Introduction by John Dunnicliff, Editor

This is the seventy-seventh episode of GIN. Only one article this time.

Do you want GIN to continue? Despite arm twisting, you're being backward in coming forward. The first step is a 200- to 300-word abstract. The ball is in your court.

Reason for only one—it's the same old story—despite arm twisting, you're being backward in coming forward. Guidelines for articles are on www.geotechnicalnews.com/instrumentation_news.php—see the link "How to submit articles to John Dunnicliff for GIN". The first step is a 200- to 300-word abstract. **Do you want GIN to continue? The ball is in your court.**

A newer, better way to measure tunnel deformations

The article by Chris Fagan and Charles Daugherty is one of those nuts-and-boltsy contributions that tell us about a better way to do something. I like such straightforward articles!

International Course on Geotechnical and Structural Monitoring

Plans for the course in Italy in June are almost complete. Details are on *www.geotechnicalmonitoring.com*.

After many years of courses in USA, most recently in Florida, I've taken a fresh look at what I think these courses should include. In addition to the monitoring methods that we've been using for many years, this course includes innovative remote monitoring methods such as total stations, satellite and terrestrial radar, Lidar and GPS - my Italian colleagues are experts at these modern methods. The course schedule (lecturers and topics) is on the website—The Course/Schedule. Additional information is on page 35.

Come and join us in the 10th century castle! (I got it wrong in December GIN, and jumped ahead three centuries!). The wine is good, too!

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.

Op uw gezondheid! (Flemish: Dutch speakers)

The Laser-Distometer: a newer, better way to measure tunnel deformations

Chris Fagan and Charlie Daugherty

The conventional method

The conventional method of measuring deformation between two points, typically in a tunnel or excavated cavern, has been to use a tape extensometer. The tape extensometer is stretched between two eye-bolts over the space where the measurement is being taken, the tape is tensioned correctly using the on-board tension sensor, and the distance shown on the tape is recorded (Figure 1). Deformation is measured by comparing subsequent readings over time.

Figure 1. Stretched tape extensometer.

When used correctly, tape extensometers will achieve accurate deformation measurements, at sub-millimeter precision. However, in practice, the manufacturer-claimed precision is difficult to achieve when monitoring deformation in a tunnel or cavern that is under active construction. This can be problematic, because the most critical time to monitor deformation is while construction is active, for instance, when a tunnel heading is advanced, or when a cavern is excavated.

It is difficult to measure deformation using a tape extensometer during active construction for the following reasons:

- During measurements the link between eye-bolts creates a physical barrier. This can cause costly delays, as equipment that can pass by is restricted.
- Measurements are often rushed because of pressure from surrounding workers delayed by the physical barrier.
- A second person is sometimes required, often assisting on a ladder, to hook the second end of the tape to the eye-bolt, which increases monitoring costs.
- Eye-bolts protrude from the monitored surface, and are easily damaged or bent by construction activity.
- The tape extensometer can be cumbersome to transport.
- Ambitious construction schedules and time constraints on workers means that an often time consuming and disruptive measurement process is easily overlooked.

Introduction of the laser-distometer alternative

These difficulties inherent in monitoring with a tape extensometer mean that readings may be skipped or rushed just when data collection is most needed. An alternative method of measuring deformation is to use a laser-distometer and targets. The laser-distometer is placed into a cradle at one point (Figure 2), the laser beam is reflected from a target at the second point, and captured again by the laser-distometer. The distance is then calculated within the instrument by recording the interval of time between sending and receiving the laser pulse.

Figure 2. Laser-distometer in cradle.

The authors have not found hard evidence of laser-distometers being specified or permitted for tunnel deformation monitoring before late 2006. At that time instrumentation specifications for New York City Transit's 7 Line Subway Extension were modified by the designer, the Parsons Brinckerhoff Team, to include the following statement, "In tunnels driven by TBM, Contractor may consider the use of laser measuring devices in lieu of tape extensometer convergence bolts in order to begin measurements as close as possible to the back of the tunneling machine. Such devices shall be able to achieve an accuracy of 1/16-inch or better across a space of 20-feet. Spot markers and reflective targets shall be provided to ensure that readings can be repeated at the same monitoring points as the tunnel progresses." This specification was published in January 2007 in time for the bidding of tunnel construction, but the construction contractor who won the job did not choose the laser-distometer option.

The laser-distometer measurement alternative had not been offered in the specifications for the Metropolitan Transportation Authority's East Side Access Project, for which the start of design had preceded the 7 Line Subway Extension's design by several years. However, when the time came to excavate the project's connecting tunnels and enlarge the cavern beneath Grand Central Terminal in 2007, it was obvious that up-to-then standard methods of deformation monitoring faced some great hurdles. Discussions were begun with the construction contractor and an agreement reached that led to a contract modification calling for any tape extensometer measurements of tunnel and cavern deformation to be replaced by laser-distometer measurements.

The laser-distometer in practice

A portable cradle for the distometer should be fabricated, and attached to an anchor bolt at the first point with a swiveling head (Figure 3). The reflective target at the second point should be small (approx. 2-inch diameter) and mounted with its face perpendicular to the direction of the laser beam from the first point. The laser-distometer uses electronic distance measurement technology, which is commonly used in the surveying industry, however it had not necessarily been tried and tested in this application.

Figure 3. Laser-distometer reading.

Project specifications will generally specify use of the tape extensometer, yet the laser-distometer offers many advantages over the former method. Some of these are:

- No physical barrier is created when taking readings.
- Reduced setup and reading time.
- Only one person is required and no direct access to the second target is necessary.
- The laser-distometer is small, lightweight and can be easily transported in a pocket.
- The likelihood of a greater number of measurements being recorded is higher, due to a simpler data collection process.
- A lesser "nuisance" factor while taking readings may result in the collection of better quality data.

Laser-distometers with millimeter accuracy are widely available, and in most cases are considerably less expensive than tape extensometers. The advantages of the laser-distometer over the tape extensometer are obvious to these authors and to others, but hard data makes for a more compelling case.

From 2007 to 2012, more than 8,000 laser-distometer readings were collected at the East Side Access Project between 310 tunnel and cavern deformation point pairs. Readings in the tunnels were collected immediately behind the tunnel boring machines between targets installed on virgin rock, and readings in the caverns were recorded immediately following excavation by drill and blast.

The data collected were analyzed to validate the suitability of the laser-distometer as a replacement for the tape extensometer. To evaluate the suitability, all erroneous data (anchor bolt damaged or destroyed) was removed from the dataset, and all point pairs indicating trending data (deformation is occurring) were removed. This left a "stable" dataset of more than 6,000 readings between 245 deformation point pairs (Figure 4). The intent of reducing the complete dataset to a "stable" dataset is to analyze the laser-distometer as a measurement tool, rather than analyze the actual deformation that may have occurred.

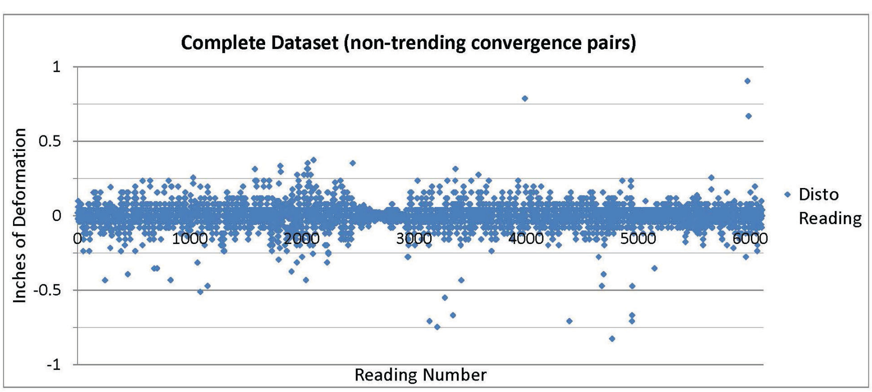

Figure 4. Laser- distometer dataset.

Results of the program and conclusions

The scatter in the stable dataset plotted as a histogram is an excellent approximation of the normal distribution. Therefore, by calculating the mean and standard deviation of the stable dataset, it follows that 93.1% of readings fall within the three millimeter manufacturer specification of instrument precision.

In reality, random errors are introduced into the measurement process by the operator. Assuming that random errors by the operator introduce an additional one-millimeter of error into the readings, it follows that 96.3% of readings fall within the instrument specifications, and if two millimeters of random error are introduced, then 99.8% of readings fall within the instrument specifications.

The most significant random error to be mindful of is "pointing" error, whereby the laser beam is reflected from different points on the second target during successive readings. Other random errors may be introduced into the readings when the laser-distometer is not snugly fitted into the cradle, or when excessive dust within the tunnel causes refraction of the laser beam.

The laser-distometer has met the requirements for deformation monitoring at the East Side Access Project, and has proven to be a viable alternative to the tape extensometer. Under ideal conditions, it is possible that the tape extensometer may yield deformation readings of higher precision, however this comes at a considerably higher cost, both in material and labor. Where project-specified limits of movement allow for the substitution of a laser-distometer for the tape extensometer, the option should be seriously considered.

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Commercial sources:

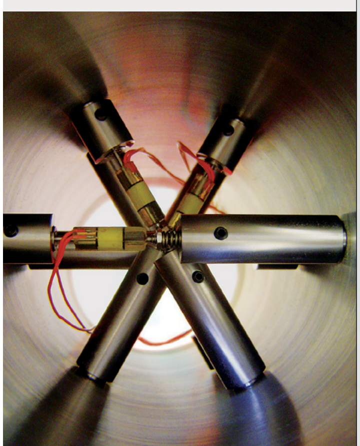
Leica Geosystems – laser-distance meters http://www.leica-geosystems.com/en/Which-DISTO-is-the-right-one_102657.htm

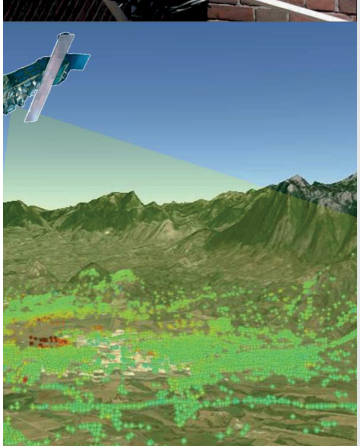
Leica Disto A3 (used for monitoring at East Side Access described in this article) http://www.leicadisto.co.uk/products/disto_a3.html

Trimble – laser-distance meter http://www.trimble.com/construction-tools/qm95-quick-measure.aspx?dtID=features

Tape Extensometer

- *Slope Indicator* - http://www.slopeindicator.com/instruments/ext-tape.html
- *Geokon* - http://www.geokon.com/tape extensometers/
- *ITMSoil* - http://usa.itmsoil.com/pages/digital+tape+extensometer
- *RST* - http://www.rstinstruments.com/Tape%20Extensometer.html





International Course on

Geotechnical and Structural Monitoring

June 4-6, 2014

"Castle of Poppi", Tuscany (Italy)

Course Director: **John Dunnicliff**, Consulting Engineer

Organizer: **Paolo Mazzanti**, NHAZCA S.r.l.

NEW COURSE: This annual course in Italy replaces the long-standing series of continuing education courses in Florida. The format will be similar to the Florida courses, but with the addition of **substantial content on remote methods for monitoring deformation**.

COURSE EMPHASIS: **is on why and how to monitor field performance.** The course will include planning monitoring programs, hardware and software, recent developments such as web-based and wireless monitoring, remote methods for monitoring deformation, offshore monitoring, case histories, and lessons learned. Online sources will be included, together with an open forum for questions and discussion.

WHO: Engineers, geologists and technicians who are involved with performance monitoring of geotechnical features of civil engineering, mining and oil and gas projects. Project managers and other decision-makers who are concerned with **management of RISK during construction**.

OBJECTIVE: to learn the who, why and how of successful geotechnical and structural monitoring while networking and sharing best practices with others in the geotechnical and structural monitoring community.

INSTRUCTION: **provided by leaders of the geotechnical and structural monitoring community**, representing users, manufacturers, designers and people of academia from Italy, England, Australia, France, Germany, Norway, Switzerland and USA.

WHERE: the 3-day course will be held in Poppi (Tuscany, Italy), in the main room of a 13th century castle (www.castellodipoppi.com). Poppi is in the countryside of Tuscany, near the city of Florence. **Dedicated transportation to Poppi from Florence main train station and city airport will be available**.

www.geotechnicalmonitoring.com