

Leica Geosystems **TruStory**

Building a Precise Monitoring Network



The structures that accompany our everyday seem static and unalterable to our eyes. Weather conditions, aging, human activity, geological changes and other factors alter these structures and pose a challenge for engineers that strive to maintain the health of the constructions that our economies and daily lives depend on.

Structural behaviours are not always predicable by design and simulations. An unexpected bridge failure cannot just prevent you from arriving to work or getting back home. A lack of proper monitoring and maintenance can also result in the total isolation of cities and even in the loss of lives. Engineers, therefore, need to detect in an accurately and timely manner any structural movements under all natural physical conditions.

To gain knowledge of the integrity and changes of any structure, engineers today have Structural Health Monitoring (SHM) tools to obtain a clear picture of the current state, degradation and

evolution of any structure to make fast informed decisions.

Led by UbiPOS UK as the prime contractor, consortium members including academics from the University of Nottingham's Geospatial Institute and industrial partners from Leica Geosystems, GVL, Amey, Transport Scotland and China Railway, are developing GeoSHM (GNSS and observation for Structural Health Monitoring), a system to provide users with an integrated solution to monitor and assess in real time the operational conditions of different types of assets. Aware of the challenges to maintain the structural safety and operation of long span bridges, the European Space Agency (ESA), has supported the grant through the Integrated Application Promotion (IAP) Programme.

The complete picture

It is of critical importance to have the ability to monitor remotely and in real time any asset. GeoSHM uses real-time data gathered with Leica Geosystems GNSS receivers and software to analyse the operational conditions of bridges with the

GeoSHM Deformation Analyst that is developed by the consortium.

Leica Geosystems GNSS monitoring systems provide the complete picture by producing 3D real-time displacements and tilt of the bridge. GeoSHM converts data into useful information to end users and delivers it through a web-based interface that provides precise deformation information that allows bridgemasters to understand the loading and response effect of the bridge under normal loading conditions.

Bridgemasters can measure the performance of structural design models against the current conditions to identify unusual deformations under extreme weather conditions and detect movement at millimetre level. When deformations surpass designated parameters, the GeoSHM Deformation Analyst issues an early and emergency warning. In this way, GeoSHM provides a service that offers 24/7 monitoring, and facilitates a targeted maintenance by identifying structural failures promptly and assessing the bridge after an event.

"We selected Leica Geosystems products for their high positioning precision and reliability. The GRIO, the GM30 receivers and the Leica GNSS Spider software are stable, easy to use, and provided excellent results," said Dr. Xiaolin Meng, GeoSHM project leader from Nottingham Geospatial Institute. "Integrating Leica Geosystems GNSS technology allowed us to simplify our process, save time, and remotely control and monitor the status of the project."

The test platform

The Forth Road Bridge, a long span suspension bridge in east central Scotland, was the test bed for GeoSHM. The bridge was inaugurated in 1964, the longest steel suspension bridge in Europe at that time. When the bridge was designed in the 1950s, engineers could not predict the increasing traffic this crucial corridor between south-east and north-east Scotland would need to support. Initially designed to sustain a traffic of 30,000 vehicles per day, the bridge can normally be exposed to support twice the traffic it was originally designed for.

The Forth Road Bridge, like many other span suspension bridges, must defy the most challenging conditions, such as unexpected deformation, unusual traffic loading, temperature changes, high winds and extreme tides. Bridgemastrs and infrastructure managers, therefore, have an urgency to understand the behaviour to develop a maintenance programme that allows access to a rapid, targeted, and automated assessment of the bridge's health to assure cost efficient maintenance and management.

A sensor network you can trust

Currently the GeoSHM service collects the Forth Road Bridge data from four permanent Leica Geosystems GNSS receivers and two anemometers to measure the speed of the wind, but the programme will be further



expanded by the consortium. The Leica GNSS Spider software provides the professional solution for controlling and operating the installed GNSS reference stations and networks. The GNSS receivers collect and stream out data through Leica Spide via internet processing in real time, providing the positioning to analyse the bridge health status with the GeoSHM Deformation Analyst.

One Leica GRIO reference station was set on top of the bridge and three Leica GM30 monitoring receivers were set throughout the bridge to acquire the data from the GNSS satellites and sent via optic fibre network to a local hub. GNSS data is sent for processing through secure internet connection to the Central Processing Centre at the University of Nottingham where it is integrated with the data collected from the bridge sensors to generate changes in deformation and displacement information with millimetre accuracy and high resolution. At the Control Centre, the further processed GNSS data as deformation information is combined with InSAR, a radar technique used in remote sensing, to measure long-term structural trends and local environmental effects.

A proven solution

Using Leica Geosystems monitoring technologies, together with other sensors, the GeoSHM project aims to establish a state-of-the-art system that can address the challenges in structural deformation monitoring of long bridges, and other critical infrastructure, with a model that combines reference monitoring systems with the engagement of multiple stakeholders. As a next stage of development, GeoSHM will be expanded on a selection of bridges in China.

Using Leica Geosystems GNSS solutions that are empowered with the GeoSHM Deformation Analyst engine, GeoSHM has demonstrated that having a deep understanding and monitoring of this critical transport infrastructure can extend and safeguard the lifetime of aging bridges. Leica GNSS Monitoring Solutions provide vital information to reduce the maintenance costs with a targeted approach of inspections and timely identification of potential structural damage.

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Connecting through monitoring



Once a major infrastructure project is completed, engineers need to monitor for movement. This is to ensure that movement or settlement occurs within expected tolerance levels, ensuring the safety of motorists and others.

For the South Road Superway project it was particularly important to analyse differential settlements, or deformation occurring at a faster or slower pace on the infrastructure. These positional changes if unchecked could eventually lead to a step in the road. Any deformation of the road surface can lead to rapid deterioration of the asset, which in turn means costly repairs and required resurfacing. This puts additional pressure on the project's budget and can impair its profitability.

When the South Road Superway in South Australia was completed,

the joint venture was tasked with this important monitoring project:

- John Holland, leading contractor and service operator for Australia, New Zealand and South East Asia
- LEED Civil & Engineering, specialists of complex infrastructures projects

Some facts about the South Road Superway project:

- 4.8 kilometre major road corridor
- Non-stop connection between the northern and southern parts of the South Australian capital city of Adelaide.
- Project cost \$812 million AUD
- Now known as part of the North South Motorway
- Included 2.8 km of elevated roadway over the original South Road, which is the longest and largest single investment in South Australia's history
- Supports up to 6 lanes of traffic for the 1.3 million residents of the capital city

Although often thought of as static, engineering structures are continually in a state of motion. Consider the several elements that stress a structure on a daily basis:

- John Holland, leading contractor and service operator for Australia, New Zealand and South East Asia
- LEED Civil & Engineering, specialists of complex infrastructures projects

Some facts about the South Road Superway project:

- Expansion and contraction caused by temperature change
- Differential heating effects caused by the movement of the sun across a structure
- Wind loading
- Ocean loading and earth tides caused by daily tidal movements
- Vehicular traffic loading



All of this combines to produce constant movement in a structure. Such movements are typically small and occur slowly over the course of a day. It is critical, therefore, to understanding the structures' behaviour that monitoring is conducted automatically and frequently so that these changes can be tracked.

The striking design of the South Road Superway, with its unusual curved piers, complex geometry, and size presented some challenging measurement tasks.

C. R. Kennedy, the largest surveying solutions supplier in Australia, was able to supply and consult the combined venture as to the best solution for this long-term monitoring project. C.R. Kennedy recommended Leica GeoMoS monitoring software and hardware:

- GeoMos Monitor
- GeoMos Option 1 (Computations)
- GeoMos Option 2 (Limit checks & Messaging)
- GeoMos Analyser
- 230x GeoMos Sensor Licences
- 5x TM50 Total Stations
- 2x TS15 Total Stations
- 7x Instrument environmental housings
- 2x Vaisala weather stations
- 7x Modems
- 7x Power supply/UPS systems
- 290x Prisms

Real-time monitoring for safety The Leica GeoMos automated monitoring system continues to monitor structural movements 24/7 delivering the data required to analyse the structures behaviour and ensuring the safety of road users.

"We recommended Leica GeoMos and total stations because we've used them in many other projects around the country with excellent results," Richard Ingham, C.R. Kennedy Survey Division New South Wales state manager. "With the real-time ability to alert engineers to any changes and the high-precision data collected by the Leica Geosystems total stations, this was a perfect fit for the super highway project."

Monitoring is to be conducted for a minimum period of 7 years to ensure that the structure 'settles down' and any movement remains within expected levels.

GeoMoS software manages the data collected by the total stations of the bridge's dramatically curved piers. These piers support the bridge deck, or road, and have finger joints built into the expansion joints of the articulated deck. These joints enable the needed expansion of the bridge in order to accommodate the forces and stresses caused by the usage and environmental factors.

Levels on either side of the joints are monitored with particular care because if settlement happens at different rates, a step in the roadway can occur. If any positioning data collected by GeoMoS should exceed the set tolerance levels, the software will send out an alert in real time to the project management, alerting them that limits have been reached. This level of information allows action to be taken avoiding any costly repairs or long term damage to the structure.

GeoMos is able to use 'virtual sensors' (calculations) to derive key performance indicators on the project, such as pier rotations, needle beams deflections and separations. These 'derived' "Using Leica GeoMoS, we're seamlessly processing and managing the data collected by the total stations. The software is automatically delivering us information on the roadway piers, around-the-clock," said Stephen Singline from John Holland. "We receive reports that are easily understandable, and we can even customise the graphs and visuals for what we need. This informs our decision making processes with the most current and reliable data available.

Long-term analysis reports can also be used to improve design of infrastructure in the future and also help improve construction practices.

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Designing a dam monitoring system



In early 2017, winter storms filled and then overflowed reservoirs in California, USA, leading to the evacuation of hundreds of thousands of citizens near Lake Oroville, California's second largest manmade lake.

About 160 kilometres away, the Pardee and Camanche reservoirs also filled from the 2017 storms, reaching 103 per cent of capacity in March, but the dams were not overtopped, and releases were sustainable within the waterways. Thanks to the installation of one of the nation's most advanced automated GNSS-based dam monitoring systems at these two facilities, along with other instrumentation improvements, East Bay Municipal Utility District (EBMUD) had the technology in place to monitor crest elevations at these dams and dikes remotely with improved temporal resolution. Having this type of data available is one more tool in

an infrastructure owner's tool belt for monitoring the condition and performance of critical facilities.

Designing for better data

Consulting with Sensemetrics, a firm specialising in networked sensor applications based in San Diego, U.S.A., EBMUD designed and proposed a sophisticated monitoring system based on:

- 31 Leica GMX901+ GPS sensors
- Four Leica GM10 GNSS reference stations
- A radio network consisting of 900 MHz mesh radios
- 2.4 GHz repeaters and two radio towers
- Leica GNSS Spider and GeoMoS software solutions

The use of Geosystems receivers is important, according to Cory Baldwin, president of Sensemetrics: "The GMX901+s are purpose-built for remote monitoring applications, with non-exposed, built-in antennas," he says. "They were my first

choice here, because other vendors don't really have a good option for monitoring in this environment."

Three of the GNSS reference station receivers are solar powered and one is powered by a 120v AC feed. All are securely fastened inside enclosures installed near the Leica AR20 antennas, which are mounted on concrete pedestals. The network is largely autonomous, needing only occasional attention. Data flow is through 900 MHz and 2.4 GHz spread spectrum radios into an existing microwave telemetry link to EBMUD's business intranet at its Oakland headquarters, where a server runs the Spider and GeoMos software necessary to process the GNSS data and results. The results are then presented through software customised by Sensemetrics.

Five of the GMX901+ sensors as well as four seismographs are installed on the Pardee Dam connected via fiberoptic



cable directly to the microwave business intranet. These instruments continuously monitor dam movement and report remotely. Two of the GM10 reference stations were installed near and on either side of Pardee Dam and are connected to the fiberoptic line by 2.4 GHz radio connections.

Downstream from Pardee Dam, the Camanche Reservoir site consists of one large earth-filled dam and six dikes. The Camanche Reservoir is primarily used to control releases to downstream agencies and maintain flows for the salmon. Twenty-six GMX901+ sensors are installed around the reservoir, and these also monitor and report continuously.

A complete picture of infrastructure performance

The State of California Division of Safety of Dams (DSOD) requires semi-annual monitoring surveys. The new system provides accurate information more rapidly, reduces staff time spent on monitoring, and is capable of being tied into state-wide emergency and seismic monitoring systems as they emerge. After almost two years of service, DSOD monitoring requirements have been met with a more complete picture of overall performance.

"EBMUD's infrastructure is spread out over a vast area and covers multiple counties," says Baldwin. "In particular, the Pardee and

Camanche sites are several hours away from main offices, and the semi-annual surveys [conducted previously] took over a week to complete. This new system provides more accurate data, more or less constantly, and, of course, reduces the time survey crews spend on this task. It's a big improvement, and it is performing beyond expectations."

Baldwin says one important design goal was interconnectivity with existing and future monitoring systems. The potential to automate and improve emergency responses to seismic events is a major advantage of monitoring networks.

EBMUD now has more survey information immediately at its fingertips regarding structure performance than at any previous moment in the district's history. By being proactive and automating monitoring systems, EBMUD has greatly improved dam safety monitoring.

"The GPS system at Pardee Dam now gives us a complete picture of the seasonal deformations due to thermal expansion and contraction of the concrete structure," says Steven J. Martin, survey supervisor for EBMUD. "With the Camanche Reservoir portion of the GPS monitoring system, we are able to meet DSOD monitoring requirements without long trips out of town by the survey crew and to check for any possible deformations remotely in near real time."

Automated dam monitoring in action

A recent example of the benefits of automating a survey monitoring scheme comes from another EBMUD automated dam monitoring project on San Pablo Dam in California, USA. In 2008 and 2009, the dam underwent a seismic improvement to buttress the toe of the dam to bedrock using a cement deep soil mixing process. Increased monitoring requirements from the DSOD, while working on an active dam, were met via an Automated Motorised Total Station System (AMTS), which has been running several times a day since that project was completed in 2009. EBMUD also has a program to visually inspect dams and reservoirs immediately after an earthquake to check for cracking or other visible damage as a quick ground truth

After a 4.4 magnitude earthquake in January 2018 on the Hayward fault centred in Berkeley, less than 8 km from the San Pablo dam site, EBMUD geotechnical engineers were able to log in to the AMTS automated monitoring system to review whether there had been any actual movement or slumping on the dam, and they confirmed that there was no significant movement. This ability to have information immediately and at their fingertips has proven to be a huge asset in managing dam safety at EBMUD.

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Ensuring Smooth Flow



Germany's busy Kiel Canal has been used as an international shipping lane for more than 100 years. Linking the North Sea to the Baltic, the canal enables ships not only to save a distance of roughly 280 nautical miles but also to avoid the potentially dangerous storm ridden conditions of Denmark's northern Jutland Peninsula - the coastal gale winds and increasingly difficult tidal changes of the Skagervak between Denmark and Norway.

After a century of heavy traffic, German's Ministry of Transport, Building and Urban Development decided to modernise and carry out safety improvements on the locks of the Waterways and Shipping Authority (WSA Brunsbüttel). The Kiel Canal is one of the most travelled artificial waterways in the world and many countries rely heavily on the canal for the economy of their industries and

businesses. Closing the Kiel Canal during this seven-year construction project would be unthinkable since the canal is the lifeline and gate that connects German ports to the Baltic Sea. Therefore, a fifth sluice chamber needed to be added to the existing infrastructure. With an expected completion in 2020, this fifth chamber will handle the shipping traffic while the older locks' renovation is being carried out.

Analysing the rise and fall of the tide

The Kiel Canal not only functions as a shipping lane but also neutralises the effects of the North Sea's tide fluctuations and the water level of the locks that continuously fluctuates, rising and sinking roughly 3 metres over the course of six hours as the tides change. The Brunsbüttel lock system also provides important coastal protection from the Baltic Sea's notorious water level differences that occur due to gale winds and storm flooding from the sea.

The WSA Brunsbüttel has numerous water sensors that continuously collect water level data to foresee any possible water-related difficulties for the locks' infrastructure and the canal's surrounding area, supplying vast amounts of historic analysis. A geodetic monitoring system is also onsite and continuously collects massive amounts of data. Further review of the data dictated the need for a programme that could read and combine sensor information into the data processing software.

Before beginning construction, the stability of this enormous project had to be assessed. The new infrastructure presented demanding technical and logistical challenges, which needed to be taken into consideration. The fifth sluice chamber, when completed will measure roughly 350 m in length, 45 m in width, with an underwater extending cill on the



lock gate at 14m below sea level.

The chamber will be built into the sluice island between the large and small locks and requires the removal of roughly 1.6 million m³ of mostly clay soil. Three months of monitoring the existing lock system at Brunsbüttel was necessary in order to analyse the stability of the structure before starting with construction. Once the project began, the seven-year construction site will be monitored until its completion.

Monitoring movements during construction

Kirchner Engineering Consultants GmbH was contracted to monitor the movements of the structure during construction. A key requirement for WSA was to incorporate data collected from existing water sensors scattered throughout the lock structure at Brunsbüttel and to easily integrate this information into the automatic, real time geodetic monitoring analysis.

ALLSAT GmbH, a company specialising in geomonitoring using high-precision total stations and has been collecting geodetic data from the Brunsbüttel for some time, was contracted by Kirchner. The project requires the best possible deviation measurements and Leica GeoMoS Monitor software used by ALLSAT delivers the highest accuracy of +/- 2 mm.

After collecting and analysing new and previous data for three months, the building of the chamber could start. During construction, the chamber walls next to the

building site will be continuously monitored three times per hour for any standard deviations (2 mm) and for any deformation activity of more than 15 mm from the position and height of each measured point being monitored.

The data collected for existing chambers gates and walls used four Leica Nova TM50 total stations set up on pillars throughout the lock infrastructure and also used Leica Geosystems monitoring prisms.

Installations were completed by ALLSAT, who used Leica GeoMoS software for data processing and visualisations. Communication boxes with GPRS data modems were also installed on top of the measuring pillars using mobile service providers to transfer data. Total stations were also secured by weather element protectors.

Necessity is the mother of all invention

Due to the special demands required by WSA, Leica Geosystems added a new format editor to its GeoMoS software. This new editor can automatically process data from one or multiple sources, such as sensors, data loggers, files or databases. With this editor addition, Intelligent Open Interface was enabled, allowing the integration of any Comma Separated Value (CSV) file. After a one-time content configuration, the GeoMos CSV-module can automatically process any new raw data content from the water sensors on the tidal range water levels surrounding the locks. Each data field, separated by a semicolon within the CSV file, received certain

configuration parameters, such as time format, identifier, observation, unit and location. With this information, any CSV file could be processed in pre-defined time intervals. In this case, the raw data of the water levels were combined with the coordinates of the geodetic monitoring system.

With the virtual sensor editor, the system could process the deformations corrected by the tide influence to become a complete monitoring analysis.

With this new file formatting editor, the monitoring software became highly flexible and able to read any software interface. Sensor data available via the Internet could be quickly integrated for real-time analyses. All changes to the canal's water levels can be taken into account when analysing the geodetic measurements for deformation tolerance levels. The software also processed this data into easily understood visualisations that can be customised to the level and needs of those responsible receiving the information.

Should any of the data measurements exceed the set maximal deformation limits, a second measurement is made immediately after the completion of that measuring cycle. If this second data measurement still exceeded the maximal allowed limits, the people responsible at Kirchner were immediately informed by an email message automatically sent so they could take the necessary actions. A version of this story first appeared in GeoConnexion at <http://www.geoconnexion.com>.

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Leica Geosystems **TruStory** GNSS Monitoring for Safety on the Brenner



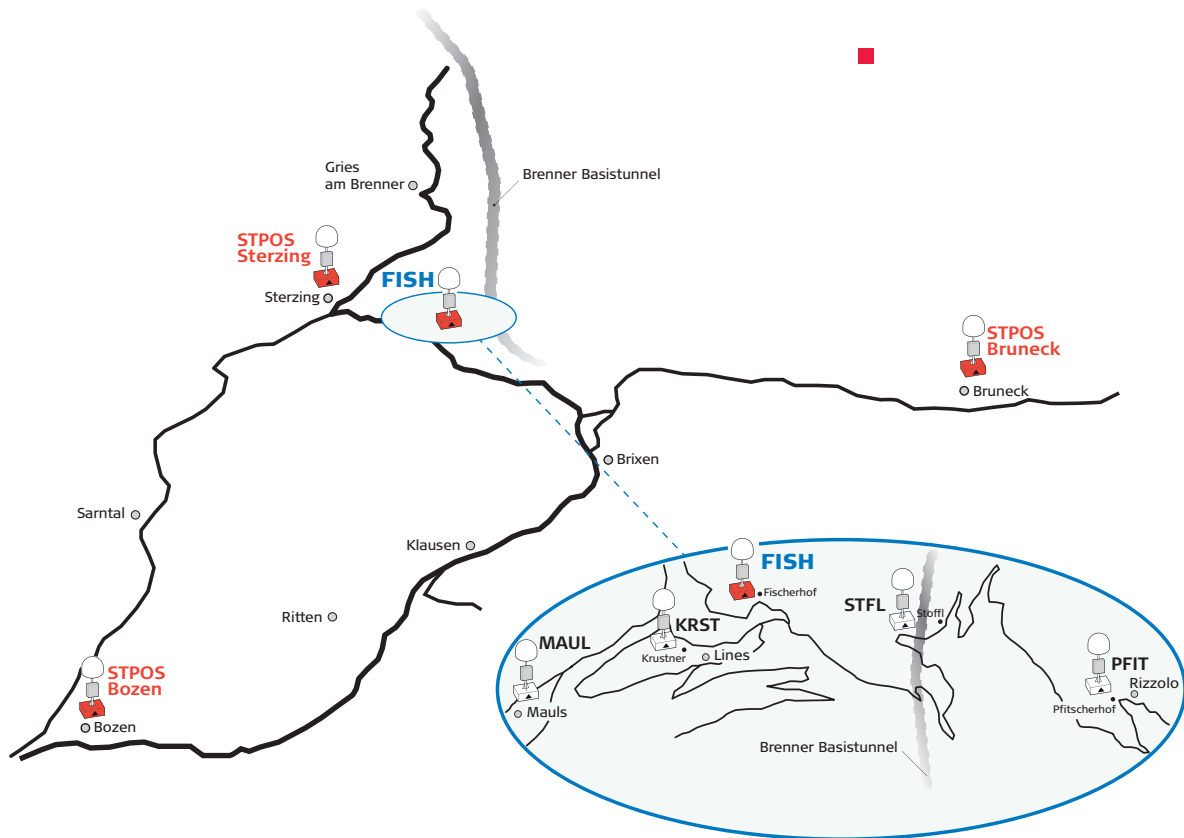
When it is complete in thirteen years the 55 km (34 mi) Brenner Base Tunnel will be only 2 km (1.2 mi) shorter than the Gotthard Base Tunnel, which celebrated its breakthrough almost two years ago. Leica Geosystems instruments ensured the centimeter accuracy of the Gotthard miners' work and the engineers in charge at the Brenner Base Tunnel have also opted to use Leica Geosystems instruments and equipment for a wide range of tasks, among them the monitoring of a geologically unstable zone on the South Tyrol side of the Brenner Pass. Consulting engineers Trigonos and the European public limited company BBT SE (Brenner Base Tunnel Societas Europaea) are responsible for developing

and executing the monitoring work, based on a sophisticated multi-stage continuous (GNSS) monitoring network.

Several sections of the exploratory tunnel for the Brenner Base Tunnel (BBT) are currently under construction. The six-meter in diameter exploratory tunnel will be centered directly below the two singletrack main tunnel tubes and will serve as an escape and service tunnel after the BBT is open. The 1.5 km (0.9 mi) "Periadriatic Seam" section of the tunnel, running under the village of Mauls (Community of Freienfeld) in South Tyrol, is particularly precarious. Here the tunnel passes through the Periadriatic Seam – a geologic fault separating the Southern Limestone Alps from the Austrian Central Eastern Alps. The main fault zone is estimated to

be about 200 m (656 ft) wide, with adjacent overstressed rock stretching for a kilometer.

The challenge posed by the Periadriatic Seam is well known to the project company – the European public limited company BBT SE, a cooperative venture between Austria and Italy. This section of the works was therefore undertaken with greatest caution. It is being carried out as a separate contract and the underground measurements required during tunnel driving are particularly complex. In addition, the Schwaz-based Tyrolean firm of consulting engineers Trigonos was commissioned to develop an aboveground monitoring concept: "In close cooperation with surveying engineers of BBT SE, we designed a GNSS monitoring concept and proved its



suitability in practice during the baseline measurement and the initial follow-up survey,” explains Lienhart Troyer, Managing Director of Trigonos, who is also involved in several other projects for the Brenner Base Tunnel.

Multistage Monitoring Network with 5 + 3 Stations

The above-ground survey has one primary question to answer: is surface settlement occurring during tunneling? The system must run fully automatically, and – should tolerances be exceeded – send text and e-mail notifications to the client and the site supervisory staff.

“We decided to set up a local GNSS network consisting of five points near the village of Mauls, which was then embedded in a higher-order network,” explains Lienhart Troyer. The monitored zone covers an area of about two square kilometers, so only a GNSS solution would be able to achieve the required accuracy. The centrally positioned station in Fischerhof (FISH) is used as a reference station for the calculation of the baselines to the other stations in Mauls (MAUL), Krustner (KRST), Stoffl (STFL), and Pfitscherhof (PFIT).

“We wanted to keep the baselines as

short as possible to maintain the highest possible accuracy. However, this also means the reference station itself is positioned in a potential deformation zone. Any settlement or movement of the reference station would influence the results of the other four stations. This is why the reference station is additionally monitored using data from three stations forming part of the GPS reference service STPOS in the Bozen/South Tyrol province,” explains Lienhart Troyer. The lengths of the baselines between the Fischerhof reference station and the three STPOS stations at Sterzing, Bozen, and Bruneck range from 10 km to more than 43 km (6 mi to more than 27 mi). “This hierarchical monitoring network can reliably detect movements of the Fischerhof station, while being able to provide precise local information about possible deformations in the area being monitored.”

Installation and First Measurements

Trigonos’ contract included implementation of their concept, including baseline measurement and the initial follow-up survey. After several visits with staff from BBT SE, the exact locations of the five stations were chosen. BBT SE conducted the negotiations with the landowners, followed by a construction company erecting the foundations and

masts for the antenna communications equipment. Four stations have a 230 V power supply. The Stoffl station was powered by battery for the baseline measurement and initial follow-up survey but will subsequently be operating continuously with a photovoltaic supply of energy. Backup batteries with a capacity of 48 hours will ensure the stations’ uninterrupted operation.

The necessary software was installed in the office and included Leica GNSS Spider to operate the network and the individual stations. “The baseline measurement took place in July over a period of 48 hours. We went through the entire GPS constellation several times,” says Lienhart Troyer. A Leica GMX902 GG dual-frequency monitoring receiver was used at the reference station, and Leica GMX901 monitoring SmartAntennas were installed at the other four stations. Data transfer was wireless over GPRS/UMTS in real time, with Leica SpiderQC continuously checking data quality. A first follow-up survey, also lasting 48 hours, was performed in August to confirm the baseline measurement data.

Specialists from Leica Geosystems, Heerbrugg were involved with the data analysis, the results of which were incorporated into the BBT frame network. "Because of the length of the base lines and the high accuracy requirements, we relied on Cross-Check, the coordinate calculation service provided by Leica Geosystems, for the calculation of the higherorder network. This meant we avoided purchasing special software for this project and saved a great deal of additional training time. Our expectations of accuracy were completely fulfilled," says Lienhart Troyer, expressing Trigonos' satisfaction with the outcome.

Europe-wide Tender

In January 2012 Trigonos was awarded the Europe-wide tender for the continuous operation of the monitoring system issued by BBT SE. This phase of the project will start simultaneously with the tunnel driving in the area of the Periadriatic Seam in April 2012 and will be maintained for at least three years.

In addition to the GNSS monitoring, a terrestrial monitoring system, using a Leica Viva TS15 imaging total station and prisms, was installed in Mauts to obtain reliable and immediate information about ground surface movements, particularly in the densely built center of the 2000-strong community of Mauts.

BBT SE

Headquarters:

Bolzano, Italy and Innsbruck, Austria

Employees: > 90

Established:

2004 as a European public limited company

Executive Board:

Raffaele Zurlo, Konrad Bergmeister

Responsible Surveying:

Pierluigi Sibilla, Claudio Floretta, Gregor Windischer

For more information, please visit:

www.bbt-se.com

The Brenner Base Tunnel

The Brenner Base Tunnel is the key section of the 2,200 km (1,367 mi) long Berlin-Munich-Verona-Bologna-Palermo high-speed railway axis. This flat trajectory, rail-only tunnel with a length of 55 km (34 mi) will be primarily used for the transport of goods. It consists of two single-track main tubes with an exploratory tunnel running below them. The main tubes will be driven 70 m (230 ft) apart and linked every 333 m (1,092 ft) by connecting side tunnels. Including the existing 7.7 km (4.8 mi) underground freight train bypass around Innsbruck, the 62.7 km (39 mi) base tunnel will be the longest railway tunnel in the world. The tunnel is designed for a maximum speed of 250 km/h (155 mph). In addition to the Innsbruck freight bypass, the line will tie-in to the existing infrastructure of the Innsbruck and Fortezza train stations. Multi-function stations in the tunnel will be located at Innsbruck, St. Jodok, and Trens. (Source: BBT SE)

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Innovative System Ensures Vertical Alignment of Gerald Desmond Bridge



Since 1968, the Gerald Desmond Bridge has been an important part of regional and national infrastructure. The bridge connects Long Beach with the major Port of Long Beach and Port of Los Angeles shipping facilities built up on Terminal Island—15% of the nation's waterborne imports are trucked across the Gerald Desmond Bridge. But the bridge's 155-foot clearance—considered generous in 1968—is now too limiting for some of the largest container ships in use. In 2012, for example, the MSC Fabiola could not pass under the Gerald Desmond Bridge and was forced to dock at another terminal. Even more problematic is the Gerald Desmond's condition; pieces of the deck are literally falling off, and a "diaper" of wire netting has been strung to protect those passing under.

So the Gerald Desmond Bridge is being replaced with California's first long span, cable-stayed bridge, with an additional 50 feet of clearance, making it one of the tallest cable-stayed bridges in the United States. The cables will be anchored on two, 515-foot tall support towers. The new bridge will also be wider, providing room for additional traffic lanes, emergency access lanes, and a bicycle/pedestrian path. When it is complete, the old bridge will be demolished.

Bridge construction began in 2012, but Long Beach citizens could be pardoned if they have been underwhelmed by visible progress to date; the project is complicated by the presence of the Wilmington Oil Field, one of California's largest oil fields, which lies directly beneath the bridge site. Subsidence has been an issue in and around the

Wilmington Oil Field since the 1930s, and the region has been a hotbed of progressive monitoring techniques for about 70 years.

Clearing out old wells and rerouting major utilities has been lengthy, challenging, tedious, and mostly invisible to commuters. But with that work done, Shimmick/FCC/Impregilo (SFI)—the joint venture team that won the project's design/build contract—is now turning its attention to construction that is more iconic and spectacular; building the bridge support towers and keeping them vertically aligned.

Given the "sinking feeling" that the oil field is known for, maintaining vertical alignment during construction is a serious concern. In a cable-stayed design like this one, achieving and

maintaining excellent vertical alignment of the bridge support towers is one of the most critical construction tasks. For the Gerald Desmond Bridge Replacement project, a vertical alignment system developed by Leica Geosystems and proven on supertall building projects like the Burj Khalifa and New York's 432 Park Avenue residential building (which is on track to be one of North America's tallest towers), was selected as the tool that project surveyors will use for this important job.

Monitoring in Long Beach

Subsidence of the Wilmington Oil Field has been startling at times; in the 1940s and 1950s, subsidence of as much as 29 feet was recorded in some areas. The problem has been mitigated since the 1950s with water injection into oil reservoirs; this grew into one of the world's largest water flooding programs, and 600 injection wells currently pump about one million barrels per day into the field.

Subsidence in Long Beach, and the effect of waterflooding (the use of water injection to increase the production from oil reservoirs), have been the subject of intense monitoring for decades, occasionally by exotic means: "Precision casing collar surveys" measured change in well casing collars, compaction recorders were used to measure subsidence in shallow aquifers, and tidal gauge recorders were used to compare tide heights to shoreline features. There was even a program that shot radioactive bullets into production wells, and later attempted to track the bullet location with a gamma ray survey.

But for many decades, the mainstay of the monitoring program was a large and



sophisticated spirit level network that ultimately included 350 benchmarks in the City of Long Beach and 540 benchmarks in the port. It was a good method—very precise—but it was also time consuming with no real-time component. So, since 2001, the city has relied on twice annual GPS surveys, and a network of twelve continuously operating receivers placed strategically around the city and port.

It's fitting, then, that the new bridge support towers also rely on an innovative use of GNSS receivers to maintain plumb during construction. The Leica Geosystems Vertical Alignment System used in this project is built around a Leica TS15i total station and up to six Leica GM10 GNSS receivers, several rovers and radios, and specialized software. GNSS and optical data are monitored and processed continuously in real-time by a custom implementation of Leica's GNSS Spider Software. Leica's SmartNet RTK network,

along with ground-based control, is used as a reference. The system is able to compare real-time tower position with design position and can be used to compensate for several factors, including crane weight, wind load, and even the thermal expansion caused by unequal solar loads. Contractors and project surveyors use this high quality information to guide concrete formwork and positioning of new steel members.

Taking GNSS to New Heights

This is an innovative system, developed by Leica Geosystems for use on supertall buildings such as New York City's 1 World Trade Center. Previously, the alignment of tall structures depended on the painstaking extension of ground control networks. "In the past, when you wanted to work on a tower or a bridge support, you'd establish a ground reference, and then have a prism up on the actual formwork," explains Leica Geosystems' Director





of Structural Monitoring David Rutledge. "As the structure began to climb in height, maintaining line of sight to the prism would become increasingly difficult. The Leica solution is to gracefully switch over to the GNSS system for primary alignment control. This is a proven methodology that has been used on the world's largest buildings."

After construction is complete, the receivers can be left in place to provide ongoing monitoring. (Incidentally, Rutledge was also instrumental in setting up the GPS subsidence monitoring system in Long Beach.)

"On previous projects, we've shown that our system can maintain tight tolerances," Rutledge says, "...well within the couple of inches specified on the Gerald Desmond Bridge."

It's interesting to consider the importance of GNSS monitoring to this part of the world. From precise monitoring of deformation caused by oil production, to precise vertical alignment of a tower 515 feet above the ground surface, the Port and City of Long Beach rely on the skillful use of GNSS receivers to keep things level and plumb ... and to avoid that sinking feeling.

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Innovative Vertical Alignment System Keeps 432 Park Ave. Plumb



'Skyscrapers' is such an '80s term—1880s that is. In the 21st century, as high-rise buildings have reached previously unimaginable new heights, architects and city planners have been forced to find new terms, eventually settling on the fairly literal 'supertall' for buildings over 300 meters (984 feet) and the clunky-but-evocative 'megatall' for buildings over 600 meters (1968 feet)—only three buildings currently qualify, including Dubai's 829.8 meter (2,722 feet) Burj Khalifa.

But there are lots of supertalls, so many that subcategories are beginning to emerge, and the sexiest so far is 'superslim' a term being applied to a new crop of supertall buildings with very small footprints. New York City's 432 Park Avenue building is perhaps the best example now under construction; when completed in 2015 it will, at 426 meters (1,398 feet), be the 2nd or 3rd tallest

tower in the United States (depending on how one defines One World Trade Center's crowning pinnacle) and easily the Western hemisphere's tallest residential building... and it will rise straight up from a perfectly square ("The purest geometric form," according to architect Rafael Viñoly) footprint measuring just 28.5 meters (93.5 feet) per side. That's about 814 sq. meters (8,760 sq. feet)—for comparison, the Burj Khalifa's footprint is about 8,000 sq. meters.

A building this tall and this skinny is very nearly in a class by itself, and calls for advanced construction techniques. One task in particular is simple in conception, but extremely challenging in practice: keeping the building plumb.

Working With Gravity

Many confounding factors affect supertall verticality and most are dynamic, changing from hour to hour. Some of the most important include thermal load (the

differing expansion rates of sunlit and shaded sides of a building), wind pressure (remember, each side of the completed building will be like a giant, 131,000 sq. foot sail), and crane loading and movement during construction. More subtle factors include slight variations in concrete settling, and even the variations, within tolerance, of steel work. So Adam M. Cronin, lead surveyor for Roger and Sons Concrete on 432 Park Avenue, really needs to know— in realtime if possible—where the building is, compared to design, and how it's responding to various loads.

For conventional urban construction, even skyscrapers, this task is relatively simple. Ground level control is transferred to permanent marks on surrounding buildings, and those marks are used as references for formwork positioning, steel assembly, and other layout tasks. Sometimes, buildings are kept plumb with sightings through slab

penetrations. But these methods won't work on a supertall. For one thing, they don't scale well—the need for vertical alignment information is so critical and urgent that optical measurements are simply not fast or accurate enough. It can take several hours, in typical ground reference systems, to take all needed measurements and perform calculations for a high altitude positional fix. More obviously, 432 Park Avenue will quickly rise well above nearby buildings, making nearby optical references useless. "We're literally in the clouds up here," Cronin points out. "Some days, we can't see the street or even other buildings."

So on this project, Cronin is using the most recent iteration of the Vertical Alignment System first developed by Leica Geosystems Engineered Solutions for use on the Burj Khalifa, and proven several times since, most notably on One World Trade Center. In essence, the system combines realtime data streams from several sources:

- GNSS positional data from four Leica receivers, posted near the corners of 432 Park Avenue's outer formwork platform (also known as the "cocoon"). The receivers monitor GPS and GLONASS, and the Brooklyn Pier and Holland Tunnel CORS stations.
- Continuously monitored optical data, derived from total station shots on 360° prisms mounted just beneath the GNSS receivers. This data gives feedback on the building's frame and shape, and the prisms are also used as resection points when doing layout and form positioning work. The prisms are 'active' control points; moving upward as construction progresses.
- Leica Nivel200 Series dual-axis inclinometers, which can measure

displacement to $\pm 0.2"$ of arc, are installed in the building's basement, and at regular intervals of about 10-12 floors. "They make a big difference. Along with the GNSS, they're helping us to make great strides in vertical alignment control, especially when predicting the effects of the day to day construction and wind loads," Cronin says, referring to movement due to the weather, crane loads, concrete placement, cocoon jumping and so on. The system's inclinometers are sometimes left in place after construction to provide continuous monitoring.

- As construction progresses, a weather station will be added; "We're working with Leica Geosystems to tie in realtime wind and temperature information," Cronin explains. "To tie that in with the GNSS/RTK observations and tiltmeter data would be very helpful."

All this data is combined and processed in a customized implementation of Leica's advanced Spider network RTK solution. Among other tasks, Spider is able to automatically apply the complex transformation between 'ellipsoid normal' (vertical relative to the WGS84 ellipsoid) and 'gravity vertical' (vertical on the job site, better known as 'plumb'). In most construction applications, the difference between the two is immaterial, but at nearly 1,400 feet it could be inches... which would be potentially disastrous. "Fortunately, thanks to Spider, I don't have to think about that too much," Cronin says.

All results can be accessed continuously, and a 'solid solution' is provided each hour. So, on an hourly basis, Cronin can check the figures and be confident he knows exactly how the building is placed within two hundredths of a foot and, over time, he can develop a sense of

how the various construction and weather loads affect verticality from day to day. If needed, he can make adjustments to form positioning to make corrections. It's a surprisingly speedy process; "We're completing a lift every three days," Cronin says. "And that's fast for this type of construction."

In sum, the Vertical Alignment System frees supertall construction surveyors from the need to tie to ground references. Building control is independent of ground control, and surveyors can generate precise coordinates as needed, compare these to design coordinates, and correct the building's vertical alignment incrementally to keep walls plumb.

"The Vertical Alignment System consists of consultation, training, installation and on-going management of the data," explained Leica Geosystems' Vice-President of Engineered Solutions Gerard Manley. "It's a modular system, and the components can be acquired based on the user's needs. We are seeing a definite trend in supertall construction, where BIM, realtime monitoring, and construction are all tightly integrated. As this trend develops, we are continuing to refine the Vertical Alignment System to be even more effective."

An Easy Transition

432 Park Avenue is Cronin's first opportunity to use a GNSS-based system on a major building construction, and he admits he was a little uncomfortable at first. "I didn't want to "flip the switch" too soon," he says. "Coming from a more traditional surveying background, it was important to me to test the system against ground references."





Fortunately, he was able to do just that for several months. Cronin essentially doubled up on verticality control during construction of the first 20 floors. That is, he started with ground control, and a network of prisms on nearby buildings, while also installing and using the Vertical Alignment System. “We compared results every floor,” he explains. “And by the 20th floor, as I lost the ability to use references I was used to, I was already super confident—the GNSS system always checked out.” In fact, as the building rises multipath issues are eliminated, and GNSS coordinates should become even more reliable.

Cronin has established some good routines for working with the Vertical Alignment System. For instance, he’s learned to use overnight results as the basis for layout work; thermal loads are balanced then, and cranes aren’t shifting a lot of weight around. He also prefers to do precise layout work in the quieter twilight hours, when the site is calmer and there is less movement in the structure. Still, he finds that he can get consistent results at any time of day; “As an exercise, we’ve performed the same positioning work at twilight and in the

afternoon, and found that the differences were negligible, which surprised me. And even during the recent polar vortex weather, which was super cold, we always had good signal and good results. It’s been a very reliable system.”

Leica Geosystems has developed the current state of the art in high-rise construction control, and the Vertical Alignment System has proven its worth on the world’s tallest buildings, including the Burj Khalifa, the tallest of all. For the first time, construction surveyors are no longer dependent on the ever receding ground for positional fixes; instead, continuously updating GNSS and inclinometer data, and optical readings give precise moment-to-moment coordinates on active control points, and help to keep the world’s burgeoning class of supertalls and superslims standing tall, and perfectly straight.

So what’s it like when your ‘office’ is a semi-exposed platform more than a 1,000 feet above the ground? “There’s nothing better!” says Cronin. “We can see from Tappan Zee Bridge all the way downtown, and we have a bird’s eye view of Central Park. It’s not for everyone, but I surelike it.” And with the security provided by excellent, realtime positional information, he likes it even more.

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Keeping a vigilant eye



Newmont's Ahafo South Mine lies within the Sefwi Volcanic Belt, one of Ghana's largest volcanic belts. These active regions contain a wealth of mineral deposits, such as gold, but are also cause for a great deal of concern amongst mining corporations and employees. A gold mine's steep walls are very fragile and in constant motion. Continuous, extensive monitoring by geotechnical engineers must be done in order to keep open pit miners safe from falling rocks or collapsing walls.

One of the world's leading gold producers, Newport Mining Corporation, selected Leica GeoMoS monitoring solution due to the software's proven track record. The Ahafo mine is equipped with this industry-leading software to provide monitoring professionals with real-time, actionable information and keep mining

responsible and safe.

In business since 1921, Newmont operates mines in seven countries across seven continents. They acquired two mining properties in Ghana in the mid-1970s, Akyem and Ahafo, which quickly became major new gold mines for Newmont. With the Newmont Ghana mines, the company generated more than \$464 million in economic value for its stakeholders in 2015 alone.

The Ahafo Mine has been a challenge for Newmont over the few past years. The western part of the mine is characterised by a weaker rock material called graphite, which can cause stability issues when coupled with volcanic belt movement. Falling rock accidents were occurring and stability was becoming an issue.

In January 2016, a team of experts were employed to implement the GeoMos monitoring solution at the Ahafo mine. This new solution makes necessary round-the-clock measurement

observations of the mine pit walls in real time. Any fast movements occurring on the walls will be immediately detected and used to predict and prevent wall failures. This in turn saves the loss of equipment and, most importantly, protects the lives of Newmont employees on location in the pit.

10 years – a world of difference

Commercial mining began at Ahafo back in 2006. Monitoring the stability of this 2100 x 450 x 120 metre pit was carried out manually by surveyors. Back then, they would periodically measure sets of prism targets installed on the mine's slopes, using manual Leica Geosystems total stations, such as the Leica TS11, and a software program located back in the office.

Deformation movement is determined by comparing sets of measurements. Ten years ago, data was collected manually once a day then brought



to geotechnical engineers to analyse based on comparisons with subsequent measurement sets. The entire process was very time consuming. Surveyors could also only take measurements during the day, dividing them in shifts. With too few skilled personnel and not enough data, the incidents at the mine continued to occur. The company decided to increase the monitoring of the steep slopes to five times a day. This brought about the upgrade from manual to automated monitoring equipment, such as Leica Geosystems robotic total stations TS15, TCRP 1201 and TCRA 1203 that automatically monitored the 30 prisms installed throughout the mine.

“All of these instruments live up to their reputation for being extremely robust and precise instruments. Newmont is convinced there’s no better accuracy or durability on the geodetic market,” says Nana Yaw Quayson from technical services and support at PDSA Ltd, author-ised service partner of Leica Geosystems.

Investing in the best for maximum return

Newmont opted for the new Leica MS60 MultiStation, which could scan critical slope surfaces in 3D point clouds and is capable of collecting data without having to access targeted locations to install prisms. Such inaccessible or dangerous monitoring points are scattered throughout the pit and are now easily monitored. Maximum deformation volume results are

delivered in these 3D point clouds, with each of the thousands of points within them being a highly precise measurement.

“The Leica MS60 not only recorded displacements in GeoMoS by collecting 3D scans, it also proved very helpful by scanning the volume of materials moved from the pit,” says Michael Muri, geotechnical engineer at the Newmont Ahafo Mine.

After considering several monitoring programs, the GeoMoS software was selected. It was the first automated monitoring system installed for a customer in Ghana by PDSA and Nana was part of the team who implemented it.

The solution consists of the Nova MS60 MultiStation, a digital terrain model (DTM) Meteo sensor for measuring atmospheric variations in temperature and air pressure, and a Netmodule Industrial WLAN Router for communicating between equipment and sending collected data. All of this is powered by a 12V solar panel power supply.

Leica GeoMoS Monitor and Leica GeoMoS Analyser software is used to monitor the mines.

All of this was set up in a shed close to the mine pit built specifically to protect the equipment. Once the instruments were configured, Nana and the team went back to the office, quickly installed GeoMoS and monitoring could begin.

Worth its weight in gold

Newmont uses the industry-leading GeoMoS monitoring solution at various other mine sites worldwide. Within the company, the software performance record is considered exceptional by monitoring professionals across the globe.

GeoMoS connects to the MS60, via a router, to collect data. It then stores and streams this data using a SQL database. The Meteo sensor, installed close to the monitoring station, measures any environmental changes, such as temperature and pressure, to correct the measured slope distances taken by the MultiStation.

The streamlined solution tracks the many movements of the gold mines. The MS60 is able to scan critical, inaccessible sections of the mine safely, without placing people or expensive equipment at risk. Using the reflectorless mode of the electronic distance meter (EDM), the MultiStation is able to measure with the highest accuracy possible, locking onto natural targets to detect deformation movements in areas of the mine’s surfaces where prisms have not yet been installed.

Simpler workflows enable faster, more informed decisions

All of this information is taken and processed by Leica Monitor, which provides monitoring professionals with understandable information instantly. Rapid movement below the earth’s surface can create instable walls and dangerous developments immediately.



Mining engineers and geologists use the results of this monitoring solution to understand the behaviour, condition and movement of a mine. If something moves, professionals using this software will know immediately. Detecting such movements around-the-clock also provides a continuous, long-term picture to form a better understanding of the pit's walls, which are continuously being chipped away at.

GeoMoS quickly processes and manages huge amounts of data collected by the total stations at the mine – reliably and around the clock. Because it is

completely automated, human errors have been significantly decreased. Wireless communication between the mine and office enables accessibility to data in real time. The analysis is also much easier for monitoring professionals to understand. Clear customised layouts of massive amounts of data enables engineers to react faster and make decisions quicker. “For Newmont, being able to provide their expensive heavy equipment a safe haven certainly saves them big. But most importantly, a safer working environment means providing employees more protection and saving lives,” concludes Nana.

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Leica Geosystems Keeping Boston's Millennium Tower on Target



Rising 685 feet into the sky, Millennium Tower Boston is the city's third-tallest building and tallest residential high-rise. It's also one of the biggest professional challenges Eric Dionisio, lead engineer for subcontractor S&F Concrete, ever faced. "It's taller and bigger than any cast-in-place building we ever worked on," he says. "Just working from the basement level up to level six was one of our most demanding projects ever." In fact, on April 26, 2014, the 6,000 cubic yards of concrete delivered for the foundation slab was the highest volume pour in Boston history for a private development.

Dionisio was responsible, among other things, for the building's vertical alignment during construction. The sheer height of the building made that a daunting task, as it ruled out conventional methods for maintaining plumb, like transferring ground control

(or control from nearby buildings) via total stations. There was also significant time pressure. "We were the first crew on a newly poured floor," he explains. "No one else could get started until we set a new zero point on that floor, set control, and completed all layout."

Excavation-related delays set the construction schedule back eight weeks by the time the third floor was completed. "Fortunately, by floor six, we'd made all that up, and we stayed ahead of schedule from that point."

Dionisio attributes much of that gain to more efficient establishment of vertical alignment and improved surveying and layout procedures.

New solutions for new challenges

For this project, S&F chose the GNSS-based vertical alignment system developed by Leica Geosystems for use on the Burj Khalifa (world's tallest building) and One

World Trade Center (tallest in the Western Hemisphere). It depends on GNSS receivers placed on the exterior protective screen and used as active control points that move up as floors are completed. On the Millennium Tower, three Leica GR25 receivers were used—two on the north wall and one on the south wall.

A fourth GR25, used as a base station, was placed permanently on the roof of a nearby 10-story building, renovated and owned by Millennium Partners. This receiver continually referenced the Massachusetts Continuously Operating Reference Station Real-Time Network (MaCORS), operated by MassDOT. "My working receivers continually referenced our own permanent base station, which in turn was tied to MaCORS," Dionisio explains. "That provided plenty of redundancy and position checks, and really raised my confidence in the system."

The base station location was chosen mainly for convenience, and Dionisio was initially concerned about its suitability. "It was only at 10 stories and was quite near the Tower, so I wondered if performance would degrade as we started doing work several stories above the base station," he says. "But by the time we reached 32 stories above the base station, we hadn't observed any issues with accuracy." S&F Concrete bought several more receivers for use on other projects, such as Boston's Lovejoy Wharf, Emerson College and The Point, and will have access to its own dedicated base station indefinitely.

The working receivers were mounted on brackets on the perimeter protection system, essentially a 40-foot screen and safety structure that surrounded the building under construction. It extended one floor up and two floors down and was moved up as floors were poured and finished. The receivers were equipped with 360 degree prisms, vertically aligned with receiver antennas, so that the continually updated positions of the receivers could be used by optical total stations and scanners for layout and as-builts. This arrangement was used to position forms after crane lifts, and to ensure that all internal structure was placed properly relative to external walls.

S&F Concrete's contract included all layout and alignment of the new structure, which was checked every 5th floor by a third party surveyor hired by the general contractor, Suffolk Construction Co. This check was performed with a vertical collimator to basically look straight down through sleeved holes in floor slabs. "We were within three-eighths of an inch every time," Dionisio says.

Without GNSS, Dionisio would have likely used optical total stations to transfer ground control, floor by floor. It's a traditional method that has been in use for decades, but it has at least two weaknesses when applied to taller buildings. One is that as the building grows taller, the geometry of optical surveying becomes unfavorable. It's more difficult to check backsights accurately as sight lines are impeded and instruments have to be pointed nearly straight down. And, thanks to trigonometry, the increasingly acute angles between the working floor and control points on the ground (or nearby buildings) inevitably expand error ellipses.

For business purposes, a less obvious but more important factor is speed; sighting several backsights from multiple positions, and performing and checking resection calculations, is unavoidably tedious, especially since, as mentioned, every other subcontractor (and S&F themselves) on the construction site is waiting for surveyors to finish control so they can perform their layout and install their work on the floor.

On some tall buildings, vertical alignment is maintained with sightings through slab penetrations, and early skyscrapers sometimes used elevator shafts to hang heavy plumb bobs on wire. This system achieves adequate accuracy and was used on Millennium Tower as a check, but its effect on modern tall-building workflows is unworkable. "If we were dependent for position on the sleeved holes we place for a vertical laser, we would have had to wait until the new slab was nearly cured before we could start work on a floor," Dionisio explains. "And frankly, that would never happen—crews want to get in there as

quickly as possible, and it's hard to hold them off. As surveyors, we don't want to be the cause of delays."

State of the art workflow

"Before we decided on the Leica system, I thought we'd be using a vertical laser that sights through holes placed in new concrete floors," Dionisio explains. "But that method has a lot of negatives. For one thing, accuracy is only good up to 250 feet or so, and if you set the zero point during a period of sway, accuracy is degraded in a way that affects all subsequent construction."

And placing holes in slabs is also a problem. They're set during the pour, which meant that setting the new zero point on a new floor would require a slab that had cured to a point where it could be worked. Actually, at least two points would have had to be sleeved up per floor in order to perform resections. That could hold up work for hours and create headaches for surveyors. "As the trades move onto a floor, their stock gets placed wherever it's needed, and things get crowded. Just keeping vertical sight lines open is a challenge. And, we would have been responsible for closing up holes. Instead, that was someone else's problem."

The surveying crew could move onto a new slab as soon as it could be walked on and set the zero point and critical layout lines before other trades moved in. Since they didn't have to work around other crews and material stockpiles, the work went faster and was more accurate.

Coordinates were provided in real-time. "I thought at first I'd be doing a lot of static work and post-processing with the GNSS receivers," Dionisio says. "But we quickly learned that





wasn't necessary." Dionisio set GeoMoS to compute an average position of the three building-mounted receivers every 15 minutes, and to average those readings every hour. "So to check for sway, I could compare the coordinates we were using to any past set. Over time, I realized that sway was not an issue on this building and that we could always use the real-time coordinates we had for resections. I observed very subtle movement, but nothing that affected our work or overall building tolerances."

Leica Geosystems' vertical alignment systems are adapted to the particulars of each construction site. Transforming the GNSS geolocated coordinates to the local coordinate system has traditionally been a little complex, requiring the GNSS feed to go into the Leica Spider software suite first for translation, and then to GeoMoS. However, an innovation was introduced on this project that greatly simplified the work. Smart receivers were used that performed the translation themselves, and the translated coordinates were passed directly to GeoMoS. This approach held down costs, simplified training, and sped up the workflow.

One reason this approach worked on the Millennium Tower was cellular communication. Verizon cards were installed in the working receivers so the receivers could talk with

each other and with the base station. Options used on other projects include WiFi and radio, but "WiFi didn't work here because the density of the reinforcing steel and concrete in this building killed connections," Dionisio said.

Although cellular connections have height restrictions (cell tower systems are oriented downward, toward people, so signals are weak over a certain height), Millennium Tower, at 650 vertical feet, was under that limit.

For his part, Dionisio was pleased with the performance of the vertical alignment system. "Because it was a new process for me, I didn't really know what to expect when we started work on the tower," Dionisio says. "I certainly expected more building movement than we observed, and I thought that using GNSS would require static work and post-processing, especially as we got to higher floors. But that wasn't the case."

In fact, Dionisio says that 12 to 14 satellites were in view at all times of day, that vertical alignment was always within a few hundredths of a foot, and that good quality coordinates were always readily available.

The workflow improvements on this project alone justified the investment in new equipment, to the point that S&F Concrete bought another three GR25 receivers for use on other projects while construction of the tower was still under way.

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Leica Geosystems **TruStory** Monitoring above and below ground in London's heart



The exponential growth in cities has an impact in transportation infrastructure – tunnels, railways and bridges are used more extensively than ever before. With this increased demand and an aging infrastructure, smarter traffic management and maintenance regimes to minimise transport disruption and manage safety risks is critical. It is important to monitor the impact of any maintenance or construction works to ensure any movement remains within expected and acceptable limits.

The required monitoring output information can come from a wide range of manual and automated survey and sensor methodologies. This is where a professional full-service surveying and monitoring company, like Murphy Surveys, comes into play. As one of the leading surveying and monitoring firms in the United Kingdom and Ireland, the

company offers a wide range of services – from aerial LiDAR survey to underground radar and monitoring of structures using geodetic, wireless geotechnical and structural sensors.

Murphy Surveys created a resilient sensor network using Leica Geosystems solutions to provide reliable processed data to monitor any changes and deformations affecting underground tunnels, assets and buildings inside the zone of influence surrounding a major development project in London's inner city.

Creating a sensor network

The Regent's Park Development project in the heart of London involves the demolishing of a series of buildings, and the excavation and construction of new of new buildings. The zone of influence for the unloading – due to excavation and later loading when constructing the new buildings – extends over a radius of approximately 80 metres. The

encompassed area includes Grade 1 and 2 listed historical buildings, London Underground tunnels, and electrical supply substations assets.

Murphy Surveys' dedicated monitoring department uses a mix of optical and sensor monitoring equipment including robotic total stations, MultiStations and GeoMos Monitoring Solution, among other sensors, to monitor any changes impacting the zone of influence building area. The monitoring configuration provides continuous automatic monitoring of above and underground structures to generate two types of reports:

1. A report analysing the above ground movement of buildings and other technical assets, such as a power supply transformer station or medical equipment in a nearby surgery, and;

2. A ground movement report monitoring the tunnel of the Jubilee Line North and Southbound tunnels as well as the Metropolitan Line tunnel that passes underneath the demolishing site.

The two monitoring processes ran continuously and, more importantly, prevented people from being sent to a hazardous area, reducing cost, risk and increasing safety.

The power of combined technologies

Murphey Surveys combined multiple geotechnical and optical monitoring technologies in a sensor network in the overall scheme:

1. Leica MS60 MultiStations for laser monitoring of facades;
2. Wireless tilt metres for stable deformation, convergence and longitudinal settlement monitoring in London Underground tunnels;
3. Automatic vibration, noise and dust monitoring;
4. Alarm features using Leica GeoMos monitoring solution, allowing all project stakeholders to have access to the monitoring data base with different set permission levels to view or modify reports and receive alarm messages;
5. The integration of all data into Leica GeoMos, an off-the-shelf software to provide the client with all the monitoring data within one software and web interface.

To monitor multiple buildings on this London inner city project, Murphey Surveys



uses three MS60 MultiStations geometrically connected over common control points and wired up to Leica ComBox5 to broadcast the monitoring data via internet broadband to the GeoMos servers.

The Metropolitan Line double track brick tunnel is being monitored by an automatically controlled MS60 MultiStation reading in track reflector and laser scan data. The two Jubilee Line tunnels are fitted with 250 Senceive wireless tilt sensors connected through a fibre optic cable to broadcast the data to the internet and GeoMos.

This innovative approach awarded Murphey Surveys in March 2015 to win the competitive tender process to monitor the above and below ground assets, as well as the environmental monitoring, for London's Regent's Park project.

An inclusive monitoring system

GeoMos software is the platform where all data are collected, validated, processed and delivered.

"GeoMos allows us to observe and record parameters of building and ground movement, deformation of railway track and London Underground tunnel segments. GeoMos recorded all monitoring data from a variety of sensor sources, such as 3D reflector data, manual levelling and inclinometre data, Senceive's wireless tilt sensors data, and laser scan data," said Andrew Masters, technical manager at Murphey Surveys.

Leica GeoMos 6.0 automatically analyses laser scan point clouds for deformation analysis. The output is a colour coded point cloud where the colour indicates the size of the deformation on a colour scale, making it easier to find deformation areas across a monitored surface.





"We suggested certain refinements on the software to Leica Geosystems' development team, which now allow us to separate longitudinal, lateral and height deviations, as well as single data points to automatically calculate the longitudinal settlement and ovalisation deformation of the tunnel lining," said Masters.

Beyond the geometrical monitoring, the team of surveyors also collects data from various environmental sensors on site, such as dust, vibration and noise sensors that run their own alarming routines but accumulate in the weekly data report within the GeoMos web interface.

The use of GeomosNow provides an integrated data interface to the client's engineers. The software narrows down the real-time data flow running through thousands of sensor channels to a simplified clear report.

"The new technology streams laser scan data from the ATS to the GeoMos software in real time. The new algorithm processes automatically the monitoring surfaces and compares them to a baseline survey," Unitalicise said Masters. "Movement exceeding the set parameters triggers automatically laser scan monitoring. This continuous live communication and data exchange from site to office, provided by our reliable equipment, eliminates delays and costly site revisits."

Choosing partners strategically

Murphy Surveys has carried out thousands of surveying and monitoring projects over three decades using Leica Geosystems solutions. Although needs vary considerably by project, detailed, precise and timely data is always required. For the monitoring of the Regent's Park Development project, the challenge was to provide the right mix of laser scanning techniques, topographic surveying and monitoring solutions to deliver precise and reliable data in a timely manner while minimising any disruptions and increasing safety.

"We concentrate on the quality of our staff and innovation. For this reason, we choose suppliers and partners that match the requirements for quality, innovation and cost effectiveness over the short, medium and long term. Collaboration with Leica Geosystems and sensor specialists like Senceive enables us to provide an innovative and flexible service for our clients," explained Kai Duebbert, managing director of Murphy Surveys.

"For a large global manufacturer, Leica Geosystems has shown great flexibility, for example in reacting rapidly to our ideas on how to customise software routines and to solve new local challenges on site. This kind of support is critical to deliver the most suitable solution and give the client the comfort to only deal with one service partner for all his survey, BIM and monitoring requirements," concluded Masters.

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Leica Geosystems **TruStory**

Monitoring Along the Construction Site of the Warsaw Metro Line 2



The Warsaw Metro (Metro warszawskie) is a rapid transit system serving the city of Warsaw, the capital of Poland. Currently it consists of a single north-south line (Line 1) that links central Warsaw with its northern and southern suburbs. The first section was opened in 1995 and then gradually extended until it reached its full planned length in October 2008. The construction for building the initial section of the second, east-west line (Line 2) started in August 2010, with completion planned for late 2013. This section will be 6.1 km long (including a tunnel under the Vistula River) and has 7 stations, one of these a transfer station shared with Line 1. The transfer station 'Świętokrzyska' also connects the center of the city via its Central Railway Station (Warszawa

Centralna) with the National Stadium for the Euro 2012 championships. Then, at the second junction (Stadium station) the line divides in two parts, one running toward the North-East (Bródno) and the other toward the South-East city region (Goław). The completion and operation of Line 2 is planned for 2015.

This tunnel project belongs to one of the most interesting underground building challenges in Europe, due to the fact that the construction is carried out below the densely built area of Warsaw's city center, the Vistula River and the Metro Line 1.

To complete such a giant project, there is a need to simultaneously lead construction works in a few places. According to the planning, three tunnel boring machines (TBMs)

■ Customer

AGP Metro Polska S.C. (Astaldi - Güllermak-Przedsiębiorstwo Budowy Dróg i Mostów Sp. z o.o.)
Metro Warszawskie Sp. z o.o.

■ Objective

3D deformation monitoring of an urban area along the construction site of the Warsaw Metro Line 2

■ Challenge

Providing geodetic real-time monitoring along the construction site of the Warsaw Metro with limited access

■ Date

June 2011 – ongoing

■ Location

Warsaw, Poland



■ Project Summary

Instruments

Leica TM30 Monitoring sensor
Leica GMP104 monitoring prisms
Leica GPR112 prisms
Meteo sensors

Software

Leica GeoMoS Monitor + Analyzer
Leica GeoMoS Adjustment
Leica GFU24 messaging modem

Communication

Moxa NPort

■ Benefits

- Stability control on the construction site
- 3D deformation control of over-laying buildings and infrastructure



are going to start in parallel with the drilling of the new metro tunnel in April 2012. In addition, some metro stations will be built with dig-and-cast method.

Above the designed metro there are many buildings, streets, historical places and public institutions. Therefore, beside the main tunnel work there are many other tasks related to such a tunnel construction, for example, securing overlaying buildings and infrastructure with 3D deformation monitoring and controlling the possible impact of the newly built tunnel on the existing north-south metro line 1.

The required and absolutely necessary deformation monitoring system is

being implemented by IMG, an Italian company with experience in deformation monitoring installations (the Metro line C in Rome, Italy). IMG works as a subcontractor for the consortium AGP Metro Poland.

Monitoring System Setup

In the central Warsaw underground section, more than 10 high accuracy total stations Leica TM30 are mounted. They are mounted on tunnel walls AND on buildings inside especially designed glass-aluminum housings boxes situated either on buildings' roofs or inside buildings. They measure 3D deformations to over 100 reference prisms Leica GPR112 and thousands of deformation control points situated on surrounding buildings.

All Leica TM30s are controlled via GPRS modems Moxa NPort from the main operation centre with the Leica GeoMoS software.

In such a large-area survey, there is undoubtedly atmospheric refraction which impacts on distances and vertical angles, so there is a need to control the refraction coefficient and to apply proper corrections in calculating the final deformations. For that reason three meteo sensors are located in the monitoring area, measuring in real-time the current atmospheric parameters, temperature and pressure. These measured values are automatically applied to the raw measurements with the Leica GeoMoS software.

Collecting and Analyzing Monitoring Data

The monitoring data is mainly presented in GeoMoS Analyzer and in addition, IMG has the access to use GeoMoS Adjustment for network adjustment and deformation analysis.

Beside the automatic deformation monitoring system, there are classical surveys performed for example, precise leveling and additional total station survey.

The complexity of the project combines the fields of geodesy and geology. Therefore, geotechnical sensors and data are part of the project. Supplementing the geodetic and geotechnical measurements with each other helps to understand the reasons for any detected movement and to improve the intervention



existing in the software solution. In Warsaw, the monitoring system is being operated exclusively by the Leica GeoMoS software package with no 3rd party solutions.

Robust and Flexible Equipment

The customer is a global, well experienced company providing construction works and other services. They have been using Leica Geosystems equipment for many years as well as being one of the most important Leica Geosystems partners worldwide.

The customer appreciates the robustness, interoperability and flexibility of the implemented monitoring system. Due the software integration, there is no need to install other supporting applications like warning systems, analytical tools etc.).

with appropriate actions. The collected geotechnical data (provided mainly by SisGeo) is analyzed in the operation center together with the geodetic results displayed with GeoMoS.

Data Sharing

There is an agreement between the consortium (AGP Metro Poland) and the purchaser (Metro Warszawskie Sp. z o.o. and The City of Warsaw) allowing the possibility of exchanging data with

scientific and public institutions for analytical purposes.

In Poland, the described deformation monitoring system is a completely new approach in terms of underground and tunnel monitoring. The customer, however, is experienced, as they provided a similar integrated surveying system in Rome, Italy, deciding to trust the already checked solution. Nevertheless, there are differences between Rome and Warsaw, mainly



Leica Geosystems **TruStory** Monitoring Mother Nature's Forces



The Messina region is considered one of Sicily's areas most vulnerable to natural disasters. As such, the communities in this northeast region have become all too familiar with "renewal" – the recovery after violent earthquakes, flooding, mudslides and landslides. Indeed, the community of San Fratello, a small village 90 kilometers (56 miles) west of Messina, is still trying to regain its footing three years after a disastrous landslide forced almost half the population of 4,500 residents from their homes. The implementation, however, of an advanced surface monitoring system is providing authorities with the ground intelligence they need to not only help avoid the disastrous element of surprise, it may help to stem the slide as well.

According to ISPRA (Italy's Institute for Environmental Protection and Research), a significant contributing factor to the landslide was rainfall. About 105 mm of rain fell over the area in the eight days prior to the destruction, overwhelming the existing drainage system and putting the hillside village at serious risk.

On 13 February 2010, a landslide was triggered in Riana, a district in San Fratello. The two-kilometer wide (1.2 miles) phenomenon descended across the area for about two days, swallowing homes, damaging important monuments such as the San Nicola church, destroying principal roads and causing extensive damage to the districts of San Benedetto and Stazzone.

The day after the landslide stopped, the authorities with the Regional Civil

Protection (RCP) of Sicily initiated plans to take a proactive approach to disaster preparedness. The plan would lead to a sophisticated, real-time, surface monitoring system that not only maintains a continual read on the stability of the terrain, it may help authorities manage Mother Nature's forces.

Setting a New Preparedness Standard

To adequately design a monitoring system, authorities first needed to study and observe the region's terrain to truly understand its movements, and consequently, its vulnerabilities. For two years, surveyors and engineers recorded and analyzed measurements from geotechnical and topographic instruments. Based on this comprehensive study, they determined



an automated, integrated surface monitoring system would be the most effective, first-alert approach for its emergency preparedness plan.

In August 2012, the RCP issued a request for proposal for such a system, and in September 2012, it awarded Leica Geosystems with the design, development and installation of the integrated monitoring solution.

Operational since January 2013, the topographic monitoring system combines both GPS and TPS technology, along with advanced software tools, to provide a precise picture of the village's surface in near-real time.

Eight Leica GMX901 GPS receivers sit on buildings and drainage wells located in the landslide area. These compact, single frequency sensors monitor the high risk zone, acquiring position data every second, enabling them to record the smallest of movements.

Completing the automated control network are two double frequency GMX902 GPS stations, which are specifically designed to provide precise correction data to the single-frequency

GPS receivers. Each GPS station is powered by 220V and/or by a solar panel, and is connected to a cabinet equipped with protected electric cables and a buffer battery.

The communication among the stations and the master unit station, which houses the management software, is guaranteed by a wireless LAN 5GHz device. The continuous GPS readings are collected by the Leica GNSS Spider software, which is installed on a dedicated PC on site. The software manages the individual GPS sensors, automatically calculates the baseline and sends the information to the RCP.

The Deformation Data Stream

The automated management of the GPS receivers and the data analysis tools are maintained by the RCP's control center, which is based in the city of Palermo, about 140km (87mi) from San Fratello. The centralized control center has a network of computers to receive the GPS and other supplemental data, and it has specialized data analysis software to enable the RCP to study the data provided by the different instruments. Although the frequency of the baseline calculation depends on the RCP's

specific needs, at present, the automated monitoring system provides measurement data every hour. RCP personnel can access the system at any time to consult the measurements and modify acquisition parameters, thanks to the remote control features of the solution and an opportune remote control software.

In addition to the automated GPS monitoring system, 50 prisms are permanently set on buildings for routine measurement by a Leica TS30 automatic total station. Using a network of six measurement pillars, a surveyor positions the total station to perform an automatic measuring cycle, surveying each prism point, and enabling users to produce a topographic analysis of the measurement data.

Measurements and surveys are made on a monthly basis but the frequency can change according to specific requests based on the stability of the area or changing environmental and climatic conditions, which are considered hazardous.



Strategies to Stabilize Subsidence

All of the information gathered by the system is promptly delivered to the Office for Civil Protection so the data can be validated and integrated into the emergency plan. By having accurate, near-real time data, authorities have been able to identify and implement strategies to improve San Fratello's infrastructure, such as installing new drainage wells and constructing other support structures, mitigating the town's risk of severe damage from future natural disasters.

It is likely that landslides will descend on San Fratello again, but by flooding the area with their own network of technology, authorities may now have the means to turn the event into an exercise in "preparedness" rather than "disaster." And that may give comfort to both the residents and the authorities charged with trying to protect them.

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Leica Geosystems **TruStory** Monitoring pays off



During the night of 14 May this year, 300,000 m³ (392,000 yd³) of rock broke off the Valegion mountain and crashed down 1,000 m (3,281 ft) to the valley floor in the Swiss canton of Ticino, near the village of Preonzo. Thanks in part to Leica Geosystems' Deformation Monitoring solution GeoMoS local authorities were able to evacuate the valley's industrial zone and to close the A2 highway and several cantonal roads at an early stage.

The community Preonzo between Biasca and Bellinzona in the canton Ticino/Switzerland has lived with rock falls for several years. Ten years ago,

a huge rock mass slid into the valley. The Cantonal Forestry Office has been watching the danger zone since 1998, and has been relying on automatic monitoring systems from Leica Geosystems AG for the past two years. Cantonal geologist Giorgio Valenti says: "We have regularly experienced small movements over the years, especially in spring time. Since the end of April of this year, the movements measured have increased to several millimeters per hour, which made the safety measures necessary."

Smallest Movements Determined from Precise 3D Data

The automatic monitoring system has provided continuous information about

every movement in the affected zone. Two years ago a Leica TM30 Monitoring Sensor was installed on a stable pillar below the slide area and connected to the Leica GeoMoS monitoring system. Since then the sensor has monitored 15 observation points located inside and outside the danger zone every hour, 24/7. The results are automatically forwarded to an FTP server in the Forestry Department and then analyzed by experts.

Michael Rutschmann, Product Manager at Leica Geosystems and technical consultant for this project, also has access to the data: "For years we have been able to track three-dimensional



data with millimeter-accuracy in real-time, knowing when movements took place and in which direction. The responsible experts were able to analyze developments and trends, and combined this data with additional information. The complete measurement history is very valuable to the geologists' further analysis."

The experts were kept informed by SMS about the movements. As their speed continued to increase, it became clear that the rock would soon break off.

Geodetic Monitoring Systems Help Save Human Lives

Based on the analysis of Leica GeoMoS and extensometer data, the necessary safety measures could be initiated early.

The industrial area at the foot of the mountain, which is important for the local economy in this region, could be evacuated in time. The police also closed cantonal roads and the highway. It could not be predicted if the mass would reach and damage the industrial zone when the one million ton load crashed down to the valley.

Future Measures

The 70 employees of the six companies in the industrial zone have resumed their work. But even after this event in Preonzo the Leica Geosystems monitoring system will continue to monitor the slope accurately to protect the people. "Some of the observation points were destroyed during the rock fall. More observation points will be installed in an extended parameter around the fracture area and will be continuously monitored for their stability," said Michael Rutschmann.

Two years ago the community of Preonzo and the Forestry Office of the Canton Ticino (Sezione Forestale, Cantone Ticino) decided in favor of funding and commissioning an additional Leica Geosystems monitoring system to observe the area.

Find a video about the rock fall on youtube: www.youtube.com/watch?v=Q6JCR1HZpeE

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Leica Geosystems **TruStory** Moving a Capital City Forward



In a country where 20 deaths a day are contributed to vehicular accidents, a public transportation system could translate into saved lives. In the capital city of Riyadh in Saudi Arabia, one of the world's largest construction projects in history is underway now to provide just such a resource.

With 90 per cent of the nearly 6 million population in the city using cars, a sustainable public transportation system was desperately needed. The current public transportation system, though, was close to non-existent with no metro and no bus lines travelling inside the city. In 2014, ground was broken to begin the Riyadh Metro Project with an ambitious due date of late 2018.

The city's first rail metro will have six lines with 85 stations covering 176

kilometres with about 40 per cent of the lines underground. The metro will be able to move up to 3 million passengers a day. All together, the project comes in at an approximate 20.1 billion Euros.

Finding common global solutions

To build one of the largest infrastructure construction projects in the world, it took a multicultural team. Three multinational consortiums are working together on the project, combining companies from around the world.

FAST Consortium, led by FCC Construcción from Spain with Freyssinet of Saudi Arabia, Atkins of England, Alstom and Setec from France, Samsung C&T from South Korea, Typsa also of Spain, and Strukton of The Netherlands, was contracted to construct and design Lines 4 (Yellow), 5 (Green) and 6 (Purple) of the metro. The project oversees 64.6km of the rail track, 29.8km

of viaducts and 24 stations at an overall cost of 7.1 billion Euros.

Construction of these three lines is overseen by three partners in the Consortium: FCC Construcción, Samsung C&T and Strukton. Each line has a dedicated survey team with all using solutions from Leica Geosystems.

Strukton, in charge of Line 6 (Purple), has been tasked with capturing data for topographic surveys, as-built checks, volume calculation, and inventory of existing utilities. The technology company specialising in rail systems and civil infrastructure is also in charge of stakeouts for construction and deviation monitoring.

"Though these are typical tasks for us, the sheer size of the project is new for us," said Clemens Tierie, survey manager

for Strukton. "Only on Line 6, I have 28 teams with more than 10 nationalities represented."

With such a diverse mix, Tierie needed to find common solutions familiar to all the team members. He found that in Leica Geosystems. Using a combination of total stations, GNSS receivers, and construction lasers and levels combined with measurement software, the Strukton team is well on its way to completing the project on time and on budget.

"Surveying is teamwork, and surveyors from all across the world know and appreciate Leica Geosystems solutions," said Tierie.

Racing against the elements

With an ambitious deadline of just more than four years for such a large project, Tierie knew the team couldn't allow for any disruption.

First, working in temperatures upward of 50 degrees Celsius in desert conditions, they needed to be able to trust the instruments to withstand.

"Due to our time schedule, there have been many days we've had to work straight through. We couldn't wait for evenings or cooler temperatures," said Tierie. "With the durability of our Leica Viva TS15 total station, we were able to perform high-accuracy stakeouts at any part of the working day. This enabled us to ensure everything was ready for construction to start on time."

Using Leica Geo Office and Infinity software, the team was able to instantly transfer reality capture data back to the office from the field for quicker processing. This way, if there were extra measurements needed, the team could do so while on site without having to return later.

The team also used the Leica Rugby rotating laser and construction levels to perform accurate as-built checks. With almost all of Leica Geosystems instruments able to operate from -20 to 50 degrees Celsius, the Strukton team is on schedule to finish the project.

Next, as the largest city in the country and with an unprecedented growth in the past decade, the city's utilities have created a complex infrastructure challenge. While constructing the Riyadh Metro Line, the team had to remain vigilant not to interfere with any of the buried utilities or lines running above, many times not knowing exactly where these utilities were located. Combining the Leica GS14 GNSS smart antenna with the Leica GR10 GNSS reference station receiver, Tierie and his team were able to precisely locate and account for rogue utilities. Saving precious time and avoiding dangerous utility strikes, the team was able to work quicker, safer and more efficiently. "Due to precise locating abilities of these instruments, we were able to inform our designers in the early stages of the project exactly where the utilities were located so they could incorporate this new information in the metro design," said Tierie.

Finally, the constant ongoing construction put roads and buildings in unstable environments. With the vibration from heavy machinery, such as when excavating trenches for cut and cover tunnels, these city assets were in danger of uneven and unsafe settlement. In conjunction with their measuring task, the surveyors were also in charge of monitoring the ongoing construction and its impact on the surrounding areas.

"With the accuracy of the Leica TM50 total station, we were able to quickly determine if construction operations were negatively

impacting surrounding structures," said Tierie. "Improving the safety for the crew and community, our work has been well received here in Riyadh."

The team has future plans to supplement the monitoring process with Leica GeoMoS monitoring software for instant alerts to deviations in the structures.

Worldwide support

Perhaps even more critical in an international environment such as the construction site of the Riyadh Metro Project is the assurance of support at anytime, anywhere.

Tierie says he arranged the project in Saudi Arabia through a combined effort of Leica Geosystems locations. His former Leica Geosystems network in The Netherlands with support from the Dubai and Switzerland locations and the local dealer in Riyadh all pitched in to make the project possible. Since moving to the desert nation at the beginning of the project in 2014, he has relied on the excellent support he receives from the many locations of Leica Geosystems.

"The quality of Leica Geosystems solutions is great, but the support for me is the biggest benefit. I've received very good support from Leica Geosystems Netherlands, Dubai and the local dealer SITML," said Tierie. "Due to the Active Customer Care support, we can quickly and efficiently handle any problems we encounter on site."

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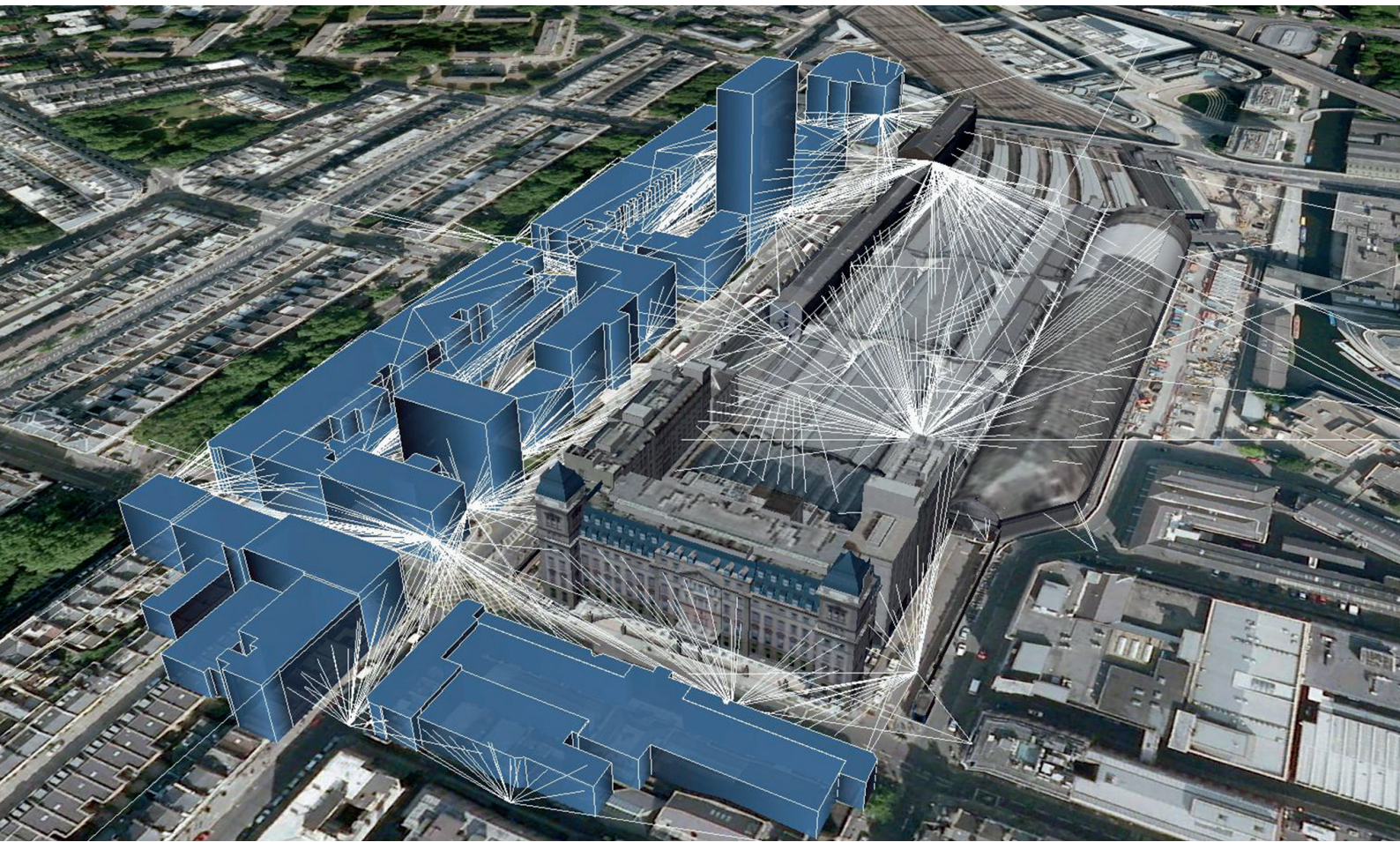
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Moving London safely forward



Paddington Station – famous worldwide not only for its creator Isambard Kingdom Brunel but also for a small marmalade loving bear. An average of 26,500 passengers travel from Paddington station every day. Despite its Victorian elegance and regality, plans were developed to build a brand new underground station directly beneath the historic landmark. This infrastructure project has been undertaken by Crossrail and forms part of Europe's largest construction project. The new station will be known as the Crossrail Paddington Station.

Since July 2011, plans have been developed by Crossrail to complete a new underground network for London. In August 2011, working as a joint venture on behalf of Crossrail Limited,

Costain Skanska was awarded Crossrail contract 405 to complete the complex £14.8 bn rail project. This project is creating a major new railway line, stretching 118 kilometres (approx. 73 miles) from Reading and Heathrow to the west of London, to Abbey Wood in the east. It will also pass directly underneath central London. The new network will now connect seven brand new mainline underground stations, all of which are important interchanges between existing Network Rail services and the London Underground. One of these new stations is the Crossrail Paddington Station.

Meticulous planning to monitor structures above and below

Working directly under the very heart of London has many challenges. The city is home to over eight million people and its underground handles a billion journey's per year. The new Crossrail station at

Paddington is surrounded not only by modern buildings but by historic ones as well. It is also located in the densely built-up zone of central London with its maze of pipes, cables and sewers, making it an extremely complicated construction project. Since London is considered a global city, it had to work without disruption, even for a project of this magnitude. Therefore, the Crossrail station is being built as a four-storey top down construction, with two-way live traffic above ground as excavation carries on below.

With all this digging, loosened dirt in central London could settle unevenly and potentially cause structures to tilt or severe cracking could develop. Constant monitoring of buildings in this area was vital to avoid possible damage and this is how Leica Geosystems products and



solutions play an important role in securing the success of this new railway line by monitoring structures and the degree of earth settlement.

Robotic total stations observing Paddington 24/7

Costain-Skanska decided to implement real-time monitoring solutions by using 52 Leica TM30's, especially for monitoring designed total stations, and over 1,800 monitoring prisms of all types in and around the Paddington area. The equipment was attached to various key positions on the outside of buildings. Highly accurate 3D data is collected from the total stations that measure key reference points of the various prisms placed strategically throughout the area's buildings. These measurements, roughly 8,500 points a day, are made in daily cycles. At the recent phase of the project which was called "the bulk dig", the data capture for the majority of the area's total stations takes place at six hour intervals each day, after which the data is sent to be processed with Leica GeoMoS, which sends the results to the web portal before they are distributed to the construction team. The use of Leica Geosystems monitoring sensors, software and

communications is vital to the Crossrail project, as these accurate measurements provide information on any variations in structures caused by earth movement and minimise risks, not only to the buildings themselves, but also to public safety.

Automated data processing in near real-time

Such projects require constant observation, repetitively measuring the same routes and reference points several times daily throughout the entire project's life span. By using robotic total stations such activities can be done automatically and data is directly transferred for processing using Leica Geo- MoS, GeoMos Adjust and GeoOffice software.

Three interlinked servers are used to run the Leica Geosystems software programs at the Crossrail construction site. The software is used to detect and analyse ground movement and the deformation of buildings above and below the site, and also helps to speed up and simplify the processing of real-time data collected by the total stations by up to 90 %, allowing data to be available from field to issue quickly. This software solution for the new Crossrail Station is entirely from Leica

Geosystems, and is the largest of its kind existing anywhere in the world. Engineering Survey Manager for Costain-Skanska Joint Venture, Steve Thurgood, reports "The software systems have to be very prescriptive and procedural to control the quality and repeatability of the project, yet also allow for dynamic change in the environment and construction phase changes. Our operation runs non stop, we manage the software system to minimise and repair any faults that might occur. Both software systems log a phenomenal amount of data which correlates with an astonishing degree of accuracy and precision."

The Leica GeoMoS software solution is a fully automated system for data generation. It offers automated processing and evaluation using statistical analysis, comparing new data to the original base model by using easy to understand graphs. The software also continuously updates deformation analysis and network adjustment with vast volumes of real time data received by the 44 to 49* total stations, resulting in highly accurate data delivered fast.

When the data is processed, it is additionally optimised by network adjustment software for co-ordinated geometry, topography and



accuracy. Should any of the data not be within a ± 10 mm sphere of the previously collected data (generally not older than approx. six hours), it is considered incorrect. The engineering surveyors overseeing the operation evaluate and compare the data with deviations to the predefined data parameters and quickly decide if measures need to be taken.

The co-ordination of displaying the processed data with on-site construction teams helps considerably to complete technical work without disruptions. GeoMoS increases not only productivity uptime by displaying real-time data but also simplifies workflows by constantly validating data before issuing it to the teams.

Dedicated teams and reliable equipment

Dedicated round-the-clock operation and maintenance teams actively maintain the

entire Crossrail project's Leica GeoMoS software solution and also clean and maintain the 42 to 49 total stations and over 1,800 prisms. The total stations take six people to run plus an additional part time support staff of five persons in the field. All involved total stations are serviced and maintained at Leica Geosystems Service Centre in Milton Keynes.

"Crossrail's motto is 'Moving London Forward'. Within our engineering surveying team who run the precise levelling scheme and the largest Leica Geosystems homogeneously adjusted total station scheme in the world, we adopted a complementary motto due to the success we've had to 'Moving surveying for monitoring forward'. None of the above however would be possible without the continued support of Leica Geosystems and its supply chain partners", concludes Steve Thurgood, Engineering Survey Manager for Constain-Skanska Joint Venture.

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Leica Geosystems Case Study

Owen Street Level Crossing, Tipton



In a world where there is no such thing as absolute stability, movement is an ever present phenomenon, how much something moves and when, has different importance to different people. One aspect of movement that we take for granted is the adequate, reliable and safe provision of transport infrastructure.

There are over 410,430 km of roads and rail track in Great Britain (Department for Transport), a figure that is constantly being extended year on year as population demands increase. This network is linked by over 7,600 level crossings on both public and private land. Each year 2,000 motorists and pedestrians are reported to have misused level crossings as we are reminded by in the news. Trains can reach speeds of 125mph and cannot stop quickly enough, making level crossings extremely hazardous and constantly exposed to risk.

The risks posed by level crossings can be eliminated by replacing them with over bridges or underpasses. One location where this is currently taking place is at the Owen Street Level Crossing where the B4517,

Alexandra Road, crosses the West Coast Mainline near Tipton Station in the West Midlands. The crossing is being replaced by 300 metres of road, which will pass under the railway line by means of a 55 metres by 9 metres box tunnel. The work is being carried out by the civil engineering contractor, BAM Nuttall Ltd. Formed in 1865, BAM Nuttall offers the full range of civil engineering services from road and rail construction, through to innovative, highly specialised construction solutions.

The £20 million 18 month project to replace the Owen Street Level Crossing is the first of four major physical regeneration schemes scheduled to take place in Tipton over the next three years. A newly constructed tunnel and high quality road layout aims to improve traffic flow and boost business in the town.

The construction work associated with the project involves jacking and piling activities that take place adjacent to the track. This heavy construction could have a big impact on the track, bearing in mind that the railway must continue to operate throughout the...

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...duration of the project. During the construction work, Network Rail must know whether the track is moving in relation to height, which can affect the twist and cant of the permanent way. In order to provide this information, it was imperative for BAM Nuttall to monitor the movement of the track throughout the duration of the project 24/7 day and night.



Pictured above: A piling rig works close to the busy West Coast mainline whilst the Leica equipment and GeoMoS software monitor the track for movement.

For agent Jamie Beech, it was vital that the development used the most cost effective and reliable monitoring solutions available on the market. For this he turned to Swiss measurement technology specialists Leica Geosystems Ltd. Leica Geosystems has been providing technology solutions since 1819 and its experience in this field was a major influence in the acquisition of the necessary items for this project.

The automated system, controlled by Leica Geosystems's GeoMoS (Geodetic Monitoring) software, enabled BAM Nuttall to make measurements of the track at predetermined intervals of time during the day and night, in order to understand and physical movement on the track.

The GeoMoS software can be tailored to report movement in just about any manner the user requires, from SMS text messages to claxon. The choice of how movement is reported is dependent on the users' requirements and can also be related to the amount of movement. GeoMoS also enables the user to monitor points at different frequencies depending on their relevance and importance. Such a system keeps cost down whilst maintaining the highest level of safety.

Pictured below: One of the two Leica TPS1200+ Total Stations measuring automatically to the mini prism at predetermined intervals, 24 hours a day.



The monitoring measurements were taken by two permanently mounted Leica TCA1201+ total stations measuring to 300 mini-prisms fixed to the rails. The GeoMoS software is capable of collecting data from virtually any sensor required for monitoring. In this case a Meteo Sensor was included to monitor temperature and pressure, which was used to 'correct' the observations so the weather would not influence the accuracy of the results. The reliability and repeatability of the assemblage exceeded the requirements of the project, for points to be recorded to better than <math><5\text{mm}</math>. The equipment has now been in place for many months and the repeatability of measurement is better than $\pm 2\text{mm}$.

Jamie Beech, Agent for BAM Nuttall comments:

'We were thoroughly impressed with the automated monitoring solution from Leica Geosystems. The off-the-shelf package not only provided us with the level of precision, detail and accuracy that was demanded of the project, but it also required no one to work unsociable hours, unless movement is detected and the alarm raised. The solution gave us 100% confidence in the project and allowed us to collect valuable information to analyse and submit to Network Rail, giving them the evidence their infrastructure remained unaffected, and the confidence in our continuing works.'



Pictured above: One of the 300 mini prisms fixed to the rails to monitor the track.

For more information about Leica Geosystems monitoring solutions contact us on +44(0)1908 256500, email uk.sales@leica-geosystems.com or visit www.leica-geosystems.co.uk ■

Leica Geosystems **TruStory** Rock Solid



Fortunately no one was injured when 100,000 cubic meters of rock slid down a rocky scarp near a hydroelectric facility northeast of Campbell River, British Columbia, Canada. But it was certainly a dramatic and destructive event; the rockslide covered approximately 350 meters of access road and crushed and ruptured the penstock (the structure that conveys water to the hydroelectric facility powerhouse) in several places.

What pushed the rockslide over the edge is something of a mystery. Sarah J. Kimball, an engineering geologist at Vancouver-based BGC Engineering Inc., wrote in a technical paper on the slide that “strength degradation of the exfoliation surface is considered the major causative factor for the rockslide release as no apparent climatic or seismic triggers were identified.” Put another way, the rockslide was likely

due to inherent underlying instability and failure along joint surfaces in the rock, making further slides possible.

After the slide, the road and penstock needed to be uncovered and repaired, including digging up and replacing most of the penstock—a rather daunting undertaking when working on a steeply sloped mountainside that has definite potential to dump tons of rock unexpectedly. To protect workers and new facilities, BGC was contracted to design and implement a slope monitoring system to provide early warning of potential landslides during repair work. The firm came up with a combination of two monitoring systems that collected and analyzed near-real-time data. The systems were ground-based interferometric synthetic aperture radar (InSAR) and two automated electronic distance meter (EDM) total stations made by Leica Geosystems. Installing the system presented a

substantial design challenge. The rock slope between the road and the rockslide head scarp is quite large, covering about 1,350 meters slope distance and several hundred meters in width. Access was difficult, the site was in remote territory, and any installations would themselves be on steep and potentially unstable surfaces. And to be effective, the monitoring system would have to identify small, dangerous movements on the slope and quickly—preferably instantly—sound alerts so that workers could evacuate, while avoiding too many false alarms that would impede the work.

Installing Sensors—The Hard Part?

Onsite work began with the installation of an IBIS-M ground-based InSAR system in February 2013 about a mile from the rockslide slope. This location provided the best available vantage point of the slope area and of a large protruding rock on the slope dubbed ‘Wynona.’

The system was configured to complete a slope scan every six minutes and has a resolution of less than 1 millimeter. Weather algorithms were used to compute corrections for changing atmospheric conditions. Since InSAR data is quite sensitive, it was important to consider changes in environmental factors such as tree cover, snow accumulation, fog and cloudiness, and rainfall when interpreting the data.

In March 2013, the two total stations were set to monitor the slope and the lower face of Wynona. These were Leica TM30s, recommended by monitoring specialists Monir Precision Monitoring as the best available precision at long distances. One station monitored the head scarp from distances of 120-200 meters, and the second station monitored Wynona from distances of 250-350 meters. Ideally, prisms would have been set for even better precision, but this was simply not possible on this project; access was limited and the terrain was steep. Instead, reflectorless monitoring points were chosen—18 points for the first TM30, and 12 for the second—that were light-colored and on flat, dry surfaces achieved accuracies of 2.5 millimeters.

Flowing surface water, fog and cloud, and other atmospheric conditions occasionally made readings difficult, but the total stations were able to confirm some of the InSAR readings that were questionable. Basically, the redundancy of two systems was helpful throughout the project.



“Installation” is probably too mild a word for the work done by the installation crews. This is a remote site in rough terrain, very steep, with no access trails. Initial work was done with helicopters and rope support as log and 2x4 platform enclosures were built. Installation took weeks, though eventually the platforms allowed easier roped access to the sensor sites. Craig Hewes, PLS, director of technology for the Leica Geosystems Engineered Solutions group, got personally involved. “Craig was great,” Kimball says. “He helped us set up the total stations for the best accuracy, and he was onsite for final commission—it was great customer service.”

There was one typical challenge of monitoring installations that wasn't a factor here; security. “No worries about security, since there's no way for the public to get to the site!” Kimball laughs. “And also, there were usually avalanche technicians and geotechnical staff around to keep an eye on the equipment.”

Monitoring and Alerting

Data generated by InSAR and the TM30s was transmitted to an office set up in a ‘Sea Can’ shipping container near the work site. No attempt was made to combine the separate streams of data; rather, all streams were analyzed separately, with their own alert protocols, and





acted as checks on each other. Given the stakes, the redundancy was appreciated by all concerned.

InSAR data was refreshed and transmitted every six minutes, and total station data was automatically refreshed and transmitted every fifteen minutes by the Leica GeoMoS software. The data was physically monitored during work hours by BGC staff, who were able to sound alarms—horns and sirens—if needed.

According to Kimball, alarm thresholds were established "... on the premise that:

- the rockmass would deform internally if slope failure was imminent;
- the downslope rockmass velocities would accelerate prior to failure; and
- the acceleration would be measurable.

Line of site displacement vectors for the main slope and the Wynona block were calculated to correct for the actual component of movement observed by the total stations and InSAR. Five alarm levels were established for actual displacement vectors over 1 hour and 24-hour

periods. The alarms would be sounded if velocity thresholds were exceeded over a defined slope area and time period (by comparing sequential scans)."

A Successful—and Safe—Repair

Using this methodology, no actual slope deformations indicating imminent failure were, in fact, observed. However evacuation alarms were sounded on five separate occasions, precipitated by InSAR alerts. After analysis, these alerts were attributed to atmospheric conditions resulting in false displacement in the data, rather than slope movement.

This would be a more exciting story if a new rockslide had occurred during the project and workers were saved by a last minute siren triggered by sensors. But the lack of drama indicates a successful monitoring project. By carefully and continuously measuring relevant spatial data during the road and penstock repair project, BGC Engineering was able to assure the safety of all the many contractors and subcontractors onsite, and they were able to do their work in a much safer atmosphere. And when thousands of tons of rock are literally hanging over your head, that counts for a lot.

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Leica Geosystems **TruStory** Safely renovating ship locks



The Kiel Canal is the most travelled artificial waterway in the world. In 2014, an average of 89 ships per day passed through the canal. It is almost 100 kilometres (62 miles) long, from Brunsbüttel to Kiel-Holtenau, and links the North Sea to the Baltic, enabling ships to save a distance of some 250 nautical miles (or roughly 450 kilometres) to bypass the northernmost tip of Denmark at Skagen. Though nautical strategic factors may have been crucial at the time of its construction, the canal is currently used exclusively for the exchange of goods between countries in the Baltic region and the rest of the world. The Kiel Canal opened after eight years of construction on 21st June, 1895 and after an additional eight years, it was necessary to widen the canal due to the amount of traffic passing through. Each end of the Kiel Canal is closed off from

the fluctuating water levels of the Elbe River and Baltic Sea by four locks: one double lock from 1895 (the small locks) and those built in 1914 (the large locks).

During a regular structural inspection, water from the 220 metre (722 feet) long by 10 metre (33 feet) deep south chamber from one of the small locks was pumped out in March 2013, with the chamber remaining dry for two and a half months. Since the water in the north chamber presses against the lock wall of the south chamber, the south chamber was monitored geodetically for safety reasons using a Leica TCRP 1201 total station and other sensors. The data collected from this monitoring provided information on the behaviour of the structure and protected inspectors and workers during the renovation.

Surveying required a measuring program to be prepared in advance for specifying

the type and scope of the required measurements. Based on this program, the small locks of Kiel-Holtenau were set up to monitor the south chamber during the pumping out period and the dry phase. An immediate response to any emergencies which might have arisen was made possible by the ability to send out information on the change in the structural behaviour at any time during renovation work.

Monitoring with a total station

The Leica TCRP1201 total station, connected to the Leica GeoMoS monitoring software for data collecting and processing, was installed on top of the lock's control station, located on the partition wall of the two lock chambers. Since the location of the sensor was in an area subject to possible movement, the monitoring method known as free stationing was undertaken. This meant measuring six different stabilised reference points



attached to surrounding buildings in the area that were not subject to movement in order for the hourly program-controlled data measurements to be possible. The measurement points on the lock were then determined in 3D. In this way, the ten measuring points from which the chamber width can be derived, served as "virtual sensors". These hourly measurements of the north and south sides of the chamber walls, as well as the control of the fjord and chamber water levels, was carried out using the highly customisable Leica GeoMoS family software programs. In addition, the coordinates of the six head-base points, the three chamber-base points and the two points on the inspection covers were also recorded. The values of each of the six groundwater measuring points on the north side and the south side, as well as the level of the fjord and chamber water level, were recorded hourly and transferred to the GeoMoS software.

Integrating geotechnical sensors into the Leica GeoMoS portfolio

A crack on the chamber wall of the southern side corridor was monitored using tilt sensors and fissurometers, and these also sent data to the Leica GeoMoS program. Any changes in the length and cross directions were displayed and analysed in easy-to-understand graphics by Leica GeoMoS Analyzer. The standard deviation tolerance of the points measure was ± 2.2 millimetres (± 0.09 inches) and controlled by Leica GeoMoS Monitor.

"A special challenge was to integrate the geotechnical sensors into the monitoring system, which ended up working flawlessly. Even under extreme weather conditions like snow, freezing rain and storms, the system worked perfectly. This ensured a high degree of reliability regarding the information on the structural behaviour during the dry period," explained Heiner Gillissen, Technical Product Manager for monitoring at Leica Geosystems.

Dipl. Ing. Uwe Sowa of the Kiel-Holtenu Water and Shipping Authority assessed the movements which occurred during the renovation and the results after successful usage: "Each sensor has its own recorded data limit levels specified in the processing software that resemble the colours of a traffic light. Should a value exceed the defined tolerance it would appear in the red range, resulting in immediate notification via text message and email and ensuring that safety measures could be implemented. Except for a few exceptions in the yellow range requiring more in-depth analysis, all of the target values were always in the green range."

Meanwhile the lock has since been flooded, and the north chamber pumped out, renovated and monitored also using the same procedure. The level and movement behaviours of the locks will still be checked using digital tilt sensors and position sensors, and the data from these sensors sent to and evaluated by the GeoMoS software programs.

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Leica Geosystems **TruStory** Safety on the High Seas



Government awareness of the need for increased safety on offshore works is increasing worldwide. Russia has a strong interest in offshore safety and is in the process of preparing a bill concerning "protecting the seas of the Russian Federation against oil pollution". There are currently two oil-drilling rigs in operation, both belonging to "Lukoil" Ltd. The bill is not yet ready or obligatory, but Lukoil's directors have already initiated geodynamic monitoring systems on a maritime, ice-resistant platform over the Yuri Korchagin oil deposit to ensure safe operation and to protect workers from unexpected occurrences on the high seas.

The Yuri Korchagin oil deposit was discovered in 2000 and is located 180 km (110 mi) from Astrakhan in the northern part of the Caspian sea, at an average sea depth of 11- 13 m (36 - 43 ft). The rig began working in spring 2010 and consists of two blocks: the production and the accommodation facility.

Preliminary Evaluation

The owner and operator "Lukoil-Nizhnevolzhskneft" Ltd. put on a competition for the monitoring project, which was won by the Perm State Technical University (PSTU). The Mining GIS and Surveying department of PSTU had already had successes with projects in the area of deposit extraction and considered professional, quality equipment and software a crucial part of successful project completion. The scientists chose Leica Geosystems GNSS equipment to monitor the vertical and horizontal displacements of the oil rig.

The Caspian rig is permanently fixed to the seabed on six carriers. During the extraction process, the deoiled rock is repacked so the terrain generally settles down. However, if irregularities occur in the process, the rig might lurch. Therefore platform position monitoring is crucial to prevent dangers.

If subsidence processes develop gradually, production-related subsidence should not impact the facilities. However, local

irregular seabed displacements can occur, which may pose a threat to the oilfield infrastructure. Natural seismic activity in the region can aggravate the risk of man-made seismic events, which is further proof that geodynamic monitoring of facilities is essential.

Mathematical deformation modeling of the rock mass and the earth surface during oil production at the Yuri Korchagin field performed by experts from the Perm State Technical University have shown that maximum seabed subsidence is 100 mm (4 in). Preliminary evaluation of the general rock stress level during commingled oil and gas production indicates that maximum pay zone compaction reaches 890 mm (35 in). This means the development of gas reserves at the field is the main driving force behind seabed subsidence.

The Right Monitoring Approach

The PSTU scientists proposed a two-segment monitoring system: the first segment is an automated monitoring



system using Leica GNSS Spider software and the second is control monitoring performed upon control reference points onshore. Both segments involve sea and onshore works.

The shore reference network uses a reference station installed on the roof of a Lukoil-Nizhnevolzhskneft Ltd. office and connected to a server running Leica GNSS Spider, which is regularly checked by the chief surveyor. In addition, raw measurements of the four constantly operating sensors are saved on this computer. The sea segment of the monitoring system consists of three sets of GNSS equipment with antennas set up permanently on the three edges of the rig's main deck.

A geodynamic polygon of ten control sites has been created for the shore segment monitoring. Baseline solutions to the rig are computed from a single master site. All other sites are used to control the stability of the master site. If the master is moved or lost for any reason, its role transfers to another site.

The combination of sea and onshore segments results in a collection of raw measurements of all GNSS sensors combined on the computer of Lukoil-Nizhnevolzhskneft's chief surveyor. Leica GNSS Spider allows gathering and archiving

data automatically. The system is configured to compute sensor coordinates (points on the edges of the main deck) in real-time every second, as well as with hourly and twelve hour intervals in post processing. The results of coordinate calculations are presented in a movement diagram and are used to make a conclusion about sensor stability – and therefore rig stability.

Section two of the system is controlling the monitoring results by making long-term GNSS observations on permanent onshore base stations. To ensure the stability of the control network, first-order leveling was performed before starting GNSS observations.

A Stable Oil Platform

Since the installation of the monitoring system, the results show that control measurements and automated monitoring data correlate: the nature of subsidence and rises is completely identical, concluding that the real-time monitoring gives correct results. The sensor displacements are of non permanent nature; their values are small and for the most part do not exceed measurement accuracy, which indicates that their location is permanent and stable.

Comparing the control monitoring results with a drilling map leads PSTU to believe that smaller movements of 20 mm (0.8 in) are mainly caused by engine lowering and lifting. The Leica Geosystems monitoring installation remains essential to keeping all relevant parties informed.

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Scanning high-traffic roads unmanned

Monitoring the roadways of Singapore



- **Tritech Engineering & Testing (S) Pte Ltd**
- **Instruments & Software**
Leica Nova MS60 MultiStation plus Leica GeoMoS monitoring software v6 and later.
- **Challenge**
Setting a real-time wireless monitoring system without disturbing the traffic flow.
- **Solution**
Tritech was able to set up an Automatic Road Monitoring System (ARMS) covering a two-kilometres critical stretch to monitor the road surface with a fully automated monitoring system on a real-time basis.
- **Benefits**
 - Wireless deliver of results soon after the completion of each measurement epoch
 - The automatic scanning ability of the system enabled quick delivery of deformation information
 - Ability to add defined areas to the measurement cycle
 - Accuracy and reliability
 - Quick interpretation of monitoring data
 - Correct remedial decision making

The Singapore Land Transport Authority's (LTA) motto is We Keep Your World Moving. The organisation had committed to it with the construction of Mass Rapid Transit (MRT) System – Thomson-East Coast Line (TEL), which enhances rail connectivity cutting across from North to South corridors of the city. The new MRT line will greatly enhance the accessibility to the Central Business District and Marina Bay area.

Significantly improving travel time for commuters, the construction of TEL includes 43 kilometres of underground tunnel from Woodlands North Station to Sungei Bedok Station. With 4.5 km of tunnels underneath the dual three-lane heavy traffic Seletar Expressway (SLE), monitoring is of paramount importance where the contractor is to ensure negligible road deformation or disturbance that will affect the traffic flow.

The engineering firm Tritech Engineering & Testing (S) Pte Ltd was contracted to monitor the road surface with a fully automated monitoring system on a real-time basis. To provide this service, due to critical circumstances and high stringent monitoring requirement, Tritech initiated with Leica Geosystems' monitoring solutions.

Laser scanning and total station in one

Using the Leica Nova MS60 MultiStation plus Leica GeoMoS monitoring software v6 and later, Tritech was able to set up an Automatic Road Monitoring System (ARMS) covering a two-kilometres critical stretch of the SLE affected by drilling of the Tunnel Boring Machines (TBM) underneath. The essential laser scanning functionality of the Leica Geosystems MultiStation combined with reflectorless and prism measurements came to the rescue, as prisms installation on the road, which is prone to destruction by passing vehicles, was not an option for this project.

"With the MS60 MultiStation, we were able to setup the ARMS, enhancing productivity as an unmanned measuring system," said Dr. Tor Yam Khoon, registered surveyor with Tritech Engineering & Testing (S) Pte. Ltd. "The system also serves as an effective measuring system delivering the results wirelessly soon after the completion of a measurement epoch."

The automatic scanning ability of the system enabled quick delivery of deformation information. With GeoMoS image assisted scan area definition feature, the firm was able



to add the defined areas to the measurement cycle. For the firm, this combined solution helped enhance:

- Accuracy and reliability;
- Quick interpretation of monitoring data; and
- Correct remedial decision making.

“Leica Nova MS60 is a good hybrid of total station and laser scanner useful in deformation monitoring of points using glass prisms and surfaces using new Leica GeoMoS n.Vec Technology. In this project of road surface monitoring, successful application of the n.Vec Technology to horizontal surfaces is well demonstrated,” said Dr. Tor. “It is definitely better to derive the vector of deformation from a scan patch of at least 500 readings rather than from a single reflectorless reading.”

The data of the eight MultiStations used on the project was collated in Tritech's proprietary automated structured monitoring system. The automatic monitoring system, with ability to measure at four hourly cycles, seven days a week, of the MultiStation and GeoMoS translated into major cost savings in labour.

Data was collected from MultiStations set up at the road shoulder on a 4-m-high observation platform at the middle of four rows of patches of road surface at 25 m apart. These four scan patches were defined in rows crossing the road over the white lane markings.

These 16 regular scan patches are monitored at regular intervals. Between each 25-m regular monitoring zone there were also defined with “standby” scan patches at 5 m apart. These standby scan patches will be added to the monitoring scheme for automatic monitoring cycles whenever there is a planned or unplanned cutter head intervention. While the above MultiStation is in active monitoring, another one will be setup ahead and ready to go when the TBM enters its monitoring zone.

Support from abroad

For such a precise setup, there were initial challenges. Leica Geosystems staff in Singapore worked diligently

with support staff in Switzerland to quickly diagnose the setup issues and effectively resolve them.

“When there was a need to change the MultiStation in the midst of the monitoring campaign, there were no adverse effects to the project due to a timely and effective response by Leica Geosystems technical support,” said Dr. Tor.

Monitoring solutions by Leica Geosystems support LTA to fulfill its promise and keep the world moving wherever heavy construction projects are underway.



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Leica Geosystems **TruStory**

The Great Ancona Landslide



On 13th December 1982, a very large zone of the city of Ancona was devastated by a huge landslide, affecting 11 % of the urban area. Homes and infrastructure were seriously damaged, about 3'000 people had to be evacuated. The railway and state highway were blocked, and water and gas supplies interrupted. After years of study authorities decided that consolidation was not a feasible option. This was due to both the cost and the environmental impact, which would have devastated the areas' natural character. Therefore, the City Council decided to ensure the safety of the local population by designing and installing a complex integrated monitoring system to provide constant control of the landslip area.

The affected area of Ancona consists of an entire hillside, approximately 341.5 hectares in total. It ranges from an approximate height of 170 metres above sea level down to the sea itself. During the 15 days prior to the landslide on 13. December, 1982, the rainfall in the area was not exceptionally high in absolute terms but was persistent. This caused a significant rise in groundwater levels.

In response to the landslide, a series of specific laws were passed at both a regional and national level. This enabled the allocation of funds needed for the emergency operations, as well as to complete the clean-up and rehabilitation of the affected area and provide aid to the local people.

After the initial emergency operations, a detailed study was done of the landslide

area, in order to draw up a plan for the repair or reconstruction of the affected homes. Preparation of a plan for continuous monitoring of the landslide area using geodetic and geotechnical instrumentation also began. This was used as the basis for a Civil Defence Emergency Plan.

The Monitoring Plan was subdivided into 2 parts; the first of these, relating to the geodetic instrumentation, was put out to tender in 2006. The contract was awarded to Leica Geosystems Italy for the supply and installation of a high-precision continuous integrated topographic monitoring system.

In association with the Ancona City Council engineers installation of the monitoring system began at the end of 2006 and was completed in the

summer of 2007. In October 2007 local and national government representatives officially presented the system to the public. This coincided with the system startup and calibration stage. This stage, currently still underway, has enabled those responsible to analyse the main results and to use them as a basis for setting the alarm thresholds in the Civil Defence Plan.

Three steps for maximum safety

Due to the large area to be monitored and the complex morphology of the landslide zone, the system was designed on the basis of three monitoring levels.

- The first (alarm) level is comprised of three main stations outside the landslide area each with a robotic total station, dual frequency GPS and dual axis inclinometer.
- The second level is comprised of five monitoring stations inside the landslide area, with identical instrumentation.
- The third level is comprised of a network of 26 single frequency GPS sensors and 200 prisms installed on homes, with all prism points measured by robotic total stations.

Each station in the 1st and 2nd level network was installed on reinforced concrete piles. Each pile is 1 meter in diameter, sunk into the ground to depths varying from 10 to 25 meters, with about 3 meters above ground level. Each concrete pile has a Leica TCA2003 robotic total station installed on top. The AX1202 GPS antennas together with the Leica GRX1200 GPS receivers were installed by means of stainless steel posts, 10 cm in diameter, with variable heights. Each station was completed with wiring for communication and power supply.

The 3rd level network stations, were created by installing single frequency GPS antennas and solar panels on the roofs of private homes. Each station was wired to protect the power supply and installed in positions allowing easy access for possible maintenance work. Approximately 200 prisms were installed on the homes in the area, for measurement by the seven Leica TCA2003 robotic total stations.



No significant movements by May

The system runs automatically and is managed by the Control Center in the City of Ancona, about 3 km from the monitoring area. A WLAN – HyperLAN main communications line provides complete and continuous real-time control of all the field sensors. The Control Center has a network of computers running Leica GeoMoS and Leica GNSS Spider software. The software controls the sensors and performs analyses of the acquired data. Custom software modules were specially developed for the management of the alert, pre-alarm and alarm thresholds and the subsequent triggering of warning systems to protect the population. Remote access to the system is possible via the Internet to enable relevant personnel to manage and oversee the system at any time.

The Leica TCA2003 robotic total stations perform a measuring cycle to the prisms every 4 hours. The GPS receivers record measurement sessions lasting 6 hours, with a 15 sec. acquisition rate. Analysis of the results obtained between October 2007 and May 2008 revealed that no significant movements of the structures in the risk area occurred. One year after the start-up of the surface topography monitoring system, the engineers in charge have been able to analyse the

first results. This period of fine-tuning of the system has been fundamental in allowing the definition of the alert, the pre alarm and alarm thresholds.

Future implementations

The tender for the second functional stage of the monitoring project includes supply and installation of underground geotechnical sensors and extremely high precision surface dual axis inclinometers. The combination of different sensors and technologies allows for the most effective monitoring of complex gravitational phenomena, such as the Ancona landslide. This will allow the landslide phenomenon and its evolution over time to be studied by analysing the acquired measurements. Therefore helping to make targeted, effective planning of any future consolidation work possible.

In Ancona, the local government and local population have taken an active approach to living with a huge landslide. This new philosophy is a fresh, dynamic response to a complex problem: the solution moves beyond the usual static concepts of ordinary engineering solutions, unfeasible or unaffordable in this case, while simultaneously reducing the risk level for the people living in the affected areas.

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Leica Geosystems **TruStory**

The Shard: London's New Skyline



Byrne Bros is both one of the UK's and the world's leading formwork construction companies. They were appointed by main building contractor Mace to carry out the concrete substructure and superstructure works for Europe's tallest building – The Shard in London – in a contract worth more than 64 Mio. Euro (78.5 Mio. US Dollar). In the summer of 2009, Leica Geosystems was approached by Byrne Bros to develop a real time slip-form rig positioning system, used to construct the central concrete core of The Shard.

The substructure of The Shard adopted 'top down' techniques and the main structural core was slipformed in parallel solutions, which delivered significant program advantages. Slip-form construction is perhaps one of the safest, efficient, and most economical methods of building vertical structures.

It enables formwork construction to rise at rates of up to 8 m (26 ft) in 24 hours. Traditional methods of controlling the position of a slip-form rig as it rises are often time consuming and labor intensive. Normally a site surveying team will compute traverse computations from observations taken with total stations and precise optical plummets. These calculations allow the position of the rig to be obtained in the site grid coordinates. As the vertical concrete core has known offsets from the rig it is therefore possible to guarantee the core is being constructed vertically in relation to its design coordinates.

Tight Tolerances

The required tolerance for The Shard project was that rig plan position should not exceed $\pm 25\text{mm}$ (± 0.98 in) deviation against the design coordinates. After some consultation between Leica Geosystems and Byrne Bros a combined system of total stations, GNSS, and dual axis inclinometers

was agreed upon. Real-time GNSS positions allowed determination of the rig's position. Both the translation and rotation of the rig could be determined using GNSS technology, but it was unable to provide information on the rig's inclination which could have been up to ± 75 mm (± 2.95 in) over the 20m (66 ft) square rig, depending on the correction factors applied by the rig manager. It was therefore necessary to calculate the tilt on the rig. This was achieved using data acquired from four dual axis inclinometers. By using the virtual sensor functionality within the Leica GeoMoS Monitoring software it was possible to compute a tilt compensated position of all four corners of the rig. The inclination sensors were chosen due to the large expected range of tilt and were integrated into the systems via a Campbell Scientific Datalogger.

Setting Up a Reliable Construction Monitoring System

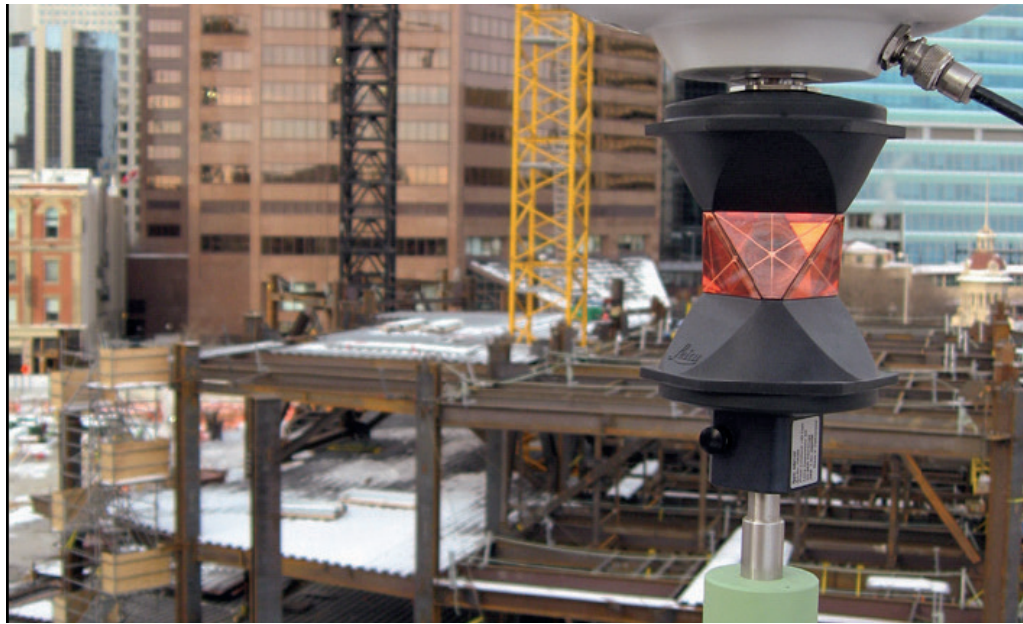
As with any other city, working with GNSS technology in London can often prove challenging. Existing buildings and infrastructure can obscure satellite signals, resulting in unreliable positions or even no possible calculation. For this reason 360° prisms were co-located with the Leica AS10 GNSS antenna to allow both total station and GNSS observations to be gathered simultaneously, which would also provide a check on the GNSS results, particularly while the rig was near ground level and the potential for difficulties with a clear satellite window were greater.

To allow the GNSS and total station results to be correlated a set of transformation parameters were calculated within Leica GeoOffice.

In addition to the problem of actually using GNSS technology in the 'urban canyon', the provision of both reliable and stable reference stations was extremely difficult. Often easy access to a stable location that provides both the necessary power supply and communication was hard to obtain. Negotiation with other building owners and businesses could have been prohibitively expensive. Finally it was decided to use a real-time data feed from Leica SmartNet NRTK correction service.

The four GMX902GG receivers were connected to the site computer running on the rig. Leica GNSS Spider received the incoming data streams for these receivers and a real-time data stream from the SmartNet service. Internet connectivity was provided by a WLAN bridge system, comprised of two directional antennas, which guaranteed reliable Internet connectivity to the site computer on the rig as it rose nearly three meters per day.

The position of each antenna on the rig was computed with respect to the nearest SmartNet reference station which was



approximately 2.4 km (1.5 mi) away. This yielded a three-dimensional coordinate quality of better than ± 25 mm (± 0.98 in).

Computing Positions Every Second

GNSS positions were computed every second within Leica GNSS Spider and the median result of these observations were sent to Leica GeoMoS every 10 seconds where they were synchronized with the data from the dual axis inclinometers and the wind speed. A computation was simultaneously carried out within GeoMoS, applying the lateral shift caused by the tilt of the GNSS antenna to the vertical position.

The rig positioning interface used the open architecture of Leica GeoMoS, which is built on a Microsoft SQL database. An ODBC (Open DataBase Connectivity) link was established between the GeoMoS database and the bespoke interface, which displayed the results graphically, so that it was easy to understand by the rig manager. This interface enabled the rig manager to make adjustments to the rig position using hydraulic pumps. A traffic light system of warnings was displayed within the interface. If the computed results exceeded ± 25 mm (± 0.98 in) lateral displacement

against the design position of ± 4 mm per meter (± 0.05 in per foot) of tilt on any corner of the rig, then an orange display was shown. An exaggerated rig display and level 'bubble' display allowed instant visualization of results.

Project Results

This new and innovative approach to controlling the position of a slip-form rig proved highly successful on The Shard project. The fact that the results obtained could be verified and correlated to those obtained via traditional methods was extremely important in building confidence in the system. This, allied to the fact that the Leica Geosystems Monitoring Support team could support this system remotely even 24/7, meant that, particularly in the early stages of this project, confidence in the system was assured. Other tall buildings being constructed in London using slipform methodology have already adopted this system and Byrne Bros plan to use this system again on future projects.

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- when it has to be **right**

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