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Recent Geotechnical Developments in Geospatial Information Systems Technology

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RECENT GEOTECHNICAL DEVELOPMENTS IN GEOSPATIAL INFORMATION SYSTEMS TECHNOLOGY

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ABSTRACT

Geotechnical engineering projects in current research and practice are increasingly undergoing geospatial analysis based on geologic and geotechnical data collected. The explosion of spatial data that is available for surface features, particularly from the raster based products, heavily used by commercial and available to the public, present only one dimension of site characterization. Geotechnical engineers are more interested in data with depth immediately below their project site retrieve from drilled and imaged subsurface surveys. The ability to optimize the use of new and existing subsurface data continues to be undermined by the lack of a common and agreed data format and structure. Over the past decade several initiatives have tried to develop some consensus, with limited success. The latest initiative for a common geotechnical data exchange standard is also described. Several projects based on the authors, experience are featured in this paper and serve as examples of the challenge of working with large and diverse subsurface geotechnical databases. Additionally, an update of a geotechnical data exchange format is also presented to point the direction for the future.

INTRODUCTION

Geotechnical data that is used to characterize the subsurface conditions have been predominantly in analog format, that is, printed boring logs, cross-sections, and maps. However, the continued increase of information technology in the practice of geotechnical engineering is slowly moving into the digital age. Many geotechnical consultants are recording field data directly in digital form. Currently, we have much of our geotechnical records documented in analog form and when a project needs to blend the available analog with the digital data it becomes a major task.

The exchange of data is another issue in the geotechnical community, due to the lack of a universal format for data exchange. In the geospatial community there have been international standards for spatial data exchange, such as the spatial data transfer standard (SDTS), that is able to cross different computing and software platforms. Several initiatives for data exchange formats have been published, even as standards, but remain to become a universal standard that is being used by all. The geotechnical community most likely converging to an international data exchange standard that will allow multiple of application driven database design using a standard for data transfer using extended markup language (xml).

The authors have participated in a number of projects that assemble geotechnical databases for use in geospatial information systems and are presented herein in the form of case studies. Additionally, the future of these computer systems can go as far as we prepare or educate the future engineering generations. A comprehensive effort to introduce civil engineers to geospatial information systems is also presented as the closing section of this paper.

GEOTECHNICAL DATA STANDARDS

Several geotechnical data standards have been proposed and published in the past 20 years, but without the authority to enforce their use it is difficult for them to become the common format for exchange. For example, the American Standards of Testing and Materials has the geotechnical standard D 6453–99, which describes a format of computerized exchange of soil and rock test data. The goal of this ASTM standard is to reduce the time and cost associated with the exchange digital data files among organizations (American Society for Testing and Materials 2007). The principal data elements are defined and the preparation of a text based data storage system is described so larger databases may be assembled. Specific rules for data formatting and organization are detailed throughout the document, including example distribution files.

The need for data standards that will combine spatially distributed data is for the exchange and sharing that will enable manipulation and analyses of these data coming from multiple sources. While basic computer based geotechnical databases have existed since the late 1970s (Toll et al. 2001), much has changed since that time. In the late 1980s developers began using Database Management Systems to create geotechnical databases in the form of exchange standards. In 1992, the Association of Geotechnical Specialists (AGS), in the United Kingdom created an exchange standard for geotechnical data. This standard was widely adopted within the UK and as time progressed, throughout the world. The AGS standard is composed of ASCII (text) files arranged in single file structure. This structure is divided into data groups, which is composed of fields which house the actual data. A data dictionary is employed to list and define the fields for each data group. In this way, spreadsheets or text editors may be used to manipulate the data. Site data, field data, and lab data are all contained within the AGS format (Toll et al. 2001). The AGS file format has gained a significant following worldwide. However, the format has some limitations, such as the lack of a logical structure, and the use of a single files for an entire project are thought to limit the file format (McPhail 2001). Since the database was designed for consultant and contractor use, it does not fulfill the needs of many in the research community (Benoit and Satyanarayana 2001).

The United States Universities Council on Geotechnical Engineering Research (USUCGER) and the National Geotechnical Experimentation Sites (NGES), has developed a standard for geotechnical data exchange based on the AGS method (McPhail 2001). Originally the NGES was to produce a central data repository for dissemination of the data acquired at limited NGES sites. The NGES file format was created as a more complex version of the AGS standard to fulfill the research needs of its users, while maintaining usability. The NGES format was originally developed within DBase. Later a Windows query module was developed to interface with the original file. Recently, the NGES database was restructured to run via an Internet interface and use a relational database that runs on a UNIX based server. A Java application is employed by the end user to access and manipulate the data in text form. Like the AGS format, the NGES format houses site data, in situ test data, specimen data, and lab test data (Benoit and Satyanarayana 2001).

The most recent standard discussed herein was developed recently by the Consortium of Organizations for Strong-Motion Observation Systems (COSMOS) in 2004 and supported by the Pacific Earthquake Engineering Research Center (PEER) Lifelines Program (LL). Based on the NGES data standard (which, as previously stated, was based in turn on the AGS standard), the COSMOS standard was created as a universally accepted standard to fulfill the needs of the research community as well as the commercial engineering community (Swift et al. 2004). Unlike the aforementioned data standards and file formats, the COSMOS standard utilizes the Extensible Markup Language or XML. XML is defined as a World Wide Web Consortium-recommended general-purpose markup language that supports a wide variety of applications (W3C XML Core Working Group 2000). XML was created in 1998 by the World Wide Web Consortium (W3C) as a format to facilitate data sharing between various platforms and languages, with primary focus on data sharing via the internet. XML provides a tree-based structure for data storage that is text-based. Data contained in XML files can be viewed and read as plain text with data interspersed that describes the hierarchy of the tree structure, and the attributes of the data itself. Since the data is visible in a text format, these files can easily be edited with text editors such as Notepad, Wordpad, TextEdit or most word processors. Additionally, though XML files are text based, many software packages can now display the data as more complicated formats. XML files are platform independent and can be imported into a variety of programs including GIS, Spreadsheet, and CADD programs. (W3C XML Core Working Group 2000). XML has been suggested for use in geotechnical databases numerous times previously; however the COSMOS database has been the first to release it to widespread use (Bardet et al. 2003). At first glance the XML data structure of the COSMOS standard resembles an inverted tree structure, however upon closer examination it can be seen to be much more complex, with circular relationships for many of the entities. Utilizing these relationships, data from the site, field, and lab is stored with minimal space and is able to be queried and accessed much more quickly than a database utilizing redundant data (Benoit et al. 2004).

Like the NGES database, the COSMOS database is accessed via the internet, and data is downloaded from a remote server. The COSMOS database takes this further by using a GIS map as an interface to locate the data (Turner et al. 2004). Additionally, COSMOS has adopted a data format for strong ground motion data, to standardize the dissemination of this data as well (COSMOS 2001). Much time, thought, and effort has been invested into the COSMOS database, including survey input from potential users (Turner et al. 2004). However, it is still to be determined whether this very complex standard will be universally adopted by the geotechnical engineering community. Electronic dissemination of geotechnical data is undoubtedly one of the newer aspects of geotechnical engineering. With the continued increase of computing geotechnics in the engineering profession, digital file dissemination has become the norm, even if no standard for dissemination exists. Even though numerous standards do exist, none have been universally accepted by the geotechnical engineering community (Wilding, 2008).

The Data Interchange for Geotechnical and Geoenvironmental Specialists (DIGGS) is the latest initiative, which moves from database standards to data interchange format. DIGGS is a coalition of government agencies, universities and industry partners that focuses on the creation and maintenance of an international data transfer standard. This coalition was formed through coordination by the US Federal Highway Administration (FHWA) sponsoring meetings and eventually forming the pooled fund study project. The initial base schema consists of geotechnical data including borehole, soil testing, site information and more (DIGGS, 2008). Other special interest groups are being formed such as the geoenvironmental and geophysics groups. More information can be found at:

http://www.diggsml.com. The sole purpose of this data interchange format is to house data for the shipment in an accurate and readily accessible manner. Data interchange standards are not work specifications or standards for the design of databases that are used to work with the data (Caronna, 2006).

BOREHOLE DATA QUALITY

Recent research has illustrated the need for a quality assessment of the data used for a particular study, particularly if the data was not originally collected for that study (Deaton et al. 2001). Generally, for a given project, those factors which contribute to a loss in quality of geotechnical data are considered and overcome by the initial engineer working with the data. However, upon use by subsequent parties, these limitations are rarely known or considered. In addition, D'Andria et al. (1995) noted that when two projects have different objectives, their assessments of geotechnical data quality may be significantly different as well, even when using similar quality measurement criteria.

CASE HISTORIES

1. VIRTUAL GEOTECHNICAL DATABASE FOR ST. LOUIS

This project was in response to the need of a geotechnical database for the purpose of earthquake hazard mapping in the St. Louis metropolitan area (Chung, 2007; Onstad, 2008). The project is a collaboration of several organizations both private and government from the states of Missouri and Illinois, brought together by the USGS National Earthquake Hazard Reduction Program (NEHRP). A brief description of the ongoing projects is available at: http://pubs.usgs.gov/fs/2007/3073/

The proposed Virtual Geotechnical Database (VGDB) for this ongoing project utilizes the database architecture developed by the British Association of Geotechnical and Geoenvironmental Specialists (AGS) and the Consortium of Organizations for Strong Motion Observations Systems (COSMOS) which is being implemented nationwide by the United States Federal Highway Administration (FHWA). This database incorporates a data dictionary and is written in Extensible Markup Language (XML). The VGDB will have web-based dissemination, making it user-friendly for clients to zoom in on an area of interest and access available geo-data.

Study Area

Currently, there is no over-arching organization of geotechnical data in the St. Louis Metropolitan Area (STL), which straddles the Missouri-Illinois boundary. As in Fig. 1, STL encompasses a land area of 4,432 km^2, or 29 quadrangles, and the southern part is about 200 km north of the New Madrid Seismic Zone (NMSZ), which produced several high magnitude earthquakes in 1811-1812 and earlier.

Both Missouri and Illinois have state geological surveys that cannot cross over state boundaries with their work. The states employ different systems of storage, database architecture and database management. There is a definite need within both the geo-professional community and government agencies to 1) combine relevant geologic and geotechnical data into one database, 2) share up-to-date information, and 3) allow for easy updating.

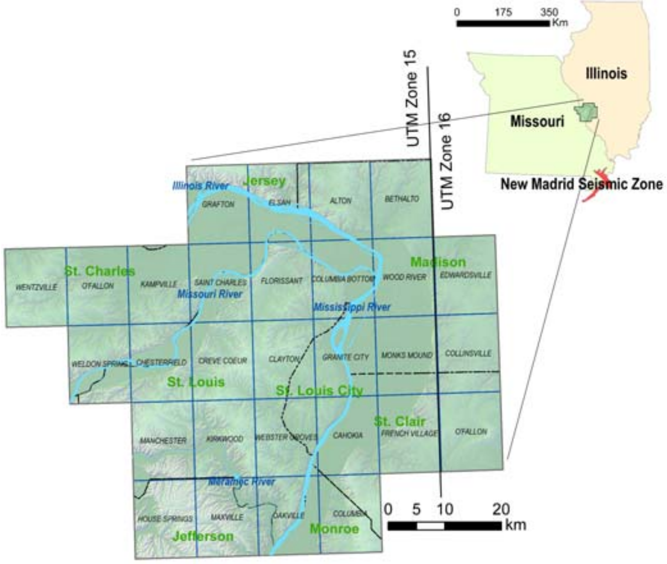

Fig. 1. The St. Louis Metropolitan Area, 200 km north of the New Madrid Seismic Zone.

ACQUIRING DATA

Because STL includes areas in both Missouri and Illinois, there is disparity between data types, formats, and availability. VGDBs need to encompass as many relevant data as possible to give users the choice of what to use.

Geology

Surficial. Surficial geological maps on the Missouri side utilized data from the Missouri Environmental Geology Atlas (MEGA) 2007 CD-ROM produced by MoDNR-DGLS. They compiled the map utilizing a digitized 1983 statewide surficial materials map as a basemap, then filling in with individual maps at a scale of 1:24,000. The stratigraphic units are not named.

On the Illinois side, the United State Geologic Survey (USGS) STATEMAP program funded the ISGS Metro-East mapping project. ISGS mapped surficial materials at a scale of 1:24,000, named stratigraphic units, and deduced depositional environment.

Bedrock. The VGDB incorporated bedrock geology maps from MEGA 2007 at 1:24,000 scale for the Missouri side. On the Illinois side however, the only available bedrock data was a statewide map at a scale of 1:500,000 (Kolata 2005). Correlating the bedrock geologic maps proves challenging due to the disparity of the map scales.

Landslides. Areas of landslide incidence and susceptibility are mapped from the USGS Landslide Overview Map (Godt 1997) at a scale of 1:3,750,000. The highest susceptibility areas are mainly along the eastern bank of the Mississippi River. ISGS georeferenced point locations of earth slumps, slumps on bedrock, rock creep, and flows. Larger landslides are depicted as polygons (ISGS 1995).

Cross Sections. Locations of seven depth-to-bedrock cross-sections for the Granite City, Monks Mound, and Columbia Bottom quadrangles were mapped. Hyperlinks were created in ArcGIS to the cross-section images produced by Karadeniz (2007).

Karst Topography. Solution of carbonate rocks cause this area to have Karst features like fissures, tubes, caves, and sinkholes. USGS mapped Karst features as applied to engineering aspects. It classified the length and vertical extent of fissures, tubes, and caves; bed dip; and rock type. Because this map is nationwide and on a scale of 1:7,500,000 (Tobin and Weary 2005), it is more accurate to use data in a smaller scale.

On the Missouri side, two layers in MEGA are sinkholes and sinkhole areas. Both map known and probable locations of sinks, and were transferred from 1:24,000 scale USGS topographic maps. The sinkholes layer contains point locations, whereas the sinkhole areas layer contains polylines representing larger areas typically about 200m (MEGA 2007).

In Illinois, ISGS mapped areas which are believed to contain sinkholes (Weibel and Panno 1997). While the scale is larger (1:100,000) than Missouri's, it is still more detailed than the USGS map and provides coverage for the east part of the Mississippi.

Geophysical

Seismic Hazard. Predicting site response to earthquakes depends on surficial material depth and composition. It is especially critical in this historically seismic area. Available maps from USGS give peak horizontal acceleration (Rukstales 2002) and point locations where earthquakes have occurred from 1568-2004 (USGS 2005). There are only four earthquakes locations within STL, all of which occurred in the 20th century. While these locations can pinpoint areas of vulnerability, it is more important to consider in the NMSZ. It may be 200 km away, but earthquakes are able to propagate through the relatively homogenous and rarely fractured bedrock and could have a dramatic effect on STL (source).

Therefore peak acceleration (given here in % *g* with 10% probability of exceedance in 50 years) becomes all the more useful. The problem is that the USGS data is nationwide, and does not take into account local site conditions. Deniz Karadeniz (2007) studied three quadrangles within STL that were most urban. Outside of these quadrangles are mostly single- and two-story buildings that would not be as dramatically affected by an earthquake. Data from the three quadrangles was incorporated into the database.

Magnetic Field. Variations in Earth's magnetic field were measured by USGS from 1995-2000. Though STL fits within an 86 km by 70 km square, there are still variations in the magnetic field. Parameters measured include direction (declination and inclination) and intensity (horizontal, vertical, and total), as well as the secular variation of each of these components over time (Tarr 2001).

Soil Survey Maps

The United States Department of Agriculture (USDA) created a nationwide soil survey. In 2004 they processed data for STL at a 1:12,000 scale, including ESRI ArcGIS shapefiles and Access database files. These detail the soil type, average percentage of slope, and areas of flooding (USDA 2004). Soil thickness maps from three quadrangles in STL, Granite City, Monks Mound, and Columbia Bottom, were calculated using the co-kriging method. Soil composition and thickness play a large role in determining the seismic site response (Karadeniz 2007).

Geotechnical Boring Logs

Locations where boreholes were collected from three different agencies were mapped. The Missouri Department of Natural Resources Division of Geology and Land Survey (MoDNR-DGLS) has a database contained in their Missouri Environmental Geology Atlas (MEGA) 2007 CD-ROM. There are 1720 of these in the STL area, and many were from the first half of the twentieth century. Each well log contains at least an identification number, well type, location, elevation, drilling depth, and owner of the well. Most logs contain at least the first six strata including geologic formation and layer thickness.

Most boreholes from the Missouri Department of Transportation (MoDOT) were drilled for bridge and highway construction. MoDNR-DGLS provided the 2,394 boring logs in Microsoft Access 97 format. Universal Tranverse Mercator (UTM) coordinates were an attribute for every log, allowing them to be mapped in ArcGIS. Each well log contains much more geotechnical information such as standard penetration test blow counts, dry unit weight, and sieve analysis.

The Illinois State Geological Survey (ISGS) collected borehole and water well data from the Illinois Department of Mines and Minerals and the Illinois Department of Public Health and county health departments, as well as some engineering borings from the Illinois Department of Transportation (IDOT). ISGS provided the 4,817 boring logs in spreadsheet format.

Borehole distribution and type is shown in Fig. 2. Illinois has boreholes more widely distributed because of the water well regulations, whereas boreholes on the Missouri side are primarily along major highways

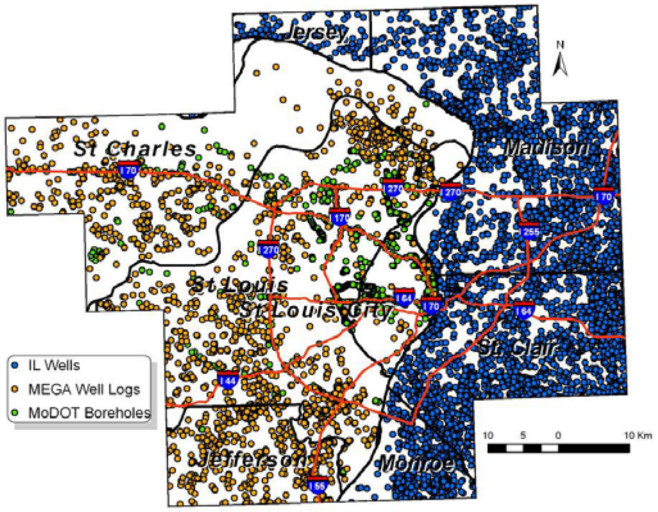

Fig 2. Locations and types of boreholes within STL.

Water

Groundwater. Two groundwater maps from USGS were added to the VGDB, one displaying principal aquifers, the other specifying aquifers of alluvial and glacial origin. Both are scaled at 1:2,500,000 (USGS 2002, 2003).

Surface Water. Lakes, rivers and streams on the Missouri side was extracted from MEGA, at a scale of 1:24,000 (MEGA, 2007). For the Illinois side, a map showing displaying surface water from ISGS at a scale of 1:100,000. On both sides, lakes and large rivers are polygons, while streams are polylines.

Historic. Old maps of STL from the nineteenth and twentieth centuries were scanned and the locations of major rivers and lakes were mapped. On the Illinois side, historic lake beds are the foundation for major highways. Rivers, especially the Mississippi, have changed their course over the past 200 years.

Human Activity

Mines. Areas containing both active and abandoned mines were added to the VGDB. MEGA provided point data for locations of both active and abandoned mines, along with the material mined. Active mines were displayed with a circle, while abandoned mines were displayed as a circle with an “X” through it. The color of the point varied with the material mined.

On the Illinois side, there are also points representing mine locations, but they are only in western Madison County. Polygons covering the eastern half of the Illinois side represent areas containing coal beds, as well as areas that have been mined. Polygons better than points convey the impact mining has had on the subsurface.

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Underground tanks. MEGA provided locations of both active and abandoned underground tanks. Active tanks are displayed with a neon green circle, while abandoned tanks are navy blue. The state of Illinois’ Environmental Protection Agency (EPA) provided data for tanks in Google Earth format (.kmz). These were converted into a shapefile for use in ArcGIS, but no metadata was provided. Only leaking tanks managed by the Illinois EPA have been mapped (Ill. EPA, 2008). These are represented by a neon green circle also.

FORMATTING DATA

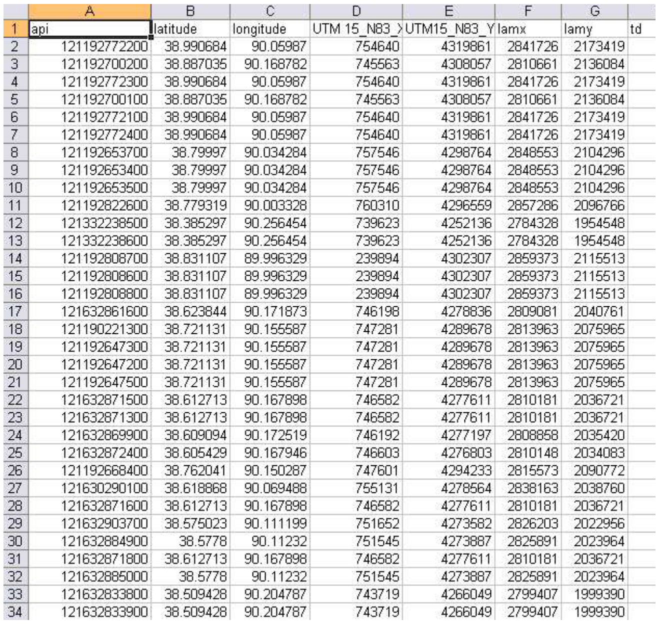
Formatting ArcGIS Shapefiles

File Type. When geodata is compiled from disparate sources, great attention to detail must be used to standardize them. Most data incorporated into the VGDB was acquired already in shapefile format. Some layers from the ISGS were in the ArcInfo interchange (.e00) file format, and the layer from the Illinois EPA was in Google Earth format (.kmz). ArcGIS imported the interchange files seamlessly, but the Google Earth files required a free translator plug-in.

Geographic Coordinate Systems and Projections. Geographic coordinate systems use three coordinates to specify locations on the earth. Most data layers used the NAD 1983 datum, which fits North America reasonably well. The “Projection Wizard” function within ArcGIS’ ArcToolbox was used to transpose layers that did not conform to the NAD 1983. Zones 15N and 16N in the UTM coordinate system were used. Zone 15 covers the Missouri side and most of the Illinois, with zone 16 covering the easternmost portion of Illinois.

Formatting XML

Conversion. The VGDB has three sources of borehole data with differing formats. Borehole data from MoDOT were in Microsoft Access format, well log data from both MoDNR-DGLS and ISGS were in Microsoft Excel spreadsheet format. In their current form, these data are difficult to read. Fig. 3 shows the spreadsheet obtained from the ISGS. Users must scroll left and right to obtain data about well logs, and it is inconvenient to use.



	A	B	C	D	E	F	G	
1	api	latitude	longitude	UTM 15_N83_X	UTM15_N83_Y	lamx	lamy	td
2	121192772200	38.990684	90.05987	754640	4319861	2841726	2173419	
3	121192700200	38.887035	90.168782	745563	4308057	2810661	2136084	
4	121192772300	38.990684	90.05987	754640	4319861	2841726	2173419	
5	121192700100	38.887035	90.168782	745563	4308057	2810661	2136084	
6	121192772100	38.990684	90.05987	754640	4319861	2841726	2173419	
7	121192772400	38.990684	90.05987	754640	4319861	2841726	2173419	
8	121192653700	38.79997	90.034284	757546	4298764	2848553	2104296	
9	121192653400	38.79997	90.034284	757546	4298764	2848553	2104296	
10	121192653500	38.79997	90.034284	757546	4298764	2848553	2104296	
11	121192822600	38.779319	90.003328	760310	4296559	2857286	2096766	
12	121332238500	38.385297	90.256454	739623	4252136	2784328	1954548	
13	121332238600	38.385297	90.256454	739623	4252136	2784328	1954548	
14	121192808700	38.831107	89.996329	239894	4302307	2859373	2115513	
15	121192808600	38.831107	89.996329	239894	4302307	2859373	2115513	
16	121192808800	38.831107	89.996329	239894	4302307	2859373	2115513	
17	121632861600	38.623844	90.171873	746198	4278836	2809081	2040761	
18	121190221300	38.721131	90.155587	747281	4289678	2813963	2075965	
19	121192647300	38.721131	90.155587	747281	4289678	2813963	2075965	
20	121192647200	38.721131	90.155587	747281	4289678	2813963	2075965	
21	121192647500	38.721131	90.155587	747281	4289678	2813963	2075965	
22	121632871500	38.612713	90.167898	746582	4277611	2810181	2036721	
23	121632871300	38.612713	90.167898	746582	4277611	2810181	2036721	
24	121632869900	38.609094	90.172519	746192	4277197	2808858	2035420	
25	121632872400	38.605429	90.167946	746603	4276803	2810148	2034083	
26	121192668400	38.762041	90.150287	747601	4294233	2815573	2090772	
27	121630290100	38.618868	90.069488	755131	4278564	2838163	2038760	
28	121632871600	38.612713	90.167898	746582	4277611	2810181	2036721	
29	121632903700	38.575023	90.111199	751652	4273582	2826203	2022956	
30	121632884900	38.5778	90.11232	751545	4273887	2825891	2023964	
31	121632871800	38.612713	90.167898	746582	4277611	2810181	2036721	
32	121632885000	38.5778	90.11232	751545	4273887	2825891	2023964	
33	121632833800	38.509428	90.204787	743719	4266049	2799407	1999390	
34	121632833900	38.509428	90.204787	743719	4266049	2799407	1999390	

Fig 3. A screenshot of the current state of borehole information, an Excel spreadsheet..

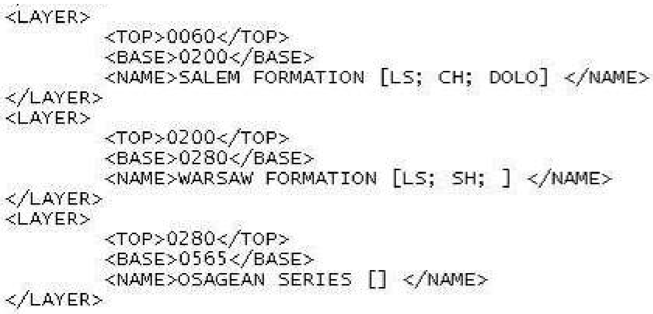
Access and Microsoft Excel translated the data into raw XML code (Fig. 4). The translation did not preserve the correct data format. Some modification of XML tags, which are elements describing the data, was performed. Having the data encoded in XML is only part of the formatting process. The XML document contains raw code and must be associated with two other XML documents: a schema which structures the XML code, and a stylesheet which formats the data in an easy to read layout.

Schema. An XML schema (a .xsd file) defines the structure of an XML document. As seen in Fig. 4, The "ID" element is the "parent" for all the other fields, making all the other fields "children." The elements "TOP", "BASE", and "NAME" are all children of "LAYER." Additionally, each element is associated with a data type classification, i.e. "string" if that data field contains text or "integer" if it contains numbers.

Schemata for data from all three sources were created. Because they all contain different information, the schemata had to be customized for each. The schema for MoDNR-DGLS contained only 12 elements, while the schema for MoDOT was most complex because there were over 30 elements to be structured.

Stylesheet. An XML stylesheet (an .xslt file) processes the raw XML code into the schema and transforms it into a readable format. It utilizes XML and HTML code to render page format including styled text, images, and tables. The resulting XML file is readable in internet browsers (Fig 5).

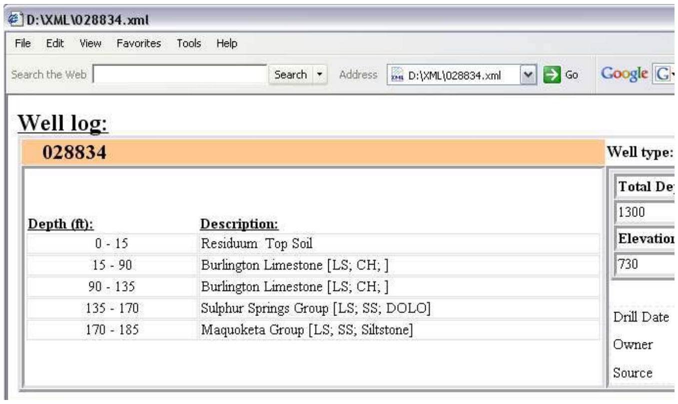
Because the boreholes data contain different elements, different stylesheets had to be created using the structure of the schemata. The primary objective when formatting the stylesheets was making the various elements easy to find for end users.



```
<LAYER>
        <TOP>0060</TOP>
        <BASE>0200</BASE>
        <NAME>SALEM FORMATION [LS; CH; DOLO] </NAME>
</LAYER>
<LAYER>
        <TOP>0200</TOP>
        <BASE>0280</BASE>
        <NAME>WARSAW FORMATION [LS; SH; ] </NAME>
</LAYER>
<LAYER>
        <TOP>0280</TOP>
        <BASE>0565</BASE>
        <NAME>OSAGEAN SERIES [] </NAME>
</LAYER>
```

Fig. 4. A portion of raw XML code displaying data for one well log.

In Fig. 5, the well log identification number is at the top in a larger font and in bold. Strata names and corresponding top and base depths were listed in table format on the left side. The top of the right side contained information such as the well type, total depth, and elevation. Below that information was the drill date, owner of the well, and source of the borehole data.



Well log:

028834

Depth (ft):	Description:
0 - 15	Residuum Top Soil
15 - 90	Burlington Limestone [LS; CH;]
90 - 135	Burlington Limestone [LS; CH;]
135 - 170	Sulphur Springs Group [LS; SS; DOLO]
170 - 185	Maquoketa Group [LS; SS; Siltstone]

Well type:

Total De

1300

Elevatio

730

Drill Date

Owner

Source

Fig. 5. A window in Internet Explorer displays the final XML output.

Data Dictionary

Because the VGDB incorporates subsurface data from three different sources, terms have to be standardized. The identification of borehole logs was dissimilar for all three sources. It was "api" for Illinois "ID" for MEGA, and "BH_ID" for MoDOT.

A data dictionary is a table that standardizes these terms. They are clearly defined so there is no confusion. A geotechnical database compiled by the Consortium of Organizations for Strong-Motion Observation Systems (COSMOS) developed a data dictionary based on needs of geo-professionals (Swift et al., 2004). The VGDB for the STL area used the COSMOS template for developing the data dictionary.

Terms from borehole data from all three borehole sources (MoDOT, MEGA, and ISGS) comprised this data dictionary. The database and spreadsheets were gone through meticulously to extract specifications and parameters for geotechnical data, such as the standard penetration test. The code is used when referring to the term within XML.

Metadata

Metadata, or data about data, almost always accompanies geodata. It includes information like the source individual or organization, map scale, geographic coordinate system, method of acquiring the data, and citation information. It is included as a separate file from the geodata, usually as a plain text (.txt) or raw XML file (.xml). The quality of the metadata is dependent on the source of the data. Sometimes metadata does not even exist, in which case it must be created.

Because this project is ultimately being produced for a national agency, metadata must be formatted to meet the Content Standard for Digital Geospatial Metadata, from the Federal Geographic Data Committee (FGDC) (FGDC, 2007). Most metadata from the USGS, MEGA, and ISGS already followed this standard. The metadata attached to the VGDB layers was checked to ensure compliance. Created layers, such as the cross-section layer, had no associated metadata. It was created in ArcCatalog, which includes an existing stylesheet titled "FGDC."

DATA OUTPUT

Map Output

There are several software options for the output of maps to the internet, including ESRI ArcIMS, Google Earth, and Scalable Vector Graphics (SVG) format. For this VGDB, SVG format was chosen because of its ability to quickly render large amounts of data, versatility across browsers, and preservability of appearance at any scale. Because ArcGIS 9.1 has limited SVG export capabilities, MapViewSVG, an ArcGIS extension was installed. MapViewSVG includes layout templates for placement of the toolbar, legend, scale, and overview map. The MapViewSVG toolbar contains zoom functions, pan, zoom to extent, measure, and coordinate read-out tools.

Once all VGDB layers were properly formatted using the methods in section three, they were selected for output. The MapViewSVG extension exported them to a folder "mapview" located in the same file structure as the ArcGIS file. Certain settings were entered, including the final size of the map window, which was set at 600 pixels. Certain layers were chosen to have their attribute tables viewable. The resulting SVG file was tested in an internet browser.

Viewing in a Browser

The resulting SVG map can be viewed in most standard browsers, including Mozilla Firefox 1.5, Opera 9, and Apple Safari 3.1 for Windows and Macintosh, which all have native SVG support. To view SVG files in Microsoft Internet Explorer, the free Adobe SVGViewer plug-in must be downloaded. In all browsers, the layout appears the same.

MapViewSVG also includes a query builder. Users can construct query expressions within layers. For example within the "Mines" layer, a user may want to see where all of the limestone mines are within the STL area. The user could then enter [material = limestone], and then either press the "Select and Zoom" button or the "Select" button. All data points matching the query would be highlighted. The query builder can also produce advanced Boolean searches. Using these searches, one would be able to find all past-producing limestone mines in St. Charles County.

VGDB APPLICATION EXAMPLE

Chung (2007) used the VGDB to map liquefaction potential indices (LPI) for the STL area. In that study, the logs of 450 boreholes were collected from MoDGLS for the Missouri side and 114 borings from the ISGS for the Illinois side, shown in Fig 6.

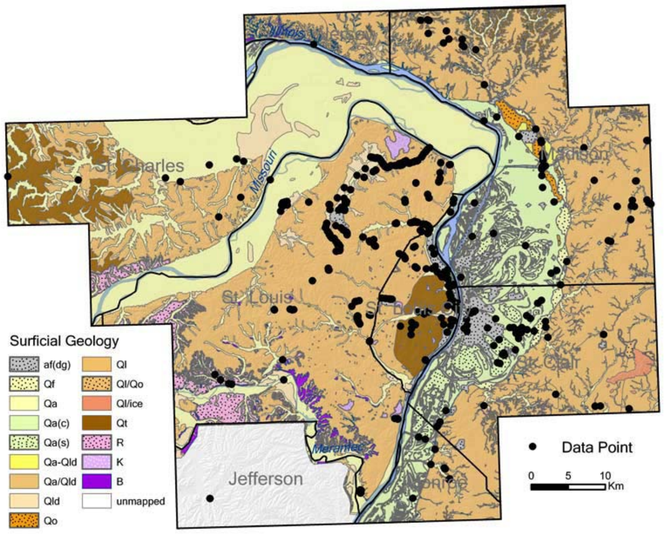


Fig. 6. Locations of geotechnical borings used to calculate the liquefaction potential index (LPI).

These geotechnical data were compiled from borehole logs made for bridge and highway construction by MoDOT and IDOT. These data provided the collar location coordinates, ground surface elevation, depth to groundwater, and a stratigraphic profile of each boring site. The soils sampled at each 115 depth interval included the following physical properties: 1) Unified Soil Classification System, 2) sample bulk density (dry and wet) (only for Missouri), 3) SPT-N blow count values, and 4) depth to groundwater at time of drilling. These borehole data were used to calculate Factor of Safety (FS) and LPI values.

LPIs of individual borings were computed by integrating the FS with depth and the depth as well as thickness of the soil layer within the soil column described in each borehole log, using the above-cited equations. Some geotechnical borings were excluded from the LPI computations, if any of the following conditions were met: 1) the boring log did not penetrate the permanent groundwater table, 2) the position of the groundwater table was not noted on the log, or 3) the groundwater table was in the Paleozoic bedrock (well below the unconsolidated soils). Where bedrock was encountered at depths less than 20m, calculations were only performed on the soil units above the bedrock.

The LPI values and the corresponding depths-to-groundwater (DTW) varied considerably within the mapped surficial geologic (stratigraphic) units. It was assumed in that study that depth-to-groundwater values exert the strongest influence on the calculated LPI values, given the body of available subsurface data. After establishing the relationship between LPI and DTW within mapped surficial geologic units, LPI values could be estimated in unsampled areas from the predicted DTW values. The liquefaction severities assessed from the estimated LPI values suggest that the alluvial filled valleys (where the DTW is shallow and the soils have low SPT values), are most susceptible to severe liquefaction in the scenario earthquakes of M7.5 with PGA values between 0.10 to 0.30g (Fig. 7).

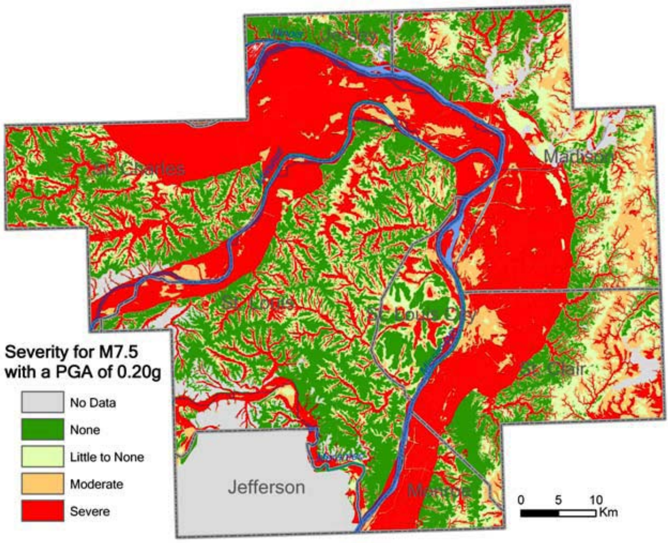


Fig. 7. Resulting liquefaction potential map inferred from LPI for an earthquake scenario of moment magnitude 7.5 with 0.20 peak ground acceleration.

2. MODOT GEOTECHNICAL DATABASES

The Missouri Department of Transportation (MoDOT) in conjunction with other state agencies has designated specific routes for vehicular access of emergency personnel, equipment and supplies in the event of a major earthquake event in southeast Missouri. These routes include portions of US 60, MO 100, I 44, US 63, and US 50. The routes traverse varied geologic settings and include or cross many critical roadway features such as bridges, slopes, box culverts, and retaining walls. The extent of damage and survivability of these critical roadway features in the event of a major earthquake event is not fully known and would impact the ability to use these designated routes to provide emergency vehicular access in a timely manner. MoDOT, the Missouri Department of Natural Resources (MoDNR) and the University of Missouri-Rolla (UMR) are working in collaboration to perform a preliminary assessment of these emergency vehicle routes.

Several roadway structures, such as bridges, are critical in maintaining service in the aftermath of an earthquake event. The first phase of this project focused on two bridge sites for site-specific earthquake engineering studies, the St. Francis River and Wahite Ditch bridges, along the US 60 route. This initial two-bridge site study outlined engineering procedures and level of effort required to perform detailed site assessment at these locations. These site-specific engineering studies consist of selection of ground motion, ground motion amplification, liquefaction and soil deformation analysis, soil-structure interaction, and dynamic superstructure performance. MoDOT does not have the capabilities to perform site-specific studies for every bridge site (approx. 70 bridges) along these routes in a timely manner. However, a geotechnical database that contains subsurface information along these routes could serve as a screening tool to identify bridge sites that require site-specific studies. For example, if the soil conditions at a bridge site are very competent and geotechnical hazards are minimal, a site-specific study is not warranted. On the other hand, poor soil conditions identified in the geotechnical database could indicate the need for additional site-specific studies. The motivation to develop the geotechnical database in this project was coupled with MoDOT’s intention to start a statewide GIS database of the subsurface data. GIS in civil engineering is becoming a more common tool for decision making (Miles and Ho, 1999) and use of geographically distributed geotechnical data can be used for more that one application.

New boreholes at the Saint Francis River and Wahite Ditch sites were performed to complement the existing data. Existing boreholes along the emergency routes were identified from MoDOT's archives for use in this project. The existing borehole data was obtained at other bridge structure sites that are located along the roadway alignment. For the purpose of this project, only boreholes located at a structure location were identified for development of the initial database. These existing borehole logs were available only in print paper form (or analog form) and an interface for data entry had to be developed in conjunction with the database design.

DATABASE DESIGN

In order to develop a database it is necessary to define the primary objective or problem to be solved - in this case, "a repository of usable geotechnical data for MoDOT". The design approach to the development of this database revolved around the overall goal of designing a MoDOT statewide geotechnical database and customizing it to the needs of the project. There are two classic ways to approach the design of a project about data management, "top-down" or "bottom-up". A top-down design approach consists of conceptualizing the problem, breaking it down into manageable sub-problems, identifying the methods and processes to use, and using these to manipulate the data to achieve a result that will impact the real world. This approach is very idealistic and applicable when there is no existing data and/or database. On the other hand, when there is abundant data, databases and information, the development of a system requires the use of a bottom-up approach. Real world situations that need an information system typically have generated large amounts of data. This requires the study of the data format and structure before the methods/processes are identified. Once the methods/processes to manipulate the data have been identified, the final model can be developed. Fig. 8 shows a hierarchical schematic of these alternative system design approaches. The two classical approaches described above present the extremes of how systems are designed (Rumbaugh, et al. 1991)

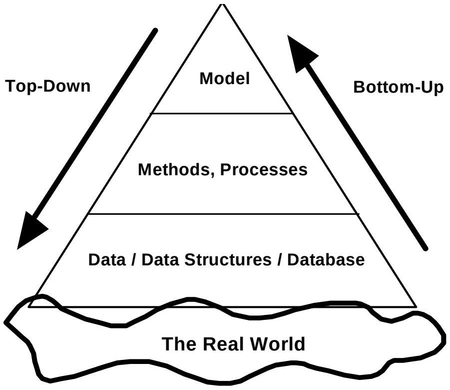


Fig. 8. Database Design - Top-Down vs. Bottom-Up

For this project an initial step was taken to model geologic and geotechnical data using a top-down approach. The topics related to the construction of transportation system and subsurface soil characterization are included in this initial phase. This resulted in modeling the information content and categorizing into different classes as shown in the following schematic, Fig. 9.

Existing borehole logs (and associated soil testing data) from the roadway alignment were also studied to consider the state of practice at the MoDOT. This prompted a modification to the database design approach and when the real data became available the database design shifted to a bottom-up approach. Notice that the categories dimmed in Fig. 9 were not pursued any further at this time. The scope of the database was focused to only include the data located at highway structures obtained by MoDOT borehole investigations. Other subsurface investigations, such as CPTs are not part of this database since they are not common practice at this time. In this case, a combination of the top-down and bottom-up approaches was used for the design of the database. The existing geotechnical data dictated the uniqueness of the application and the model developed. However, the design of the different tables was organized from a hierarchical point of view. In other words, the design was an iterative process of studying the data definitions, format, data structure and developing the conceptual model and methods.

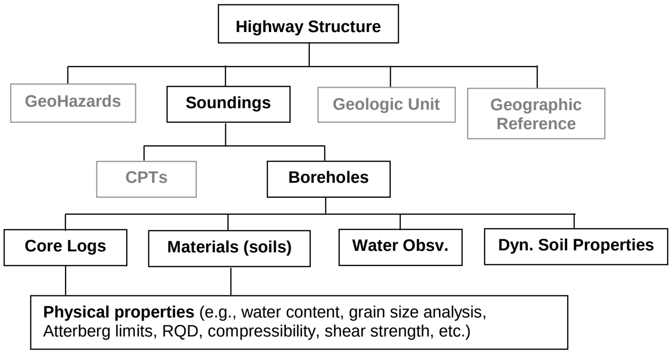


Fig. 9. Organization of MoDOT subsurface data

A GENERIC GEOTECHNICAL EXAMPLE

A traditional geotechnical engineering project typically concentrates on the subsurface characterization of a specific site and the interaction of man made structures with the earth mass, however, multi-disciplinary projects usually expand the focus of the project into other related fields (e.g., bridges, environmental, geology). For this purpose, the engineer is required to collect a broad range of available information to help solve the problem. The sources of information are the subsurface data recovered by invasive (e.g., boreholes, soundings) and non-invasive (e.g., geophysical, remotely sensed) explorations, the existing surface features, and the future surface and subsurface features planned for the site, if any. The multiple types of information are available in different physical forms and the engineer's expertise and judgment are used to synthesize this information and make decisions and recommendations about how to proceed with the project. When the amount of information that can be effectively collected and manipulated is abundant, the use of an information and database management systems can aid in the problem solving process for the engineer.

The data introduced into a database can serve a purpose for a continued period of time and not only for the particular purpose of a specific project. However, problems involving the legacy and integrity of the data may become an issue. For example, when data is retrieved and used it may incur changes that alter the database, depending on the read/write permissions allocated to a user. Spatial information uses coordinate systems and map projections that may be modified during the life of the data and a record of these transformations needs to be stored. Also, something as simple as the date and the units of a value stored in a field, need to be documented. Therefore, a record that keeps track of the data transformation and contents should be used and is usually referred as "data about the data" or *metadata*. Since a database may be intended to serve information for a continued period of time it is important to identify the data sources, the data requirements, and the data structures.

The general principles of object-oriented modeling and design were followed. The three models used in the Object Modeling Technique (OMT) are the object model, the dynamic model, and the functional model and they each represent a different aspect of the system: object model - static, structural, "data"; dynamic model - temporal, behavioral, "control"; functional model - transformational, "function" (Rumbaugh, et al. 1991). For this database, the object model has been adopted to represent subsurface geotechnical data and a generic example is shown in Fig. 10. These three kinds of models separate a system into three orthogonal views and are not completely independent, but each model can be examined and understood by itself to a large extent. The final architecture of the database was a product of the data structures and the module integration and will be discussed in more detail later.

Implementation

The database design was implemented using a Microsoft Access® software package. It is currently operational on a Pentium-based computer using the Windows NT operating system. The database is being populated by means of an interface designed specifically for this project and the following sections describe in detail the rationale and usage of these "forms" for data entry and are subsequently referred to as "tables". Over 100 highway structures and over 1000 boreholes have been entered to date and should suffice for the testing and analysis period of the database.

Data sources. This database of site and borehole data was designed for systematic data entry from Boring Data Report Forms of the Missouri Department of Transportation. There are some additional data that are included within the tables of this database and on the data entry forms that are from sources other than the MoDOT "Boring Data Report Forms". These additional sources of data include the UTM (Universal Transverse Mercator) coordinates for highway structures and the dynamic soil properties. UTM coordinates for borehole locations have not been provided at this time, but may be derived from georeferenced plans or may be calculated and provided by or entered by MoDOT as part of a Phase 2 of this project. These borehole locations must be added later through the edit routine in order to migrate the database to a geographic information system. Geotechnical data that is not traditionally generated by MoDOT was developed as a separate class to allow future modifications depending on the data provider. For example, dynamic soil properties were obtained based on field and laboratory tests performed by UMR for the site-specific studies, and it is handled as specialized data related to the bridge structure and related to specific boreholes, if applicable. In some cases, geophysical methods, such as a cross-hole geophysical test, may be related to two or more boreholes. The separation of the dynamic properties and earthquake data should be an advantage as MODOT expands the use of this database to other areas of the state where earthquakes are not a major consideration. It will also facilitate moving this table to a separate database if that should prove to be advantageous for data management.

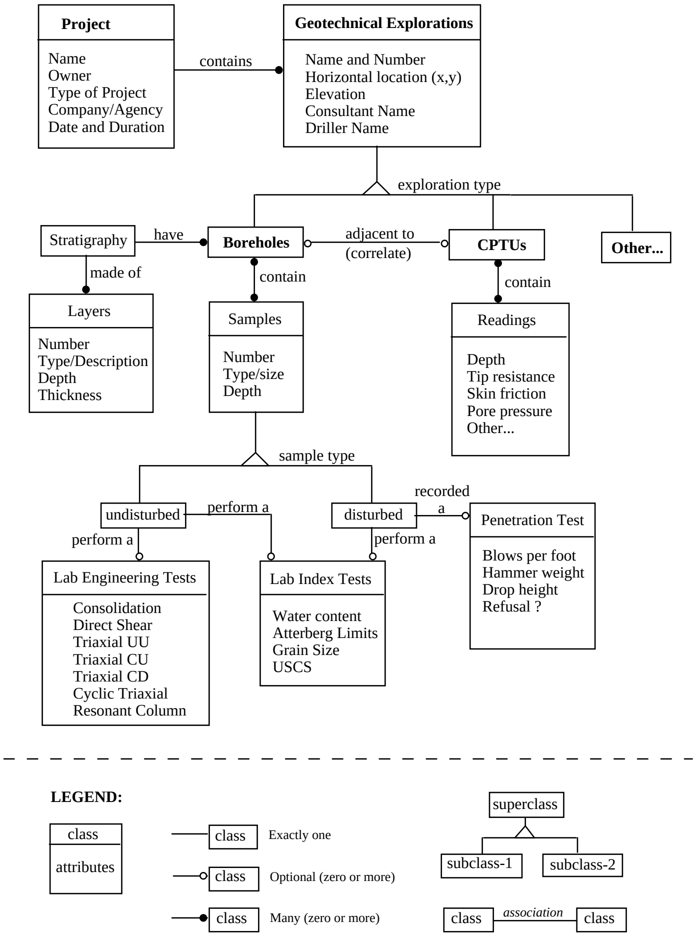
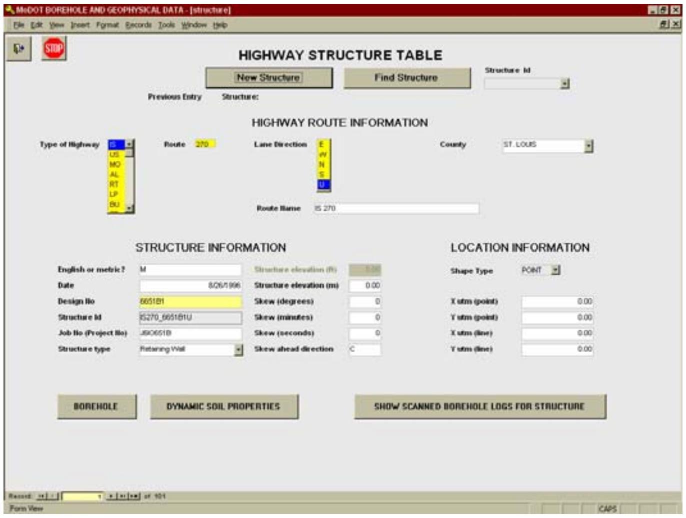


Fig. 10. An example of an object oriented geotechnical database model (Luna and Frost, 1995)

Organization of Data. There are eight tables of data within the MoDOT geotechnical database. The data is organized first with respect to a highway structure, such as a bridge, retaining wall, or box culvert, and then with respect to each borehole associated with that structure as shown in Fig. 11. The *highway structure table* includes data that identifies the structure, including the highway type, route designation, structure type and location information. The data entry form developed to populate the *highway structure table* is shown in Fig. 11. The *borehole table* includes data that identifies the borehole, including elevation, coordinates, roadway alignment stationing and fields that relate the borehole to a highway structure. The data entry form developed to populate the *borehole table* is shown in Fig. 12. There may be many borehole table entries for each structure. The remaining six table types contain the drilling, sampling, and testing data related to the borehole.



HIGHWAY STRUCTURE TABLE

Structure Id

HIGHWAY ROUTE INFORMATION

Type of Highway: IS (US, MO, AL, RT, LP, BU)
Route: 270
Lane Direction: E, W, N, S, U
County: ST. LOUIS
Route Name: IS 270

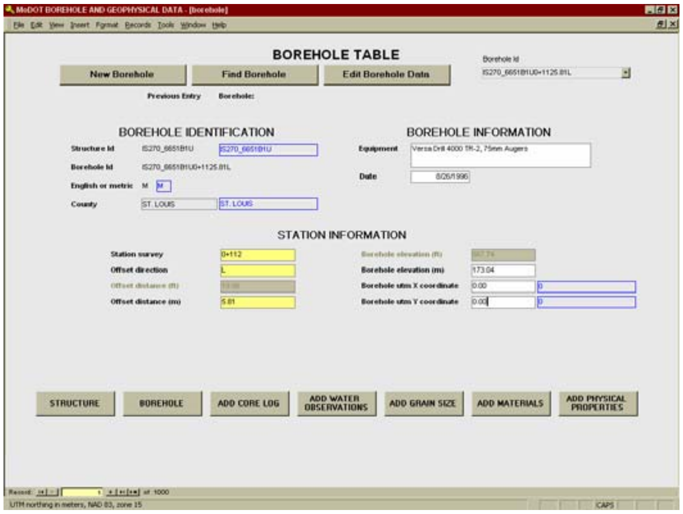
STRUCTURE INFORMATION

English or metric?: M
Date: 8/26/1996
Design No: 6651B1
Structure Id: IS270_6651B1U
Job No (Project No): J6IO651B
Structure type: Retaining Wall
Structure elevation (ft):
Structure elevation (m): 0.00
Skew (degrees): 0
Skew (minutes): 0
Skew (seconds): 0
Skew ahead direction: C

LOCATION INFORMATION

Shape Type: POINT
X utm (point): 0.00
Y utm (point): 0.00
X utm (line): 0.00
Y utm (line): 0.00

Fig. 11. Highway Structure Table – data entry form.



BOREHOLE TABLE

Borehole Id: IS270_6651B1UD+1125.81L

BOREHOLE IDENTIFICATION

Structure Id: IS270_6651B1U IS270_6651B1U
Borehole Id: IS270_6651B1UD+1125.81L
English or metric: M M
County: ST. LOUIS ST. LOUIS

BOREHOLE INFORMATION

Equipment: Versa Drill 4000 TR-2, 75mm Augers
Date: 8/26/1996

STATION INFORMATION

Station survey: 0+112
Offset direction: L
Offset distance (ft):
Offset distance (m): 5.81
Borehole elevation (ft):
Borehole elevation (m): 173.04
Borehole utm X coordinate: 0.00 0
Borehole utm Y coordinate: 0.00 0

UTM northing in meters, NAD 83, zone 15

Fig. 12. Borehole Table – data entry form

These tables separate the data based upon the type of analysis and conforms to the way this transportation department documents that data on the existing logs of MoDOT Boring Data, as provided. The tables are as described below:

- *core log table* – contains recovery and rock quality data about continuous cores advanced in rock.
- *water observations table* – contains the water level observations made while the borehole remained open allowing for different dates and times. This is not intended for water observations made from a piezometer or screened well.
- *grain size table* – contains the sample depth, percent sand, silt and fines, and the percent passing of each sieve tested.
- *materials table* – contains data related to the stratigraphy of the soil or rock encountered in the borehole. It includes descriptions, consistency, relative density and moisture documented in the field.
- *physical properties table* – contains summary data from most common soil testing results performed on samples (split spoon and "undisturbed" tubes) following ASTM and AASHTO procedures. They include: N-value, fines content, clay portion, dry unit weight, natural water content, plasticity index, liquid limit, classification, pocket penetrometer, Torvane, unconfined compression, internal angle of friction, and compressibility.
- *dynamic soil properties table* – contains field and laboratory data results of dynamic soil properties such as shear modulus and damping ratio as they vary with strain. The field geophysics was limited to those tests performed in one or multiple boreholes.

These tables each include identification fields that relate the data to the highway structure and to the borehole from which it was collected. There may be multiple records for each borehole within each table. The data entry form for the *highway structure table* (Fig. 11) includes an action button labeled "show scanned log" that may be used to view Microsoft Powerpoint displays of scanned images of the original MODOT reports. All of the reports from the suite of data provided are included within these Powerpoint displays. Each presentation includes images of all of the pages for a highway structure in a file named after the structure ID.

Data Entry and Editing

Each table includes fields that are mandatory, fields that are optional, and fields that are calculated or entered automatically based upon some previous entry. On the data entry screens, mandatory fields are in yellow (highlighted), calculated or automatic entry fields are grayed (dimmed) out, and optional fields are white (neutral).

The basic flow of data entry is to first enter the data into the *highway structure table*, and then proceed to the *borehole table*. After entering the data in the *borehole table*, data may be added into any of the other tables in any order. Upon completion of entering the data for a given borehole, the *borehole table* entry form can be accessed repeatedly to enter data for the next borehole until all of the boreholes for a structure have been entered.

Variations of this basic flow were designed to accommodate interruption of data entry within a borehole or structure and to permit editing of data that has already been entered. The *edit borehole data form,* was developed to provide the user with a comprehensive summary of the data entered in a borehole and it allows modification and checking of data entries. This functionality was proven to be very popular with the data entry users.

LINK TO A SPATIAL DATABASE (GIS)

The database was designed to link to a Geographic Information System (GIS). In principle, the geotechnical database can be referred to as a spatial database since georeferenced spatial coordinates have been included. However, the functionality has not been implemented. The data fields with geographic coordinates and referenced coordinate system are entry fields identified as key items in the databases. However, at this time the coordinates for each borehole are not all available. As in most DOTs, it is not standard practice to collect borehole locations from a geographic reference, instead a relative measurement of alignment stationing or an offset from an existing structure is made. It is essential to link the boreholes to a common geographic reference so they can be related to the other spatial themes.

Other spatial themes (e.g., geology, roadways, hydrography, political boundaries, etc.) are available from MoDOT and MoDNR and other common GIS data sources. The geotechnical database can be available as a new layer of information available in a highway project, only then the benefits of this spatial information can be exploited with the combination of the other spatial themes.

SUMMARY

The geotechnical database developed is MoDOTs initial step to make geotechnical data electronically available and hopefully more accessible to engineers and geologists. Geologic and soil conditions are factors that are taken into account in the decision making process of developing a transportation corridor. For the purpose of making decisions about earthquake susceptibility of emergency vehicle routes the same information may be used to locate problem areas or critical structures at risk. This geotechnical database will be used as a screening tool to determine where additional earthquake engineering studies are necessary. MoDOT has added many other boreholes to the database extending to additional emergency routes, such as US 100 route and will analyze the possibility of moving to a universal electronic geotechnical database once this prototype is used for the stated purposes and eventually migrate to a statewide system. Actually, the data for the US 60 route was recently used by Wilding (2008) in the development of a GIS-based seismic hazard screening tool.

3. GIS IN CIVIL ENGINEERING EDUCATION

Geospatial Information Systems (GIS) are now common place in practice and widely defined as computerized database management system that provides geographic access (capture, storage, retrieval, analysis and display) to spatial data. While the geotechnical industry sector is ahead in the implementation and use of GIS, the academic world has been slower to respond. Since civil engineering is replete with applications for GIS functions, public agencies' (the civil engineer's primary employer) use of GIS technology is increasing rapidly. There exists a consequent need for civil engineering students to be versed in GIS and able to apply GIS tools to civil engineering problems in innovative ways. Initially the goal was to decompose the basic elements of GIS applications and encapsulate them into sharable content objects utilizing progressive scaffolding as an important aspect of the object management design.

The learning system developed for the civil engineering curriculum focuses on a *geotechnical* application. The objective of the engineering problem is to make a decision based on the earthwork construction objective for a site and select an appropriate and cost effective soil borrow site for use in construction. The problem solving utilizes a map within the GIS. The prototype consists of a comprehensive problem and an associated repository of learning objects organized using progressive scaffolding (Sullivan et al., 2004). Fig. 13 represents a schematic of the basic system framework. The system consists of three parts, foundational knowledge in civil engineering, operational procedures in *Arcview*^{TM}, which is a popular GIS software application, and an applied problem. The system will be used in classes where students are already knowledgeable in the civil engineering concepts, so modules for these components were not be developed as part of the prototype, though they may be developed in later iterations. The students' knowledge of GIS is diverse, since the classes where the system is to be used are multidisciplinary with students from various engineering disciplines. Therefore, the GIS modules are an important part of this prototype system. The learning objects are organized as scaffold media; designed so they will be applicable to students with different levels of knowledge. Novice students may require very rich scaffolding in the form of videos illustrating how to use the software, while other students may require less elaborate scaffolding in the form of text directions, while others may not require any extra guidance at all.

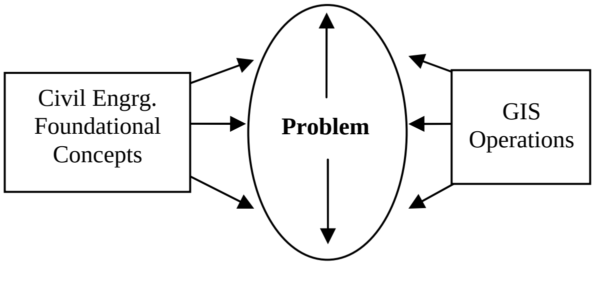
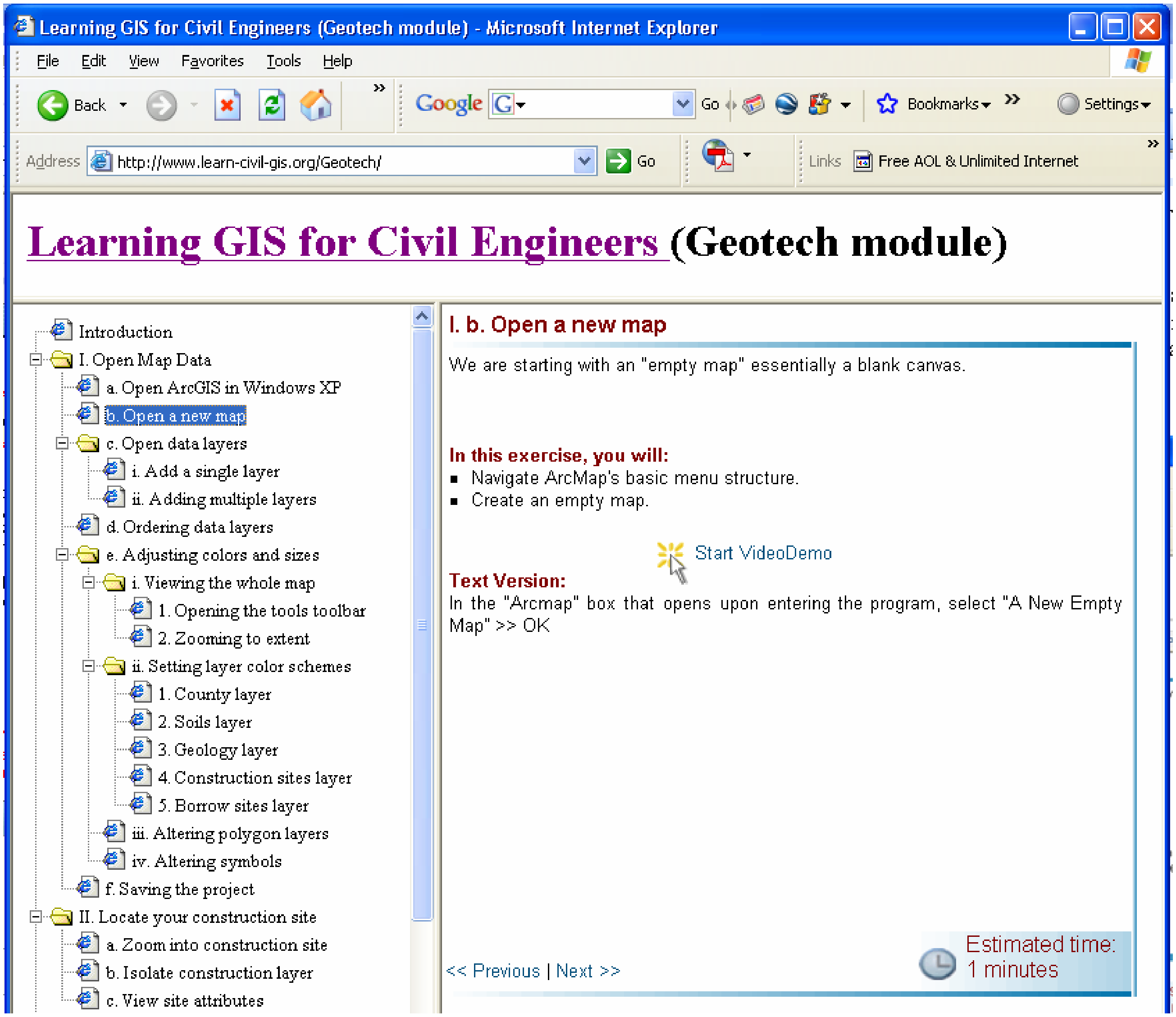


Fig. 13. Learning System Model

The applied problem was at the heart of the system, with the GIS learning objects providing support as needed. One of the common learning objects for this learning system is the "*ArcView™* Basics" topic, which was created using several content objects. These content objects consist of a text and video representation of the following topics: opening a map, displaying labels, *ArcView™* navigation bar, and adding layers. Students can select their own learning pace. The video demos were created with *Macromedia's Robodemo*©, and they are web-viewable via *Flash*©. Fig. 14 consists of a screen shot from one of the screens of the learning system displaying a learning object, and in Fig. 15 there is an example of the corresponding captured video. Other examples of the video components of this type of learning object can be found at http://campus.umr.edu/lite/gis, as well as a ZIP file containing the SCORM compliant object.



Learning GIS for Civil Engineers (Geotech module)

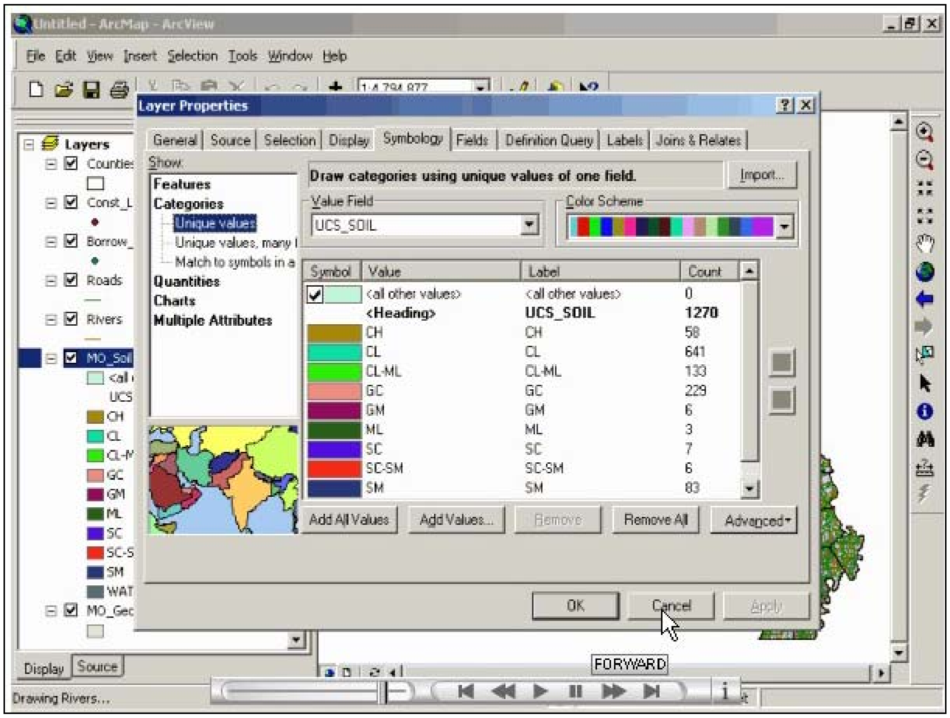
I. b. Open a new map

We are starting with an "empty map" essentially a blank canvas.

In this exercise, you will:
- Navigate ArcMap's basic menu structure.
- Create an empty map.

Text Version:
In the "Arcmap" box that opens upon entering the program, select "A New Empty Map" >> OK

Fig.14. Typical web-based window of the learning management system (Geotech module)



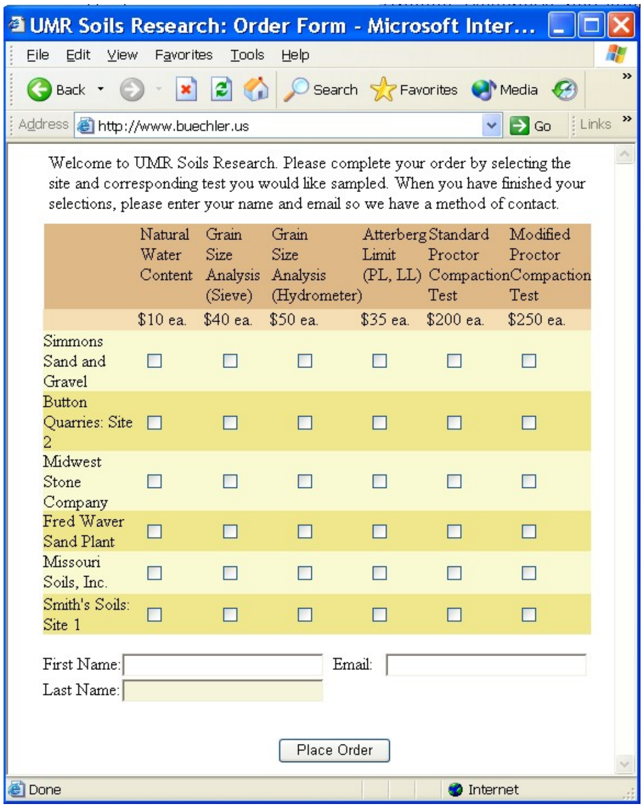
Draw categories using unique values of one field.

Value Field: UCS_SOIL

Symbol	Value	Label	Count
☑	<all other values>	<all other values>	0
	<Heading>	UCS_SOIL	1270
	CH	CH	58
	CL	CL	641
	CL-ML	CL-ML	133
	GC	GC	229
	GM	GM	6
	ML	ML	3
	SC	SC	7
	SC-SM	SC-SM	6
	SM	SM	83

Fig. 15: Snapshot of the Video Demo showing an example of the particular learning object.

To simulate a "real world" engineering scenario for the students during the exercise, a learning object was developed to request laboratory analysis thereby simulating a virtual commercial laboratory. An engineer often needs to run laboratory tests of the materials used in construction. Samples are obtained in the field and then sent for testing to a laboratory. In this case, a student goes to a website that represents the portal of the virtual lab (see Fig. 16) to assign laboratory tests for the different soil borrow sites. The student selects from the matrix the type and quantity of tests and sends that request to the virtual lab. The student is asked to enter his/her email address to be able to send back to him/her confirmation messages. This website was developed as an applet that queries a virtual lab database, processes lab data results and generates two email messages, the test results and invoice. This way the student is aware that the laboratory data is essential to make the engineering decision and that this effort in generating the data incurred "real" costs. The applet describe above is a critical learning object. Coupled with the informational (or training-style) learning objects, it enhances the level of learning objectives obtainable by the repository of objects. It also serves to demonstrate the heterogeneity allowable by the ADL/SCORM standard. Students have a wealth of knowledge available to them via the e-learning system and professors have the freedom to implement a variety of possible learning experiences.



Welcome to UMR Soils Research. Please complete your order by selecting the site and corresponding test you would like sampled. When you have finished your selections, please enter your name and email so we have a method of contact.

	Natural Water Content	Grain Size Analysis (Sieve)	Grain Size Analysis (Hydrometer)	Atterberg Limit (PL, LL)	Standard Proctor Compaction Test	Modified Proctor Compaction Test
	$10 ea.	$40 ea.	$50 ea.	$35 ea.	$200 ea.	$250 ea.
Simmons Sand and Gravel	☐	☐	☐	☐	☐	☐
Button Quarries: Site 2	☐	☐	☐	☐	☐	☐
Midwest Stone Company	☐	☐	☐	☐	☐	☐
Fred Waver Sand Plant	☐	☐	☐	☐	☐	☐
Missouri Soils, Inc.	☐	☐	☐	☐	☐	☐
Smith's Soils: Site 1	☐	☐	☐	☐	☐	☐

First Name:
Email:
Last Name:

Place Order

Fig. 16. Applet Matrix for Virtual Soils Laboratory

Engineers need to provide reliable and cost effective solutions and throughout the learning system these principles are emphasized. Since the critical learning objective is to decide which soil borrow site to use for a particular construction objective, the issues of distance to the site, truck hauling costs and quality of material must be considered before a final decision is reached by the student. This information is provided via the GIS data learning objects incorporated into the repository. In combination, the complete set of learning objects provide an educational experience that exceeds what is traditionally obtainable via traditional text book instruction supplemented with laboratory experimentation. More recently, the scope of this geotechnical module has been expanded by the NSF Award (DUE 0717241) to include other discipline learning modules in civil engineering, such as, environmental, transportation, water resources and surveying. More information is available at: http://www.learn-civil-gis.org

CONCLUSIONS

The authors have provided brief summaries of some of the recent developments in Geographical Information Systems, as they apply to geotechnical engineering. These include the example of constructing a virtual geotechnical database (VGDBs) for the St. Louis metro area, which allows the compilation of subsurface geodata from an unlimited array of sources. The goal of VGDBs is to allow subsurface geodata to be accessed in a geospatially referenced interface, such as ArcIMS or Google Earth. The second case study involving the Missouri Department of Transportation highlights some of the problems the geotechnical profession faces in transferring analog records to electronic format, in the absence of overarching standards and established protocols for this purpose. To date, Great Britain has been the only nation to adopt specific database architecture (AGS) for subsurface information, although the USA is moving in this direction. The third case study points to the need for integrating all forms of information pertinent to any civil engineering project, and the challenge this poses for engineering education. GIS systems have the potential to provide context of a project to its surroundings, by varying the scale of examination; from the most minute project details, to bird's eye views of a project, all the way up to a global perspective. Most civil engineers have not previously considered projects in such a diverse range of scales, and geoengineers should begin appreciating the possibilities posed by these developments.

The exchange of geotechnical data will continue to be a major hurdle, due to the lack of a universal format for data exchange. In 1987 the National Institute of Standards and Technology began establishing Federal Information Processing Standards (FIPS) codes, initially for census data, such as states, counties, and named populated places. This soon evolved into standards for electronic data interchange, including Electronic Data Interchange (FIPS-161-2) and Integration Definition Function Modeling (FIPS-183), for engineering and architectural data.

In 1993 the American National Standards Institute (ANSI) developed Spatial Data Transfer Standards (SDTS) as a mechanism for archiving and transferring of spatial data between dissimilar computer systems.

DIGGS has been developed as an international geotechnical and geoenvironmental data interchange framework, based on XML and GML. Its implementation has recently been sponsored by the FHWA. The first special interest group (SIG) extending the schema is the geoenvironmental industry, which seeks to include insitu testing. More SIGs and expanded membership are under development, such as geophysical, hydrologic, and seismology databases.

These developments will inevitably draw a much broader exposure to geodata than in the past. A diverse range of agencies, engineers, geoscientists, and geospatial specialists will be sharing digitized geodata because GIS technology is rapidly becoming the primary medium by which surface and subsurface data is being collected, stored, synthesized, and summarized for products; such as maps, scientific studies, regulations, and project-level reports and designs. In the near future we can expect that geodata will be manipulated electronically to produce three-dimensional representations of subsurface conditions, similar to what already exists in the seismology and geophysical exploration disciplines (where virtually all of the data has been collected in electronic format for 20+ years now).

The geotechnical discipline has been slow to digitize their collected geodata, in part, because subsurface data has been collected for upwards of 100 years in an analog format, using dissimilar systems of data collection and reporting. Added to these factors are necessary decisions about database management and maintenance, QA/QC of errant data, differences in geologic interpretation (or, no interpretation at all), and the evolution of stratigraphic nomenclature (formation names used in the past are no longer recognized). There has been the additional complication of data ownership and securing permission to share what many clients view as proprietary information. Similar hurdles once existed in regards to sharing of water well information, and most states passed laws requiring that such information be shared in the greater interest of the public benefit. Legislation was recently enacted in several states to allow subsurface data collected from geoenvironmental monitoring wells to be placed in a state-managed repository. Similar measures may need to be undertaken with regards to reporting and release of subsurface geotechnical and geoenvironmental information in the USA.

Paper information stored in analog format, such as old boring logs, is rapidly disappearing. In the 21st Century technical information will either be converted to digital database formats, or it will disappear. Every other scientific discipline and practice area of civil engineering has begun exchanging GIS data, except geotechnical and geoenvironmental engineering. Existing subsurface data in analog format needs to be converted to, and combined with, GIS-based digital formats that allow reliable electronic access. It would appear that organizations like COSMOS and the State DOTs, encouraged by FHWA, will likely adopt DIGGS as a national standard. Geodata holders will increasingly find themselves obliged to depending on offsite geodata stored within open-source databases that employ the requisite standards for information exchange adopted on state-wide and nation-wide levels. One thing is for certain, the information technology revolution of the 21st Century will have an enormous impact on geotechnical and geoenvironmental engineering, and those who fail to appreciate these changes will suffer some undesirable consequences, soon finding themselves at a serious disadvantage in an increasingly competitive marketplace.

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