Geotechnical Instrumentation NEWS

# Geotechnical Instrumentation News

*John Dunnicliff*

### Introduction

This is the fifty-eighth episode of GIN. Two articles this time.

### Cause and Effect

Measurements by themselves are rarely sufficient to provide useful conclusions because the use of instrumentation normally involves relating measurements to causes. It's therefore necessary to maintain complete records of all factors that might cause changes in the measured parameters, including construction details and progress.

In his article in the previous episode of GIN (December 2008) about manual and/or automated optical survey, Joel Volterra wrote, "In other monitoring programs ... vital construction records are not available—records that are essential for comprehending, validating or writing-off the observed trends or spikes". The article in the current episode by Youssef Hashash and his colleagues describes techniques for tracking excavation activities, thereby providing causal construction data.

### Time Domain Reflectometry (TDR)

The June 2008 episode of GIN included an article by Kevin O'Connor about alarm systems based on TDR technology. The article in the current episode by Chih-Ping Lin introduces some recent advances that extend the use of TDR technology in geotechnical engineering.

Remember that Joel Volterra's and Kevin O'Connor's articles can be downloaded from BiTech's website www.bitech.ca by clicking on the link "Geotechnical News".

### ShapeAccelArray (SAA)

In the previous episode of GIN (December 2008, pp 28-30) Erik Mikkelsen and I published an article with some of our views on the SAA instrument. This has generated significant back-and-forths among various colleagues. The manufacturer, Measurand Inc. has responded to some of the views on their website, www.measurandgeotechnical.com. Look for a link to "SAA Facts" on the homepage.

### March Instrumentation Course in Florida

In case you're reading this before mid-March, it isn't too late to register for the once-every–two-years (I had to get my dictionary out to check on the meaning of "biannual"!) continuing education course in Florida. The next course will be on 15-17 March, 2009 at Cocoa Beach. Details are on http://conferences.dce.ufl.edu/geotech. This reminds me of what someone wrote on the course evaluation form a few years ago in response to "How did you register for the course?" "By caesarian section". He'd learned about it two days before the start!

### The Importance of Correct Punctuation

This is probably 'going the rounds' but I thought it was good enough to include here. It was sent to me as "GIN Editor in Chief". There are two versions:

Version 1:

*Dear John*

*I want a man who knows what love is all about. You are generous, kind, thoughtful. People who are not like you admit to being useless and inferior. You have ruined me for other men. I yearn for you. I have no feelings whatsoever when we're apart. I can be forever happy—will you let me be yours?*

*Gloria*

Version 2:

*Dear John:*

*I want a man who knows what love is. All about you are generous, kind, thoughtful people, who are not like you. Admit to being useless and inferior. You have ruined me. For other men, I yearn. For you, I have no feelings whatsoever. When we're apart, I can be forever happy. Will you let me be?*

*Yours,*

*Gloria*

### 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 mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. +44-1626-832919.

Kkong gang ul wi ha yo (Korea)

# Tracking of Excavation Activities by Laser Scanning and Image Reasoning-based Techniques

*Y. M. A. Hashash*
*C. A. Quiñones-Rozo*
*D. R. Groholski*

## Introduction

Monitoring programs applied to excavations have focused mainly on the measurement of movements such as lateral wall deformations and settlements. However, the success of a monitoring program does not reside exclusively in providing such measurements, but in helping to establish why an excavation exhibits a certain behavior. A key part of achieving this understanding is to establish a cause-effect relationship in which the occurrence of a particular movement can be associated with a specific construction activity in the field. In this article we describe the use of two complementary imaging techniques which can be used to provide the needed record of construction activities: Three Dimensional Laser Scanning (3DLS) and image-based reasoning.

## Three Dimensional Laser Scanning (3DLS)

### Principles of Technique

Three Dimensional Laser Scanning (3DLS) is a technique that uses laser pulses to measure distances and is also commonly known as LIDAR (Light Detection and Range). The distance can be calculated as the time required for the laser pulse to travel between the target and receiver multiplied by the speed of light. Two rotating mirrors are employed to orient the laser beam in different directions, thus creating a grid of measured points usually referred to as a "point cloud".

The laser scanner used by the authors was the first-generation HDS 2500 from Leica Geosystems (Figure 1). This scanner provides a positional accuracy of ± 6 mm in a distance range between 1.5-50 m. A field of view equal to 40º by 40º and a maximum point resolution of 1 million points (1000H x 1000V) can be attained. The time required to perform a scan varies according to the resolution specified, reaching a maximum of 14 minutes when the highest resolution is selected.

### Laser Scanning Applied to Urban Excavations

Monitoring of urban excavation construction progress by means of 3DLS allows the collection of precise information about the geometry of a job site in prompt fashion. Data is obtained in a digital format compatible with most popular CAD software. This allows for swift use of the information gathered by 3DLS in subsequent analysis tasks (Hashash et al. 2005) such as:

- Input for numerical modeling
- Calculation of indicators regarding task performance and efficiency
- Calculation of construction quantities

During a scanning session the scanner is positioned at several locations in the vicinity of the excavation, such that multiple scans are conducted to capture the entire site. The string of point clouds collected in the session are combined through a post-processing procedure known as "stitching". This procedure relies on the use of common points registered in overlapped portions of adjacent scans. Common points can be corners from non-moving construction equipment or reflective targets. For those cases where reflective targets have been employed to identify the common points the stitching procedure is automatic and takes place in seconds – other cases require minutes or hours. The level of effort required for "stitching" is directly associated with the planning conducted prior to the execution of the scanning and the procedures used in the field.

The locations of the scanner should meet the following criteria:

- They must provide an unobstructed view of the most relevant features to be captured by the scanner
- They must be in safe areas where no interference is caused to the ongoing construction activities
- A minimum overlapping angle of 8º is allowed between adjacent scanning locations to facilitate the "stitching" process
- The amount of scans required to cover the whole site is minimized.

It is commonly found that all the above criteria cannot be met easily, thus the exercise of good judgment is required to achieve an adequate balance. Prior review of the site configuration and careful planning of the scanning locations is the best way to achieve a safe and efficient scanning session.

Once the stitching process is complete, the resulting unified "point cloud" is ready to provide detailed information about the as-built condition of the excavation. Terrain information acquired during a scan session can be condensed

*Figure 1. HDS 2500 from Leica Geosystems – formerly Cyrax.*

by converting "point clouds" into Triangulated Irregular Network (TIN) meshes. A TIN mesh is a grid of triangular elements that do not overlap in the vertical direction. The volume of excavated material is obtained by integrating the vertical distance between the mesh and a defined reference plane (e.g. the original ground level or the previous excavation stage).

#### Case Study: Ford Center Excavation

The Ford Motor Company Engineering Design Center is a 7,800 $m^2$ floor area facility located in the heart of the Northwestern University campus. Construction of this building included excavation of a 44.4 m x 36.6 m area to a maximum depth of 8 m to accommodate two underground stories. Construction activities were monitored weekly by means of laser scanner, starting with the installation of the sheet pile wall supporting system (January 2004) until the completion of excavation activities (May 2004). Scans made by the laser scanner captured the configuration of installed supports at a given moment in time and helped to establish a relationship between excavation, support installation and recorded ground movements (Su et al. 2006). A view of the job-site is shown in Figure 2.

The number of scans required to cover the excavation area varied between 8 and 17 for each scan session. It was found that placing the scanner at the corners of the excavation reduced interference with the ongoing excavation activities and minimized the number of scans required to capture the area. Although the presence of materials and equipment within the excavation pit created areas where the shape of the excavation could not be captured by the scanner, it was found that such areas could be filled digitally using a TIN mesh. This procedure renders good results provided that materials and machinery tend to be positioned in even and level portions of the excavation.

### Image Reasoning-Based Techniques

The frequency of laser scanning sessions typically falls on a weekly basis, thus they are unable to capture daily or hourly changes in construction activities and their effect on ground movement. A faster technique is required to monitor such daily events. Photographs taken from digital cameras and webcams can be used to capture daily activities, but these photographs supply only a two-dimensional picture of the site and analysis of the photographs to discover any changes in the site require a significant investment of time. To overcome these deficiencies, image reasoning-based techniques are employed to automate and expedite the process of scanning, modifying, and/or comparing digital-based images. Such techniques include Close-Range Digital Photogrammetry (CRDP) and Enhanced Pattern Detection and Comparison (EPDC). CRDP can be used to transform a 2D image into a 3D model. Likewise the newly developed EPDC technique has been developed to quickly assess changes in the excavation site.

CRDP is a technique that uses digital photographs to create three-dimensional models. A series of images taken from different positions are related to each other by triangulating between common points of interest captured in each image. The requirement of placing targets makes this technique impractical for active excavation sites because of interference with ongoing construction activity (Quiñones-Rozo et al. 2008). To overcome this difficulty, EPDC techniques have been developed to monitor daily excavation activities without the need for targets.

#### Enhanced Pattern Detection and Comparison (EPDC)

The EDPC technique employs an image reasoning approach to monitor changes between static digital images. The application of these techniques requires digital images taken from a stationary digital camera or webcam.

Pattern recognition is achieved by carrying out a series of morphological operations on the image under consideration. Essentially, pattern recognition focuses on finding differences within a neighborhood of pixels as opposed to individual pixels. This can be achieved with morphological operations which dilate and erode features within an image. The dilation operation tends to emphasize borders within the image, while erosion has the opposite effect.

A primary attribute of the morphological operations is that they are not commutative. The results of using the dilation operation followed by erosion will be different than the results of using erosion followed by dilation. The combinations of morphological operations are termed "closing" and "opening" of the image. "Closing" refers to the operation of dilation followed by erosion, while "opening" refers to the operation of erosion followed by dilation. Closing has the characteristic of emphasizing smaller details and merging those with

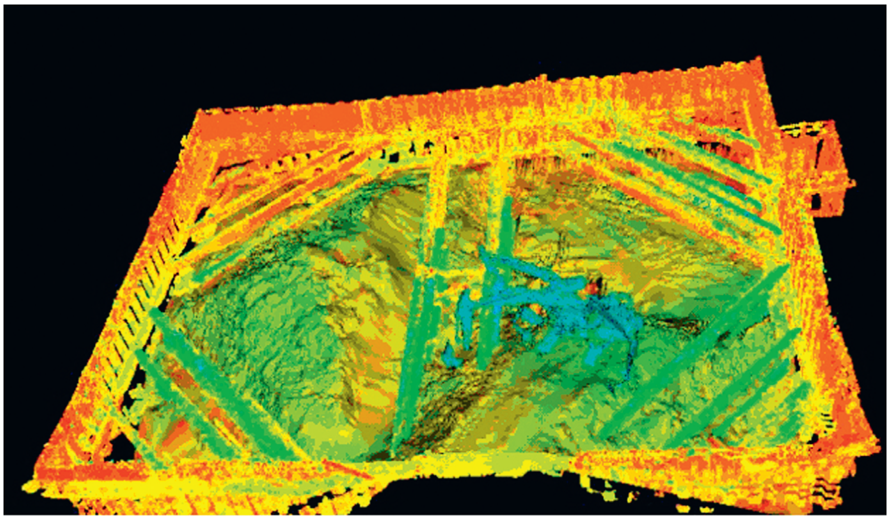

*Figure 2 Stitched and processed laser scan image of Ford Center Excavation, Evanston, IL.*

more relevant features. Opening erodes the irrelevant features, allowing patterns of the most dominant features to remain.

The application of morphological operations can be supplemented by the combined use of original (positive) and negative images corresponding to different excavation stages. According to set theory the sum of a positive image and its corresponding negative, results in a perfect white canvas. However, if instead of using two images belonging to the same excavation stage, one of the images (positive or negative) corresponds to a different excavation stage, the result is a comparison of the intensity variations between the two stages, where the uncommon elements (changes) between them appear as colored zones in the output image. This resulted in the development of the EPDC technique as described by Quiñones-Rozo et. al (2008).

### Application of EPDC for Remote Tracking of Excavation Activities

To demonstrate the applicability of the EPDC technique in practice, the technique was applied to images taken during the excavation at what is popularly known as Block 37 in Chicago. Figure 3 illustrates the application of the EPDC technique between images taken via webcam on different dates. Figure 3a shows the image of the site to be used as the basis for comparison in the EPDC technique. The areas which underwent change including excavation of soil and change in location of construction equipment are circled in red in Figure 3b to verify the accuracy of the EPDC technique. Figure 3c shows good agreement between the EPDC output image and the marked changes as the EPDC algorithm has highlighted the areas of the image which have changed. It can be seen that there are some areas where the EPDC technique has not detected any change as the circled areas of change are not completely highlighted in Figure 3c. This is due to the resolution of the webcam (0.3 MP) and can easily be resolved by using a higher resolution camera. In general, the results indicate that the application of EPDC for remote tracking of excavation activities provides reliable results.

### Summary

This article demonstrates the viability of two imaging techniques for the tracking of construction activities. These techniques are employed to aid the engineer in establishing the cause-effect relationship in which the occurrence of a particular ground movement can be associated with a specific construction activity in the field

Three Dimensional Laser Scanning (3DLS) provides 3-D images of the construction site, to scale, with unprecedented level of detail. These images can have a range of uses, including development of as-built records, correlation of construction activities to measured response, and for the development of numerical modeling. The amount of time and effort required for a successful scanning session and post-processing of the data is heavily dependent on the planning performed before execution. Due to the time demands 3DLS is able to provide details of the excavation activity on a weekly basis.

The enhanced pattern detection and comparison (EPDC) technique allows for the rapid processing of images obtained from digital cameras to track excavation activity at a construction site. EPDC provides a complementary capability to laser scanning when used to process images taken on a daily or even hourly basis.

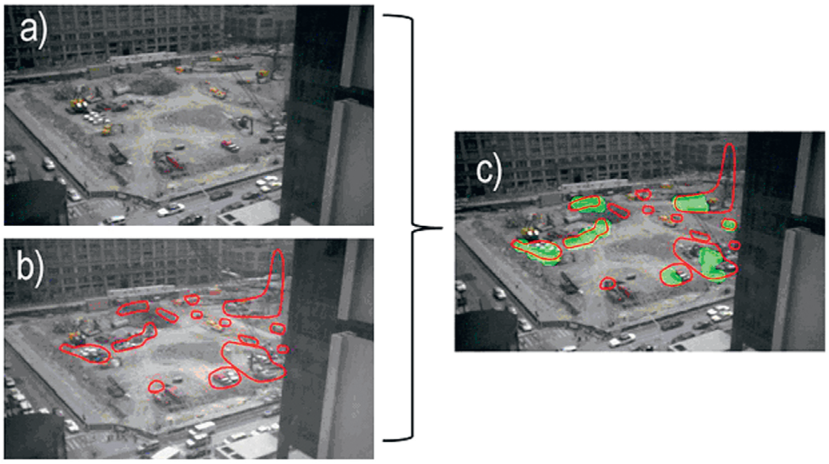


*Figure 3. Enhanced pattern detection and comparison (EPDC) technique applied to Block37 excavation works, Chicago, IL.*

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*Youssef M. A. Hashash, Associate Professor of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, 2230c Newmark Civil Engineering Laboratory, 205 N. Mathews Avenue, Urbana, IL 61801, Tel. (217) 333-6986, email: hashash@illinois.edu*

*Camilo Quiñones-Rozo, Project Engineer, URS Corporation, 1333 Broadway, Suite 800, Oakland, CA 94612, Tel. (510) 874-1766, E-mail: camilo_quinones-rozo@urscorp.com,*

*David R. Groholski, Graduate Research Assistant, University of Illinois at Urbana-Champaign, 2220 Newmark Civil Engineering Laboratory, 205 N. Mathews Avenue, Urbana, IL 61801, Tel. (217) 333-6943, email: groholsk@illinois.edu*

# TDR as Geo-Nerve: A Slope Monitoring System Example

***Chih-Ping Lin***

**Abstract**
Time domain reflectometry (TDR) devices that interrogate passive mechanical transducers are advantageous for monitoring of geotechnical parameters in situ. TDR technique is based on transmitting an electromagnetic pulse through a coaxial cable connected to a sensing waveguide and watching for reflections of this transmission due to changes in characteristic impedance along the waveguide. Depending on the design of the waveguide and analysis method, the reflected signal can be used to "feel" various engineering parameters. When embedded in a geotechnical structure, TDR can be seen as a "geo-nerve" system.

## Time Domain Reflectometry and TDR Monitoring System

Time domain reflectometry (TDR) is a principle of measurement based on a cable radar (formally called time domain reflectometer) and metallic sensing waveguides, as opposed to optical fibers in optical time domain reflectometry (OTDR). It was originally developed for detection of cable faults and later applied to dielectric spectroscopy in physical chemistry. In the past two decades, TDR technique has been adapted to geotechnical applications. A TDR installation is composed of a TDR pulser-receiver (i.e. cable radar), a transmission line and a sensing waveguide. The pulse generator sends an electromagnetic (EM) pulse along the lead cable and the sensing waveguide directs the EM wave into the material under test or environment to be monitored. The sensing waveguide may be a coaxial cable (e.g. for monitoring of localized shear deformation and groundwater level) or a specially-designed multi-conductor waveguide (e.g. for monitoring of soil moisture, electrical conductivity, and deformation). Impedance change occurs when the measurement waveguide is subjected to deformation or electrical property of the surrounding material changes. Reflections from the impedance change are recorded and used to interpret engineering parameters.

Unlike conventional electronic transducers, TDR technique is a versatile pulsing method in which the transducers (i.e. the inserted sensing waveguides) require no electronic component. The output of a time domain reflectometer is digital data, which can be easily acquired and manipulated by a computer or a data logger. A communication module can be used with the data logger for remote monitoring. Figure 1 illustrates an example configuration for monitoring of slope stability. The TDR can also play important roles for geo-environmental, agricultural, and water resource problems. The TDR monitoring system can use a single pulser to continuously interrogate multiple physical parameters at multiple points through a multiplexer. Simultaneous measurements of these parameters are valuable for engineering analysis and understanding of the process dynamics. TDR waveguides for engineering applications can be grouped into three categories according to their measuring principles. They are briefly explained as follows.

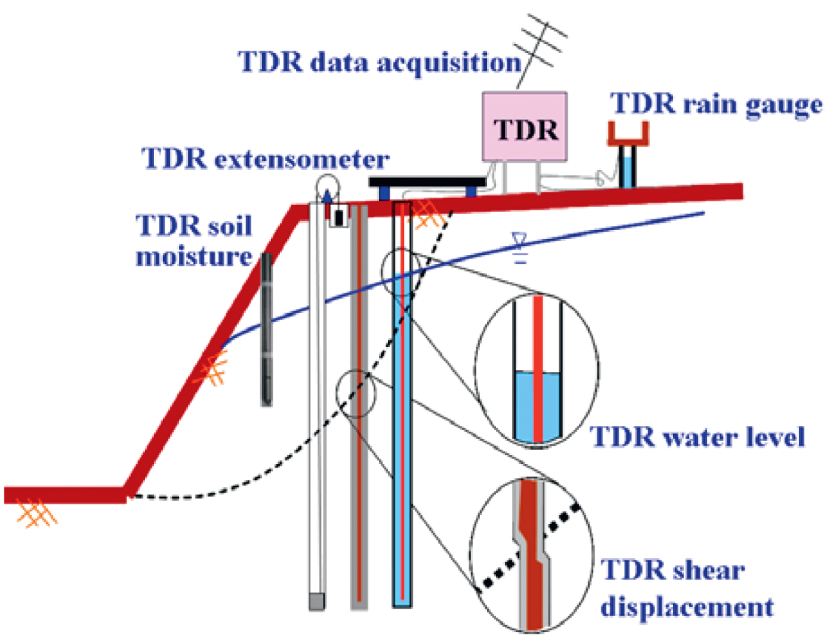


*Figure 1. TDR monitoring system example for slope stability*

## Dielectric Type Measurements

A waveguide probe with impedance mismatches on both ends is used for dielectric type measurements. The probe may be a coaxial waveguide (Figure 2a) for laboratory samples or a multi-rod waveguide (Figure 2b) to be inserted into soils in situ. The EM pulse is reflected at the beginning and end of the probe. A travel time analysis of the two reflections can determine the apparent dielectric constant, while the electrical conductivity can be measured using the steady-state response. The apparent dielectric constant and electrical conductivity are related to the soil water content and density. Current TDR multiple-rod probes are made for near surface applications. To make TDR measurements at various depths, a TDR penetrometer for simultaneously measuring dielectric constant and electrical conductivity during cone penetration was recently developed (Lin et al. 2006a and 2006b). A TDR penetrometer is formed by placing a multi-con-



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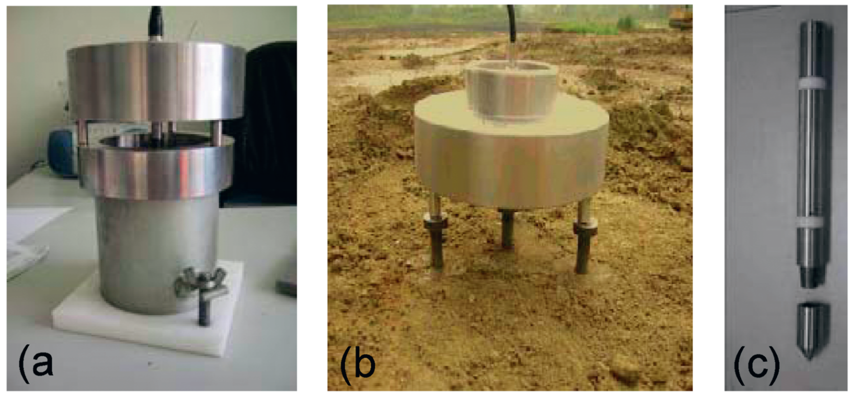


*Figure 2. (a) Coaxial probe, (b) multi-rod probe, and (c) TDR penetrometer.*

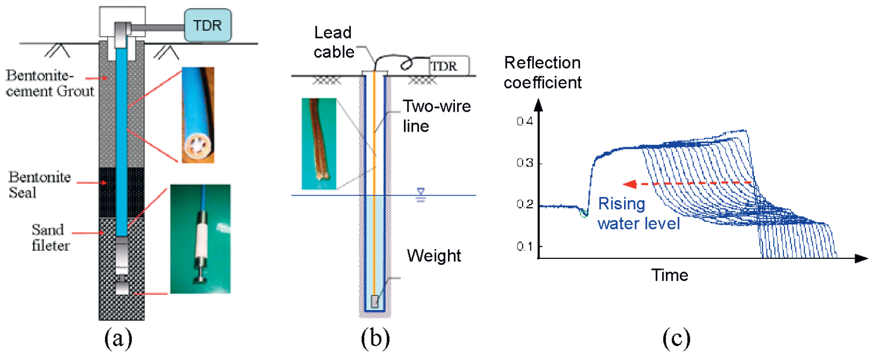


*Figure 3. (a) The TDR Casagrande piezometer by replacing the standpipe with an air-filled coaxial cable, (b)a simple two-wire line for detecting water level, and (c) reflection waveforms in response to rising water level.*

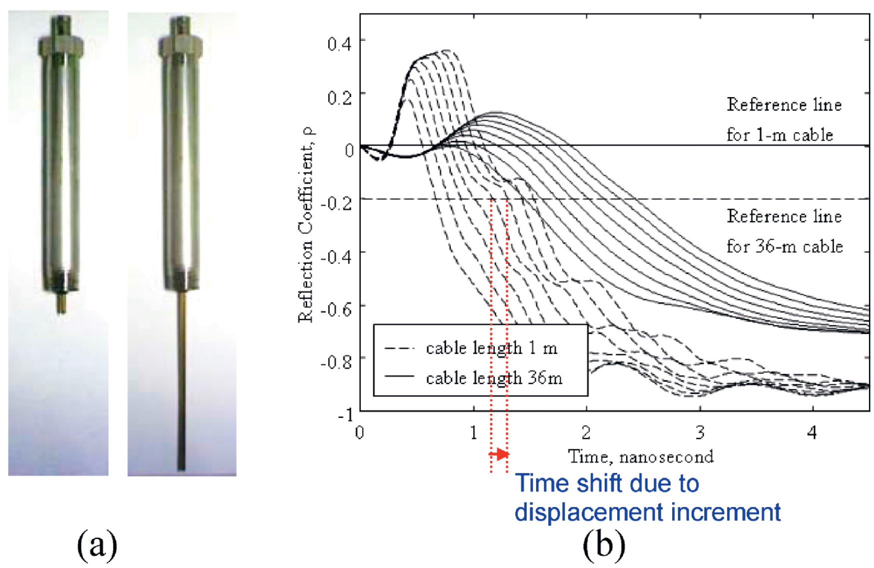


*Figure 4. (a) The TDR extensometer and (b) reflection waveforms in response to displacements.*

ductor waveguide around a non-conducting shaft, as shown in Figure 2c.

### Interface Type Measurements

Reflection of the EM pulse occurs at the interfaces of impedance mismatches due to changes in dielectric properties. These interfaces may represent ground water level (air-water interface) or scouring depth (soil-water interface) depending on the design of the waveguide. TDR can efficiently be used to locate the positions of these interfaces. A hollow coaxial cable can be used as the standpipe in a Casagrande piezometer as shown in Figure 3a. Existing open standpipe piezometers or observational wells can be easily automated by hanging down a hollow coaxial cable or two-wire line, as shown in Figure 3b. A TDR waveform is often expressed in terms of reflection coefficient (the ratio of reflected voltage to input voltage) versus time. Figure 3c shows typical waveforms of a two-wire line in response to water level changes. The TDR water level sensing technique can also be adapted to liquid level settlement gauge and rain gauge. Besides determining the interface of two different materials, Lin and Tang (2005) invented a TDR extensometer for displacement measurements based on similar principle. The TDR extensometer is mainly a waveguide with an impedance mismatch interface inside it (see Figure 4a). The movement of the impedance mismatch interface is coupled with the displacement of interest such that the time shift in the reflected TDR signal (see Figure 4b) becomes a measure of the displacement.

### Crimp Type Measurements

The characteristic impedance of a cable is determined solely by its cross-sectional geometry if the insulating material between conductors remains unchanged. Reflections of the EM pulse are recorded if the coaxial cable is deformed or “crimped”. When a coaxial cable is grouted in a rock or soil mass, it can be used to monitor the localized shear deformation of the rock or soil mass. As illustrated in Figure 5, a reflection spike occurs due to cable deformity induced by the ground deformation. Unlike other TDR measurements, there is a lack of quantitative interpretation for localized shear deformation monitoring since the TDR response is affected by cable resistance, soil-grout-cable interaction, and shear bandwidth. Nevertheless, field experiences have shown that TDR is able to detect localized shear deformation prior to failure in various geological conditions. A full-sized induced slope failure test was conducted to give the most direct and detailed demonstration of the effectiveness of TDR on slope stability

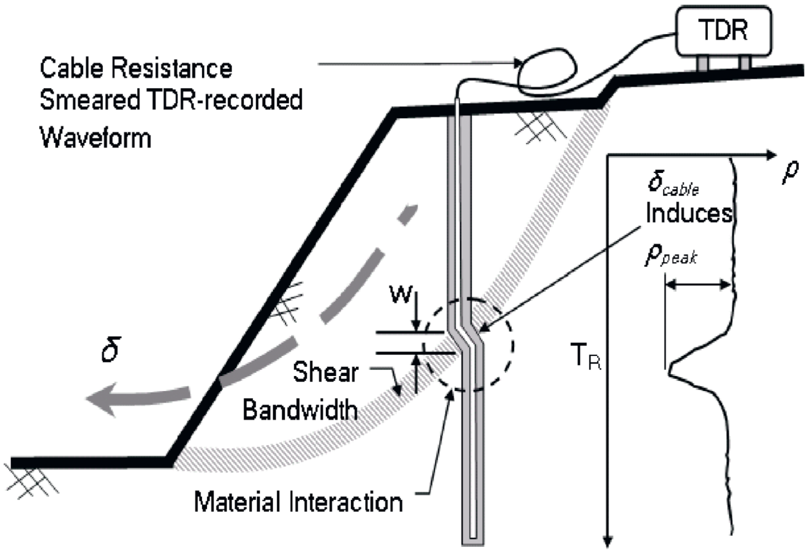


*Figure 5. Illustration of TDR monitoring for localized shear deformation.*

monitoring. A 3m (10 ft) high dipped slope with thick sandstone and mudstone was surcharged by adding dead load from stacked steel plates on the top. The test slope was instrumented with an in-place inclinometer (IPI) and a coaxial cable both 5.5m (18 ft) deep. The reflection spike was detectable at a loading of 100 kN (11.2 ton) when IPI observed a maximum deformation about 10 mm (0.4 in). The reflection occurred at the depth of 1.5 m (5 ft) that was exactly the level of mudstone/sandstone interface. The magnitude of the reflection spike increased with increasing applied loading, as shown in Figure 6a. The trend of TDR reflection and IPI deformation appeared similar. When the surcharge was raised to 300 kN (33.7 ton), some fractures began to develop and propagated through the interface of mudstone and sandstone. When the loading was further raised to maximum load 345 kN (38.8 ton), the cracks obviously increased in their number, length, and opening size. Figure 6b shows the variation of TDR and IPI readings with time after the maximum loading. It reveals that the TDR successfully picked up the process of slope deformation during the induced slope failure.

## Conclusions

TDR is a monitoring technique based on transmission line theory, in which the sensing waveguide is part of the transmission line. A time domain reflectometer transmits an electromagnetic (EM) wave into the transmission line and receives a reflected EM wave, which responds to the physical parameter to be monitored. This article introduces some recent advancement that extends the usefulness of TDR technology in geotechnical engineering. Depending on the design of the waveguide and analysis method, the reflected signal can be used to "feel" various engineering parameters in a fashion similar to human nerve system. Multiple TDR sensing waveguides can be connected to a TDR data acquisition system through a multiplexer and automated, hence increasing the system functions and spatial coverage. The versatility and merits of TDR are highlighted by a TDR slope monitoring system example. The monitoring of localized shear deformation is truly distributed along the sensing cable. When embedded in a geotechnical structure, the transmission lines including the sensing waveguides can be seen as a "geo-nerve" system. Unlike other techniques having a transducer with a built-in electronic sensor, TDR sensing waveguides are simple and durable mechanical device without any electronic components, and can be altered in dimension and accuracy according to the measuring environment. In addition, the resulting monitoring system can even has a self-diagnosis function because a reflected waveform can be used to check the condition of the entire wiring for monitoring.

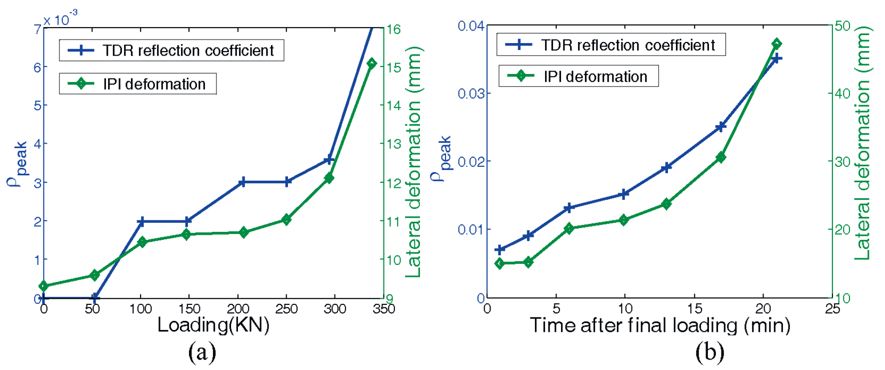


*Figure 6. Variation of TDR peak reflection coefficient and IPI lateral deformation with (a) surface loading and (b) time after final loading in a full-size induced slope failure test.*

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*Chih-Ping Lin, Professor, Department of Civil Engineering, National Chiao Tung University, 1001 Ta-Hsueh Rd., Hsinchu, Taiwan;*
*Tel: +886-3-513-1574;*
*email: cplin@mail.nctu.edu.tw*