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Spring 2006

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AUTOMATIC DEFORMATION MONITORING




Safety of structures, equipment and – most importantly – people working in and around the hole are paramount considerations for any large-scale below-ground excavation or tunneling project. It is imperative to provide accurate and frequent monitoring of structures, buildings and tunnel linings to detect any movements that could pose a safety hazard. In recent years, technology advances have permitted this deformation monitoring process to be automated through the use of robotic total stations and specialized software.

Like most passengers who have been recent frequent flyers out of Washington Dulles International Airport, editor Marc Cheves and publisher Allen Cheves have been watching the ongoing construction of an underground train system that is part of a massive $3.4 billion improvement program currently underway at the airport. When the opportunity arose for the Cheves Media team to take an up-close look at the tunnel project, they eagerly agreed. The tunnel construction work is being done by Clark Construction LLC and its subsidiary Guy F. Atkinson Inc., and joint-venture partner J.H. Shea. The automatic deformation monitoring system was supplied by Leica Geosystems through its dealer Loyola Spatial Systems, Inc.

Major Airport Expansion Project

Since it first opened in 1962, Washington Dulles has been one of the fastest-growing airports in the United States. During the late 1990s, Dulles' annual passenger traffic increased from 1.2 million to nearly 16 million. In 2000 the airport surpassed the 20 million passenger mark, and in 2003, even after the events of September 11, 2001, Dulles served 17 million passengers. Today, Dulles provides flights to 40 different countries and 85 U.S. cities. The airport employs a workforce of about 20,000 people, with thousands more employed by companies associated with airport activities.

To sustain this rapid rate of growth, the Metropolitan Washington Airports Authority has invested heavily in ongoing expansion programs, including the construction of two permanent midfield concourses. In 2000 the Authority unveiled the $3.4 billion D2 Dulles Development Program. The program includes two new daily parking garages, renovation of the original portion of the main terminal, a passenger walkway connecting the main terminal with Concourses A and B, extension of Concourse B, construction of a new airport traffic control tower, reconstruction of the cross-wind runway 12-30, construction of a new north/south

>> By Howard James


Note instrument at right. A slight amount of movement in the support columns for this overhead pedestrian walkway resulted in the installation of increased lateral support. More prisms were also installed to allow increased monitoring.

Data can be accessed through a real-time web-based portal from any PC or laptop.

runway and an underground train system connecting the terminal and concourses.

The underground train system, called Automated People Mover (APM), will replace the familiar Dulles "mobile lounges" that have been used for decades to carry passengers between the main terminal and midfield concourses. Initially, the train system will connect the main terminal to the east and west ends of Concourse B and C. Ultimately, it will be extended to form a loop encompassing the midfield concourse and the planned south terminal.

The 3.11 miles of tunnels for the underground train system are being built using three different methods. Cut-and-cover techniques are being used to excavate approximately 7,700 track feet in areas close to existing facilities and where above-ground construction will not affect ongoing airport operations. The New Austrian Tunneling Method (NATM) is being used in areas where the tunnels curve. The Tunnel Boring Method (TBM) is being used to bore approximately 4,300 track feet for straight tunnel runs. A 23-ft diameter tunneling machine is boring through solid rock approximately 55 ft below grade, with precast concrete lining segments mechanically put into place by the machine as it moves forward. The TBM machine is guided in real-time using a precision Tunnel Measurement System, also supplied by Leica Geosystems (see sidebar).

Deformation Monitoring Requirement

In mid-2004 Clark/Shea/Atkinson was awarded a contract for the West Automated People Mover (WAPM) construction job, followed in early 2005 by the East Automated People Mover (EAPM) contract.

Dieter Agate, Manager, Clark Field Engineering, said, "The nature of the job meant that tunneling work would take place in close proximity to airport buildings and active taxiways, and it was imperative that the work be completed safely and on time without disrupting airport operations. This meant a very extreme monitoring operation."

"From the beginning, it was made clear to us that real-time deformation monitoring was a top safety priority for the Metropolitan Washington Airport Authority," said Agate. "They issued very precise and detailed specifications

To speed up tunnelling progress, a second boring machine is prepared. Note spoils train in foreground and track switch to the left of the train. A train full of spoils comes out, and an empty train with new tunnel-liners goes in.

TUNNEL MEASURING SYSTEM GUIDES BORING MACHINES UNDERGROUND

Clark Construction's joint venture partner, J.F. Shea, is responsible for the underground drilling operations for the East Side tunnel construction job, using an automated tunnel boring machine (TBM) guided by robotic reflectorless total stations and special Tunnel Measuring System (TMS) software.

TMS was originally developed in Europe by Leica Geosystems in cooperation with the Swiss tunneling giant Amberg Nesstechnik AG, and is now making its debut in the North American market with the Dulles tunneling project.

The TMS software is used to load the projected tunnel profile onto a Leica TCRP1201 R300 robotic total station, which takes continuous measurements to reflectors affixed to the walls of the tunnel. These measurements are used to provide guidance inputs to the TBM as it cuts its way through the solid rock layer about 50 ft beneath the surface. The total station and reflectors are moved forward with the boring machine.

The TMS application programs include TMS SETout, TMS PROfile, and TMS Office. TMS SETout is a versatile setout tool that can be used on a mobile tripod for one-man setout or as a stationary console-mounted motorized round-the-clock surveyor. TMS PROfile provides automatic profile measurement for precise geometric information, exact profile compliance and reliable calculations for quantity surveying. TMS Office is used for tunnel profile design, provides multiple TMS applications, all running within a single database, and encompasses management of all measurements, setout and survey point data for every TMS software application module. Data for the full tunneling project is exported to the total station using a PCMCIA or compact flash card, allowing the total station to operate on the design data anywhere in the tunnel.

TMS SETout uses the remotely controlled reflectorless robotic total stations for rapid, efficient one-man setout of points with predefined coordinates. The TMS SETout PLUS program is designed for operation as a motorized tunnel laser by the tunneling construction crew without the need for a surveyor on the job.

TMS PROfile, which is comprised of the TMS PROscan and PROscan PLUS onboard software and TMS PROfit analysis packages, provides precise geometric data, continuous comparison of design vs. actual profiles and reliable quantity calculations. PROscan and PROscan PLUS deliver precise 3D measurement data, while TMS PROfit performs intelligent, results-oriented analysis.

calling for an automated multi-tiered system that would use motorized total stations to take continuous real-time measurements to multiple reflectors at strategic locations, networked through reliable radio data links to locations where the results could be monitored by Clark/Shea personnel as well as the customer's resident engineer."

Agate and the Clark/Shea WAPM and the Clark/Shea/Atkinson EAPM teams realized that this would involve a large-scale commitment to acquire the necessary hardware and software systems. The team's research indicated that the only instrument that would meet the specification of 24/7 monitoring and having the robustness to sit on a ten-foot stand for 24 months was the Leica TCA1800 robotic total station. Accordingly, in the summer of 2004, Agate contacted Bill Murphy at Loyola Spatial Systems, a major Leica Geosystems dealer in Virginia and Maryland.

"We determined that it was important to bring this technology in-house rather than contracting it out," said Agate. "It was also important to us that we have a single-source supplier who could provide a turnkey solution with a high level of technical support, and that's why we turned to the Loyola and Leica Geosystems team."

The specification called for high-quality, precision optical monitoring targets mounted on buildings, structures, support of excavation and tunnel linings, with fully automated motorized total stations under computer control to monitor remotely the three components of movement. Also required was a measurement precision of 1 mm for sight distances up to 100m, with wireless data links to the control site. The robotic total stations would have to be totally automatic and operate unattended 24/7 under all weather conditions, and also be insensitive to refraction effects caused by temperature or pressure variations. Each target would have to be "hit" at least every 30 minutes. The spec also stated that bicycle-style reflectors were not to be used; they had to be high-quality precision optical targets.

Murphy put together a proposal that included multiple TCA1800s, located where they could monitor hundreds of target prisms to be affixed at predefined intervals to the structures to be monitored. The measurement data would be transmitted at specified intervals via radio data links to a central location, situated three miles from the actual

Radio modem enclosure made from off-the-shelf watertight plastic gun case.

Murphy observed that the new Tunnel Measuring System offers unique user benefits. "The TMS programs provide long-term access to all project data and geometric elements directly on the total station without the need for separate field computers and time-consuming coordinate calculations. With all project data onboard, it is easy to switch between various construction tasks seamlessly and handle ad hoc work as it arises. Routine surveying tasks are performed automatically, increasing productivity and minimizing downtime. The modular software packages are scalable to meet specific job requirements, and the logical straightforward user interface makes it easy for the system to be used by both skilled surveyors and tunnel construction crews alike."

Custom-made instrument mount for transferring control into the tunnel.

Top & bottom: Two styles of mobile lounges are currently used to transport passengers from the main terminal to outlying concourses.

instrument monitoring stations. The total network would be tied together and controlled by Leica's GeoMoS (Geodetic Monitoring Software) system.

Training was another critical element. Murphy therefore made arrangements for Mike Eason, who would be responsible for managing the monitoring system for Clark/Shea and Clark/Shea/Atkinson, to attend a GeoMoS training session in Salt Lake City in March 2005. As soon as the training program was complete and the monitoring instruments installed, Eason was able to get things up and running.

Installation Challenges

Installation of the monitoring system was completed in April 2005 for the West Side, and August for the East Side. There were two TCA1800 total station sites on each side, for a total of four. The total stations were permanently mounted on 10-foot concrete and steel pillars with vented heavy-duty glass enclosures to protect the system from the elements. Each installation included an Intuicom radio and modem with directional antenna to transmit data from the site to the controller. Band pass filters were added to overcome the high levels of RF activity in the airport environment. The pedestals were isolated to eliminate vibration and movement.

"On the West Side, there was no permanent power, so had to use battery power instead," said Eason. "We decided to use deep-cycle marine batteries. Experience has shown that we can typically go for about one week between charges. On the East Side, we were able to tie into permanent power, but we added battery backup for redundancy."

The GeoMoS software was installed on the computer network in the Clark/Shea trailer, and was configured so that data can be accessed via a secure IP link by authorized Clark/Shea personnel and the resident engineer.

Protecting the remote sites from wind and weather presented special challenges, according to Eason. The glass enclosures had to be robust and rugged, capable of withstanding heavy winds, rain, snow and ice, and they had to be non-reflective so as not to distort the EDM signal. Necessity being the mother of invention, they experimented with a number of different types of enclosures – including clear round dog igloos – until they found the right solution.

"What we ended up using were large square glass terrarium enclosures that we bought from a pet supply store," said Eason. "They worked perfectly. They have hinged access doors so we can get to the total station easily. They are vented to avoid moisture and heat buildup inside and are sturdy enough to stand up to the extreme weather conditions year-round. Most important, there is almost no refraction of the EDM."

Likewise, it was necessary to improvise when it came to enclosures for the radio modems. Murphy said they eventually settled on watertight pelican-style plastic gun cases from a local sporting goods store.

Monitoring Software

"The GeoMoS software is a powerful tool for controlling the network of the remote sites, as well as collecting data, providing alarms, post-processing, reporting and visualizing data," said Murphy. "The software represents the data and results in graphical or numerical format. You can select a time-line graph showing the trends of movement over selected time periods. Multiple points can be viewed simultaneously in the same graph. Alternatively, you can select a vector view that shows displace-

Top & bottom: Converted terrariums from a pet supply store proved to be the perfect on-site enclosures for the TCA1800 total stations.

ment for a selected area, to easily see where the greatest movement has occurred."

Senior-level project engineers and other authorized personnel can access the GeoMoS data through a real-time web-based portal from any PC or laptop. They can log onto the secure GeoMoS site and download system status and reports. "Measurement tolerances are established and loaded into the GeoMoS system," said Murphy. "If any of these tolerances are exceeded, an automatic alarm is activated to notify the appropriate engineers."

After getting the system up and running, Eason was transferred to another Clark construction project at the Quantico U.S. Marine Corps base, and Aquiles Torres took over as the GeoMoS control engineer for the Dulles job. "It takes awhile to get used to the natural daily fluctuation cycles that show up," said Torres. "Most of them are caused by natural events, like weather. Also, the daytime environment is more noisy, but it settles down at night. We're really more concerned about trends than isolated spikes, but we're careful to investigate any unusual spikes. Fortunately, we have seen very few serious deformation events since the system was installed, and we've never had to shut down work due to any detected variances."

Eason recalled one particular incident in which movement was detected in one of the steel columns supporting an overhead pedestrian walkway. "It was close to a cut-and-cover excavation site. We strengthened the support and added more prisms so we could monitor that area more closely."

Agate is convinced that the automatic deformation technology is the wave of the future, and expects to see similar specifications from customers for other large civil engineering construction projects. "We expect to get a good return on our investment," he says, "not only in hardware and software, but in on-the-job experience. It'll give us an important competitive edge in bidding on future work."

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