USING THERMAL INTEGRITY PROFILING TO EVALUATE THE STRUCTURAL INTEGRITY OF SOIL NAILS

George Piscsalko, P.E., Pile Dynamics, Inc., Solon, Ohio gpiscsalko@pile.com, Camilo Alvarez, P.E., GRL Engineers, Inc., Los Angeles, California, Daniel S. Belardo, GRL Engineers, Inc., Solon, Ohio, Marcus Galvan, P.E., TXDOT, Austin, Texas

Soil nails are often utilized as a temporary or permanent earth retention technique for slope stabilization and for excavation retention for existing or new structures. Soils nails are generally advantageous as installation is relatively rapid and they can be installed beneath existing structures and where site access for equipment is limited. Due to the typically small cross-section of these elements, the inability to inspect the holes prior to grouting/concreting, and the various installation techniques utilized, quality control for assessing the integrity along the entire length is limited. Currently, quality assurance is conducted by load testing to verify the pull out capacity after installation. The load testing is typically done on a small percentage of the total number of soil nails. This paper will provide the results of a demonstration where the new Non-Destructive Test (NDT) method Thermal Integrity Profiling (TIP) was used to access the integrity of several soil nails along their entire lengths. This TIP method has been successfully used for several years to assess the integrity in drilled shafts and ACIP piles. The TIP method assesses the integrity across the entire cross-section and can identify regions where bulges, necks, and insufficient grout/concrete are present. TIP testing can also help assure that the contractor's installation methods are adequate and consistent for the intended design. For the project presented, instrumented Thermal Wire were affixed to the centered tension bars prior to placement in the excavated shafts. Temperature measurements were recorded from the hydration energy generated after grout/concrete placement, capturing the entire heating cycle. Manufactured defects were installed on the center bar at multiple locations. The results and conclusion will be discussed as well as recommendations for future use.

Introduction

Soil nailing is a slope stabilization technique typically used to stabilize existing slopes or excavations where top-to-bottom construction is advantageous compared to other retaining wall systems (Lazarte et al., 2003). Typical designs include the installation of the nails, in close proximity to one another, in layers of rows that together act as a reinforcement for the soil strata in which they are placed. When used for excavations where vertical or near vertical cuts are required, benching of the soil, in typically 5 ft. unsupported layers, is followed by the installation of a row of nails. A typical nail is composed of a tensioned center bar, typically 60 to 72 ksi, placed in an excavated shaft, typically 4 to 6 in. in diameter, prior to or immediately following the placement of grout (Figure 1). As the layers of nails progress, shotcrete is applied over the face of the surface being retaining. A bearing plate and washer secured by a hex nut on the reinforcing center bar is the final step in the nailing process.

By design, the primary component of the nailing element is the centered tension bar. The complete system is passive in that post-tensioning is not performed. Tension loads are transferred to the element through deformation of the surrounding soil. The grout not only serves as corrosion protection for the steel tension bar but also as a means of transferring the stresses from the soil to tension bar (Lazarte et al., 2003).

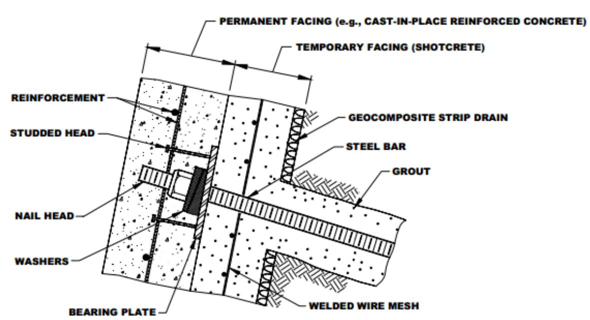

Figure. 1: Typical Soil Nail Elements

(Source: Lazarte et al., 2003)

Advantages

Soil nail walls offer multiple advantages when compared to other earth retaining methods such as driven soldier pile and lagging walls or sheet pile retention systems with tie back helical anchors and walers. Generally, systems requiring driven piles require sizable heavy equipment, including both a crane and hammer system. In comparison, soil nails require much smaller equipment to install, generally an excavator with a mountable drill attachment (Figure 2). Advantages can be recognized on projects where site access is limited, there are right-of-way restrictions, stabilization is required under an existing structure, and where transporting equipment to remote locations is required. Other advantages include rapid construction, low noise pollution on the surrounding environment, ease of material procurement, and cost savings. Experience on U.S. highway projects indicate that permanent soil nail walls can provide a 10 to 30 percent cost savings when compared with similar retaining methods involving soil excavation (Lazarte et al., 2003).

Figure 2: Excavator Mounted Drill Attachment

Limitations

Soil nail walls are typically not compatible in locations where the retained earth is composed of gravels and sands. Soil nail walls may not be appropriate for applications where very strict deformation control is required for structures and utilities located behind the proposed wall, as the system requires some soil deformation to mobilize resistance; post tensioning of the soil nails can overcome this shortcoming in most cases, but this step increases the project cost (Lazarte et al., 2003). Generally, it is not recommended to install the nails in regions with high water tables as water seepage can contaminate and weaken the external shotcrete facing as well as make it difficult to maintain the soil face of open benches during excavation.

Quality Control Measures

Verification and proof testing are two widely accepted quality control measures used to ensure the nails can withstand the design loads. Typically, the set up includes a reaction frame that bears directly against the existing soil or shotcrete facing (Figure 3). A hydraulic jack and pump is used to apply the required loads to the centered tension rods and the distance of movement is monitored. When verification tests are performed, the nails are loaded to the designed pull out capacity. During proof tests, nails are loaded incrementally and held for a specified duration of time. Generally, when a contractor moves to a new location or when the soils encountered during excavation are different than those present in the location of the load testing, additional load tests are required.

Figure 3: Jack and Reaction Frame

The limitation of load testing is that only a small quantity, typical 5 percent, of elements are tested. Load testing is also highly dependent on the assumption that the contractor’s installation means and methods, as well as soil conditions, are consistent on elements installed following load testing. Figure 4 presents the failure of a nailing wall after load testing was performed.

Figure 4: Failed Soil Wall System – It is evident the nails had insufficient grout coverage

Evaluating the excavated shaft prior to grouting is difficult to assess because of the relatively small diameter. Ensuring adequate grout coverage around the tension bar for the entire length is another limitation. It is not possible to assess the integrity of soil nail elements with Non-Destructive Testing (NDT) methods such as Cross Hole Sonic Logging (CSL) and Gamma-Gamma Logging because they require access tubes. Pile Integrity Testing (PIT) is typically limited to a length/diameter ratio (L/D) of 30. Due to the small diameter of soil nails in relation to the length, PIT testing is likely not a feasible option. Figure 5 and Figure 6 present soil nails that were extracted after completion. It is evident in the results that there were lengths of the tendon with insufficient grout coverage.

Figure 5: Insufficient Grout Coverage

Figure 6: 100% Loss in Section Coverage

<u>Case Study: Soil Nail Integrity Testing</u>

A demonstration was performed to evaluate the effectiveness of Thermal Integrity Profiling (TIP) in assessing the integrity of four soil nails in Huntsville, Texas. The demonstration was performed by GRL Engineers, Inc. and Pile Dynamics, Inc. in coordination with the Texas Department of Transportation. In addition to viewing the effectiveness of TIP, soil nails were installed using two different techniques to evaluate whether there was a difference in results. The first method of installation consisted of placing the tension bar into the excavated shaft prior to placement of grout. The second method consisted of placing grout in the excavated shaft and then immediately introducing the tension bar.

<u>Thermal Integrity Profiling</u>

Thermal Integrity Profile (TIP) testing is a relatively new NDT method that has been used over the past several years to evaluate both drilled shafts and auger cast piles. The testing method is traditionally performed by affixing Thermal Wire® cables to the longitudinal bars of a shafts reinforcing cage. Similar to augercast piles with only a reinforcing center bar, the soil nails tested during this demonstration were instrumented along the tensioned center bar. The TIP system, manufactured by Pile Dynamics Inc., uses the temperature generated by curing cement (hydration energy) to access the integrity of the elements.

The Thermal Wire cable used for the purpose of this demonstration consisted of digital sensors spaced every 6 inches. Once the instrumented tension bar was set and after grout was placed, a Thermal Acquisition Port (TAP) box was attached to each cable and data acquisition began. Every 15 minutes the TAP units automatically record the measured temperature at each sensor location along the length of each wire, generating a profile of temperature versus depth for each discrete time increment. Data was collected on the TAP units throughout the hydration process until the peak temperature was achieved and the soil nail element began to cool.

The TIP results were evaluated for soil nail shape and integrity, grout quality and for location of the center bar. The overall average temperature for all Thermal Wire readings over the embedded depths can be directly related to the overall volume of grout installed. Soil nail integrity may be identified by comparing the temperature measurements from each sensor at each depth increment with the overall average temperature of the entire nail. If the measured average temperature versus depth is consistent, the soil nail is considered to be of uniform shape and quality. Bulges can be identified as localized increases in average temperature, while insufficient grout quality or section reductions can be identified as localized decreases in average temperature. Because soil and slurry pockets produce no heat, areas of soil intrusion or inclusion are indicated by lower local temperatures.

Testing Procedures

The soil nails tested were 6 inches in diameter and contained a #6 epoxy coated center bar. Centralizers were located at 3-4 locations along the length of the shaft. The Thermal Wire cables measured 20 ft. in length (40 digital sensors) and were affixed to the center bars of Test Nails 1-4 using zip ties spaced ever 1-2 ft. The cable connection to the center bars was completed while the center bars were staged on the ground prior to placement in the excavated shafts (Figure 7).

Figure 7: Thermal Wire Affixed to Tension Bar

Test Nail 1 was installed with no planned manufactured defects. The installation procedure consisted of placing the center bar in the drilled hole prior to grout placement. Once the center bar was in position a tremie tube was inserted to the back of the shaft and placement was achieved via pressure grouting. Centralizers were located along the center bar at approximately 2.1 ft., 9.9 ft., and 19.3 ft., measured from the end of the bar nearest the wall face.

Test Nail 2 was installed with no planned manufactured defects. The installation procedure consisted of placing the center bar in the drilled hole prior to grout placement. Once the center bar was in position a tremie tube was inserted to the back of the shaft and placement was achieved via pressure grouting. Centralizers were located at 2.1 ft., 10.6 ft., 17.2 ft., and 18.8 ft., measured from the end of the center bar nearest the wall face.

Test Nail 3 was installed with two planned manufactured defects (Figure 8).

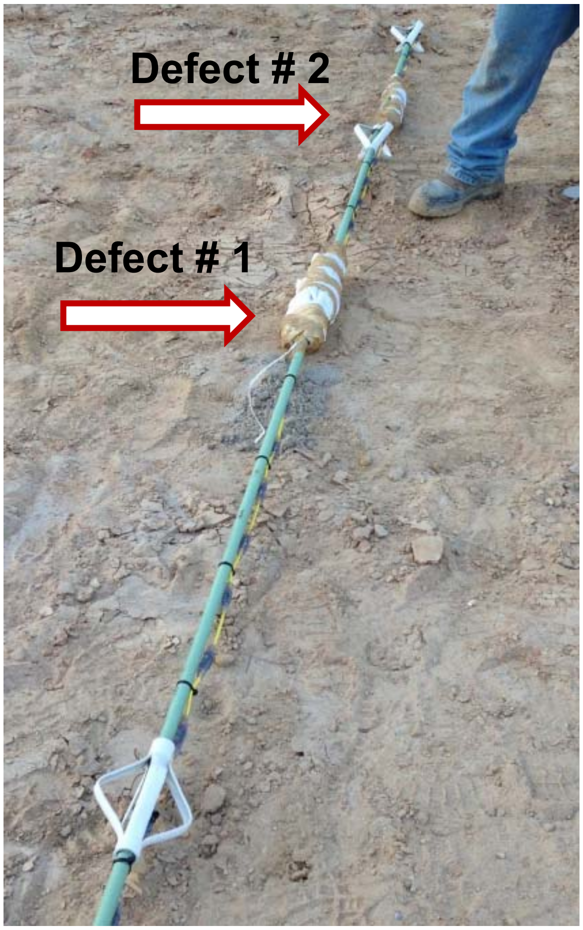

Figure 8: TN-3 Tension Rod with Installed Defects

Note that TP-3 was a sacrificial soil nail. The installation procedure consisted of placing the center bar in the drilled hole prior to grout placement. Once the center bar was in position a tremie tube was inserted to the back of the shaft and placement was achieved via pressure grouting. Centralizers were located at 2 ft., 8.5 ft., 16.9 ft., and 19.8 ft., measured from the end of the center bar nearest the wall face. Defect 1, which was composed of a sand bag taped to the center bar, measured 3 in. x 4.5 in. x 15 in. and was located 13.5 ft. from the end of the center bar nearest the wall face. Defect 2, which was also composed of a sand bag taped to the center bar, was slightly smaller and measured 2 in. x 3 in. x 15 in. Defect 2 was located 17.9 ft. from the end of the center bar nearest the wall face.

Test Nail 4 was installed with no planned manufactured defects. The installation procedure consisted of placing grout in the drilled hole prior to placement of the center bar. Once grouted, the center bar pushed through the grouted shaft into position. Centralizers were located at 2.1 ft., 8.4 ft., and 16.5 ft., measured from the end of the center bar nearest the wall face.

Results

The measured Thermal Profiles present the measured temperature versus depth for each active Thermal Wire cable at a selected time interval. The optimal time selected for each profile reported usually corresponds to near the time when maximum temperature occurs. In general, variations of +/- 2 degrees Fahrenheit are within normal range for this technique due to variations in the cable location and unavoidable shifting of the center bar. Anomalies would be indicated by abrupt reductions in temperature at a particular depth.

The Thermal results are presented in Figure 9 through 12. These figures present the measured temperatures (Fahrenheit degrees) vs. depth (feet) at different curing times. The roll-off (e.g. reduction) in temperature at the top is caused by extra heat losses due to the grout/air interface at the ground surface. There is generally a roll-off in temperature near the end of a grouted element caused by extra heat loss due to the grout/soil interface at the base but for TN-1, TN-2, and TN-4 the Thermal Wire stopped short of the end of the shaft.

Test Nail 1: ***Temperature readings throughout the length of the nail are consistent and thus no major indications of structural integrity problems are observed***. Minor changes in temperature are noticeable, most likely due to the center bar shifting slightly within the nail. The upper 8 to 9 ft. of the nail recorded higher than average temperature values which is likely an indication of an increase in cross sectional area at these locations. At the centralizer locations of 9.9 ft. and 19.3 ft. measured temperatures are very similar to the average temperature, as the center bar gets closer to the center of the soil nail.

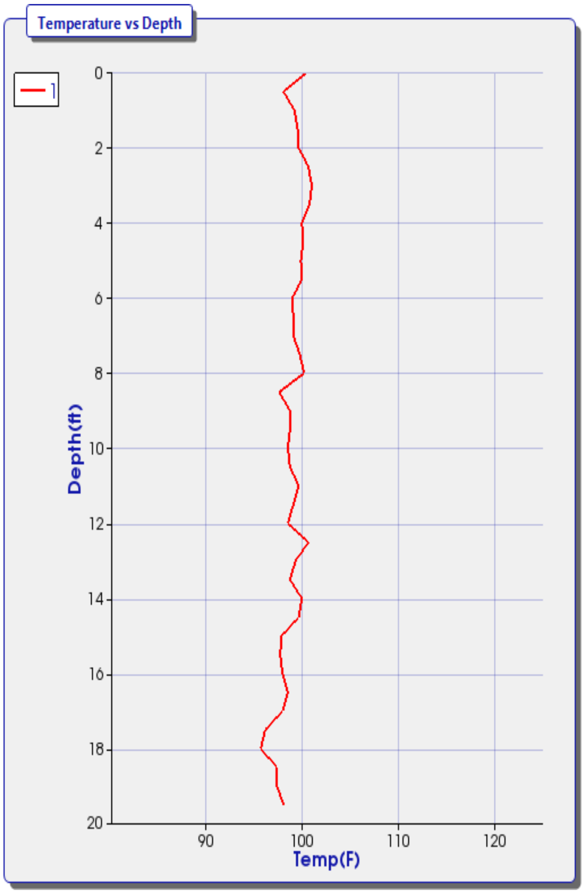

Figure 9: TN-1 Measured Temp. vs. Depth

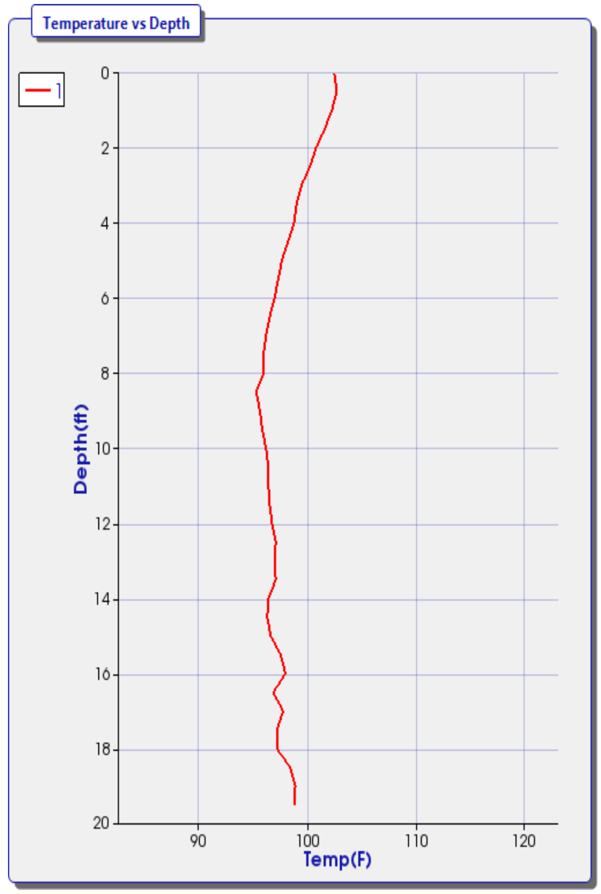

Figure 10: TN-2 Measured Temp. vs. Depth

Test Nail 2***: Temperature readings throughout the length of the nail are consistent and thus no major indications of structural integrity problems are observed***. Minor changes in temperature are noticeable, most likely due to the center bar shifting slightly within the nail. The upper 5 to 6 ft. of the nail recorded higher than average temperature values which is likely an indication of an increase in area at these locations. Temperature is relatively constant between 11 and 20 ft. due to the presence of the centralizer locations at 10.6 ft., 17.2 ft., and 18.8 ft.

Test Nail 3: ***Temperature readings throughout the length of the nail present anomalies at the expected installed locations***. The major anomaly installed measured 3 in. x 4.5 in. x 15 in. for a cross sectional area close to 13.5 in^2 which implies a theoretical reduction of 48% based on a nail cross sectional area of 28.3 in^2. At the expected location of installation, 13.5 ft., a temperature reduction of 7 degrees is evidenced. The second anomaly was built to be 2 in. x 3 in. x 15 in. for a theoretical cross sectional area of 6 in^2 for a theoretical reduction of 21%. At the expected location (17.9 ft.) a temperature decrease close to 4 degrees is present.

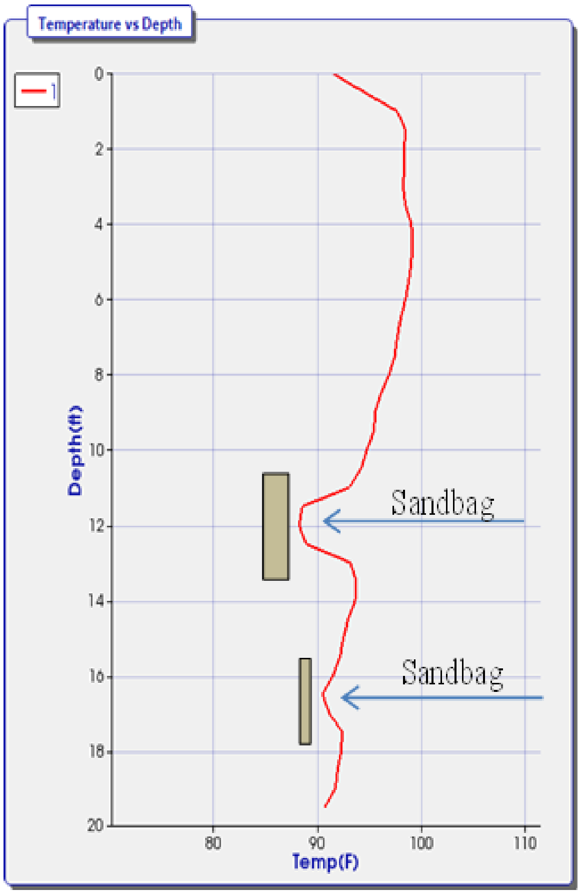

Figure 11: TN-3 Measured Temp. vs. Depth

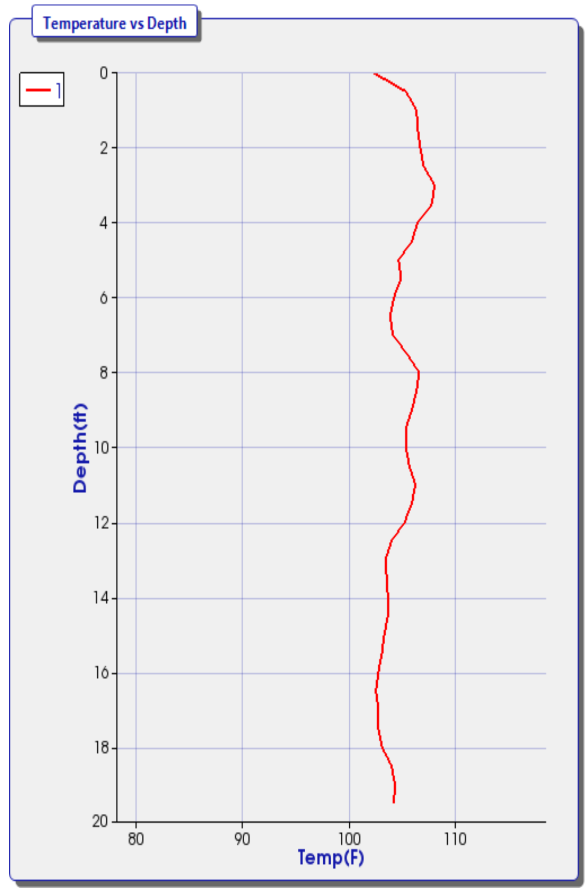

Figure 12: TN-4 Measured Temp. vs. Depth

Test Nail 4: ***Temperature readings throughout the length of the nail are consistent and thus no major indications of structural integrity problems are evidenced***. Minor changes in temperature are noticeable, likely due to the center bar shifting slightly within the nail. At a depth of 4 to 5 ft. the higher temperature values is likely an indication of an increase in cross sectional area. . At the centralizer locations of 8.4 ft. and 16.5 ft. measured temperatures are very similar to the average temperature, as the center bar gets closer to the center of the soil nail. At the 2 ft. centralizer location the measured temperature is higher than the average which is likely due to a slightly higher volume as previously mentioned for the top portion of the nail.

TIP Limitations

As Thermal Integrity Profiling is based on the heat generated during the grout hydration process, the test method is then highly dependent on acquiring data early in the hydration process, generally from the time of placement until peak temperature is achieved. Some degree of pre-planning is necessary as the Thermal Wire is required to be installed on the center bar prior to grouting. When creating 3-D models of the shaft and estimating the radius and grout coverage, the results are dependent on the accuracy of the recorded grout volume installed. Also, when modeling and estimating the radius and grout coverage, the assumption is made that the center bar is located in the center of the shaft. Shifting is evidenced in the results however the analysis becomes more involved.

Conclusions

Four soil nails were installed and tested with Thermal Integrity Profiling (TIP) to evaluate the feasibility of the TIP method in evaluating the integrity of a soil nail. Three production soil nails were instrumented as well as one sacrificial test nail with two defects manufactured from sand bags filled with onsite sandy drilling spoils. The following conclusions can be determined based on the comparison of the production and test nail results:

Temperature decreases due to planned soil inclusions are easily identified via TIP testing. These anomalies can be quantified and a reduction and an approximate cross sectional area reduction can be predicted and presented as a percentage decrease from the planned cross sectional area (BTA). Planned reductions were expected to be close to the installed manufactured defects of 48 and 21%. The estimated reductions based on TIP testing were 37 and 17%, respectively.

Reductions below 10 to 15% although measurable, will likely not be predicted by TIP testing due to the effects of center bar shifting as well as minor changes in soil diameter. All soil nails, production and test elements, evidenced slight temperature decreases as expected due to this effect. These temperature decreases are clearer due to the effect of the centralizers. Shifting is evidenced by temperature reductions at spans between the centralizer locations while temperatures near the centralizers are closer to the average nail temperature.

The test results indicate that TIP would be an effective method for use in determining the integrity of soil nails. Significant changes to the cross-section can be easily detected with TIP method. Volume measurements can be correlated to the various temperature measurements to determine the local radius at each sensor location. Considering the ease of installation and modest cost associated with installing Thermal Wire cables into soil nail elements, it is recommended that all demonstration soil nails and at least 20% of production soil nails be integrity tested using the TIP Method.

Lazarte, C., Elias, V., Espinoza, D., and Sabatini, P., 2003. Soil Nail Walls, Geotechnical Engineering Circular No. 7, Federal Highway Administration (FHWA) Report FHWA0-IF-03-017