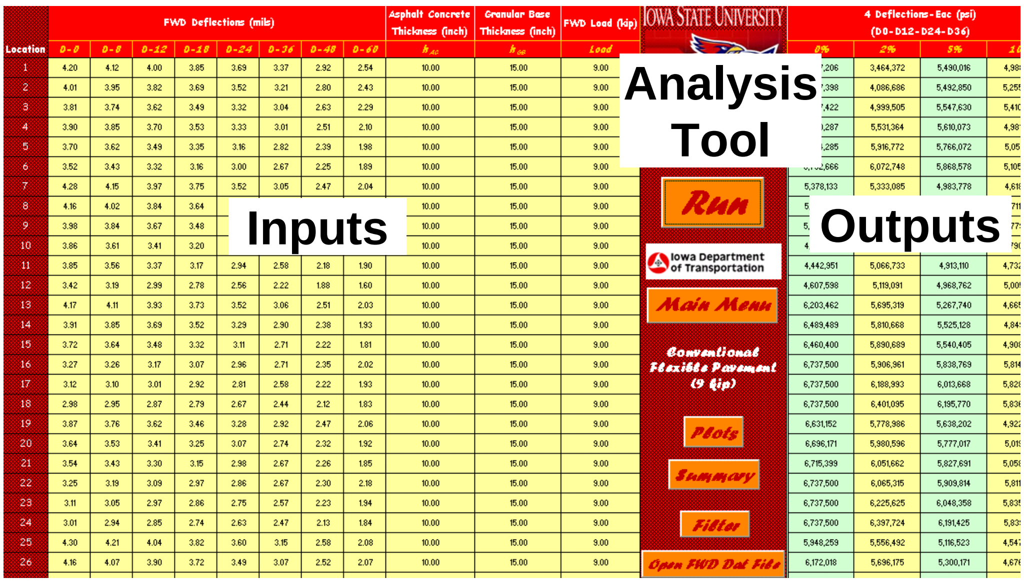


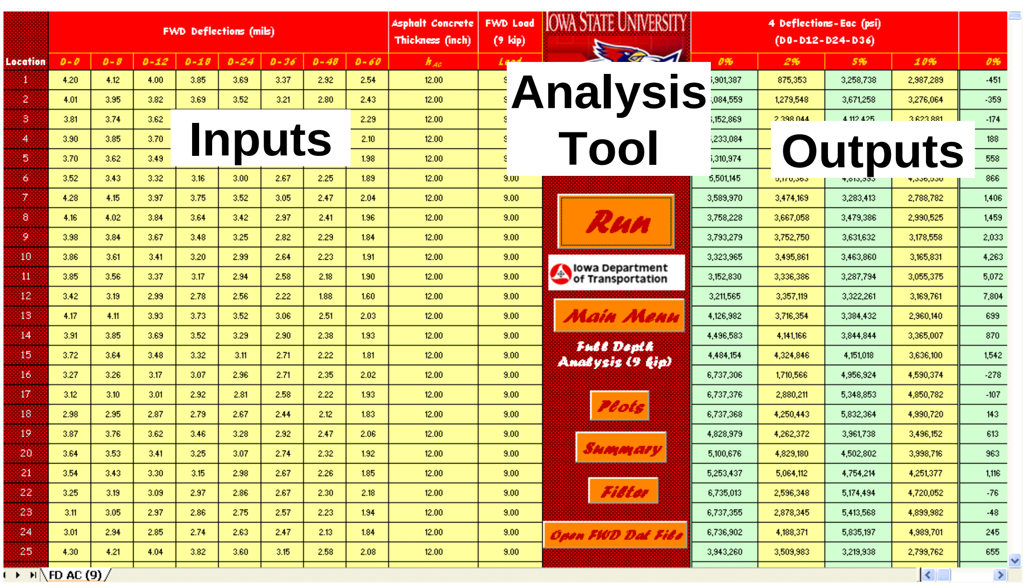
Figure 4. Sample Excel sheet showing ANN model information

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.



(a)



(b)

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.

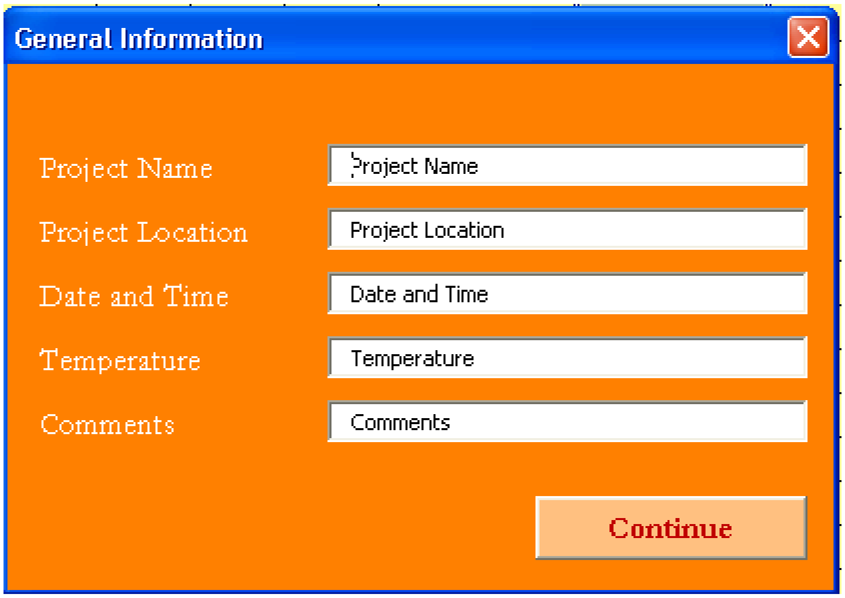


Figure 6. General information window

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 (x10^6).

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

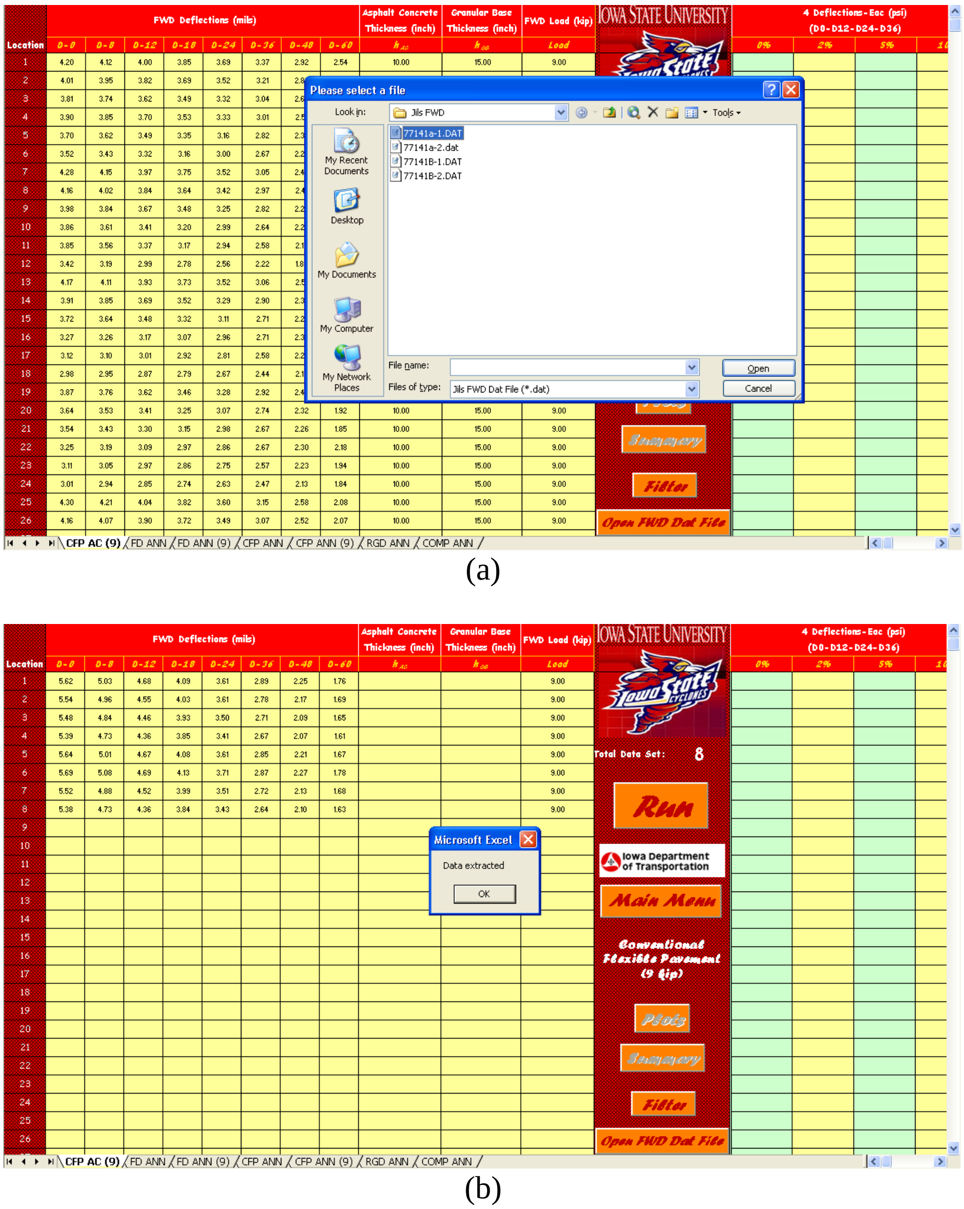


Figure 7. Screen shot of FWD data extraction through open FWD data file button: (a) choosing raw FWD file, (b) FWD data extracted

Location	FWD Deflections (mils)								Aaphalt Concrete Thickness (inch)	Granular Base Thickness (inch)	FWD Load (kip)
	D-0	D-8	D-12	D-18	D-24	D-36	D-48	D-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 (mils)								Asphalt Concrete Thickness (inch)	Granular Base Thickness (inch)	FWD Load (kip)
	D-0	D-8	D-12	D-18	D-24	D-36	D-48	D-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.

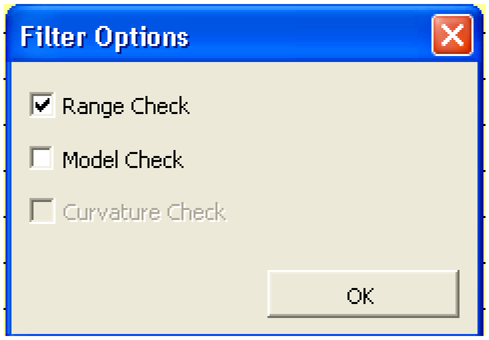
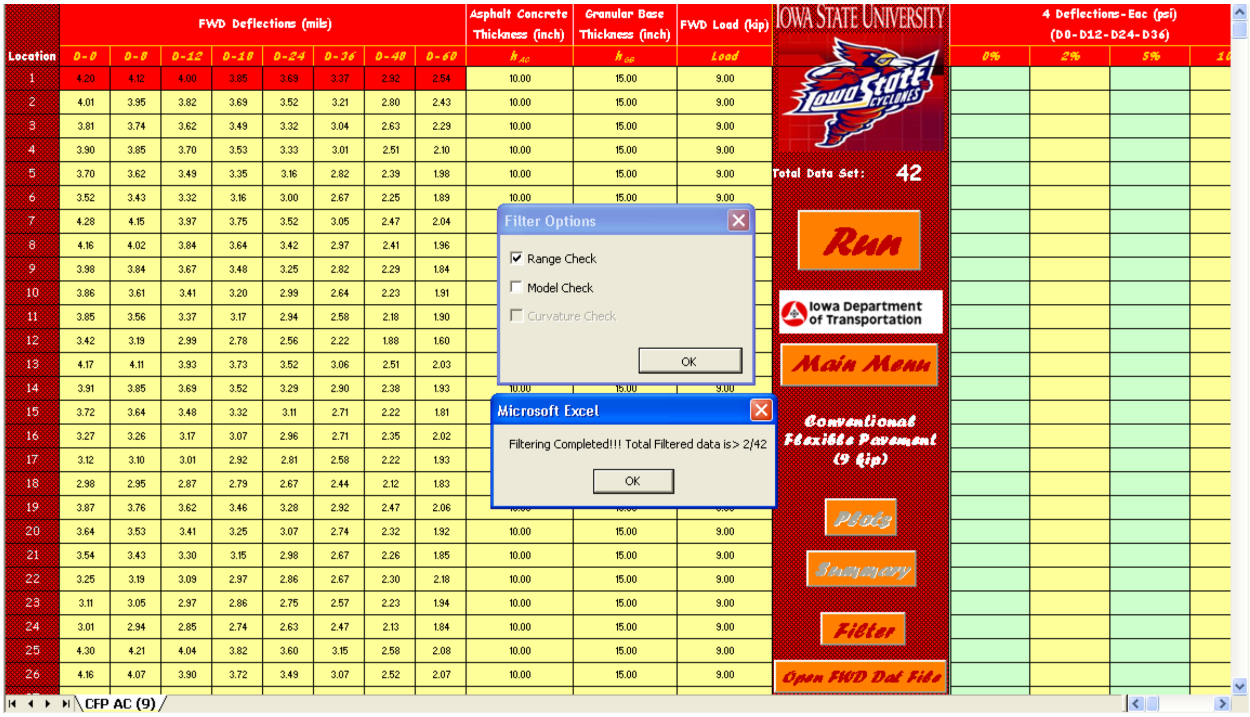
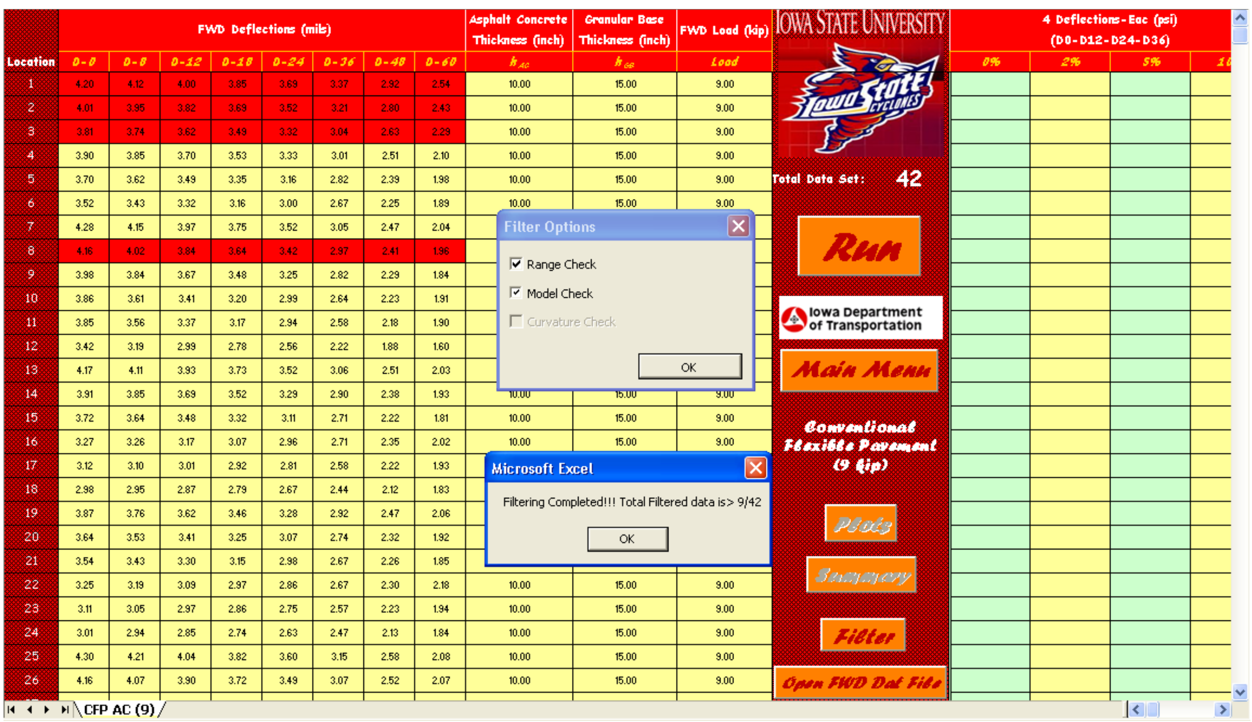


Figure 9. Filter options menu



(a)



(b)

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

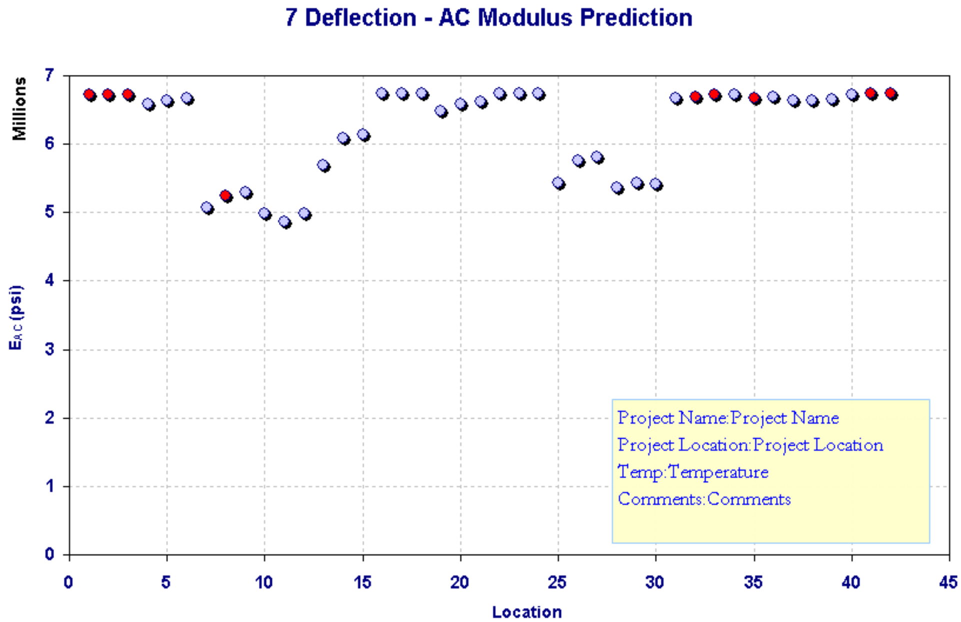


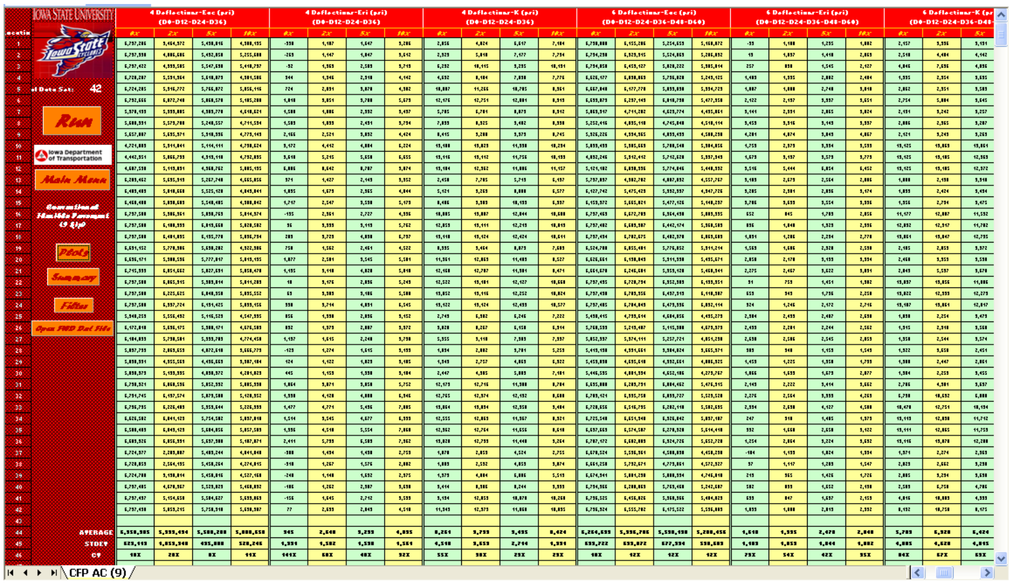
Figure 11. Sample pavement analysis results identifying analysis results from FWD data that falls outside filtering range

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%, ±2%, ±5% and ±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).

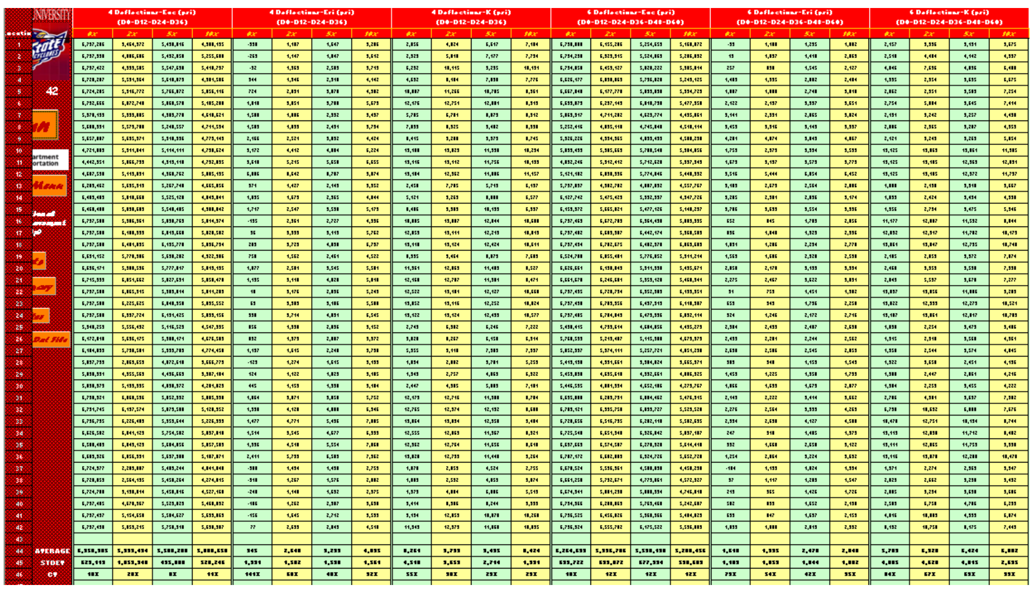
For each model, the analysis results will be displayed on the right side of the screen. The user should scroll right to see all results. Also, disabled menu commands of plots and the summary will be activated. The conventional flexible pavement analysis results are E_{AC}-modulus of AC, K_b-base modulus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



(a)



(b)

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

Location		4 Deflections-Eac (psi) (D0-D12-D24-D36)				4 Deflections-Eri (psi) (D0-D12-D24-D36)				4 Deflections-K (psi) (D0-D12-D24-D36)				
		0%	2%	5%	10%	0%	2%	5%	10%	0%	2%	5%	10%	0%
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	5,459,89
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	5,446,53
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	6,695,80
32		6,731,745	6,137,574	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	6,728,65
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	6,725,54
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	6,697,66
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	6,707,17
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	6,670,52
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	6,661,25
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	6,734,36
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	6,736,52
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	6,736,92
43														
44	**AVERAGE**	**6,350,305**	**5,339,434**	**5,508,208**	**5,000,658**	**945**	**2,640**	**3,233**	**4,835**	**8,261**	**9,739**	**9,495**	**8,424**	**6,264,63**
45	**STDEV**	**623,113**	**1,059,948**	**435,888**	**528,246**	**1,331**	**1,582**	**1,538**	**1,561**	**4,518**	**3,653**	**2,714**	**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														

CFP AC (9)

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.

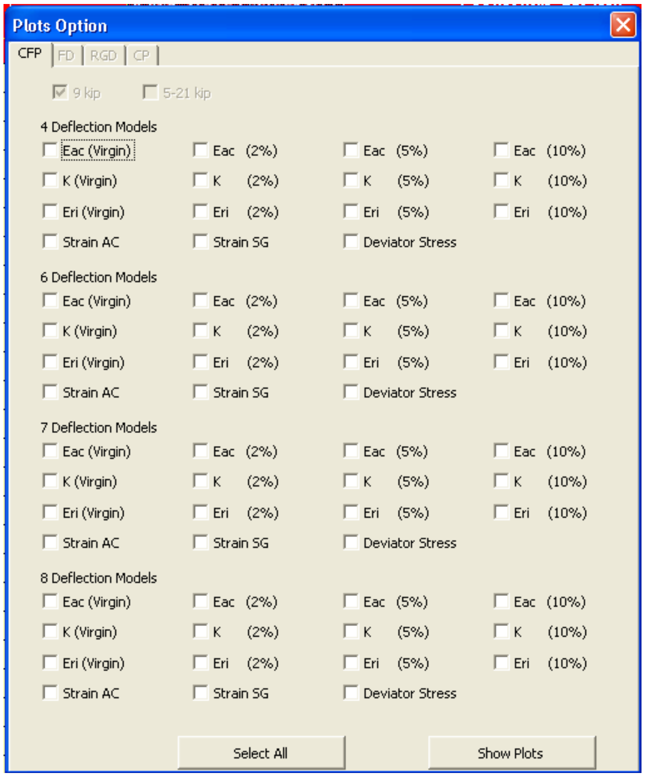


Figure 14. Plot option window

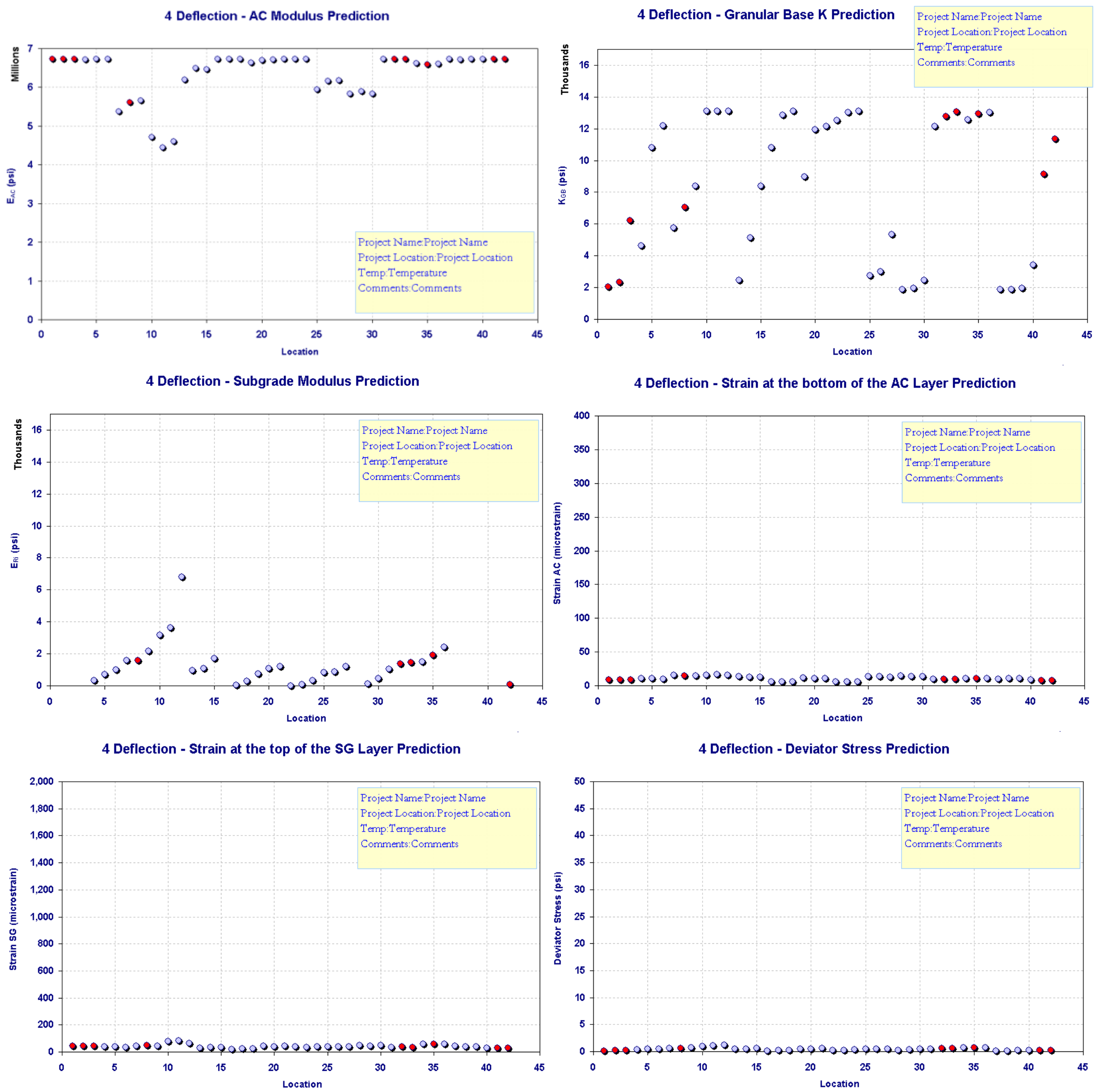


Figure 15. Sample Excel plots for conventional pavement analysis results

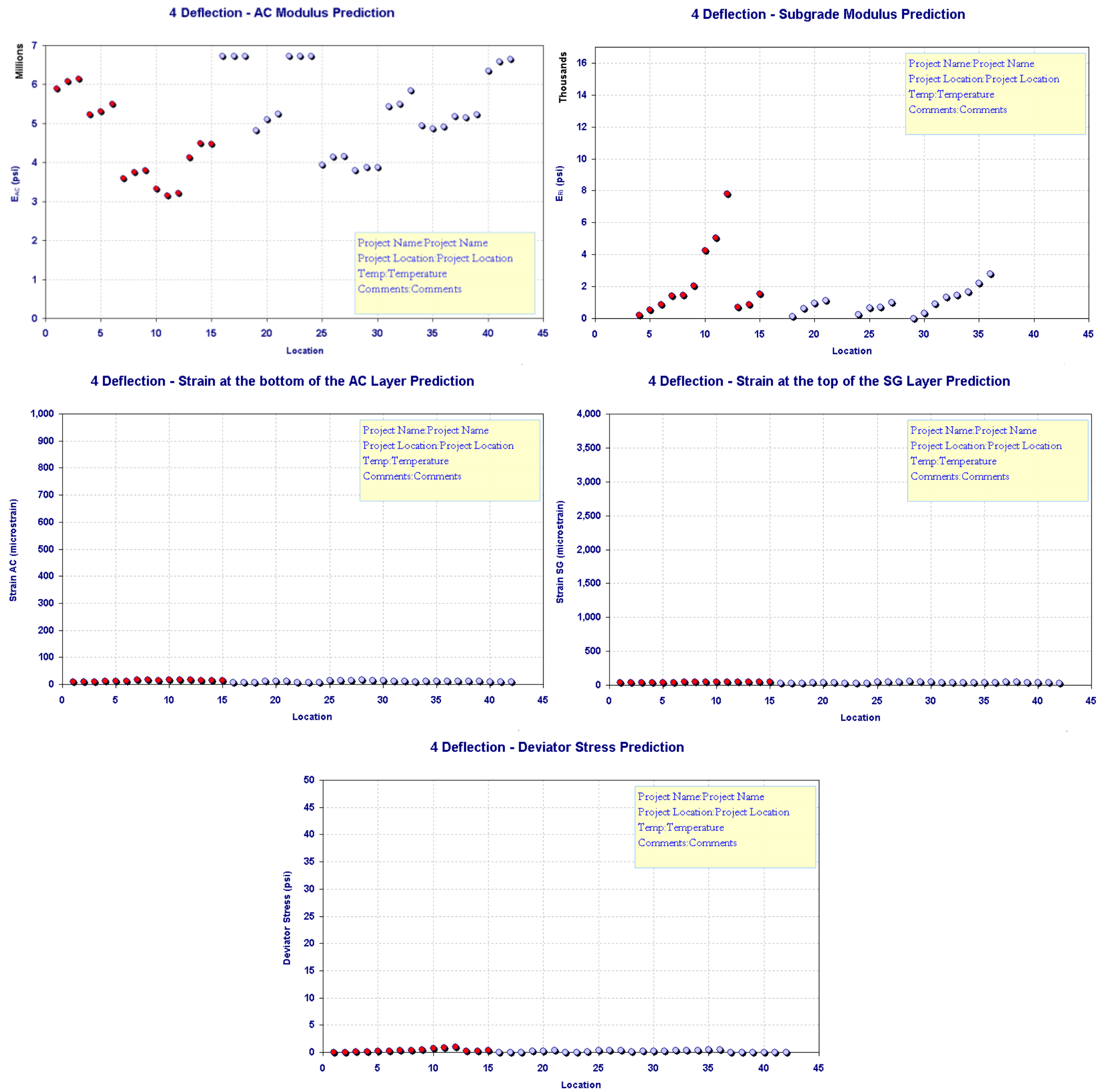
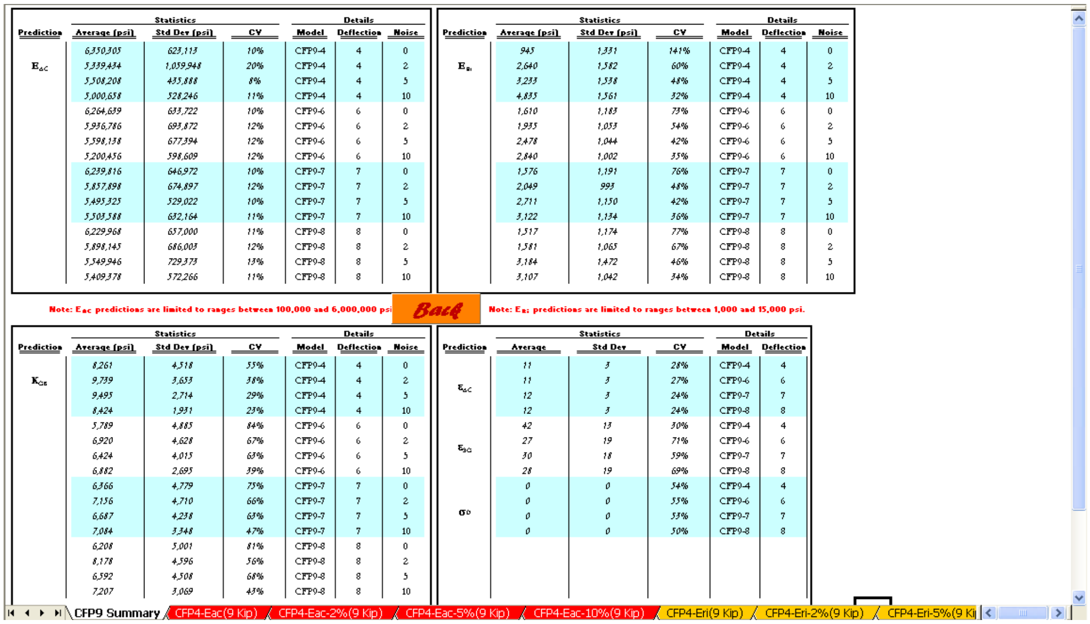


Figure 16. Sample Excel plots for full-depth asphalt pavement analysis results

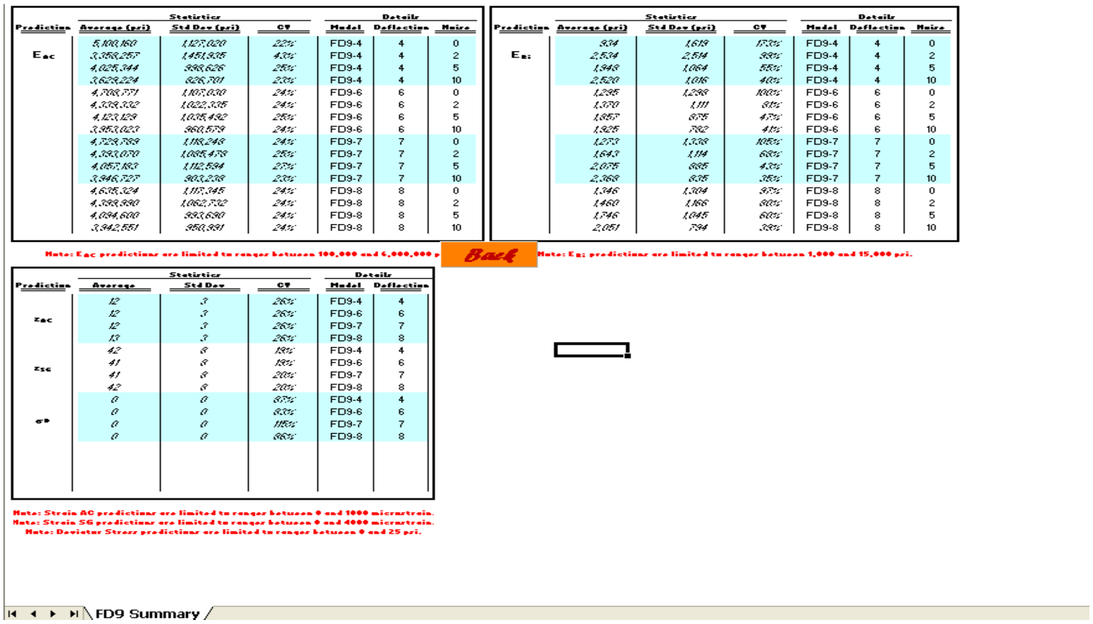
The Summary button within the pavement analysis Excel spreadsheet is disabled until the “Run” button is clicked. It summarizes the statistical output information for each model. It opens up a new Excel sheet with tables of each output and summary statistics for every model (see Figure 17). The reported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



(a)



(b)

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.

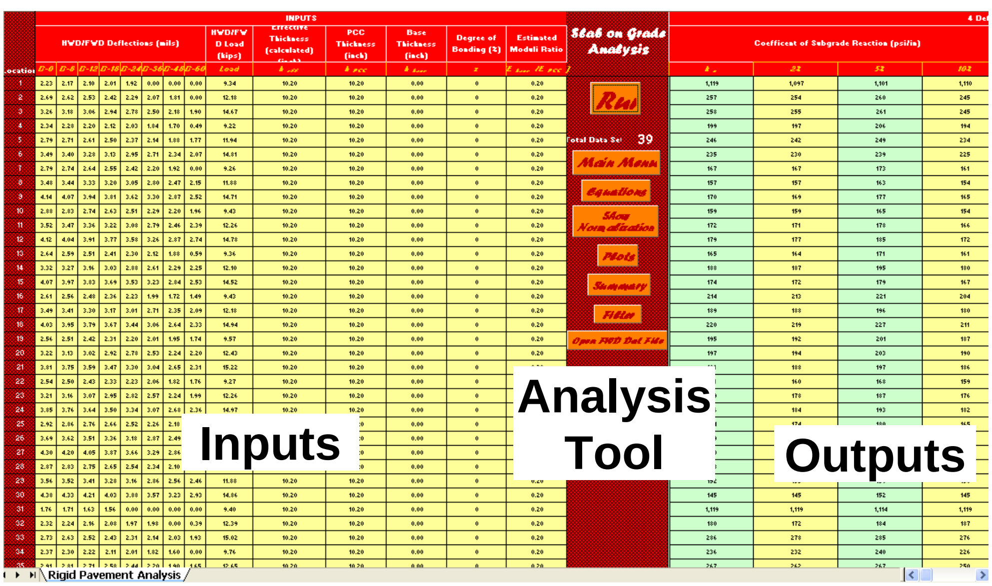


Figure 18. Rigid pavement analysis menu

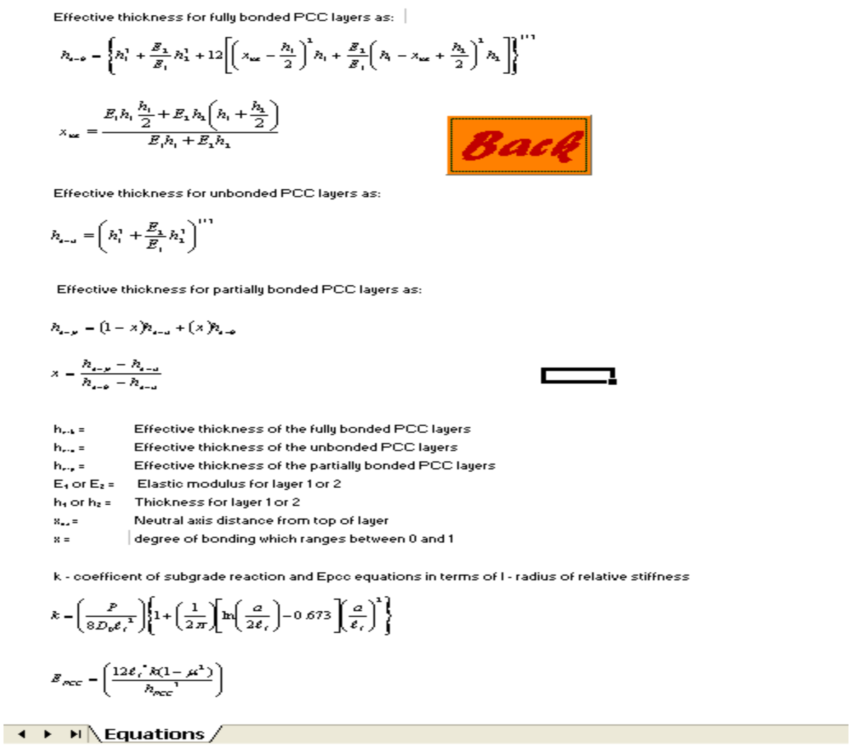
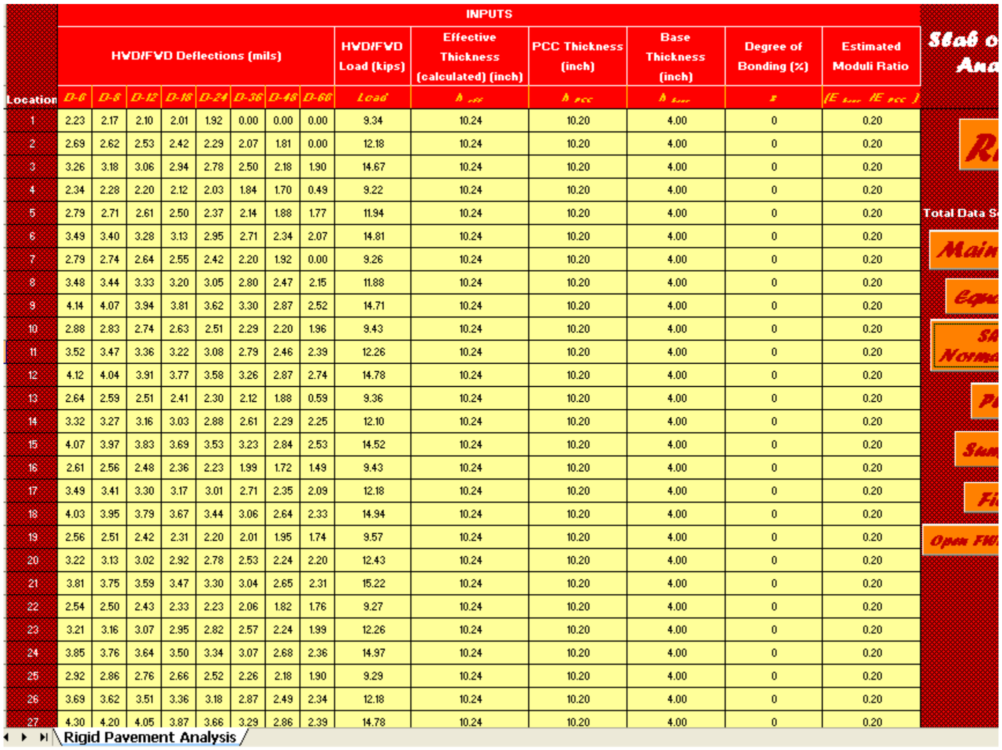
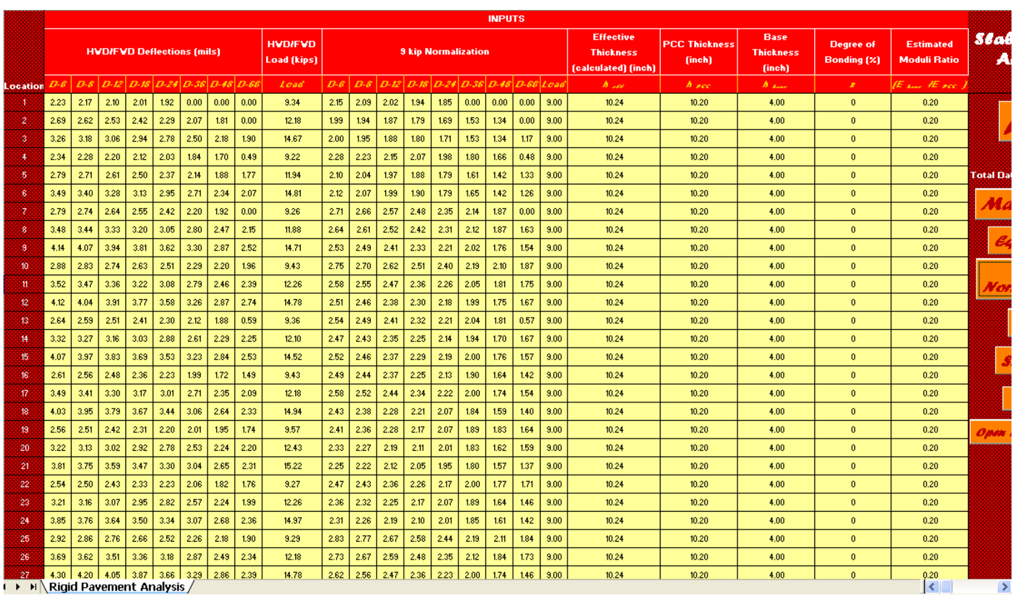


Figure 19. Screen shot of Equations sheet



Location	HVD/FVD Deflections (mils) D-6	D-8	D-12	D-18	D-24	D-36	D-48	D-60	HVD/FVD Load (kips) Load	Effective Thickness (calculated) (inch) h_{eff}	PCC Thickness (inch) h_{pcc}	Base Thickness (inch) h_{base}	Degree of Bonding (%) z	Estimated Moduli Ratio (E_{base}/E_{pcc})
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
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

(a)



Location	HVD/FVD Deflections (mils) D-6	D-8	D-12	D-18	D-24	D-36	D-48	D-60	HVD/FVD Load (kips) Load	9 kip Normalization D-6	D-8	D-12	D-18	D-24	D-36	D-48	D-60	Load	Effective Thickness (calculated) (inch) h_{eff}	PCC Thickness (inch) h_{pcc}	Base Thickness (inch) h_{base}	Degree of Bonding (%) z	Estimated Moduli Ratio (E_{base}/E_{pcc})
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	2.10	2.04	1.97	1.88	1.79	1.61	1.42	1.33	9.00	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	2.12	2.07	1.99	1.90	1.79	1.65	1.42	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	1.75	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	1.83	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
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

(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%, ±2%, ±5% and ±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, σ_{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 (D0-D8-D12-D18-D24-D36-D48-D60)								
	Coefficent of Subgrade Reaction (psi/in)				PCC Modulus (psi)				Radius of Relative Stiffness (inch)
Location	k_s	2%	5%	10%	E_{PCC}	2%	5%	10%	RRS
1	1,110	1,111	1,119	1,070	1,292,560	1,050,745	1,441,097	1,094,962	17
2	496	799	760	764	6,579,101	9,712,902	9,912,425	9,949,425	32
3	297	224	229	224	16,599,961	15,979,994	15,402,995	14,902,901	52
4	296	419	422	420	8,575,901	5,807,017	5,502,061	5,197,459	39
5	289	109	101	179	16,717,490	16,272,947	16,211,196	15,142,557	56
6	217	289	289	289	16,569,861	15,979,289	15,996,296	14,281,690	59
7	989	541	552	550	5,095,502	2,697,554	2,914,910	2,617,946	39
8	150	146	145	141	16,179,141	15,609,417	14,861,006	19,790,999	57
9	165	159	150	156	16,046,994	15,610,425	14,072,510	19,054,470	55
10	116	106	107	107	16,740,479	16,921,495	16,100,056	14,055,050	65
11	141	120	127	126	16,700,669	16,219,929	15,019,566	14,665,600	60
12	149	197	196	195	16,690,657	16,190,949	15,707,590	14,652,222	59
13	264	960	975	969	7,757,009	5,252,950	5,047,044	4,672,097	39
14	152	196	196	195	16,710,904	16,240,425	16,011,105	14,062,242	60
15	159	152	151	147	16,519,059	15,946,050	15,024,299	19,004,169	57
16	200	109	109	100	19,721,051	14,225,175	19,945,060	19,062,029	50
17	175	165	169	169	14,906,709	15,197,909	14,791,422	19,655,062	59
18	204	191	191	190	14,274,052	14,756,119	14,449,796	19,410,604	51
19	194	122	129	121	16,746,500	16,407,019	16,590,565	15,965,060	65
20	154	190	190	197	16,741,949	16,409,490	16,401,412	15,910,201	61
21	105	170	177	177	16,645,429	16,001,006	15,295,109	14,102,505	55
22	195	124	124	129	16,742,022	16,969,057	16,901,900	15,144,510	69
23	172	165	164	162	16,600,211	15,974,972	15,150,959	14,001,125	56
24	177	170	160	167	16,640,644	16,010,707	15,905,050	14,176,099	56
25	127	116	117	115	16,629,191	16,100,409	15,210,556	14,041,099	61
26	155	149	141	197	15,904,046	15,697,461	14,064,476	19,791,199	56
27	191	104	104	102	19,010,605	19,927,705	19,009,609	12,497,509	50
28	119	109	104	109	16,790,750	16,919,999	16,072,097	14,061,917	65
29	125	114	114	114	16,725,229	16,256,691	15,005,251	14,701,701	69
30	127	119	120	119	16,720,909	16,216,550	15,790,794	14,569,001	62
31	1,119	1,110	1,117	1,007	721,210	1,009,790	9,125,062	4,919,999	15
32	700	1,047	1,042	1,019	4,620,711	9,155,709	9,401,942	9,594,564	26
33	107	166	166	165	16,740,652	16,719,209	16,749,920	16,594,000	60
34	997	676	690	697	6,059,059	9,971,916	2,959,502	9,116,726	32
35	249	229	227	229	16,109,199	15,740,427	14,907,915	14,150,499	51
36	210	204	209	204	16,667,521	16,001,700	15,664,479	14,622,712	54
37	100	107	110	107	16,749,429	16,590,199	16,691,202	15,476,969	71
38	195	129	124	122	16,740,164	16,592,210	16,704,759	15,697,004	66
39	141	129	129	120	16,745,409	16,450,495	16,561,695	15,967,940	64
40									
41	240	279	274	271	19,522,495	12,999,019	12,690,906	11,047,990	51
42	297	200	202	275	4,026,991	5,242,769	5,000,209	4,560,979	14
43	95%	109%	109%	102%	96%	41%	40%	90%	27%

Rigid Pavement Analysis

Figure 21. Sample Excel sheet of rigid pavement analysis outputs

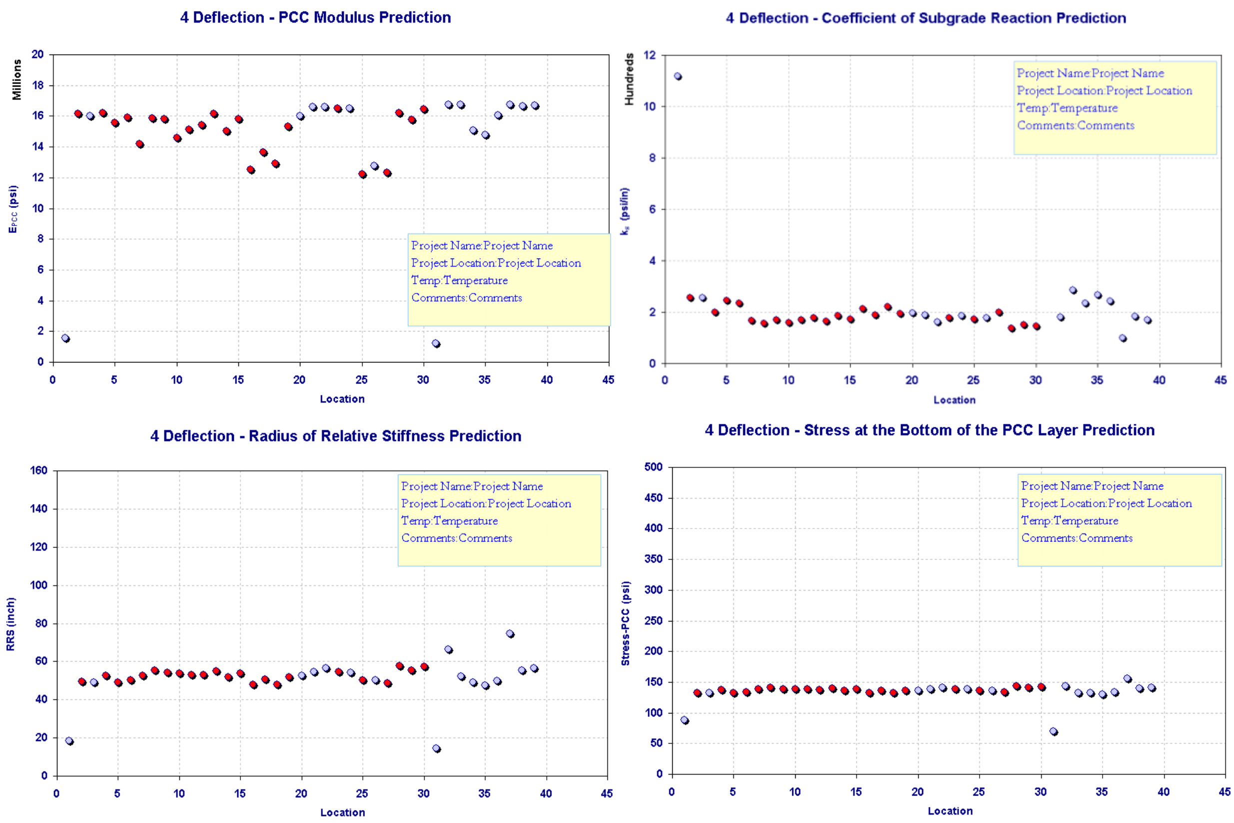
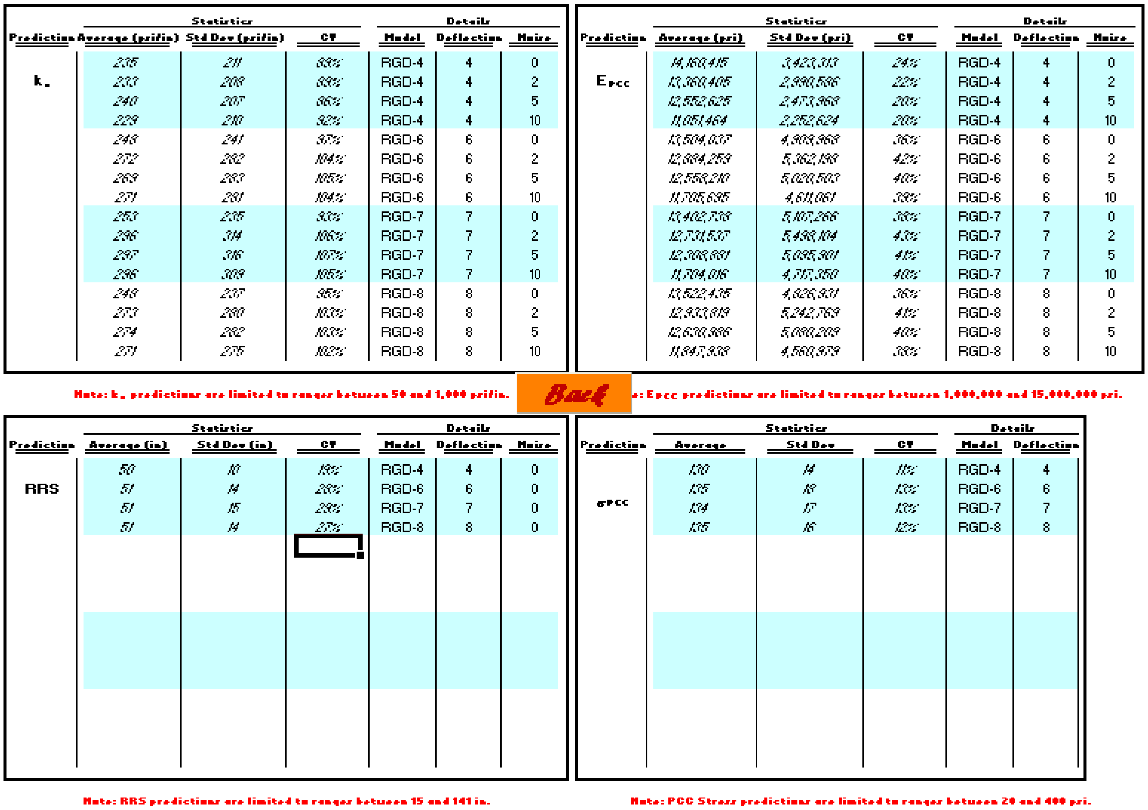


Figure 22. Sample Excel sheet rigid pavement analysis charts



Prediction	Average (psi/in)	Std Dev (psi/in)	CV	Model	Deflection	Noise
k_s	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	282	104%	RGD-6	6	2
	269	283	105%	RGD-6	6	5
	271	281	104%	RGD-6	6	10
	253	235	93%	RGD-7	7	0
	296	314	106%	RGD-7	7	2
	297	316	107%	RGD-7	7	5
	296	309	105%	RGD-7	7	10
	248	237	95%	RGD-8	8	0
	273	280	103%	RGD-8	8	2
	274	282	103%	RGD-8	8	5
	271	275	102%	RGD-8	8	10

Note: k_s predictions are limited to ranges between 50 and 1,000 psi/in.

Prediction	Average (psi)	Std Dev (psi)	CV	Model	Deflection	Noise
E_{PCC}	14,160,415	3,423,313	24%	RGD-4	4	0
	13,360,405	2,990,586	22%	RGD-4	4	2
	12,552,625	2,473,968	20%	RGD-4	4	5
	11,051,464	2,252,624	20%	RGD-4	4	10
	13,504,037	4,909,968	36%	RGD-6	6	0
	12,884,259	5,362,198	42%	RGD-6	6	2
	12,558,210	5,020,503	40%	RGD-6	6	5
	11,705,695	4,611,061	39%	RGD-6	6	10
	13,402,738	5,107,266	38%	RGD-7	7	0
	12,731,537	5,498,104	43%	RGD-7	7	2
	12,308,881	5,095,901	41%	RGD-7	7	5
	11,704,016	4,717,350	40%	RGD-7	7	10
	13,522,435	4,826,931	36%	RGD-8	8	0
	12,933,819	5,242,769	41%	RGD-8	8	2
	12,630,986	5,080,209	40%	RGD-8	8	5
	11,847,938	4,560,979	38%	RGD-8	8	10

Note: E_{PCC} predictions are limited to ranges between 1,000,000 and 15,000,000 psi.

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Prediction	Average (in)	Std Dev (in)	CV	Model	Deflection	Noise
RRS	50	10	19%	RGD-4	4	0
	51	14	28%	RGD-6	6	0
	51	15	29%	RGD-7	7	0
	51	14	27%	RGD-8	8	0

Note: RRS predictions are limited to ranges between 15 and 141 in.

Prediction	Average	Std Dev	CV	Model	Deflection
σ_{PCC}	130	14	11%	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 ranges between 20 and 400 psi.

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, ε_{AC}-tensile strain at the bottom of asphalt layer, and σ_{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.

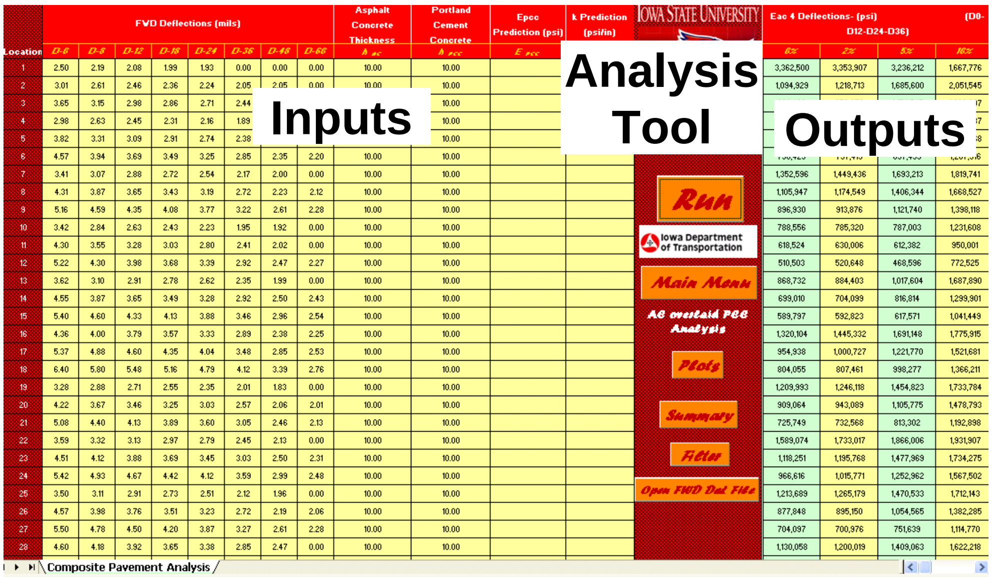


Figure 24. Composite pavement analysis menu

Location	Eac 4 Deflections- (psi) (D0-D12-D24-D36)				Epcc 4 Deflections- (psi) (D0-D12-D24-D36)				ks 4 Deflections- (psi/in) (D0-D12-D24-D36)			
	0%	2%	5%	10%	0%	2%	5%	10%	0%	2%	5%	10%
4	1,234,639	1,265,899	1,519,102	1,836,437	9,499,322	9,147,157	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	6,151,698	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	4,883,209	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	592,823	617,571	1,041,449	7,019,359	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	2,582,748	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	4,339,281	119	123	129	118
24	966,616	1,015,771	1,252,962	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

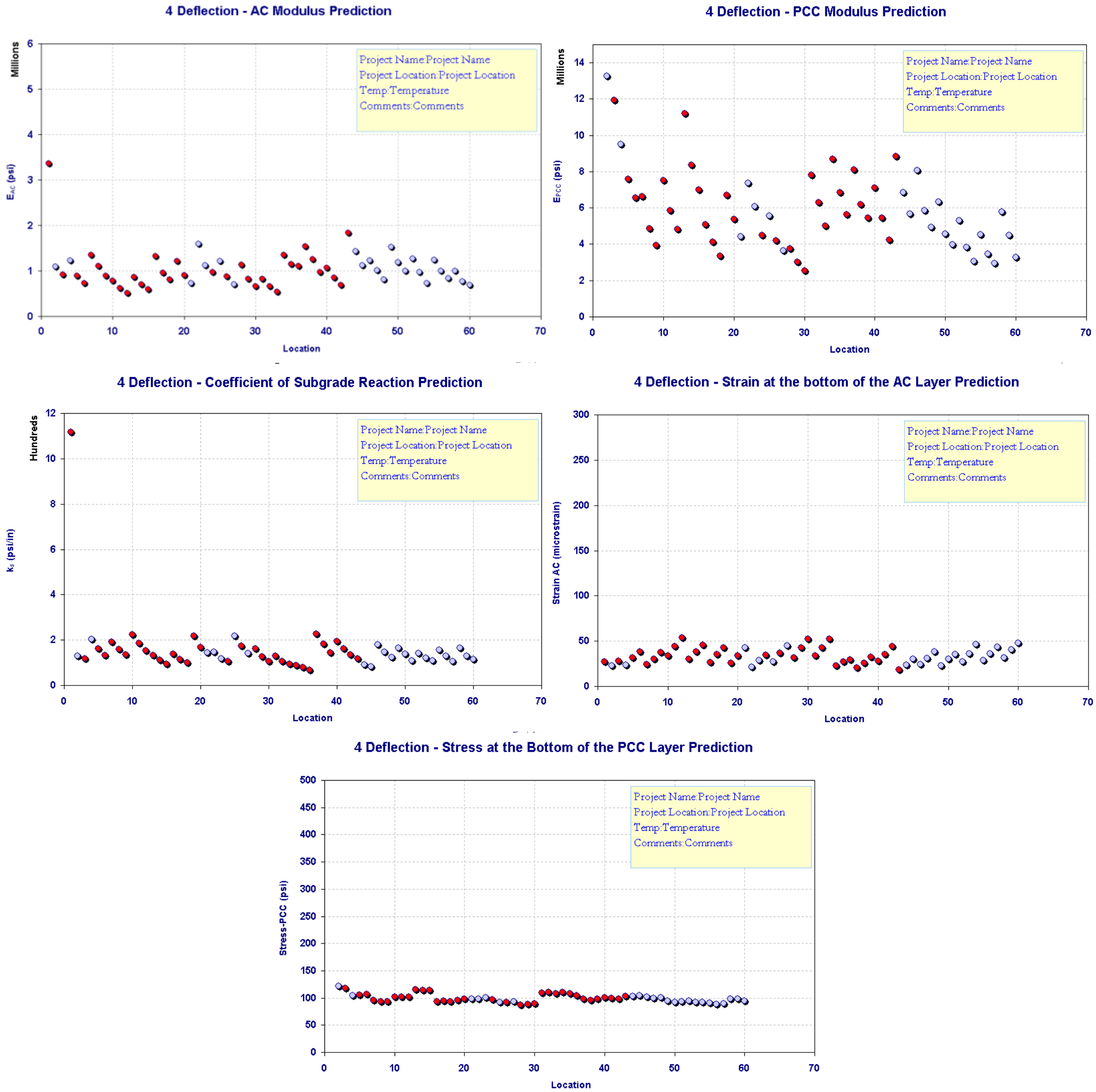
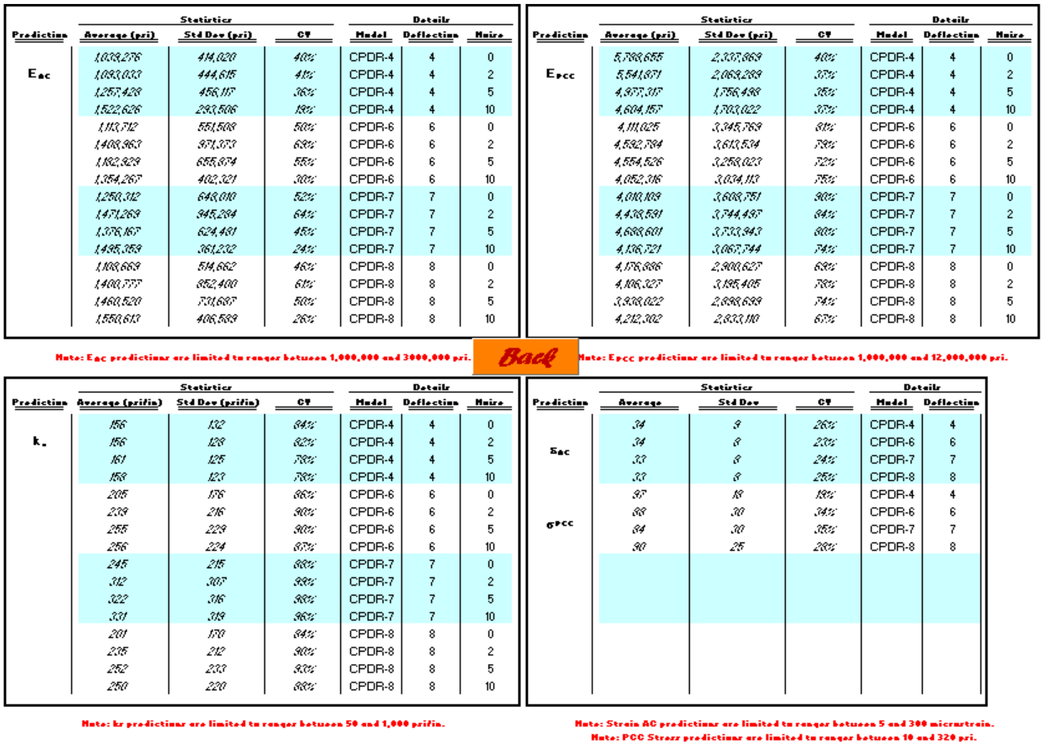


Figure 26. Sample Excel sheet charts of composite pavement analysis



Prediction	Statistics: Average (psi)	Std Dev (psi)	CV	Details: Model	Deflection	Noise
E_{ac}	1,039,276	414,020	40%	CPDR-4	4	0
	1,093,033	444,615	41%	CPDR-4	4	2
	1,257,428	456,117	36%	CPDR-4	4	5
	1,522,626	293,506	19%	CPDR-4	4	10
	1,113,712	551,508	50%	CPDR-6	6	0
	1,408,963	971,373	69%	CPDR-6	6	2
	1,182,929	655,874	55%	CPDR-6	6	5
	1,354,267	402,321	30%	CPDR-6	6	10
	1,250,312	648,010	52%	CPDR-7	7	0
	1,471,269	945,284	64%	CPDR-7	7	2
	1,376,167	624,481	45%	CPDR-7	7	5
	1,495,359	361,232	24%	CPDR-7	7	10
	1,108,669	514,662	46%	CPDR-8	8	0
	1,400,777	852,400	61%	CPDR-8	8	2
	1,460,520	731,687	50%	CPDR-8	8	5
	1,550,613	406,589	26%	CPDR-8	8	10

Note: E_{ac} predictions are limited to ranges between 1,000,000 and 3000,000 psi.

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Prediction	Statistics: Average (psi)	Std Dev (psi)	CV	Details: Model	Deflection	Noise
E_{pcc}	5,788,655	2,337,869	40%	CPDR-4	4	0
	5,541,871	2,069,289	37%	CPDR-4	4	2
	4,977,317	1,756,498	35%	CPDR-4	4	5
	4,604,157	1,703,022	37%	CPDR-4	4	10
	4,111,025	3,345,769	81%	CPDR-6	6	0
	4,592,784	3,613,534	79%	CPDR-6	6	2
	4,554,526	3,259,023	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
	4,438,591	3,744,497	84%	CPDR-7	7	2
	4,688,601	3,733,943	80%	CPDR-7	7	5
	4,136,721	3,067,744	74%	CPDR-7	7	10
	4,176,886	2,900,627	69%	CPDR-8	8	0
	4,106,327	3,195,405	78%	CPDR-8	8	2
	3,938,022	2,898,699	74%	CPDR-8	8	5
	4,212,302	2,833,110	67%	CPDR-8	8	10

Note: E_{pcc} predictions are limited to ranges between 1,000,000 and 12,000,000 psi.

Prediction	Statistics: Average (psi/in)	Std Dev (psi/in)	CV	Details: Model	Deflection	Noise
k_s	156	132	84%	CPDR-4	4	0
	156	128	82%	CPDR-4	4	2
	161	125	78%	CPDR-4	4	5
	158	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	99%	CPDR-7	7	2
	322	316	98%	CPDR-7	7	5
	331	319	96%	CPDR-7	7	10
	201	170	84%	CPDR-8	8	0
	235	212	90%	CPDR-8	8	2
	252	233	93%	CPDR-8	8	5
	250	220	88%	CPDR-8	8	10

Note: kr predictions are limited to ranges between 50 and 1,000 psi/in.

Prediction	Statistics: Average	Std Dev	CV	Details: Model	Deflection
ε_{ac}	34	9	26%	CPDR-4	4
	34	8	23%	CPDR-6	6
	33	8	24%	CPDR-7	7
	33	8	25%	CPDR-8	8
σ_{pcc}	97	18	19%	CPDR-4	4
	88	30	34%	CPDR-6	6
	84	30	35%	CPDR-7	7
	90	25	28%	CPDR-8	8

Note: Strain AC predictions are limited to ranges between 5 and 300 microstrain.
Note: PCC Stress 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., Bayrak, M. 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.