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NETWORKED GEOTECHNICAL NEAR REAL-TIME MONITORING FOR LARGE URBAN EXCAVATION USING MULTIPLE WIRELESS SENSORS

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ABSTRACT

A massive urban excavation is required to construct the below-grade rail platforms for the Transbay Transit Center. A performance-based approach was used to design the minimum stiffness of the shoring system to limit excavation-induced ground movements to appropriate magnitudes and minimize impact to adjacent infrastructure. During construction, a fully-automated near real-time digital geotechnical monitoring system that integrates wireless sensor data streams into an integrated database and decision support system called the Global Analyzer is used to track the performance of this excavation. Instrumentation used for monitoring includes inclinometers, deep settlement markers, extensometers, piezometers, and an automated total station network. Some of the advantages of the Global Analyzer system include (a) integration of all project monitoring data and construction history information in a centralized database, (b) the ability to compare measured and estimated or target performance, (c) the use of early indicators to understand problems areas prior to excavation reaching critical stages, (d) the distribution of geotechnical monitoring data to adjacent building owners and other stakeholders through a web-based portal, and (e) the generation of computer generated email alerts when threshold values are exceeded by a given instrument. The Global Analyzer is a key tool in supporting an efficient decision process informed by more complete and timely performance data. It represents a component of the decision support process needed in the observational approach and deformation control. This application is relatively new to such a large scale project in the US and provides an example of a large complex data collection and distribution system. The monitoring process used for this project takes advantage of the latest communications technologies in the monitoring of the construction of the Transbay Transit Center excavation in its complex urban environment.

INTRODUCTION

The Transbay Transit Center (TTC) will be a multi-nodal transportation facility located in the densely developed downtown portion of the SOMA district in San Francisco, California. This structure will house a below-grade train station to be used by the regional rail system, Caltrain, and the California High Speed Rail, connecting the urban centers of San Francisco and Los Angeles. To facilitate the construction of this below-grade train box, a large excavation is required. The excavation is a half of a city block wide by approximately four city blocks in length and is directly adjacent to twenty existing properties which range from one to 58 stories, 100-year old masonry buildings to modern high-rise towers comprising of some of the tallest and heaviest buildings in San Francisco.

The performance of the shoring system was specified to limit excavation-induced ground movements to appropriate magnitudes and minimize impact to adjacent infrastructure. In order to safely and efficiently construct this temporary excavation, a comprehensive geotechnical monitoring program was developed and implemented which gives feedback and insight into the performance of the shoring system. This enables the performance of the retaining wall and shoring systems to be compared to the movements pre-contract and enables troubleshooting guidance to be developed in near real time.

The geotechnical monitoring system is constructed using a variety of digital sensors which are connected to data loggers with wireless communication capabilities. The sensors track the horizontal and vertical movement at various depths along the perimeter of the excavation, water level changes inside and outside of the nearly impermeable shoring wall, heave in and around the excavation, excavation-induced movements of adjacent structures, and other important performance benchmarks. It is through the reliable monitoring of the excavation's performance that informed decisions regarding the means and methods of construction and deviations from the baseline design to be made purposefully and confidently as articulated in the observational approach proposed by Peck (1969). The system and its components build upon the deformation control cycle framework illustrated in Fig. 1 and described in Hashash and Finno (2008)

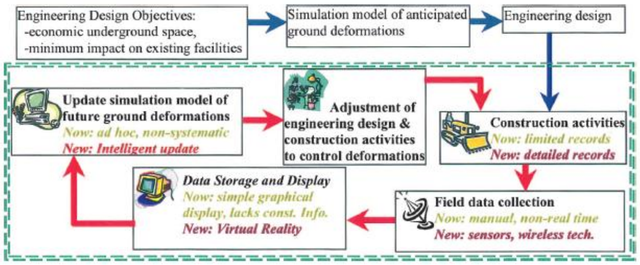


Fig. 1. Deformation control cycle for during deep excavations (after Hashash and Finno 2008)

PROJECT DESCRIPTION

The excavation is constructed using a system of internally braced temporary soldier piles embedded in a continuous cement deep soil mixing (CDSM) wall. The excavation is approximately 1,500 feet long by 180 feet wide and ranges from 55 to 65 feet deep. At the west end, the excavation tapers out to a width of 250 feet. There are four levels of internal bracing comprised of 3-foot diameter steel pipes, one-inch in diameter and spaced approximately 22 feet on center. The soldier piles extend to a depth of 95 feet and the CDSM wall extends to 105 feet, approximately 10 to 15 feet into a continuous marine clay aquitard, referred to in this paper as the Old Bay Clay, which acts as an impermeable cut-off.

GEOLOGIC SETTING

The site lies within the tectonic boundary of the North American and Pacific plates. This portion of California is locally referred to as the Coast Range geologic province. The landscape is generally composed of parallel hills and valleys, trending northwest to southeast. The hills are typically steep and the valleys can be quite deep and in some cases filled with deep sedimentary soil deposits.

The TTC excavation is in the middle of one of these deep sediment filled valleys located near the coast of the San Francisco Bay. The recent geologic processes involve the erosion of this valley and subsequent deposition of approximately 180 to 250 feet of sediments consisting of colluviums, marine sands and clays, alluvial and aeolian sands. Upon the arrival of the first Americans settlers to the area, the eastern portion of the TTC site was still part of the bay, an inlet called Yerba Buena Cove. During the rapid settlement of San Francisco, clean dune sands were used for the un-engineered reclamation of the bay fringes.

Figure 2 illustrates the idealized geologic cross-section at the site. Important units include the very dense sand and silty sand known locally as Colma Sand which acts as the bearing layer for many of the heavily loaded towers around the site, the Bay Mud and Lower Bay Mud which are a Holocene marine clay, and the Old Bay Clay Units I and II which are Pleistocene marine clays. The Old Bay Clays at this site are one of the thickest and deepest deposits in the San Francisco urban center.

As shown in the cross-section, a distinction is made for the east and the west sides of the underlying site materials which change considerably in the upper 90 feet. This change in stratigraphy corresponds roughly with the location of the historical 1852 shoreline. On the west side of the site, the original coastal side, the Colma Sand is quite thick and the Bay Mud is found to be overconsolidated by a factor of approximately 3 due to roaming sand dunes in the area. The east side of the site, originally part of the San Francisco Bay, has seen the erosion of the Colma Sand. This portion of the

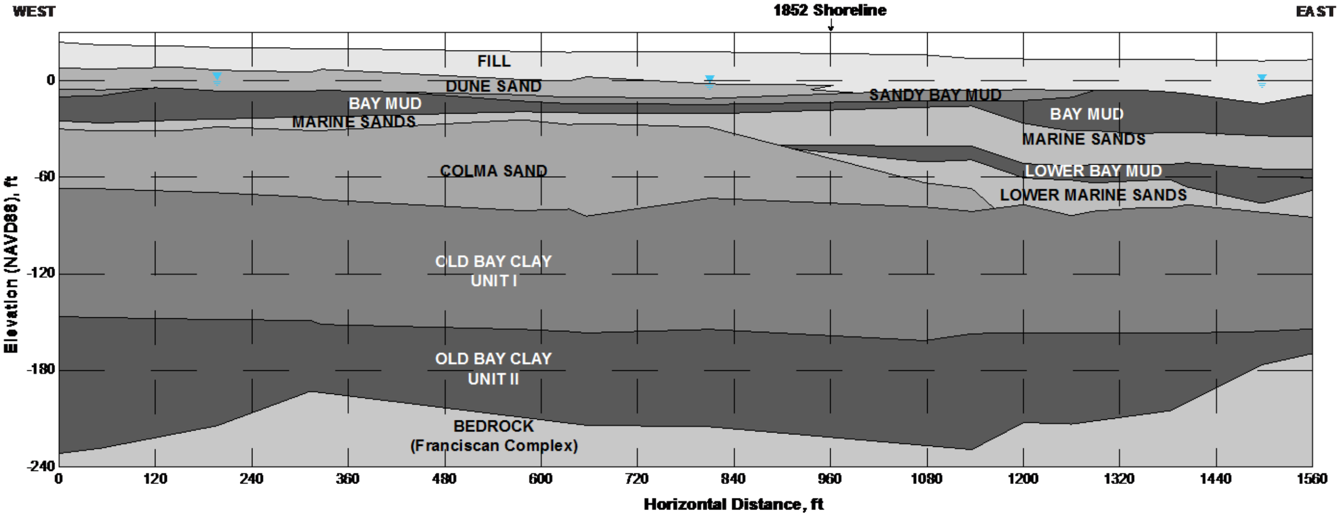


Fig. 2. Idealized Geologic Cross-Section.

stratigraphy was subsequently refilled with an additional sequence of marine clays and sands referred to in the illustration as Lower Marine Sands and Lower Bay Mud. Both the Bay Mud and the Lower Bay Mud were found to be nearly normally consolidated. Additionally, the dune sand is not found on the east side, instead the Fill, only distinguishable from the dune sand due to a slightly lower in-situ density and lack of cross bedding structure, is much thicker.

GEOTECHNICAL CONSIDERATIONS

Excavations in soil cause both vertical and horizontal reductions of stresses. As the stresses change, the soil will strain accordingly, resulting in excavation-induced movements and settlements. While these movements are unavoidable, it has been shown that the stiffness of the shoring wall and the number of horizontal supports used can be tailored to the ground conditions to reduce the excavation-induced movements to meet a targeted performance criterion of the shoring support system.

Movement of Adjacent Buildings

One of the important considerations in determining the performance criteria is the potential deleterious effects which the excavation-induced movements can cause adjacent buildings. It is important to understand the building’s construction type including structural system and foundation system, current performance and other issues affecting the performance of the building. Differential lateral and vertical movements can cause slight to major structural damage. The job of the shoring designer is to carefully understand the potential impacts to the adjacent buildings in order to strike a balance between an economical and effective shoring system.

Performance Objectives of the Excavation

For the TTC excavation, a minimum stiffness for the shoring wall and the bracing as well as the excavation and lift levels were evaluated using a combination of numerical analyses and traditional hand calculations using empirically derived relationships such as Clough and O’Rourke (1990).

The internal bracing system is design-built by the excavation contractor, following the minimum stiffness and guidance by the geotechnical engineer. The contractor must also meet performance criteria set forth in the contract documents. Connection details, sequencing, and other construction means and methods are decisions left to the contractor. The contractor may elect to take aggressive approaches to excavation at the start of the project and can tailor more cautious techniques, for instance leaving berms in place or limiting the distance of excavated lifts, to respond to the performance feedback of the monitoring system.

PHILOSOPHY OF THE GEOTECHNICAL MONITORING SYSTEM

Important geotechnical performance parameters can be monitored using a variety of methods. Vertical and lateral excavation-induced movement outboard of the excavation at the surface and of adjacent structures can be optically surveyed. Vertical and lateral movements at depths can be evaluated using deep settlement markers and inclinometers. Changes in water table can be tracked using piezometers and strain gauges can measure the forces in the internal braces.

In order to successfully construct the excavation meeting the required performance objectives, reliable and accurate geotechnical monitoring is imperative. As discussed above, the performance feedback from the geotechnical monitoring of the excavation will inform decisions regarding construction sequencing, remediation troubleshooting, and handling of adjacent structures. Additionally, the monitoring can yield assurance in the results of predictive geotechnical analyses during the early stages of the excavation, allowing the critical lifts to be performed efficiently and with confidence. Alternatively, monitoring results can illuminate problematic locations of the excavation at early stages if deviation from the predicted geotechnical response is found. For these locations, adjustments from the baseline scheme can be made to ensure successful completion of the deeper and more critical lifts of the excavation.

For the geotechnical monitoring of the TTC excavation, an array of digital automated sensors were used. For a large geotechnical construction project such as the TTC excavation, the procurement, installation, commissioning, and setup of the automated storage and processing of the digital data is more efficient than installation of a similar array of manually read instruments when considering the time to read the instruments and process the data by an engineer. Additionally, the reading intervals of the data can be more aggressive, about once every two hours for the digital readings at the TTC excavation, as compared with manual readings which would be taken on a two week interval assuming one engineer working full-time, circling the excavation while performing continual readings. Thus, the digitally automated data collection and distribution system gives more up-to-date data and enables much quicker responses to unforeseen deviations from anticipated performance of the shoring system.

Baseline Monitoring Data

Without adequate baseline monitoring data, the geotechnical engineer will find interpretation of the data challenging or impossible, or will simply interpret the data incorrectly. Therefore, proper baseline data is necessary to gain the benefits of the monitoring system.

At the TTC site for example, a digital piezometer was installed in one of the water-bearing strata over a one year prior to the commencement of the excavation. This piezometer tracked the seasonal fluctuations of the water table which showed approximately 2 feet of head change between the rainy and the dry seasons. This piezometric data can be used to assist in understanding the difference between the dewatering influence and the seasonal influence on the water table.

With regards to adjacent structures, buildings in downtown San Francisco have been shown to settle under their own weight. While the movements may be small, for critical buildings, a baseline data set of the building's performance prior to the commencement of excavation is important if the on-going settlement of a building is to be distinguished from the excavation-induced settlement of the building.

GEOTECHNICAL MONITORING COMPONENTS

A variety of instrumentation has been installed to monitor the TTC excavation. Nearly all of the instrumentation is comprised of digital sensors which are connected to dataloggers with wireless capabilities. The digital components and data transfer technology for instruments supplied on behalf of the owner have been solely installed and sourced by Geo-Instruments based out of Narragansett, Rhode Island. The internal bracing strain gauges have been provided and installed by the design-build contractor.

These various geotechnical monitoring components provide the data used in interpreting the performance of the excavation as described above. In total, there are approximately 46 inclinometers, 74 piezometers, 16 deep settlement markers, 11 extensometers, 230 optical survey targets, and 65 internal bracing strain gauges. A layout of the instrumentation can be seen in Fig. 3. The various components are described in additional detail below.

Inclinometers

Inclinometers have been installed around the perimeter of the excavation. These instruments provide a vertical profile of two-dimensional lateral movement over the depth of the instrument. For the TTC excavation, inclinometers were installed to depths ranging from 180 feet to 270 feet, each ending approximately 5 feet into the bedrock.

The majority of the inclinometers contain 15 discrete measured intervals also known as gauges, each of which have two sensors which measure absolute tilt off of the vertical axis in the direction perpendicular to the excavation (A-axis) and the direction parallel to the excavation (B-axis). Due to the depths of the inclinometers, a standard 10-foot gauge length between sensors was not possible with just 15 gauge intervals. Modifications were made to the inclinometers by suspending the deeper gauges from wires over the depths of the Old Bay Clay Units where it is anticipated that the lateral deformations will be linear and quite small. To date, this modification has been reasonably successful in most instances but has yielded difficulties in interpretation as compared with some inclinometers which have continuous gauge length where more than 15 sensor gauges were used. The fully continuous in-place-inclinometers were used in the most critical locations.

Piezometers

Piezometers have been installed around the perimeter and inside of the excavation. These track the influence of dewatering outboard of the excavation, the progress of dewatering inside of the excavation, and the changes in pore water pressures in the Old Bay Clays caused by the unloading from the excavation.

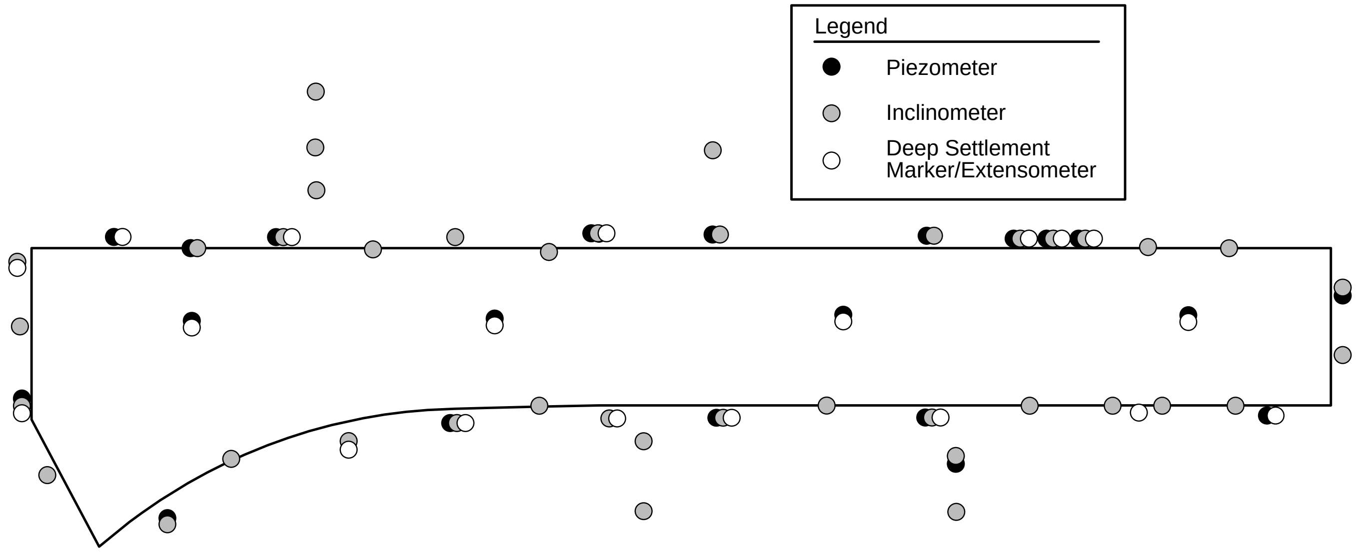


Fig. 3. Layout of Geotechnical Monitoring Components.

These piezometers are comprised of a digital pressure sensor using a vibrating wire and are installed simply by grouting the pre-saturated sensor into a standard geotechnical borehole. Wires are extended to the surface where they are connected into a datalogger. In many cases, a borehole used for and inclinometer casing, deep settlement marker, or extensometer was used to install digital piezometers alongside the other instrument.

Inside the excavation, there are four instrumentation clusters which contain ten piezometers each, installed at different heights. Two piezometers are located in the dewatered aquifer and are used to track the internal dewatering while the other eight are located at a variety of depths in the Old Bay Clay. These piezometers track the building and equalization of excess pore water pressures and are used in conjunction with adjacent extensometers also located in the Old Bay Clay, giving insight into the heave of the clay due to unloading.

Deep Settlement Markers

Deep Settlement Markers are located around the perimeter of the excavation approximately halfway between the shoring wall and the nearest adjacent building. These are comprised of a deep anchor installed at the approximate depth of the nearest adjacent building foundation. The deep anchor is grouted in place as well as a fiberglass rod which extends to the surface. This rod is sheathed so it can move freely and in conjunction with the deep anchor. The fiberglass rod frames into an anchored surface vault box where a digital sensor reads the differential movement of the fiberglass rod, tracking the relative movement between the deep anchor and the surface anchored vault box. Finally, to interpret the settlement of the deep anchor, an optical survey target is located at the surface near the surface anchored vault box and this reading is used in conjunction with the differential movement of the two anchors.

Extensometers

Some of the extensometers used at the site are similar to the deep settlement marker but instead of one deep anchor, five separate deep anchors are located at a variety of depths in the same borehole. Each deep anchor is connected to the surface with a different sheathed fiberglass rod. All five rods frame into a surface anchored vault box and each one's differential movement is tracked digitally.

In the center of the excavation, four instrumentation clusters containing nested piezometers at various depths are also instrumented with extensometers. As explained above, the differential vertical heave and the accumulation and dissipation of excess pore water pressures are monitored to understand the current heave and to better predict the final magnitude and time for the maximum heave to occur. The top surface anchored vault boxes for these extensometers are connected to the temporary internal trestle system installed in the middle of the excavation. Used to support the construction of the excavation, this fixed point allows the benchmark against which the relative movement can be compared to. Lastly, this internal trestle system is optically monitored so the absolute and not just the relative heave of the ground can be interpreted. A photograph of this installation can be seen in the photograph in Fig 4.

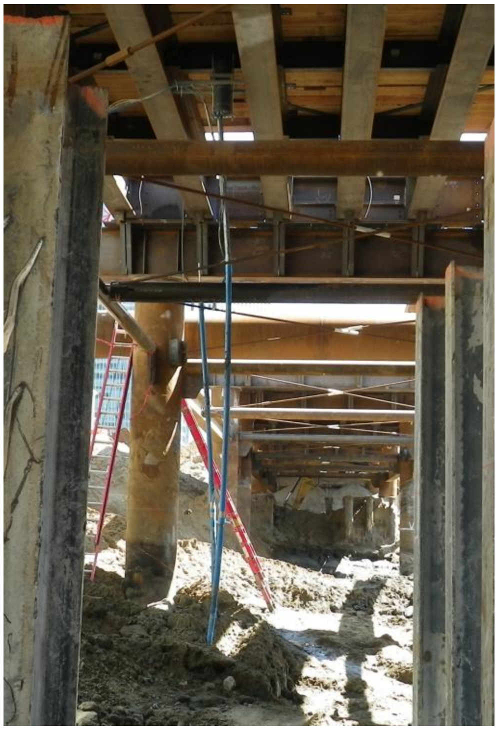


Fig.4. Photograph of the installation of the internal extensometers.

Additionally, the extensometers in the center of the excavation have the ability to be cut-down during the build-out of the train box and the surface anchored vault box can be reinstalled at the base mat. This allows the various heaves and settlements to be tracked throughout the build-out of the train box and the decommissioning of the dewatering wells, yielding more accurate predictions to be made for the various heaving and settling of the structure during all of these heave inducing construction processes.

AMTS

An automated total station (AMTS) network has been setup which performs optical surveys of over 100 survey prisms every two hours. The system is comprised of six automated theodolites evenly spaced around the excavation. These machines "learn" the location of survey prisms and using modern surveying techniques can interpret the location of these prisms based on their own location. As their own location may move slightly due to excavation-induced ground movements, the theodolites also monitor backsight survey prisms, located significantly outside of the excavation's zone of influence which are assumed to be fixed and not moving. The monitoring of backsights allows them to update their own position, thus producing more accurate absolute surveying of the monitoring prisms.

The monitoring prisms are installed at the tops of the soldier piles around the perimeter of the excavation. These prisms are monitored for weeks, where possible, prior to beginning of excavation to collect baseline data. Additionally, street mounted prisms are installed out-board of the excavation which can track surface settlements and lateral movements away from the face of the excavation. For all locations where deep settlement markers or extensometers are used, a surface mounted prism is used to track the movement of the top surface anchored vault box.

In some instances, survey prisms are installed on adjacent structures. This monitoring data is extremely useful in understanding the effects of the excavation on the structure itself. Based on the building's foundation system and the performance of the excavation, it can be easily shown that while the nearby face of the shoring wall may move, a building located adequately far from the shoring wall does not move at all.

Survey prisms are installed on the temporary internal trestle system and on temporary bridges, used to keep open live traffic roads over the excavation during construction. These prisms allow tracking of the performance of these temporary structures including assisting with the interpretation of the internal extensometers and the heave of the Old Bay Clays as described above.

The accuracy of the AMTS system has been impressive and the data collection and distribution has been practically seamless. Based on the monitoring results to date, readings appear to be accurate to 0.05 inches or better. Daily fluctuations of movement based on the expansion and contraction of the sunlight and heat absorbing structural components of the shoring system are easily tracked, allowing them to be accurately understood.

Figure 5 shows typical data for a survey prism located at the top of a soldier pile. Three-dimensional relative movement is plotted versus time. The daily fluctuations of the soldier pile can be seen as well as the accuracy at which the data is collected.

Strut Strain and Strut Forces

The strut strain and strut forces are monitored using groups of three strain gauges attached to each monitored strut. Approximately one out of four to five struts are monitored and at locations where a strut is monitored, all four levels of struts are instrumented.

The struts are instrumented by the design-build contractor. The contractor is also tasked with processing the data and transferring it to the Global Analyzer, the geotechnical monitoring data base.

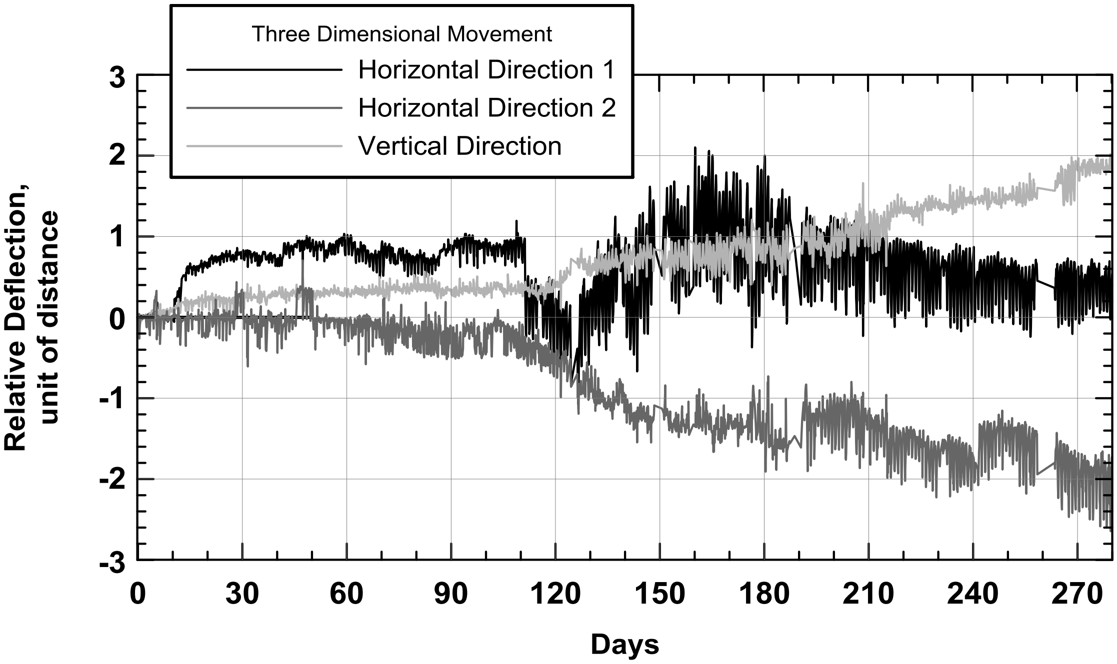


Fig. 5. Typical three-dimensional relative movement data collected for a survey prism.

Strut forces allow for a measure of the active pressures which the shoring wall is transmitting into the internal bracing system. Like all of the other monitoring data, these forces can be compared with the forces estimated during the design of the shoring system allowing confidence in the design or giving insight into areas which may need further evaluation or an adjusted approach to the excavation.

Back-up Manual Monitoring

All of the monitoring data discussed in the above subsections is collected digitally. While most of the technology used to collect this data has an established history of proven performance, a back-up manually read instrumentation system is very important to successfully monitoring the performance of the excavation.

It has been the experience with the TTC geotechnical monitoring that all the sensors will not be working all of the time. Sensors may fail unexpectedly, the batteries powering the data loggers may die, a cable connecting sensors to the data logger may be destroyed by construction activities, or data transfer can be impeded by the temporary failure of any of the various communication components. It is for these reasons that the monitoring system has partially redundant components which can be evaluated using manual collection techniques.

At important locations around the perimeter of the excavation, two inclinometer casing were installed side by side. The first inclinometer casing is instrumented with an in-place inclinometer which obtains digital readings while the second inclinometer casing remains vacant, allowing a standard inclinometer probe to be used to read its lateral movement. The two readings can be compared with one another to validate the digitally read inclinometer with a commonly used monitoring approach. Additionally, the in-place digital inclinometer is limited in accuracy based on only 15 sensors. The manually read inclinometers are read at two foot intervals, yielding approximately 125 individual tilt readings, making for a much better defined profile of lateral movement. Figure 6 compares the lateral movement of a digital in-place-inclinometer with that of an adjacent manually read inclinometer.

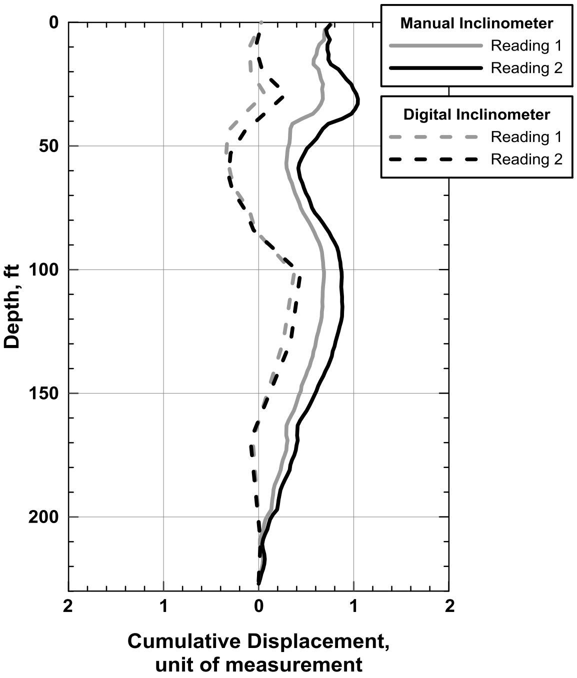


Fig. 6. Comparison of digital in-place inclinometer with an adjacent manually read inclinometer.

Manually read standpipe piezometers were also installed outboard of the excavation. These are read approximately once a month by an engineer using a standard water level reader. The results can be compared with adjacent digital automated piezometers to confirm they are accurately collecting data. Additionally, a digital piezometer can be lowered into the standpipe piezometers to a known submerged elevation and connected to a data logger with wireless capabilities. This makes for a comprehensive piezometer which collects and distributes near real time data but can also be manually read to both confirm the digital data and be used in the event that digital data collection or distribution is hampered by a glitch in the system.

THE GLOBAL ANALYZER, A WEB-BASED DATA PORTAL

In order to process, manage, review, and distribute the automatically collected digital geotechnical monitoring data, a secure web-based data portal, called the Global Analyzer, was created, specifically for the TTC excavation monitoring. Through this software, the instrument data can be easily reviewed by the various teams involved in the successful completion of the TTC excavation. The software also has a variety of tools which help ease the processing and management of the data. Some of the most helpful and efficient features are discussed below.

Data Processing

The software's first function is to receive the raw sensor readings from the data loggers. These raw sensor values are then processed using a variety of calibrations and mathematical equations to produce a representative engineering value. For instance, a vibrating wire piezometer is queried by its data logger and produces a raw sensor value. This specific sensor has been previously calibrated and its raw sensor value signifies a certain pressure which can be interpreted with a simple pressure conversion into feet of water. Additionally, the elevation of the sensor is known through the preparation of careful as-builts during instrumentation installation. The sensor elevation is used in conjunction with the sensor's interpreted pressure in feet of water to yield the piezometric elevation. This engineering value data is stored along with the time of the reading in a separate database which is kept ready for quick and efficient data presentation and distribution.

Secure Password Protected Access

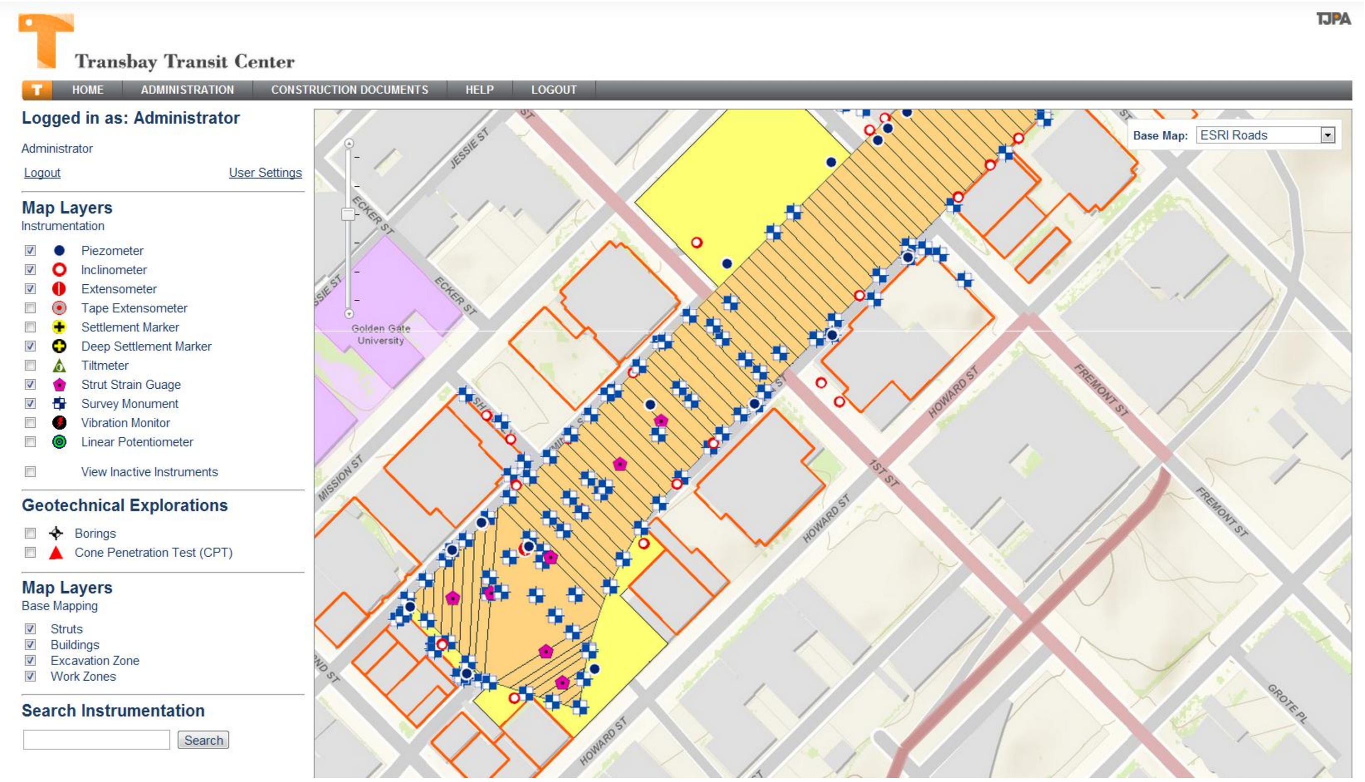
Upon navigating to the Global Analyzer website, the user is prompted for a username and password. There are a variety of data distribution and management tools which can be toggled on and off for various parties involved with the project. Logged in as an administrator, all of the data management tools are available but logged in as one of the third party accounts, only limited amounts of the data can be viewed and many of the management tools are disabled. The various user accounts are controlled through the Global Analyzer itself through the administrator account.

Spatially Distributed Icons with GIS Base Map

When a user enters successful login credentials, they are taken to the site's home page. The main feature of the home page interface is a GIS based standard road map with layers representing the limits of construction, the perimeter of the excavation and internal bracing system, and a variety of icons representing each instrument for which data can be viewed. The user can easily view data by simply clicking on one of the instrumentation icons. Figure 7 shows a screen shot of the home screen of the Global Analyzer.

The ability for the user to manipulate the map is straightforward as its functionality is based on standard internet map sites. For instance, the user can easily pan around by click and dragging. Zooming in or out can be done by using a slide bar or by simply using the scrolling tool on the mouse.

To the side of the map is a legend of the various instrument types and corresponding symbols. Check boxes next to the instrument types allow the user to toggle on or off a given instrument type to allow them to search for a given instrument type, for instance, only piezometers.


Logged in as: Administrator

Base Map: ESRI Roads

Fig. 7. Home screen of the Global Analyzer.

Data Presentation

When an instrument icon is selected, a pop-up window displays the data for that instrument. For most instruments, the engineering value, the raw sensor reading interpreted through sensor calibration or other automated manipulation, is displayed versus time. The entire data set collected and stored for that instrument is available and the user can manipulate the time interval in order to review data from a specific time range. Figure 8 shows a typical plot from a piezometer.

For inclinometers, there are two dimensions required to be plotted. For these instruments, three individual plots are created from the raw sensor data. The most current reading is displayed as well as the reading from two weeks and four weeks prior. The user can alter the date range of the three plots to query the rest of the inclinometer data available.

Once in the data presentation pop-up window, the user can quickly change both instrument and instrument type by using a pair of drop-down menus. This function allows the user to efficiently navigate through data without having to go back to the map-based home page and select another icon.

The data presentation window also contains a tool which allows the user to download the data. Once downloaded, the data can be easily analyzed and manipulated in spreadsheet form.

Instrumentation Management

An instrumentation dashboard is accessible for users with administrator credentials. This dashboard contains a table showing all of the instrumentation, its status as active or inactive and when the last reading was delivered to the database.

Each instrument can be selected in the dashboard and a pop-up window containing the properties of the instrument is displayed. These properties are editable and contain information about the location of the data files, GIS coordinates of the instrument for displaying the icon, the instrument calibration files which sometimes need updating if the instrument has to be fixed and recommissioned, the user logins which have permission to view the data from this instruments, and the error and alert thresholds for the instrument.

Email Alert System

As the Global Analyzer converts raw sensor data into a meaningful engineering value, it also evaluates that value against alert threshold limits. These alert thresholds are prescribed by the administrator and can be adjusted easily through the instrumentation dashboard.

About the Graph

The graph is generated from the live instrument data. Depending on the number of data points and user internet connection speed, graphs may take time (10-15 sec.) to load.

Instrument Type: Piezometer
Instrument Name: PZ-000
Start Date: 3-8-2011
End Date: 7-17-2012
Y Axis Min: -2.683
Y Axis Max: 6.54

Fig. 8. Typical data presentation from a piezometer.

When an instrument reports a value which is outside of the set thresholds, an email alert is sent out to a movement review panel which is comprised of members from various organizations such as the geotechnical engineer, the architect, the construction oversight team, the general contractor, the excavation and shoring subcontractor, and the project management team. An alert will be sent out every time an instrument's reading is outside of its threshold.

In practice, this threshold, once surpassed, is readjusted to allow another email alert to be sent when movement begins to happen again. There have been a number of instances where an alert has notified the movement review panel of movement almost immediately as it happened. The movement occurring in an area of no construction activities, thus there was not active reviewing of monitoring results for this location. After evaluation, it was obvious the movement was caused by a non-construction related event and prompt action allowed a successful and easy remedy.

Distribution of Selected Results to Adjacent Property Owners

Traditionally, geotechnical monitoring data is shared with adjacent property owners through the preparation of memoranda and reports. These documents are then distributed directly to interested third parties who are interested in the performance of the excavation with regards to their building. The Global Analyzer allows the process of data collection and distribution to be automated thus reducing the engineer's effort in preparing these data only transmittals.

Specific user accounts are created for the adjacent properties through the administrative tools on the Global Analyzer. Each third party property owner can view a limited group of the instrumentation data, typically only the sensors which are immediately adjacent to their own property. A seven day lag on the data is imposed to the data available to the adjacent property owners to allow for review and interpretation of false or misleading readings which are an inevitable nuisance with a completely computer automated system.

Mobile Access

The mobile revolution has expanded the ability to access data on personal devices such as cell phones and electronic tablets. The Global Analyzer is capable of reporting data directly to a cell phone or other hand-held device, allowing the geotechnical engineer to make observations in the field and immediately view corresponding geotechnical data. During discussions of excavation performance at meetings, any of the participants can access the near-real time data, reducing speculation and better informing decisions.

The implications of this new technological capability are immense. The efficiency at which data can be absorbed and analyzed is incredible, allowing quicker and more informed decisions. Additional improvements are needed to better streamline mobile access. Specific development of applications for the various source coding is needed in order to have more efficient access to the data on a variety of mobile devices.

SUMMARY

The TTC excavation is designed and constructed using a performance based approach. This technique requires accurate and reliable geotechnical monitoring in order to confirm estimated excavation performance and to illuminate the locations where additional conservative measure are required to successfully meet the necessary performance criteria.

The decisions made for the TTC project are heavily influenced by results of the comprehensive monitoring system that has been installed in and around the perimeter of the excavation. Most of this instrumentation is fully automated digital sensors connected to data loggers with wireless capabilities. These data loggers send the data to an ftp site and from there the data is automatically interpreted and checked against threshold values by the Global Analyzer.

This new tool, the Global Analyzer, is used to manage and distribute the data. The efficient distribution of the monitoring data helps to inform engineering decisions. Also, the capability to distribute the data to third parties streamlines the effort of the engineer, reducing documentation preparation.

CONCLUSIONS

The data management and distribution web-portal has proven to be a helpful and efficient tool in assessment of the excavation performance. There have been numerous specific performance concerns which were easily identifiable and understood through access to up-to-date and comprehensive data review.

While the understanding of the limits and potential future uses of this tool is growing, it is understandable that there is a need for significant customization of how the system accepts digital data. This challenge requires close interaction with the software developer. The inter-disciplinary efforts between the geotechnical engineer and the software programmers are important to improve the capabilities and wider use of this data management and distribution tool.

The use of automated system is not without the consequences of having only automated evaluation of data as it is dispensed to the greater team. This allows erroneous data to be available for review. As the geotechnical engineer, it is easy to evaluate data for its reasonability, however, other parties which are involved with the project may take the data as presented for facts when it could be a sensor malfunction or equivalent.

This can cause temporary confusion and additional effort by the geotechnical engineer to provide interpretation of results.

Finally, a geotechnical monitoring system is only as beneficial as the collaborative decision making process and execution of decisions of the greater excavation team. While the monitoring is important, only through successful interpretation and action of observed problems will an excavation proceed successfully.

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