Geotechnical Sensing by TDR: A Slope Monitoring System Example

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ABSTRACT

Up-hole time domain reflectometry (TDR) devices that interrogate passive mechanical transducers are advantageous for engineering monitoring in situ. This technology 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 “sense” various engineering parameters. When embedded in a geotechnical structure, TDR can be seen as a “geo-nerve” system. New design concepts and data reduction procedures for each type of sensing waveguide are introduced in this article. The versatility and merits of TDR are highlighted by a TDR slope monitoring system example composed of a single TDR device and multiple sensing waveguides.

KEY WORDS: Time Domain Reflectometry (TDR); slope monitoring

INTRODUCTION

Time domain reflectometry (TDR) is a principle of measurement based on a cable radar (formally called time domain reflectometer) and sensing waveguides. The cable radar transmits an electromagnetic pulse through a coaxial cable connected to a sensing waveguide and watches for reflections of this transmission due to changes in characteristic impedance along the waveguide. It was originally developed for detection of cable faults and later applied to dielectric spectroscopy in physical chemistry. In the past two decades, TDR technology has been adapted to geotechnical applications. A basic overview of TDR technique can be found in a book by O’Connor and Dowding (1999). This article introduces some further developments that improve the understanding and extend 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 “sense” various engineering parameters. When embedded in a geotechnical structure, TDR can be seen as a “geo-nerve” system. In particular, an example of an integrated TDR monitoring system composed of a single TDR device and multiple sensing waveguides are given in the context of slope monitoring.

TDR AND TDR MONITORING SYSTEM

A TDR installation is composed of a TDR pulser-receiver (i.e. cable radar), a transmission line and a sensing waveguide (see Figure 1). The pulse generator sends an electromagnetic pulse along the lead cable and the sensing waveguide directs the electromagnetic 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 up-hole 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 2 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 precious for stability analysis and understanding of the process dynamics. TDR waveguides for engineering applications can be grouped into three categories according to their measuring principles. These three types of sensing waveguides are introduced in following sections.

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 3a) for laboratory samples or a multi-rod waveguide (Figure 3b) to be inserted into soils in situ. The electromagnetic pulse is