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Virginia Transportation Research Council

research report

Geotechnical Data Management at the Virginia Department of Transportation

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16. Abstract:

This report describes the development and implementation of the geotechnical data management system at the Virginia Department of Transportation (VDOT). The purpose of this project was to develop a practical, comprehensive, enterprise-wide system for entry, storage, and retrieval of subsurface data. The resulting product satisfies the work flow requirements of VDOT and streamlines the delivery of geotechnical information.

Main components consist of gINT software for geotechnical data processing and the ESRI Arc Internet Map Server (ArcIMS) for distributed GIS data delivery via a web browser. These programs are currently widely adopted by the geotechnical and GIS user community. Custom command scripts and configuration files were developed in the form of an extensible applet framework called GDBMS (Geotechnical Database Management System) to manage and process geotechnical data. The project was built on the extensive interaction among VDOT geologists, engineers, and information technology personnel. Their expertise was harnessed to create a system that is user-friendly, rugged, relatively easy to maintain, and capable of delivering the required data in a consistent format across operating divisions. GDBMS is flexible enough to be employed by both VDOT designers and VDOT consultants (free access is provided to these groups). Its greatest advantage is that it greatly improves the efficiency of geotechnical data management and delivery on large transportation projects, typically those initiated under Virginia's Public-Private Transportation Act of 1995. A free customized set of support files can be downloaded from the website of VDOT's Materials Division for use on all VDOT projects.

The study recommends that GDBMS and the associated methodology be mandated for use on all VDOT geotechnical projects. Significant cost savings can be realized on large new projects planned in the vicinity of the existing infrastructure, where the proximate subsurface data are already available. Additional exploration is often very expensive, with many over-water drilling projects costing more than $10,000 per day to carry out. GDBMS can provide a more comprehensive picture of local conditions and thus reduce the expense of drilling additional boreholes.

This technology can be applied to all transportation projects involving subsurface exploration, including bridges, retaining walls, and sound walls. It is estimated that on the average, the use of this technology would cut in half the time required to gather and process borehole data, resulting in approximately 16 person-hours of savings at an average rate of $100 per hour (including overhead). For the past 15 years, VDOT has been approving an average of 102 bridges per year for construction. Therefore, the potential cost savings are on the order of $160,000 per year, excluding the consideration of retaining walls, sound walls, and megaprojects.

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ABSTRACT

This report describes the development and implementation of the geotechnical data management system at the Virginia Department of Transportation (VDOT). The purpose of this project was to develop a practical, comprehensive, enterprise-wide system for entry, storage, and retrieval of subsurface data. The resulting product satisfies the work flow requirements of VDOT and streamlines the delivery of geotechnical information.

Main components consist of gINT software for geotechnical data processing and the ESRI Arc Internet Map Server (ArcIMS) for distributed GIS data delivery via a web browser. These programs are currently widely adopted by the geotechnical and GIS user community. Custom command scripts and configuration files were developed in the form of an extensible applet framework called GDBMS (Geotechnical Database Management System) to manage and process geotechnical data. The project was built on the extensive interaction among VDOT geologists, engineers, and information technology personnel. Their expertise was harnessed to create a system that is user-friendly, rugged, relatively easy to maintain, and capable of delivering the required data in a consistent format across operating divisions. GDBMS is flexible enough to be employed by both VDOT designers and VDOT consultants (free access is provided to these groups). Its greatest advantage is that it greatly improves the efficiency of geotechnical data management and delivery on large transportation projects, typically those initiated under Virginia's Public-Private Transportation Act of 1995. A free customized set of support files can be downloaded from the website of VDOT's Materials Division for use on all VDOT projects.

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INTRODUCTION

Transportation projects routinely require subsurface exploration to acquire data needed for foundation design. Typically, the process involves drilling boreholes and collecting soil samples at predetermined locations. The information compiled from the drilling program is used to create the most likely spatial distribution of subsurface soil and rock properties based on the limited number of point samples. This information is subsequently provided to designers.

As the drilling program progresses, large volumes of records are collected. There is a critical need to process these records as efficiently as possible since no foundation design can be undertaken without a geotechnical report first being obtained. Thus it is important to process the information quickly and in the format consistent with the expectations of designers.

In the past, geotechnical data processing consisted of generating paper copies of borehole logs and cone penetrometer soundings, presenting subsurface conditions in a cross-sectional form. These logs were based on field notes and some laboratory testing. With the advent of modern computers, the process became more automated, but until recently there were very few practical tools to manage geotechnical data effectively on a large scale.

Every large organization faces challenges with enterprise-wide data management. There are the usual issues of quality, accuracy, consistency, and access. For geotechnical reports there are also strict requirements concerning the output format. Typically, there are two issues to resolve. One is to make processed subsurface data quickly available for the current design. The other is to have the relevant existing borehole logs, sometimes created many years previously and often in different formats, readily accessible for planning a subsurface exploration program for a new project. For a department of transportation, the volume of assorted records can be overwhelming.

PURPOSE AND SCOPE

The purpose of this project was to develop and implement a production environment geotechnical database management system for the Virginia Department of Transportation (VDOT). Ultimately, it required successful integration of a multitude of existing tools and procedures. Key building blocks of this project had been investigated previously.[1,2] The main focus of the current study was incorporating the user feedback, improving the reliability of existing systems, and ensuring the seamless integration of various components.

The researchers recognized that the effort expended in creating a large centralized database of geotechnical information would pay off on future transportation projects that would benefit from accessing and using previously stored data. As a consequence, in this project, emphasis was placed on the ease of data entry and retrieval and, most of all, the usability of information by automating the necessary data translation among heterogeneous data formats.

The researchers decided to create an easily scalable and extensible database that would accept a comprehensive list of routinely prepared geotechnical outputs, including borehole logs, laboratory reports, and project photographs. In addition to serving static data, the system was designed to generate subsurface cross sections (fence diagrams) on demand based on the user defined input.

METHODOLOGY

Five tasks were conducted to achieve the study objectives:

1. Develop the schema of the geotechnical database system.
2. Develop the format of various database output reports.
3. Develop the output conversion to MicroStation and Geopak.
4. Develop the integration with Google Earth.
5. Develop the integration with the ESRI Arc Internet Map Server (ArcIMS).

Development of Database Schema

VDOT selected gINT software as the mainstay for geotechnical data processing. The program has been used by consultants, contractors, and government agencies for more than 20 years. Widespread acceptance of gINT stems from its design flexibility. It offers a framework upon which the database and output reports are structured by a user. It allows data to be entered once and then processed and presented in many formats.

The first step in customizing gINT to VDOT business needs involved deciding on the types of data that must be collected for a given project. Staff of VDOT's Materials Division and Structure & Bridge Division jointly arrived at elements that would form a core of every data entry set. The underlying philosophy was to minimize the amount of required inputs yet define a common denominator in the data category so that the resulting interoperable data format could be used by multiple VDOT units without creating additional subsets. Subsequently, data entry templates were developed for data collection pertaining to standard penetration test (SPT) boreholes and cone penetrometer test (CPT) soundings. Relevant standards of ASTM International, such as D2487 (Standard Practice for Classification of Soils for Engineering Purposes) and D2488 (Standard Practice for Description and Identification of Soils), were followed. In addition, descriptions of Virginia rock types were incorporated in data entry templates.

The researchers decided to use gINT for processing only the core geotechnical data, essentially adopting the basic file structure that has been used by gINT through all upgrades. Additional project information, such as laboratory reports, site photographs, and background maps, would be handled by a geographic information system (GIS) database installed on ArcIMS. The primary reason for this decision was that, inherently, gINT is not a GIS tool (with the possible exception of the recently released gINT Enterprise platform) and a robust GIS program is needed as a primary delivery mechanism to the user.

Development of Format of Output Reports

The primary client for geotechnical data at VDOT is the Structure & Bridge Division. VDOT bridge designers were consulted on the type and layout of output reports that needed to be provided by gINT software. The researchers decided to produce single SPT borehole logs, single CPT logs, multiple (composite) SPT logs on a single page, and multiple CPT logs on a single-page output. In addition, so-called "fence diagram" output reports were created to depict subsurface cross sectional views of soil and rock types. Borehole logs were developed with the capability of automatically adjusting the content and the page layout depending on the availability of particular data types ("smart forms").

Development of Output Conversion to MicroStation and Geopak

Project workflow at VDOT necessitates that geotechnical data be accessible to MicroStation and Geopak software. For VDOT's Structure & Bridge Division, the ability to process output in MicroStation is critical because borehole logs become a part of the project drawings. Theoretically, it is possible to generate a gINT output in DXF format that would be readable by MicroStation. In practice, the resulting DGN file lacks various text and line attributes. MicroStation is unable to process font types, line styles, and line weights from a typical gINT DXF file.

To produce a MicroStation output that conformed to VDOT CADD standards[3] and satisfied the requirements of VDOT's Structure & Bridge Division, the researchers decided to create a macro that would convert the DXF file contents into the DGN format. The macro, written in Visual Basic, runs within MicroStation after being activated from a drop-down menu. Initially, it executes a set of instructions that adjust MicroStation system settings to the VDOT environment. The macro discovers the type of output report by reading a unique identification string from a DXF file. Then it uses a predefined map to assign each and every element a font type, line weight, line style, color, text size, and level as per VDOT standards. To accomplish this task, all elements are identified by their respective coordinate regions on a report. All mapping definitions are contained in a separate MS Excel file. The macro executes the conversion based on the spreadsheet criteria and saves the resulting DGN file to a specified folder. A customized version of the MicroStation program containing the macro was created for use on VDOT projects.

The conversion from gINT to Geopak was accomplished by creating correspondence files in gINT. These files translate the relationship between the tables and fields in the source data file and the target (Geopak) database structure. In this case, the conversion is performed on the input data structure, as opposed to the output report for MicroStation.

Development of Integration with Google Earth

The latest version of gINT software allows for integration with the widely used Google Earth web-based mapping program. This feature enables users to display borehole locations superimposed on the air photo background. Google Earth also offers the ability to show element data and overlaid graphic images (proposed road alignments, ground details, etc.). As a result, it is very easy to generate an XML-based Keyhole Markup Language (KML) file within gINT and then distribute it to team members who may not have a direct access to gINT software.

The integration was accomplished by configuring the gINT data structure to interface with Google Earth input and modifying the code in gINT Rules. The resulting KML file displays popup descriptions that include borehole length, surface elevation, and groundwater elevation. In addition, a provision was made to show the PDF file of a borehole log, when available. Customized borehole icons were created and placed on a web server for the consistency of map display.

Development of Integration with ESRI Arc Internet Map Server

Following pilot studies,[1] VDOT selected a GIS-based implementation of the developed Geotechnical Database Management System (GDBMS). This concept was further validated on two megaprojects. One involved the Hampton Roads Third Crossing, and the other the

Woodrow Wilson Memorial Bridge and Route 1 Interchange. Experience from these site-specific projects was used to develop procedures a statewide GDBMS.[4]

At the core of the statewide GDBMS is ArcIMS, a widely used web platform designed for facilitating spatial processing and GIS data display over the Internet. ArcIMS uses the ESRI ArcXML format to receive and respond to requests from the client. The spatial and attribute data behind ArcIMS are typically stored in the Shapefile format.

Geotechnical and spatial map data streams are simultaneously processed by ArcIMS. Geotechnical data are supplied from gINT project files. Spatial map data are accessed from various database sources, including VDOT GIS layers and U.S. Geological Survey (USGS) color digital orthophotographs. These two data streams are georeferenced and enveloped to provide a standard web browser user interface.

The interaction of various components of GDBMS is accomplished through the use of customized scripts in the form of an extensible applet framework, written in PHP and JavaScript languages. The objective was to create a user-friendly interface and minimize the need for IT (information technology) support. Initially, new data entry into GDBMS required some technical assistance from IT personnel. These operations typically involved setting up new project folders, creating the map service, updating shape files, and modifying PHP and JavaScript files. Ultimately, all these tasks were automated and made transparent to a user. After data verification, a gINT project file is entered into the system through a series of web page entries. Typically, it takes only a few minutes to update GDBMS with a new set of borehole data. It is extremely important to verify data prior to upload to ensure and sustain the integrity of the system. GDBMS was developed to handle inherent variations in geotechnical data formats by automating the necessary data translation.

One of the most widely used features of GDBMS is the ability to generate a dynamic fence diagram. Typically, a user zooms into a group of boreholes and selects some that provide a suitable cross section of subsurface information. GDBMS then interacts with gINT to simultaneously produce a PDF file containing the fence diagram and a project data file that includes all selected boreholes. Both files can be downloaded for further manipulation. The process of fence diagram generation is limited to one at a time in order to satisfy the gINT software single user license requirement. It takes approximately 1 minute to generate a fence diagram file via a web interface. There are no limitations on the number of simultaneous borehole log requests since these files are stored on the web server as static images after they are created and do not require any additional gINT interaction.

GDBMS was designed to accept various auxiliary inputs, such as site photographs, rock core photographs, and laboratory reports (i.e., any file related to a particular borehole). The researchers decided to separate these add-on files from the initial gINT data entry. Frequently, these add-ons were available long after the gINT project file was posted on the system. GDBMS became the logical collection point for all auxiliary data. All add-ons are entered into the system through a customized data entry web page and are automatically georeferenced to a particular borehole. They are displayed in a web browser when a user requests borehole information. Thus, all pertinent data can be accessed from one location.

GDBMS created on the ArcIMS platform offers powerful data search capabilities. It is possible to locate a particular borehole with associated add-ons based on the district, project number (full or partial), and GDBMS borehole identification. As the borehole is identified by the search engine, it is displayed on the district map and in a table format for further queries.

There are two identification strings assigned to each borehole. One is created when the project is being drilled. Typically, this string is not unique as it a common practice to start each new project with a borehole labeled “BH-1.” In the statewide GDBMS environment, such designation does not allow for unique borehole identification. As a consequence, a second label is assigned as the primary searchable key attribute in GDBMS when the project is entered into the system by the individual in charge of database maintenance. This string, called GDBMS ID, allows users to locate a particular borehole and retain information about its initial attributes.

RESULTS AND DISCUSSION

System Architecture

Figure 1 shows the main elements of GDBMS. Representative outputs provided by GDBMS are shown in Figures 2 through 6. Data entry and processing of final report are accomplished through gINT software. ArcIMS serves to disseminate GIS data to users via a web browser. VDOT users can view the data at an internal VDOT website[5] entitled “Statewide VDOT Geotechnical Database Management System (GDBMS) Framework.” Currently, the

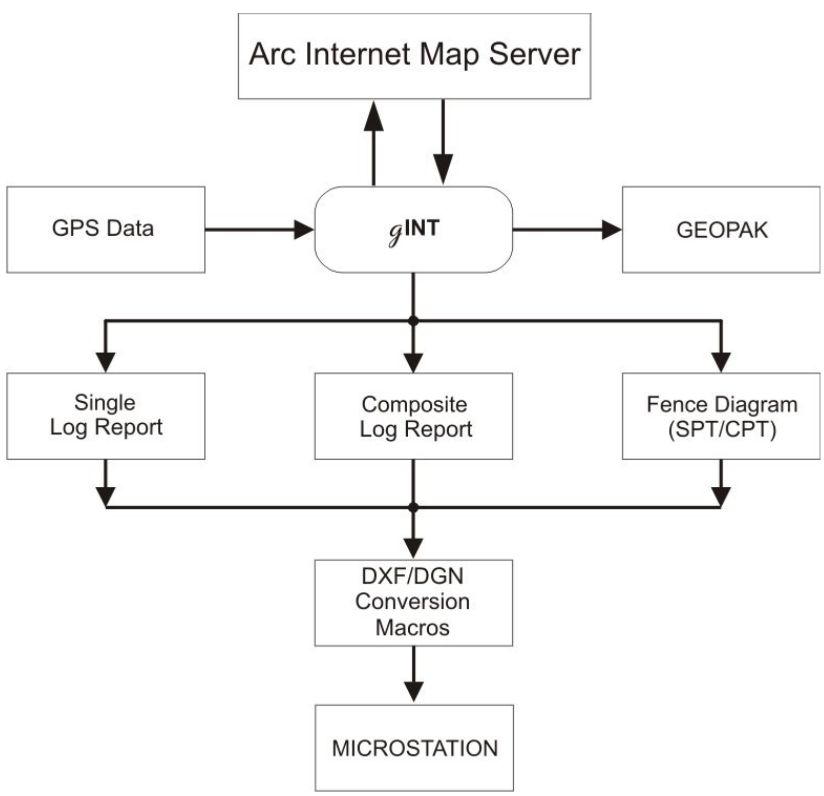


Figure 1. System Architecture

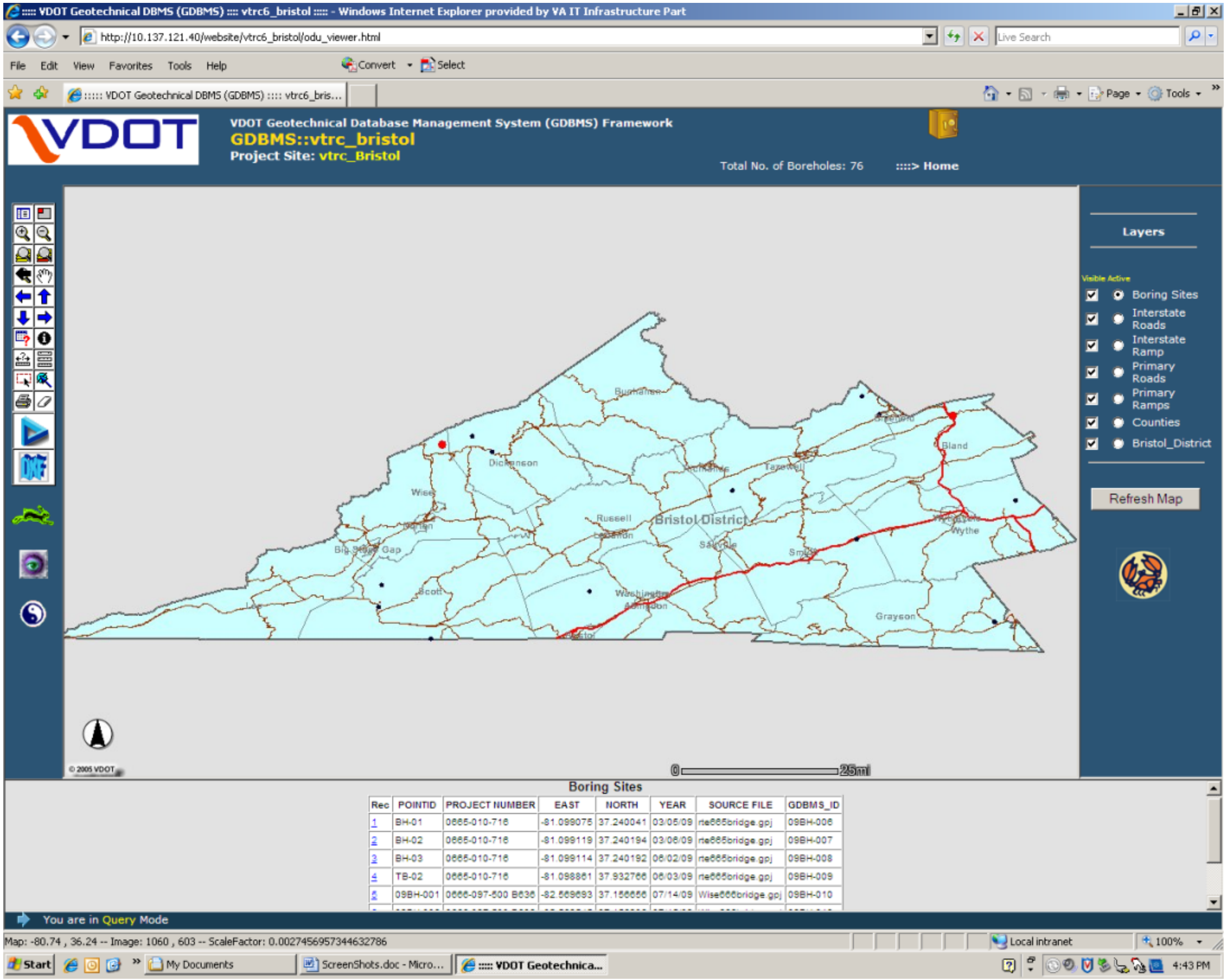
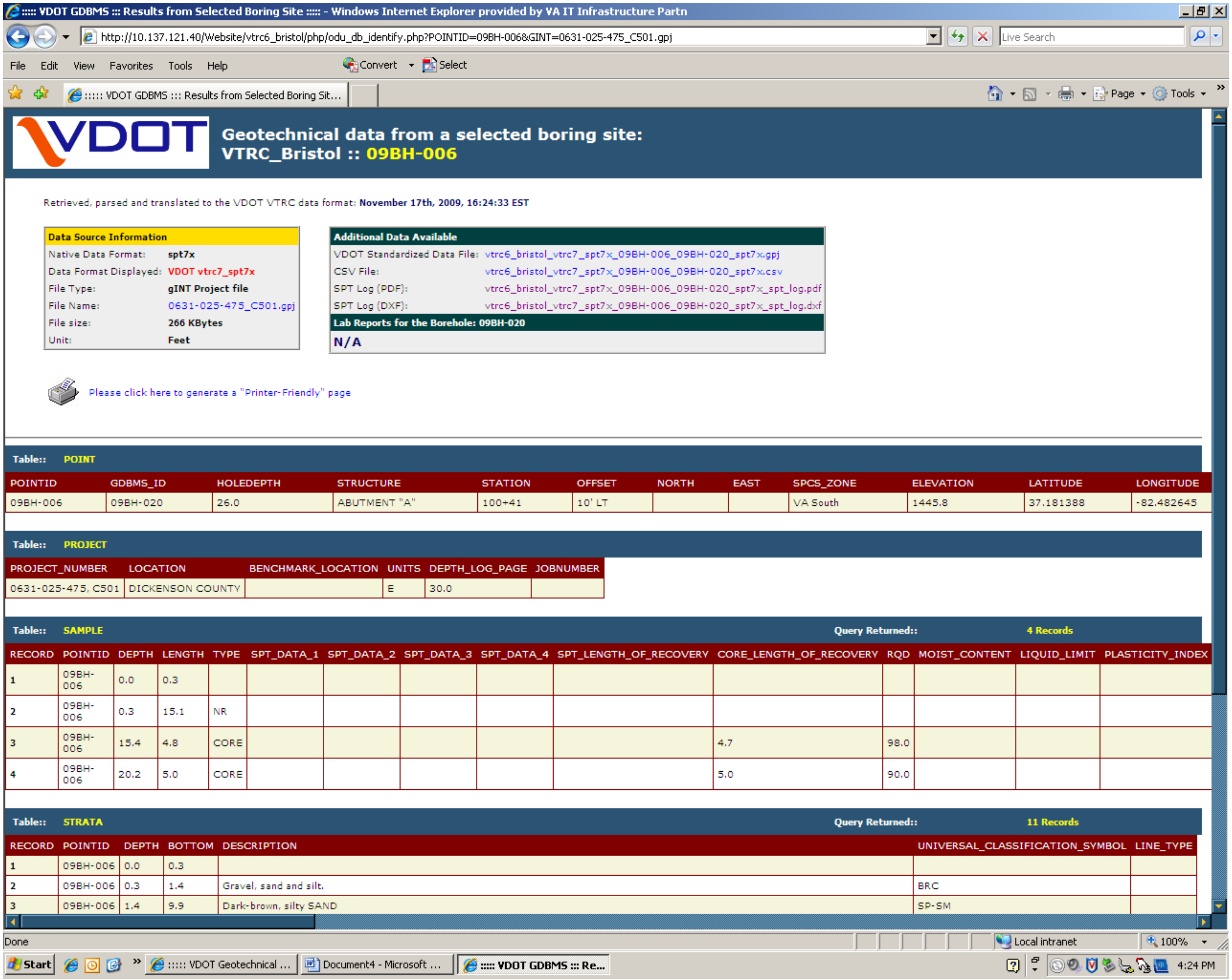


Figure 2. Borehole Search Results (boreholes highlighted on map)


:::: VDOT GDBMS ::: Results from Selected Boring Site :::: - Windows Internet Explorer provided by VA IT Infrastructure Partn

http://10.137.121.40/Website/vtrc6_bristol/php/odu_db_identify.php?POINTID=09BH-006&GINT=0631-025-475_C501.gpj

Geotechnical data from a selected boring site:
VTRC_Bristol :: 09BH-006

Retrieved, parsed and translated to the VDOT VTRC data format: November 17th, 2009, 16:24:33 EST

Data Source Information	
Native Data Format:	spt7x
Data Format Displayed:	VDOT vtrc7_spt7x
File Type:	gINT Project file
File Name:	0631-025-475_C501.gpj
File size:	266 KBytes
Unit:	Feet

Additional Data Available	
VDOT Standardized Data File:	vtrc6_bristol_vtrc7_spt7x_09BH-006_09BH-020_spt7x.gpj
CSV File:	vtrc6_bristol_vtrc7_spt7x_09BH-006_09BH-020_spt7x.csv
SPT Log (PDF):	vtrc6_bristol_vtrc7_spt7x_09BH-006_09BH-020_spt7x_spt_log.pdf
SPT Log (DXF):	vtrc6_bristol_vtrc7_spt7x_09BH-006_09BH-020_spt7x_spt_log.dxf
Lab Reports for the Borehole: 09BH-020	
N/A	

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Table:: POINT

POINTID	GDBMS_ID	HOLEDEPTH	STRUCTURE	STATION	OFFSET	NORTH	EAST	SPCS_ZONE	ELEVATION	LATITUDE	LONGITUDE
09BH-006	09BH-020	26.0	ABUTMENT "A"	100+41	10' LT			VA South	1445.8	37.181388	-82.482645

Table:: PROJECT

PROJECT_NUMBER	LOCATION	BENCHMARK_LOCATION	UNITS	DEPTH_LOG_PAGE	JOBNUMBER
0631-025-475, C501	DICKENSON COUNTY		E	30.0	

Table:: SAMPLE — Query Returned:: 4 Records

RECORD	POINTID	DEPTH	LENGTH	TYPE	SPT_DATA_1	SPT_DATA_2	SPT_DATA_3	SPT_DATA_4	SPT_LENGTH_OF_RECOVERY	CORE_LENGTH_OF_RECOVERY	RQD	MOIST_CONTENT	LIQUID_LIMIT	PLASTICITY_INDEX
1	09BH-006	0.0	0.3											
2	09BH-006	0.3	15.1	NR										
3	09BH-006	15.4	4.8	CORE						4.7	98.0			
4	09BH-006	20.2	5.0	CORE						5.0	90.0			

Table:: STRATA — Query Returned:: 11 Records

RECORD	POINTID	DEPTH	BOTTOM	DESCRIPTION	UNIVERSAL_CLASSIFICATION_SYMBOL	LINE_TYPE
1	09BH-006	0.0	0.3			
2	09BH-006	0.3	1.4	Gravel, sand and silt.	BRC	
3	09BH-006	1.4	9.9	Dark-brown, silty SAND	SP-SM	

Figure 3. Individual Borehole Information

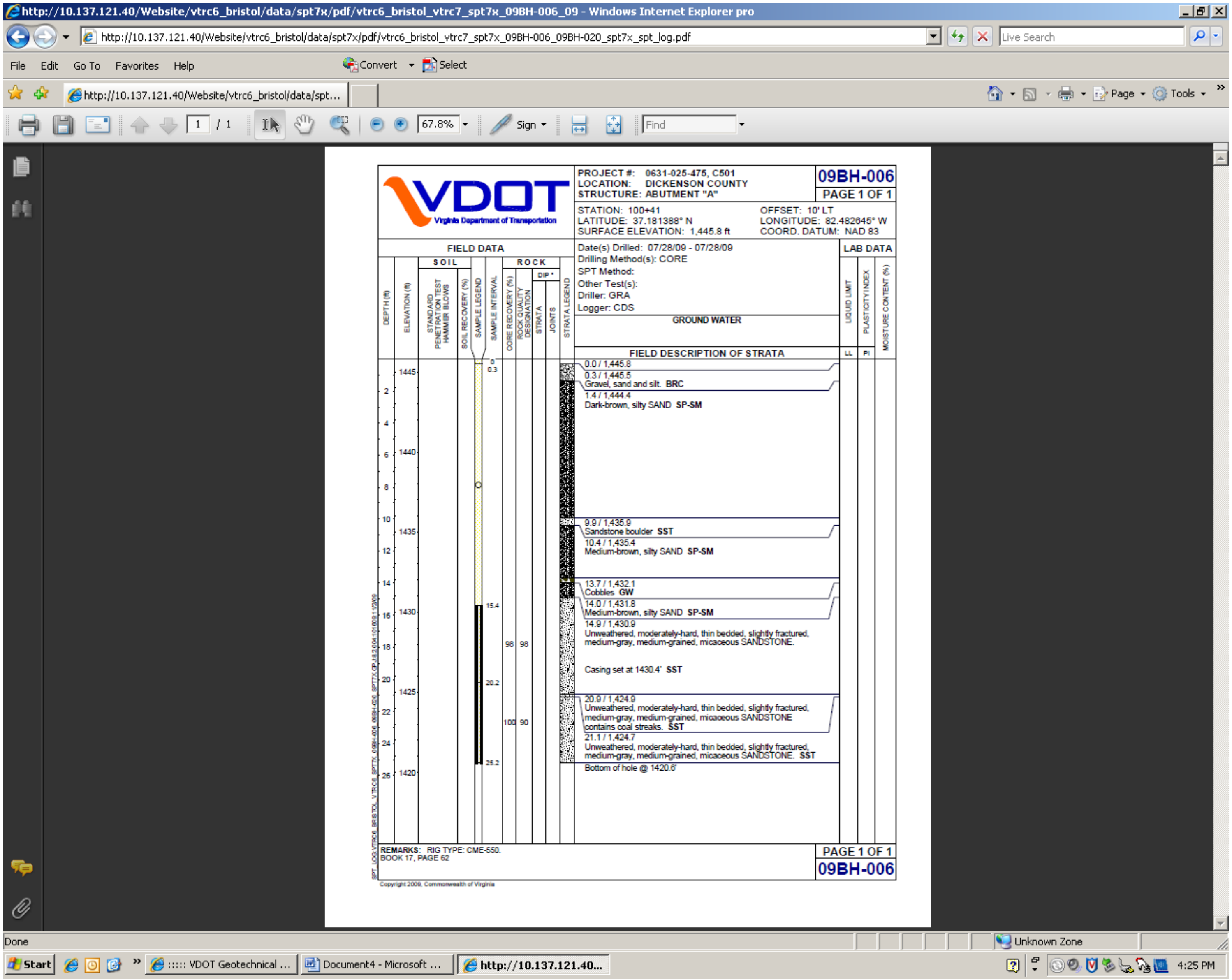

Figure 4. Borehole Log Display

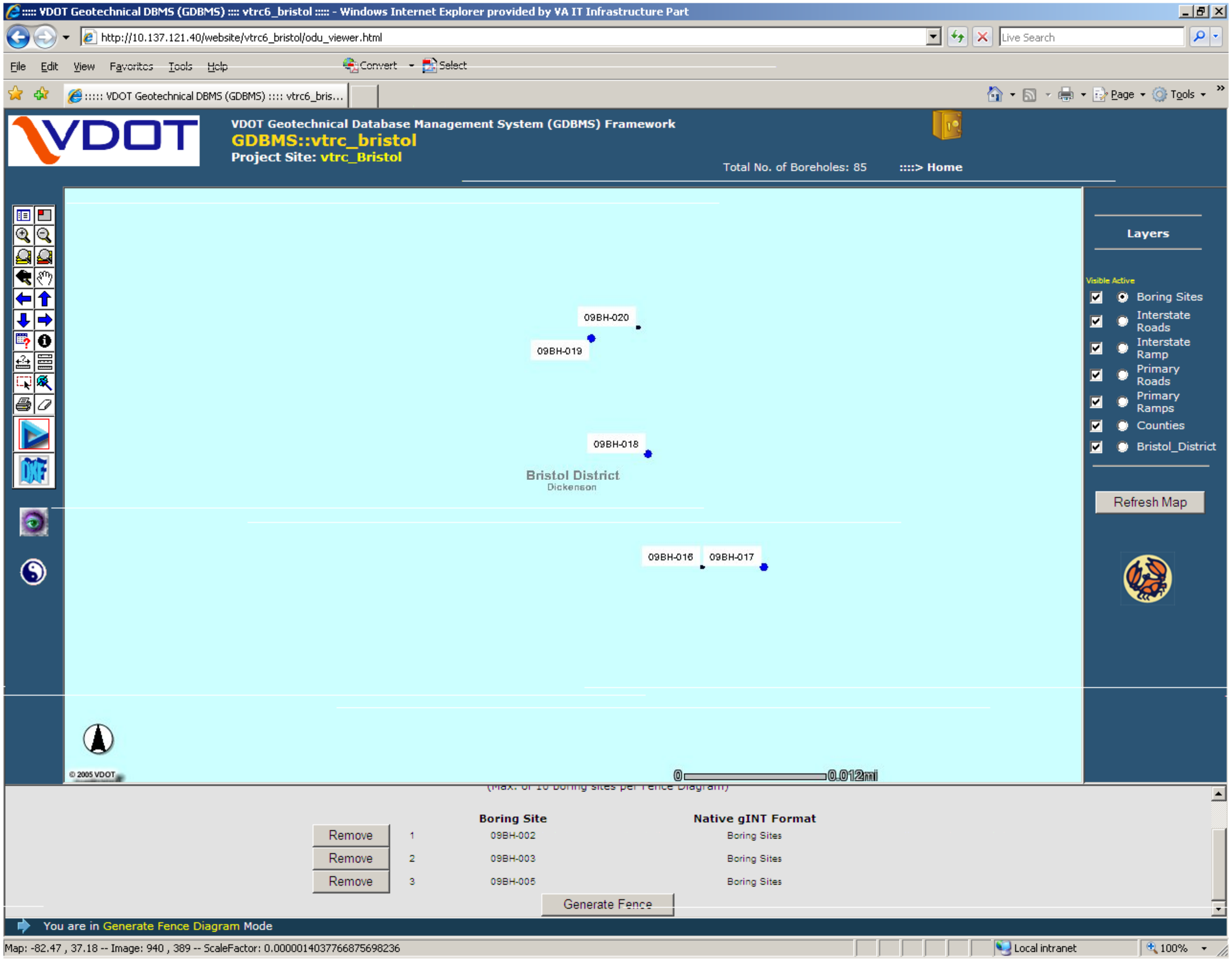

Figure 5. Selecting Boreholes for Fence Diagram

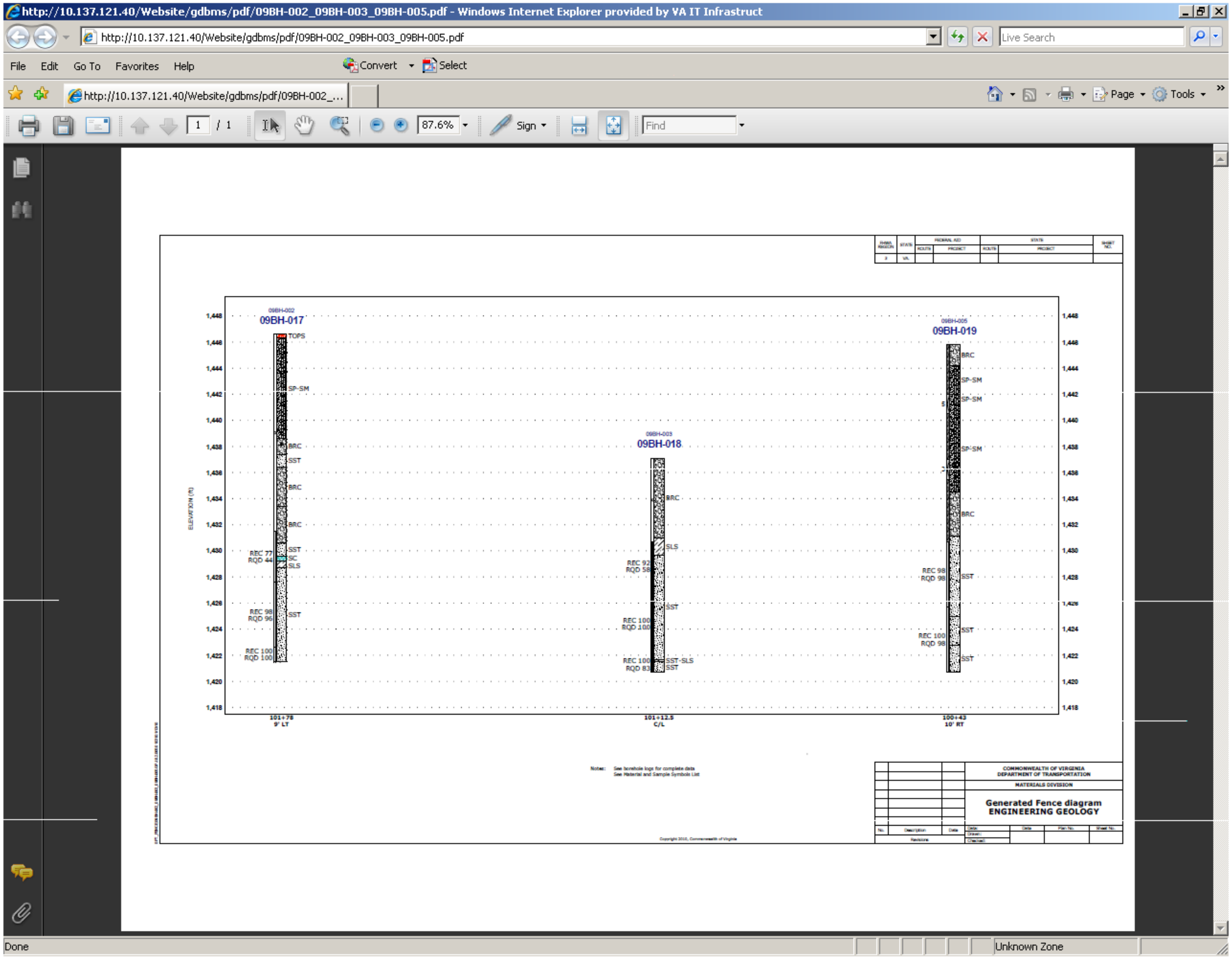

Figure 6. Fence Diagram Display

server operates on the VDOT Intranet and external access by VDOT consultants is allowed over a VPN connection. Proposals have been made to set up an external web server that would mirror all data contained on the intranet server. This would greatly facilitate general access to VDOT geotechnical data by consultants.

The essential characteristic of GDBMS is uniformity. It ensures that the type of data collected and the manner of presentation are the same for every road and bridge project undertaken by VDOT. The resulting process is transparent in terms of the expected output and enforces data consistency. Most important, it lends itself to an automated task of data archiving and retrieval.

All customized software tools required for the geotechnical data entry and processing were bundled into a single executable installation package entitled “GEOXT, GINT, Microstation, and GEOPAK Integrator.” It can be downloaded from the VDOT’s Materials Division website.[6] The package automatically installs various configuration files in the proper folders on the user’s computer. It also provides detailed instructions for data processing.

A customized gINT library file allows users to convert gINT borehole data into the Google Earth environment. This feature allows for a rapid generation and dissemination of KML files that can be subsequently shared by project team members. It also provides an important step in data verification. It is possible to detect at a glance if the borehole coordinates entered in gINT are correct. Figure 7 shows an example of a Google Earth display that includes gINT data with a superimposed project alignment extracted from MicroStation drawings (the alignment placement is approximate, for demonstration purposes only).

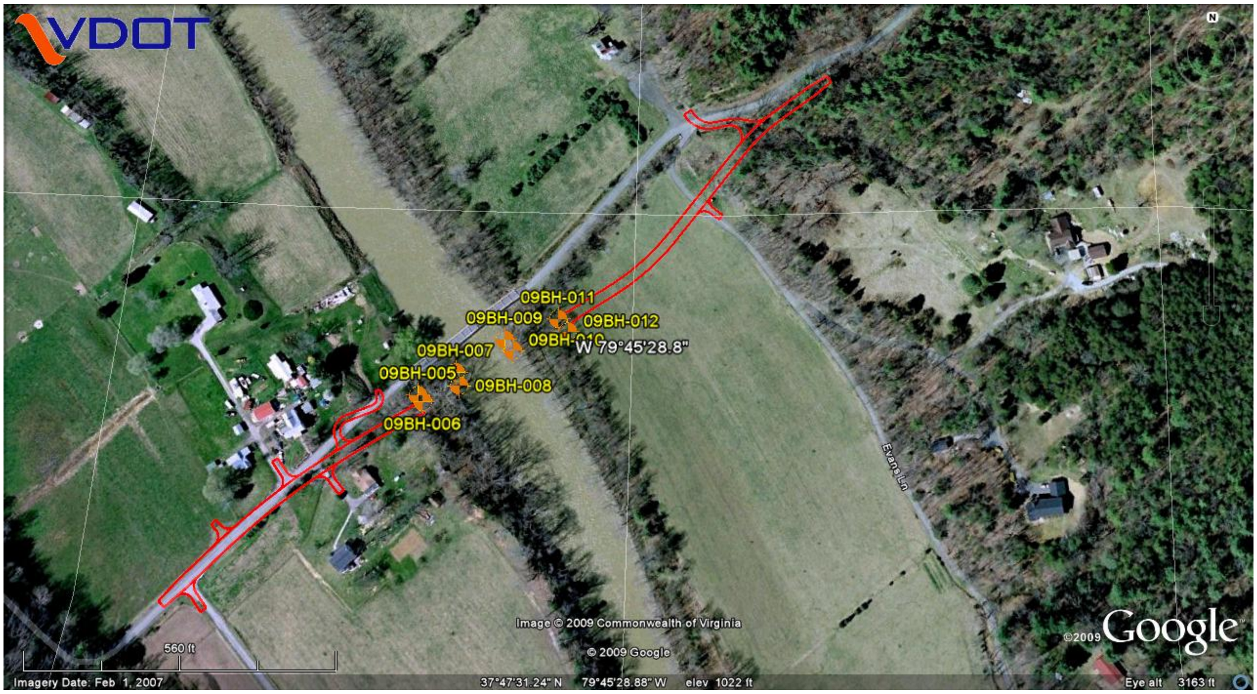

Figure 7. Example of Combined Display of gINT and MicroStation Data in Google Earth

Google Earth provides a significant step forward in terms of data integration. It is considered to be a very useful data mining and viewing tool. With regard to the accuracy of the projections and transformations, Google Earth is not a replacement for a sophisticated GIS platform, but it offers a completely adequate and rapid solution in routine applications. The latest release of gINT allows for seamless integration with Google Earth, requiring only a couple of keystrokes to transition between the programs. Software licensing considerations necessitate the purchase of the Google Earth Pro version for commercial applications.

Although this project was managed by personnel of the Virginia Transportation Research Council (VTRC), its successful completion depended on the expertise gathered across several technical disciplines. Some of this expertise was provided by VDOT personnel, and some was accessed through academia. It must be recognized that as a complex database, this system will require upkeep to remain functional and responsive to VDOT's business needs. As a consequence, it is important to maintain in-house expertise in this area. VTRC personnel can provide the required technical assistance when needed.

CONCLUSIONS

- *The fully operational, production level GDBMS is available for use at VDOT. The system allows VDOT personnel and VDOT consultants quick access to geotechnical data.*
- *GDBMS will require periodic technical upkeep and software revisions to maintain its usefulness*.
- *GDBMS should be maintained by the individual(s) responsible for geotechnical data quality assurance*.
- *The use of the Google Earth software as a display tool will enhance and leverage the existing software infrastructure at VDOT.*
- *A dedicated web server will be required for external access to GDBMS by consultants. This server should mirror the information contained on the internal server.*

RECOMMENDATIONS

1. *VDOT's Materials Division should mandate the use of GDBMS and associated processing software on all geotechnical projects. The mandate should include all consultant work and work under Virginia's Public-Private Transportation Act. Freely available technical support should be provided by VDOT's Materials Division where needed.*
2. *VDOT's Materials Division should be in charge of maintaining the geotechnical database.*

3. *VDOT's Information Technology Division should set up and maintain an externally accessible web server that will mirror all geotechnical data contained on the VDOT intranet server. The external server should be set up to check on a regular basis the intranet server and synchronize when any new data are posted. For security reasons, this server should not have any external file upload capabilities. All consultant requests for geotechnical information should be directed to the external server.*

4. *VDOT's Information Technology Division should provide VDOT's geologists copies of Google Earth Pro (commercial version) so that they can fully use and augment the potential of the existing software.*

5. *VTRC should continue to provide an advisory role to ensure reliable GDBMS service and to enable further system development as defined by the future business needs of VDOT.*

COSTS AND BENEFITS ASSESSMENT

Cost savings associated with fully implementing GDBMS at VDOT will result primarily from the increased workforce efficiency. Once data are entered into the system, they can be processed in a number of ways to output a variety of reports. The process of data retrieval is streamlined, because all relevant information is contained in one centralized database and ready for immediate access. This functionality reduces the need and the space required for local physical storage of paper reports.

Another potential source of cost savings will stem from data processing capabilities of the new system. For example, substantial time savings can be realized from the automated generation of subsurface cross sections (fence diagrams), which would otherwise require a considerable manual effort.

Significant cost savings can be realized on large new projects planned in the vicinity of the existing infrastructure, where the proximate subsurface data are already available. Additional exploration is often very expensive, with many over-water drilling projects costing more than $10,000 per day to carry out. GDBMS can provide a more comprehensive picture of local conditions and thus reduce the expense of drilling additional boreholes.

The synergy introduced by Google Earth is expected to result in new, innovative, and more efficient ways of processing project data. The capability of overlaying borehole locations and roadway alignments on Google Earth image maps will enhance and streamline current design procedures and expedite project delivery.

This technology can be applied to all transportation projects involving subsurface exploration, including bridges, retaining walls, and sound walls. It is estimated that on the average, the use of this technology would cut in half the time required to gather and process borehole data, resulting in approximately 16 person-hours of savings at an average rate of $100 per hour (including overhead). For the past 15 years, VDOT has been approving an average of

102 bridges per year for construction (J. M. Hall, personal communication, 2010). Therefore, the potential cost savings are on the order of $160,000 per year, excluding the consideration of retaining walls, sound walls, and megaprojects.

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REFERENCES

1. Ishibashi, I., and Yoon, J. *Feasibility Study of VDOT's Geotechnical Database Management System.* Old Dominion University, Department of Civil and Environmental Engineering, Norfolk, Va., 2003.

2. Hoppe, E.J., and Whitehouse, D.H. *Implementation of gINT Software at the Virginia Department of Transportation.* VTRC 08-R19. Virginia Transportation Research Council, Charlottesville, 2008.

3. Virginia Department of Transportation, Business Center. VDOT CADD Manual 2009. http://www.virginiadot.org/business/locdes/vdot_cadd_manual.asp. Accessed April 21, 2010.

4. Yoon, J. *Procedures for Implementing VDOT Statewide Geotechnical Database Management System (GDBMS) Framework.* Old Dominion University, Department of Civil and Environmental Engineering, Norfolk, Va., 2004.

5. Virginia Department of Transportation. Statewide VDOT Geotechnical Database Management System (GDBMS) Framework. http://matrix2/website/index.html. Accessed April 21, 2010.

6. Virginia Department of Transportation, Business Center, Materials Division. GEOXT, GINT, Microstation, and GEOPAK Integrator. http://www.virginiadot.org/business/materials-download-docs.asp. Accessed April 21, 2010.