Geotechnical Instrumentation News

John Dunnicliff

Introduction

This is the fifty-sixth episode of GIN. Three articles this time, all focusing on the same subject.

Surveying

On many occasions when we measure deformation with geotechnical instruments, we measure relative rather than absolute deformation, and we have to rely on our surveying colleagues to convert our measurements to absolute values. We must therefore be able to communicate with them about our technical needs, and to understand their responses.

In recent years our surveying colleagues have developed a significant number of measuring techniques that are being used in geotechnical applications, and I decided that it was time to twist arms and include up to date information in GIN. For a start, here are three articles

"I know you've had over 100 articles published, but my question was 'Have you ever made a contribution to the literature?'"

The first one, by Colin Hope and Marcelo Chaqui, tells us about monitoring deformation with manual total stations.

The second one, by Allen Marr, tells us about monitoring deformation with automated total stations (ATS). The subject of ATS (also referred to as AMTS - automated motorized total stations and RTS - robotic total stations) is increasingly relevant to our geotechnical monitoring community, and there are important cases in recent years of both successful and unsuccessful use of this exciting technology. We've had two previous articles in GIN:

- Robotic Total Stations and Remote Data Capture: Challenges in Construction, by David Cook. GIN- 49, December 2006. Followed in GIN-50, March 2007 by six discussions and the author's reply.
- Monitoring with Electronic Total Stations: Performance and Accuracy of Prismatic and Non-Prismatic Reflectors, by Kontogianni et al. GIN-50, March 2007.

The third article, by Lars Krangnes, describes various methods that are being used for monitoring a large potential landslide in Norway. If you decide that this third article *isn't your thing,* at least please read the third paragraph about how the potential landslide was discovered. And perhaps sign up for a cruise along the stunning Geirangerfjord and see the area for yourself!

I've been promised another article on surveying, by a colleague who has very wide experience, and hope to have it for December GIN.

Contract Practices, Yet Again

Regular readers of this column will be aware of my soap-box topic—"Don't low bid instrumentation tasks, instead use a professional selection method". The primary argument has been often been one of quality, but an argument that owners are more likely to listen to is one of scheduling for baseline data. Here are some quotes from the above articles:

- *Hope and Chaqui:* "If relatively small construction-related movements are to be identified, then obtaining a series of readings prior to any construction to determine any non-construction related movements becomes critical".
- *Hope and Chaqui:* "By installing and initializing before any heavy site activities commence, strong baseline readings can be collected and the control targets can be surveyed without interference from vibrations, dust, machinery, etc. Failure to obtain the baseline readings before construction starts can cause significant movements to be missed".
- *Marr:* "Try to avoid using the low bid procurement process for instrumentation services. A low bidder must be optimistic about the work and take shortcuts to manage costs. Instrumentation always involves surprises that impact data quality and unexpected performance that requires more effort. Instrumentation is much more professional services type of work than it is 'bricks and mortar.' Qualifications based selection is recommended".
- *Krangnes:* "We normally need at

least a full annual cycle of data in order to define thresholds values (site-specific baseline data)".

On a typical construction site, how can the goal of adequate baseline data be achieved if instrumentation tasks are part of the general construction contract? There is rarely enough time between selection of a (low-bid) instrumentation subcontractor and construction-caused deformations.

Please do everything you can to convince the owner to select an instrumentation firm well ahead of awarding the general contract, using a "quality based selection" method, to contract directly with the firm, and have the firm go to work to obtain adequate baseline data. There are some very strong arguments in favor of this approach and there are real-word experiences of its success. If you want more ammunition when you discuss with owners, you'll find some in a GIN article that I wrote with Alan Powderham, "Recommendations for Procurement of Geotechnical Instruments and Field Instrumentation Services", *Geotechnical News, Vol. 19, No. 3, September 2001, pp 30-35.* If anyone would like an electronic copy, please let me know.

The Use of the Fully-grouted Method for Piezometer Installation

The previous episode of GIN had a two-part article on the fully-grouted method, by Contreras et al. I wrote, "If any reader has other data, pro or con, about the fully-grouted method, I'd very much welcome hearing about it, and will consider it for publication in a later episode of GIN". Zilch! Is anybody out there?

Next Instrumentation Course in Florida

The next course will be on 15-17 March, 2009 at Cocoa Beach Florida. See pages 37 for more information. Details are on http://conferences.dce.ufl.edu/geotech/

Humph

The great jazz-master Humphrey Lyttleton (Humph) died recently. In his own words: "As we journey through life discarding baggage on the way, we should keep an iron grip, to the very end, on the capacity for silliness. It preserves the soul from desiccation". What a wonderful attitude!

Closure

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

Kanpai! (Japan)

Manual Total Station Monitoring

Colin Hope
Marcelo Chuaqui

Introduction and History

Manual total station monitoring is most commonly used to monitor the deformation of various earth retention systems, buildings, dams, railways, bridges, roads, subway tunnels and other sensitive structures. This involves accurate and precise measurement and comparison of the three dimensional location of reference and surface monitoring targets. Under typical field conditions, if work is carried out methodically with a high standard of care, accuracies can range from ± 2mm to ± 1mm.

The following is a partial list of some of the questions that need to be answered when planning a monitoring program:

- Why do we need to monitor?
- What is the likelihood and consequence of each undesirable outcome?
- Is the risk high, low or moderate?
- How can monitoring be used to reduce the potential for an undesirable outcome?
- Is it doable?
- What are the right instruments for the job?
- What will be learned from the monitoring?
- What are the tolerances for the project and what sort of accuracies are needed?
- What reading frequency is suitable for the expected cause of movement and associated risk?
- What are the alarm levels and what will be done if they are approached or exceeded?
- Where do the reports go and is the report itself understood?
- Do the stakeholders understand how the monitoring works?
- How are the data presented?

Within this article we discuss total station monitoring in general but will focus on the practical issues related to obtaining and processing a set of readings. Some of the important considerations include:

- Site constraints and safety issues
- Structural, architectural, and geotechnical concerns relating to structures being monitored
- Range of expected background and construction movements
- Instrument selection
- Errors and error management
- Planning, installing and initializing the control network and monitoring targets
- Determination of baseline readings prior to construction activities commencing
- Client liaison
- Frequency of readings
- Data storage

- Report presentation and distribution
- Development of a monitoring-related action plan

Manual total station instruments have been steadily refined and enhanced over the past 25 years. From originally using purely optical instruments and manually chaining the distances (1 Chain = 20.1168 meters, 20 links in a chain, 1 link = 1.0058 meters), we have progressed to today's precision instruments. It used to be necessary for us to compute manually the various variables that affect the measurements. But nowadays we have instruments capable of calculating the correct location based on programmed and measured variables, with built in compensators, Electronic Distance Measurement (EDM), automatic target recognition, servomotor drives, onboard program files for surveying, an onboard CPU and data communication ports. These latest precision instruments have increased the efficiency, productivity and most importantly, the accuracy and precision for the surveyor in the field.

Instrument Selection

It is important to understand that most total station instruments are not suitable for precision monitoring. A standard total station instrument can be defined as an instrument accurate to 5 or more seconds in angular measurement and 3mm or more in the EDM measurement. They are normally lighter and cheaper than a precision instrument, less robust and have unacceptable built-in inaccuracies. By being lighter and less robust, they are more likely to be affected by wind, vibrations and other variables. An instrument rated at 1 second in the angular measurement and 1mm per 100m in the Electronic Distance Measurement (EDM) is normally sufficient for monitoring on a typical site. Sub-second manual total station instruments with highly accurate EDM are available however, unless atmospheric conditions can be controlled, these instruments can be too sensitive when exposed to normal site conditions and instrument sensitivity has to be turned down. (Normally referred to as "A Stability Check", where the instrument checks its stability before reading each target) Instruments with built-in compensators are recommended, as the instrument will drift while it is being used. In summary, instruments accurate to 1 second in the angular measurement and 1mm per 100m in the Electronic Distance Measurement (EDM) with built-in compensators would be classed as a precision manual total station.

Background Movements

By background movements we mean, thermal loading, frost invasion, settlement and weather fluctuations. Everything moves, all the time. By keeping this in mind, we can allow for background movements when the control and monitoring targets are installed and initialized. If relatively small construction-related movements are to be identified, then obtaining a series of readings prior to any construction to determine any non-construction related movements becomes critical. By keeping a note of the temperature and other weather or geotechnical variables, it is possible to map movements caused by these conditions and the impact they have on the observations. By knowing the instrument specifications, it is possible to allow for background variables when measuring distances or bearings over long distances.

Planning, Installing and Initializing

Planning and timing for the monitoring is exceptionally important. Careful coordination is often required among various parties to achieve the best results. It is important to plan how and when to install the control targets, precision survey targets and any other target locations needed. By installing and initializing before any heavy site activities commence, strong baseline readings can be collected and the control targets can be surveyed without interference from vibrations, dust, machinery, etc. Failure to obtain the baseline readings before construction starts can cause significant movements to be missed. Careful consideration must be given to the placement of the control targets. Ideally, the control targets should be placed on four axes around the site, strengthening the geometry of the free station solution – see Figure 1, showing a typical control network layout. As a minimum, control should be placed on two axes at 90 degrees to each other. By doing this, we strengthen the network and have solid measurements in 3 dimensions as opposed to using a single axis and placing too much emphasis on the bearing instead of the distance to calculated the instrument position. Control targets should always be placed away from the site so they are not influenced by the excavation and other site activities. A minimum of four control targets should be used, however, the

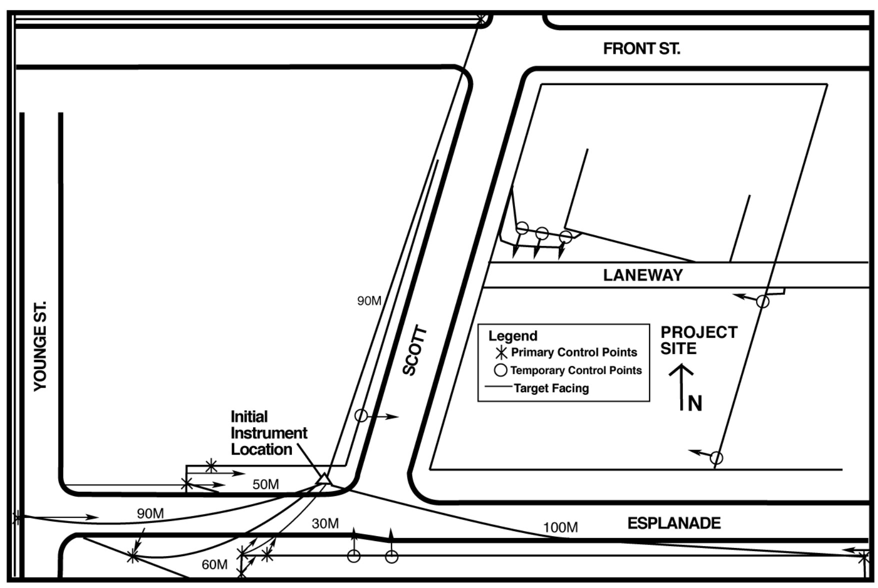

Figure 1. Typical control network.

more control targets used, the tighter the free station solution will be. With a strong and stable control network, any project can be approached with confidence.

Targets need to be protected both from construction activities and/or the public. Targets that are damaged or destroyed ruin the continuity of the readings and will need to be replaced and re-initialized. Also, attention must be paid to the construction process details such as hoarding, construction and excavation phasing etc., as temporary control targets will normally need to be traversed into site from outside of the zone of influence. By doing this we can make sure that the targets are not obscured from line of sight after their installation. It is also advisable to take multiple observations to each target at initialization and to use the averages of the readings for the final initial location. Control targets also need to be maintained over the course of the project as one or more may move. By taking regular check measurements to control targets, it is possible to identify and correct any targets that appear unstable.

Errors and Error Management

There are many errors that can impact on the quality of the data collected. These can include:

- sighting errors when the target is not sighted correctly, either due to site conditions or operator error
- compensator errors where the instrument goes too far out of level
- calibration errors where the instrument is not calibrated properly and/or regularly enough
- vibration errors caused by machinery, subway lines, roads, etc impacting on the setup of the instrument
- observation errors where the instrument is too oblique to the targets being measured with the EDM, causing the EDM to smear across the target
- deflection errors, where the laser is deflected by an object too close to its path of travel
- instrument drift, where the instrument will drift out of alignment, normally caused by strong winds, poor instrument setup or nearby vibrations
- keep in mind that if the EDM laser is measuring through exhaust from machinery, the distance measured will be affected
- Heat shimmer from weather conditions and site activities can also cause degradation in visual sighting. The targets can become very hard to see clearly if they are too distant from the instrument; say more than around 80m

By exercising care, proactive planning and attention to detail, it is possible to identify errors, their causes and manage them.

Data Processing, Reporting and Archiving

Once the data have been collected, processing can commence. By following a structured and controlled system, it is possible to cross-check the data for errors and false readings before reporting the results. By keeping a raw data file archived, any corruption of data from files that have been worked on can be replaced. Data should be presented clearly and concisely in such a way that the reader can quickly understand the ramifications of the observations. Tables of numbers are not as effective as graphical representation of the movements. For many applications, the rate of movement is as important as the total movement. Including a scaled drawing showing target locations is always a good idea, and facilitates the understanding of what is moving where. By keeping records of all the files, they can be retrieved if any questions arise and used again if needed. Archiving files in a safe, secure location off site is a safe practice and allows for easy recovery if files are lost or corrupted.

Conclusions

As we stated earlier, under typical field conditions, if work is carried out methodically with a high standard of care, accuracies can range from ± 2mm to ± 1mm. Within this article we expand on the critical aspects of the methodology and standard of care required. It is clear that experienced staff, the proper equipment, detailed methodology, time and care is required to perform this work to such a standard. Hopefully the reader will conclude that for accurate and precise monitoring, it is best to think from the perspective of what is best for the project, not the bottom line.

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Monitoring Deformations with Automated Total Stations

W. Allen Marr

Status Check

Deformation of existing facilities that are caused by new construction is one of the primary components of an effective performance monitoring system for construction. Traditionally these measurements were obtained with optical surveys performed manually by a surveyor and rod man. Such surveys have become expensive, which limits the number of readings sets that can be obtained. In our experience, the general quality of manual surveys has decreased considerably over time. On one recent project, results from level surveys by unionized surveyors differed by as much as 0.3 inch (8 mm) from one day to the next and among three survey entities. This variation is unacceptable in an environment where the project requirements on allowable deformations are increasingly stringent. We frequently see requirements to limit deformations to less than one inch (25 mm), or even one-half inch (13 mm). When the project has a stop work limit on deformations, scatter in the measured data of more than 0.2 inches (6 mm) complicates the enforcement of the restriction.

Measurements of vertical movement accurate to ±0.05 inches (1.3 mm) are possible with manual surveys but this requires careful, consistent technique and a surveying team motivated to produce accurate results. Measurements of horizontal movement more accurate than ±0.1 inches (2.5 mm) are possible with the best of surveying practices but this accuracy is difficult to obtain with the manual surveying techniques used on today's construction projects. Obtaining accurate measurements with optical methods more than once per day, or within each shift for a 24 hour tunneling operation can be prohibitively expensive.

New Technology for Better Results

Automated Total Stations (ATS) offer more options for comprehensive monitoring of deformations and promise relief from the some of the problems with manual surveys. These devices have been used by surveyors for about ten years to do layouts faster and with less manpower. The equipment contains servo motors that rotate the instrument in the horizontal and vertical planes to align it with the cross hairs of a prism. Internal instrumentation accurately measures the distance between the instrument and the prism, the azimuth of the prism relative to the instrument, and the dip of the lens relative to horizontal as defined by the pull of gravity.

The best equipment with good installation and operating practices can provide x, y and z locations accurate to ±0.5 mm (0.02 inches). The equipment can take measurements on a single target every few seconds and on tens of targets every hour. It works day and night and in most weather conditions. Figure 1 shows a unit mounted in the arch of a tunnel that monitored 30 targets along the tunnel alignment during new construction. The unit worked day and night and survived vibrations, grout, smoke, dust, and construction workers for twelve months.

The targets, or prisms, must be in line-of-sight with the total station. This requirement restricts where targets can be positioned and may force the use of multiple total stations. In monitoring applications it may be necessary to position the ATS on a mount that may itself move over time. In this situation reference prisms are set at locations that will not move and these prisms are used to obtain the current position of the instrument prior to beginning a set of readings on the monitoring prisms. The measurements are then relative to the reference locations. By using several reference prisms, the reliability of the ATS can be assessed prior to the start of each reading set.

Figure 1. Automated total station in underground transit station construction.

Figure 2 shows some typical data obtained with an ATS for movement of a bridge bent while the load was being transferred from the old pile foundation to new drilled shaft foundations. The piles were in the way of a new subway tunnel. The old piles would be cut away one by one and adjustments made in the new foundation system to pick up the load in a way that the bent did not move by more than 0.25 inches (6 mm). The figure shows measurements of change in elevation for 3 prisms mounted at different locations on the bent taken with an ATS every 5 minutes. The data are remarkably consistent and accurate to about ±0.01 inch (0.2 mm) standard deviation. The small time interval between points made it possible to use the ATS data to control the jacking operations for the load transfer in real time around the clock for the three day period it took to perform the work. Movements in the horizontal plane were also measured at the same time and showed similar consistency and accuracy. For this monitoring, the ATS was positioned on a stable reference and the shot distances were less than 100 ft (30 m). This case shows the power of using an ATS to monitor and help control deformations in real-time.

Some Best Practices for ATS

Unfortunately there are too many instances where the data from ATS systems are not of the quality of that shown in Figure 2, including some of my own projects. Careful examination of the installation generally reveals a multitude of poor or misguided practices that de-

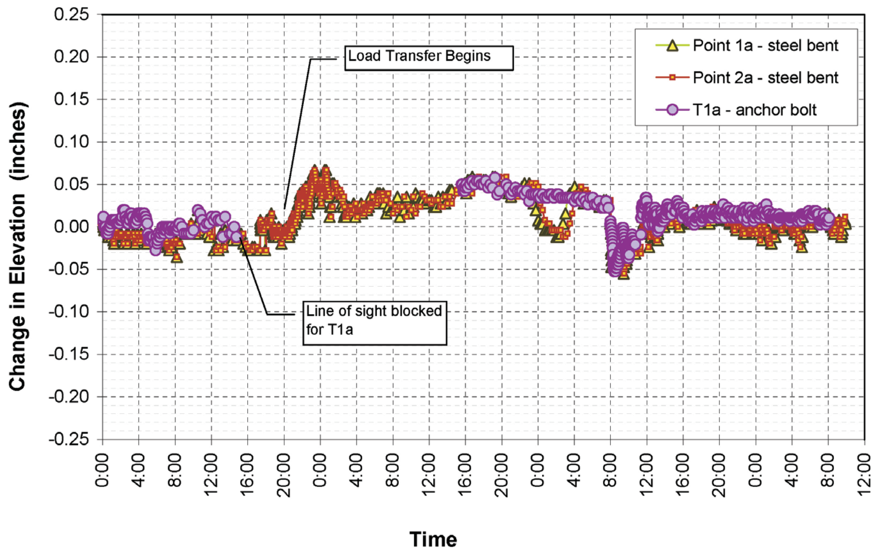

Figure 2. Typical measurements of change in elevation with an automated total station.

grade the quality of the data. The following list provides some guidelines to apply to improve the reliability and accuracy of deformation measurements taken with ATS.

Total Station

- Mounting must be stable over the interval of readings.
- Position should be measured before each set of readings by reading fixed reference prisms.
- Mounting should be configured and constructed of materials that minimize temperature effects on the instrument, particularly its verticality.
- Cover with a hood to reduce rain and sun impacts.
- Avoid sighting through transparent materials if possible.

Reference Prisms

- Must be of high quality type for best repeatability with Automatic Target Recognition.
- Must be mounted on fixed stable locations.
- Locate at similar elevation to total station, i.e. avoid dip angles of more than 30 degrees.
- Use minimum of three, preferably five or more reference prisms.
- Locate reference prisms in multiple quadrants of monitoring.
- Check and evaluate consistency of data from all reference prisms to determine that the instrument is functioning properly. Reference prisms should not move relative to each other.
- Clean prisms of dust and moisture as necessary.

Target Prisms

- Must be of high quality type for best repeatability with Automatic Target Recognition.
- Must be placed on mounts that remain fixed for the duration of the measurement set.
- Locate at similar elevation to total station as much as possible.
- Clean prisms of dust when necessary.
- Avoid shots parallel to the southern face of buildings and other locations with high "heat shimmer" problems.

Software

- Use software which automatically makes consistency checks to data and corrections.
- Use the Automated Target Recognition and correction feature of the system.
- Reread reference targets to check repeatability of the instrument.
- Read each prism twice by flipping the optics 180 degrees between readings. Average the results to reduce or eliminate for systematic errors in the instrument.

General

- Where temperature is affecting the data by unacceptable amounts, limit readings to times of relatively constant temperature, e.g. between sundown and sunup. When readings must be taken during periods of temperature change, it is useful to also record temperature to potentially develop a calibration to remove temperature effects from the data.
- An ATS instrumentation specialist must review the data and remove periodic "hiccups" in the measurements.

Some Guidelines on Specifications

Requirements in the specifications that are enforced can greatly affect the success of monitoring with an ATS system. A few sentences in the specifications can make a big difference in the quality and utility of the measurements. The following are some suggestions from my own experience.

Do not Require an Unrealistic Accuracy for the Survey

The best instruments with best practices (read more expensive) provide readings to ±0.5 mm (0.02 in) accuracy at distances up to 100 m (330 ft). This value quoted by the manufacturer is one standard deviation of multiple readings taken on targets that do not move. About 10% of the measurements would be outside the range of ±1 mm (0.04 in). It is possible to obtain better accuracy for change in position in some circumstances, but this requires a skilled team using best practices.

Do not Require that Deformation Monitoring with an ATS be Done by a Licensed Surveyor

Instead require that they be performed by instrumentation technicians trained in the use of ATS for deformation monitoring and that a Professional Engineer experienced in the use of ATS for deformation monitoring on at least three projects of similar scope supervise their work. In my experience, many surveyors are not equipped to measure positions to the high accuracy and repeatability required by our work and they are not familiar with the special techniques required to use ATS for deformation monitoring to high accuracy. Additionally, even with best practices data from ATS contain quirks and outliers in the data that result from disturbances to the lines of site, dust or moisture on prisms, and the instrument electronics. These must be identified and removed from the performance evaluation. Engineers better understand what the data and trends are supposed to look like. They are better equipped to identify false readings and outliers (data clearly outside the range of believable results) quickly so that the sources of these anomalous data can be located and isolated. This vetting of the ATS data must occur before it reaches the project staff, to avoid a loss of confidence in the data. In my experience placing a surveyor between the instrument and the engineer complicates and delays the identification and correction of problems with the ATS system.

Do Require that the Party Responsible for ATS Measurements Submit a Monitoring Plan that Shows How They Are Going to Achieve the Project's Requirements for Accuracy

Also consider requiring a submittal of the prior experience showing that the proposed ATS approach was successful at achieving the accuracy requirements of your project. This will force that party to consider how they will meet the project's requirements for accuracy and it will provide a basis for helping you to ensure that the requirements are met.

Do be as Detailed as Possible in the Specifications for What Locations are to be Monitored and at What Frequency

Automated total stations are expensive. For projects awarded by lowest bid, winning and losing can depend on how many total stations the instrumentation contractor decides to include in its bid. This creates pressure to keep the number of ATS as low as possible with the consequence that best surveying practices for distances, angles and redundancy are not possible.

Do Try to Avoid Using the Low Bid Procurement Process for Instrumentation Services

A low bidder must be optimistic about the work and take shortcuts to manage costs. Instrumentation always involves surprises that impact data quality and unexpected performance that requires more effort. Instrumentation is much more professional services type of work than it is "bricks and mortar." Qualifications based selection is recommended. If the instrumentation services must be procured by low bid, include minimum qualifications in the bid documents and make it clear to bidders that you will enforce all requirements of the specifications. Also provide for penalties, usually withholding of payment, if the instrumentation specifications are not being met. I strongly urge that pre-bid meetings include a few minutes on the instrumentation, its importance to the project, and the Owner's intent to fully enforce all of the provisions of the instrumentation specifications. In principal, these practices should reduce the number of low-ball, unqualified bidders for instrumentation services.

Do Enforce the Requirements of your Specifications and Make the Instrumentation Field Personnel Perform

To allow substandard performance results in a poor image to the instrumentation community, to the instruments themselves, and to the other industry personnel who are committed to completing the work properly.

Closure

Automated total stations provide a powerful tool to monitor deformations in three directions in real-time and 24 hours, 7 days a week. The equipment is becoming more reliable and durable as the manufacturers learn from in-service failures. Since deformations are the primary measurement we use in performance monitoring, I fully expect to see ATS become an expected part of most performance monitoring systems where the consequences of excessive deformations are significant. But great care needs to be taken in specifications, field work and project management to achieve the necessary accuracy and reliability of measured data.

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Monitoring Norway's Largest Potential Rockslide

Lars Krangnes

Introduction

In one of Norway's most scenic and popular tourist areas, the Geirangerfjord, a major potential rockslide was discovered 10-15 years ago. This area is located on Norway's west coast, in a UNESCO World Heritage area, surrounded by steep mountains and a narrow fjord. The sliding area is approximately 500 meters wide, with its main rift at 900m above sea level. Geological and geophysical investigations at Åkneset indicate that the unstable area covers almost 0.8 km^2.

Figure 1 shows two of the areas where there are potential rockslides: Åkneset and Hegguraksla. Both are monitored.

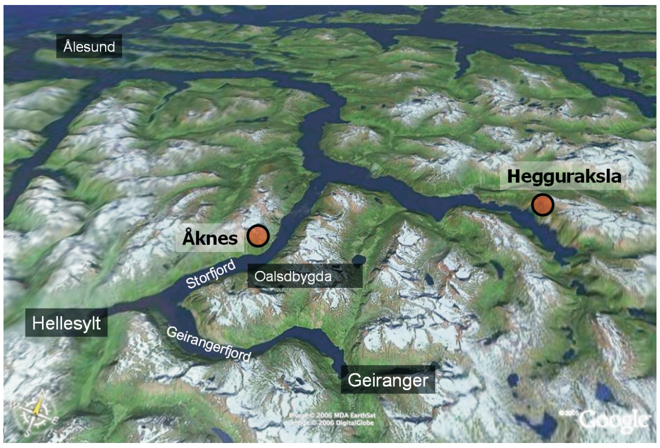

Figure 1. Location map showing the monitored sites at the Åkneset rockslide.

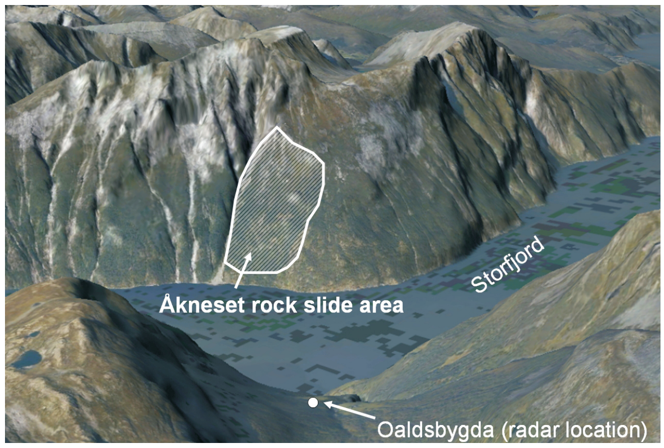

Figure 2. Åkneset rock slide and the surrounding area. The radar position is marked on the other side of the Storfjord.

This story starts with a boy who grew up on a farm just a few meters north of the Åkneset rockslide area. When he was young he used to walk around the mountainside looking after his family's animals. At that time he discovered small cracks in the ground, just wide enough to put his hand inside. He used to place small rocks in these cracks. When he checked these rocks the next year most of them had fallen into the cracks, indicating that they were getting wider. He then moved away from the farm, but came back in the late 1980s, found the same cracks, and discovered that he could hardly jump over them. He notified the Norwegian Geological Survey and they started investigation with some simple surveys of the area.

The Åkneset/Tafjord project is today a large monitoring and early-warning project related to these two large unstable rock slopes. The Åkneset rockslide is estimated to have a volume of 30-100 million m^3, moving with a velocity of 2-15 cm/year. The major risk is the possibility of a large tsunami, generated if a rockslide plunges into the fjord. The tsunami would generate a wave up to 40m in height, which would have a devastating affect on several local communities in the area.

The most common, and normally the only possible way of managing the risks associated with a rockslide of this type, is to develop an effective monitoring and warning system. A monitoring system based on different types of both geotechnical and geodetic instruments has been established in the area. Several measurements and observations in the same area with different types of instrument are carried out, both to ensure redundancy in observations, to cover subsurface ground changes and deformations, and to correlate the data from the different types of sensors. Since most of the equipment has obvious limitations in bad weather conditions, and since the challenging topology in the area leads to limitations in accessibility and power, it was necessary to have redundant systems to ensure data collection all year round.

Fugro Survey's part in the project has been to provide laser data for early site investigations, different geodetic instrumentation and the data management system.

Site Investigations

Before a permanent monitoring system was established the movement of the Åkneset area had been measured by a series of different methods, including GPS, total station, ground-based radar, extensometers and single lasers. The movement data measured by periodic GPS and total station demonstrated that there is a movement in a large area of between 2 and 4 cm/year. The south-western flank has a much larger movement with a general trend of 5-10 cm a year, and locally up to 15 cm/year. The same trend can also be seen on the measurements done by the ground-based radar placed in Oaldsbygda (see Figures 1 and 2) on the other side of the fjord.

Monitoring Systems

In order to establish a reliable continuous monitoring network, a series of methods are used, both on the surface and in boreholes. The array of sensors was chosen to provide the best set of information possible in order to cover the entire slope, especially the upper flank. However there are a series of practical limitations in terms of distance from measurement points to the monitoring instrument, local slope conditions, rock falls, snow/avalanche hazards and problematic atmospheric conditions. An overview of the established monitoring systems is presented below.

To handle all the data from approximately 150 different sensors in the area, a data management system was developed.

Surface Monitoring Methods

Surface monitoring methods are:

- Permanent GPS network with 8 antennas
- Total station with 30 prisms
- Ground-based radar with 8 reflectors
- Five large surface extensometers
- Surface crackmeters
- Surface tiltmeters
- Two single lasers (see Figure 3)
- Eight 3-component geophones

When choosing the type of surface monitoring system the designer has to evaluate the qualities of the different methods, such as: measurement accuracy, amount of information from sensor, possible measurement frequency, system stability, required maintenance

Figure 3. Laser system on the upper part of the sliding area.

intervals and power consumption. For the design of the monitoring system all of these qualities were taken into account, and several different systems were established for monitoring the same area.

When establishing a monitoring system and critical alarm functions, it is essential to base the alarms on more than one type of sensor. We have seen that weather conditions such as lightning or heavy snowfall can cause errors in some of the measurements.

Geodetic instruments play a vital role in the monitoring system for measuring surface movement. The GPS network is very stable and produces results at two different time intervals. A result of approximately +/- 1.5 cm accuracy result is achieved every 10 minutes and an accuracy of +/- 5 mm is achieved every 12 hours. A typical GPS antenna and prism setup is seen in the photograph on the cover of this issue of Geotechnical News.

The total station is set up in a stable area that overlooks most of the sliding area. Due to harsh weather conditions, limited results are given from the total station during the winter season. We see that for distances with great height and temperature difference, the accuracy decreases considerably when compared to the manufacturer's instrumentation specifications. The advantage of using a total station is that a large number of observation points that can be used. The accuracy specification given by the manufacturer is 1mm + 1mm per 1km distance to the target, but the accuracy depends on local weather conditions and distance to the target.

An example of movement data from one of the single lasers from Åkneset during snowmelt in 2006 is presented in Figure 4. A normal movement is seen until the 5th of May, but due to snowmelt the movement increased during the following 12 days.

New Ground Based Radar System

One of the greatest successes in the monitoring project is the use of an interferometer radar system. This radar system measures relative movement between stable reference points and an unlimited number of monitoring points in the sliding area. The radar system has been developed by a Norwegian company, ISPAS AS, and it is also used for monitoring an unstable rock slope close to the Åkneset site, the Heguraksla site area shown in Figure 1. A second radar system has also been used at Åkneset, and was permanently installed in July this year on the opposite side of the fjord overlooking the Åkneset rock slide (see Figure 2). The advantages of using radar technology are the achievement of sub mm accuracy over very long distances, and high sampling rates (up to 100Hz). It is weather independent and has no moving parts, which gives a very long operational lifetime and few equipment problems.

Borehole Monitoring

Borehole monitoring methods are:

- Two 50 meters long Differential Monitoring of Stability (DMS) systems. It is an in-place borehole instrumentation system consisting of 50 tiltmeters, 2 piezometers and 50 temperature sensors. The sensors are installed in 1 m long modules, which are connected by strong joints and at the top by extensions of different length to adapt the installation for different depths.
- Piezometers, conductivity and temperature sensors in 3 boreholes

The DMS Åkneset monitoring systems were installed in two 200m long boreholes, and the 50 m long continuous instrumentation columns were placed at the depths where the sliding was assumed to take place. The DMS systems show several sliding zones and provide data for determining the velocities of sliding.

Piezometer readings from the boreholes show rapid fluctuations, with an increase of up to 4.5 m/day at the upper location, where the groundwater level increased from 45 to 40 m depth. There is a groundwater level increase of several meters in the spring, and simultaneously a well-defined increase in movement from the extensometers and single lasers.

Climate Station

The climate station is used to monitor the following parameters:

- Temperature
- Precipitation
- Snow depth
- Wind speed
- Ground temperature
- Amount of sunshine

As the velocity of the rockslide movements and incidents in the sliding area are correlated with climatic changes and weather conditions, it is very important to have detailed meteorological data for the area. The velocity of the sliding area, errors in the data,

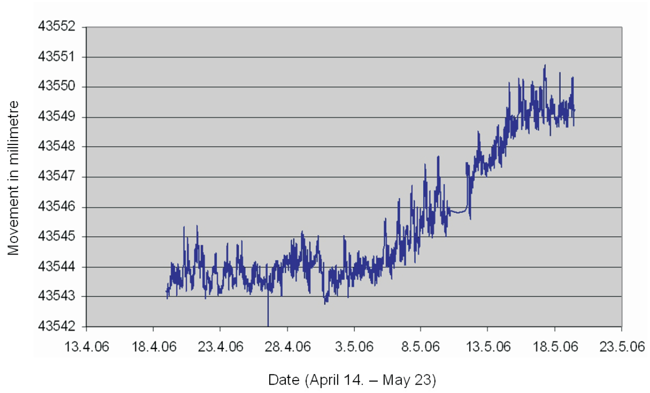

Figure 4. Example of movement data from one of the single lasers from Åkneset during snowmelt in 2006.

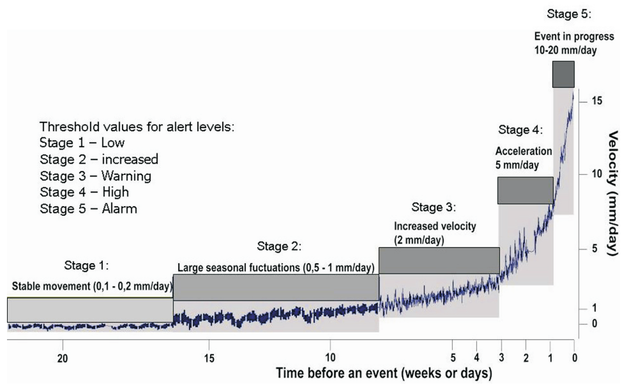

Figure 5. A schematic diagram showing the possible development of an event at Åkneset, exemplified by surface movement at the upper flank area. The different alarm levels are indicated by the five different stages.

and failing or non-working equipment can often be explained by the weather conditions. Meteorological information is also very important for predicting possible incidents and periods where a collapse might occur. As the accuracy and quality from many sensors are affected by the weather condition, metrological data are also used to evaluate the quality and reliability of the incoming data.

Web Cameras

Five web cameras have been set up and are used to give visual information of the area. The cameras can be panned, tilted and zoomed. By running the cameras through intelligent processing software we are able to automatically track visible changes such as avalanches and personnel close to equipment. All these images are stored in a database.

Live images are very useful in visual control of the area and for analyzing sensor data errors or breakdown.

Data Management, Presentation and Alarm System

A central part of a monitoring program is the data management system. The data management system has two important functions: to import and store the data from the sensors and to present the data for the users of the system. The data management system is a module-based system based on GeODin, a data management system developed by Fugro Survey.

The data management system currently has the following capabilities:

- Transfer data from field to database
- Validation of incoming data
- Technical monitoring of equipment
- Alarm functions (via email and mobile phone text message)
- Automatic reporting from all instruments, on request and once a week (PDF on email)
- Web portal with plots, interactive map module and instrument status
- Smartphone setup for portal devices
- Desktop solution for advanced analysis of data

Experience from the Åkneset/Tafjord project has shown us the importance of having a data management system that can handle all the different data from the field. It is much easier for the user to understand the behavior of the rockslide and to make good risk assessments when all data are available in the same system.

Threshold Values

The operative early-warning system needs different threshold types and values for the different sensors, including multi-sensor thresholds. Alarm-thresholds should be defined according to following criteria:

1. Total displacement (absolute readings)
2. Velocity in defined time periods
3. Acceleration

We normally need at least a full annual cycle of data in order to define thresholds values (site-specific baseline data). Main issues are to find the different types of noise in the data and also to define thresholds that:

1. Do not lead to false alarms
2. Are able to catch real events
3. Provide adequate warnings

The alarm system should be able to pick up some of the largest and distinct seasonal fluctuations, in addition to more serious events. The prediction provided by threshold values should be supported by expert judgment. This type of judgment will include evaluation of factors such as the reliability of the monitoring network, the complexity of the displacement patterns, and the short-time evolution of meteorological and snow loading conditions.

Initially, velocity-based threshold values have been chosen for the Åkneset/Tafjord project. Threshold values for the sensors in the upper part of the slide are presented in Figure 5. We need to define the length of the period on which the velocity trend is to be based, and this period will be different from instrument to instrument. For the surface extensometers, which are very stable, we can base the trend on one day or one hour, while the total station needs a much longer time due to larger fluctuations in the data.

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full page 4 colour ad

Instrumentation Course

Friesens has pdf file

position on baseline