The Ohio Department of Transportation
Office of Research & Development
Executive Summary Report

Inclinometer – Time Domain Reflectometry Comparative Study

Start date: February 8, 2002

Duration: 28 months

Completion Date: June 18, 2004

Report Date: October 2004

State Job Number: 14798(0)

Report Number: FHWA/OH-2004/010

Funding: $80,732

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Problem:
Slope stability is an ongoing issue in hilly or mountainous terrains with clay rich soil, constructed embankments, fluctuating temperature, and changing soil moisture conditions. Landslides constitute a major geologic hazard, occurring in all 50 states. Accurately determining the shear plane depth in a landslide is needed to devise an effective remediation plan.

Slope inclinometer probing, the current method for slope movement analysis, is costly to install and monitor, and it becomes ineffective in measuring large lateral deflections. An economical alternative to monitor slopes is electrical Time Domain Reflectometry (TDR). The cables used to implement TDR in slope studies are inexpensive, simple to install, and provide long-term monitoring of slope movement. Measurements take only seconds, a vast contrast to the traditional time intensive 'cable pull' process of inclinometer probing.

Objectives:
The main objective of this research was to complete a side-by-side comparison of TDR and slope inclinometer probing to identify shear planes. In addition to comparing the two methodologies on the technical basis of accuracy and dependability, other objectives for this

study included a comparison on the basis of cost and relative ease of installation and data collection.

Four pairs of Time Domain Reflectometry (TDR) cables and slope inclinometer casings are installed side by side at two test sites in Meigs County selected for their ongoing soil movement. SR 124 and SR 338 are two-lane asphalt pavement roads that run parallel to the Ohio River.

Description:

The TDR slope inclinometer borings were located on the shoulder of the road. A TDR cable and its corresponding inclinometer casing were close enough to be comparable but far enough so that installing the second instrument would not disturb the first.

The inclinometer casings selected for this research were PVC RST glue and snap casings. The TDR cables were Belden Precision Video Type NG-59/u coaxial cable. The TDR cable was scaled and terminated and cut to a length of 70 feet (21.3 meters).

The borings were drilled 10 feet (3.3 meters) into the bedrock to allow the inclinometer casings and TDR cables to be anchored into the bedrock.

Results:

On SR 124, an initial deformation of the TDR cable occurred at 42 feet (12.8 meters) followed by a shear at 31 feet (9.4 meters) which caused water leakage and prevented further monitoring below that depth. The inclinometer registered a shear plane and was deformed beyond use at 30 feet (9.1 meters), where there is an interface between two soil layers. At the second location at SR124, the TDR cable was deformed at 41 feet (12.5 meters) and the inclinometer detected a shear plane at 40 feet (12.2 meters), at the interface of weak and strong layers of gray siltstone.

On SR 338, at one hole, the TDR cable showed deformation at 16 feet (4.9 meters) and cable shear at 31.8 feet (11.6 meters) where water leaked into the cable, affecting readings. The inclinometer also showed a shear plane at 16 feet (4.9 meters), which is at the interface of a red silt and a clay layer. The other site on SR 338 showed TDR cable deformities at 18 feet. The inclinometer also detected shearing at 18 feet (5.5 meters) before the casing failed completely at 17 feet (5.2 meters), again at the interface between two layers of soil.

Conclusions and Recommendations:

During the sixteen months of monthly monitoring, the TDR cables and inclinometers detected the shear planes at nearly the same depth at all test locations. The depth of movement detected for the two methods was within one foot (0.3 meter) for all test sites. Although the TDR system cannot provide exact rate of movement, the TDR system can be more economical than slope inclinometer probing for basic identification of shear plane depth in slope movement analysis installations.

The coaxial cable for the TDR method costs less than inclinometer casing. TDR readings take less than a minute and can be easily automated and read remotely. Multiplexing cables in automated remote reading setups allows for analysis of many TDR cables at one site. This is a significant reduction in the time required for data acquisition since the crew does not have to travel to the site to take readings. Additionally, TDR cables can be extended to a convenient or safer location away from the boring and slope movement can be determined immediately during data collection rather than waiting for data analysis in the office.

Identifying the location of shear planes with TDR cables is relatively straightforward, however, the amount of movement cannot be accurately determined from a TDR signature at this time. Also, damage to the protective coating of the cable can allow water intrusion, which changes the electrical properties of the cable and makes traces difficult to interpret.

It is recommended to use smaller diameter auger bits for TDR cable installation, preferably under 3 inches (7.6 centimeters). The 6 ¼ inch (15.9 centimeter) bits were oversized for the small 0.2 inch (5.1 mm) diameter coaxial cables. Additionally, ensuring the top-of-hole cable connectors are not submerged will increase the life span of the cable. Finally, combining the TDR cables with Cone Penetration Testing (CPT) would be an efficient method to obtain in-situ soil parameters.

Further research should be conducted to develop a more independent technique for detecting slope failure — one less dependent on sampling intervals or time differences. Also, alternatives to drilling for inserting TDR cables can be explored, such as direct push technology.

Implementation Potential:

Districts could take the technology and develop a more comprehensive monitoring system of all sensitive zones with potential for slip using TDR systems instead of inclinometers. These areas could then be monitored with wireless technology. Each district will determine how to implement TDR technology to best serve their specific needs.

Cost savings can be realized by multiplexing several cables at one site onto one set of data collection equipment, or by implementing remote data monitoring that eliminates or reduces costly site trips.