Feasibility of Using Cone Penetrometer Truck (CPT) to Install Time Domain Reflectometry (TDR) and Fiber Optic Slope Failure Detectors in Pavement Structures

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ABSTRACT

A new method of cable installation using a heavy-duty Cone Penetration Test (CPT) truck was developed and practiced successfully in this study. The coaxial and fiber optic cables were pushed along with the cone rods by the hydraulic system integrated with the CPT truck. A disposable tip—unable to carry tension along the axes of the rods—for the cone rods was designed and built to stay at the desired depth of installation holding the cables after the cone rods are pulled out.

ACKNOWLEDGMENTS

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CHAPTER 1: INTRODUCTION

The monitoring of earthen or soft rock slopes is one of the tasks civil engineers are expected to accomplish. Sloped land areas such as natural slopes, excavated slopes, and compacted road embankments may experience unstable soil conditions leading to landslide or slope failure. Integrating a proper monitoring system into the slope to determine the depth of failure plane, known as shear plane, in early stages of movement is essential to stabilize the slope and control the slope failure.

1.1. Unstable Soil Conditions

Sloped land areas fail due to the unstable soil conditions they may face. McCarthy (2007) explains that the unstable soil condition can be caused by either natural or human-made events. Natural events include earthquake, collapse of underground caverns, occurrence of seepage force due to changes in the elevation of the water table, subsurface damage caused by groundwater flow or chemical reactions, and slope weakening caused by water intrusion through cracks developed by potential shrinkage and tension. Excessive loading on the surface of the slope or close to its crest and removal of materials from the slope surface or its toe, that make the slope unstable, can be counted as man-made events that cause slope failures.

Since the slope surface makes an angle with the horizontal, the weight of the unstable soil mass, W, can be resolved into two components: one acting perpendicular to the slip surface, N_a; and the other acting tangential to the slip surface, S_a, which are illustrated in Figure 1.1. The perpendicular component of the gravity, N_a, helps the soil mass to retain in its position, while the tangential component of the gravity, S_a, is forcing the soil mass to slide. R_a is the reaction from the ground against the soil mass weight which can be resolved into two components N_r and S_r.

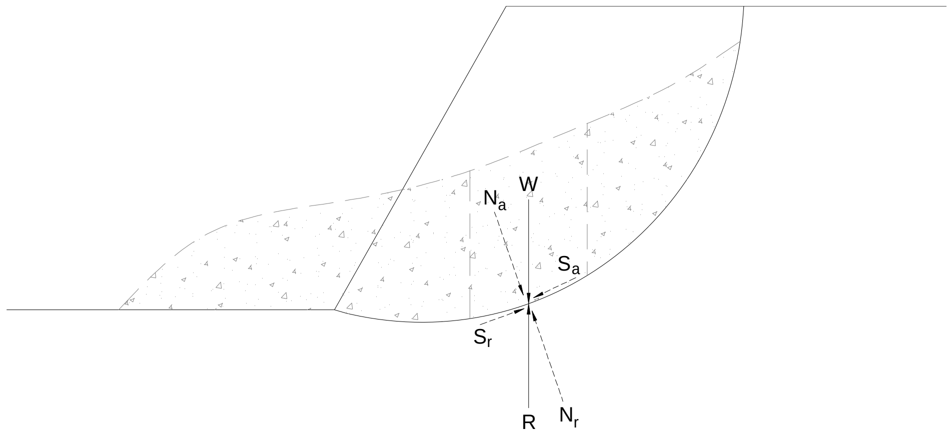

Figure 1.1. Typical slope failure.

As the tangential component of the gravity, S_a, forces the soil mass to move down the slope, a shearing stress is being developed at the slip surface. The shear strength of soil acts as resistance against the shearing stress developed at the slip surface and counteracts the slope failure. Das (2005) describes the shear strength of a soil and states its role in soil stability problems:

> The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside it. Engineers must understand the nature of shearing resistance in order to analyze soil stability problems such as bearing capacity, slope stability, and lateral pressure on earth-retaining structures. (p. 205)

The slope will experience sliding when the shear stress developed at the slip surface exceeds the shear strength of the soil. Practical consideration are required to improve the stability of the slope at the primary stage before failure occurs, leading to negative impacts on the safety of people.

Kane and Beck in their work (1994) recommend three alternatives to stabilize an unstable roadway: Alternative one is to construct a tunnel that crosses below the slide plane; the second alternative is to support the materials below the roadway by a soldier pile and a tieback wall, and stabilize the top materials with rows of slope stressing; the third option then is to excavate the slip area and realign the highway behind the failure plane.

In order to use a proper procedure of slope stabilization at the primary stage of slope failure, it is necessary to determine the location and depth of the failure plane—known as shear plane. There are two commonly used methods to detect earthen slope movements: electrical Time Domain Reflectometry (TDR) and Inclinometer. Also, a third method, Optical Time Domain Reflectometry (OTDR), has been practiced and introduced in this particular research.

1.2. Conventional Methods of Monitoring Slope Stability Problems

As briefly explained in the previous section, there are two conventional methods for monitoring of earthen and soft rock slopes movements—whether natural slope, excavated slope, or compacted road embankment: electrical Time Domain Reflectometry (TDR) and Inclinometer. Both methods have their own advantages and disadvantages, which will be briefly explained in the following section.

1.2.1. Electrical Time Domain Reflectometry (TDR) Method

The method of Time Domain Reflectometry (TDR) uses coaxial cables and a cable tester for determining the depth to the shear plane (Kane, 2000). Figure 1.2 shows a section of coaxial cable. TDR is an easy to use and relatively economical method; the measurement can be performed in a few minutes. One of the disadvantages of the TDR technology is its susceptibility to water intrusion, which will considerably alter the results (Sargent, 2004). The results of the TDR method were shown to be equivalent to those of the traditional inclinometer method in a previous report (Sargand, Sargent, and Farington, 2004).

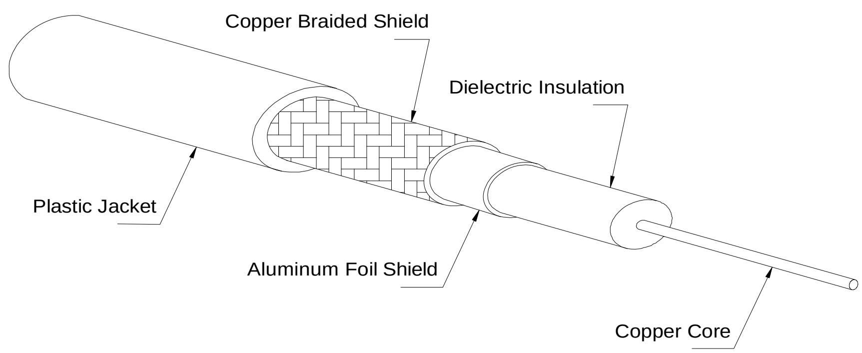

Figure 1.2. Typical section of a coaxial cable.

1.2.2. Inclinometer Method

The Inclinometers are conventionally used to monitor slope stability and embankment problems. The most common type of inclinometers used in geotechnical practices for monitoring slope stability is a traversing probe, which is installed in a casing to record casing deformation and to plot the casing profile over a course of time (Machan & Bennett, 2008). The main components of an inclinometer system consist of slotted pipe casing, inclinometer probe with a control cable, and an inclinometer readout unit. The inclinometer probe is composed of a stainless steel main body, a connector for control cable, two pairs of rolling wheel assembly (Durham Geo Slope Indicator [DGSI], 2006). Figure 1.3 shows an inclinometer probe with its components. The inclinometer probe is manually inserted in the inclinometer casing which is placed in a vertical borehole drilled or the location of study.

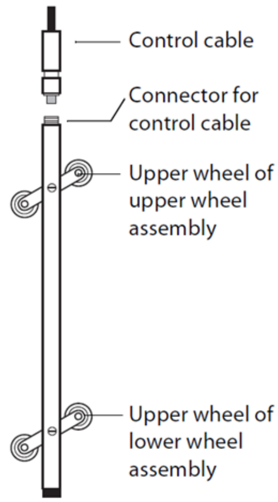

Figure 1.3. Inclinometer probe (DGSI, 2006).

1.3. Optical Time Domain Reflectometry (OTDR) Method

In recent years there has been an increasing adoption of fiber optic technology in civil engineering practices. Fiber optic cable is glass or plastic transmission medium that is used to transfer information from one point to another by means of light signals (Sterling, 1993). The main components of single-mode fiber optic cables consist of: a core, the light carrying part; a buffer, the plastic coating applied to the fiber; strength members, added threads that cover the plastic coating to add mechanical strength to the cable; and a jacket, that protects the fiber from damage. Figure1.4 shows a section of single-mode fiber optic cable.

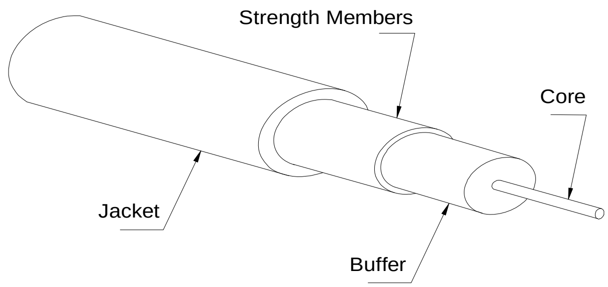

Figure 1.4. Typical section of single-mode fiber optic cable.

Optical Time Domain Reflectometry (OTDR) is used for variety of purposes in research and industry. In this particular research, OTDR is utilized to detect subsurface movement of soil or to locate the share planes by determining fault locations in fiber optic cables that are pushed in earthen slopes or highway embankments. The principle of OTDR is similar to that of electrical Time Domain Reflectometry (TDR)—a light pulse is sent through a fiber optic cable that will be reflected from a damaged or break point; whereas in electrical TDR, an electrical pulse is sent through a coaxial cable that will be reflected from a damaged or break point.

1.4. Research Objectives

The objectives of this research consist of demonstrating a new procedure for installation of fiber optic and/or coaxial cables in earthen slopes or road embankments to monitor slope stability problems. This new procedure involves using a truck-mounted cone penetration test apparatus with a special disposable tip to insert the cables at the test site.

CHAPTER 2: SITE DESCRIPTION AND EXPERIMENTAL SETUP

This chapter presents an overview of the test site; a discussion of the preparation of electrical TDR and fiber optic instrumentation; a review of the equipment used to install the instrumentation; and a description of a new method of cable installation in earthen slopes.

2.1. Site Description

A section of the State Route 690 (SR 690) that was suspected of having slope movements was selected by the Ohio Department of Transportation (ODOT) to be investigated by Ohio University. The SR 690 is located in ODOT District 10 in southeast Ohio, 7.8 miles to the east of the city of Athens. The highway crosses some of the hills in Wayne National forest and connects US Route 50 and SR 55. In Figure 2.1 the star marks the approximate location of the SR 690. Figure 2.2 shows the corridor of SR 690; the star mark at 4.6 miles northbound indicates location of the study.

Figure 2.1. Approximate location of SR 690 in ODOT District 10, southeast Ohio (Retrieved from ODOT District Map.).

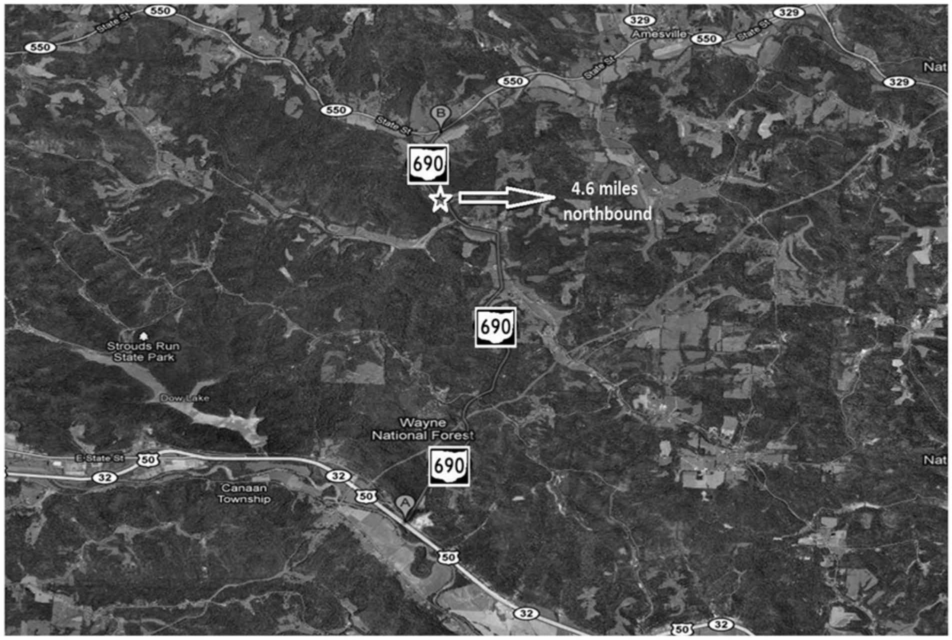

Figure 2.2. The SR 690 corridor (Retrieved from Google maps).

The highway has two lanes, one lane in each direction, with a total width of 22 ft—11 ft each lane with no shoulder. Figure 2.3 illustrates a typical cross section of the SR 690. Although several sections of the highway are stabilized by constructing soldier piles and steel lagging, there have been sections that experienced slope movement that caused the pavement to crack severely. Land slide signs have been placed on the roadside to warn traffic entering the zone.

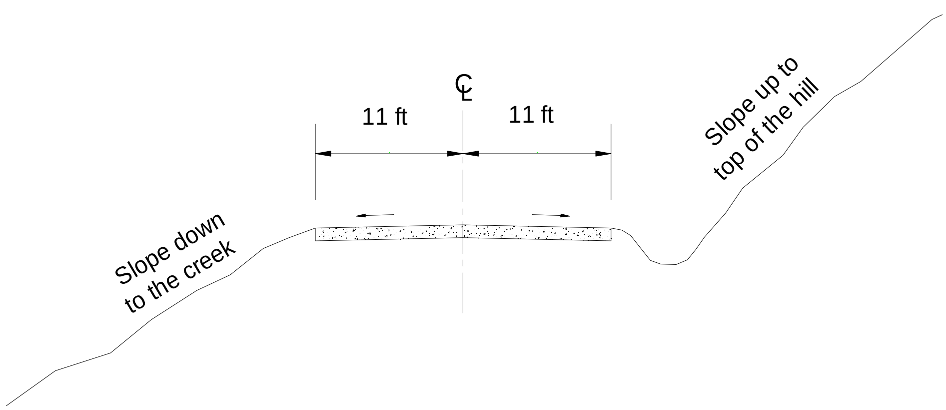

Figure 2.3. Typical cross section of the SR 690 at the test site.

The test section of SR 690 was selected because it appeared to have experienced slope movement. The test site was close to the bottom of a hill at the beginning of a horizontal curve at mile marker 4.6 northbound on SR 690. The highway is paved with asphalt concrete. After the team from ODOT and Ohio University visited the site in April 2010, they reported that the zone had severe cracks and deformations on the surface of the asphalt pavement that could be sensed through simple visual inspection. Figure 2.4 shows a picture of the cracked pavement section of the SR 690 which was believed to be affected. The total length of the section that cracked and deformed was around 100 ft; the crack started from edge of the asphalt pavement, on the southbound, all the way to the centerline. It was decided that two pairs of coaxial and fiber optic cables to be installed in two spots, ATH 690-1 and ATH 690-2, within the suspected area of slope movement. Each spot was located 4 ft inside from the edge of the pavement on southbound lane, and 55.5 ft apart from each other.

Figure 2.4. Pavement crack on SR 690 at 4.6 miles northbound.

2.2. Instrumentation

The instrumentation was prepared and tested in the lab prior to installaton at the test site. In order to accurately determine the location of the shear plane, two pairs of coaxial and fiber optic cables were installed side by side in the zone of suspected movement. A new procedure of installallation for coaxial and fiber optic cables—which is different from that of the traditional drilling borehole method—was developed and practiced successfully in this research. The equipment used to accomplish the installation, provided by ORITE, and the installition procedure are explaineed in section 3.2.3.

2.2.1. Preparation of Electrical TDR Instrumentation

Based on the literature related to the subject, an RG-59/U coaxial cable with copper core conductor, solid foam polyethylene dielectric insulation, copper braided shield, and PVC outer jacket was selected. Table 3.1 gives a summary of the specification for this coaxial cable. The cables were checked in the laboratory and electrical tape was used to mark the cables every 5 ft to easily control the depth during installation. The top ends of the cables were stripped to a total length of 0.630 inch to accommodate the 75NBC type connector attached, as recommended in Switchcraft product manual.

Table 2.1. Specification of Video Type RG-59/U Coaxial Cable

Video type coaxial cable	Specification
RG type	59/U
Impedance	75
Velocity of propagation	0.66 c
Shielding	Copper braid
AWG	22
Stranding	Solid
Core diameter (inch)	0.146
Jacket diameter (inch)	0.242
Applications	CA Prop 65, MIL-JAN-C-17A/RG-59/U, UL AWM 1354 60 C 30V
Part#	9830

The bottom ends of the cables were capped using TC4005 caps to prevent water intrusion to the system and avoid alteration of the result. A heat gun was used during the cap fitting in the lab—TC caps are designed to shrink as they are exposed to heat.

2.2.2. Preparation of Fiber Optic Instrumentation

Since Krohn (1988) stated that single-mode fiber optic cables have greater sensitivity to wavelength changes than multi-mode fiber optic cables, single mode fiber optic cable was selected for this study. The fiber optic cable used was Simplex 9/125 SM with FC/UPC-SC/UPC (Fixed Connection/Ultra Physical Contact-Subscriber Connector/Ultra Physical Contact) connectors. Table 3.2 presents a summary of this cable.

Table 2.2. Specification of Simplex 9/125 SM Fiber Optic Cable

Fiber optic cable	Specification
Number of fibers	1 (simplex)
Fiber type	SMF 28E
Core/cladding size	9/125 µm
Attenuation (max)	1.29 dB/mile
Jacket material	PVC yellow
Strength members	Aramid yarn
Weight	22.5 lbs/mile
Pull load (install/operate)	200/160 lbs
Bend radius (install/operate)	1.14/0.75 inches
Storage temperature range	-40°F to 158°F
Operating temperature range	-4°F to 158°F
Cable type	Riser
Connector	FC/UPC-SC/UPC

One fiber optic cable was installed in each of the two spots at the test site, designated ATH 690-1 and ATH 690-2. The cables and connectors were checked in laboratory before installation. Electrical tape was used to mark the cables at every 5.0 ft as depth checking references during installation. The length of cable prepared to be installed at ATH 690-1 was 75.0 ft, whereas the length of the cable to be installed at ATH 690-2 was 82.0 ft. The fiber optic cables were supplied from Fiber Instrument Sales, Inc. The cables came with FC/UPC-SC/UPC connectors. The available optical connector in the Yokogawa AQ7275 OTDR system was FC, therefore the FC/UPC connectors were left in both cables, whereas the SC/UPC connectors were cut from the second ends of the cables—the ends which would be affixed to the disposable tip to be pushed with the con rods in the ground. No insulation or cap was put on this end of the fiber optic cable—as it was used in coaxial cables to prevent water intrusion. Since the depth of installation was unclear prior to installation, the cables were left long enough to avoid splicing and unnecessary splice reflections that could easily be mistaken for shearing reflection later on in the case of slope movements.

2.2.3. Grouting Materials

The grout mixture used was NS Grout which was produced by the Euclid Chemical Company. The NS Grout is a non-shrinking and non-metallic mixture of natural aggregate and an expansive cementitious binder. The grout is designed for uses where positive expansion and high strength are required, and it meets the performance requirements of both ASTM C-1107 and CRD C-621 Corps of Engineers Specification for Non-Shrink Grout. Based on the requirements given in Table 3.3, a fluid mix of the grout was prepared and pumped in the holes immediately after mixing.

Table 2.3. NS Grout Mixing Requirements

Consistency	Water content
Fluid	1.2 gal/50 lb bag
Flowable	1.0 gal/50 lb bag
Plastic	0.9 gal/50 lb bag

2.2.4 Installation Equipment and Procedure

A new procedure for installation of electrical TDR and OTDR cables was developed and utilized in this research. The new procedure is economical, fast, and easy to implement in comparison to the convential drilling borehole method used for installation of the electrical TDR cables. The installition of the cables was accomplished by means of a heavy-duty Cone Penetration Test (CPT) truck provided by ORITE.

The heavy-duty truck, shown in Figure 2.5, was used to push the coaxial and fiber optic cables in the desired spot of suspected slope movement zone. The truck was originally designed and built by the Center for Geotechnical and Environmental Research at Ohio University to perform the Cone Penetration Test (CPT), seismic profiling, and sampling of soil, water, and gas. The truck featured a push frame with a capability of over 25 tons pushing or pulling force to be applied on cone rods for subsurface explorations. Table 3.4 summarizes the specification of the heavy-duty CPT truck used in this project.

Figure 2.5. Heavy-duty CPT truck in level condition.

Table 2.4. Specification of Heavy-duty CPT Truck

Feature	Specification
Push frame capability	25 tons pushing or pulling load
Hydraulic cone rod clamp	Capable of gripping rods of 1.4-1.75 inches in diameter
Coring system	6 inch coring drill as a peripheral
Electrical power generating capability	Up to 7500 W of electrical
Hydraulic cone circuit capability	28 gpm at 300 psi
Data acquisition system	Capable of real-time display and analysis software

Before penetrating the cone rods and installing the cables, the two spots on the asphalt pavement were cored up to 24 inches—to reach the untreated base or subbase materials beneath the pavement—by means of a 4.25 inch concrete core drilling machine. After the pavement was cored, the heavy-duty CPT truck was centered over the hole and the cone rods were pushed into the ground while holding a pair of coaxial and fiber optic cables that was fixed to a disposable tip.

Each cone rod was 1 meter (39.37 inch) long. The outer and inner diameters of the cone rods were 1.75 inch and 1.00 inch, respectively. A special disposable tip was designed and built to fit on the end of the cone rod and also hold a pair of coaxial and fiber optic cables while being pushed in the ground. The tip was placed on the leading end of the first cone rod. The tip was designed to remain in the hole while the rods were withdrawn. Figure 2.6 shows a disposable tip and a short piece of the cone rod. The disposable tip was designed to penetrate along with the cone rods and remain at desired depth to hold the cables in place after the cone rods were removed. The detailed drawings of the disposable tip can be found in Appendix B of this document. Each pair of cables was pushed to a depth below the anticipated shear plane until hitting bedrock. At ATH 690-1 the cables were pushed to a total depth of 17.5 ft, and at ATH 690-2 to a depth of 21.0 ft.

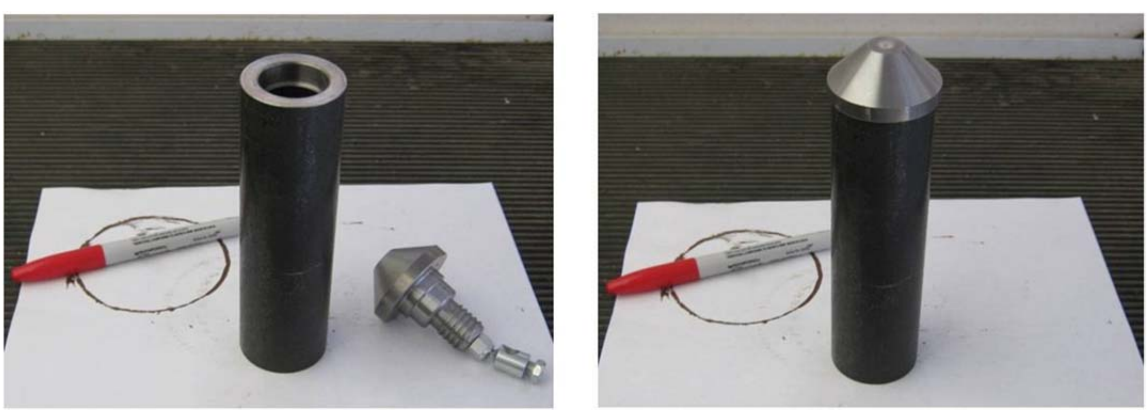

Figure 2.6. A disposable tip and a piece of cone rod.

The coaxial cable installed at ATH 690-1 was cut with an11.5 ft loose end to allow connection to the data acquisition system; and the cable at ATH 690-2 was cut with a 9.5 ft loose end for the same purpose. The total lengths of cables—grouted and not grouted—at ATH 690-1 and ATH 690-2 were 29.0 ft and 30.5 ft respectively. Figure 2.7 and Figure 2.8 illustrate the installation diagrams at ATH 690-1 and ATH 690-2 respectively. The fiber optic cables had loose ends of additional cable around 57.5 ft at ATH 690-1 and 61.0 ft at ATH 690-2. Figure 2.9 depicts the ATH 690-1 hole and a pair of cables, after the cone rods were pulled out before grouting.

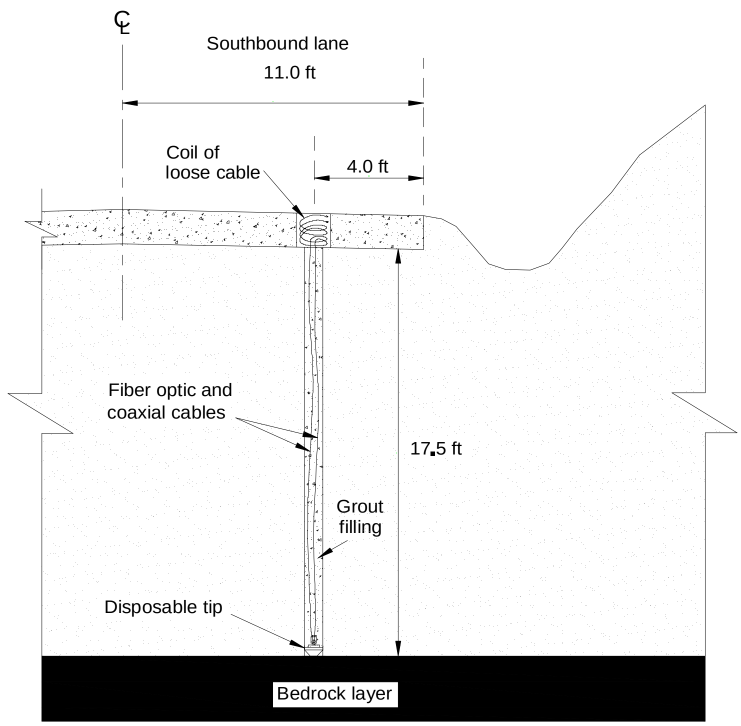

Figure 2.7. Instrumentation diagram at ATH 690-1.

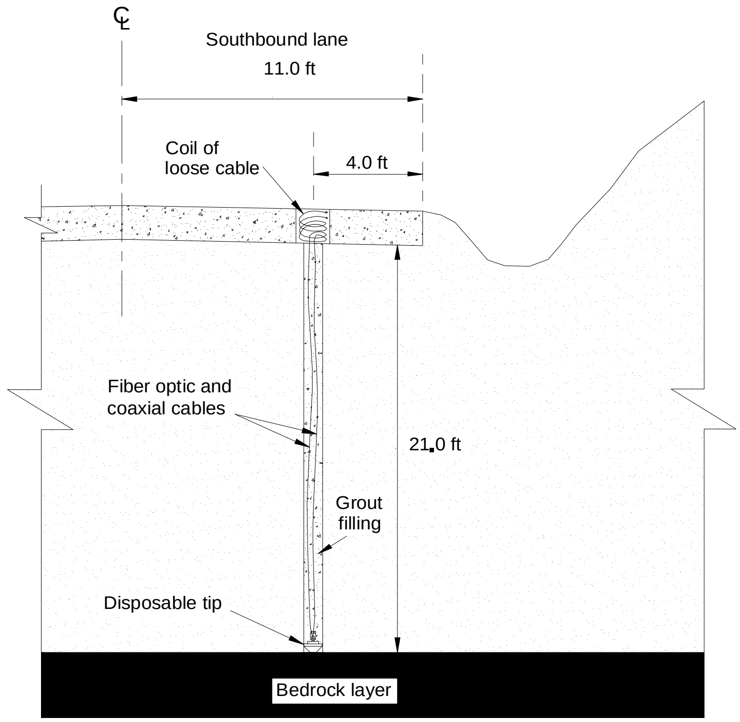

Figure 2.8. Instrumentation diagram at ATH 690-2.

Figure 2.9. ATH 690-1 after the cone rods were pulled out and cables are being held by the disposable tip.

After the cone rods were pulled out, grouting materials were prepared and pumped into the 1.75 inch in diameter hole containing coaxial and fiber optic cables. A CG-050M portable hand operated grout pump, shown in Figure 2.10, was used to pump the grout. An extended 1 inch in diameter PVC pipe was attached to the grout hose and lowered into the hole to facilitate pumping of grout to the bottom of the hole. The portable CG-050M grout pump can be assembled and disassembled without requiring any tool before or after work for cleaning and maintenance. Table 3.5 gives a summary of the specifications for the manual grout pump.

Figure 2.10. CG-050M manual grout pump.

Table 2.5. Specification of the CG-050M Manual Grout Pump

CG-050M	Specification
Piston model	2 inch piston pump
Power	Hand operated (manual)
Hopper capacity	5 gallon
Maximum output	2-3 gpm
Maximum induced pressure	200 psi

The grout was pumped in each hole up to a height of 8.5 inches below the surface of the pavement. A 4 inch diameter and 8.5 inch long PVC tube with a screw cap, shown in Figure 2.11, was provided to be placed at the top of the holes after grouting. The additional coaxial and fiber optic cable—left to allow data collection—were placed inside the tube after initial data collection.

Figure 2.11. PVC tube with a screw cap to protect additional cable from damage.

The PVC protective tubes were set into the asphalt concrete holes using Unitex Pro-Poxy 300 Fast—a high-strength two-component epoxy adhesive gel. The fast epoxy materials needed 30 minutes to completely set; therefore the traffic was controlled for 30 minutes more to make sure the PVC protective tubes had bonded with the surrounding asphalt concrete. The screw cap was tightened after all the additional cables were placed inside the tube.

CHAPTER 3: CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to adopt fiber optic technology, Optical Time Domain Reflectometry (OTDR), to monitor slope stability problems; to compare OTDR to the conventional method of electrical Time Domain Reflectometry (TDR); to investigate suspected slope movement in a road embankment; and also to demonstrate a new method of installation of fiber optic and/or coaxial cables in earthen slopes to monitor slope stability problems. This report discusses some of the background of OTDR and the installation of OTDR and TDR cables using a CPT truck; the other portions of this study are covered elsewhere (Momand, 2010). Two pairs of fiber optic and coaxial cables—one coaxial cable and one fiber optic cable in each pair—were installed side by side in the zone of suspected slope movement under SR 690 near the city of Athens, Ohio, on May 17, 2010.

A new method of fiber optic and/or coaxial cable installation in earthen slopes was developed and implemented in this study successfully. Fiber optic and coaxial cables were paired and pushed by means of cone rods using the heavy-duty CPT truck. A disposable tip was designed and built for the cone rods to hold the cables while they are being pushed and to remain in place at the desired depth of installation after the cone rods are pulled out. As was noticed during installation, the disposable tip was detached at the very first inch of pulling the cone rods and held the cables successfully as designed.

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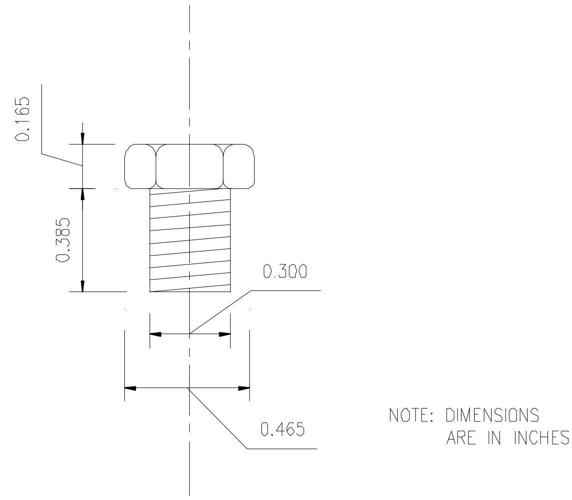
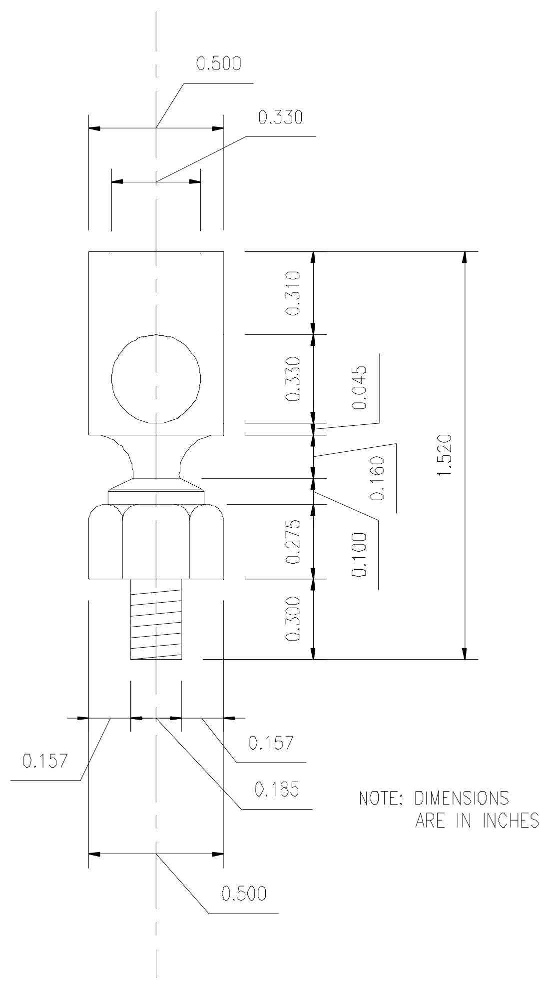
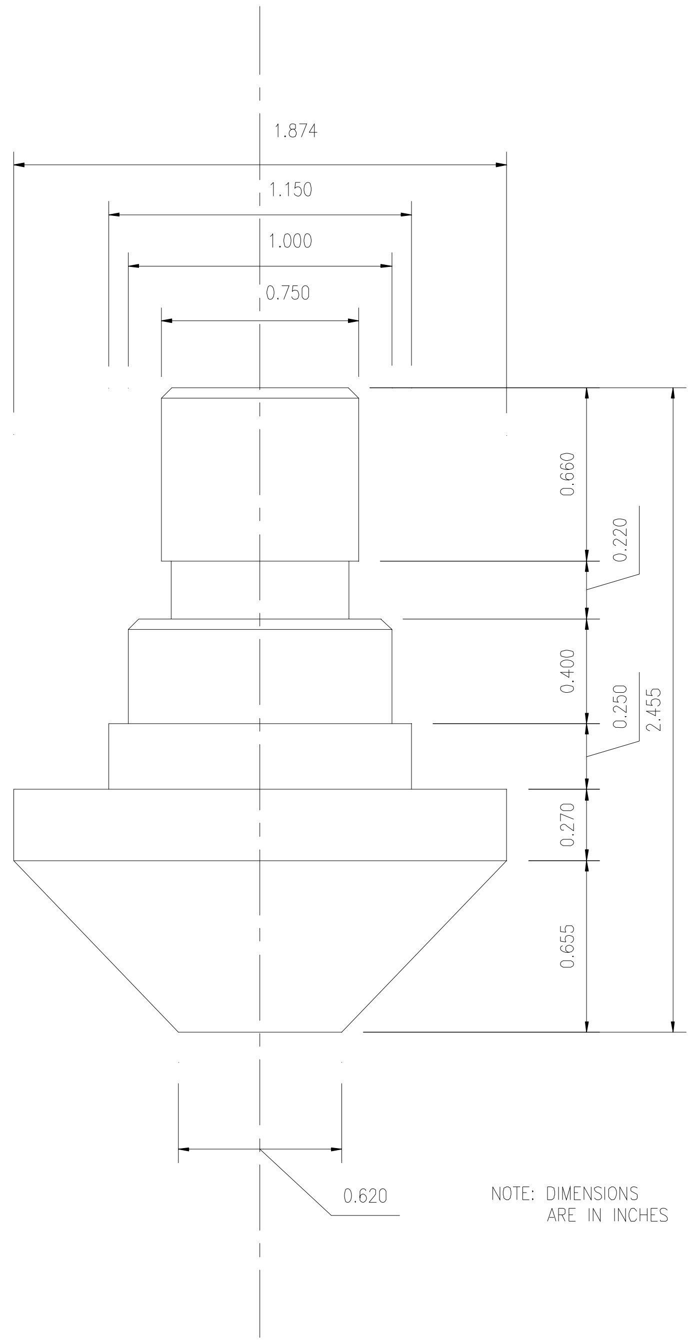
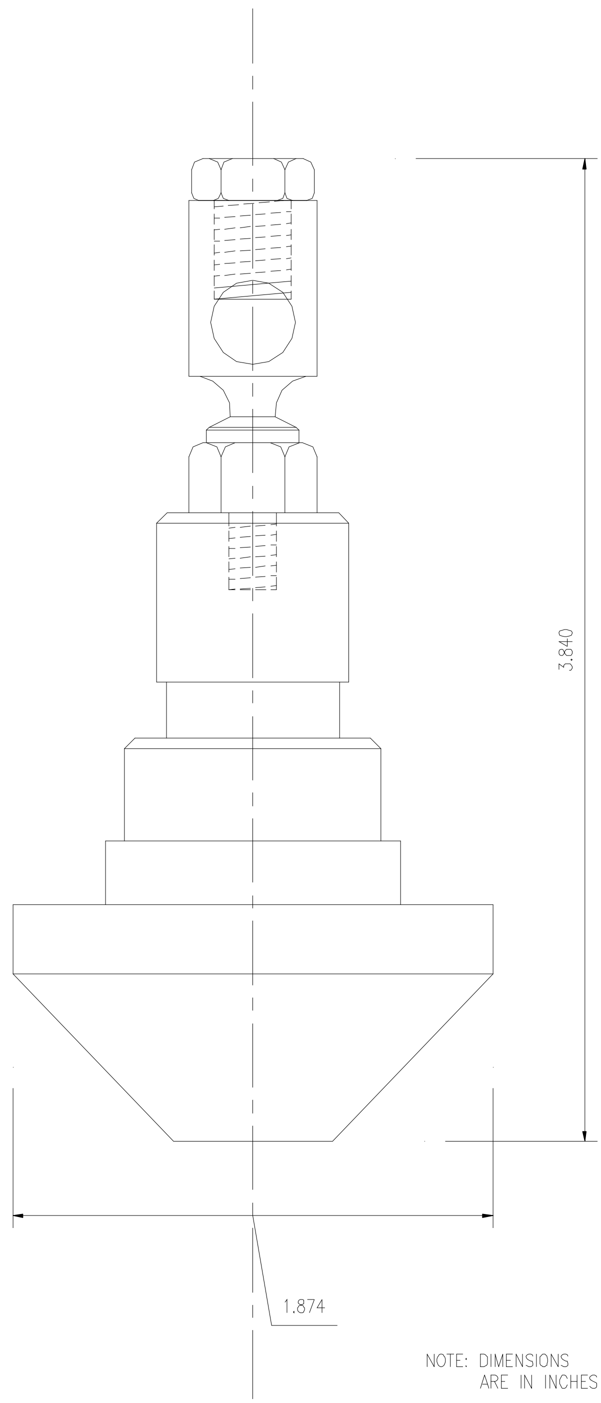
APPENDIX A: DETAILED DRAWINGS FOR DISPOSABLE TIP






1.874
1.150
1.000
0.750
0.660
0.220
0.400
0.250
2.455
0.270
0.655
0.620
NOTE: DIMENSIONS
ARE IN INCHES


3.840
1.874
NOTE: DIMENSIONS
ARE IN INCHES

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