Tailings and Mine Waste '98 © 1998 Balkema, Rotterdam, ISBN 90 5410 922 X

Embankment monitoring with time domain reflectometry

W.F. Kane
KANE GeoTech, Inc., Stockton, Calif., USA

ABSTRACT: Time domain reflectometry (TDR) is used to determine embankment slope movement and piezometric levels easily, safely, and economically. The digital nature of the data allows remote monitoring by telemetry. A cable tester sends a waveform down a coaxial cable embedded in a vertical hole. If the pulse encounters a deformation or the presence of water, it is reflected. The distance to the point of reflection is determined by the cable tester. This is used to locate shear failure in the embankment. The amplitudes of the reflections in a TDR signature indicate the severity of damage to the cable. Changes in amplitude with time correspond qualitatively to the rate of ground movement. Piezometric levels are determined by using a hollow coaxial cable as a standpipe. Water levels are measured by noting the location where the cable displays an electrical fault.

1 INTRODUCTION

Using an electronic pulse to detect changes in an embedded coaxial cable is a new technique to assess the stability of slopes and embankments. It has been successfully used to monitor unstable slopes by grouting a cable in a vertical borehole (Kane & Beck 1996; Kane et al. 1996). When earth movement occurs, the cable experiences damage detectable by electronic equipment. The method, known as time domain reflectometry (TDR), indirectly measures the electrical impedance between two conductors. In a coaxial cable, the impedance changes because of damage (deformation) to the cable. The presence of water can also affect the impedance of the cable. TDR is routinely used to measure soil moisture (Topp & Davis 1985; Rada et al. 1994).

Embankments usually fail due to two factors: 1. high water content that reduces the soil shear strength, and 2. high water pressure in the soil which decreases the effective stress between the soil particles. Since TDR has the ability to measure both deformation and water level, an investigation was made to determine the feasibility of measuring these in an actual embankment with coaxial cables.

Four 12 m cables were installed in vertical boreholes in Venice Island, San Joaquin County, California, USA. The cables were installed beside a conventional inclinometer which allowed the comparison of water and deformation in the cables.

1.1 *Regional setting*

The California Delta is a complex system of waterways and islands at the confluence of the San Joaquin and Sacramento Rivers (Figure 1). The construction of embankment levees around the islands deprived them of additional sediment. Oxidation and wind removed the peat soil causing subsidence. All the islands are now below sea level.

Figure 1. Location of study on Venice Island in the California Delta.

The soft peat soil also allows the levees to settle and become unstable. There have been notable levee failures, and some islands which, once flooded, were never reclaimed.

The cause of levee slope instability is a combination of differential settlement of the embankment, a decrease in the strength of the levee soil due to water infiltrating from the Delta, and an increase in water pressure during high tides and floods which decrease the soil's effective stress. Knowledge of the water level in the levee is an important parameter when the the embankment stability is analyzed. Repair of the levees is a continuous process. Repair is done by compacting soil on top, and on the side of the levee. This has the effect of further contributing to instability.

Failure occurs when the driving forces tending to cause a slope to move downward are greater than those that can resist such movement. An increase in driving forces can be due to additional weight placed at the top of a slope, or an increase in the weight of slope material due to saturation of the slope by water. Resisting forces can be decreased by removing material from the base of a slope or by adding water. Water has the dual effect on resisting forces by reducing the strength of the slope material and increasing the pore pressure in the slope. The presence of water, then, increases the forces tending towards failure and decreases the ability of the slope material to resist such failure.

1.2 *Conventional embankment monitoring practice*

Monitoring levees for movement and potential catastrophic failure is of extreme importance. Engineering firms are contracted by the various reclamation districts to monitor embankments and make repairs where necessary. Current practice uses surveying to track the movements of targets on the slope surface and the installation of inclinometers. The crests of the levees are also routinely patrolled, especially during times of high water and storms.

When a section of levee is determined to be unstable, an inclinometer is installed. This involves boring a hole in the embankment and casing it with a slotted PVC pipe. The casing is flexible enough to deform as the slope moves. Periodically, an inclinometer probe is lowered down the casing and retracted. The probe uses accelerometers to determine the direction of gravity, and the plotted data depicts the shape of the casing at the time of reading. A change in the shape of the pipe provides an indication of how the slope is moving and its velocity. Water levels are determined by inserting another probe down the inclinometer hole until it comes in contact with the water in the pipe.

The chief disadvantage of the inclinometer is that data recording is time-consuming. An operator must physically visit the site to record each inclinometer hole. The probe must be lowered to the bottom of each hole, and time allowed to equilibrate the probe with the ambient temperature in the hole. The operator must record data, usually by pushing a button, at each interval and pull the probe up to the next location to be read. Once the data has been collected, the probe must be turned 180° and the process repeated. This must be done for every inclinometer hole on a particular site. The shape of the casing cannot be examined until it is plotted on computer.

2 TIME DOMAIN REFLECTOMETRY (TDR)

Time domain reflectometry (TDR) is a relatively new approach to monitoring landslide and embankment movement. Originally developed to locate breaks and faults in communication and power lines, TDR can be used to determine failure depths and monitor rates of movements of failures in earth slopes.

2.1 Principle of TDR

The basic principle of TDR is similar to that of radar. An electrical pulse is sent down a cable. When the pulse encounters a break or deformation in the cable, it is reflected. The location of that reflection can be determined accurately using a cable tester.

The use of TDR for civil engineering purposes began in the early 1980's. The U.S. Bureau of Mines used TDR to determine the location of the extent of collapsed mine roof above coal mines (Wade & Conroy 1980). This was done by drilling boreholes from the ground surface down to mine level and placing a coaxial cable in the hole. The borehole was then filled with cement grout. The cable was monitored periodically to determine the location of its end. As the roof of the mine collapsed due to additional mining activity, the cable broke at subsequently higher levels above the mine. Thus, the researchers were able to determine the locations of rock deformation and collapse above the mine.

The chief advantages of TDR are:

1. Cables are inexpensive (about 20% of the cost of inclinometer casing).
2. Cables can be read in a matter of minutes no matter how deep the monitoring hole is.
3. The cable signature is viewed instantly on the tester, it is not necessary to plot the data first.
4. The data are digital and can be read remotely using telemetry.
5. Many TDR cables can be read from the same location, even when using telemetry.

In TDR, an electronic pulse is sent down a coaxial cable. If the pulse encounters a deformation or the end of the cable, part or all of it is reflected. The returned pulse is compared with the emitted pulse, and the reflection coefficient (in rho's or millirho's) is determined. If the reflected pulse equals the transmitted pulse, the reflection coefficient is +1 and the cable is broken. If the opposite occurs, and the cable is shorted, all the energy will be returned by way of the ground, and the reflection coefficient will be -1. If the cable is damaged or deformed, the reflection coefficient will be between -1 and +1. A negative reflection coefficient occurs if the cable is stretched and/or sheared.

The speed at which the pulse travels down the cable as a percentage of the speed of light is called the velocity of propagation (Vp) and is a property of each cable. By knowing the velocity of propagation, the distance to, and the type and severity of any cable fault can be determined (Su 1987).

Coaxial cables are composed of a central metallic conductor surrounded by an insulating material, a metallic outer conductor surrounding the insulation, and a protective jacket (Figure 2). The cables have a characteristic impedance determined by the thickness and type of insulating material between the cables. This insulating material is called the "dielectric," and may be made of almost any non-conducting material. Common dielectric materials are PVC-foam, Teflon, and air. If the cable is damaged, the distance between the inner and outer conductors changes, as does the impedance at that point. The TDR cable tester can then determine the location of the fault.

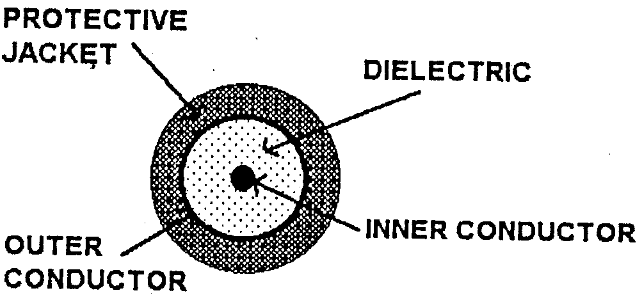

Figure 2. Cross-section of coaxial cable.

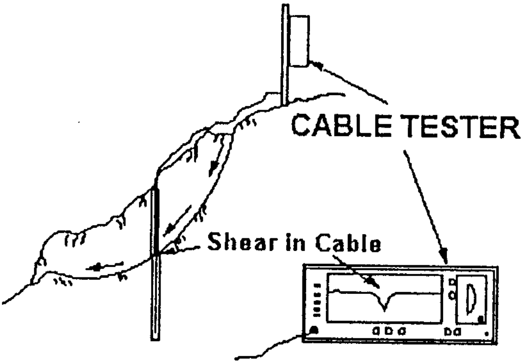

Figure 3. Deformed cable resulting in signature spike on cable tester screen.

The data consist of TDR signatures (Figures 3 and 4). Different wave reflections are received for different cable deformations. The length and amplitude of the reflection indicates the severity of the damage. For a cable in shear, a reflection spike of short wavelength is recorded. The amplitude increases in direct proportion to the shear deformation. A distinct negative spike occurs just before failure. After failure, a permanent positive reflection is recorded. For cables in tension, the wave reflection is a subtle, trough-like voltage signal that increases in length as the cable is further deformed. Water causes the cable signature to curve negatively.

2.2 TDR for Embankment Monitoring

In addition to monitoring deformation in embankments, TDR can be used for determining water levels. Because TDR is affected by shorts circuits in a coaxial cable, the presence of water shorting a cable will have an effect on the cable signature. Dowding et al. (1996) used TDR to locate the air-water interface in a standpipe piezometer using a hollow, air-dielectric coaxial cable. The interface was shown as a pronounced, curved, negative trough, as opposed to a sharp negative rise that indicates a shorted cable. They also proposed an installation scheme for using TDR for monitoring water levels.

In other developments, Nicholson et al. (1997) described the development of a TDR field tester for measuring water levels.

It appears that the water level in a borehole can be determined by analysis of TDR data. Since the location of, and movement along, a failure plane within a slope can already be determined using TDR, the extension of the technology to monitoring both slope movement and water level is important.

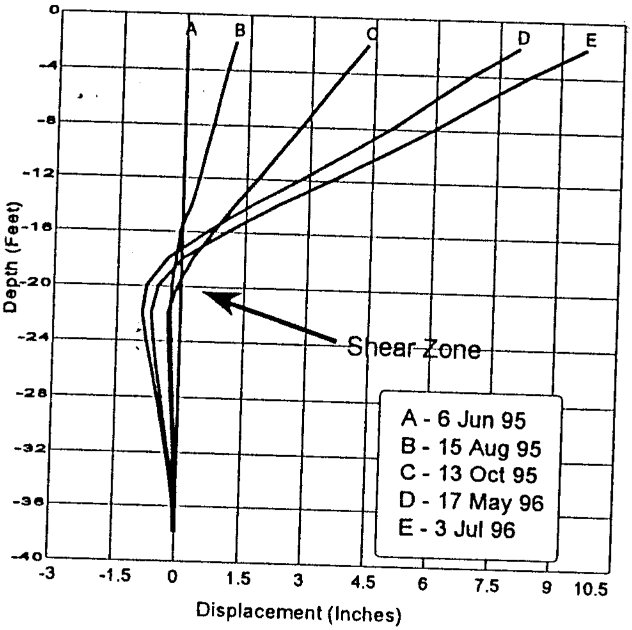

Figure 5. Inclinometer readings for comparison with Figure 6 readings. Note shear zone at approximately 6.1 m (20 ft).

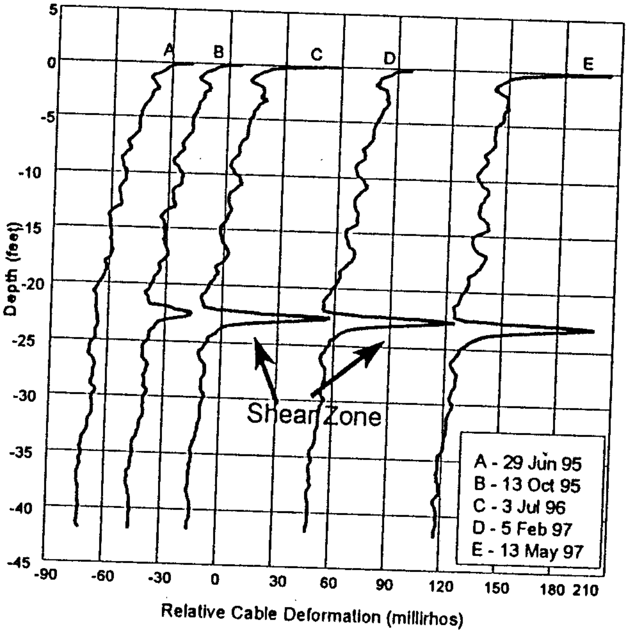

Figure 6. TDR cable signature indicating shear zone at approximately 6.4 m (21 ft).

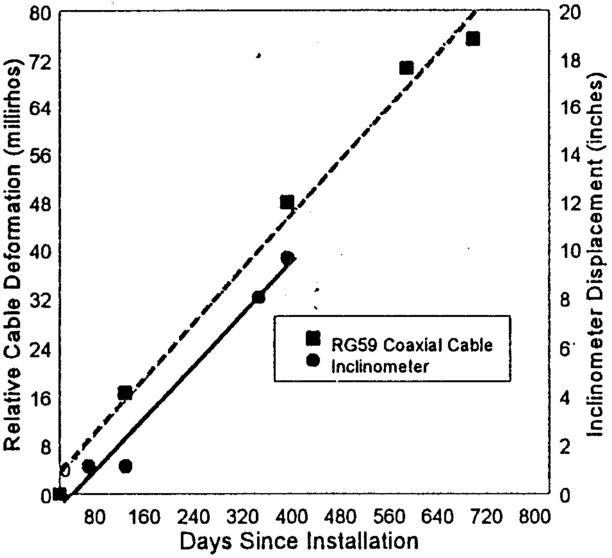

Figure 7. Correlation of surface displacement as determined by inclinometer with growth of TDR signature spike (1 in = 25.4 mm).

4.2 TDR and Phreatic Surface Measurement

Air-filled cables have the potential to monitor both deformation and water levels. Figure 8 is a plot of a TDR signature for an air dielectric cable. The location of the water table is given by a large curve in the signature at about 6.1 m (20 ft), as opposed to a sharp square waveform at the end of a cable without water. The change in signature indicates grounding of the cable by water filling the annular space in the cable.

Slope movement above the water table is indicated by the signature spikes at 2.4 m (8 ft), 4.3 m (14 ft), and 5.8 m (19 ft). Additional slope movement beneath the water table is possible. Small irregularities in the cable signature between 6.7 m (22 ft) and 11.6 m (38 ft) may indicate shearing. However, the cable broke at a depth of about 5.5 m (18 ft). This roughly corresponds to the shear zone as determined by the inclinometer and the solid cables.

5 SUMMARY

TDR is a promising technique to monitor embankments and acquire information to assess their stability. It can accurately locate zones of slope movement and qualitatively provide information on rates of movement. TDR can also serve as a piezometer to monitor water levels in an embankment.

At this time TDR, cannot be used to determine exact amounts of movement, nor can it give the direction of any slope movement. Additional experience and research should resolve these problems. Evidence obtained thus far indicates that it may be able to locate shear zones below the water table. Future data from Venice Island and other locations will provide the answers.

The attractiveness of TDR is that TDR data is digital and can be transmitted by telecommunications to a central site. This results in a significant savings of time and money. In addition, remote acquisition allows for more frequent monitoring, thereby, increasing safety for sites that may be near failure.

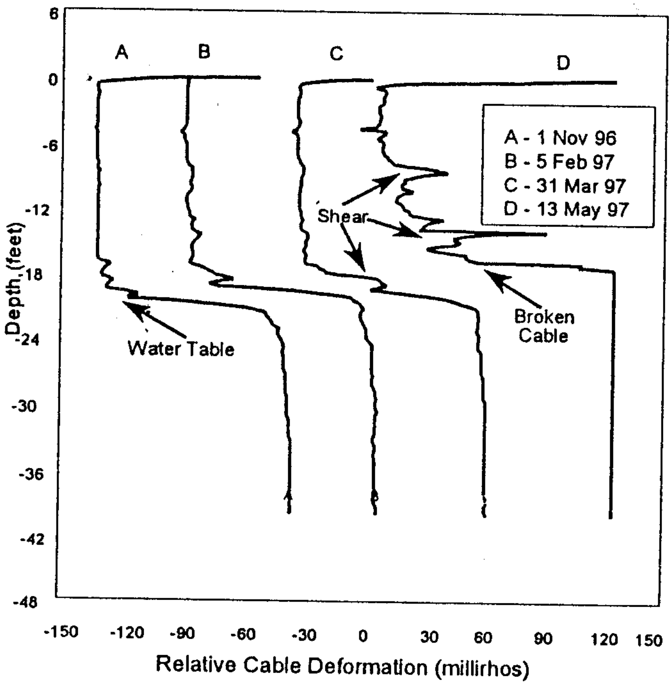

Figure 8. TDR cable signature for air-filled dielectric cable (1 ft = 0.3048 m).

REFERENCES

Dowding, C.H., F.C. Huang & P.S. McComb 1996. Groundwater pressure measurement with time domain reflectometry. *Geotechnical Testing Journal*, (19): 58-64.

Kane, W.F. & T.J. Beck 1996. Rapid slope monitoring. *Civil Engineering*, (66)6: 56-58.

Kane, W.F., N.O. Anderson & H. Perez 1996. Remote monitoring of unstable slopes using time domain reflectometry. Proc. Eleventh Thematic Conference and Workshops on Applied Geologic Remote Sensing, ERIM, Las Vegas, (II): 431-440.

Nicholson, G.A., J.F. Powell & K.M. O'Connor 1997. *A time domain reflectometry (TDR) pulser for monitoring groundwater levels with piezometers.* U.S. Army Corps of Engineers, Technical Report CPAR-SL-94-1, Vicksburg, MS.

Rada, G.R., A. Lopez & G.E. Elkins 1994. Monitoring of subsurface moisture in pavements using time domain reflectometry. *Proc. Symposium on Time Domain Reflectometry in Environmental, Infrastructure, and Mining Applications, Evanston, Illinois, 7-9 Sept. 1994*: 422-433. U.S. Bureau of Mines, Special Publication SP 19-94, NTIS PB95-105789.

Su, M.B 1987. *Quantification of cable deformation with time domain reflectometry.* PhD Dissertation, Northwestern University, Evanston, IL.

Topp, G.C. & J.L. Davis 1985. Measurement of soil water content using time domain reflectometry (TDR): a field evaluation. *Jour. Soil Sci. Soc. Amer.*, (49)1: 19-24.

Wade, L.V. & P.J. Conroy 1980. Rock mechanics study of a longwall panel. *Mining Engineering*, Dec. 1980: 1728-1734.