COASTAL BLUFF MONITORING/ALERT SYSTEM FOR RAILWAYS

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ABSTRACT

The desire to monitor a section of coastal bluff for slope movements along the North County Transportation District/Amtrak tracks in Del Mar, San Diego County, California led to the development of a continuous monitoring system along approximately 1000 m of track. Because of the length to be monitored, the use of conventional single-point monitoring systems such as multiple tiltmeters or in-place inclinometers (IPIs) was deemed impracticable. Since bluff failure could occur anywhere along the track, the use of single-point instruments would require a large number of instruments, with the possibility that a movement could still occur between points and be missed by the monitors. Instead, it was proposed to install horizontal time domain reflectometry (TDR) coaxial cable sensors along high-concern segments of the track.

The TDR monitoring system works similar to radar. It uses a coaxial cable as a sensor grouted in a trench between the bluff edge and the tracks. Any slope movement will deform or shear the cable at the location of movement. A reflectometer sends a voltage pulse along the sensor. When the pulse encounters a deformation, or the end of the sensor, some or all of the energy is reflected. The amount of reflected energy is proportional to the extent of the deformation with all energy reflected from the end of the sensor. The reflectometer accurately determines the location of the deformation and the relative extent of movement as noted by the magnitude of the reflection.

The Del Mar Bluffs TDR monitoring system used three on-site dataloggers and reflectometers to monitor three different sections of the bluff. Each reflectometer was

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connected to two sensors about 175 m long through a multiplexer. The sensors were pulsed every several minutes to determine if sensor deformation had occurred. In the event of a deformation, a signal was sent to a central monitoring unit where an automated telephone dialer notified railway personnel of possible bluff movement. Personnel could then contact the system by telephone and determine the location of the cable deformation so that a safety inspection of the bluff and track could be made.

INTRODUCTION

When it is desired to monitor slope movement along a segment of a transportation facility such as a roadway or railway, many vertical inclinometers must be installed to ensure adequate protection. This is especially true in the area of slope monitoring where single inclinometer values are usually spaced over a significant period of time and might miss a significant movement or trend. Besides the singular nature in time of inclinometer readings, they are also singular in space.

An alternate approach to a standard inclinometer installation is the use of an automated and remote data collection and monitoring system using time domain reflectometry. The use of automated and remote data collection and monitoring equipment for geotechnical applications is growing rapidly. Instead of providing an isolated reading at a single point in time, automated data collection can record data at small intervals and allow for trends to be determined relatively quickly. Time domain reflectometry allows monitoring over a continuous length rather than at discrete points. Coupling an automated data collection system with an alert based on threshold values can be very valuable.

The singular nature of the inclinometer can be eliminated by installing a horizontal sensor, capable of determining movement at any point, along the length of the transportation facility's exposure to the slope

The North County Transit District (NCTD) of San Diego County, California determined that three segments of track above coastal bluffs in Del Mar, California should be monitored for possible movement. Although the bluffs appear stable there had been some erosional problems that had required soldier pile walls, drainage enhancements, and shotcrete reinforcement. In addition, over fifty years ago, one segment of the bluff had failed causing the wreck of a freight train.

SITE DESCRIPTION

Overview

The monitored areas consisted of sections of coastal bluff prone to erosion and relatively small block failures. The bluffs were about 15 m above the beach. Railroad tracks along the bluffs ranged from as little as 6 m to as much as 30 m from the edge of the bluff. Soldier pile walls had been installed in sections where the distance to the edge of the bluff was small.

General Geology

The bluffs consisted of the Eocene Torrey Sandstone and the slightly older Eocene Del Mar Formation. At this location, the Torrey Sandstone was a relatively strong, but fractured and jointed sandstone, while the Del Mar Formation was soft and erodible siltstone. Wave action and a significant amount of ground water from landscape irrigation contributed to weakening and softening of the siltstone. The result was the undermining of the Torrey Sandstone and local coastal bluff failure.

INSTRUMENTATION OVERVIEW

The remote data acquisition equipment included a datalogger, multiplexer, communication devices, and a power source. In addition, software wss necessary to program and interact with the datalogger. Only the equipment used in the case studies is described here. The reader is encouraged to investigate other manufacturers and approaches.

Time domain reflectometry

Time domain reflectometry (TDR) is a relatively new approach to monitoring slope movement. Originally developed to locate breaks and faults in communication and power lines, TDR is used to locate and monitor slope failures. This technology uses coaxial cable as the sensor and a time domain reflectometer for measurement.

The basic principle of TDR is similar to that of radar. The reflectometer sends an electrical pulse down a coaxial cable grouted in a trench or borehole. When the pulse encounters a break or deformation in the cable, it is reflected. The reflection shows as a “spike” in the cable signature. The location of the spike indicates the location of cable damage. The size of the spike increase correlates with the magnitude of cable deformation. Cement grout or lean concrete is necessary to insure that any earth movement is transferred to the sensor cable. The brittle, rigid grout will crack under even small movements and deform the cable enough to cause a reflection.

Datalogger

A datalogger is essentially a small computer CPU/voltmeter with memory. It is programmed to do certain tasks, such as applying specified voltages over certain durations, reading voltages, and storing values. It can also be programmed to do calculations and store the results, such as converting the readings of a piezometer to meters of head.

Control ports on the datalogger and excitation ports can be programmed to output voltages at certain times to turn on peripheral equipment, such as cell phones or cable testers. Other ports are wired to the sensors and are used to measure output voltages.

Multiplexer

A multiplexer allows many sensors to be attached to a single datalogger. The multiplexer is wired to a single set of ports on the datalogger. A set of contacts in the multiplexer switches between each sensor attached to it. The data is collected sequentially by the logger. Multiplexers can even be multiplexed to each other creating the ability to read a very large number of instruments.

Communications

Communications with the datalogger can be by several means. “Hardwired” telephone lines are typically the most reliable, but not always available. A telephone line only requires a modem to transmit data and receive instructions. Cellular and satellite telephones can be used as well as radio transceivers. These methods require a modem in addition to the wireless telephone or radio.

Power

Power requirements vary depending on the number of instruments and the communications device. Ideally, power is available at the site but that is not always the case. A small system with a phone line and one or two sensors requires only a small rechargeable gel-type battery. A large system with cellular phone and cable tester requires a larger batteries. Typically 12 V deep cycle batteries are used. The battery is recharged by regulated solar panels.

Software

In order to program and communicate with the datalogger, software is written that runs under the datalogger’s operating system. This software allows the user to contact the remote station, either automatically or manually; monitor instrument readings; and download data. Once TDR data are downloaded, they can be plotted and analyzed using applications running under Microsoft Windows.

MONITORING SYSTEM DESIGN

The basic layout of the system is shown in Figure 1. It consisted of a central control and monitoring unit and three TDR monitoring stations. The central monitoring unit checked the status of each monitoring station and controlled the alert notification function of the system. The TDR monitoring stations each polled two TDR sensor cables for cable deformation or break.

Central Control and Monitoring Unit

A simplified schematic of the central control and monitoring unit is shown in Figure 2. An uninterruptible power supply with surge protection supplied power to the unit. It was recharged by a 120 V AC power source. The power was converted to 12 V DC to operate a Campbell Scientific CR23X datalogger and three telephone autodialers, one for each monitoring station.

The purpose of the CR23X was to monitor output voltages from each of the TDR monitoring stations. Zero voltage on any monitoring station channel meant that there was no alert condition. If a voltage was present, then an alert condition existed and the appropriate telephone dialer was activated to make an alert call.

The 120 V AC was also converted to 48 V DC and supplied to each monitoring station through individual wires enclosed in conduit below and alongside the tracks.

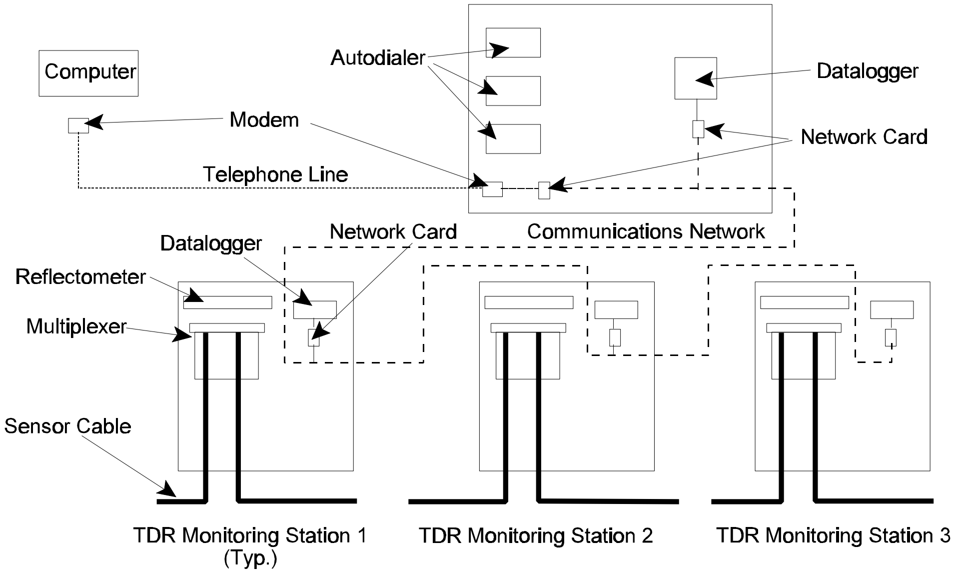

Figure 1. Central control and monitoring unit schematic.

TDR Monitoring Stations

At each monitoring station the voltage was stepped down to 12 V DC to power a Campbell Scientific CR10X datalogger, SMX50 TDR multiplexer, and TDR100 reflectometer (Figure 2). The datalogger polled two horizontal TDR cables every four minutes and compared the reflected waveform to a baseline signature. If the reflected data indicated a deformed or broken cable, an alert signal, consisting of 5 V DC was applied to a wire monitored by the CR23X at the central control and monitoring unit.

The datalogger was capable of distinguishing between a low level alert (deformed cable indicating small movement), and a high level alert (sheared cable and possible large magnitude slope failure).

TDR sensor cables were routed under the tracks and installed parallel to the tracks in a shallow trench. The cables were enclosed in a cement/sand grout to ensure deformation should a slope movement occur. A total of approximately 1000 m of sensor cable was installed.

Telecommunications

Telecommunications were made using a multidrop network (Figure 3). Each datalogger was connected to a Campbell Multidrop MD-9 network interface. RG59 coaxial cable was used to connect these network nodes. At the central monitoring station an additional MD9 was attached to a null modem/power supply connected to a telephone modem. The telephone modem was used for accessing the network dataloggers through the telephone line.

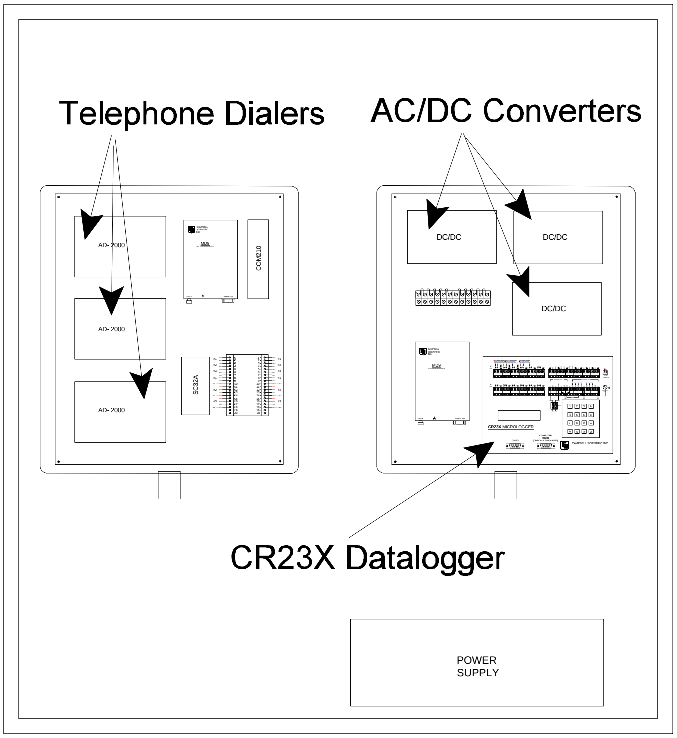

Figure 2. Monitoring system schematic.

In addition to the modem, the three autodialers also used the telephone line. When activated, the dialers called up to eight telephone numbers and delivered an alert message applicable to the type of action required.

Construction

Coaxial sensor cables were installed using a tractor-mounted trencher. Trenches were cut 0.7 m deep parallel to the tracks about 4 m from the track centerline between the track and the bluff edge. A 50 mm layer of lean concrete was placed on the bottom of the trench and the sensor cable was laid on top. An additional 0.3 m of concrete was placed on top of the cable. After the concrete set, the remainder of the trench was backfilled with compacted fill.

The Central Monitoring Unit and the Remote Monitoring Stations were housed in stainless steel enclosures with a powder coating colored to blend with the surrounding soil. The enclosures were mounted on poured concrete slabs with conduit cast into the slab. Pre-existing conduit buried alongside the track was utilized for communication, power, and alerting cables.

All instrumentation and power supplies were placed in weatherproof enclosures within the main enclosure.

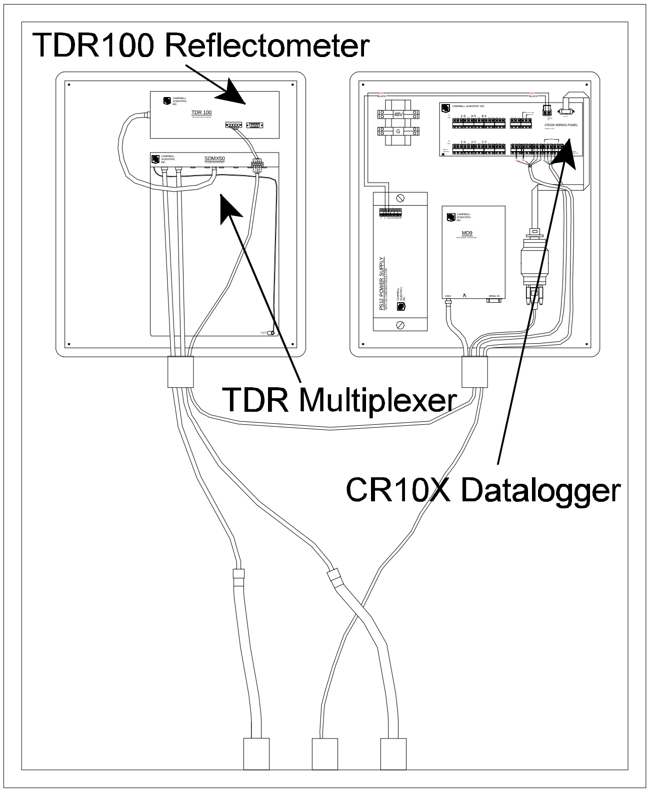

Figure 3. TDR monitoring station schematic.

IMPLEMENTATION

Programming

The remote monitoring station dataloggers were programmed to pulse the TDR sensors every ten minutes with the TDR100 reflectometer. The program then compared the sensor reflectance to a predetermined value. Cable deformation or failure triggered an alert condition. This condition caused a datalogger control port to output 5 V DC to one of the alerting cables. An alert condition was also set if the station power supply fell below a minimum level.

The Central Monitoring Unit datalogger was programmed to read the alerting cables and detect a non-zero voltage on any of the cables. When a voltage was detected, the datalogger activated one of the telephone autodialers depending on the nature and location of the alert.

Alerts

One aspect of the alerting feature was the ability to call up to eight different phone numbers to notify personnel of a possible failure condition. Each of the three dialers was dedicated to one fo the remote monitoring stations. For example, a sensor deformation on Remote Monitoring Station 2 would trigger calls to eight different individuals to alert them of a possible slope movement in the vicinity of Station 2.

Data

Data consisted of digitized TDR signatures that were downloaded automatically by a computer at the office of the owner's consultant. Data were plotted periodically to determine if there were any cable deformations not located by the datalogger alerting feature.

CONCLUSION

To the knowledge of the authors, this project represents the largest single application to date of TDR slope monitoring with movement alerting capability. The use of multiple telephone autodialers to notify key personnel was one of several innovative features of the project. In addition, the areal extent monitored and the distances that cables had to be run presented many challenges. TDR-based monitoring has excellent potential for safeguarding railroads and highways wherever they are threatened by dangerous slope movements..

ACKNOWLEDGMENTS

The authors would like to acknowledge the following for their assistance and expertise in helping to make this project successful: Paul McKee, J. C. Baldwin Construction, Steve Hoyle, North County Transit District, and Rafael Martinez, KANE GeoTech, Inc.