Development of a Time Domain Reflectometry System to Monitor Landslide Activity

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Presented at:
45th Highway Geology Symposium
Portland, Oregon
August 17-19, 1994

Reference: Kane, W. F. and Beck, T.J. (1994). "Development of a Time Domain Reflectometry System to Monitor Landslide Activity," *Proceedings*, 45th Highway Geology Symposium, Portland, OR, 163-173.

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ABSTRACT

Time domain reflectometry (TDR) was originally developed to find breaks in power transmission cables. This testing method uses the characteristics of a returned pulse to monitor the shear or rupture of a coaxial cable. The use of TDR to measure rock mass deformation is relatively new. Some applications were successful in the mining industry to monitor strata movement. The capability for remote access of the data exists. Economic advantages of such a system over the traditional inclinometer method include: no need to physically visit the site to collect data; readily available, inexpensive, and disposable cable; no need to clean debris from the inclinometer hole before taking measurements; and the ability to monitor up to 512 holes with one tester and multiplexer hook-up.

As a field test of a prototype system, the California Department of Transportation (Caltrans), the University of the Pacific, and Neil O. Anderson and Associates installed a coaxial cable in a large landslide along U.S. Highway 101 near Crescent City, California. The area is being studied to develop roadway stabilization alternatives. The landslide is occurring in rocks of the Franciscan Complex. In the area of the roadway it moves on the order of 1.5 to 3.0 m/yr (5 to 10 ft/yr). Two inclinometers were installed in the slide to determine the depth to the failure plane(s). One of the inclinometers is located in the roadway, and requires traffic control before it can be read. The coaxial cable of the TDR system was strapped to the outside of this inclinometer's casing to allow for a comparison of the data.

The initial data show a spike in the TDR reading at approximately the depth where the inclinometer casing is deflected. This suggests that TDR may be used in place of an inclinometer in some instances.

INTRODUCTION

Time domain reflectometry (TDR) is a method of analyzing electrical signals for testing purposes. It originally was developed to find breaks in power transmission cables (Franklin and Dusseault, 1989). This testing method uses characteristics of a returned pulse to determine the amount of strain, or a rupture, in a coaxial cable.

Although developed for cable testing, TDR is finding use in geotechnical applications, especially mining (O'Connor and Wade, 1994). For example, a study by the U.S. Bureau of Mines determined the height of rock caving above longwall coal mines (Dowding, et al., 1989). Coaxial cables embedded in bore holes prior to mining were used to infer deformation and collapse in the overburden. This information gave an indication of the extent of caving and shearing, and the associated bending of rock strata.

Currently, the California Department of Transportation (Caltrans) uses inclinometers to measure landslide movement and occasionally uses wire extensometers as failure warning systems. The inclinometer is a probe manually lowered down a specially cased borehole drilled into the slope. Accelerometers are used to monitor the orientation of the probe as it moves down the hole. Changes in orientation over time indicate slope movement; rapid changes can indicate imminent failure. The primary disadvantage with the inclinometer is the necessity of a site visit by a technician to take readings. In contrast, the wire extensometer is placed across the head scarp, or some other prominent feature, assuming that the movement measured can be used to predict a catastrophic failure. The problem with this system is that it can be triggered by birds, deer, or falling tree limbs (Cann and Steiner, 1992).

Caltrans investigated the Last Chance Grade landslide along U.S. Route 101 in Del Norte County, California, Figure 1. The investigation included drilling, bore hole logging, geologic mapping, and developing recommendations for stabilizing the highway. As a part of the field work for this investigation, inclinometer casing was installed in two borings. A coaxial cable was secured to the outside of one of the casings for comparison of TDR and inclinometer data.

There are three recommended alternatives for stabilizing the roadway. Knowledge of the slide plane(s) location will be essential in selecting one of the roadway stabilization measures. The first alternative is to realign the highway in a tunnel excavated behind the slide plane. Alternate two is to realign the roadway slightly, stabilize the material below the roadway with a soldier pile and tieback wall, and stabilize the material above the roadway with several rows of slope stressing. The third choice is to realign the highway in a cut excavated behind the slide plane. The first option is expected to have the least environmental impact and the third, the most. Combinations of these alternatives could also be used to stabilize the roadway.

SITE DESCRIPTION AND GEOLOGY

This section of U.S. Route 101 was constructed on the west-facing flank of a 300 m (1,000 ft) high ridge. It is bounded on the west by the Pacific Ocean and on the east by Wilson Creek. The elevation of the roadway at this site is approximately 215 to 260 m (700 to 850 ft). Most of the area is covered with a dense growth of redwoods, douglas firs, and alders with a thick undergrowth of ferns and berry vines. The site is underlain by interbedded shale, sandstone, and conglomerate of the Franciscan Complex. These rocks are intensely fractured, sheared, and weathered to a depth of 15 m (50 ft). A major joint set strikes parallel to the ridge and dips 40° to 50° toward the ocean.

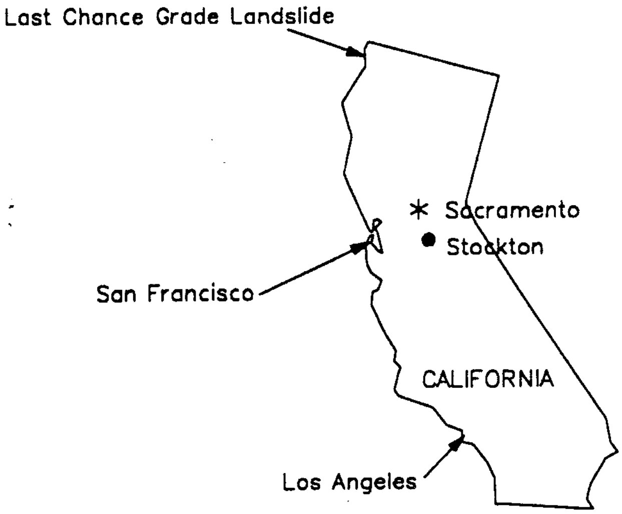

Figure 1 Location of Last Chance Grade Landslide.

Superimposed on the west-facing flank of this ridge is a large landslide complex. The slide complex is at least 915 m (3,000 ft) wide and 550 m (1800 ft) long in plan view. The slide complex appears to be a number of translational/rotational slides and debris flows that have coalesced. The highway crosses the upper portion of the complex.

The Last Chance Grade landslide, in the northern portion of the slide complex, is approximately 520 m (1700 ft) wide and 460 m (1500 ft) long in plan view, Figure 2. The slide is very active, affecting approximately 235 m (775 ft) of the roadway. This active area is composed of at least three translational/rotational slides (map units Qals1, Qals2 and Qals3 in Figure 2) with a debris flow (Qadf) snaking up the middle. The two lower units (Qals1 and Qals2) move as the ocean and rain erode the toes of these slides. As the two lower slides move forward, the upper slide (Qals3) is left unsupported and moves down behind the other slides. The three slides move as intact masses. During the rainy season soil, rock fragments, downed trees, and other material in the debris track flow downhill toward the ocean.

The southern portion of the slide complex is dormant. This conclusion was based on the fact that no evidence of recent movement (fresh scarps, bulges, or downed trees) was found during the field mapping. Eroded and tree-covered head scarps, side scarps, and closed depressions were used to map the dormant translational/rotational landslide (Qdls). Other eroded and tree-covered topographic features were interpreted as dormant debris flow tracks (Qddf).

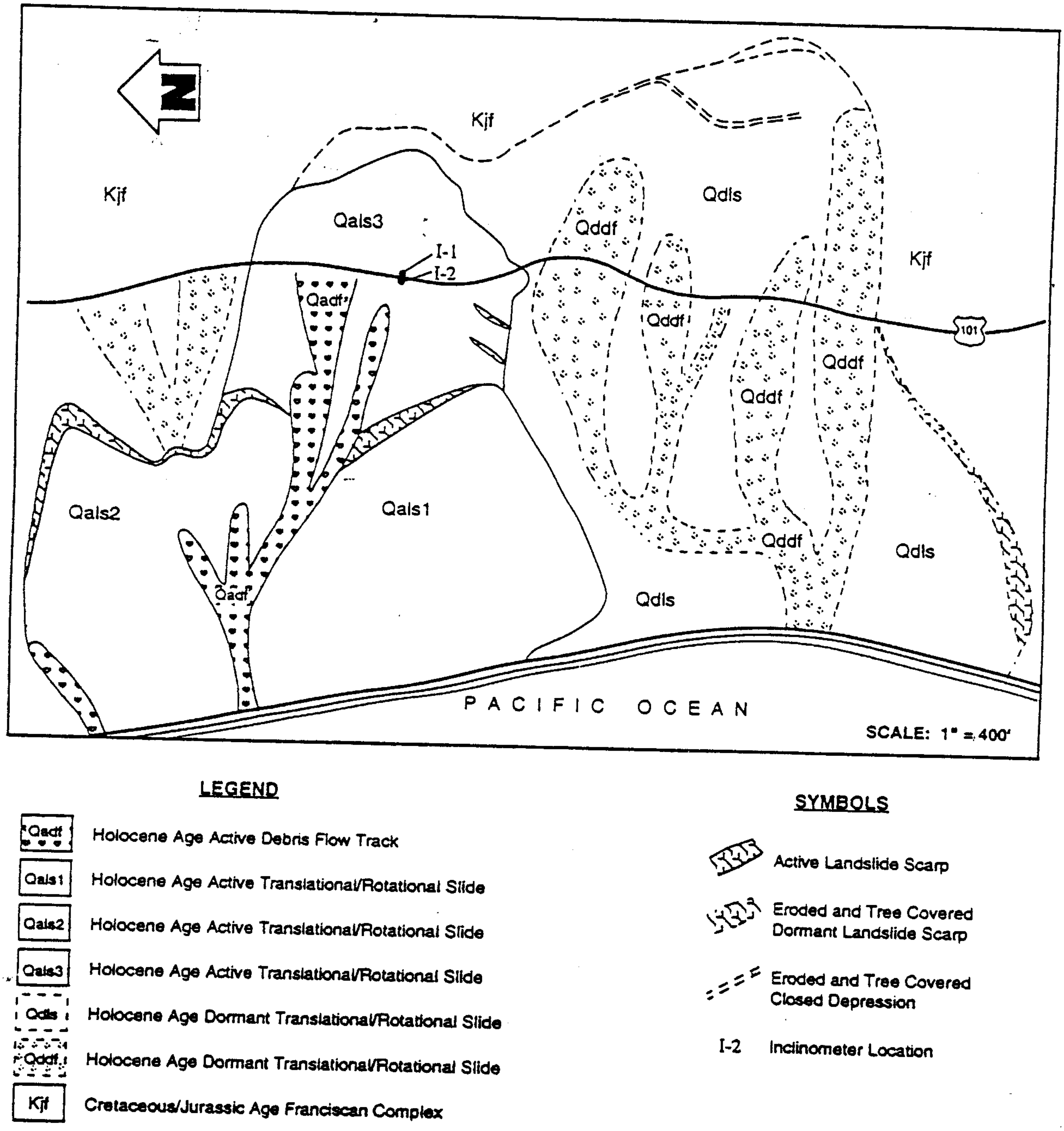

Figure 2 Geology of Last Chance Grade Landslide. I-1 and I-2 indicate slope inclinometer locations.

Two core borings were drilled into the center of the active slide, along the roadway, to obtain samples of the slide mass. Inclinometer casing was installed in the borings (I-1 and I-2 on Figure 2) to allow the determination of the depth to the slide plane. The coaxial cable for TDR measurements was installed in borehole I-2.

TIME DOMAIN REFLECTOMETRY

TDR is an electrical pulse testing technique where a cable tester, connected to a coaxial cable installed in a borehole, emits a stepped voltage pulse, Figure 3. Rock mass movements deform the cable, changing the cable capacitance and the reflected waveform of the voltage pulse. The time delay between a transmitted pulse and the reflection from a cable deformity determines the damage location. The sign, length, and amplitude of the reflected pulse defines the type and severity of the cable deformation (Dowding, et al., 1989).

The cable tester can be connected to a datalogger which records and stores reflections. The datalogger controls the cable tester and supplies power during measurements. The data then can be collected by computer automatically from a remote location using telecommunications

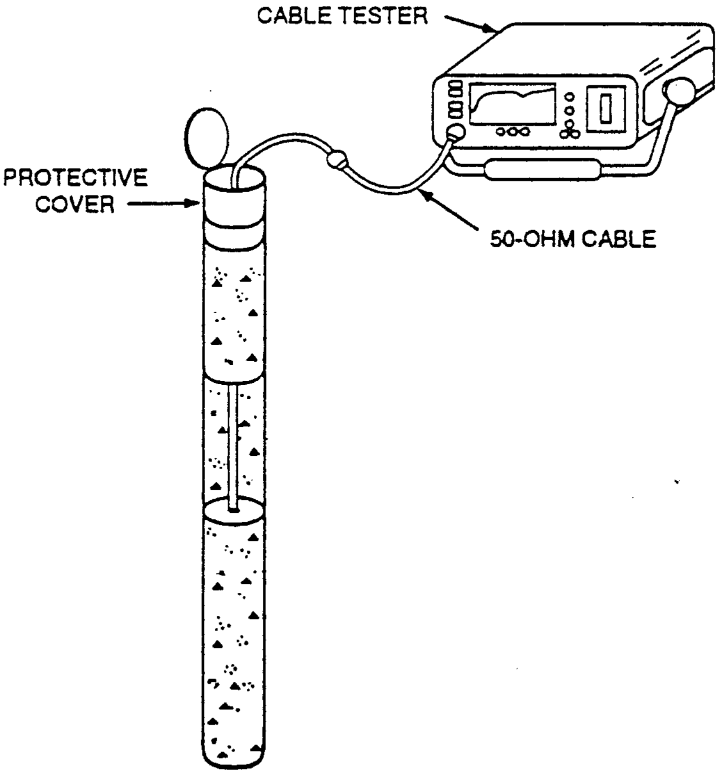

Figure 3 TDR installed in borehole (Dowding and Huang, 1994).

such as a phone or radio as shown in Figure 4 (Dowding and Huang, 1994).

The data consists of a series of TDR signatures. Different wave reflections are received for different cable deformations. The length and amplitude of the reflection indicates the severity of the damage. A cable in shear reflects a voltage spike which increases in direct proportion to shear deformation. A distinct spike occurs just before failure. After failure, a permanent reflection is recorded. In tension, the wave reflection is a subtle, trough-like voltage signal that increases in length as the cable is deformed. At failure a small necking trough is visible, which is distinguishable from a shear failure (Dowding, et al., 1989).

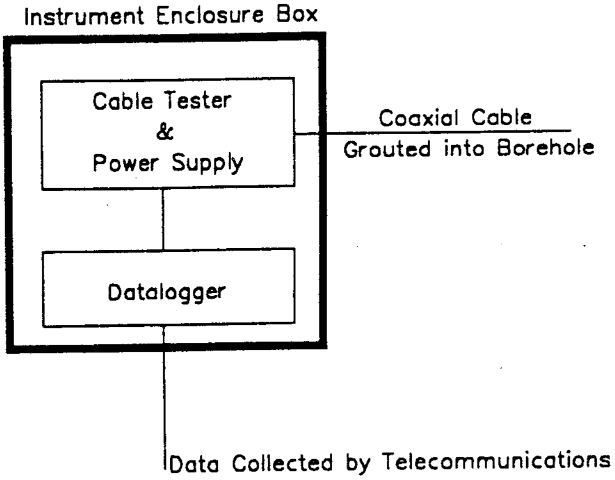

Figure 4 Schematic of a TDR installation.

By using the wave reflection data, rock mass movement can be monitored. As the amplitude of the wave reflection increases, zones of possible failure can be predicted.

TDR INSTALLATION AND RESULTS

A coaxial cable, RG 59, commonly used for videocassette recording, was attached to the outside, upslope side, of an inclinometer casing with nylon ties spaced approximately every 1.5 m (5 ft). The cable was installed in inclinometer hole I-2, 82 m (270 ft) of cable were used. The hole was backfilled with coarse aquarium sand, and a tremie pipe was used to flood the hole and compact the sand. A groove was cut in the asphaltic concrete overlay and extended beneath a K-rail barrier. The cable was laid in the groove and a BNC screw cable connector was attached to the end. The cable and connector were run beneath the K-rail, safely away from traffic, and placed in a plastic bag for moisture protection. The groove and the top of the inclinometer hole were backfilled with cold patch. An initial reading was taken on the cable, Figure 5. Four days later an initial inclinometer reading was performed, Figure 5. Twenty-eight days after inclinometer installation, an offset of about 23 mm (0.9 in) occurred at a depth of approximately 38 m (125 ft) in the N78W direction. Movement of the slide continued. Sixty-six to seventy days after installation, the casing moved upward 102 mm (4 in) relative to the road surface, leaving the inclinometer casing protruding. The top of the casing was cut off to allow for the smooth flow of traffic and the inclinometer data was reinitialized, beginning 74 days after installation. The inclinometer readings, therefore, indicated that the slide plane was approximately 40 m (132 ft) below the roadway at the center of the slide, Figure 6.

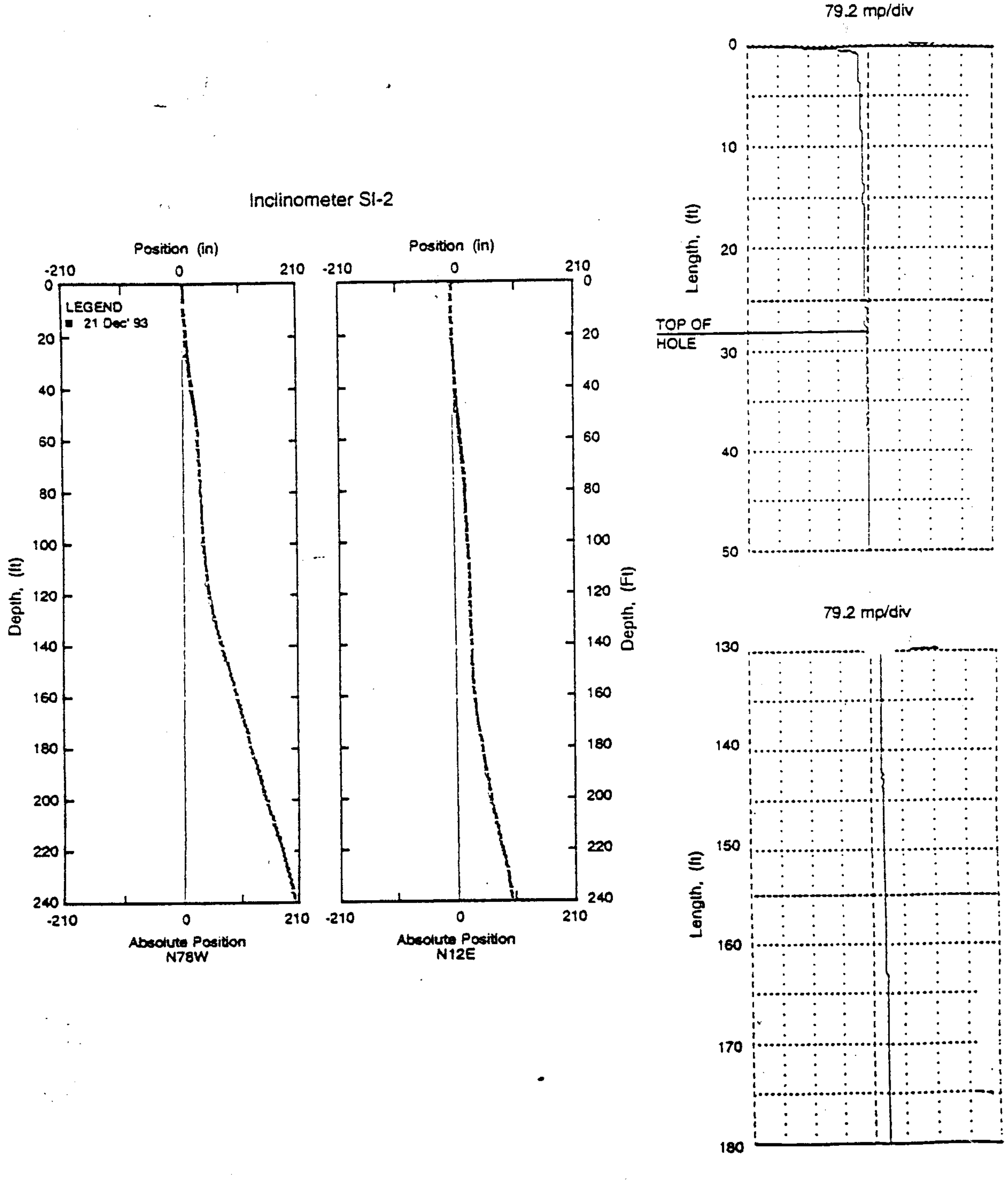

Figure 5 Comparison of initial inclinometer (I-2) and TDR readings (0 to 50 ft and 130 to 180 ft).

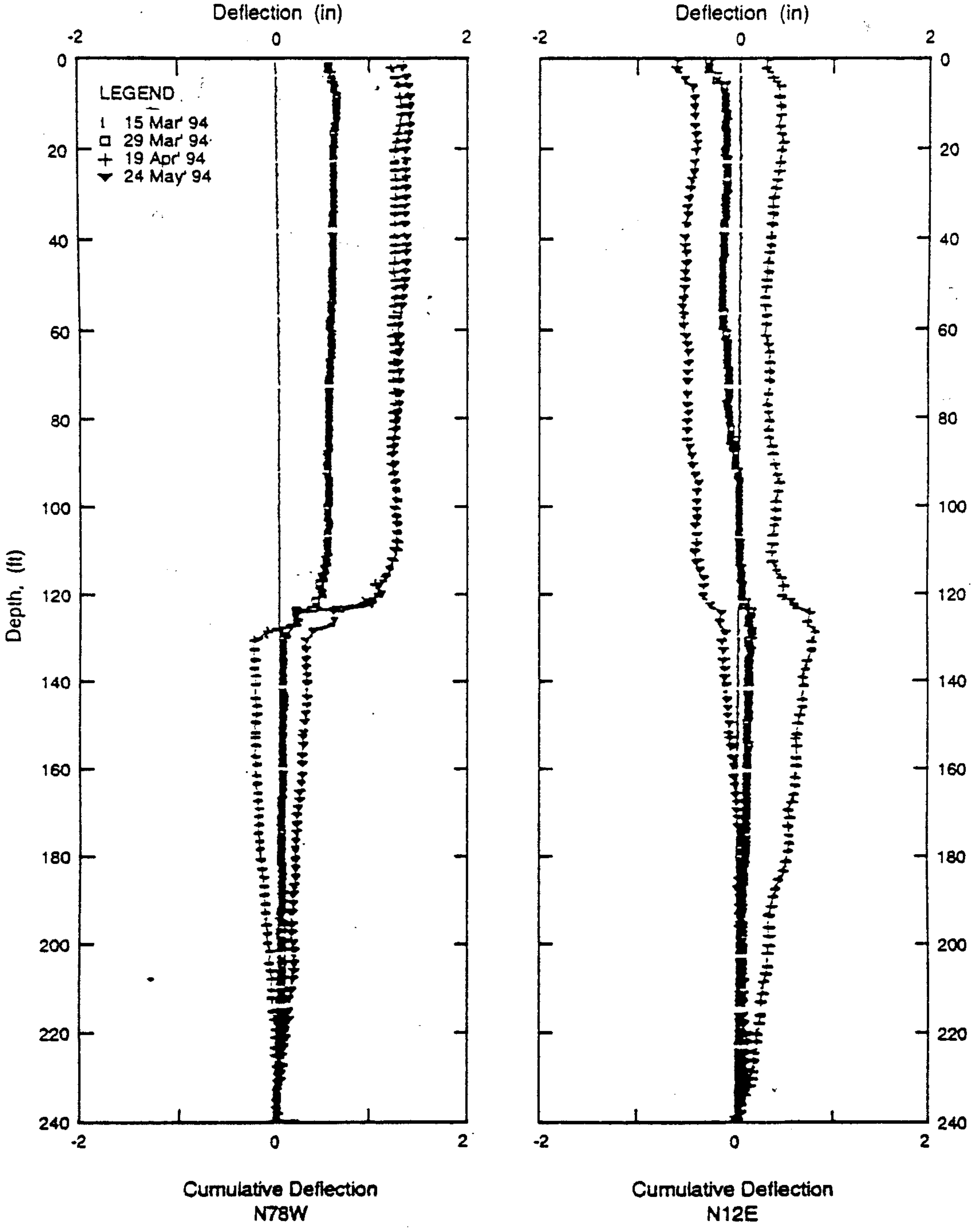

Figure 6 Output from inclinometer I-2 indicating slide plane at about 40 m (132 ft).

The TDR cable was read 148 days after its installation. The reading, Figure 7, showed two notable spikes. One spike, at 8.6 m (28 ft) indicated a crimp in the cable, probably where the cold patch squeezed the cable against the lip of the casing where it was bent to go down the hole. At a depth of approximately 40 m (132 ft), roughly the same depth as the inclinometer deflections, a trough in the signature was visible. The interpretation of this reading was that it indicated distress of the cable at the slide plane.

In order to read the inclinometer, it was necessary to implement traffic control for the safety of personnel. The TDR cable was read from behind the K-rail. No traffic control was necessary and personnel were protected from vehicular traffic.

CONCLUSIONS

Initial results of this study indicated that TDR may be used instead of inclinometers for landslide monitoring in some situations. A correlation between TDR signature and slide plane, as indicated by the slope inclinometer, appeared to exist. Reading data from the TDR cable was accomplished by safely standing behind the K-rail barrier.

The technology exists to remotely access the TDR installation. Caltrans, the University of the Pacific, and Neil O. Anderson and Associates are in the process of installing such a system at the Last Chance Grade. The advantages of such a system will be:

- No need to physically visit the site and, therefore, no traffic control is necessary
- No need to clean debris from the inclinometer casing before taking measurements
- Readily available, inexpensive cable
- Ability to monitor up to 512 holes with one tester and multiplexer hook-up

If successful, this will result in a cost savings to Caltrans in person-years (PY), possibly up to 6 PY's per year. Remote data collection also means that hazardous areas can be closely monitored by frequent sampling to determine incipient movements. Another application of this technology could be as part of an early warning system to alert highway officials of a possible catastrophic failure.

ACKNOWLEDGMENTS

The authors thank Dr. Kevin O'Connor, U.S. Bureau of Mines Twin Cities Research Center, Minneapolis, MN for technical support. Mr. Ken Cole, Office of New Technology, Materials, and Research, California Department of Transportation, Sacramento, California, supplied much encouragement for the project.

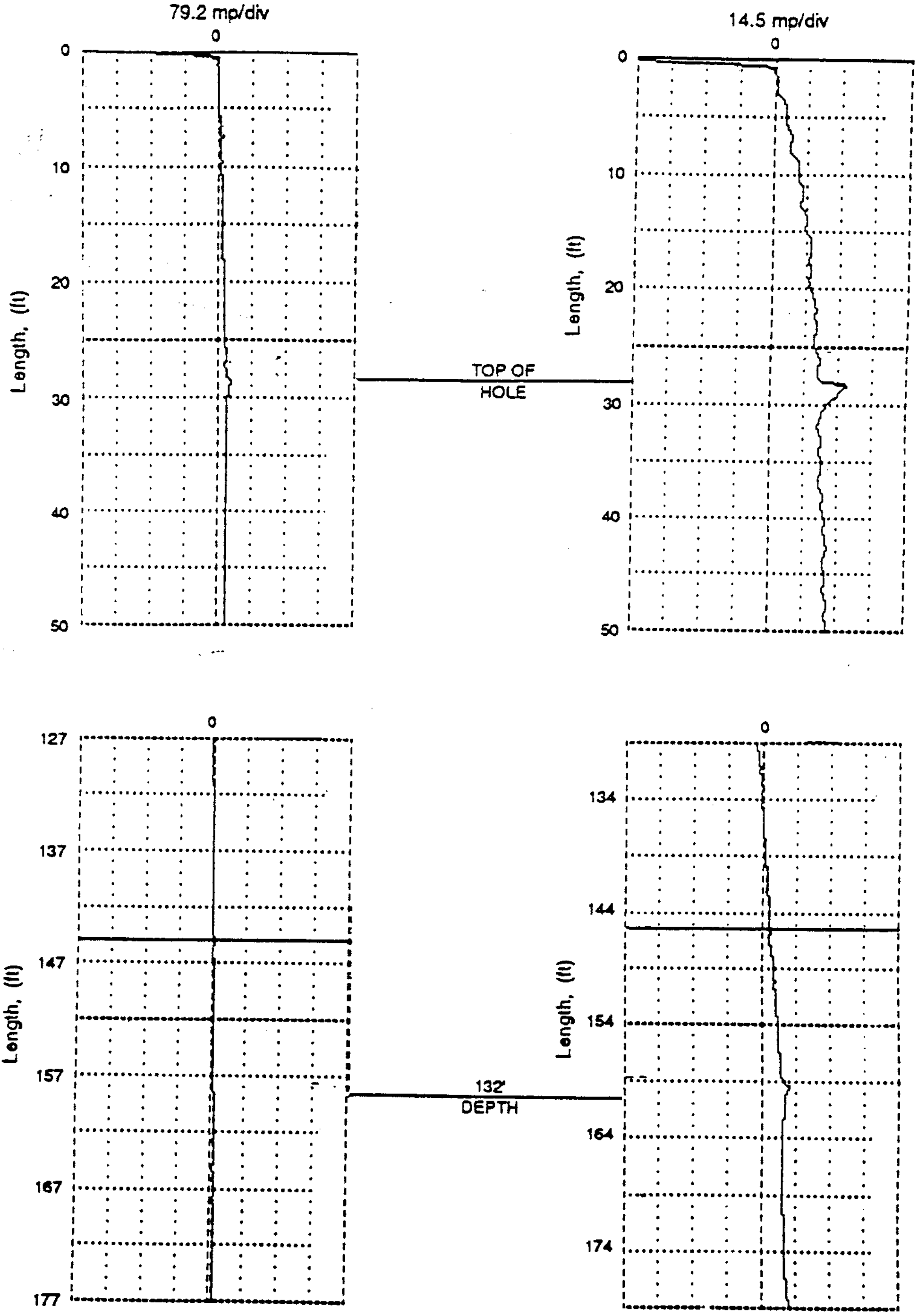

Figure 7 TDR output 148 days after installation. Note spikes where cable enters inclinometer hole and in vicinity of slide plane.

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