Introduction by John Dunnicliff, Editor

This is the sixty-ninth episode of GIN. One full-length article this time, and a series of brief articles about remote methods for monitoring deformation.

Response values (a.k.a. trigger levels and hazard warning levels)

In the September 2011 episode of GIN I wrote, "I'm working with a colleague to put together answers to the question, 'How should we determine response values?' and hope to include this in a later GIN". The following article by Mike Devriendt helps us to face this challenging task.

Remote methods for monitoring deformation

In the December 2011 episode of GIN I wrote that I was planning to provide an overview of various remote methods for monitoring deformation in one or more later GINs—a one-page overview of each and a concluding article with a comparative analysis of the various techniques. Here's an introduction by me and the first four one-page articles on:

- Terrestrial laser scanning (light detection and ranging): TLS Terrestrial LiDAR, by Matthew Lato.
- Terrestrial interferometric synthetic aperture radar: TInSAR, GBInSAR, by Paolo Mazzanti.
- Robotic total stations (automatic total stations, automated motorized total stations): RTS, ATS, AMTS, by Rob Nyren, Ryan Drefus and Sean Johnson.
- Reflectorless robotic total stations: RRTS, by Damien Tamagnan and Martin Beth.

In the next GIN we'll have three more:

- Satellite interferometric synthetic aperture radar: SInSAR, including DInSAR and PSInSAR, by Francesca Bozzano.
- Digital photogrammetry, by Raul Fuentes and Stuart Robson.
- Differential global positioning system: D-GPS, by Rob Nyren and Jason Bond.

As one of my colleagues said to me, "The basic difference between these remote sensing techniques and our stuff is that **they** measure on the outside, whereas **we** measure on the inside. E.g. for a landslide, they measure the effect, we measure the cause". Not too shabby!

The next continuing education course in Florida

This is now scheduled for April 7-9, 2013 at Cocoa Beach. Details of this year's course are on http://conferences.dce.ufl.edu/geotech. The 2013 course will follow the same general format but with significant updating, including remote methods for measuring deformation. Information will be posted on the same website in late summer this year.

Closure

Please send contributions to this column, or an abstract of an article for GIN, to me as an e-mail attachment in MSWord, to john@dunnicliff.eclipse.co.uk, or by mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. +44-1626-832919.

Zivili! (Serbia)

Trigger levels for displacement monitoring

Mike Devriendt

Introduction

This article discusses the use of trigger levels for monitoring geotechnical or tunnelling projects. Trigger levels are also known as response values and hazard warning levels. The content of the article focuses primarily on trigger levels for instrumentation used to monitor strain or displacement. However, some of the principles would also extend to trigger values relating to other parameters such as water level, pressure or temperature. The article refers to the measurement of 'displacement' throughout much of the text, while later sections use the term 'deformation' to indicate the interpretation of measured displacements to calculate a strain or other form of distortion of a structure.

Trigger level systems

This section provides a framework for defining trigger levels.

A trigger level is a pre-defined value of a measured parameter. If an instrument reading is higher than this value, then a pre-defined action is carried out.

It is common to use two or more trigger values during monitoring of construction to denote different levels of response, given the magnitude of the reading and urgency or significance of the required response.

From the author's experience the adoption of a 'traffic light' system is most effective, with the use of Green, Amber and Red trigger levels. The use of such a system is useful to provide a simple and robust system that is clear for monitoring and non-monitoring specialists. Some practitioners propose having numerous other trigger levels defining different actions. While further trigger levels may have the benefit of allowing more detailed planning of escalating contingency responses, if a trigger doesn't result in a defined process, it is proposed that there should be no need for the trigger.

The following zones are commonly defined:

- Green = OK, proceed
- Amber = Monitor more frequently, review calculations and start implementing contingency measures if trends indicate the Red trigger may shortly be reached
- Red = Implement measures to cease movements and stop work.

Alternative words are also commonly used to describe the Amber and Red triggers. These include:

Amber = Threshold, Alert, Review, Warning

Red = Limit, Maximum, Action, Response, Tolerable limit

Prior to construction work starting a process and timeframe should be defined that project participants adhere to once a trigger has been reached. It is also recommended that consideration is given, prior to construction work starting, of the actions or mitigations that can be readily deployed once trigger values are reached. This may avoid scenarios where the program is impacted due to cessation of work once a Red trigger has been reached or exceeded.

Consideration should then be given to the rate at which movements are likely to occur. For instance, the rate at which movements take place around a tunnel excavation formed using a tunnel boring machine is generally much quicker than the rate of movement around open or retained cut excavations. This will influence project participants' views on what actions are appropriate and possible as and when trigger values are exceeded.

Defining trigger values

While the previous section provides a framework for defining trigger levels, the following approach is commonly used for defining the value of the trigger levels based upon earlier design analysis:

- Amber trigger is set close to the 'calculated' displacement from analysis;
- Red trigger is based on a tolerable 'damage' or deformation criteria.

When setting Red trigger levels, an alternative definition is, "a conservative estimate of when a serviceability limit state is likely to be exceeded". In this regard it is useful to consider the Amber and Red trigger levels to be set on two separate unrelated scales; one related to calculated movements and one relating to tolerable movements.

An example of how trigger values can be set is provided in Figure 1.

Consideration should be given to the degree of conservatism adopted in the calculation to define the Amber trigger level.

For assessing movements caused by tunnelling and with reference to the example provided in Figure 1, good practice suggests carrying out serviceability limit state calculations using a cautious estimate (or conservative) volume loss rather than a 'best estimate'. Therefore if setting the Amber trigger at 80% of the calculated movement, the actual movement can be expected to be of similar magnitude or less than the specified Amber trigger level. Measured displacements greater than the Amber trigger will therefore identify that the movements are in excess of calculated displacements using 'best estimate' parameters and should therefore prompt a review.

It is also common to relate contractual requirements to trigger values with respect to responsibility of causing impact and requirements for repair to third party structures. Commonly the Amber trigger is used to define where responsibility transfers from the project client or promoter of a project to the construction contractor. The Amber trigger may therefore represent a level that should not be exceeded provided 'reasonable skill and care' is adopted in carrying out the construction work.

Further considerations

What movement is tolerable?

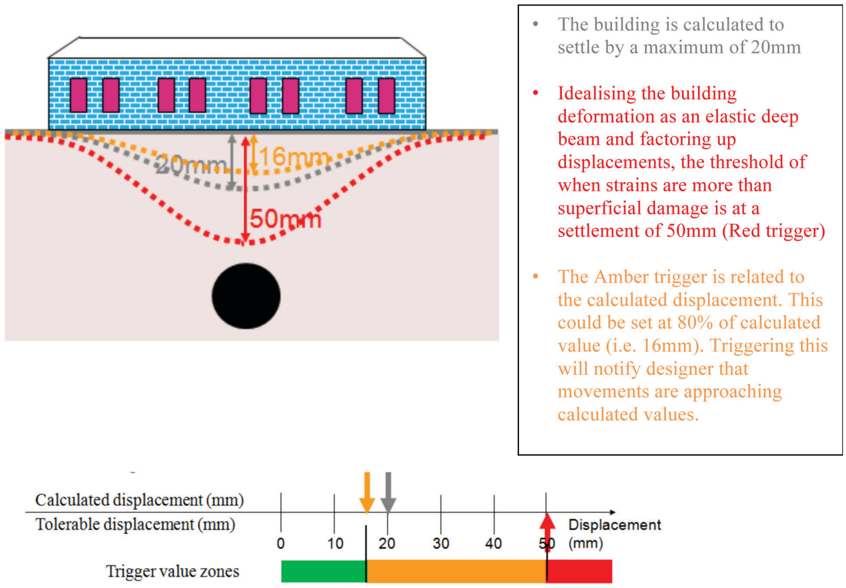
It was recommended above that Red trigger levels should be based on a tolerable damage or deformation criteria. When assessing some third party assets, tolerable deformations are not always easy to calculate. An example of where this could be difficult is assessment of deformation of a tunnel being used as part of an operational urban metro system. Tolerable deformations under this scenario can be related to several elements:

1. Structural deformation;
2. Clearance of trains to tunnel lining;
3. Deformation of track within the tunnel; and
4. Deformation of services and utilities within the tunnel.

Assessing the amount of deformation that each of the above elements can tolerate have varying degrees of difficulty. Specifying trigger levels on each of these factors is also challenging as it may result in a complex range of trigger values for the same 3rd party structure. Where possible it is advantageous to identify the critical element(s) and base triggers on these.

On what parameters should you set trigger values?

Consideration must be given regarding which measured parameters to set trigger values for. One particular challenge is that parameters (or deformations) that cause damage such as imposed curvature are not straightforward to calculate from monitoring results. Interpretation is often required to calculate an appropriate curvature. The requirement for interpretation may lead to disagreement between project participants. Parameters that are easier to report from monitoring data results such as settlement or tilt



- The building is calculated to settle by a maximum of 20mm
- Idealising the building deformation as an elastic deep beam and factoring up displacements, the threshold of when strains are more than superficial damage is at a settlement of 50mm (Red trigger)
- The Amber trigger is related to the calculated displacement. This could be set at 80% of calculated value (i.e. 16mm). Triggering this will notify designer that movements are approaching calculated values.

Figure 1. Setting trigger levels for a building subject to settlement from tunneling.

are less susceptible to the requirement for interpretation, however, they may not result in any impact or damage to a structure. For instance if an entire building settled by 25mm or rigid body tilt occurred to the structure, the structure may not be damaged in any way.

A common solution to this issue is to set triggers on parameters that are easier to report such as settlement and tilt, then only calculate and carry out interpretation on parameters such as curvature once the Amber trigger has been reached. There remains some residual risk with this approach and therefore it is prudent for interim checks to be carried out by the engineer responsible for interpreting the monitoring data prior to an Amber trigger being breached.

Trigger values for compensation grouting

Following on from the previous section, further consideration is required regarding triggers where compensation grouting is proposed. Specifying limits on just settlement can lead to significant amounts of grout being unnecessarily pumped into the ground and consequently additional cost. However it is considered prudent to specify triggers relating to heave movements to check against inappropriate operation of the grouting system. Where settlement occurs, it is recommended that triggers are specified relating to limits on imposed gradient and potentially deflection ratio, if agreement can be made among the project participants of how to calculate the latter.

Instrument reading accuracy and triggers

Care should be taken when selecting instruments to ensure they can be read to sufficient accuracy and precision. Accuracy in this article is defined as a measure of how close the measured value of the parameter is to the true value, while precision is the repeatability of a measurement when there is no real change in the parameter being measured. Trigger levels should be at least several times larger than the accuracy of measured changes. Account should also be made of any diurnal trends that could take place and these should be identified from baseline readings. If the calculated displacements are small (for example only a few millimetres) and tolerable values are considerably larger, it is prudent to set the Amber trigger at a displacement higher than the calculated value and in keeping with the general recommendation that they should be at least several times larger than the accuracy of measured changes. This represents an alternative to setting trigger values close to calculated values identified earlier.

Identifying trends of data

As the construction work progresses, it is important to review trends of movement even if the readings are within the Green zone and haven't exceeded any trigger values. Trends within the Green zone can give useful forewarning. A pro-active approach is therefore recommended for reviewing monitoring data. Review of the data and trends must be made with knowledge of the construction progress and any important environmental factors. In determining trigger levels and defining the process initiated once they are exceeded, consideration should be given to the time needed to instigate any pre-planned response to a developing trend.

Conclusions

This short article has identified some of the key considerations for setting trigger values relating to monitoring displacement and deformation. The article has highlighted the requirement that the person setting triggers must have intimate knowledge of the design. Guidance is also given relating to which deformation parameters to set trigger values on and appropriate review of monitoring data relative to triggers during the setup of a monitoring system and during construction.

Mike Devriendt
Associate, Arup, 13 Fitzroy Street,
London, W1T 4BQ, England.
T: +44-20-77552163,
E: michael.devriendt@arup.com

Remote monitoring of deformation. Introduction

John Dunnicliff

I was very impressed by the number of papers about remote methods for monitoring deformation at last September's International Symposium on Field Measurements in GeoMechanics (FMGM) in Berlin. Because I knew almost nothing about several of these, with their multiple acronyms, I decided to read the papers and learn. But then a colleague had a better idea – find knowledgeable people and ask each to write a brief article. So that's where we're going.

In this and the following GIN there are/will be seven one-page articles about the monitoring methods in the table below.

Monitoring Method	Acronym(s)	Author(s)	Author's Company
Terrestrial laser scanning (light detection and ranging)	TLS Terrestrial LiDAR	Matthew Lato	Norwegian Geotechnical Institute
Terrestrial interferometric synthetic aperture radar	TInSAR GBInSAR	Paolo Mazzanti	NHAZCA (Natural HAZards Control and Assessment), Italy
Robotic total stations (automatic total stations, automated motorized total stations)	RTS ATS AMTS	Rob Nyren, Ryan Drefus and Sean Johnson	Geocomp, USA
Reflectorless robotic total stations	RRTS	Damien Tamagnan and Martin Beth	SolData, France, USA and other locations
Satellite interferometric synthetic aperture radar	SInSAR, including DInSAR and PSInSAR	Francesca Bozzano	University of Rome, Italy
Digital photogrammetry		Raul Fuentes Stuart Robson	University College London
Differential global positioning system	D-GPS	Rob Nyren Jason Bond	Geocomp, USA Gemini Navsoft Technologies, Canada

I considered including airborne laser scanning (ALS or Aerial LIDAR), but have been advised that this is more applicable to topographical mapping than for displacement monitoring due to the low accuracy. I also considered including digital image correlation, but have learned that this method is still in the R&D stage, and not yet ready for our use on our projects.

We've had full-length articles in previous GINs about three of these methods:

- *Robotic total stations* (by David Cook, December 2006, with discussions by Martin Beth, Brian Dorwart, Richard Flanagan and Trevor Greening, March 2007. Also by Allen Marr, September 2008)
- *Terrestrial interferometric synthetic aperture radar* (by Paolo Mazzanti, June 2011
- *Reflectorless robotic total stations* (by Damien Tamagnan and Martin Beth, September 2011)

but I decided to include them among the current one-pagers for completeness.

So that we'd have some uniformity, I've given the authors some guidelines about format and subheadings.

This episode of GIN has articles about the first four methods in the table (in alphabetical order of first author's name), and the remainder will be in the June episode. To close out this topic, in June there will also be a concluding article by a colleague from Italy who has experience with most of these methods. He will read all the one-pagers and write a comparative analysis of the various methods for remote monitoring of deformation.

This is helping me to clarify my muddled brain—I hope yours too.

Two important action items for you:

- I recognize that, if you've had experience with any of these methods, you may not agree with all that the authors say. If that's the case, or if you'd like to add something that would be useful to readers of GIN, please send me a discussion.
- We've included the commercial sources in North America that we know about, but are likely to have missed some. If you know of others, please tell me, and I'll include those in a future GIN.

Remote monitoring of deformation using Terrestrial Laser Scanning (TLS or Terrestrial LiDAR)

Matthew J. Lato

Principle of operation

Terrestrial Laser Scanning (TLS) is a remote measurement technique that employs Light Detection and Ranging (LiDAR) technology. TLS calculates the distance between the scanner and the target by measuring the time delay between an emitted laser beam and the reflected signal (illustrated in Figure 1). This is a similar technology to total stations; however, the laser is robotically rotated through the scanners field of view measuring up to one millions points per second. The georeferencing of TLS data is done through placement of targets in the scene, typically flat circles are used. The targets are also used for measuring deformation at specific locations.

Main fields of application

TLS is used for geotechnical monitoring of tunnels (during construction and post construction degradation); rockcuts along transportation corridors; construction (piles, shoring, etc.); landslides; dams; and building deformation. Non-geotechnical applications include forensics; archeology; and architecture.

Accuracy and pixel resolution

TLS accuracy is determined by systematic and random error. Systematic error is governed by range error and angular error. Range error is error in the measurement of distance between the scanner and the target. Angular error is the error in the positioning of the scanners mirrors. Systematic errors translates to an accuracy of +/- 5 mm at 25 m, to +/- 30 mm at 1000 m. Random errors are in relation to the incidence angle between the scanner and target, as well as the reflectivity of the target. Random errors affect the precision of the measurement, which is variable, generally 0 – 10 mm, regardless of distance.

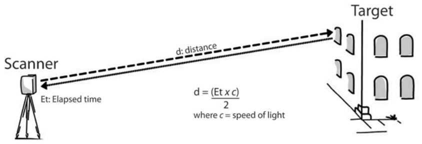


Figure 1. Operating schematic of a TLS scanner.

Pixel resolution of TLS equipment is based on the distance between the target and the scanner, as well as the type of scanner. This value can be as high as 5 mm at 25 m. However, due to beam divergence, the pixel spacing in the point cloud and the sampling resolution must be evaluated for every project.

Main advantages

Using TLS for deformation monitoring is advantageous for many reasons relating to data collection, processing flexibility, and presentation of results. TLS is an extremely fast, accurate, non-destructive technology. Data collection can be integrated with construction projects or implemented in remote regions. Processing options are diverse, including investigating individual TLS models for geometry, comparison to CAD, and temporal modeling over time. As well, the high resolution nature of the data enables realistic images and models for reporting of results.

Main limitations

TLS is an emerging technology with variable equipment and processing options. Users must be aware of their options and the limitations of each system. As well, it is essential that data be collected properly, without occlusion (shadowed regions) and processed in a manner that preserves accuracy.

Future challenges

There are three main challenges for using TLS in geotechnical monitoring: data format, processing standards, and timely collection of data. Data formats are critical in an industry that employs various TLS technologies, each of which uses its own binary format to reduce file size. A standard format will ensure that data collected today will be processable on future computers. For example, airborne LiDAR (ALS) data is stored in the industry-approved LAS format. No such format exists for TLS data. The use of TLS for monitoring is generally performed on an on demand basis; there exist no general guidelines for data manipulation, analysis, or presentation of results. For TLS technologies to be adopted, this must be addressed. Finally, TLS is viewed as a costly tool and therefore is generally used once site conditions have deteriorated. This is a challenge for achieving the optimal monitoring results because a baseline cannot be established. To achieve the best results from TLS, data must be collected before problems arise.

Some commercial sources

- Applied Precision: Mississauga, Canada, www.applied3Dprecision.com, +1 905-501-9988
- Norwegian Geotechnical Institute, Norway, www.ngi.no, +47 414 93 753
- Precitech AB, Sweden, www.precitech.se, +46 31 762 54 00

Matthew J. Lato
Engineer, Norwegian Geotechnical Institute, Oslo, Norway,
T: +47-465-42-970,
E: mjl@ngi.no

Remote monitoring of deformation using Terrestrial SAR Interferometry (TInSAR, GBInSAR)

Paolo Mazzanti

[Please refer to Mazzanti, GIN June 2011, pp 25-28 for more details. Ed.]

Principal of operation

Terrestrial Synthetic Aperture Radar Interferometry (TInSAR, also referred to as ground based SAR interferometry, GBInSAR) is a RADAR technique for the remote monitoring of displacements. By the movement of a RADAR sensor along a linear scanner (i.e. a rail that allows precise micrometric movements of the sensor), 2D SAR images are derived. By comparing the phase difference, i.e. interferometric technique, of each pixel between two or more SAR images acquired at different times, the displacements along the instrument line of sight (LOS) are derived. Thus, 2D color images of LOS displacement can be achieved as well as the displacement time series of each pixel (Figure 1). TInSAR monitoring can be performed by installing the equipment at a stable location in a panoramic position, and it does not require the installation of contact sensors or reflectors in the monitored area.

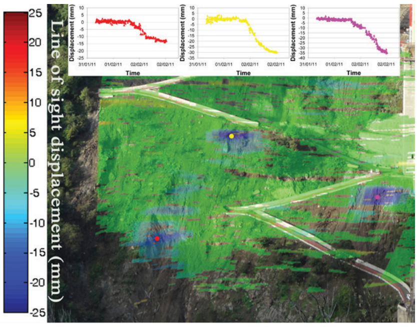


Figure 1. TInSAR displacement map overlaid on the slope picture and time series of displacement.

Main fields of application

The best application of TInSAR is the continuous monitoring of unstable slopes and dams. Other applications include linear infrastructures such as bridges, localized subsidence and buildings. TInSAR monitoring of buildings is quite challenging because although it is possible to collect highly accurate displacement data by a non-contacting technique, it is quite complex to detect vertical movements.

Accuracy and pixel resolution

The theoretical accuracy of TInSAR equipments is on the order of +/- 0.1 mm. However, both the precision and the accuracy are strongly reduced by the atmospheric noise. The precision ranges from few tenths of mm to a few mm, depending on the monitoring distance and the atmospheric conditions. The pixel resolution of a terrestrial SAR image ranges from few decimetres to several meters (depending on the equipment and on the monitoring distance). At a distance of 1 km, the most common commercial equipment has a resolution of about 0.5 x 4 m.

Main advantages

The main advantage of TInSAR is probably the ability to monitor displacements from a remote position without the installation of targets or sensors on the monitored ground or structure. Other advantages include applicability under any lighting and weather conditions, including rainfalls, clouds and fog; high data sampling rate (few minutes); long range efficacy (some km); high accuracy and spatial control.

Main limitations

The main limitation is the complex management, processing and interpretation of TInSAR data. Other limitations include: i) the size of commercial equipment (up to 3 metres long); ii) limited cone of view (some tenths of degrees in both the H and V planes); iii) unidirectional measure of displacement (along the instrument LOS) and iv) signal phase ambiguity (i.e displacement higher than 4.5 mm between two consequent images are not easily detectable).

Future challenges

- The increasing number of applications will contribute to improve both the technique and monitoring good practice.
- Cheaper and smaller hardware may improve the use of TInSAR, especially in urban areas.
- Advanced algorithms and software for the processing of data may improve the usability and effectiveness of TInSAR.

Commercial sources in North America

In the author's knowledge the following two companies are providing services with TInSAR: Olson Engineering Inc., Colorado (USA), http://olsonengineering.com.and C-Core, Kanata, Ontario (Canada), www.c-core.ca. European companies with longer expertise are listed in the article referred to above.

Paolo Mazzanti
NHAZCA S.r.l. - spin-off "Sapienza"
Università di Roma,
Via Cori snc, 00177, Rome, Italy,
T: +39-3469776508,
E: paolo.mazzanti@nhazca.com

Remote monitoring of deformation using Robotic Total Stations (RTS)

Rob Nyren, Ryan Drefus, Sean Johnson

Robotic total stations (RTS) are remotely operated theodolites that can deliver continuous (24/7) near-to-real-time survey measurements on reflective prismatic targets. They are also referred to as automated total stations (ATS) and automated motorized total stations (AMTS). In the past 3-5 years RTS systems have become an essential component of performance monitoring programs for urban infrastructure projects across North America. The essence of the RTS system operation has been explained by others in this publication, including David Cook (GIN December 2006) and Allen Marr (GIN September 2008).The authors refer the readers to these issues for additional information.

Applications

RTS systems are most frequently used as a tool for monitoring deformation of buildings and structures due to large civil works. However the authors have used these system to monitor many other applications including load tests (pile loading, lateral loading of bridge foundations, static and dynamic load testing of bridges), MSE wall performance (wall face monitoring and internal strain), ground deformation monitoring around deep excavations for power (please clarify), compaction grouting beneath various structures, automated crack monitoring on basement walls. The application of RTS systems is seemingly limitless.

Accuracy

The best instruments available coupled with proper installations and best operating practice deliver accuracies of +/-0.5mm (0.02in). For this accuracy it is reasonable to expect about 90% of the readings within +/-1mm, and to see statically "real" readings up to +/-2mm every now and then. Consideration of "relative movements" of targets can yield much better accuracies (nearer +/0.3 mm (0.01 in).

Main advantages

RTS systems deliver the highest quality survey data from a fixed survey layout with little manual field effort once installed; multiple readings done at the instrument instantaneously improves overall precision, (why do you need to refer to precision?) accuracy, and helps to identify erroneous readings. Systems can easily accept the addition of new targets to accommodate unforeseen monitoring needs with low cost. Newer systems can capture photographic images in conjunction with monitoring to provide additional information and insight.

Main limitations and other performance considerations

Measurements from RTS systems are optical with accuracy and precision (as above) limited by many conditions, such as weather changes, atmospheric conditions, suspended particulate in air due to construction, traffic, and vibrations. Poor installations of RTS instruments expose them to vandalism and other severe weather issues. Maintenance of difficult-to-access locations (e.g. an RTS high on a building facade) can be both dangerous and expensive; careful planning and system design can reduce maintenance. The RTS system by design concentrates all the monitoring effort to the RTS; any failure of the RTS (including power, remote access, computer software) results in a total failure of the monitoring program until the problem is mitigated. Monitoring points installed at extreme angles from the reference points used for re-sectioning the RTS can contribute to errors. Large zones of construction influence often make finding an adequate quantity of reference point locations problematic.

Challenges

Many RTS monitoring systems used for civil projects in the U.S. are comprised of multiple instruments in urban settings. It has been the experience of the authors that multiple units can be 'networked' to overcome some of the common limitations listed above – notably a lack of good reference sights. In a networked solution each RTS shares common targets with other RTSs. These common targets establish redundant geometries between the RTS positions and known reference locations, and the position of each RTS can be solved using a least squares adjustment solution. This process minimizes random and systematic error associated with raw measurements, gives better solutions on RTSs with poor referential control, and allows the overall movement calculations to be more statistically qualified. With these improvements also come new limitations: the loss of measurements from any one RTS that provides observational continuity along the network can cripple the ability for commercially available software to process raw measurements into monitoring data. Based on this experience, it is recommended that one (or more) spare RTSs be maintained on each project to respond quickly to potential issues when using networked systems.

Commercial sources

Robotic total statin instrument manufacturers include Leica, Sokkia, Trimble. Implementing these systems is best done by professionals experienced with RTS systems (e.g. design, installation, operation, and maintenance); these professionals are most often not traditional land surveyors but instrumentation specialists/engineers with broad geotechnical and structural monitoring expertise.

Rob Nyren, Ryan Drefus, Sean Johnson
Geocomp Corporation, 125 Nagog Park, Acton, MA 01720
139 Fulton St., Suite 917 New York, NY 10038
www.geocomp.com, E: info@geocomp.com

Remote monitoring of surface deformation with Robotic Total Stations using reflectorless measurements (RRTS)

Damien Tamagnan and Martin Beth

[Please refer to Tamagnan and Beth, GIN Sept 2011, pp 21-24 for more details. Ed.]

Principle of operation

A remote monitoring system able to measure surface deformation 24 hours a day is made up of:

- A robotic total station (RTS) equipped with a reflectorless distance meter.
- A support platform, electronics box, and 3G or Wi-Fi system.
- A data logger which can be operated remotely with specific software able to drive the total station to the predetermined locations of the monitored points.
- Computation software, which can be more or less advanced, for calculating the movements of the points of interest.

During each monitoring cycle the instrument sights at (see Figure 1):

- The reflectorless surface points (RSPs) on a flat, homogeneous and planar surface for which vertical deformation is to be monitored. RSPs are not physically marked and are not physical objects; they are just a location on the ground at which the RTS is sighting.
- The stable reference prisms, which permit computation of the correct position and orientation of the RTS.
- If necessary, the same total station and software can sight monitoring prisms installed on structures to be monitored in 3D, as for a standard RTS.

On completion of the cycle, the raw and/or calculated data are sent to the database via Wi-Fi or 3G. The system can also trigger alarms sent by SMS or e-mail if predetermined thresholds are exceeded.

Main fields of application

Monitoring of road surfaces during underground work.

Accuracy

The accuracy of the RRTS method has been confirmed by comparing precise levelling with RSP movements. External controls confirmed a consistency better than ±1 mm.

Main advantages

- High frequency of readings possible (down to one reading per hour for example)
- Uninterrupted traffic, neither for installation nor for taking readings
- Very safe, no surveyors on the road
- Very cost effective for high frequency of readings

Main limitations

The range of the distance meter is limited, and so is the angle of incidence of the laser beam on the measured surface. Weather conditions also downgrade the emitted distance meter signal.

Case histories

The RRTS method has been well proven in practice in many work sites since 2005.

- In Amsterdam (Netherlands) over 82 RTS are used to measure more than 5000 RSPs above the tunnel boring machine during the construction of the metro line.
- In Toulon (France) a network of 1830 RSPs has been measured over roads and pavements from 36 RTSs during four years.
- In Barcelona (Spain) long-term monitoring of the high speed railways tunnel and of Metro Line 9 has been set up to monitor settlement on roads, sometimes with heavy traffic.

Damien Tamagnan
SolData Group, Head of survey department, Travesia Industrial, 149 -3ª C 08907 Hospitalet de Llobregat Barcelona (Spain).
T: +(34) 93 263 29 69.
E: Damien.Tamagnan@soldata.fr

Figure 1. A Reflectorless Robotic Total Station (RRTS) measuring RSPs and prisms.