GIS FOR GEOTECHNICAL DECISION MAKING: VISUALIZATION OF CUT-OFF WALL CONSTRUCTION DATA

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ABSTRACT

Large scale geotechnical earthworks projects, specifically those related to earth dams, dikes, and levees, often require construction of deep vertical seepage barriers. With increasing frequency, the demands of contract compliance, resource scheduling, quality control, and budget management require structured and efficient management of large data sets. Unless properly recognized, the data management requirements can contribute to the complexity, duration and budget of the project. This paper discusses an application of Geographic Information Systems (GIS) technology to capture information from multiple data streams and provide geotechnical feedback, quality control, and project control feedback. This technology was used to provide information to the U.S. Army Corps of Engineers (USACE) as part of the high-profile rehabilitation of the 232-kilometer long Herbert Hoover Dike (HHD) around Lake Okeechobee in South Florida. The implication of this technology to other earthwork projects is demonstrated.

RÉSUMÉ:

Grands projets de travaux de terrassement, en particulier ceux liés à des barrages de terre, les digues et levées, nécessitent souvent la construction d'un parafoille. De plus en plus, les exigences de respect du contrat, la planification des ressources, contrôle de la qualité et la gestion budgétaire, nécessitent un système de gestion des données structuré et efficace. Sauf si cela est correctement reconnu, les exigences de gestion de données peuvent contribuer à la complexité, la durée et le budget du projet. Cet article examine une application de systèmes d'information géographique (SIG) pour capturer les informations de plusieurs sources de données et fournir une boucle de rétroaction des données géotechniques, contrôle de la qualité, et les informations de contrôle du projet. Cette technologie a été utilisée pour fournir de l'information à l'US Army Corps of Engineers (USACE) pour la réhabilitation à haute visibilité de la Digue Herbert Hoover (HHD), long de 232 kilomètres, autour du lac Okeechobee en Floride du Sud. L’implication de cette technologie à d'autres projets de terrassement est démontrée.
1 INTRODUCTION

Regardless of the contracting vehicle, large and high-profile construction projects are now requiring that the contractor capture large amounts of information to demonstrate compliance with ever-demanding project specifications. The challenge to the contractor community is how to best collect and manage this information without having an adverse impact of project execution and budget. GIS technology affords the construction industry an excellent “tool” to facilitate the contract requirements, while providing several advantages to the contractor. Geosyntec Consultants (Geosyntec) has developed GIS techniques to manage and visualize information from geotechnical, environmental, and construction projects. A deep cut-off wall around the HHD in South Florida was being constructed by Bauer Foundation Company (BFC) under contract to USACE. The cut-off wall technique used for the project employed the cutter soil mixer (CSM) process developed by BFC. In collaboration with BFC, Geosyntec developed a GIS application titled “WallTracker” to manage, visualize and remotely access in near-real time, data from the HHD project. This paper was prepared to achieve three primary objectives: briefly introduce the challenges associated with construction of the HHD cut-off structure; describe the CSM technology to address these challenges; and importantly, fully describe the capability and functionality of WallTracker to address the information demands imposed by USACE. The “collateral benefits” of WallTracker and other similar GIS applications are also introduced.

2 CASE STUDY – HERBERT HOOVER DIKE REHABILITATION

The HHD is the levee around Lake Okeechobee, the nation's second largest freshwater lake. It protects people, their properties and the agricultural industry south of the lake from hurricane-induced flooding. The levee was constructed in the early 1900s, raised after failing during hurricanes in 1926 and 1928 and finished in the early 1960s (USACE 2008). Later, the average lake level was increased to supply water to the growing population along Florida’s East Coast.

Potential hazards and problems within the HHD have been observed over the past decade, including sinkholes, heaves, toe saturation and internal piping. After the devastations caused by Hurricane Katrina in 2005, the urgency and importance of a rehabilitation of the HHD levee led the USACE in 2007 to place the HHD near the top of its list of high priority dams in need of repair (USACE 2009).

The main safety measure selected at the HHD was the construction of a cut-off wall through the existing levee. Starting in 2008, three contractors began to construct the cut-off wall. BFC was awarded two Task Orders to construct a 6.8-mile (11km) long cut-off wall using the CSM technique.

A generalized soil profile of the HHD is shown in Figure 1. In general, interbedded layers of limestone and sand, shell or sandy shells are found underneath fibrous peat.

![Figure 1: Generalized soil profile](image-url)
3 CUTTER SOIL MIXING AT THE HHD

CSM is a method developed by the German company BAUER Maschinen GmbH for the construction of cut-off walls and retaining walls. As with other deep soil mixing methods, the soil is mixed in situ with cement slurry. The result is a cemented soil possessing concrete-like properties. The main advantages of the CSM method over other methods include: (i) use of in-situ soil as a construction material; (ii) minimization of construction spoils; (iii) no ground vibrations during construction; (iv) continuous support of excavation side walls, and (v) applicability to large depths.

The CSM unit (Figure 2) consists mainly of the cutter wheels, the wheel-propelling gearboxes, shear plates, and a slurry nozzle located in between of the wheels. The in situ soil or rock is loosened by the cutter wheels. The slurry flows out of the nozzle (white arrow) and is mixed with the soil particles by the cutter wheels turning contrary to the slurry flow (dark arrows). The cutting teeth push the soil particles through the shear plates which have the effect of a compulsory mixer. Different types of cutter wheels with different types of cutting teeth are available to adjust the method to different types of ground like fine-grained and coarse-grained soils as well as in low-strength rocks.

![Figure 2: CSM unit (from BAUER 2009)](image)

The panel installation starts either with the excavation of a guide trench in the case of rigidly mounted CSM units or with the construction of guide walls in the case of suspended units. The trench serves mainly the temporary storage of excess volume of mix. The following steps are shown in Figure 3: positioning of the cutter head at the planned location; driving the CSM tool vertically into the ground (during which a homogenous, plastic mix is created by adding either a bentonite or binder slurry; and withdrawing the CSM tool while slurry is added. In this way brick-shaped CSM panels can be produced with length of 2.4 or 2.8 m, a thickness of 0.5 to 1.5 m and a depth up to 60 m. The continuous wall is created by a series of overlapping primary and secondary panels. At the HHD, the cut-off wall is designed to end 1.5 m below the highly permeable limestone layer (see Figure 1), resulting in a total wall depth of approximately 17 m. Further design criteria for the HHD project required by USACE include:
minimum wall thickness: 0.46 m;
permeability: \( k < 10^{-6} \) cm/s; and
Unconfined Compressive Strength (UCS) at 28 days: between 100 psi (0.7 MPa) and 500 psi (3.5 MPa).

To fulfill those criteria, BFC placed 25-inch (0.64-cm) thick CSM panels using binder slurry. Most of the slurry was added during penetration and the remainder during withdrawal.

The CSM method performed well in the loosely packed non-organic dike fill as well as in the sandy and shelly layers. Because of the negative impact of the organics on the strength evolution of the binder, the organic dike fill, peat, and organic silts were removed prior to mixing. This material was replaced by non-organic backfill materials by predrilling holes to the depth of the peat, replacing the peat with non-organic backfill, and then backfilling the hole using imported sand and/or non-organic native soils.

4 GIS AS THE SOLUTION TO INFORMATION MANAGEMENT

For the HHD project, Geosyntec worked in collaboration with BFC to develop a comprehensive geotechnical and construction quality control (QC) system utilizing GIS technology. The final product, WallTracker, proved to be an invaluable construction asset to the project. The remainder of the paper focuses on the development and use of WallTracker, including sections regarding the components, data flow, and functionality. A final section describes how WallTracker is used in decision processes for the HHD project.

4.1 Components

The WallTracker system consists of three primary and discrete components:
1. desktop GIS software to provide a graphical user interface (GUI);
2. relational database and associated automation used by project administrators (Master Database); and
3. secure File Transfer Protocol (ftp) site used to serve data to users.
The desktop software package is a Microsoft Windows® application developed using Visual Basic® and ESRI® GIS tools. It consists of a “front-end” GUI and a “back-end” relational database. The desktop software can be installed and used by multiple users and on multiple computers. It is intended to be used off-line, and can be “synched” with the Master Database when an internet connection is available.

The desktop software allows the user to view the site data in a graphical format (showing data in plan and cross-sectional views) or a tabular format (showing data in interactive tables). The functionality of the GUI is described below.

The Master Database is a relational database management system consisting of a Microsoft Access® or SQL Server® database and a series of geo-processing tools. The Master Database is used by one or more project administrators to assemble input data into a format that can be used with the desktop software package.

The secure ftp site is managed by project administrators, and is used to host three types of files:
1. input data files generated in the field and uploaded to the ftp site by field personnel, intended to be downloaded and assembled by the Master Database;
2. data files assembled and uploaded by the Master Database available for automatic download (“synchronization”) by users of the desktop software package; and
3. QC Reports generated by project managers with the desktop software package.

These components are related through the following formal workflow, illustrated in Figure 4. Letter designators on the figure are explicitly referenced in italicized type.

### 4.2 Data Flow

Input data are shared with WallTracker from five main sources. The three field sources include: Borehole Logs that present lithology interpreted and depicted in CAD format profiles \((A)\); Predrill and Cut-off Wall Panel dimensions logged in the field and entered into spreadsheets \((B)\); CSM data generated with drill rig instrumentation \((C)\). The contract laboratory provides test results that are delivered in spreadsheets \((D)\) and reports \((E)\).

Each of these input data streams are provided to project administrators in an automated fashion. Data from the field are uploaded by field personnel to the project ftp site \((F)\) and laboratory reports are posted by the contract laboratory on the laboratory’s ftp site \((G)\). When new data from any of these data sources are posted to either ftp site, the Master Database \((H)\) automatically downloads and imports them to its input tables \((I)\). The input tables are then processed by automated “input routines” (consisting of database and GIS tools) \((J)\) that append the new data to the master tables \((K)\) and format the data into spatial objects \((L)\).

In the GIS model, explicit geospatial referencing is absolutely critical. Point data, including the CSM and laboratory sample data, are simply assigned coordinates to reflect the location where the information was obtained. Coordinates are assigned both in a projected coordinate system used by the project (e.g., State Plane) for the plan view and in a cross-sectional coordinate system (i.e., station and elevation values). Boring, Predrill and Panel data, however, need to be converted into line and polygon data features. This is achieved by assigning coordinates (as above) to each vertex of the features (i.e., the top and bottom of borings and the four corners of predrills and panels) and using geoprocessing tools to join those vertices into shapes. Locations associated to laboratory reports are equally critical. The input routines identify newly posted laboratory reports on the contract laboratory ftp site, download them to a local drive, and compile a table with a relative filepath to each report (allowing them to be associated with specific georeferenced spatial features). Point, line and polygon features created by the input routines (and laboratory reports assembled by the input routines) are then uploaded to the ftp site \((F)\).

Any files on the ftp site \((F)\) that are newer than the associated files on a given user’s computer are automatically downloaded to the local hard drive (replacing the older files) when a user runs the “update routine” accessible
from the GUI (M). This way users can synchronize their data with the Master Database on a frequency appropriate to their work needs.

Users with appropriate permissions (i.e., project managers) have the ability to comment and check a box to “approve” data through the data view in the GUI (N). When the user has finished reviewing a series of data, they can run the GUIs “QC upload routine” (O) to output a “QC file” with the results of their review (P). This file is automatically uploaded to the ftp site (F).

When a new QC file has been uploaded to the ftp site (F), the Master Database downloads the file(s), and runs a “QC update routine” (Q) to update the master data tables (K) and uploads the modified data to the ftp site using the same tools as in the input routines (J). Only approved data are available for download and view by users with “client” permission.

When a given section of the Cut-off Wall has been completed and approved, the Master Database is used to automatically generate As-Built Drawings (R) in a format consistent with the client’s specifications. Approved sections of the Cut-off Wall are also output in a format viewable in three-dimensions with the C-Tech 4Dim Viewer® (S).

4.3 GUI Functionality

One of the key benefits of WallTracker is that users do not have to maintain any software licenses (all required software installations are available for free). The GUI portion of the WallTracker desktop system can be downloaded and installed on any computer with a Windows operating system. It requires an installation of the ESRI® ArcReader® software, available for free. The GUI can be used to interactively view all of the data and reports assembled in the WallTracker Master Database using several methods.
There are two primary “views” available in the GUI: a “Map View” and a “Data View” (Figure 5).

The Map View is constructed using GIS technology, mostly with standard tools and features in the ESRI® ArcGIS® system. In this view, users can visualize the data in two systems: a plan view, based on the State Plane projected coordinate system; and a section view (Figure 6), constructed parallel to the plane of the cut-off wall.

The functionality of the Map View allows users to:

- Select which layers to show on the screen by “checking” them in the Table of Contents, including (but not limited to):
  - Station markers and gridlines
  - Base map features (survey map and aerial imagery)
  - Pre-drilling lithology
  - Predrills and CSM Panels
  - CSM suspension pressure and volume
  - Verification Borings, color-coded by permeability and unconfined compressive strength
  - Geotechnical samples, sized by curing duration and color-coded by permeability and unconfined compressive strength

- Expand groups in the Table of Contents to show sub-layers and layer legends
- Navigate around the screen by using pan and zoom tools, or by entering a Station or Section code into available form items
- View the map scale and cursor position on the bottom of the screen
- Click on a feature with the “identify” tool to reveal data associated with that feature (Figure 6)
- Click on a feature with the “hyperlink” tool to open a report associated with that feature
The functionality of the Data View allows users to:

View (in a user-defined sort order) the permeability, unconfined compressive strength, moisture content, and other attributes of geotechnical samples and verification borings

Identify the local filepath of reports associated with individual samples

(if permitted to do so) comment and approve data for submission to the USACE, and view the results of that approval in the map view and upload the results to the Master Database

4.4 Use for Making Decisions

Two specific examples of how WallTracker was used on the HHD project to facilitate decision making processes are described below.

1. The contractor may need to adjust the cut-off wall construction process based on the encountered ground conditions. By visualizing the longitudinal soil profile (see Figure 6) potentially represents the initial information that is uploaded into the WallTracker system, as it comes from boring logs, geologic maps, etc. that may be readily available. By visualizing this information it allows the contractor to easily obtain the required design depth for any Predrill to replace all organic material.

2. Permeability and strength evolution of the cementitious mix were found to be strongly influenced by boundary conditions, including the permeability of the surrounding soil and temperature. The visualization of 7- and 14-day strength test results help to early recognize trends in the strength evolution. This capability allows the contractor to adjust the slurry mix design to the changing subsurface conditions.
5 CONCLUSIONS

The HHD is a technically challenging project that represented an ideal opportunity for the contractor (BFC) to introduce an innovative soil mixing technique (i.e., CSM) to USACE. Furthermore, the selected contracting mechanism and the detailed specifications developed by USACE for the HHD project allowed BFC and Geosyntec to introduce another innovative technology, specifically the use of a collaboratively developed GIS application (WallTracker) to manage and visualize data for the project. The CSM and WallTracker were up to the challenge and proved an ideal combination. Through this collaboration, both BFC and Geosyntec recognized the viability of these innovative systems to address progressively more challenging geotechnical undertakings.

6 REFERENCES

BAUER (2009) CSM Cutter Soil Mixing, Process and equipment, BAUER Maschinen GmbH

http://www.saj.usace.army.mil/Divisions/Everglades/Branches/HHDProject/HHD.htm

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