TRANSPORTATION RESEARCH

RECORD

JOURNAL OF THE TRANSPORTATION RESEARCH BOARD

NO.

1764

Assessing and Evaluating Pavements

Pavement Design, Management, and Performance

A PEER-REVIEWED PUBLICATION OF THE TRANSPORTATION RESEARCH BOARD

TRANSPORTATION RESEARCH BOARD – NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
Washington, D.C.
2001

Paper No. 01-2467

Virtual Environment for Transportation Data Management System

Koon Meng Chua, Gordon McKeen, John Burge, and George Luger

The New Mexico State Highway and Transportation Department has routinely been collecting traffic data and pavement nondestructive testing data (pavement surface deflections) and realized that unless a more efficient way to retrieve and review voluminous amounts of transportation data were developed, the highway engineer would be overwhelmed and some of the data would have to be ignored for practical reasons. The Virtual Environment for Transportation Data (VETD) management system was developed as a proof-of-concept software package to overcome this problem. The VETD management system is a comprehensive front-end software package that allows the user to easily locate and retrieve data files through a map and to visualize large data sets. The user can then invoke numerical or analytical tools to facilitate the decision-making process. The user can also call any off-the-shelf three-dimensional topographical software package to access the virtual-reality representation of the surrounding area associated with the data in question. The visualization routine is unique in that it allows charting of two-dimensional, three- dimensional, or radar-time plots even as the data are scrolled (dynamically accessed) from the database. The front-end package was designed to be easily interfaced with other software by allowing on-screen data to be parsed into other programs as text. This project was funded through the FHWA Priority Technologies Program and was managed by the New Mexico Division of FHWA.

In New Mexico, routine evaluation of pavement projects for design or rehabilitation work is a three-step approach. Step 1 involves the acquisition of deflection data measured with either the falling weight deflectometer (FWD) or the Road Rater. Typically, this involves testing at every 61 m (200 ft) along the project. In the case of a project of 16 lane-km (10 lane-mi), this would result in more than 260 tests. In the future, if the rolling wheel deflectometer, which can measure pavement surface deflections every 22 mm (0.88 in.) at 80 km/h (50 mph), is used, the number of datum points collected would be in the thousands. Step 2 is the review of these data to identify those areas that should be investigated by obtaining cores to evaluate layer thickness, test materials, and measure subgrade conditions. A pavement surface profile is also measured at this time. Step 3 is analysis of the engineering data and incorporation of traffic data to develop the work plan.

FHWA PRIORITY TECHNOLOGY

As more and more data are collected and stored in a single or multiple databases, there will come a point at which traffic and highway engineers would be so overwhelmed that they would seek only the minimal and most accessible data that could be used in their work. Therefore, for the massive amount of data collected to remain useful to these engineers, there would be a need for a computerized system that would capitalize on the strength of the human mind in being able to make sound on-the-spot decisions based on visual perception by providing a virtual environment. A user-friendly computer system suggests an interactive environment in which the program queries the user and helps the user derive an answer by both explaining and providing suggestions. The virtual environment takes this user friendliness one step further by allowing the user to select data visually on the basis of the locality and relevance of the data to the project of interest (instead of by searching through a list of file names) and then providing a means for the user to visualize the data, look for data anomalies or identify similarities, and, if necessary, be transported to the project site in virtual reality.

The Virtual Environment for Transportation Data (VETD) management system is a prototype computer front-end system that was developed as a proof of concept to answer the need to manage transportation data efficiently for highway professionals. The development of this prototype system was funded through the FHWA Priority Technologies Program and was managed by the New Mexico Division of FHWA.

VETD MANAGEMENT CONCEPT

The VETD management system is a comprehensive analysis system that allows the user to rapidly investigate large or complex test data sets as well as to call up additional numerical or analytical tools to facilitate the decision-making process. The two recent computing tools used to construct this environment are (*a*) data visualization and (*b*) virtual reality.

Data visualization is the use of graphical images to convey useful information by helping the user easily recognize patterns or anomalies. Virtual reality refers to the interaction of a person with a computer-simulated virtual world, as if the person was interacting with reality. This enables a person to interact with an artificial three-dimensional environment that may include sight and sound. Therefore, virtual environment data visualization suggests placement of the evaluator in a situation in which he or she can access and view data in relation to what seems to be real time and real space.

The VETD management system provides an interactive, virtual reality-based data analysis environment. The set of data navigation and exploration tools in this system provides qualitative and quantitative perspectives of data that may be obscured by numeric-only approaches. The virtual environment uses three things that the human mind does well: (*a*) pattern recognition, (*b*) trend analysis, and (*c*) anomaly detection (*1*). The prototype system has the following features:

K. M. Chua, Department of Civil Engineering, University of New Mexico, Albuquerque, NM 87131. G. McKeen, Alliance for Transportation Research Institute, University of New Mexico, Albuquerque, NM 87131. J. Burge and G. Luger, Computer Science Department, University of New Mexico, Albuquerque, NM 87131.

- A quick way to determine what data are available; this is done from an interactive map that indicates what data are available when queried by the cursor;
- An easy method of retrieving data of interest; this is done simply by clicking on a file from the list of database files associated with a particular location on the map;
- A method of retrieving large data files, for example, files with 20 columns and 10,000 rows of data, and being able to view a selected portion or all of the file in real time; this is done by accessing the chunks of data in the database file selected by the user on the screen by using a scrollbar and moving the cursor along the road in question;
- A method of visualizing the retrieved data; this is done with the help of a graphical display routine that allows different data sets (up to seven data sets) to be compared side by side as well as to be able to plot the data against each other;
- A method of analyzing the data by using a statistical package or a pattern recognition package; this is done by enabling an interface with any desired program by providing a text data transfer file; the return data will also be in the form of a text file, and the user has the option to add the new data to the original database file or not;
- A method of visualizing the site from a birds-eye view as well as at the ground level to better appreciate the features and geography of the site; this is done by having a stand-alone topographical system displayed simultaneously on another video monitor (two video display cards are required to do this); a number of inexpensive off-the-shelf and stand-alone topographical software programs are available and can be used alternatively, the U.S. Geological Survey (USGS) has both viewers and mapping data, which would also suffice; and
- The ability to call up engineering programs to interpret the raw data, such as determination of the elastic moduli of the different pavement layers from the deflection database; this is also done by enabling an interface with any engineering program by providing a text data transfer file. The engineering program will have to be written to read the text data, execute the run, and write the output data in a text file that can be read by the VETD management system; the user has the option to add the new data to the original database file or not.

SOME BACKGROUND INFORMATION

Highway data can be divided into two types: traffic data and pavement data. The former deals with traffic volumes and distributions over different observation periods at different locations. The latter refers to engineering data related to the roadway, such as construction configurations (material types and layer thicknesses), and information indicative of the level of serviceability, such as roughness (or smoothness), stiffness, residual deformation, and the pavement surface distress condition. Highway data are usually stored at two different levels of details: (*a*) the network level and (*b*) the project level.

Network-Level Data

A network-level information system typically includes a collection of information at, say, the statewide level, in which the information is routinely collected without a specific intent except for the purpose of archiving. The general information is, however, extremely useful to pavement management engineers for the preparation of status reports as well as the development of projected costs for maintenance of the network.

Examples of data collected at the network level include traffic data [average daily traffic (ADT), average daily truck traffic (ADTT), intraday ADT and ADTT, and monthly or seasonal ADT and ADTT]. The monthly ADT and the seasonal ADT are used to obtain the annual ADT, which is an important piece of information that is indicative of the remaining lives of particular highways in the road network. Pavement surface deflections are also obtained on a routine basis through nondestructive testing (NDT). These pavement surface deflections are then used to backcalculate pavement layer moduli. Changes in pavement layer moduli are indicative of the structural integrity of the roadway. Pavement deflections are generally collected for the entire network at a minimum of once every 2 years. Pavement distress surveys are also conducted, usually at not more than 2-year intervals. At present, the distress survey requires a crew to visually inspect the sample sections from the network. The distresses considered include rutting, cracking, shoulder conditions, and so forth. The status of the highway is reported as a pavement condition index (PCI). Pavement roughness data [usually expressed as the international roughness index (in meters per kilometer)] are indicative of the ride quality of the roadway. This can easily be related to the present serviceability rating (PSR). PSR and PCI can be used to determine the pavement serviceability index, which is a quantitative way of describing the serviceability of the highway network in question. This network-level information is especially useful for the development of future budgets needed to maintain or improve the highway network.

The network-level information system may also include geographical and geological data. Seasonal and sometimes daily and monthly variations in temperature, rainfall, freeze-thaw conditions, and so forth are also information usually found in a network-level information system.

Project-Level Data

A project-level information system includes information that is specifically collected to help engineers decide if a particular course of action (such as rehabilitation, application of an overlay, or road widening) is necessary for the particular stretch of the highway in question. Project-level data that may be useful would include more accurate traffic counts and better estimates of the traffic distribution. The traffic engineer can use this information to determine whether a road needs to be widened or whether the geometric design needs to be reset. The pavement engineer may want to obtain pavement surface deflections collected every 30 m (100 ft) or 0.16 km (0.1 mi). The surface deflections can be used to obtain layer moduli, which in turn can be used to determine an overlay thickness.

Summary of Data

Table 1 presents some of the types of information collected at the network and project levels.

Pavement NDT

NDT techniques evaluate the structural adequacy of the existing pavement and its response to loads without destroying the pavement and its components. It follows that the measurements can be taken only at or near the pavement surface. One common device is the FWD. The FWD delivers an impulse load onto a pavement through a circular loading plate. Seven geophones are used to record the [illegible]

TABLE 1 Types of Information Collected

Types and examples	Network Level	Project Level	Remarks
Geographical data Relief, industries, land use, population, etc.	X		
Geological data Geological classification, soil type, road type, outcrops, groundwater, etc.	X		
Climate (Daily, Monthly, Seasonal) Temperature, rainfall, snow, freeze/thaw, sunshine, wind, etc.	X		
Traffic ADT, ADTT, truck distribution, traffic characteristics, intraday, daily, monthly, seasonally, annually, etc.	X	X	Network information usually used at project level.
Construction Rigid or flexible pavement, layer, thicknesses, material types, stiffnesses, soil moisture fluctuation, etc.	X	X	
Pavement Condition (Distress Survey) Roughness, rutting, extent of cracking, surface and air temperature, surface deflections and corresponding loads, etc.	X	X	Network information usually used at project level except for deflections.

deflection experienced at the seven locations during a single drop. The pavement surface temperature is also measured for each test. The newer FWD will measure up to 11 deflection readings. It is common to perform up to 1,000 to 2,000 tests for a single project of about 80 to 161 km (50 to 100 mi).

The rolling wheel deflectometer is another NDT device that is being developed. It measures deflections in the vicinity of a loading wheel while the test vehicle is rolled down the test section at highway speeds of up to 80 km/h (50 mph). A scanning laser is used to measure deflections at an interval of 22 mm (0.88 in.). At the maximum speed, the rolling wheel deflectometer would be generating over 36 million datum points per hour.

Global Positioning System and Geographic Information System

Global Positioning System

The Global Positioning System (GPS) consists of a network of satellites that has been put in place to facilitate navigation. Twenty-four satellites circle the globe once every 12 h to provide worldwide position, time, and velocity information. The GPS was conceived in 1960 and was the consolidation of other navigation projects. Development began with the U.S. Air Force, but in 1974 the other branches of the U.S. Department of Defense joined the project, which was renamed the project Navstar Global Positioning System. The system became fully operational in April 1995. Since midnight of May 1 to 2, 2000, the average GPS accuracy in latitude and longitude readings has improved from 36.2 m (119 ft) to 13.2 m (44 ft). The deliberate selective availability (SA) error, which was initially introduced, was removed from the U.S. GPS. In practice, 95 percent of the readings captured at one location fell within 13.2 m (44 ft) before the SA was removed and within 4.2 m (14 ft) after the SA was removed. Therefore, several readings should be taken at a particular location to obtain a good latitude-longitude reading.

The latitude and longitude system is one that is familiar to the general public. The number of degrees north or south of the equator and the number of degrees east or west of the prime meridian, which runs through Greenwich, England, describe the location. The equator and the prime meridian are designated 0 degrees latitude and 0 degrees longitude, respectively. The international date line is 180 degrees longitude from the prime meridian. The other coordinate format used in the GPS is the Universal Transverse Mercator format, which is based on a system of grid squares superimposed onto a map of the world. At the greatest resolution, the grid forms squares that are 1000 by 1000 m (or 1 by 1 km).

At present, features on highways are located by using road names, milepost, and direction of travel. For example, one would refer to a test location as 0.6 km (0.4 mi) from Milepost 150 along US-54 in the north direction. The proposed VETD management system will eventually replace the traditional system with the latitude-longitude and elevation format to describe locations.

Geographic Information System

The geographic information system (GIS) is a computer program that uses a mapping system to display stored information to show particular features in the region of interest (e.g., population), geographical information, particular information of interest over a period of time, and spatial implications for the region.

Many highway agencies have been developing the GIS to help with information management. Use of a GIS for this purpose is a long-term commitment. First, a particular commercially available GIS package must be selected, and second, all information must then be entered according to the system selected. Other commitments would include acquisition of workstations and sometimes even specialized computer systems. Also, it is quite inconvenient to link the system to analytical programs that are not sold by the vendor as add-ins or add-ons.

Implications

The VETD management system has an advantage over a commercially available GIS for the following reasons:

1. The front-end program is relatively simple and, except for the OpenGL graphics library, was written as a stand-alone package; the OpenGL graphics library is found in almost all operating systems for the personal computer;
2. The program can be run on any personal computer system;
3. The VETD management system can easily be linked with any off-the-shelf computer program;
4. The VETD management system can easily be adapted to read any popular database structure; and
5. The VETD management system can be kept simple by including only features that are necessary to support its purposes.

FEATURES OF VETD MANAGEMENT SYSTEM

At the heart of the VETD management system is a one-stop workstation where the user can search and retrieve available data, compare and visualize data sets, and also view in virtual reality the field location with which the data are associated.

The hardware required for the VETD management system is a personal computer with two video monitors driven by two video cards (Figure 1).

The software consists of the front-end user-friendly interface called the VETD management system. Figure 2 describes the three components in the VETD package. It consists of a mapping screen in which database files are linked to map locations, a database selection screen from which database files can be selected and retrieved, and a visualization package. Main complementary software would be an inexpensive, stand-alone, off-the-shelf topographical package or, as an alternative, the USGS cartographical data system. The cartographical package completes the virtual-reality component of the VETD management system.

The VETD management system retrieves database files that, at present, are compatible with the Microsoft Access (Microsoft Corporation) database file format. The VETD system is being written to read the ORACLE (Oracle Corporation) database file format, which is a common format for many highway agencies. Because the VETD system is reading only database files, database applications are not required (although the application would be necessary to develop these database files).

The VETD system was also written to facilitate interfacing with other software packages. Some of these packages are shown in Figure 2. A layer modulus backcalculation package such as NDRATER98 (which is being used by the New Mexico State Highway and Transportation Department) would be useful. NDRATER98 (2) was also rewritten to determine the depth to the stiff layer, which is an important consideration for layer modulus backcalculation by use of pavement surface deflections. Other software packages that can be considered include a statistical package (for example, to identify outliers, variances, or goodness-of-fit), a pavement management package (for example, to perform life-cycle cost analysis), a pattern recognition package (for example, to do data delineation or to recognize relationships through data-mining algorithms), and others.

The following sections will demonstrate features of the VETD management system.

DEMONSTRATION OF VETD SYSTEM WITH THE US-54 PROJECT

The FWD was used on US-54 from Mileposts 130 to 200. More than 1,500 datum points were collected. Coring was done at more than 60 locations to determine the layer thicknesses. Layer moduli were backcalculated by using NDRATER98 (2).

Selecting a Project from a Map

For this particular demonstration, the New Mexico map was loaded (Figure 3). In a fully developed map, Interstate highways, primary roads, secondary roads, low-volume roads, and city or municipality roads would be shown. For the purpose of demonstration, the user locates the US-54 database by passing the cursor over the highway location, and because at least one database is available, the road is highlighted.

The user can see what data are available by clicking on the desired database file. Figure 4 shows a drop-down menu of what is available. At this stage the VETD system reads only the header in the database file, not the entire database file.

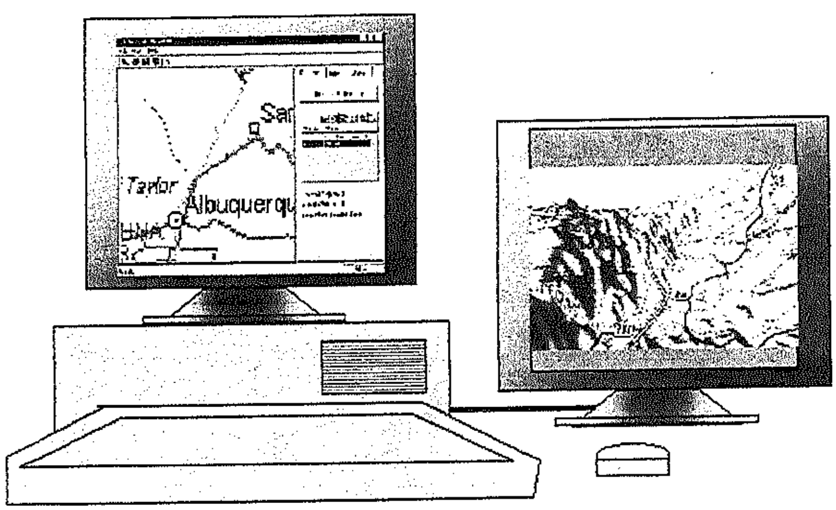


FIGURE 1 Workstation for VETD management system.

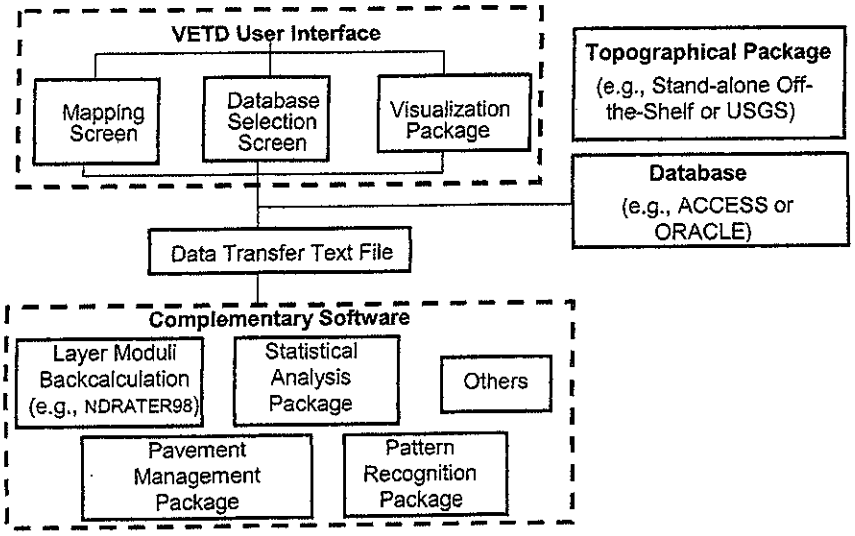


FIGURE 2 Overview of VETD management system.

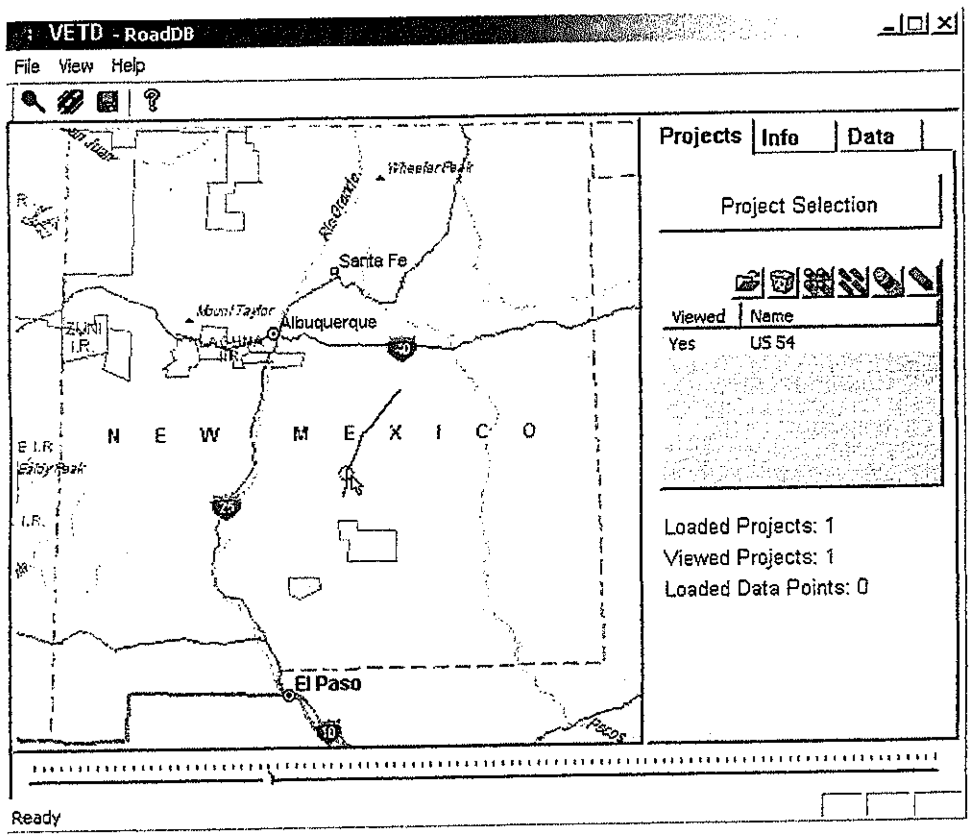


FIGURE 3 Opening window of VETD management system.

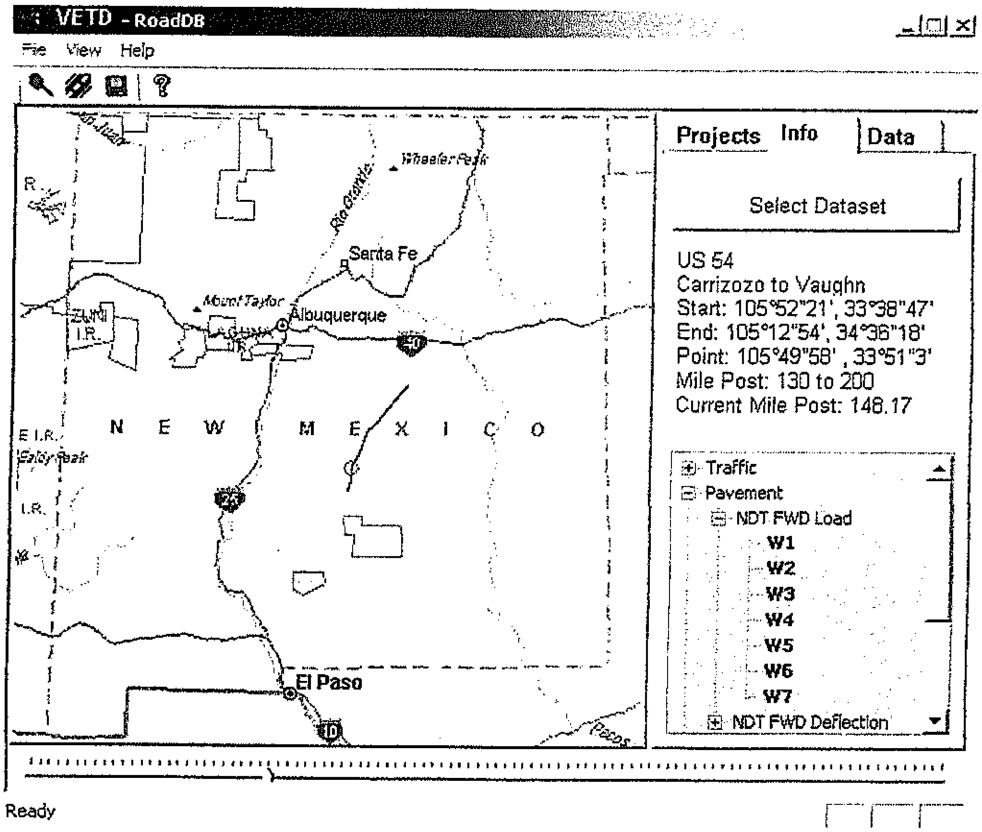


FIGURE 4 Selecting data to display.

oominq In

ıe area of interest on the map can be enlarged by clicking on the agnifying glass found in the tool bar and then boxing the area to : magnified.

ɜlecting Center of Data Set to Retrieve

ıe red circle on the highway corresponds to the scroll bar at the ttom. By moving the scroll bar, the user can select the specific rtion of the highway for which to retrieve data.

ɜtabase

e VETD system will read a flat database file. At present, the pro-ype VETD management system was developed to discriminately rieve desired chunks of data from selected arrays from a Microsoft cess database file format. Only this will be loaded onto random-:ess memory, and no database application is required. The size of database to read from is not a limitation of the VETD system :ause there is no need to open the entire file.

ɔtting Data Sets on Screen

'D deflections W1 through W7 are selected in this case (Figure 4). ɜning the data folder would show the screen shown in Figure 5.

The advantage of showing the plots on the same screen is that it allows the user both to compare data of the same type and to determine if there are correlations between data of different types.

Comparing Data Sets

The small plots shown on the screen shows 206 datum points. The user can view data for the entire highway by moving the horizontal scroll bar at the bottom of the screen from the left to the right. This will also move the red circle on the map. The number of datum points around the red line (which correspond to the location marked by the red circle on the map) can be adjusted with the horizontal scroll bar on the right of the screen. The user may bring in complete data arrays if so desired, but that would clutter the plots. Checking off the boxes shown on the right can disable individual small plots. The vertical scale is adjusted with the vertical scroll bars next to each of the plots. The maximum vertical scale is also reported for each plot.

Plotting a Single Chart

The user may also merge all the plots into one graph by clicking on the "Toggle Detailed Graph" button (Figure 6). The user may also deselect individual curves using the boxes on the right of the screen. This is a relatively simple way of comparing data taken at the same reference location or at the same reference time. A similar plot can be called from the visualization package, which will be discussed in the next section.

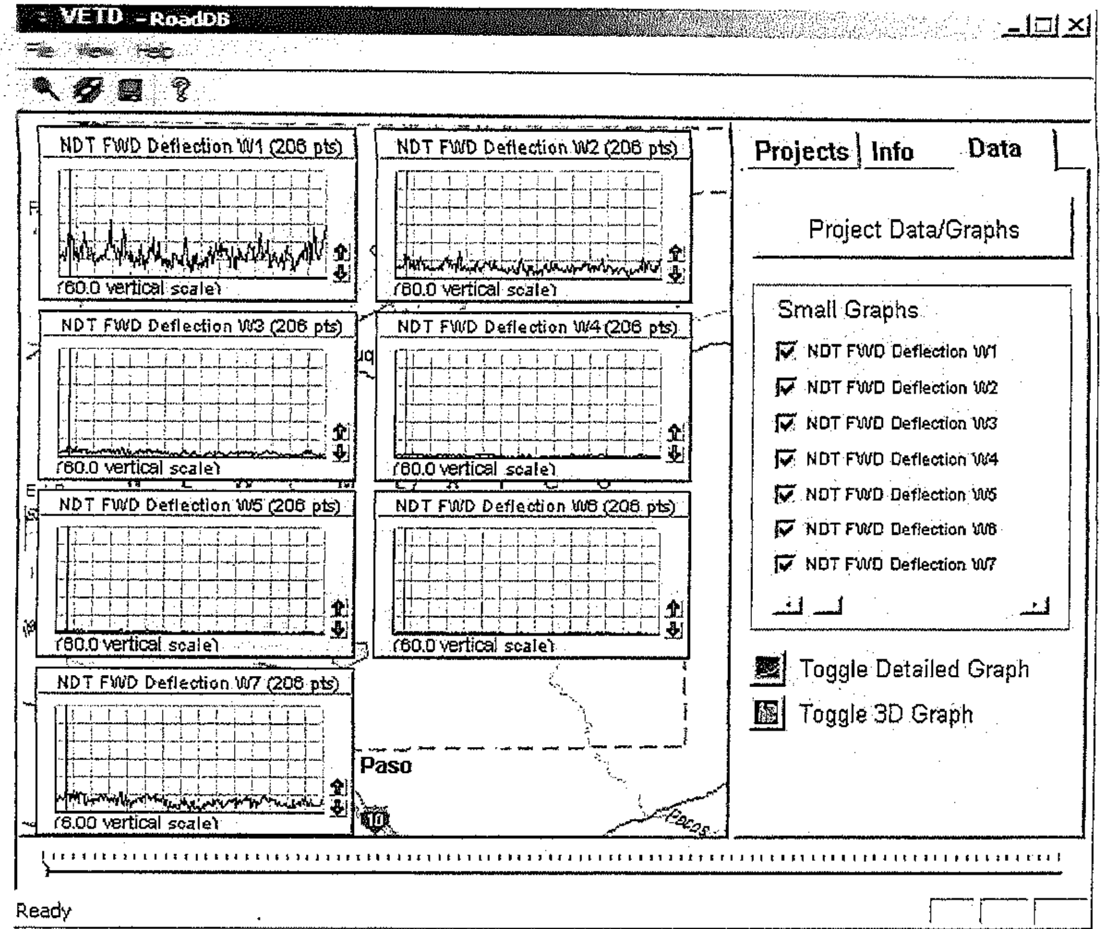


FIGURE 5 Comparing data sets.

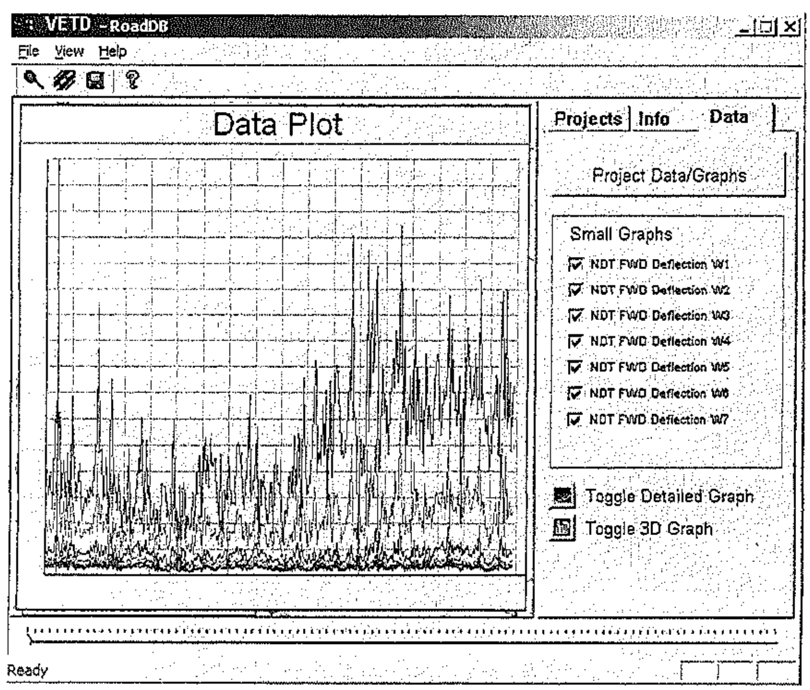


FIGURE 6 Combined data plot.

Visualization Package

The visualization package was developed separately and was then incorporated into the VETD management system. The types of plots that can be made include

- An *x-y* plot (similar to that shown in Figure 6);
- Colored charts in two dimensions;
- Colored charts in three dimensions (Figure 7): the charts can be rotated by using the four buttons at the bottom right of the screen, and the data can be scrolled even as the chart is being rotated; clicking on the mouse a second time will halt the rotation;
- Radar plot in two dimension, in which the data are plotted on the radial coordinate system; and
- Radar plot in three dimensions (Figure 8): the radar chart consists of 360 radial arms with the radial distance representing a data value; the 360 radial arms approximately correspond to the 365-day year and hence are very useful for displaying, for example, year-round traffic data; the 360 radial arms corresponding to 360 degrees may also be used to represent traffic data over a 24-h period; Figure 8 shows traffic on the two directions of a highway on a weekend.

Zooming

The user can zoom in and out of a plot by first clicking on the magnifying glass icon on the top left side of the tool bar. The picture can then be enlarged or reduced by using the left click or the right click of the mouse, respectively.

Complementary Topographical Package

Having studied project data from the user interface, the user may now want to access the topographical package to better assess the project area. Because one of the purposes of the VETD management system is to provide the user with comprehensive information in a single workstation, the topographical package can be run on a second video monitor. In this way the user can continue to refer to the data plots and at the same time enter the virtual-reality representation of a specific location on the project site.

The topographical package used in the demonstration is an inexpensive stand-alone package. An alternative would be to use digital cartographic data from USGS. The two digital cartographic products available from USGS contain vector (digital line graphs) and terrain elevation (digital elevation models) data in the spatial data transfer standard (SDTS) format. The SDTS format is a relatively new format that is being required for federal use. Numerous software packages, some commercial and some in the public domain, can be used to display the topographical information.

Figure 9 shows a map of the project site. The stretch of US-54 considered in the project length is from Carrizozo to Vaughn.

Figure 10 shows how VETD can be used to display up to seven plots of deflections (Deflections W1 and W7, which are the deflections from the geophone below the loading plate and from the farthest geophone, respectively), layer thicknesses (H1 and H2, which refer to the asphalt concrete and the base course, respectively), and the back-calculated layer moduli [E1, E2, and E3, which refer to the moduli of the asphalt concrete, base course, and subgrade, respectively, in 6894 kPa (1,000 lbf/in.^{2})]. The vertical scale for each of the plots can be adjusted by using the vertical arrows to the right of each plot.

The user can use the topographical software to zoom in to the test site to study the terrain and other features (Figure 11). The user can also ask for a three-dimensional plot of the test site, which is shown in Figure 12. The user can look at the contours as well as the drainage around the test site, and this information may be useful for explaining, for example, a low subgrade modulus.

Profiling

Another useful feature of a topographical package is the ability to see contours or profiles of the project road. Figure 13 illustrates this with a stretch of US-54 starting from Carrizozo to Vaughn. The red circle would indicate the location on the highway corresponding to the location on a map similar to that shown in Figure 9.

FUTURE DIRECTIONS

The demonstration of the VETD management system suggests how transportation and pavement data could be kept and used in the near future. In its fully developed form, the system will enable the user to be virtually on site, investigating the terrain, looking at the surrounding geography and geology, and seeing well beyond what the line of sight can offer. The system can also be developed to integrate different databases, thus enabling the user to first determine what data are available and to then access those data. The user can also easily access historical information on the site, for example, maintenance history, traffic loading, and pavement configurations. Projected data can also be accessed from the database and viewed when available. The engineer may also select the information of interest and visualize the information in relation to other suspect parameters. Off-the-shelf, stand-alone computer programs can also be easily linked to the front-end package, thus making the VETD system a one-stop workstation. The ease of use of this VETD management procedure will encourage engineers to take a broader view of the physical attributes of a candidate before making a costly decision.

Potential Enhancements

Below are some considerations on how the prototype system may be improved as it evolves into an operational system.

Mapping Database

The map shown on the user-interface window can be written to show multiple layers of data. For example, the Interstate, primary highway, and secondary highway networks will each be stored as a different overlay on the state map. Other information, such as 10- or 20-year equivalent single-axle load information can also be stored as a different overlay.

Database

The compatibility between Microsoft Access and ORACLE database should be maintained. In other words, the VETD management system can be written to also accept data from ORACLE's database.

Visualization Package

The visualization package can be expanded to include other plots such as contours and three-dimensional meshes.

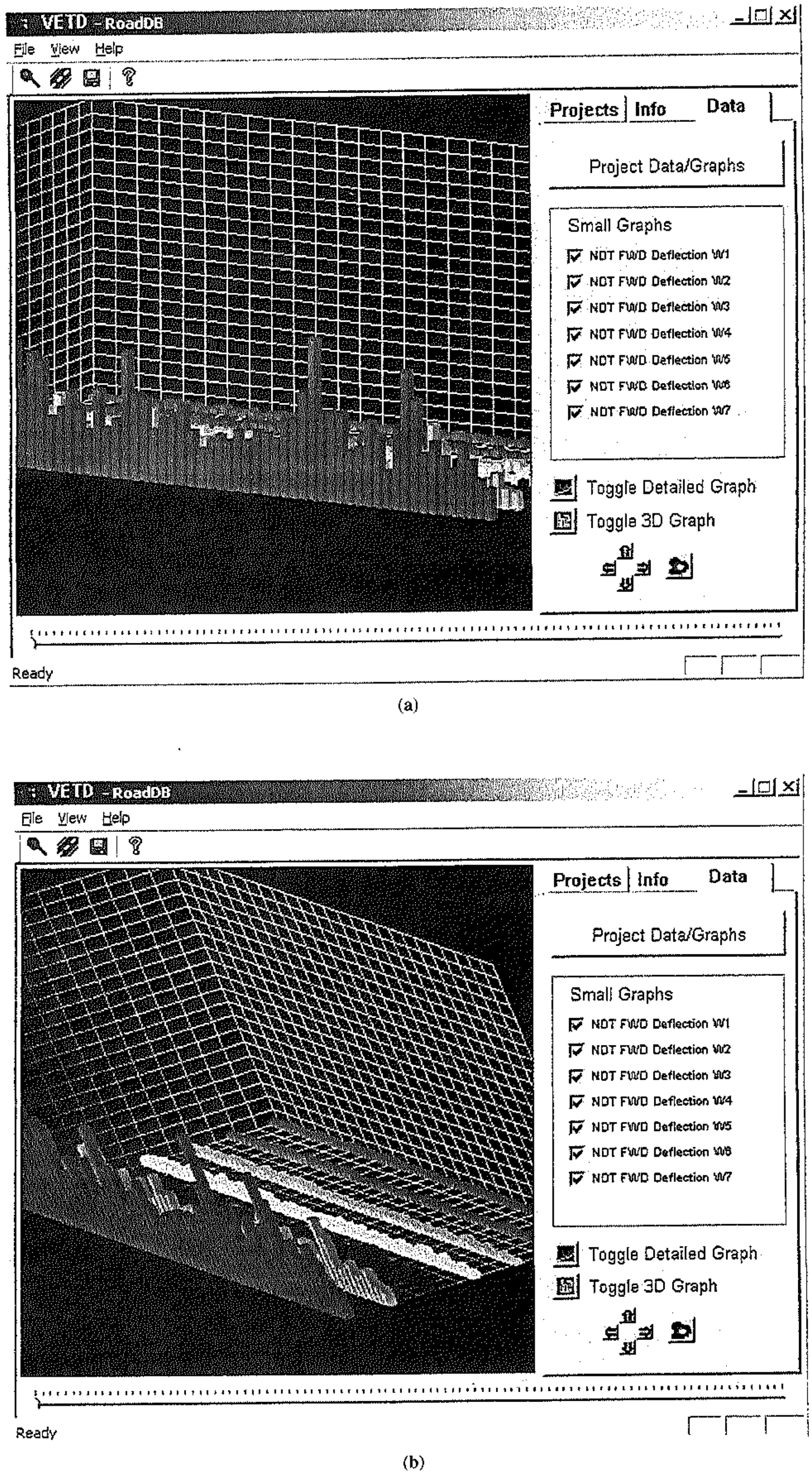


FIGURE 7 Three-dimensional charts.

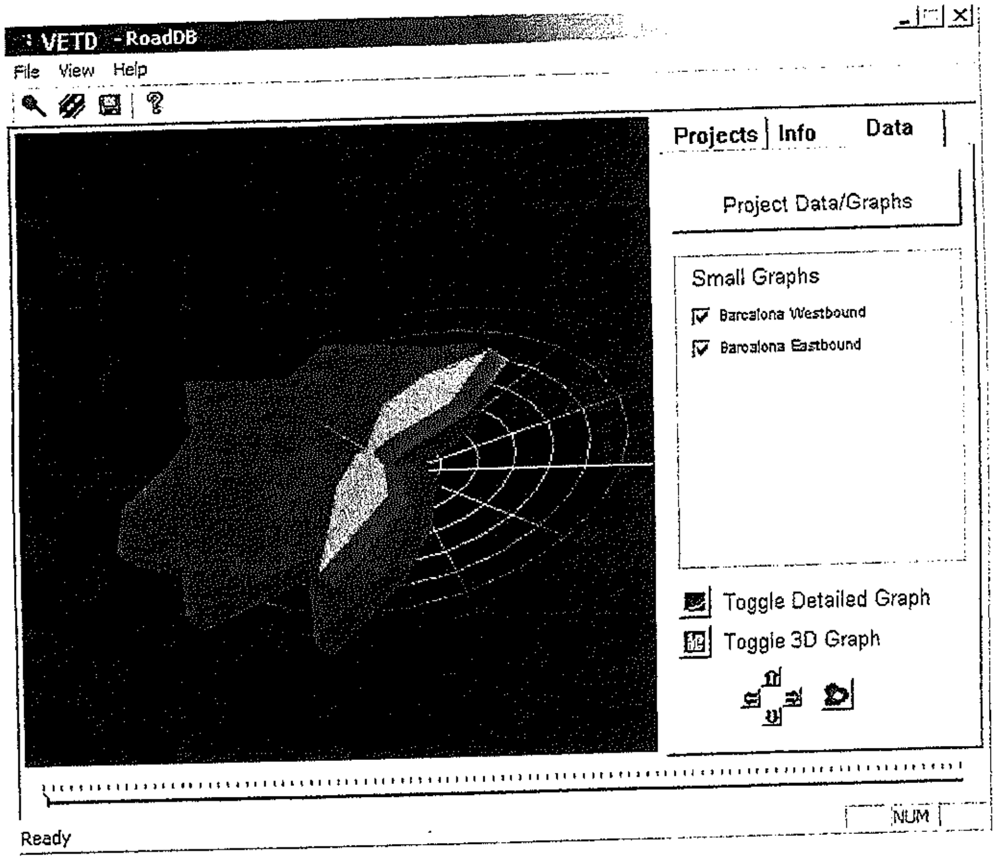


FIGURE 8 Three-dimensional radar plot.

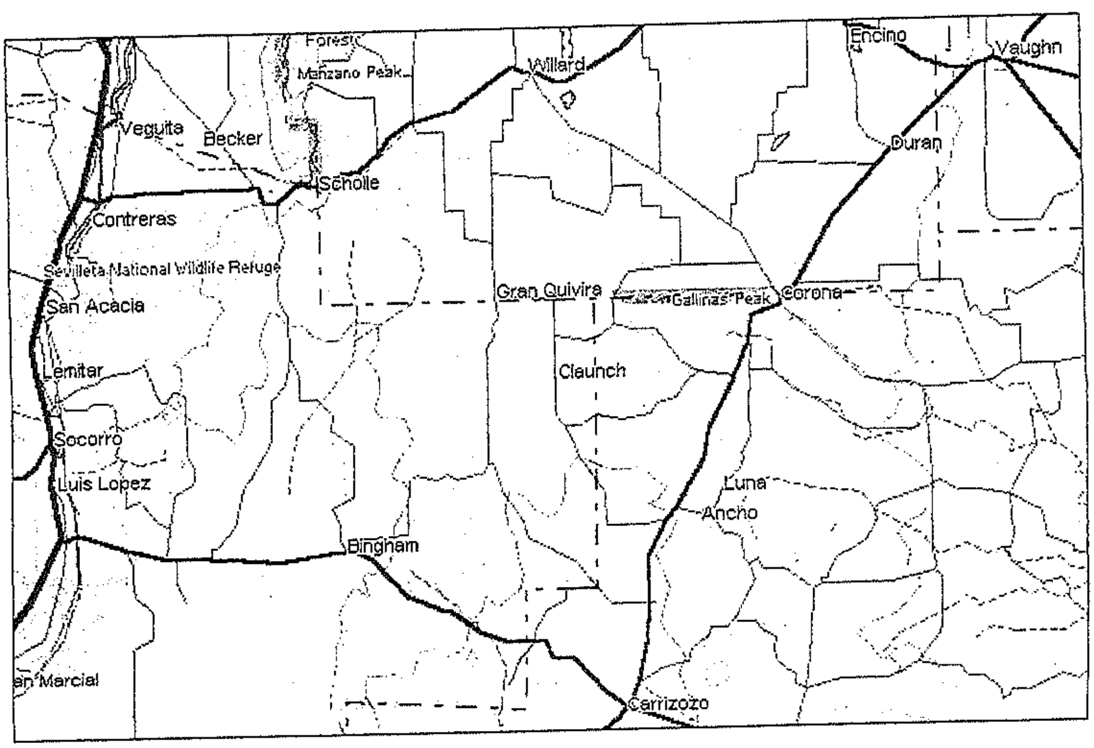
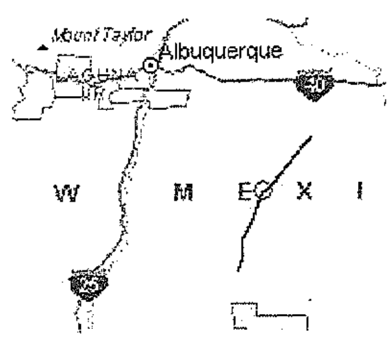
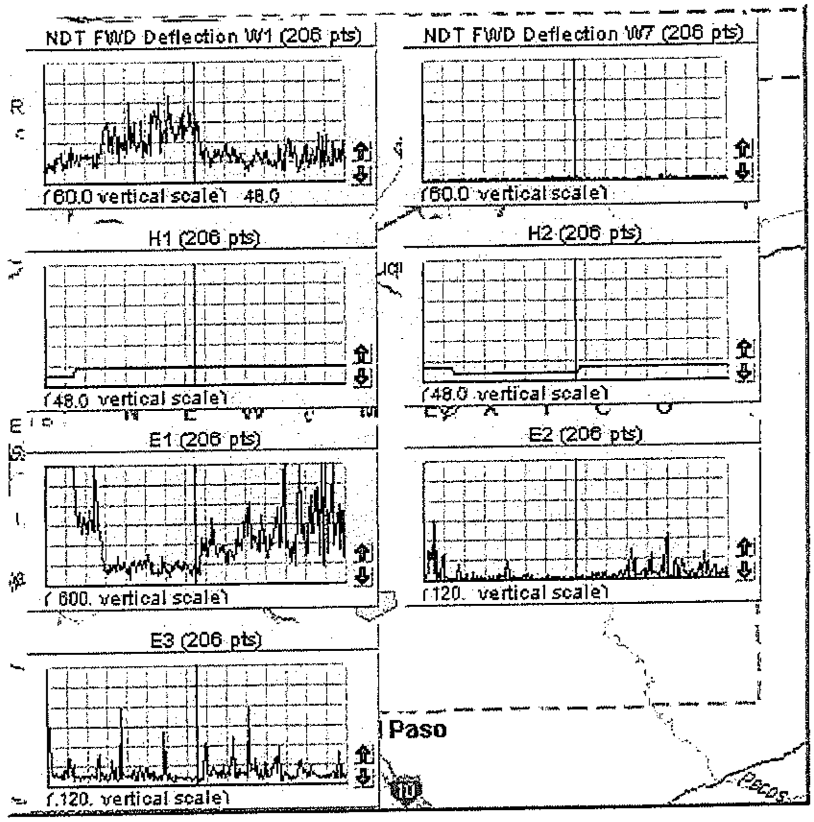


FIGURE 9 Map of project site (US-54 from Carrizozo to Vaughn).



(a)



(b)

FIGURE 10 VETD (*a*) data location and (*b*) NDT information.

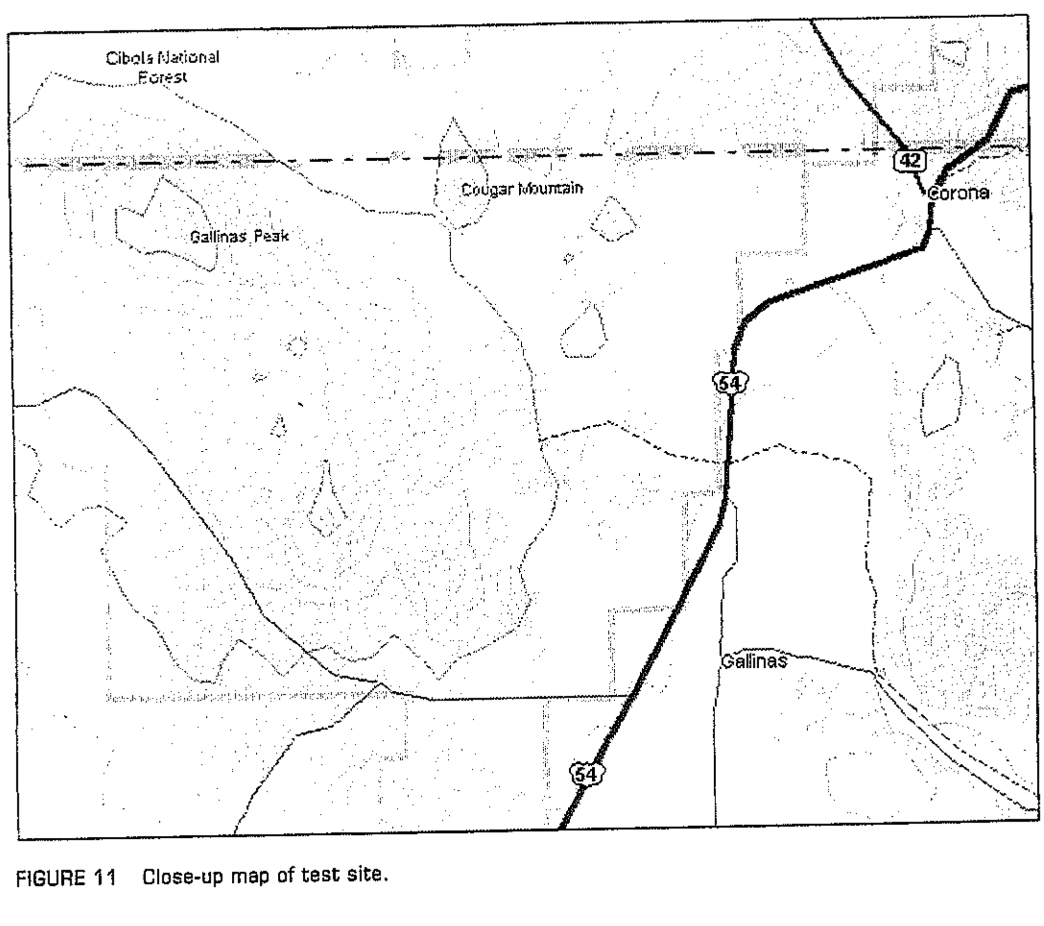


FIGURE 11 Close-up map of test site.

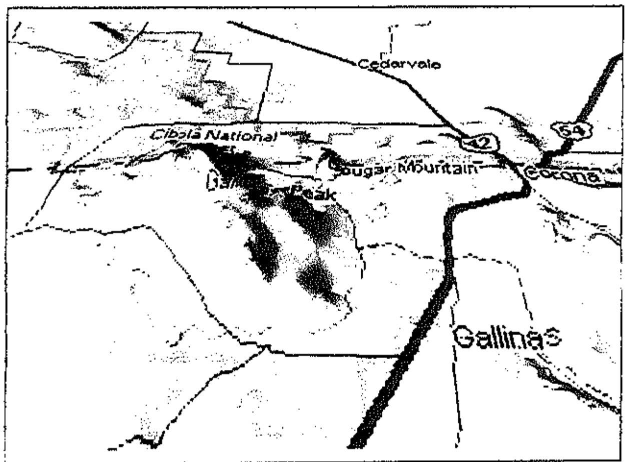


FIGURE 12 Three-dimensional view of test site.

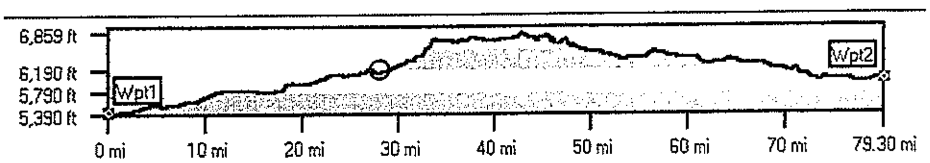


FIGURE 13 Contour profile of US-54 from Carrizozo to Vaughn (1 ft = 0.3 m; 1 mi = 1.6 km).

Implementation

At present, the VETD management system is being used in two projects sponsored by the Materials Bureau of the New Mexico State Highway and Transportation Department. The VETD system is being used to track FWD data, coring data, and laboratory test data for highway materials retrieved from three project sites. It is anticipated that the VETD management system will be used to manage comprehensive data that the state of New Mexico would be collecting in preparation for the implementation of the pavement design procedure in the AASHTO 2002 Design Guide.

ACKNOWLEDGMENTS

Work on this project was funded by FHWA, U.S. Department of Transportation, through a contract with the University of New Mexico under the Priority Technologies Program. Joseph Maestas and Steven von Stein of the New Mexico Division Office, FHWA, provided oversight for the work. Their assistance and guidance were very helpful. John H. Tenison, Jr., of the Materials Laboratory Bureau, New Mexico State Highway and Transportation Department, assisted by providing data for use in this demonstration.

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Publication of this paper sponsored by Committee on Pavement Monitoring, Evaluation, and Data Storage.