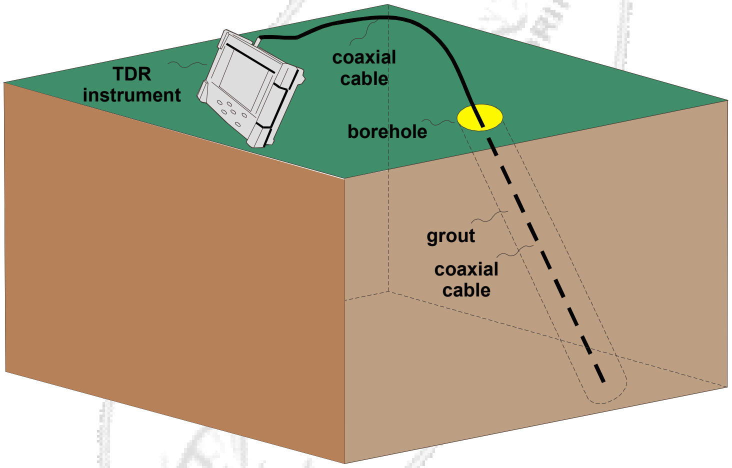
BASIC GEOTECHNICAL TIME DOMAIN REFLECTOMETRY (TDR) PRIMER

TDR is based on transmitting a pulse of energy as a waveform within a medium and watching for reflections of this transmission. As the velocity of propagation is known within a medium, the distance to the disturbance can be calculated.

The most familiar form of TDR is that of radar. Radio waves are transmitted in a predetermined direction at a specific frequency. Any object that interferes with this signal will cause reflections, with all, or part of the energy being reflected to the source. The arrival time and characteristics of these reflections are measured by sensitive detectors, allowing determination of the distance to the object.

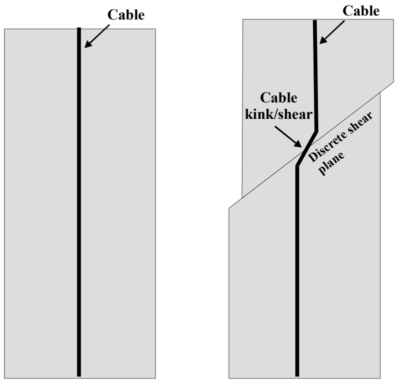
Geotechnical TDR is generally applied to coaxial cables inserted, and grouted, into a drillhole. The properties of the grout, and cable, are determined by geotechnical conditions, expected failure modes, and required results.

GEOTECHNICAL TDR CABLE - AS INSTALLED



As the ground displaces, the installed cable is sheared or displaced. This causes a change in the material properties of the cable. This change in properties is detectable, as noted above, and allows us to locate the actual area of dislocation.

TDR CABLE DISLOCATION



BEFORE SHEAR

AFTER SHEAR

TDR Function

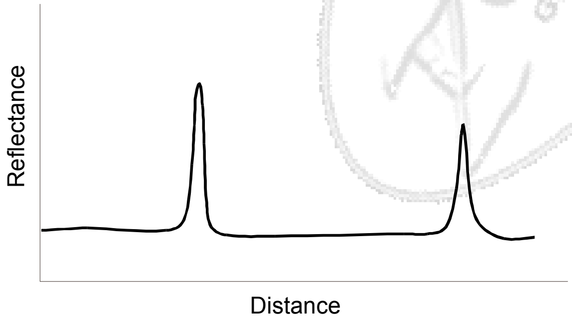
In order to describe the cable trace, we must first go back and lay the groundwork with some elementary descriptions of how a coaxial cable functions.

Coaxial cable is composed of an outer and inner conductor, separated by a dielectric material. This dielectric material is traditionally air, foam polymer, or solid polymer. When a voltage pulse is applied to the cable, a current is generated between these two conductors. The rate of propagation of this pulse, and the characteristics of propagation, are a function of the dielectric material properties and the distance between the inner and outer conductor. Resistance is also present in the cable, causing some line loss, as well as other factors. These are generally summarized in a single value as the cable's operating impedance at a fixed frequency.

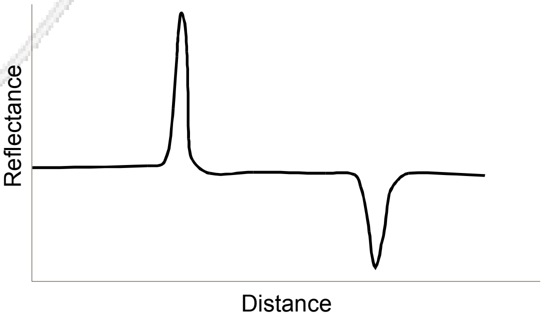
If the cable remains undeformed, and unaltered, along its length, then the characteristic impedance remains unaltered. As no changes in material properties are encountered along the cable, a transmitted pulse will not be reflected.

On the other hand, if a change in the cable properties is encountered, some energy is reflected as the waveform must change to pass through this area of difference. This reflected energy has been traditionally quantified in TDR work as "reflectance" and is measured as the ratio of transmitted voltage to the reflected, or return, voltage.

For coaxial TDR, the arrival time and pulse characteristics are generally displayed as a "trace" on a display screen (CRT, LCD, etc.). The general form of the trace is that of distance along the X, or horizontal axis, and "reflectance" on the Y, or vertical, axis. This trace may be either analog or digital, depending on the nature of the test apparatus.



Dead open TDR trace



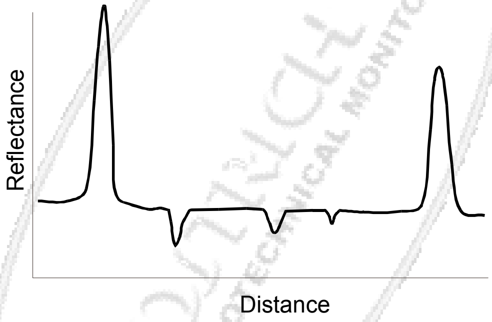
Dead short TDR trace

Operating constraints and conditions

There are a variety of operating constraints and conditions that control the sensitivity and shape of the cable trace. For example:

- Pulse width – the wavelength of the pulse that is launched into the cable is generally controllable. The shorter the pulse, and the faster the "rise time" or the time required by the pulse generator to reach maximum voltage, the greater the accuracy in terms of locating actual position of the cable fault. However, the drawback to this is that the shorter the wavelength, the greater the attenuation within the cable. Thus, one cannot "see" as far down cable with a short wavelength as compared to a longer one. At times, the loss in accuracy is more than compensated for by the increased voltage transmitted downline.

- Energy loss/pulse modification – as the transmitted pulse travels down the cable, especially as it encounters faults, its characteristics change. Energy is lost as it is reflected back to the source. This results in a lesser amount of energy being reflected from any faults further down line. In addition, the pulse itself changes, causing a change in both transmission and accuracy characteristics. Remember that if, for example, two faults are found on a cable, that the pulse energy received by the second fault will be reduced by the energy reflected by the first fault. In addition, the first fault will impede (reflect) some of the reflected energy from the second fault down cable as the reflected pulse attempts to return to the detector. Multiple faults reduce accuracy and impede detection downline. In geotechnical work it is common to "crimp" or induce a cable fault for location and calibration purposes. Each crimp changes the cable characteristics and reduces accuracy.

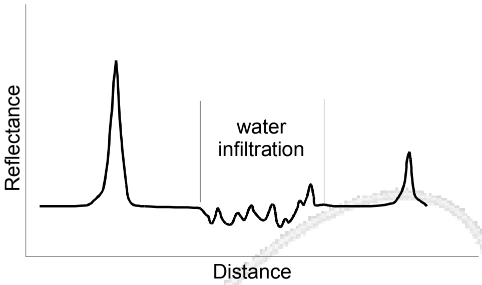


Attenuated TDR - identical events

- Dead zone – when a fault is encountered downline, a "dead zone" is created immediately down cable from the encountered fault. This is a function of the pulse width, the encountered fault, and the instrument receiver. In most cases, in geotechnical TDR work, this is not significant. However, faults may be masked within this zone.

- Cable squeeze – in geotechnical work, it is common to grout the cable in a borehole. If the outer conductor is rigid, such as solid aluminum or corrugated copper, this has little, if any, effect on the thickness of the dielectric. However, if a braided outer conductor is utilized together with a foam dielectric in such a situation, the foam compresses as a function of depth down hole. Thus, the characteristic impedance changes as a function of depth, as should the propagation velocity of the cable. This results in variations in results which may be difficult to explain, as well an increase in signal attenuation with depth.

- Water leakage – water can, and will, leak into a coaxial cable. As this changes the dielectric constant of the cable, it impacts on the received trace. This is likely most significant for the solid outer conductor cables as the solid outer conductor functions somewhat as a hoop supported rigid tube. If water leaks inside, then the foam that is generally utilized as the dielectric is compressed and the “hoop” or outer conductor, remains undeformed. The bond strength of the foam to the outer conductor is generally insufficient to retard this foam shrinkage allowing water to propagate up and down cable. For braided outer conductors and solid dielectrics this is less significant as the braid will somewhat conform to the dielectric as it compresses. For solid dielectrics, no compression is expected and water must pass through interstices in the braid and under the jacket that remain as a function of the manufacturing process.



Water infiltration effect on TDR trace