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16. Abstract

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As the rate of use, VDOT engineers recognized the need for additional engineering analysis and design functionalities. In response, five geotechnical engineering applications used to calculate slope stability and foundation pile capacity were identified. Analysis and Design Modules (ADM) for these five applications were designed, developed, and implemented in the existing GDBMS.

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In addition to the ADM, a powerful new borehole data search algorithm, *GDBMS Borehole Search Rabbit*, was developed to augment the existing search functionality. This new search algorithm provides both hierarchical and partial search capabilities based on GDBMS site module, VDOT project number, source level gINT project file, and boring site ID. Once a borehole data search is completed, VDOT engineers can directly access particular site data in various formats such as the original legacy data format, translated standard data format, gINT and Excel files of translated standard data format, and borehole data log and laboratory results.

A cost-benefit analysis determined that approximately 1,120 hours of engineering time can be saved by using ADM with a total annual cost savings of $112,000.

VDOT's GDBMS can be accessed on the Internet at http://172.16.20.2 and at http://gis.virginiadot.org/GDBMS_menu.htm.

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FINAL CONTRACT REPORT

DEVELOPMENT OF GEOTECHNICAL ANALYSIS AND DESIGN MODULES FOR THE VIRGINIA DEPARTMENT OF TRANSPORTATION'S GEOTECHNICAL DATABASE

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Charlottesville, Virginia

June 2005
VTRC 05-CR23

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ABSTRACT

In 2003, an Internet-based Geotechnical Database Management System (GDBMS) was developed for the Virginia Department of Transportation (VDOT) using distributed Geographic Information System (GIS) methodology for data management, archival, retrieval, and analysis. The system has been used for accessing geotechnical data pertaining to the Hampton Road Third Crossing project and the Woodrow Wilson Bridge Route 1 Interchange.

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INTRODUCTION

In 2001, the Virginia Department of Transportation (VDOT) initiated a study designed to implement an Internet-based, spatiotemporal Geotechnical Database Management System (GDBMS) using a distributed Geographic Information System (GIS) methodology. A feasibility study (Ishibashi and Yoon, 2001) was conducted to identify a number of GDBMS implementation alternatives, and the GIS-based strategy was recommended as the most viable implementation model in terms of ease of use, cost-effectiveness, flexibility and future expandability.

A demonstration pilot study of GDBMS was carried out for the Third Hampton Roads Crossing Project (Yoon an Ishibashi, 2002). The main goal of the demonstration project was to design, develop and implement a deployable Internet-based GDBMS for accessing and utilizing historical and current geotechnical data specific to the Hampton Road Third Crossing project. In 2003, the GDBMS was further developed and scaled up to include the Woodrow Wilson Bridge Route 1 Interchange project (Yoon, 2003). The system has been actively utilized and recognized as an effective and efficient tool to manage geotechnical data.

As the rate of utilization of the GDBMS grew, VDOT engineers recognized the need for additional engineering analysis and design functionalities. In response, five geotechnical engineering applications used to calculate slope stability and foundation pile capacity were identified. A study was initiated to enhance the existing Internet-based database system with new analysis and design capabilities.

PURPOSE AND SCOPE

The objective of this study was to design, develop and implement a non-proprietary Analysis and Design Modules (ADM) in the VDOT Geotechnical Database Management System (GDBMS). Five commonly used geotechnical engineering programs used for analysis and design were identified: DRIVEN, RSS, LPILE Plus, SHAFT, and GALENA. These applications are routinely used for foundation pile analysis and design, as well as for slope stability calculations. The IT effort was structured to provide a user-friendly interface for automatically extracting, filtering, translating and generating input data sets for these five applications. In addition, the need for a more effective search algorithm was identified to facilitate data retrieval.

METHODS

VDOT'S GDBMS source codes were developed, revised and updated to add the Analytical and Design Module (ADM) functionality for DRIVEN, RSS, LPILE Plus, SHAFT and GALENA. During the study, all prototype designs were posted on the GDBMS development server to allow VDOT engineers to evaluate the functionality and provide feedback. In addition, two meetings were held at the VDOT Bridge Division office in October 2004 and in April 2005 to guide the study.

ADM Conceptualization and Design Components

The main purpose of Analysis and Design Modules (ADM) is to provide VDOT engineers with fully functional, user friendly, rugged, flexible and expandable middleware for automatically extracting, filtering, translating and generating input data sets within the GDBMS. Thus, ADM facilitates specific analysis and design tasks by automatically generating input data sets instead of the traditional task of manually preparing an input file. A substantial increase in productivity can thus be achieved, particularly on large engineering projects.

Components of the ADM fully utilize the existing adaptive translative filter implementation in the VDOT GDBMS. Schematic flowchart of core ADM processes is shown in Figure 1. Additional flowcharts that describe internal logic and interactions with the GDBMS in detail are provided in Figures 2 and 3. Full PHP source code for core ADM processes is available from the authors.

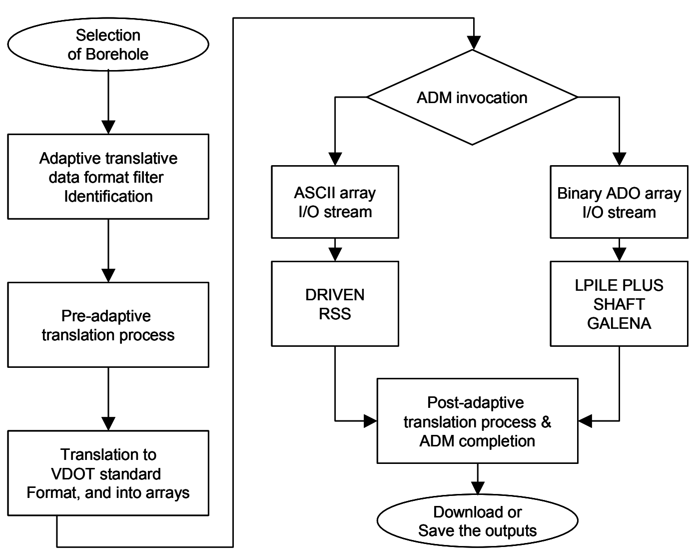


Figure 1. Core Schematic of the ADM Process

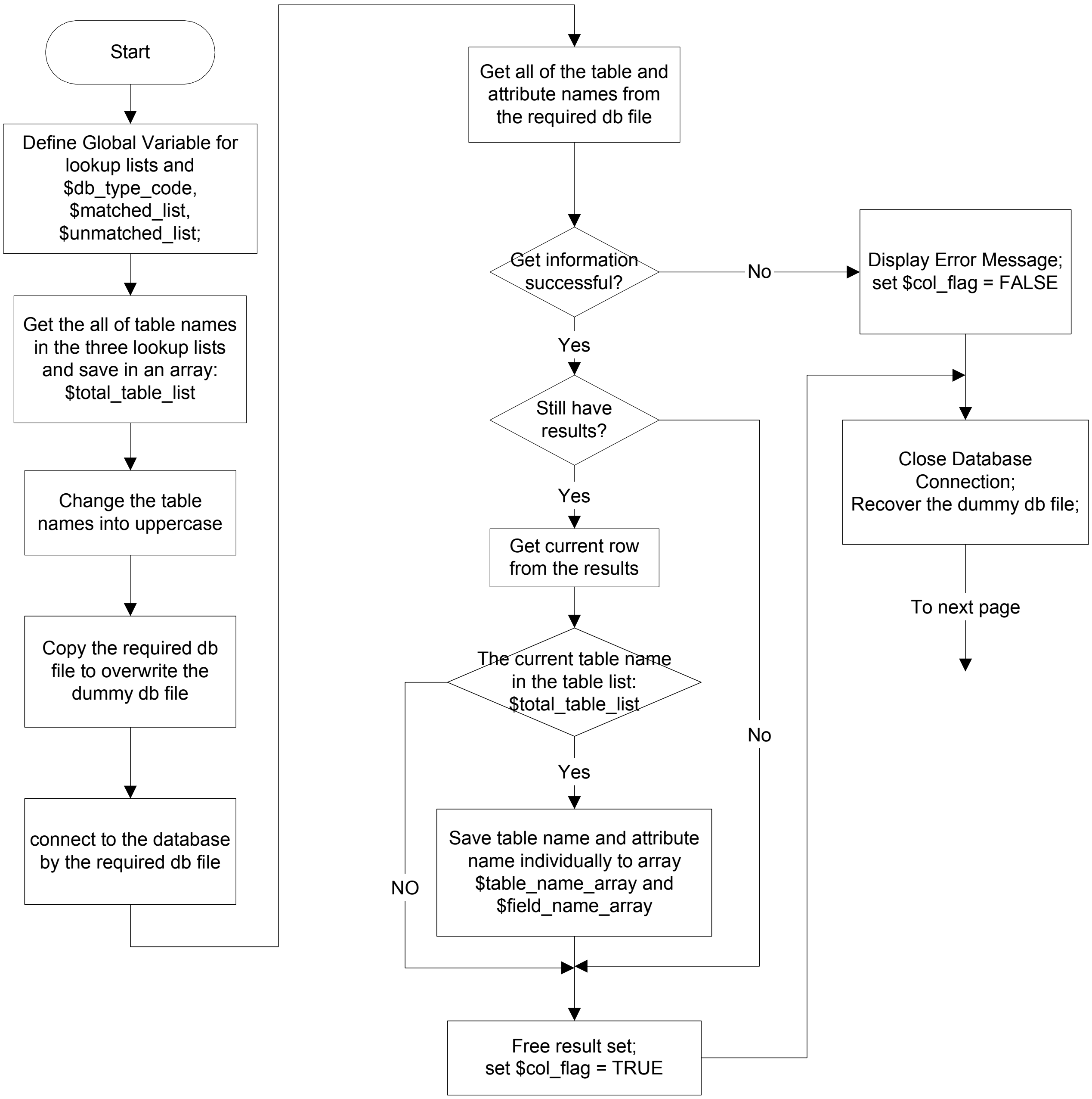


Figure 2. Schematic Flowchart of Adaptive Data Translation in ADM/GDBMS

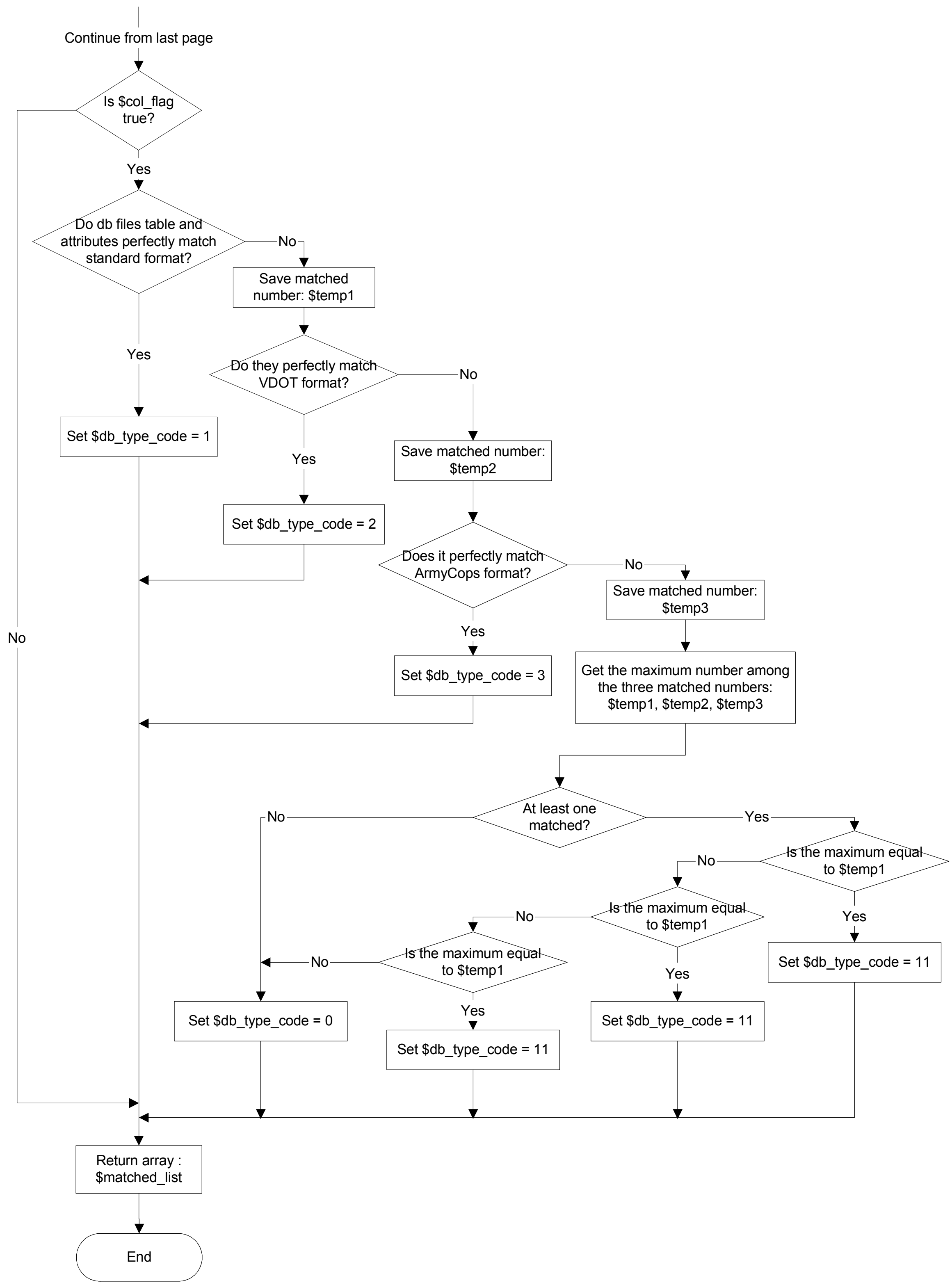


Figure 2. Schematic Flowchart of Adaptive Data Translation in ADM/GDBMS (cont'd)

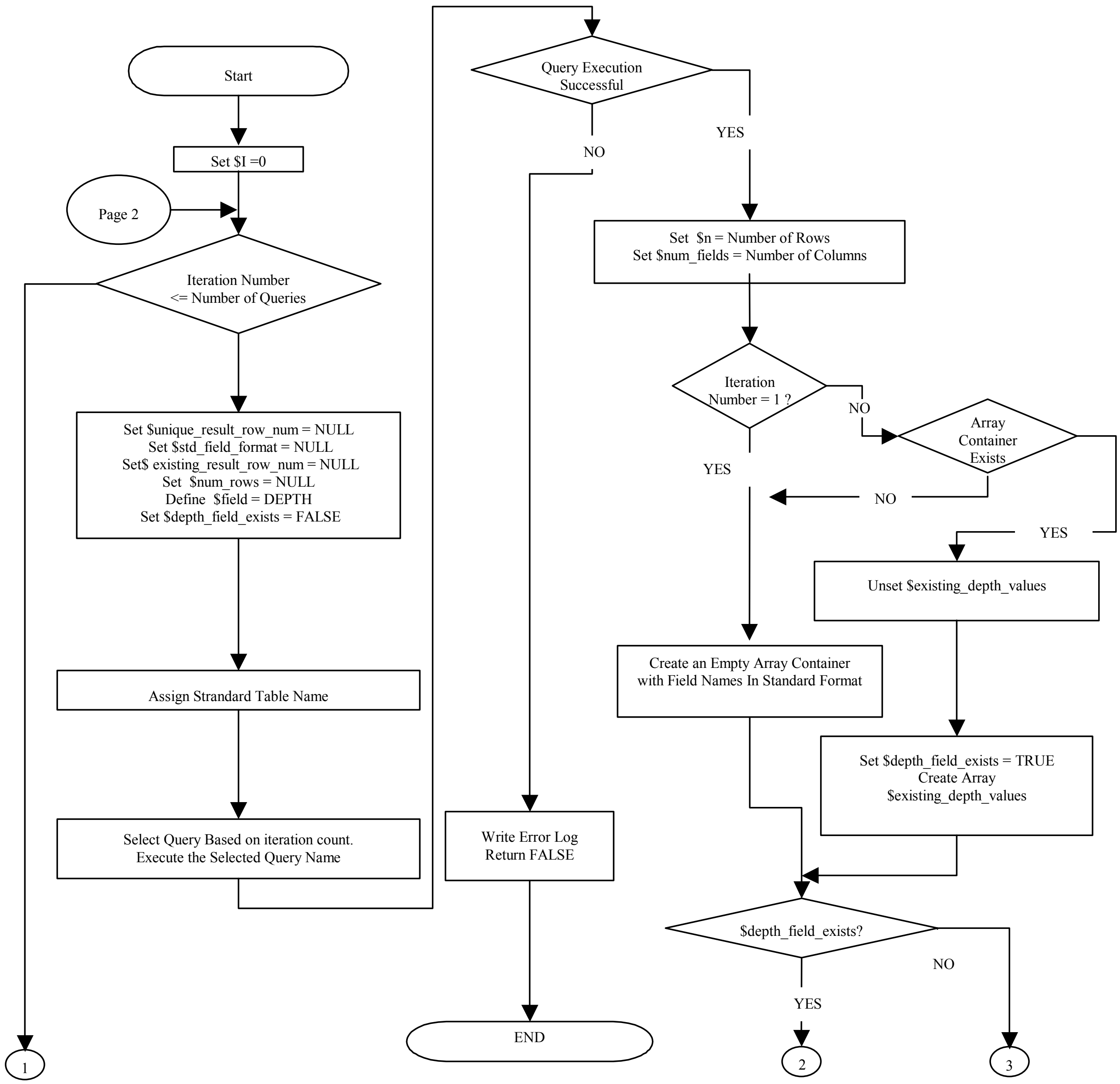


Figure 3. Post-Adaptive Data Translation and Application-Specific Output Generation in ADM/GDBMS

VDOT's GDBMS operates on a web server. It uses gINT software to dynamically generate borehole logs and fence diagrams. A user does not need to have gINT program installed on a local PC to access geotechnical data. The use of ADM, however, requires that a user have local access to programs for which data files are generated.

Description of Geotechnical Engineering Applications Implemented in ADM

ADM were designed, developed and implemented for five geotechnical engineering applications: DRIVEN, RSS, LPILE Plus, SHAFT and GALENA. Each application's purpose, capability and applicability is documented as follows:

DRIVEN

DRIVEN (Mathias and Cribbs, 1998) is a Microsoft Windows program, developed by the FHWA in 1998, to analyze the axial capacity of driven piles. This program is based on works of Thurman (1964), Meyerhof (1976), Cheney and Chassie (1982), Tomlinson (1980, 1985), and based on reports by Hannigan et al. (1997). Nordlund and Tomlinson static analyses methods used by the program are semi-empirical methods and have limitations in terms of correlations with field measurements and pile variables which can be analyzed. DRIVEN can be freely downloaded from the FHWA website. Currently implemented ADM is designed for DRIVEN version 1.2.

RSS

RSS (FHWA, 1996) is a MS-DOS based program, developed by the FHWA in 1989 for the design and analysis of reinforced soil slopes. The program is largely based on the FHWA manual "Reinforced Soil Structures Volume I-Design and Construction Guidelines" (Christopher et al., 1989). RSS analyzes and designs soil slopes strengthened with horizontal reinforcement, and unreinforced slopes. Analysis is performed using a two-dimensional limit equilibrium method. RSS calculates the required spacing of a given reinforcement to achieve a specified factor of safety, the required strength of reinforcement for a given spacing to achieve a specified factor of safety, and the factor of safety for a specified pattern of reinforcement.

All analyses involving soil reinforcement are performed using the simplified Bishop circular arc method of slices. The simplified Janbu method is used to determine the most critical sliding block for the purpose of finding the minimum distance to extend the reinforcement into the slope to prevent sliding. RSS can also be used to determine factor of safety for unreinforced slopes using the simplified Bishop method and sliding block analysis using the simplified Janbu method of slices. RSS uses extensively modified version of the STABL program. Guidelines for design of soil reinforcements are stated in the FHWA-SA 96-071 (Elias and Christopher, 1996). RSS can be freely downloaded from the FHWA website. Currently implemented ADM is designed for RSS version 1.0.

LPILE Plus

LPILE Plus (Ensoft, 2004) is a commercial program for analyzing foundation piles subjected to lateral loading. The program computes deflection, shear, bending moment, and soil response as a function of depth. Soil behavior is modeled with p-y curves generated based on published recommendations for various types of soils. Alternatively, user can manually introduce specific p-y curves. Special procedures are programmed for developing p-y curves for layered soils and for rocks. Several types of pile-head boundary conditions may be selected, and the properties of the pile can be varied as a function of depth. The program can compute the ultimate-moment capacity of a pile section and provide design information for reinforcing bar layout. The program can also generate and take into account nonlinear values of flexural stiffness (EI) based on specified pile dimensions, material properties, and cracked/uncracked concrete behavior. LPILE Plus can be purchased from Ensoft, Inc. Currently implemented ADM is designed for LPILE Plus version 4.0.

SHAFT

SHAFT (Ensoft, 2004) is a commercial program used to compute the axial capacity and the short-term load versus settlement curves of drilled shafts in various soil types. The program allows for any combination of soil layers to be placed in a layered profile. The analytical methods employed by SHAFT are based on experimental data obtained from hundreds of instrumented load tests. Many of the analytical methods are based on suggestions from the FHWA-IF-99-025 (O'Neill and Reese, 1999). SHAFT can be purchased from Ensoft, Inc. Currently implemented ADM is designed for SHAFT version 4.0.

GALENA

GALENA (Clover Technology, 1999) is a commercial program designed to provide slope stability analysis and design capability. GALENA incorporates the Bishop Simplified, the Spencer-Wright and the Sarma methods of analysis to determine the stability of slopes and excavations. The Bishop method is used to determine the stability of circular failure surfaces, the Spencer method is applicable for circular and non-circular failure surfaces, and the Sarma method is used for problems where non-vertical slices are required, or is used for more complex stability problems. It is possible to analyze multi-layered slopes with tension cracks, earthquake forces, externally distributed loads, and water pressures from within or above the slope (e.g. dams) including phreatic surfaces and piezometric pressures. Back analyses can also be performed to obtain critical material strength parameters from known or assumed failure surfaces. GALENA also allows either the traditional shear strength values (c and phi) to be used as input data, or shear strength values in terms of the Hoek-Brown failure criterion using values m, s and UCS. GALENA can be purchased from Clover Associates Pty Limited of Australia. Currently implemented ADM is designed for GALENA version 3.0.

RESULTS

VDOT's GDBMS can be accessed on the Internet at http://172.16.20.2 and at http://gis.virginiadot.org/GDBMS_menu.htm. Examples of a new borehole data search algorithm and ADM usage are shown in the following figures to illustrate implementation details.

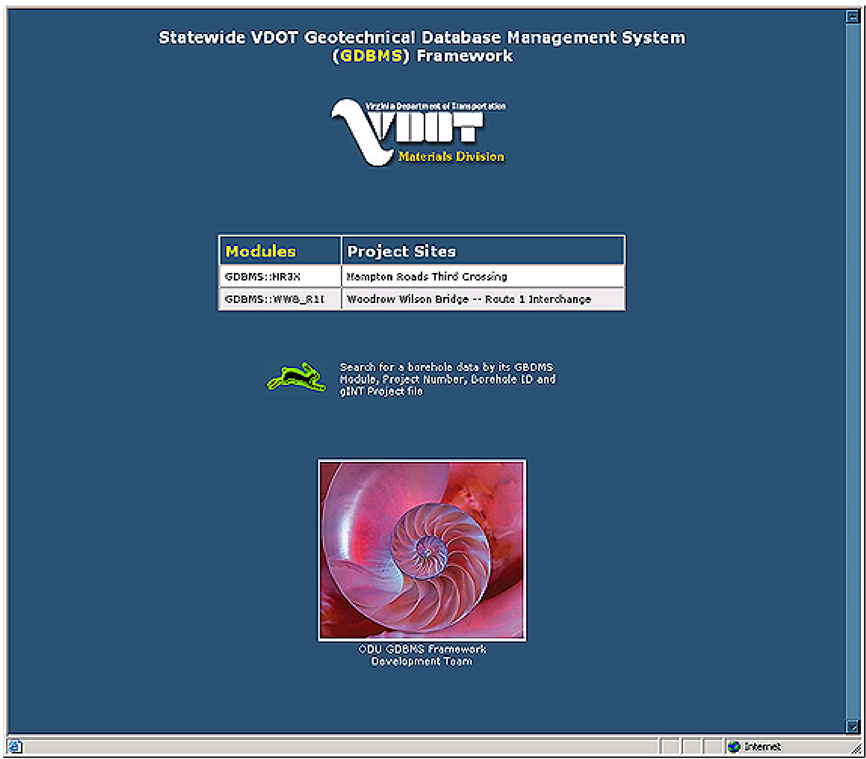


Figure 4. New Borehole Data Search Algorithm - *GDBMS Borehole Search Rabbit*

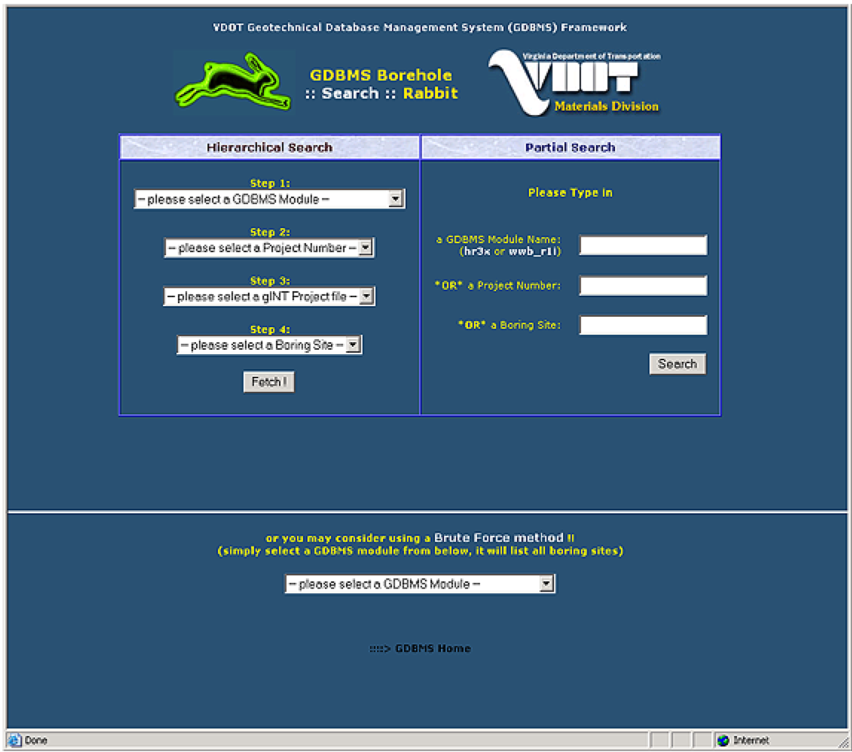


Figure 5. Main Borehole Data Search Interface - *GDBMS Borehole Search Rabbit:* Borehole data search interface provides three different search modes: (a) Hierarchical search mode to constrain the query to get an exact borehole data, (b) Partial search mode to create a "matching" query to all existing GDBMS data, and (c) Site module search mode for a full listing of borehole data.

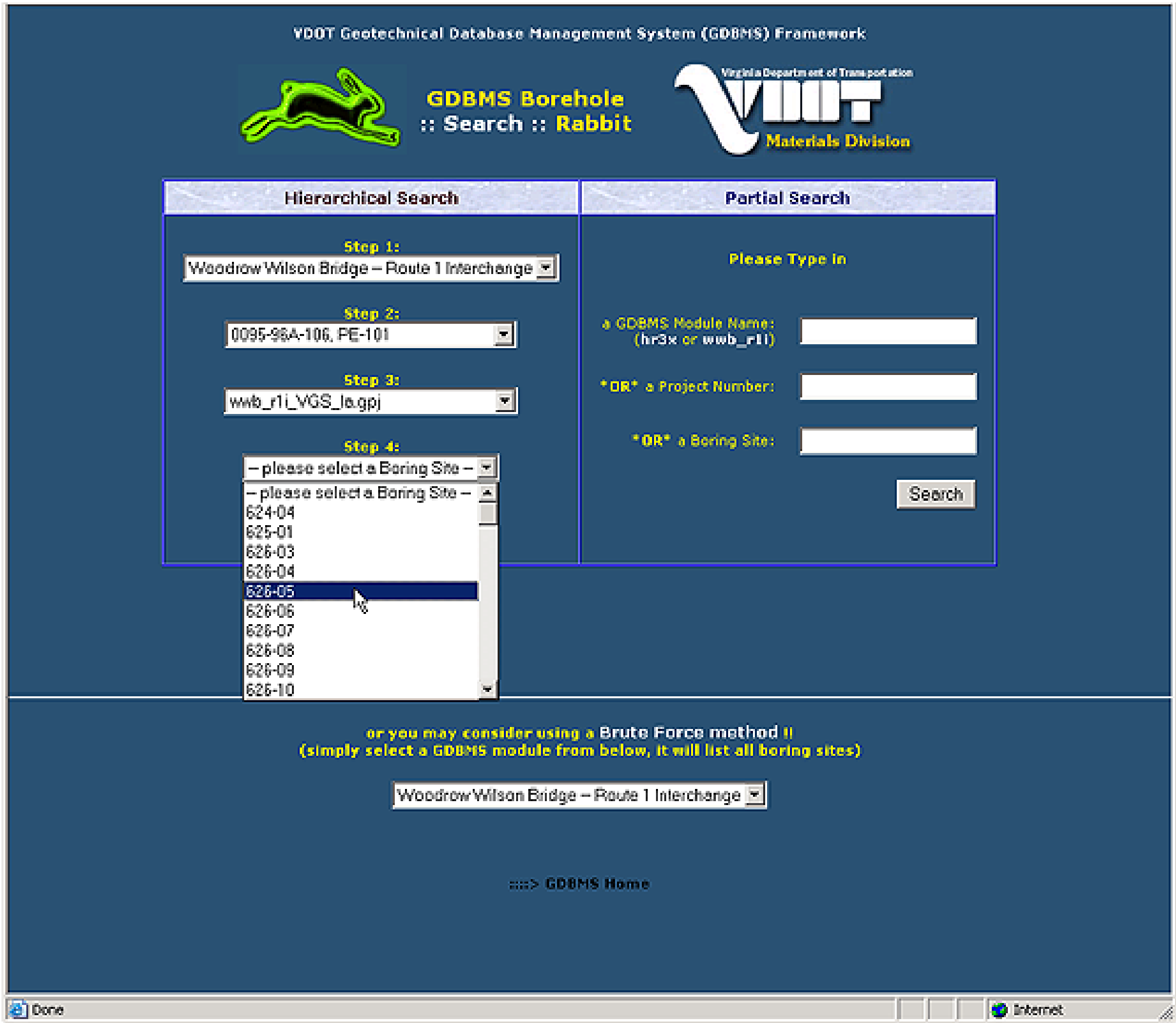


Figure 6. Example of Hierarchical Search Mode

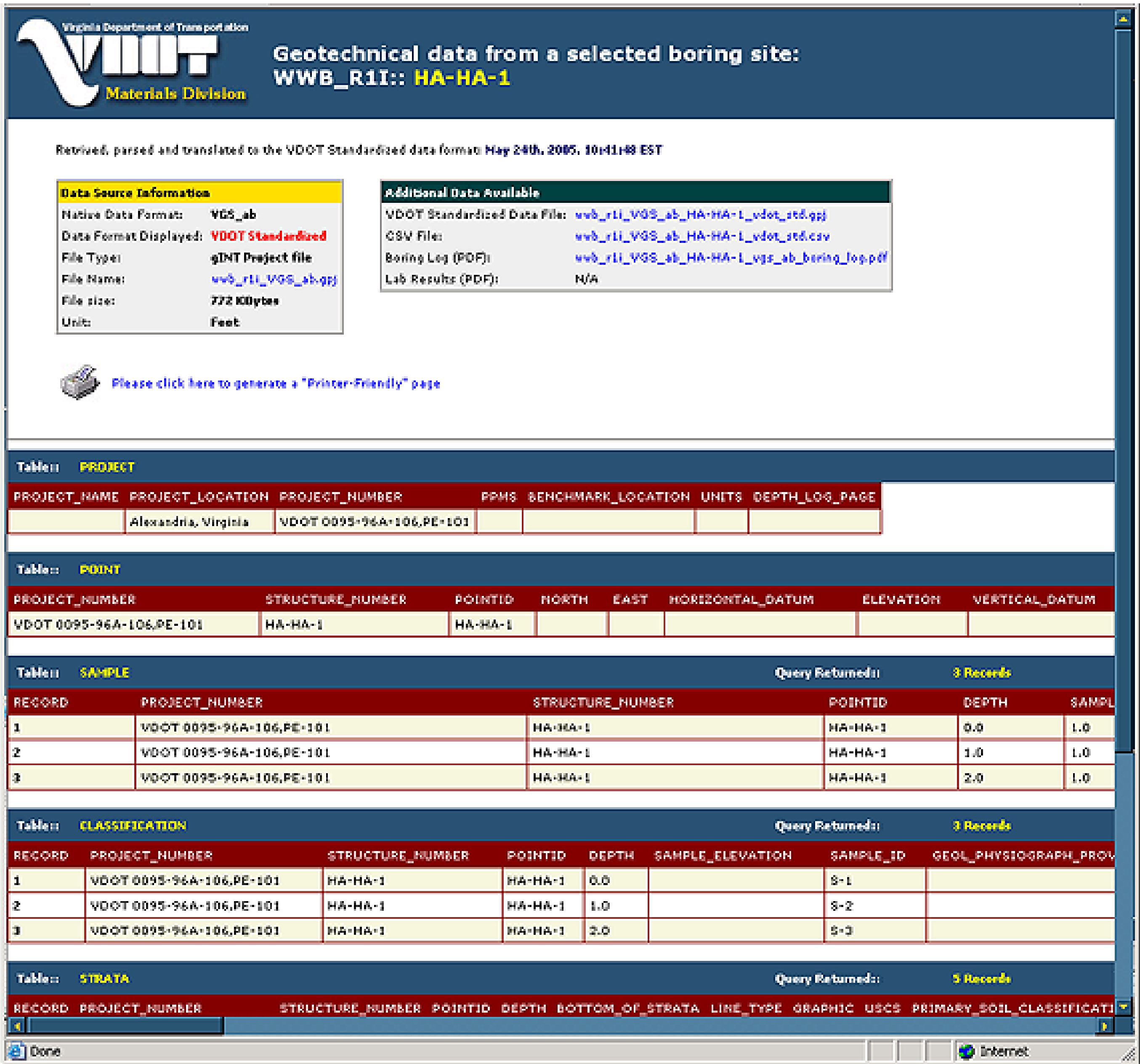


Figure 7. Example of Singular Query Result Listing by Hierarchical Search Mode

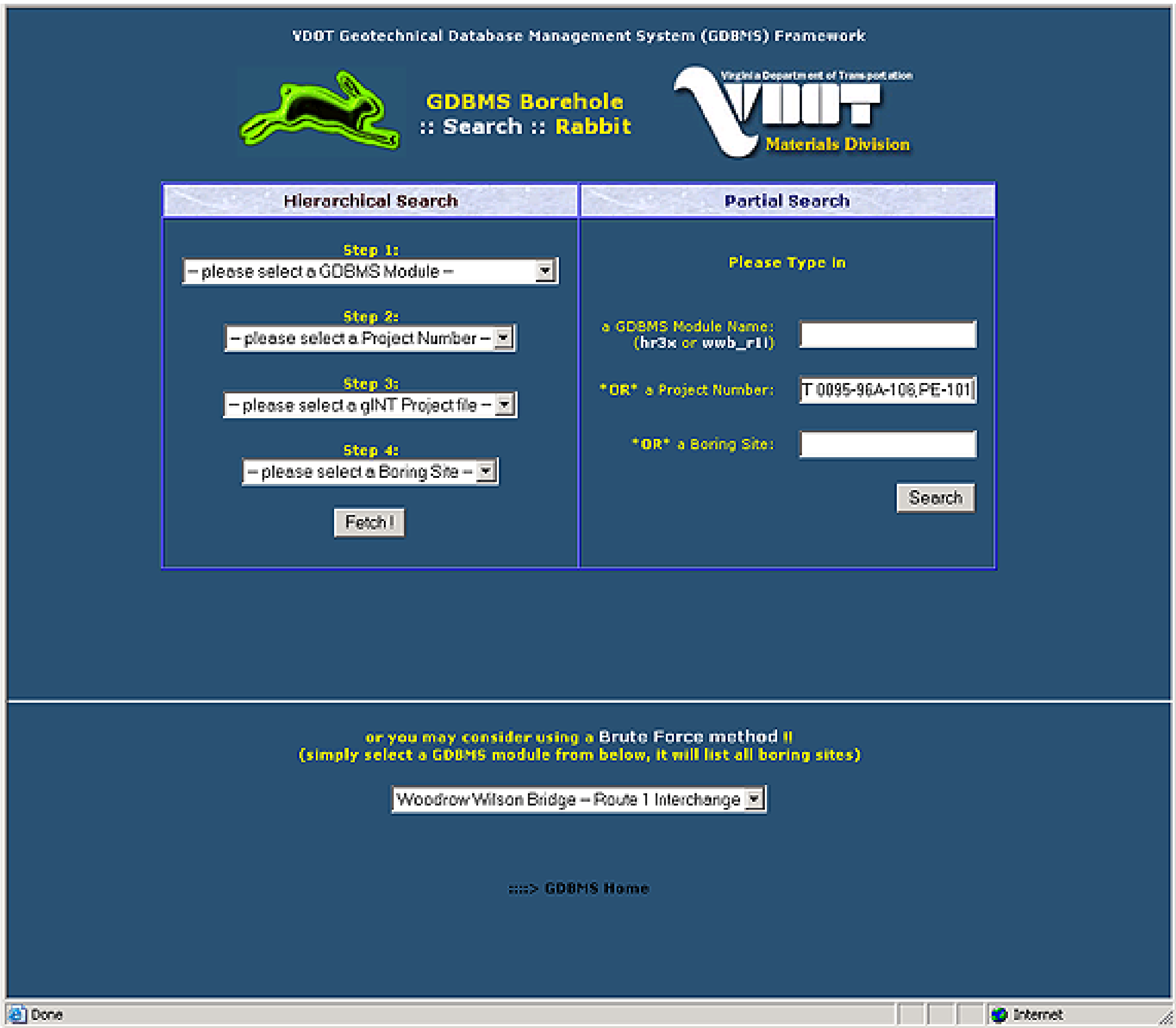


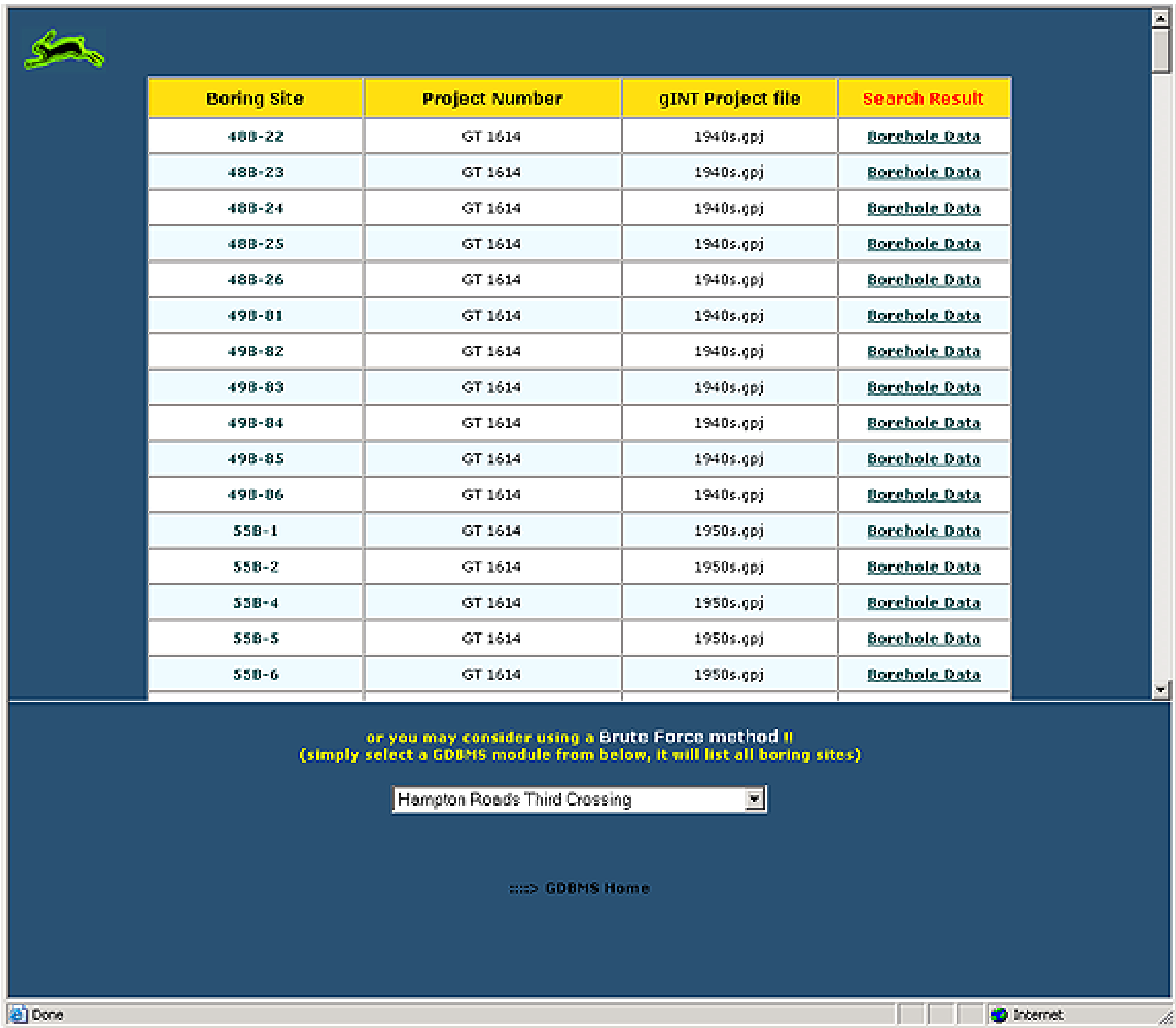
Figure 8. Example of Partial Search Mode to Create a Matching Query

Partial Search Results

GDBMS Module	Project Number	gINT Project file	Boring Site	Search Result
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	HA-HA-1	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	HA-HA-2	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-1	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-1A	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-1B	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-2	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-2A	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-2B	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-2C	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-2D	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-2E	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-2G	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-2I	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-3	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-3A	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-3B	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-3C	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-3D	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	TES-3E	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	VA-S-C0-B-006-01-2	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	VA-S-D0-B-005-03-2	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	VA-S-F0-B-013-02-2	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	VA-S-K0-B-002-01-2	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	VA-S-K0-B-002-01-2A	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	VA-S-K0-B-002-03-2	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	VA-S-K0-B-002-03-2A	Borehole Data
wwb_r1i	VDOT 0095-96A-106,PE-101	wwb_r1i_VGS_ab.gpj	VA-S-L0-B-001-02-2	Borehole Data

Internet

Figure 9. Example of Query Result Listing by Partial Search Mode



Boring Site	Project Number	gINT Project file	Search Result
48B-22	GT 1614	1940s.gpj	Borehole Data
48B-23	GT 1614	1940s.gpj	Borehole Data
48B-24	GT 1614	1940s.gpj	Borehole Data
48B-25	GT 1614	1940s.gpj	Borehole Data
48B-26	GT 1614	1940s.gpj	Borehole Data
49B-81	GT 1614	1940s.gpj	Borehole Data
49B-82	GT 1614	1940s.gpj	Borehole Data
49B-83	GT 1614	1940s.gpj	Borehole Data
49B-84	GT 1614	1940s.gpj	Borehole Data
49B-85	GT 1614	1940s.gpj	Borehole Data
49B-86	GT 1614	1940s.gpj	Borehole Data
55B-1	GT 1614	1950s.gpj	Borehole Data
55B-2	GT 1614	1950s.gpj	Borehole Data
55B-4	GT 1614	1950s.gpj	Borehole Data
55B-5	GT 1614	1950s.gpj	Borehole Data
55B-6	GT 1614	1950s.gpj	Borehole Data

Figure 10. Example of Site Module Search Mode for a Full Listing of Borehole Data

Figure 11. Example of ADM Implementation

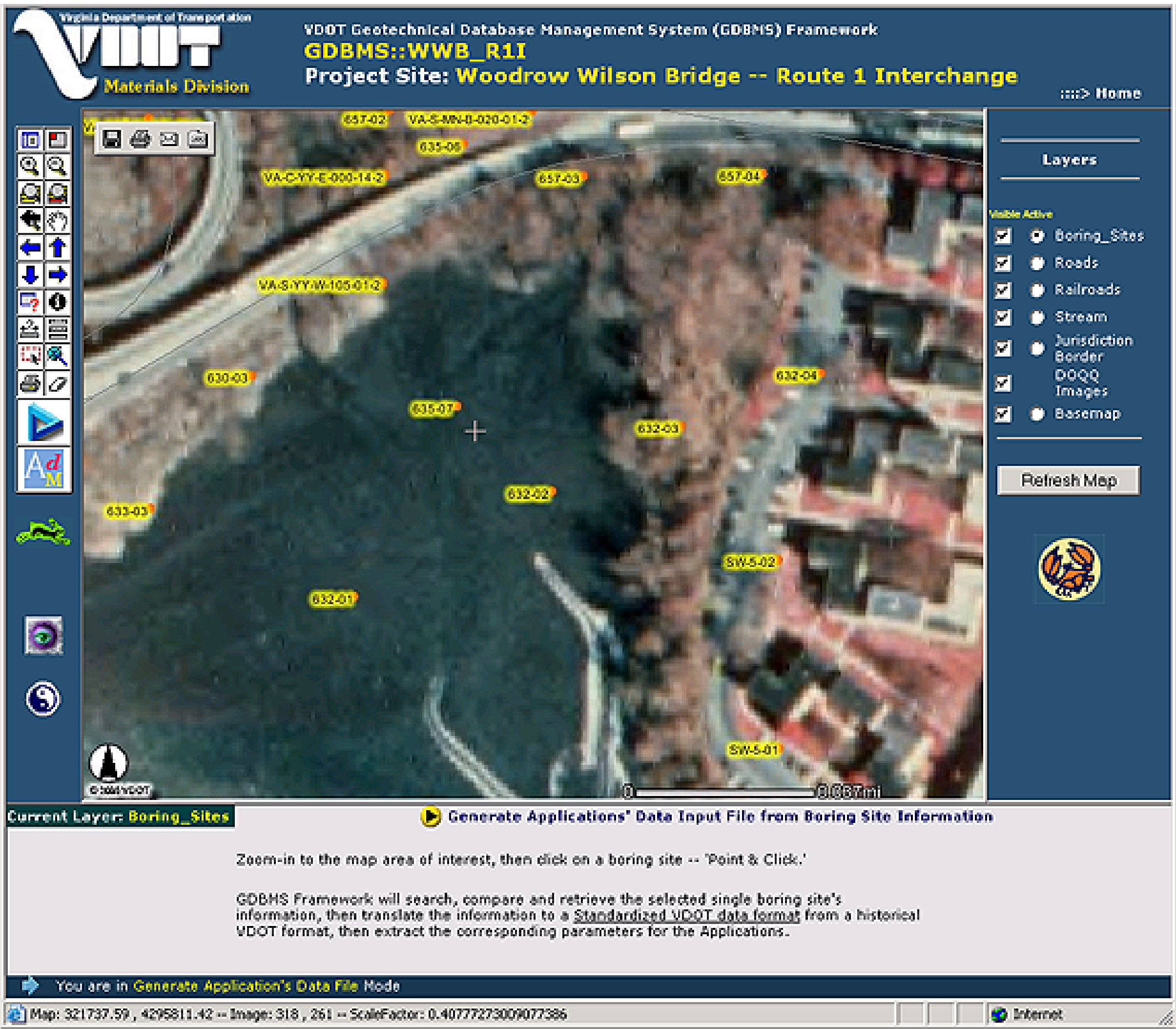


Figure 12. ADM Initialization and Borehole Selection Procedure for Generating Geotechnical Application Input Data File

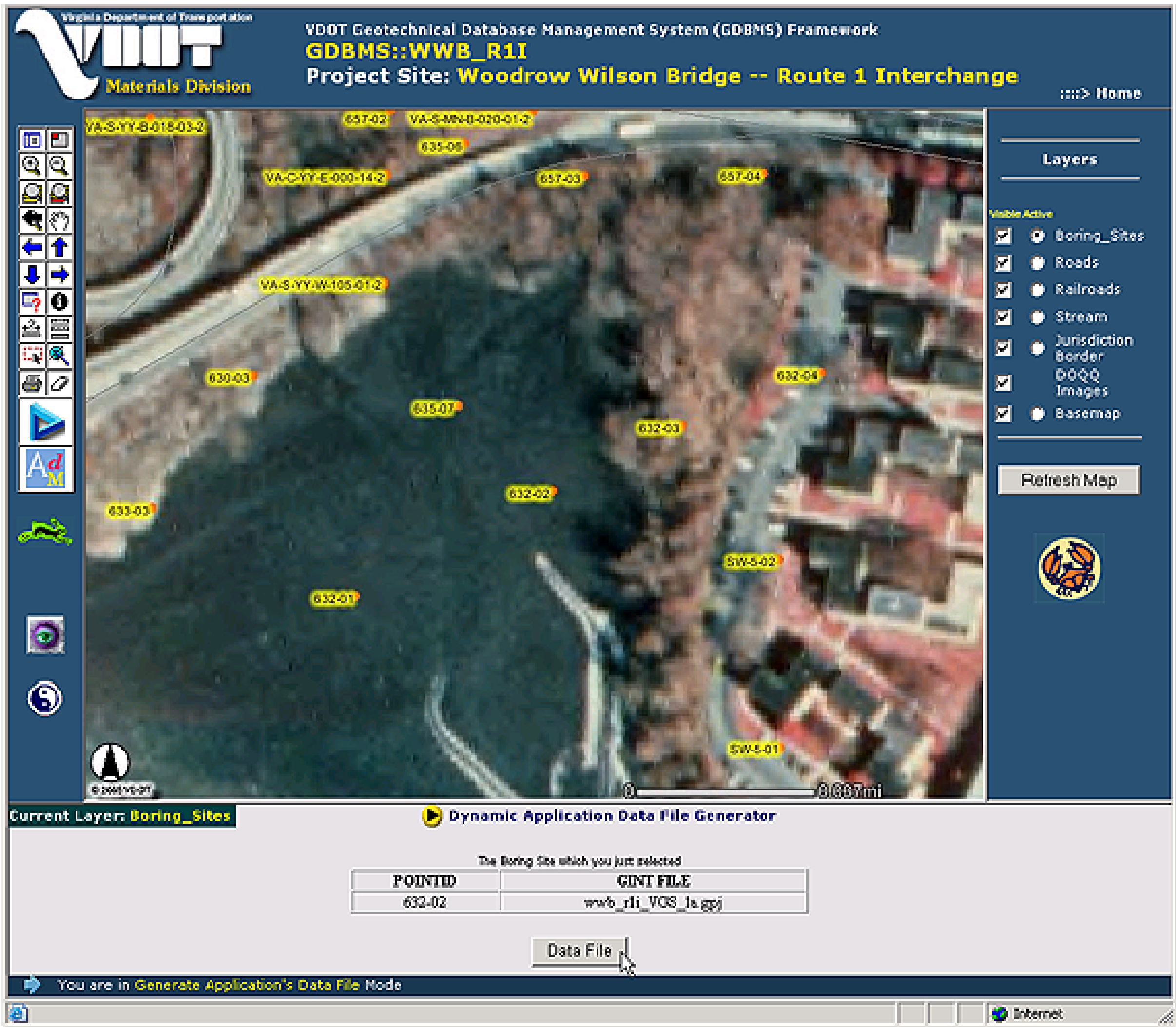


Figure 13. ADM Borehole Selection Confirmation and Pre-Step to Geotechnical Application Input Data File Generation

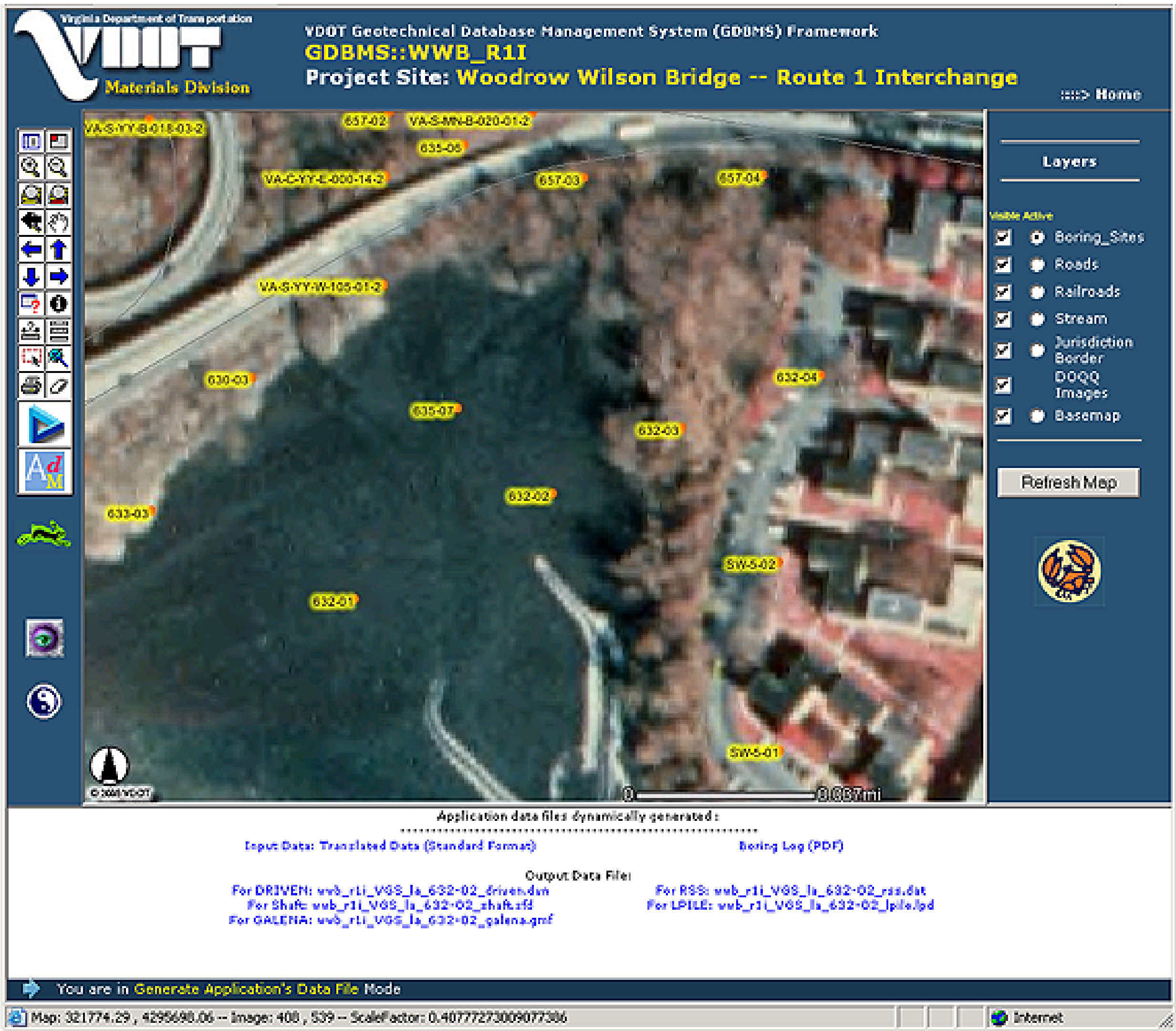


Figure 14. ADM Result Display of Generated Geotechnical Application Input Data Files

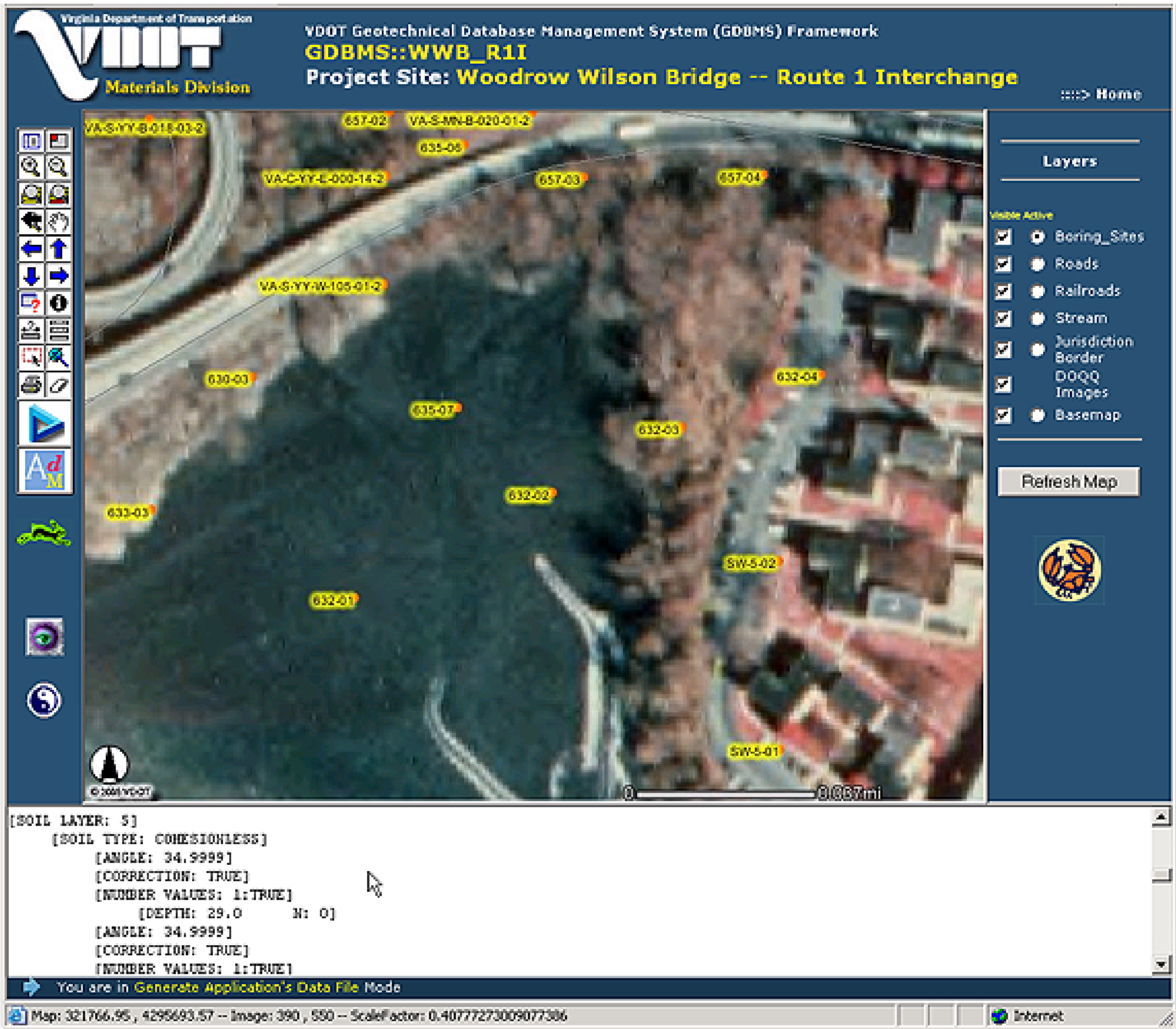


Figure 15. Display of DRIVEN Input Data Generated by ADM

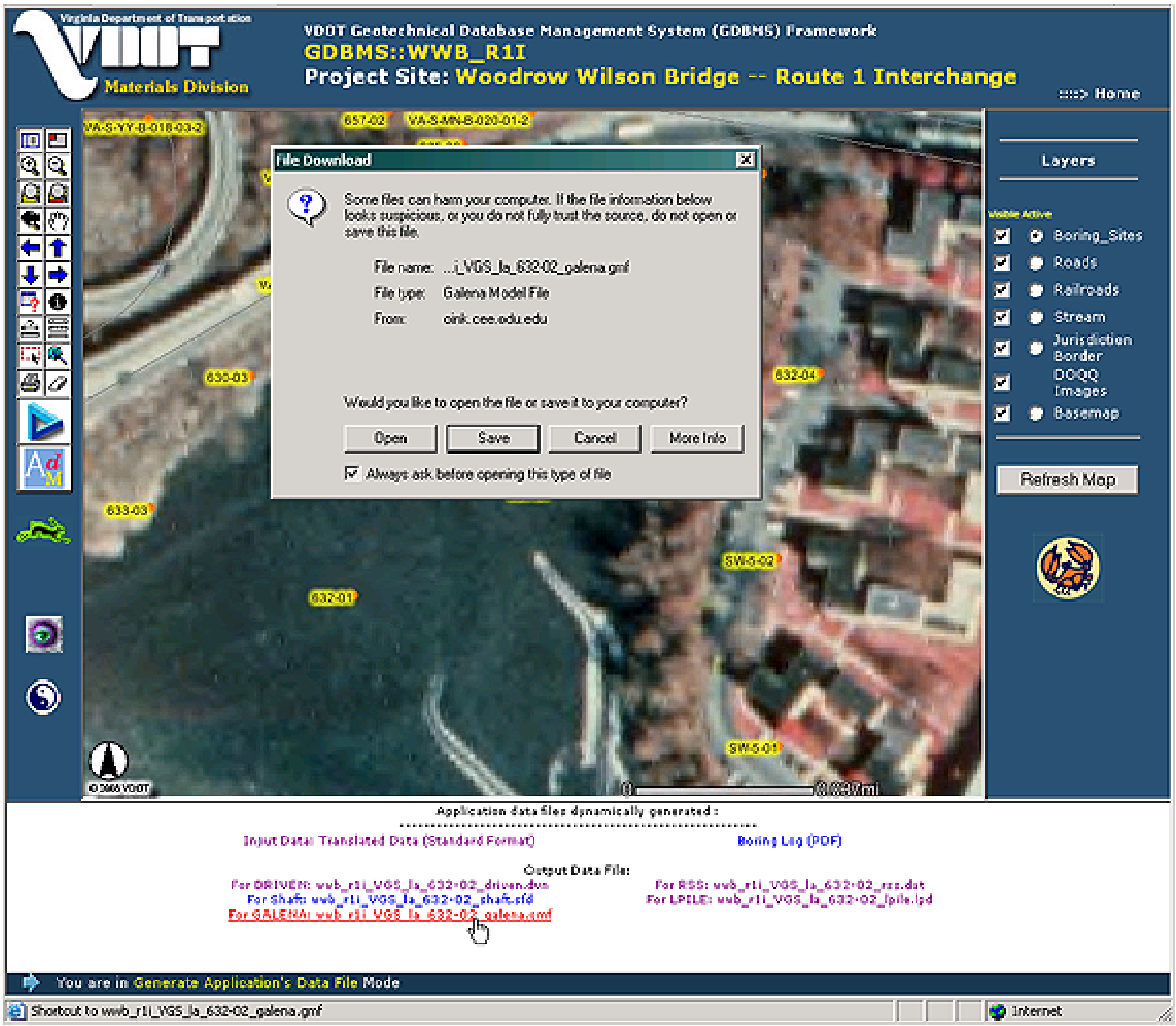


Figure 16. Galena Input Data (Binary Format) Generated by ADM

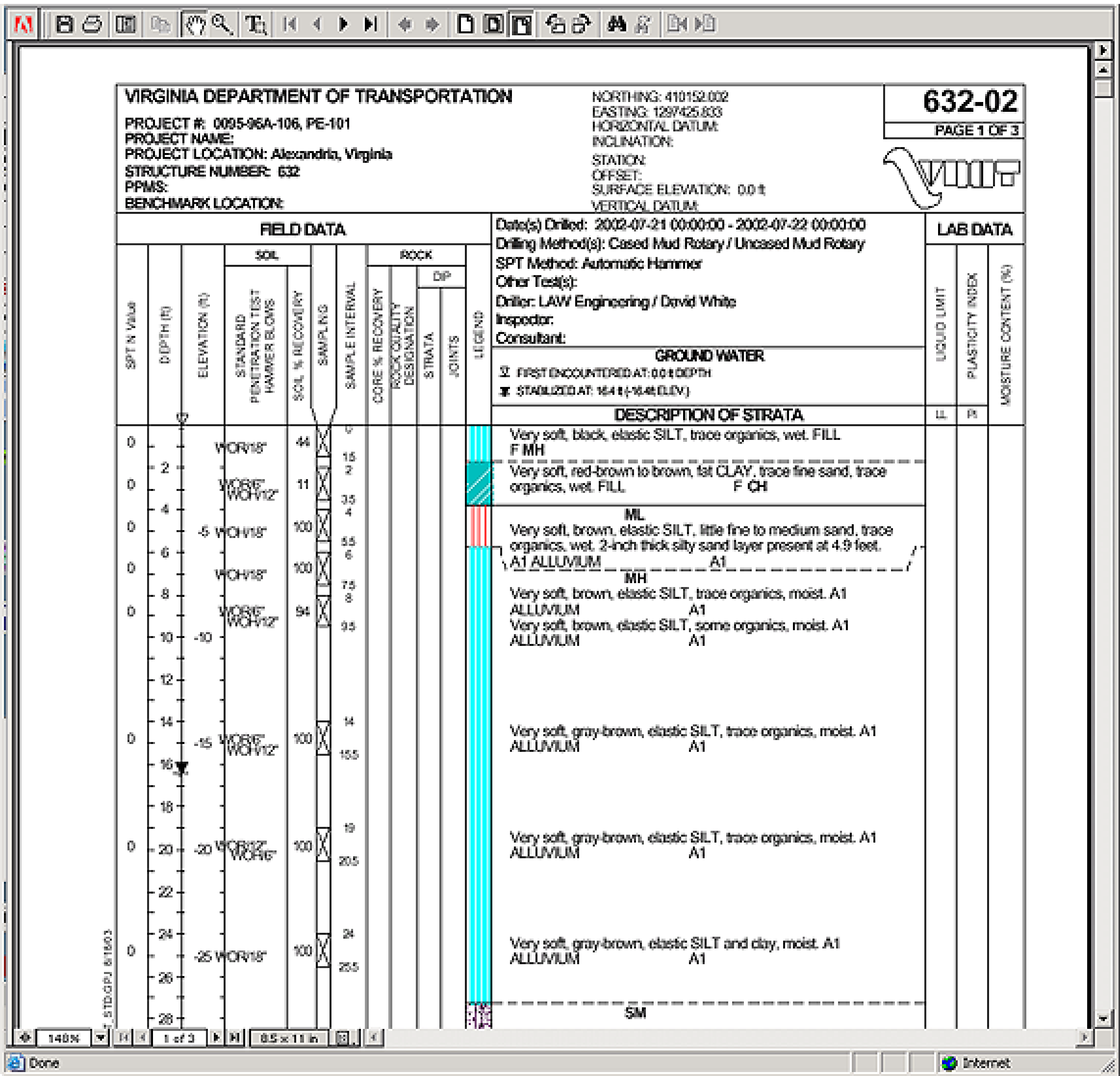


Figure 17. Corresponding Borehole Log generated by ADM

CONCLUSIONS

Non-proprietary ADM were designed, developed and implemented in the VDOT GDBMS using a distributed GIS methodology. The resulting ADM implementation facilitates engineering analysis and design by automatically generating input data sets, thus enhancing productivity. Compared to a conventional manual preparation of borehole data for analysis and modeling, this ADM implementation offers a more efficient way of calculating slope stability and pile capacity on VDOT projects. The container for ADM was conceptualized and designed so that any number of additional modules can be implemented incrementally without changing the GDBMS structure.

In addition to the ADM development, a powerful new borehole data search algorithm, *GDBMS Borehole Search Rabbit*, was developed to augment the existing search functionality. This new search algorithm provides both hierarchical and partial search capabilities based on GDBMS site module, VDOT project number, source-level gINT project file and boring site/ID. Once a borehole data search is completed, VDOT engineers can directly access particular site data in various formats such as the original legacy data format, translated standard data format, gINT and Excel files of translated standard data format, as well as borehole data log and laboratory results. VDOT's GDBMS can be accessed on the Internet at http://172.16.20.2 and at http://gis.virginiadot.org/GDBMS_menu.htm.

RECOMMENDATIONS

It is recommended that VDOT's GDBMS be expanded to include all geotechnical projects undertaken by VDOT and effectively become the main repository of geotechnical data. Presently, only two major projects are listed. In addition, other geotechnical analysis and design programs should be considered for inclusion into ADMs.

COSTS AND BENEFITS ASSESSMENT

The following assumptions (Hall, personal communication) were used to estimate the benefits of implementing ADM:

1. Typical engineering time saved per each borehole by using ADM: 1 hour.
2. Typical bridge: three-span structure with four foundation units.
3. Typical site exploration: two boreholes per foundation unit.
4. VDOT six-year plan projections: 820 bridges (VDOT and consultants).
5. Consultant billing rate: $120/hour.
6. VDOT "billing" rate = 2/3*consultant rate = $80/hour.

Consequently, with 820 bridges over 6 years, approximately 140 bridges per year are projected for analysis. Therefore, (140 bridges/year)*(8 boreholes/bridge)*(1 hour/boring) = 1,120 hours of engineering time that can be saved by using ADM.

Assuming that half of the time saved is the consultant time (560 hours), and the other half is VDOT time (560 hours), the total annual cost savings on engineering projects is estimated to be $112,000 [(560 hr)*($120/hr)] + [(560 hr)*($80)].

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REFERENCES

Cheney, R.S. and Chassie, R.G., Soils and Foundations Workshop Manual, Report No. FHWA HI-88-009, Federal Highway Administration, Washington, DC, 1982.

Christopher, B. R., Gill, S. A., Juran, I., and Mitchell, J. K., Reinforced Soil Structures, Volume 1: Design and Construction Guidelines, Volume 2: Summary of Research Systems Information, Report Nos. FHWA/RD-89/043 and 044, Federal Highway Administration, Washington, DC, 1989.

Clover Technology, User's Guide: GALENA version 3.00, October 1999, Robertson, Australia, 1999.

Elias, V. and Christopher, B. R., Mechanically Stabilized Earth Walls and Reinforced Soil Slopes: Design and Construction Guidelines, Report No. FHWA-SA 96-071, 1997; reprinted September 1998. FHWA Demonstration Project 82, Federal Highway Administration, Washington, DC, 1996.

Ensoft, Inc., LPILE Plus 4.0, User's Manual, Austin, TX, 2004.

Ensoft, Inc., SHAFT 4.0, User's Manual, Austin, TX, 2003.

FHWA, Reinforced Soil Slopes (RSS), Office of Technology Applications, Federal Highway Administration, Washington, DC, 1996.

Hannigan, P. J., Goble, G. G., Thendean, G., Likins, G. E., and Raushe, F., Design and Construction of Driven Pile Foundations, Volume I and II, Report No. FHWA-HI-97-013 and 014, Federal Highway Administration, Washington, DC, 1997.

Ishibashi, I. and Yoon, J., *Feasibility Study of VDOT Geotechnical Database Management System (GDBMS)*, Virginia Transportation Research Council, Charlottesville, 2001.

Mathias, D. and Cribbs, M., User's Manual: DRIVEN 1.0, A Microsoft Windows Based Program for Determining Ultimate Vertical Static Pile Capacity, Publication No. FHWA-SA-98-074, Federal Highway Administration, Washington, DC, 1998.

Meyerhof, G.G., Bearing Capacity and Settlement of Pile Foundations, Journal of Geotechnical Engineering Division, ASCE, Vol. 102, No. GT3, Proc. Paper 11962, 1976, pp. 195-228.

O'Neill M.W. and Reese, L., Drilled Shafts: Construction Procedures and Design Methods, Report No. FHWA-IF-99-025, and ADSC-TL-4, August 1999, Volumes I and II, Federal Highway Administration, Washington, DC, 1999.

Thurman, A.G., Computed Load Capacity and Movement of Friction and End-Bearing Piles Embedded in Uniform and Stratified Soil, Ph.D. Thesis, Carnegie Institute of Technology, 1964.

Tomlinson, M.J., Foundation Design and Construction, Pitman Advanced Publishing, Boston, MA, 4th edition, 1980.

Tomlinson, M.J., Foundation Design and Construction, Longman Scientific and Technical, Essex, England, 1985.

Yoon, J. and Ishibashi, I., *Pilot Study of VDOT Geotechnical Database Management System (GDBMS) Framework: The Hampton Roads Third Crossing (HR3X)*, Virginia Transportation Research Council, Charlottesville, 2002.

Yoon, J., *Implementation of Statewide VDOT Geotechnical Database Management System (GDBMS) Framework: The Woodrow Wilson Bridge (WWB) Route 1 Interchange (R1I) Site*, Virginia Transportation Research Council, Charlottesville, 2003.