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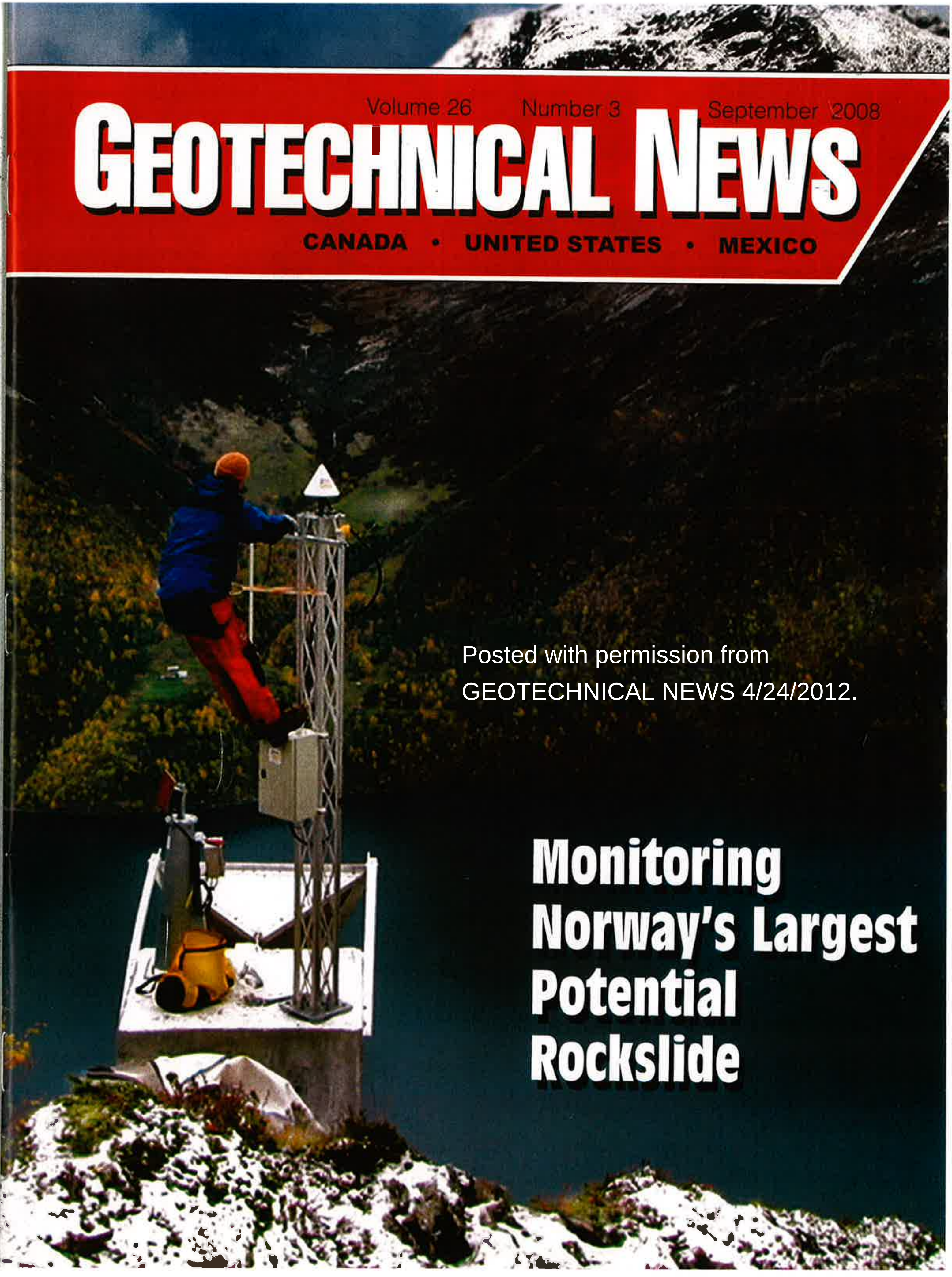

Monitoring Norway's Largest Potential Rockslide

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.

Colin Hope, Survey Manager, Marcelo Chuaqui, General Manager, Monir Precision Monitoring, 2359 Royal Windsor Drive, Unit 25, Mississauga, Ontario, Canada, L5J-4S9, Tel. (905) 822-0090 ,emails: colin@monir.ca and marcelo@monir.ca

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.

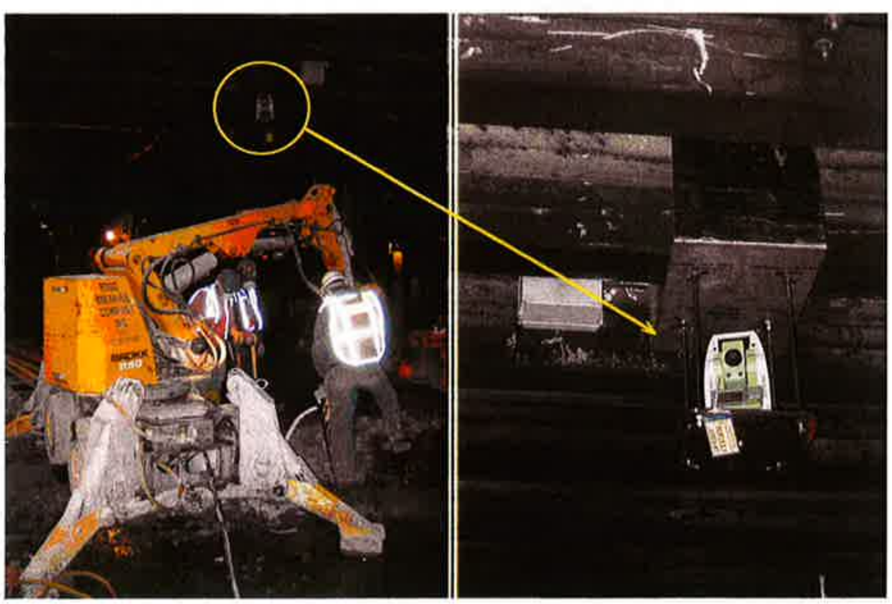

Figure 1. Automated total station in underground transit station construction.

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-

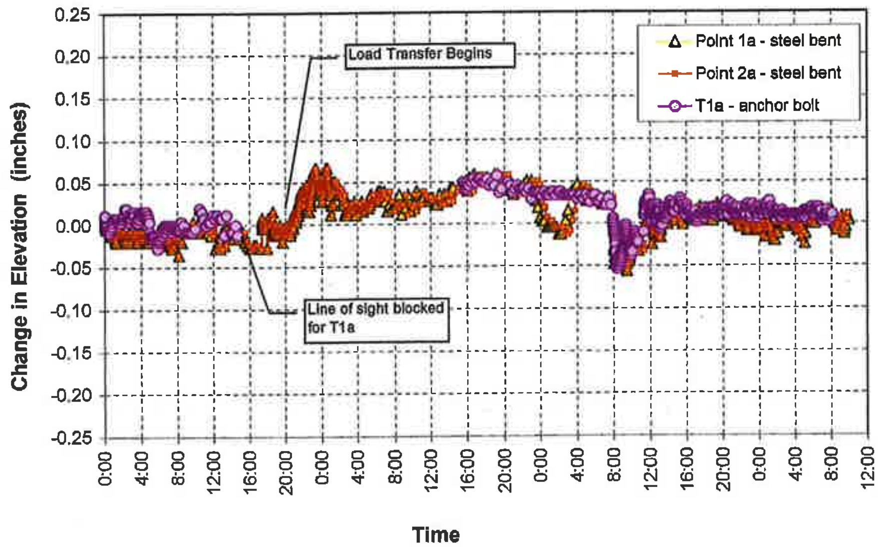

Figure 2. Typical measurements of change in elevation with an automated total station.

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.

W. Allen Marr, President and CEO, Geocomp Corporation, 1145 Massachusetts Avenue, Boxborough, MA 10719, Tel. (978) 635-0012, email: wam@geocomp.com

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.