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AUTOMATIC GEODETIC MONITORING SOLUTIONS EARLY WARNING SYSTEMS FOR STRUCTURAL ENGINEERING RISK'S MANAGEMENT

Since the prestigious optical theodolite Wild T3, Leica Geosystems AG Heerbrugg, has continually innovated in the high accurate geodetic instrumentation for the monitoring of the large civilian engineering structure.

Mixing up single and multi-frequency, multi-constellation GNSS receivers and Automatic Total Stations as well as with the most precise inclinometers in its software suites GNSS Spider, GNSS QC and GeoMoS, Leica Geosystems is delivering solutions worldwide for all large engineering structures where a geodetic monitoring solution is needed alone or to complement geo-technical sensors installations and to provide early warning systems for risk management.

Monitoring tasks and deformation analysis present some of the most sophisticated challenges in the surveying industry today, because they require the highest accuracy, maximum reliability of the sensors, automatic measurements, and highly flexible computation and analysis tools.

With close to 200 years of pioneering solutions to measure the world, professionals worldwide to help them capture, analyse, and present spatial information trust Leica Geosystems products and services. Leica Geosystems is best known for its broad array of products that capture accurately, model quickly, analyze easily, and visualize and present spatial information.

Those who use Leica products every day trust them for their dependability, the value they deliver, and the superior customer support. Based in Heerbrugg, Switzerland, Leica Geosystems is a global company with tens of thousands of customers supported by more than 2,400 employees in 21 countries and hundreds of partners located in more than 120 countries around the world.

AUTOMATIC DEFORMATION MONITORING SYSTEM OF HIGH-SPEED RAILWAY SETTLEMENT IN KOWLOON SOUTHERN LINK PROJECT

The Kowloon-Canton Railway Corporation (KCRC) in Hong Kong acquired an Automation Deformation Monitoring System from Leica Geosystems in December 2005 for continuously monitoring settlement and overall deformation of a section of existing Airport Express Railway during the construction period of the new Kowloon Southern Link project.

The solution package contains 18 units of fully automatic, high-precision Automatic Total Station TCA2003, 5 packages of GeoMos monitoring software, more than 560 prisms, several computer workstations with networking facility and professional technical services delivered by local Leica Geosystems' specialists.

The Total Stations automatically measure all prisms located at reference control points and also monitoring points every 2 hours and then send the observation data back to GeoMos software operating at a Control Center for routine automatic settlement and deformation analysis, graphical presentation, generating reports and sending alarm messages to engineers when settlement values reach critical level.

Besides, before the departure of the first Airport Express train every morning, a general report is sent to engineers automatically for inspection and they can also access full railway deformation information via Intranet webpage anytime.

As said by Mr. Andrew Wong - Engineering Solution Manager of Leica Geosystems Hong Kong: “It is a well-proof solution for engineer making quick and right decisions and also take necessary actions regarding the influence of new construction works to existing structure”.

INTEGRATED GEODETIC MEASUREMENT AND ANALYSIS SYSTEM FOR LARGE DAMS MONITORING

Large earth fill and concrete dams are a critical infrastructure for water supply and power generation. Loading and unloading of the dams due to fluctuations in the water level and settlement of the structure must be monitored to ensure the safety of the structure and the people living in its shadow. Monitoring is the basis for disaster preparedness and early detection of signs of a breach is critical to effective dam safety. Early detection of a weakness in the structure allows for remedial measures to be taken to repair it and prevent a disaster from occurring. Even if repair is not possible, with early warning of a problem action may be taken to mitigate its effects, for example by lowering water levels, thereby saving lives and property.

The monitoring of such large engineering infrastructure is thus becoming more and more important. Geodetic monitoring involves periodic or continuous and automatic measurements of characteristic points in and around an active area to determine the magnitude of deformation but also the velocity and acceleration of the associated displacements.

The Consorzio di Bonifica of Basso Sulcis is one of the numerous associations existing in Italy that manages the water resources. Car-bonia’s Dam is one of the biggest dam in Sardinia and allows water supply for thousands and thousands people.

The Central Government Authority (Servizio Nazionale Dighe) obliges such associations to monitor dams periodically or in real time in order to prevent eventual problems related with cracking or failure of the structures, ageing of materials with which dams are built and possible deformations caused by big hydraulic loads.

The system installed in Carbonia’s dam uses a Leica Automatic total stationTCA2003 which measures every four hours a series of prisms positioned on the crest and on the face of the dam. Data from a chain of seven Leica NIVEL high accurate inclinometers installed inside the main underground tunnel are collected every five minutes with the aim to detect eventual rotations of the main body of the dam, caused by the growing mass of water in the dam.

The Gotthard base tunnel will be the longest rail tunnel in the world upon its completion. There is a small risk that construction of the tunnel will cause movements in the land above because of water being drained from the rock mass. Above the area of the tunnel are three of the largest dams in Switzerland.

The awarding authority, "AlpTransit Gotthard AG", decided that it is necessary to continuously monitor the dams and the nearby valleys and mountain peaks.

Realization of the monitoring system has been complicated by the altitude (~2000m), harsh winter conditions and remoteness of the site. The system composed of 10 TCA2003, 80 high accurate reflectors and 4 licenses of GeoMos uses solar power and data communication via GSM phone to power and communicate with the sensors.

The monitoring system has been running successfully all year round for several years and produces millimeter-accurate measurements of the movements.

The Leica Total Stations have a specially manufactured angle measuring system that facilitates a measuring accuracy of 0.15mgon (0.5") on the TCA2003. Key elements here are the precise drives and the quadruple detection of the graduated circles.The TCA2003 is equipped with coaxial high accurate distance meters and a distance measuring accuracy of 1mm+1ppm is achieved due to the use of specially developed components. The Automatic Target Recognition (ATR) that equipped this “monitoring” Total Stations demonstrates its full benefits during automatic repeat measurements and allows measurement at two telescope faces. Using the sight, the observer aligns the telescope roughly with the target point and triggers a distance measurement. The total station automatically moves the telescope to the centre of the prism, measures the distance and corrects the angle 1 mm with the deviation to the centre of the prism. Once all points have been measured the Leica Geodetic Monitoring software GeoMoS can repeat the sequence automatically.

The Leica Geodetic Monitoring software is based on two main applications called Monitor and Analyzer:

- The Monitor is the on-line application responsible for the sensor control, collection of data and event management.
- The Analyzer is the off-line application for the analysis, visualization and post-processing of the data.

The Leica Geodetic Monitoring software integrates various types of sensors like GPS and GNSS receivers, high accurate total stations, precise clinometers, etc in their appropriated recording rate.

The Leica GeoMoS Analyzer represents the data and results graphically and numerically. The results can be visualized in time series graphics, which show the trends of the movement over selected time periods. Multiple points can be viewed simultaneously in a same graph.

A vector view shows an overview of the displacement for a selected area and the operator can easily see where the greatest movement has occurred.

The Leica GeoMoS uses standard data transaction technologies to exchange data. This ensures the data integrity even if the connection is interrupted. The connection between the computers in the system configuration can be via various media links, including modem, GSM, WAN, LAN, radio link or cable using TCP/IP Internet technology.

A SQL Database is the kernel of the Leica GeoMoS solution and handle all the measurements as well as the various settings and configurations. Any external applications can access the GeoMoS SQL Database that has been designated as a true open system.

The benefits for the responsible of large water dams stability monitoring are certainly the integrated aspects of the GeoMoS system but also the various level of services, the support and expertise of Leica Geosystems as well as the high quality and reliability of the associated sensors.

INNOVATION AND EXPERIENCE IN GNSS BRIDGE REAL TIME 3D-MONITORING

In recent years, GNSS RTK technology has being used by more and more bridge operation and management facilities in dynamic bridge displacement monitoring.

In 1999, Leica Geosystems on the Tsing Ma Bridge, Hong Kong, deployed the world’s first GPS-based bridge monitoring project. After that, Leica Geosystems’ software and hardware have been deployed to monitor bridge structural health of numerous bridges including the Shandong Yellow River Bridge and the Jiangyin Bridge, earning Leica Geosystems a high regard in this field.

At the beginning of 2005, Leica Geosystems released Spider 2.0, a new generation of GPS monitoring software based on an advanced RTK processing kernel. Compared with the traditional real time RTK monitoring solutions based on existing surveying GNSS RTK receivers, this technology is far superior.

The Jiangyin Yangtze River Highway Bridge is the first super-large steel box-girder suspension bridge that spans more than one kilometer in China. It is the longest steel box-girder suspension bridge in China, the fourth longest in the whole World. It services a super highway that is the national key trunk route crossing the Yangtze River. The Jiangyin Yangtze River Highway Bridge is the second suspension bridge that was constructed over the Yangtze River. It lies between Jiangyin and Jingjiang of Jiangsu Province, at the lower reaches of Yangtze River. The north and south towers are 190 m high. The Bridge Monitoring Center was built at one side of the bridge (Jingjiang), equipped with Communication System, Closed Circuit Television, Information Management System, Message Sign System, Emergency Call System, Broadcast System, etc.

The advanced GPS Spider Bridge monitoring solution with centralized RTK function developed by Leica Geosystems has been installed in the monitoring center. The communication requirements are greatly simplified with GPS Spiders' centralized RTK concept. The receiver equipment can be remote controlled and monitored, and the status of the system can be obtained at anytime. With the standardized output interface, it can be easily connected with third party analysis software. Operating at a 20Hz measurement rate, the bridge monitoring system is able to detect high frequency vibrations.

With this new technology, the geometric form of the bridge is monitoring in real time and in all weather conditions. The three dimensional displacement of the towers, main span and suspension cables is measured directly. All of this characteristic information that reflects the bridge's health can be combined with structural models to analyze the internal forces affecting the main components of the bridge. The reliability of the bridge health monitoring and evaluation can be increased and the risk of potential damage to the structure bridge can be detected. Therefore, GPS monitoring improves the efficiency and effectiveness of the maintenance work; provide the quantification information to the management and decision making of the traffic and structure safety of bridge, and make reliable assessment of the safety of the bridge.

With the ongoing development and improvement of GNSS hardware, processing algorithms and software GNSS monitoring systems will be applied widely to the structural monitoring such as bridges, building and other structures. Meanwhile, the Jiangyin Bridge's structure health monitoring system will play an active role in the promotion and development of the digital and intelligent bridge engineering.

Leica Geosystems has developed dedicated GNSS receivers like the Leica GPS L1 GMX901 and the Leica GMX902 GG for structural monitoring applications complemented by GNSS antenna's that has the capacity to mitigate and reduce the multi-path effects induced by the structure itself in many cases.

The kernel, which is integrated into the Leica GNSS Spider reference station and GNSS QC monitoring software, is able to process single and dual frequency data from GPS and/or GLONASS in real time and post processing mode. Three ambiguity resolution techniques has been implemented and successfully checked on many projects: Kinematic On the Fly (OTF), Initialisation on a Known Mark and the new Leica innovative Quasi-Static approach.

The Leica GNSS Spider also has the capacity to re-process complete observation files in RINEX format in those two modes. It's particularly interesting during the design phase whereby receivers can be placed temporarily to collect 24hour or 48-hour data and then processed at a later stage. The advantage of this is that performance of the system can be analysed prior to permanently fixing cabling for power and communications as well as estimating any errors associated with multipath.

Due to the nature of the different sources that affects the solution of GNSS measurements like the atmospheric delays, the orbital errors and the multi-path effects in some extend, the results are generally noisy and will not reflect at first look the full potential of the solution.

Leica GNSS Spider has that capacity to reduce the noise by using efficient digital signal processing filtering techniques (FIR), and multiple trials have demonstrated that up 30% to 45% of the noise are effectively suppressed.

CORE WALL SURVEY CONTROL SYSTEM FOR HIGH RISE BUILDINGS.

The Burj Dubai tower in Dubai, UAE, will rise to a height of over 800m when complete in 2008. In addition to being very tall it is also quite slender and it is anticipated that there will be movement of the building at upper levels due to wind loads, crane loads, construction sequence and other factors.

The self climbing formwork system for the building is complex, due to the shape of the structure and requires a large number of control points. It has been necessary to develop a survey system that can efficiently provide the large number of control points and can be used when the building is moving.

The movement of the structure creates several problems for precise survey; at a particular instant in time, theoretically, you need to know exactly how much the design centre line of the building is offset from the vertical axis and at that same instant you need to know the precise coordinates of the instrument. However a ‘mean’ position taken over a short period for both elements can provide a suitable solution.

GPS operating in kinematic mode are being used to establish survey control at the upper levels. The system comprises a minimum of 3 GPS antenna/ receivers mounted on tall fixed poles at the top level of the formwork. In kinematic GPS mode, satellite signal data is received and recorded every second for a period of up to 1 hour. During this same period of time, the TPS instrument is used to measure a series of angles and distances to the prisms mounted below the GPS antennas. The TPS then measures to the reference marks placed on fresh concrete, which are the reference points for control of the formwork.

After completion of observations, data is returned to the office for processing. Computation of GPS antenna positions is carried out, processed against data from a Continuously Operating GPS Reference Station Leica GPS GRX1200 Pro with AT504 choke ring antenna and Leica GNSS Spider software, using Leica Geo Office software (LGO).

Computation of TPS position is then carried out actually as an advanced least squares resection. 3D transformation is performed of the 3 WGS84 antenna coordinates and resected TPS coordinates into the local coordinate system and from this a determination of coordinates of all measured reference marks is made. These steps yield coordinates of survey instrumentation and reference marks in the site project coordinates.

The Core Wall Survey System uses also Leica NIVEL220 dual-axis precise inclinometers to accurately determine displacement of the tower alignment from vertical. Inclinometers measure absolute tilt to +/-0.2” arc. This angular measure is applied to the vertical distance of the clinometers sensor above the foundation raft to provide a computed plan displacement in X and Y at that elevation due to the tilt of the structure.

A total of 8 precise clinometers have been networked at approximately every 20 floors up the tower as construction proceeds. Each instrument is mounted in the center core wall in a box out within the wall where casual disturbance is unlikely.

An analysis of predicted movements has been completed and a system installed which delivers accurate positioning for construction set out at the top level of the formwork.

Extensive results are available to date and monitoring indicates that the required accuracy is being achieved.

“You may be interested to know that we have now reached top of concrete for the Burj tower at Level 156, at level 585.7meters” said Doug Hayes, Chief Surveyor Burj Dubai Tower Samsung, Besix and Arabtech Jvof.

“We have used our Leica GPS/ Nivel system all the way - the system has proven to be fantastic. Vertical walls are straight, lift shafts are too - standard deviations of concrete core walls are generally around 7mm. At the very top I have computed the mean displacement of all core walls: dE 0mm, dN 5mm from design position. Of course this quality has come about due to a lot of effort on all sides - not just survey. But for our part I am very pleased with the way things have gone. The system has also allowed to monitor the structure continuously and remotely, from a dynamic perspective as well as from a long term one, to quite amazing accuracy” Doug Hayes added.

Joel van Cranenbroeck is Senior Manager for Leica Geosystems AG - Geomatic Business Area in Heerbrugg, Switzerland. Acting as Business Development Manager for GNSS Networks and Monitoring he is also Vice-Chair for the FIG Commission 6 Working Group 4 on Surveying Engineering – Deformation Measurements of Engineering Structure and Analysis. Scientific Collaborator for the University of Liège and the Faculty of Agronomy in Gembloux, Belgium, his main focus is currently geodetic monitoring of engineering structures, where Leica Geosystems is world leader in terms of innovative solutions and market share. He has designed many structural monitoring projects worldwide and especially for long bridges, towers, high raise buildings, large dams and reservoirs, landslides and ground motion.

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