

TPADana 1.0: User's Manual for the TPAD Data Analysis Software

By

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1. Summary:

The TPAD is a continuous pavement deflection testing device enhanced with several additional survey features. Since the device is designed for total acceptance of pavements, we have combined the deflection testing with Ground Penetrating Radar (GPR), digital video and GPS technologies; the final system will be suitable for testing both new pavements in a quality assurance capacity and those scheduled for rehabilitation to determine suitable strategies. This user's manual describes the data processing system and uses the data collected on a 2012 survey of US 287 in the Wichita Falls District for illustrative purposes. The executable load module for this software and the associated data from US 287 are supplied with this manual.

The TPADScan data acquisition software developed by TTI to collect TPAD raw data is run on one laptop computer. After each field test, TPADScan will create four files:

- GPR raw data (also has DMI and GPS information), file extension is .DAT.
- RDD raw data (also has Infrared temperature and DMI information), file extension is .RDD.
- Digital video data file (also has DMI data imbedded), file extension is .IMG.
- GPS raw data file (also has DMI on trace number and time data), file extension is .GPS.

The detailed data structure inside each file type is given in the TPAD data acquisition user's manual. An example of output file volume based on test survey settings for the US287 field testing is given in Table 1. The basic settings for the test surveys were as follows:

- The deflection data collection rate is 1000 Sample/s with four channels of data.
- Video collection rate is 5 feet per frame; the video resolution is 1280×800, collected in distance mode.
- GPR collection rate is one trace per foot, and collecting in the distance mode.
- GPS location is collected once per second, as is the infrared (temperature) data.

Table 1. File Size for the US287 Field Testing.

File name	Comment	Speed	length	GPR file	Video file	RDD file	GPS file
		mph	miles	Kbytes	Kbytes	Kbytes	Kbytes
SBTA	SB	2.0	5.0 miles	51400	491700	76000	653
SBTB	SB	2.0	1000 feet	2010	22460	3175	26
SBTC	SB	3.0	1000 feet	1988	22980	2069	18
SBTD	SB	4.0	1000 feet	1972	23380	1614	14
SBTH	SB	1.0	500 feet	968	9120	4880	29

From the above table, we noticed that based on the quoted settings, the video file size is more than 10 times the GPR data file size, and for a 2.0 mph running speed, the RDD data file size is around 1.5 times the size of the GPR data file. Compared to these files, the GPS file is much smaller.

Since the TPAD geophone data are processed in the frequency domain, we cannot collect the deflection data in the distance mode. So the TPAD data file size is only dependent on the sampling rate (user defined) used for collecting data. In contrast, the GPR and video data are collected in the distance mode so the file size is only tied to the tested distance and trace collection interval.

From the above table, we noticed that for a 5-mile data set the file size is quite big; if we read data from just one geophone sensor, there are around 9,267,000 data points. The current data processing software (TPADana) processes and displays the deflection, video, GPS and temperature data. Currently the GPR and video data are processed with the Pavecheck software. Future versions of this software will integrate the evaluation of both data sets.


2. Installation of TPADana

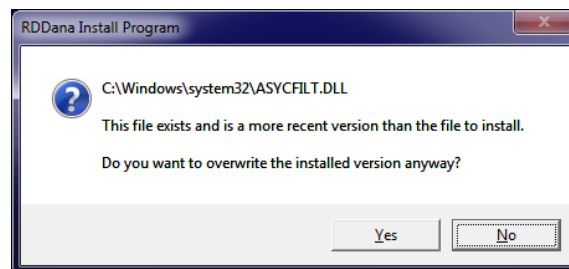
System Requirements

TPADana has been developed for computer systems that meet the requirements listed below.

- Windows 2000 with Service Pack 3 or Windows XP with Service Pack 2.
- 1.0G Hz Processor.
- 2 GB RAM.
- 20 GB free hard drive space.
- 17 inch monitor with at least 1440×1024 resolution.


Most newer computers meet the above requirements.

The TPAD data processing software is installed by running the setup software as follows. Double click the TPADana setup program with the icon:  **RDDanasetup.exe** , then follow the instructions step by step. If the following similar dialog box shows on the screen, this means the version of the existing installed DLL file (Dynamic link library file) is older than the file already existing in your computer. Always answer “No” to keep the latest version of the DLL file.



The installation procedure also asks the user for the installation folder, and you can select the default folder or select/create the folder you like. The whole installation takes about two minutes. The

installation program also loads one set of TPAD data into a folder called Testdata; this is a 1000-foot set of data collected on US 287.

After the installation, you can find the installed program icon  TPADana.exe on the desktop or in the program folder. Double click this icon to start the TPADana program and the first screen shown below will appear.

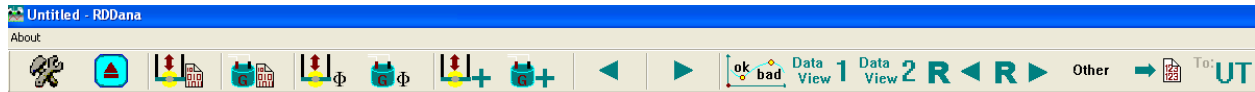


Figure 1. Main Menu Screen of the TPADana Software.

We can see that all the functions can be accessed from the toolbar buttons. Table 2 describes the function of each button. The correlation of icon symbols to TPAD functions is as follows:























-  means the geophone.
-  means the raw data of geophone.
-  means the load related.
-  means the raw data chart of load signal.

Table 2. Function of Each Toolbar Button.

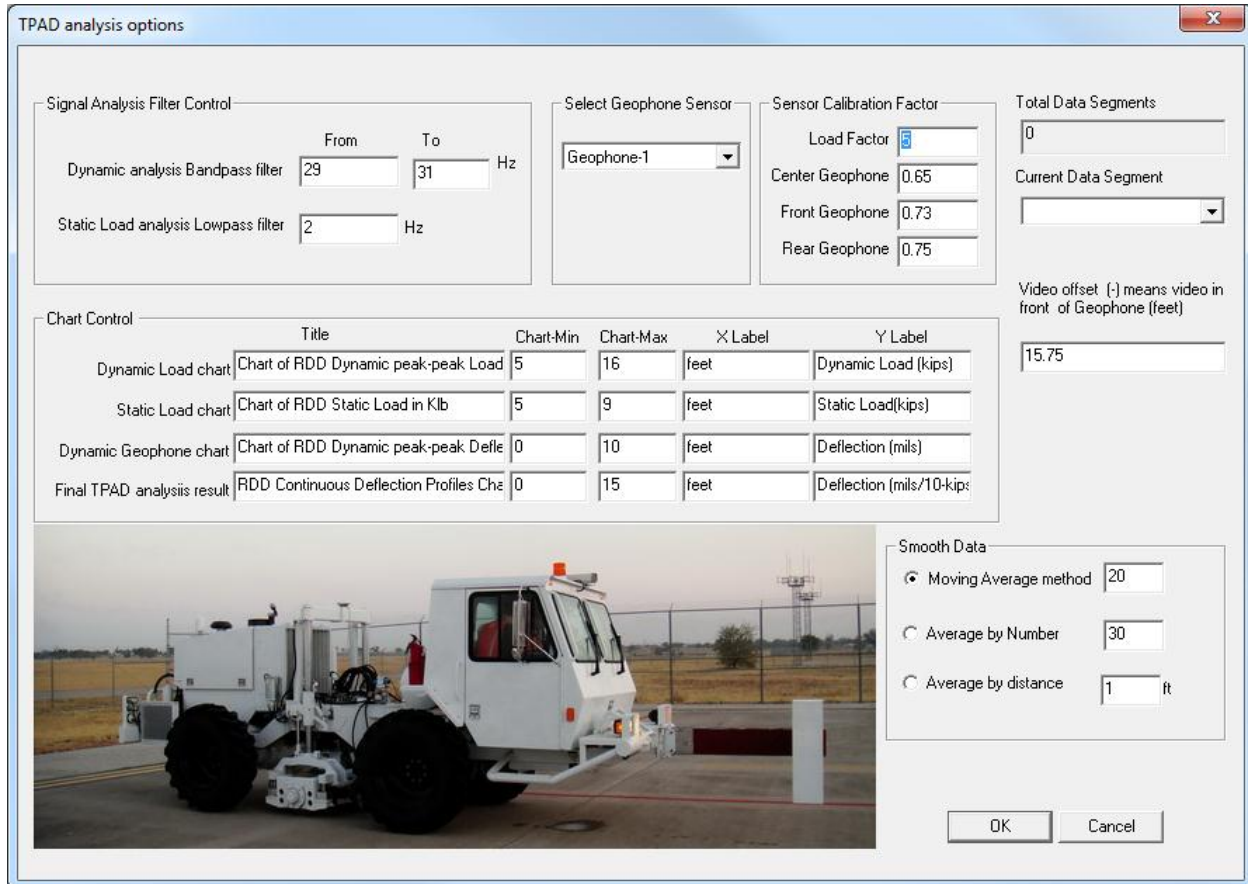
No.	Icons	Functions
1		Program setup or options (clicking this button will show the options dialog box) used to set up the basic parameters for running this software.
2		Load the analysis file to be processed, this is the first step required to analyze test data.
3		Show the raw load chart (similar buttons shown in #9,10 below are used for turning to other pages of data to be displayed).
4		Show the raw geophone chart.
5		Show the power spectrum chart for each 5000 raw load data points (button on #9,10 are used for turning to other pages of data to be displayed).
6		Show the power spectrum chart for each 5000 raw geophone data points.
7		Show the raw and filtered load chart (button on #9,10 are used for turning to other pages of data to be displayed).
8		Show the raw and filtered geophone chart.
9		Turn to previous page for the operations controlled by buttons #3 to #8.
10		Turn to next page for the operations controlled by buttons #3 to #8.
11		Show the continuous normalized deflections trace chart (deflections for each 10-kip dynamic loading). Use when wishing to return to analysis of deflections after using other features.
12		Comprehensive Results view (Important - this displays the deflection and Video data on a single screen).
13		Comprehensive Results view (similar to above but with different summary graphs).
14		Turn to previous segment of data (each max segment size is 3,200,000 data points).
15		Turn to next segment of data (each max segment size is 3,200,000 data points).
16		Showing the chart of elevation above sea level, surface temperature and survey speed vs. DMI.
17		Save the normalized deflections to disk for viewing using other software (like Excel).
18		Change the TTI format to UT Austin format for analyzing the data by UT procedure.

The first and second buttons are used for loading and setting the parameters in the analysis. Buttons #2~8 are used for viewing the raw and filtered data in chart form. Buttons #9 and 10 are used with #3~8 buttons for scrolling thru the data file. Buttons #11~13 are used for showing the analysis results in different formats. Button 14 and 15 are for scrolling to earlier or later sections in the data file. Button 16 is used to display the temperature, vehicle speed, and elevation data. Button 17 is for saving a table of deflections vs. DMI data into ASCII format, and these data can be used by Excel for report generation. The last button (18) is used to transfer the raw TTI formatted data to the raw UT Austin format, allowing UT researchers to analyze the data with their existing software.

In the following section, we will discuss the function of each button in detail.

2.1 Program Options and Configuration Button

Click this button and Figure 2 will be displayed; this shows the options available to process and display the TPAD data.



The dialog box titled "TPAD analysis options" contains the following sections:

- Signal Analysis Filter Control:**
 - Dynamic analysis Bandpass filter: From 29 Hz, To 31 Hz
 - Static Load analysis Lowpass filter: 2 Hz
- Select Geophone Sensor:**
 - Geophone-1 (selected)
- Sensor Calibration Factor:**
 - Load Factor: 1
 - Center Geophone: 0.65
 - Front Geophone: 0.73
 - Rear Geophone: 0.75
- Total Data Segments:** 0
- Current Data Segment:** (dropdown menu)
- Video offset (-) means video in front of Geophone (feet):** 15.75
- Chart Control:**

	Title	Chart-Min	Chart-Max	X Label	Y Label
Dynamic Load chart	Chart of RDD Dynamic peak-peak Load	5	16	feet	Dynamic Load (kips)
Static Load chart	Chart of RDD Static Load in Klb	5	9	feet	Static Load(kips)
Dynamic Geophone chart	Chart of RDD Dynamic peak-peak Defle	0	10	feet	Deflection (mils)
Final TPAD analysis result	RDD Continuous Deflection Profiles Cha	0	15	feet	Deflection (mils/10-kips)
- Smooth Data:**
 - ☒ Moving Average method: 20
 - ☐ Average by Number: 30
 - ☐ Average by distance: 1 ft

At the bottom left is a photograph of a white TPAD vehicle. At the bottom right are "OK" and "Cancel" buttons.

Figure 2. Program Setup or Options Screen.

This software is supplied with a data set collected on US 287, stored in the folder "TestData" under the name US81SBTB.RDD. This is a short run of just over 1000 feet in length. Loading the raw data is described in section 2.2.

Once the file is loaded, the total number of segments in the selected data set is displayed (1 for the provided short data set) in the upper right dropdown edit box. The maximum number of data points that can be displayed in one segment is 3.2 million points; at a TPAD speed of 2 mph using the default sampling rate this corresponds to roughly 9000 feet of data. For long runs such as were made on US 287, over 5 miles of data were collected in a single complete run. In this case the data is broken into 3 segments for viewing.

Figure 3 shows a small dialog box with two sections. The top section is labeled 'Total Data Segments' and contains a text input field with the value '0'. The bottom section is labeled 'Current Data Segment' and contains a dropdown menu with a downward-pointing arrow.

Figure 3. Showing the Total Number and Current Segment Selected.

In the top left dialog box, the user can input the filter parameters to control how the raw data will be processed using a digital software filter. Inside the software, a band-pass filter is used to remove unwanted noise and to get the geophone and load peak to peak amplitudes.

The TPAD currently uses a 30 Hz loading frequency, a band-pass filter range of 29 Hz to 31 Hz is used to remove unwanted components of other frequencies for both the dynamic loads and dynamic deflections on each geophone. The TPAD's load signal comprises of both a static load and a dynamic load. To measure the static load a low pass 2 Hz filter is applied to the load signal. The remaining signal is used to estimate the static load. Both filters are set in the Signal Analysis Filter Control box shown in Figure 4.

Figure 4 shows a dialog box titled 'Signal Analysis Filter Control'. It contains two rows of controls. The first row is for the 'Dynamic analysis Bandpass filter' and has two input fields labeled 'From' and 'To' with values '29' and '31' respectively, followed by a 'Hz' unit label. The second row is for the 'Static Load analysis Lowpass filter' and has one input field with the value '2' followed by a 'Hz' unit label.

Figure 4. Filter Parameters.

At the top center of the options dialog box the user can select which geophone sensor is to be analyzed and displayed; also here the user can input the sensor calibration factors. The units of the load calibration factor is 5.0 klb/V, and the geophone calibration factor is V/(in/sec). The units of the geophone calibration factor are tied to velocity, the final deflection results are reported in mils (one thousandth of inch). The software converts the geophone output into mils. Geophone 1 is the sensor between the loading rollers of the TPAD, whereas sensor 2 is the lead sensor and sensor 3 is the trailing sensor.

Figure 5 shows a dialog box with two main sections. The left section is titled 'Select Geophone Sensor' and contains a dropdown menu with 'Geophone-1' selected. The right section is titled 'Sensor Calibration Factor' and contains four input fields: 'Load Factor' with a value of 5, 'Center Geophone' with a value of 0.65, 'Front Geophone' with a value of 0.73, and 'Rear Geophone' with a value of 0.75.

Figure 5. Sensor Selection and Calibration Factor Input Screen.

At the right middle section of the dialog box the user is asked to input the offset distance from the loading wheels to the video image. Since the video camera is mounted on front of the TPAD vehicle the image from the camera does not match the TPAD's deflection test location. The goal is to provide an offset so

the user can view the pavement condition at the location of high deflections. At the moment a default value of 15.75 feet is input, this is the distance from the loading rollers to the GPR antenna. This may be revised at a later date if an alternate camera aim point is selected. With the proper value, the program automatically lines up the data; this offset is automatically added to each display chart.

Video offset (-) means video in front of Geophone (feet)

15.75

Figure 6. Offset and Moving Average Parameters Input Screen.

The user is provided with three options to smooth the deflection data. These are shown below in Figure 7. When selected, a smoothed data curve is plotted on top of the raw data as a red line as shown later in Figure 10. For the TPAD travelling at 2 mph with a data collection system operating at 1000 Hz using a 30 Hz loading frequency, approximately one deflection point is collected for every 1 inch of travel. Figure 7 provides the user with options to down-sample and smooth these data plots. The down-sampled data can also be output to Excel for further data analysis and display (Button 19).

Smooth Data

☒ Moving Average method 20

☐ Average by Number 30

☐ Average by distance 1 ft


Figure 7. Options to Smooth Raw Deflection Data.

From the center of the options dialog box (as Figure 2), the user can format the output data charts. The user can define the chart title, minimum, maximum, and x-y labels of each chart.

	Title	Chart-Min	Chart-Max	X Label	Y Label
Dynamic Load chart	Chart of RDD Dynamic peak-peak Load	5	16	feet	Dynamic Load (kips)
Static Load chart	Chart of RDD Static Load in Kilb	5	9	feet	Static Load(kips)
Dynamic Geophone chart	Chart of RDD Dynamic peak-peak Defle	0	10	feet	Deflection (mils)
Final TPAD analysis result	RDD Continuous Deflection Profiles Cha	0	15	feet	Deflection (mils/10-kips)

Figure 8. Output Chart Format Parameters.

2.2 Load the Raw Data Button

This  button is used for loading the TPAD raw test data file collected using the TTI data acquisition system. When the user clicks this button, the open file dialog box shown in Figure 9 appears.

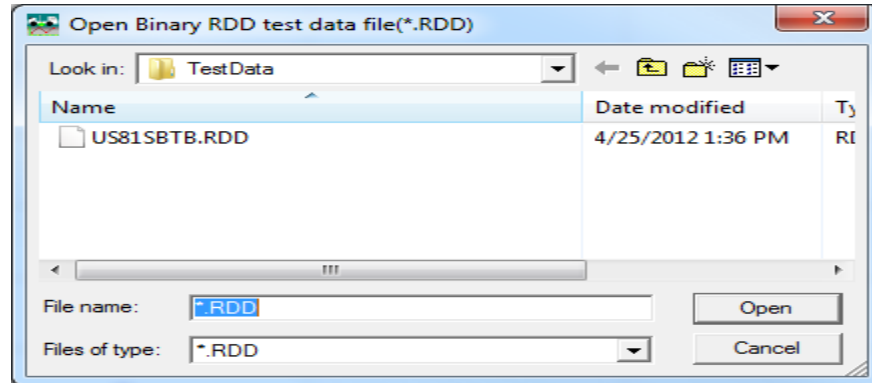


Figure 9. Open File Dialog Box.

The TPAD raw field data file is given the extension name of .RDD; this file is in binary format and cannot be edited or viewed with any other software. In the background, the software actually reads three files: one is the RDD geophone file, another is the video file, and the last one is the GPS file.

After the user selects the raw data file from the dialog box in Figure 9, then clicks the “Open” button data processing will begin. Figure 10 is automatically displayed as a plot of sensor deflection in mils versus distance in feet, the blue line being the raw deflection data and the red line being the smoothed data. The red line can be removed by putting a zero in the selected box in Figure 7.

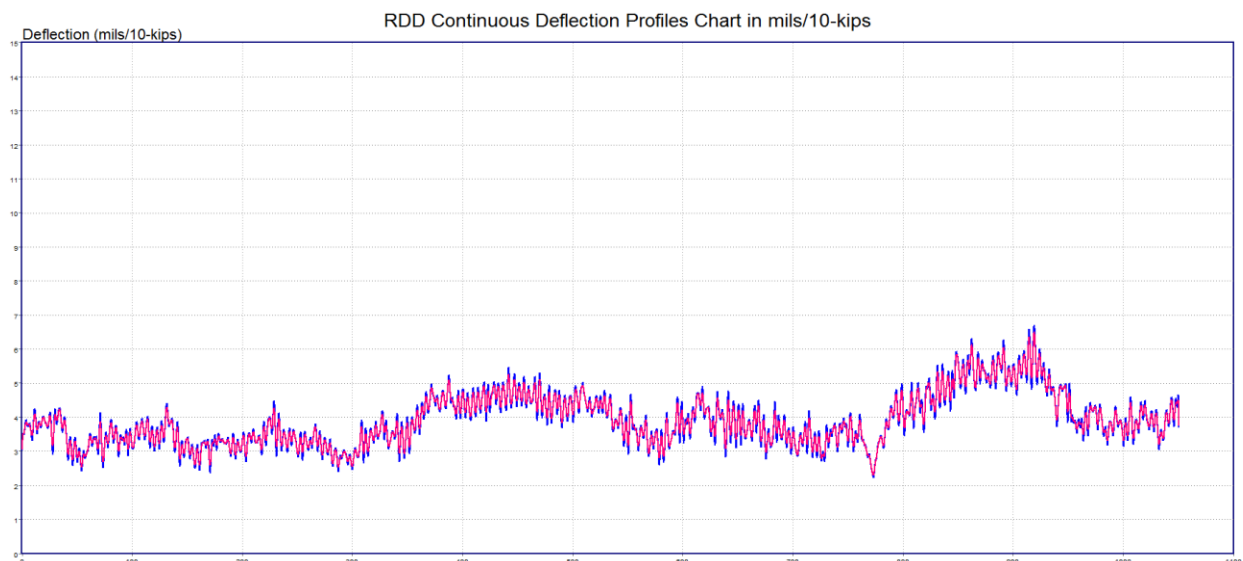







Figure 10. Plot of Raw Data (Blue Line) and Filtered Data Using the Options Selected in Figure 7.

2.3 Button for Showing the Raw Load Chart



After you click the  button and the raw data are loaded, selecting the  button will display the raw load data chart shown in Figure 11. At the top left corner, the information shows the data point range displayed on this screen. The buttons  and  can be used to turn to other pages. This chart shows the raw load signal vs. the DMI in feet. This is the beginning of the data file, the TPAD is not moving. Therefore all the DMI values in Figure 11 are zero and the load signal is a perfect sine wave. When turning to other pages using the  button Figure 12 is displayed, now the load signal changes with time and the DMI is no longer zero.

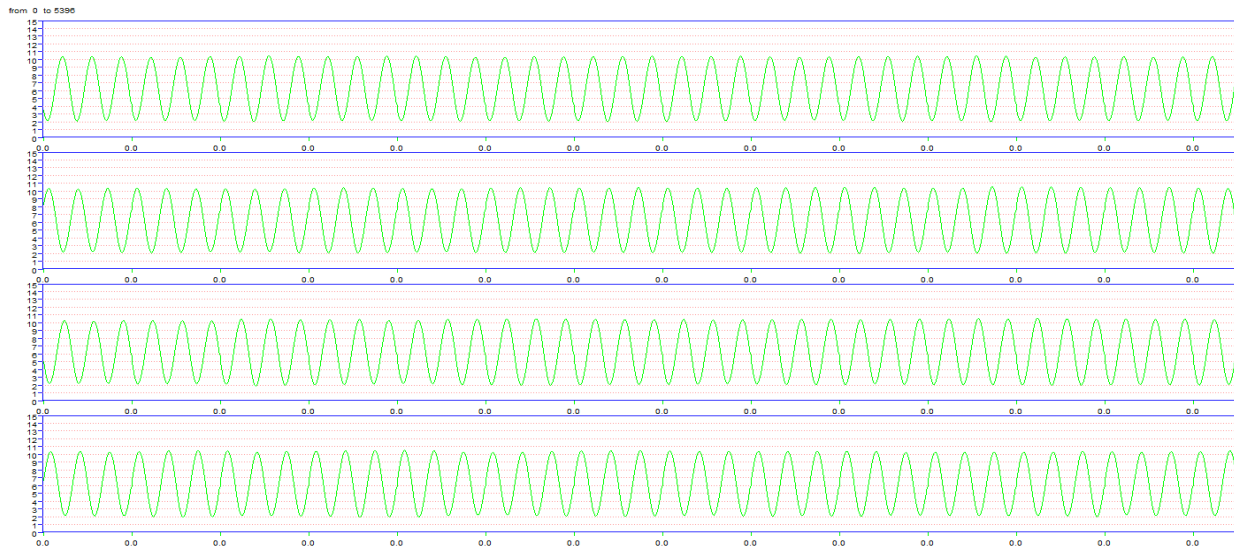


Figure 11. Raw Load Data Chart (DMI vs. Load in kip).

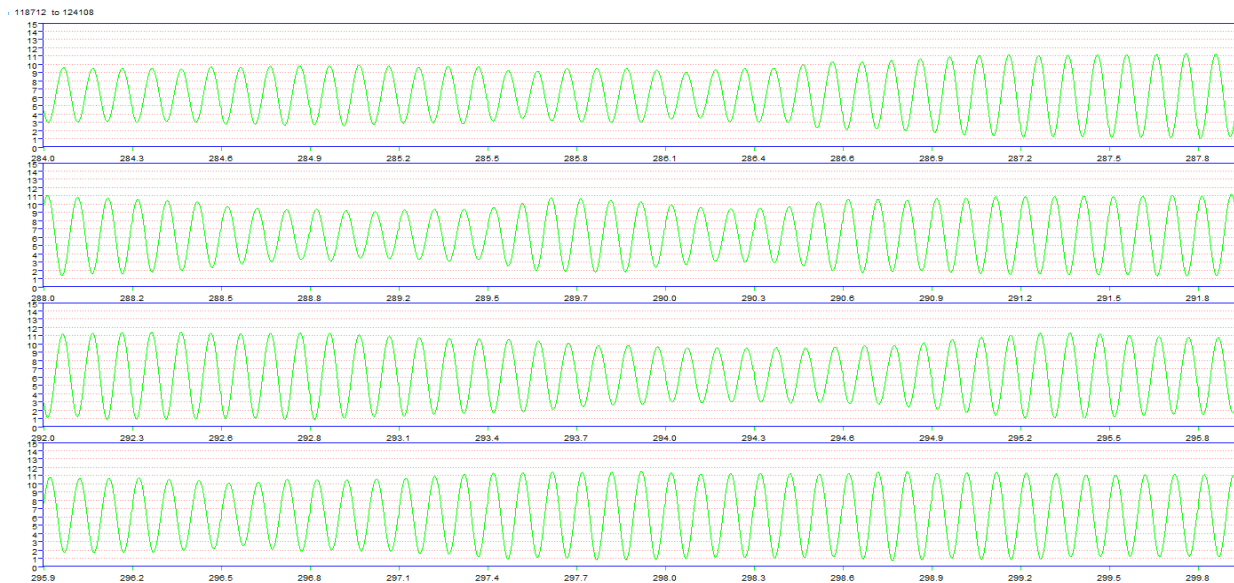



Figure 12. Raw Load Data Chart When Turning to Other Pages.

2.4 Button for Showing the Raw Geophone Chart



As in section 2.3, when the  button is selected the screen will show the raw geophone data chart as in Figure 13. The Y-axis is in mils and X-axis is in feet. The geophone data are much more variable than the load signal (these data come from US287 near Bowie, TX, survey in the north bound direction, running at 2 mph). Work is continuing with the TPAD to determine the best sensor mounting arrangement and operating speed.

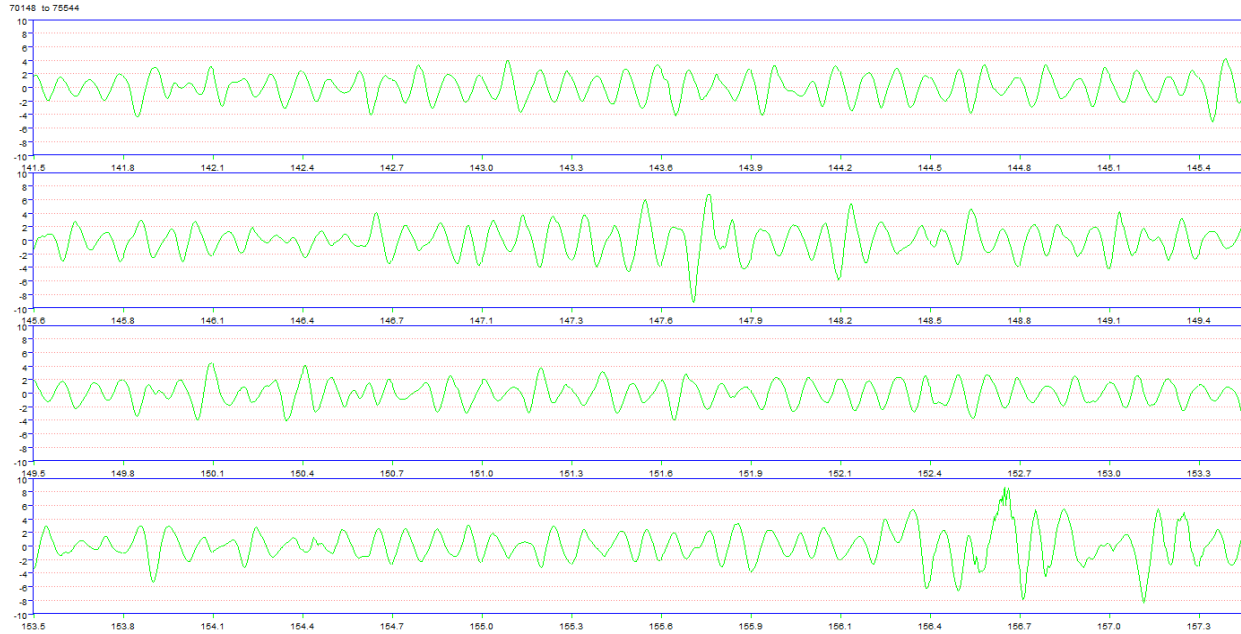





Figure 13. Raw Geophone Data Chart (Y-axis in mils, X-axis in feet).

2.5 Button for Showing the Power Spectrum Chart of Raw Load Data

Power spectral density (PSD) or alternately, the power spectrum of the time series, describes how the power of a signal or time series is distributed with frequency. It is a method of defining the signal to noise ratio where the value at 30 Hz, which is the input loading frequency, should be significantly different from that observed at other frequencies (background noise). The power spectrum shows the strength of the variations (energy) as a function of frequency. It shows at which frequencies variations are strong and at which frequencies variations are weak. The units of the PSD are energy per frequency (width), and it is possible to obtain energy within a specific frequency range by integrating PSD within that frequency range. Computation of the PSD is done directly by the method called Fast Fourier Transform (FFT) or computing the autocorrelation function and then transforming it.

When clicking the button , the PSD chart of raw load time series will show on the screen as in Figure 14. The analysis is currently performed for each set of 5000 data points (this segmenting option is under review at this moment). Figure 14 shows data points from 65,000 to 70,000 (accordingly the DMI

is from 126.49 feet to 141.09 feet). The chart's Y-axis is in log10 units, and the X-axis is in frequency. This chart shows the dynamic load frequency is exactly 30 Hz.

Buttons  and  can be used to turn to other pages. Each page covers 5000 data points.

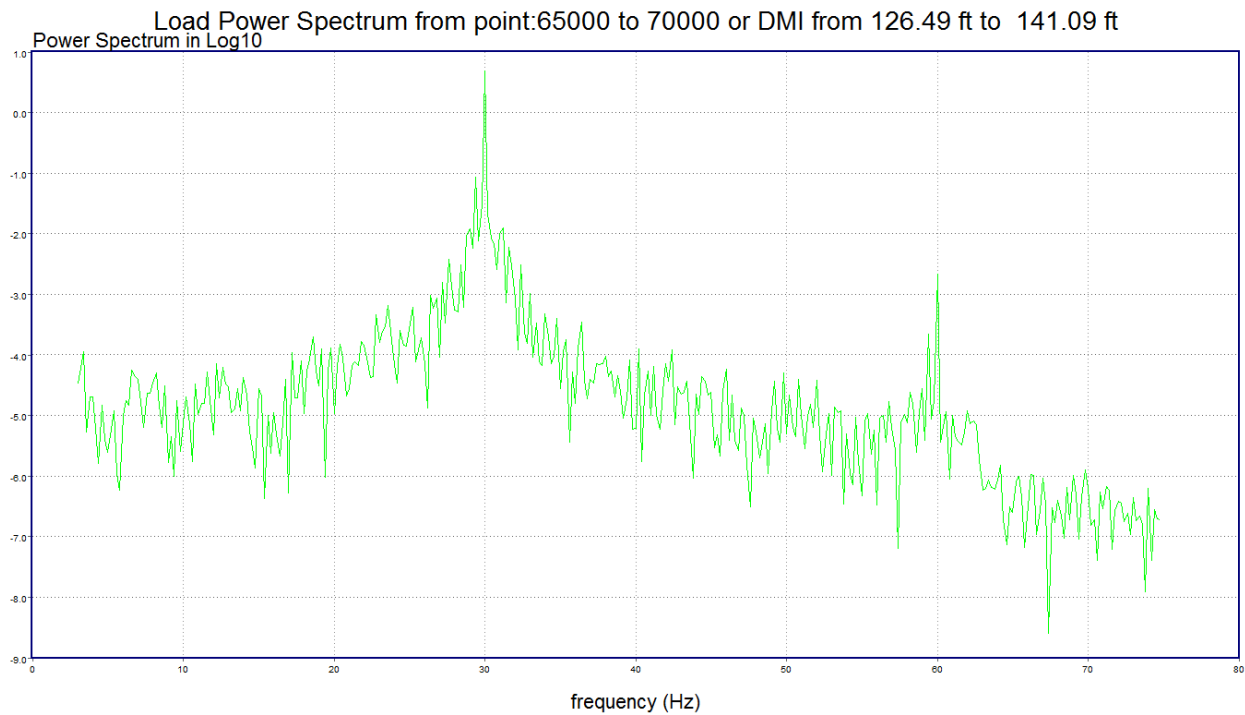



Figure 14. Power Spectrum Chart of Raw Load Signal.

2.6 Button for Showing the Power Spectrum Chart of Raw Geophone Data



Similar to section 2.5, the  button is used for showing the geophone's Power Spectrum chart as given in Figure 15.

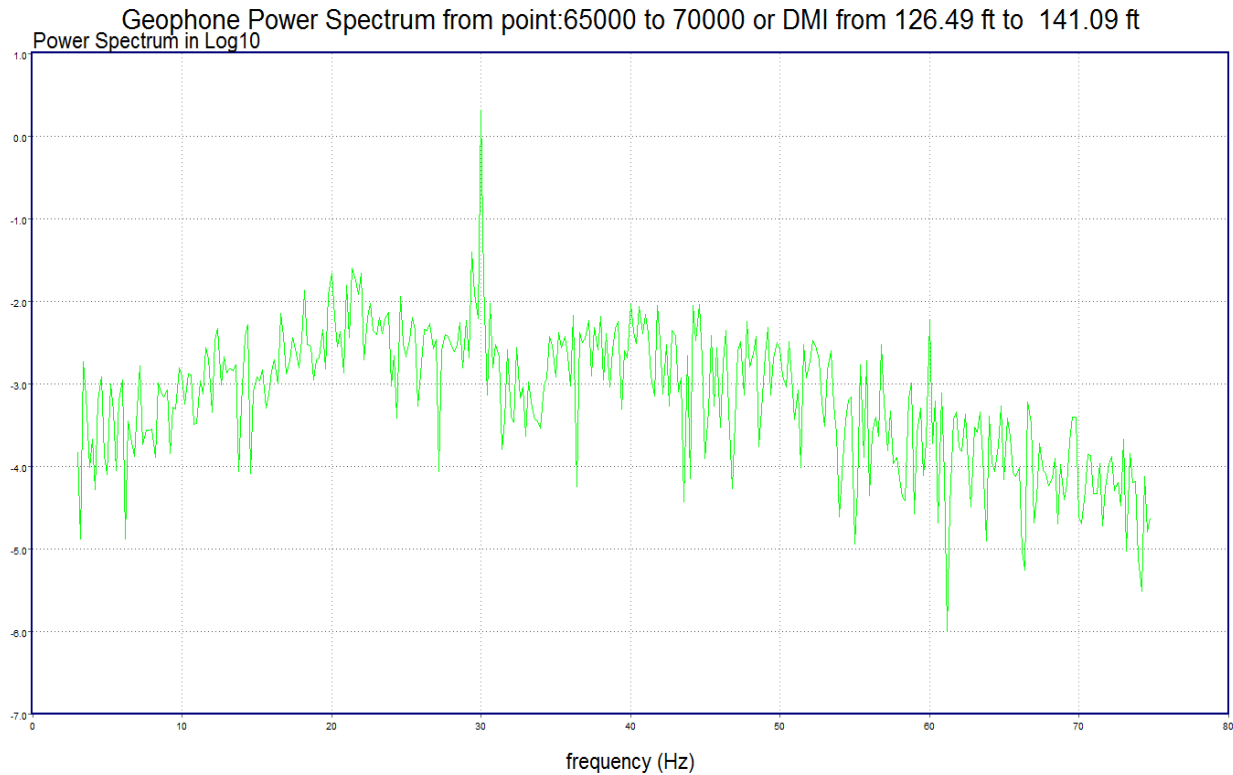



Figure 15. Power Spectrum chart of Raw Geophone Signal.

2.7 Button for Showing the Chart of Raw and Filtered Load Data

This button's operation is very similar to the button  as discussed in section 2.3, except the chart when clicking this button will show the raw and filtered data together as given in Figure 16. Notice that the filtered data are depicted as the blue colored line; the green colored line is the raw load data. Since we use the 29~31 Hz band filter, the static load component is removed, and the filtered data oscillate around the zero. On the filtered load signal, the red dot specifies the peak location. This peak will be used for calculating dynamic load, which is used to compute the normalized continuous deflection value.

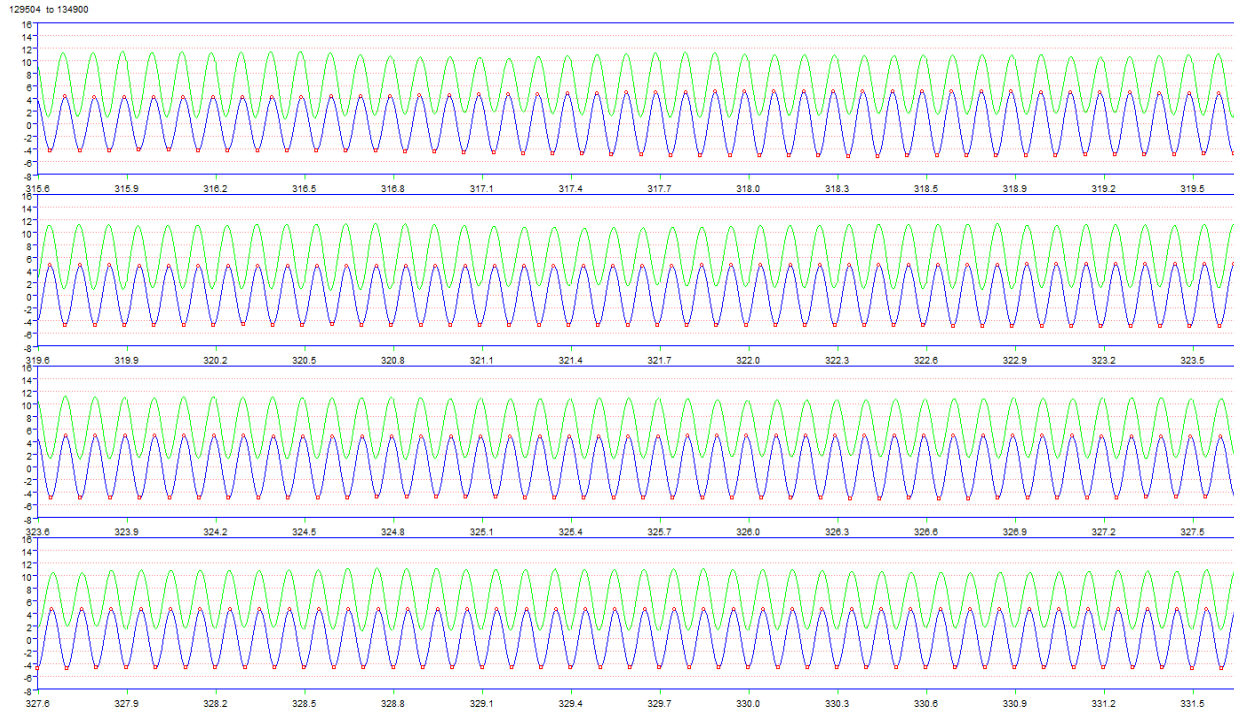



Figure 16. Chart of Raw and Filtered Load Data.

2.8 Button for Showing the Chart of Raw and Filtered Geophone Data



This button's operation is very similar to the button  as discussed in section 2.7, except this button is used for showing the geophone's raw and filtered data chart as given in Figure 17.

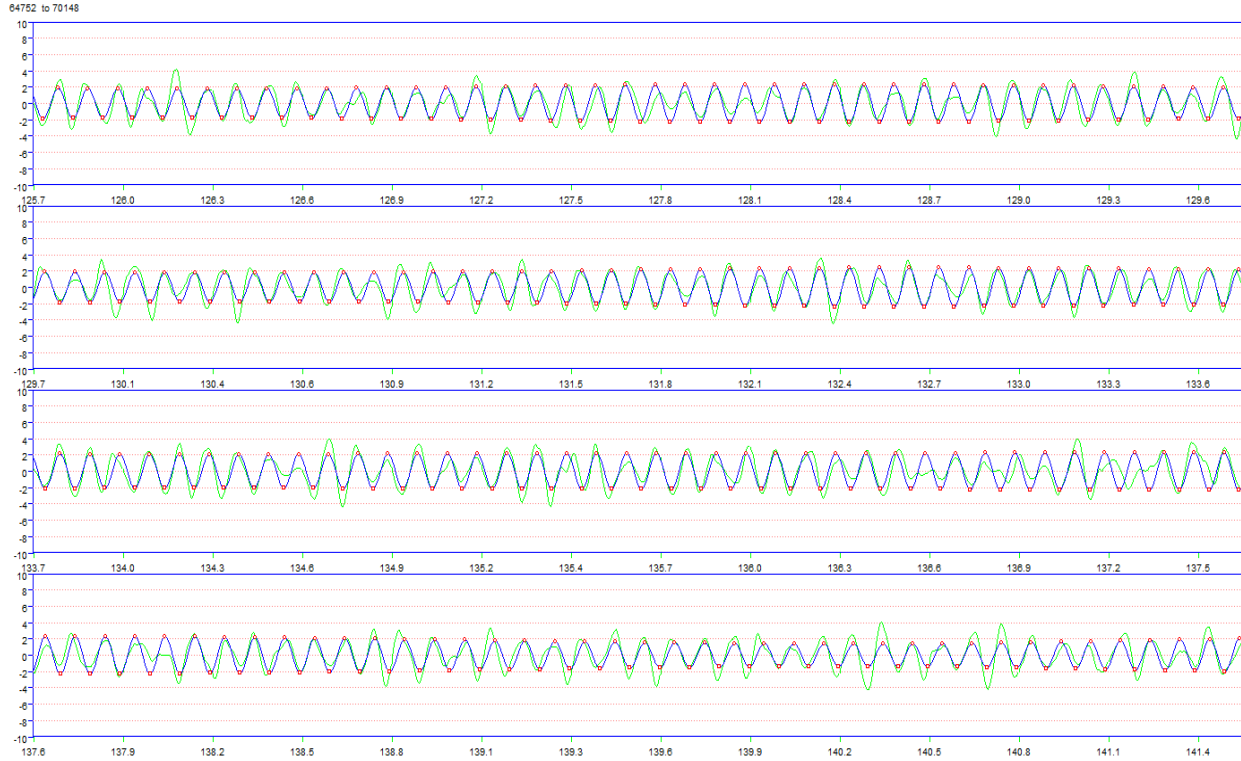




Figure 17. Chart of Raw and Filtered Geophone Data.


2.9 Button for Showing the Normalized Continuous Deflection Results



When the user clicks the  button as in section 2.2, all the data are loaded to the memory and the chart shown earlier in Figure 10 is displayed. The user can also return to evaluating deflections after using other program features by clicking the  button. This chart shows the deflection normalized to a 10 kip load. The X-axis is in the units of feet, and Y-axis is in mils/10 kips.

2.10 Comprehensive Results View Option 1



By clicking , the comprehensive results screen shown in Figure 18 will be displayed. The top part of this screen shows the normalized deflections results as in Figure 10. On the top right side of this chart, you can find the GPS coordinates, DMI offset, and the deflection value in mils that are updated when the user moves the mouse inside the chart. On the bottom left side of the screen, the video frame shows the video with the DMI offset in miles and feet corresponding to the location on the deflection trace that the user clicks on.

This view of the data is potentially the most useful to the user. Once the mouse is clicked in the top graph two lower graphs are generated that zoom in on the area around the cursor location in the top graph. The upper of these graphs shows the deflection plot for a total of 100 feet, 50 feet either side of the selected


location. The lower graph zooms in even closer, with a deflection plot of approximately 15 feet, 7.5 feet either side of the selected location.





Figure 18. The Comprehensive Results View Screen, View Option 1.

If the user moves the cursor to any of these three charts, the DMI offset and the “Value” field will show the normalized deflection magnitude of the mouse location.

The overlap buttons on the video frame can be used to control the play mode of the video. The function of each button is listed below:

- Go to the first frame of video.
- Play the video backwards.
- Go to previous video frame.
-  Go to next video frame.
- Play the video forwards.
- Go to the last frame of video.
- Save the current frame to a JPEG image file.

When the user plays the video by using button  or , the vertical red line showing the current location on the normalized deflections trace chart also moves together with the video.

2.11 Comprehensive Results View Option 2

Data View 2

This data view shows the normalized continuous deflections plot in the upper part of the screen and a blown up video image of the highway surface. Clicking on any location in the deflection plot will cause the image from that location to be displayed.

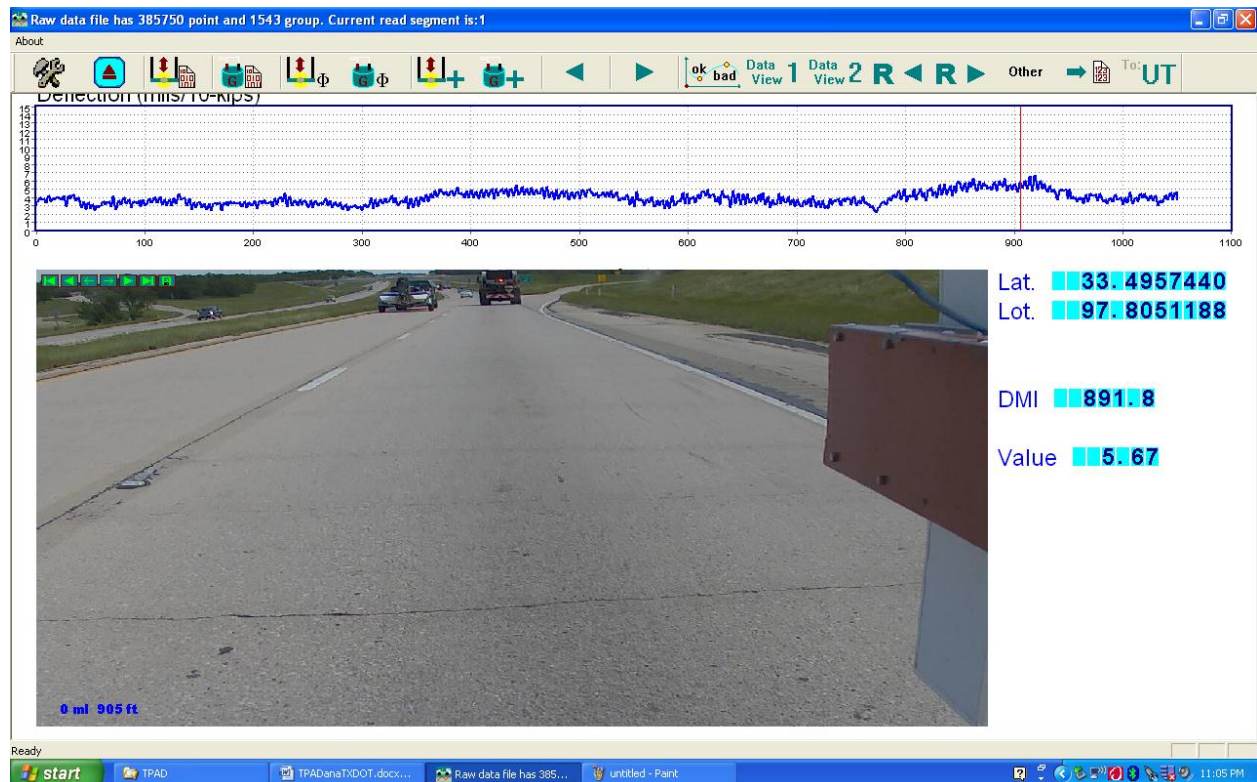


Figure 19. The Comprehensive Results View Screen, View Option 2.

2.12 Button for Showing Other Information

Other

As shown in Figures 20 and 21, the TPAD is equipped with an infrared surface temperature sensor and an accurate GPS antenna, mounted on top of the loading frame. A GPS allows the user to permanently record the test location in the data file. In cases where the user wants to go back to the site to further investigate problematic locations, the GPS is the best tool for locating problem areas. Also a concrete pavement's behavior under loading (especially at joints and working cracks) is related to slab temperature when tested, and it is necessary to account for temperature effects when evaluating deflections.

Other

The button is used for showing this information. By clicking this button, the screen shown in Figure 22 will be shown. From this chart, we noticed that there are four locations where the pavement surface temperature is low compare with other locations, and the temperature drops nearly 25°F. These four locations are marked with red circles. When we looked at the video frames at these locations, we find that where the temperature drops is where the TPAD passes under a bridge. Figure 23 shows the video frames for the four low surface temperature locations.

The middle chart of Figure 22 shows the elevation above sea level in feet. Since the elevation data are obtained from the GPS system, when the TPAD passed under the bridge, the GPS had poor signal reception. Compared with the top temperature chart, we noticed that when the temperature drops, the GPS reading under the bridge has an error and the elevation data point fluctuates much more than at other locations.

The bottom chart just shows the TPAD running speed with DMI offsets. We can see the TPAD's speed was close to 2.0 mph, and this reading matches the specified test speed of 2 mph.



Figure 20. Infrared Sensor for Getting the Surface Temperature.



Figure 21. GPS Antenna Mounted at the Top of the Loading Frame.

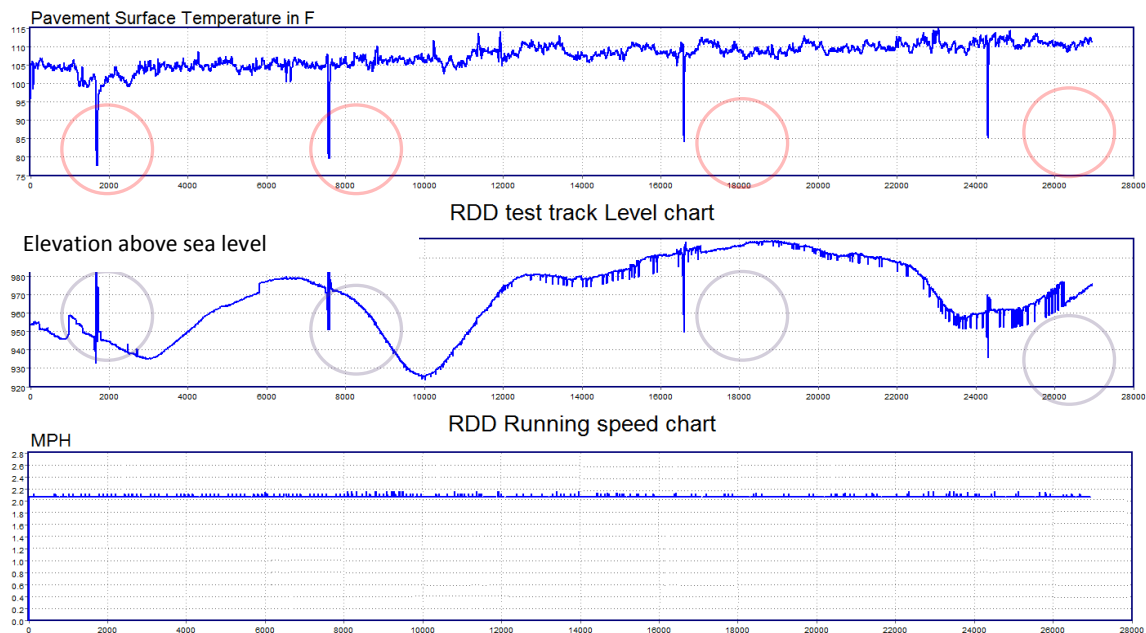



Figure 22. Other Information Charts (Surface Temperature, Elevation, and Running Speed).



Figure 23. Video Frames Showing the TPAD Cross the Bridge.

2.13 Button for Saving Output of the Normalized Deflections Results

If the user wants to import the data into other software such as Excel this button  is used to save the results to an ASCII format. The output format has two columns, one is the DMI offset and the other is the normalized (10 kip) deflections. The DMI offsets are in feet, and the deflections are in mils/10 kips. Executing this operation is straight forward and will not be covered further here.

2.14 Button for Saving Output of the Raw Data to the UT Austin Format

Since UT Austin already has a history of evaluating continuous deflection data using their own process, this feature allows sharing the data with their system by changing TTI's TPAD data format to the UT Austin format.

The TTI researcher went to great lengths to fully understand the UT Austin format. The main problem is that the UT Austin's MathLab software outputs the data according to an old Apple® Mac format. The sequence for saving the raw sensor and DMI data are reversed from the normal Windows format.

Now the process has been made simple for the user; click the **UT** button, then the open file dialog box will appear as in Figure 24 (same as Figure 8) . After clicking the “Open” button, the conversion process will start. Based on the size of the file, conversion time varies. When the toolbar button begins to respond again to the mouse actions, the converting process is finished. As a check, the user can browse the raw data folder and find the two new files for the UT Austin analysis system. For example, if the user selects US81NBTB.RDD file as the file to convert as in Figure 24, then the two new files names are:

- US81NBTB_A.DAT, which is the sensors and DMI raw data file (32 bit floating point data format).
- US81NBTB_C.DAT, which is the DMI processed data format (two column, time and distance in feet, in 64 bits).

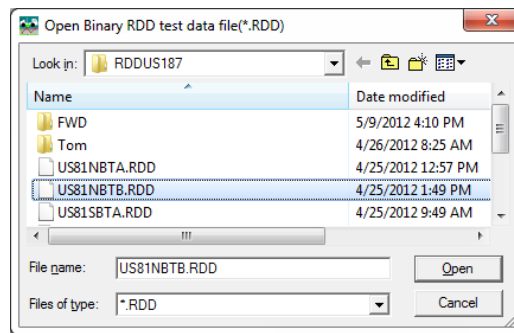


Figure 24. Open File Dialog Box.