Non-destructive method for evaluating installed lengths of soil nails using electromagnetic waves

Jung-Doung Yu
Research Center for Disaster Prevention Science and Technology, Korea University, Korea, noorung2@korea.ac.kr

Junguk Song, Sang Yeob Kim & Jong-Sub Lee
School of Civil, Environmental, and Architectural Engineering, Korea University, Korea

ABSTRACT: Soil nails have been widely used for reinforcing slopes. The length of soil nails is a critical design factor because soil nails are installed into the soil slope considering the potential slip surface. As soil nails, however, are often installed with different length to designed length, the installed length of soil nails should be evaluated for the ground stabilization. The purpose of this study is to evaluate the installed length of soil nails with the non-destructive method using electromagnetic waves. The experiments are performed with soil nails of lengths of 1 m, 2 m, 3 m, 4 m, and 5 m. The electromagnetic waves are generated and detected by the time domain reflectometer. The lengths of soil nails are evaluated using the travel time of the electromagnetic waves. The experimental results show that the travel time increases with an increase in length of soil nail. This study demonstrates that the electromagnetic waves may be effectively applied for evaluating the installed length of soil nails.

1 INTRODUCTION

Soil nails are widely used for stabilizing slopes as a soil reinforcement system. Soil nails reinforce a slope's stability by increasing the shear resistance of soils (Singla, 1999). The design of soil nail length depends on the location of potential slip surfaces. If the soil nail length is not long enough, slope failure may occur. Soil nails, however, are occasionally installed at shorter lengths than those of the designed lengths. Lazarte (2003) therefore mentioned that each soil nail has to be inspected to ensure that the installed length is in accordance with the designs.

Recently, significant studies using non-destructive method for inspecting earth reinforcement systems have been performed. Yu et al. (2013) evaluated the integrity of rock bolts using guided waves. Yu et al. (2016) also conducted laboratory and field test to evaluate integrity of pipe roof support system using the group velocity and frequency response of guided waves. Pernica et al. (2002) analyzed frequency response of elastic waves to inspect the lengths of soil nails. Salloum (2003) conducted experimental and numerical studies using the impulse response method for evaluating the length of the soil nail. Gong (2006) used the sonic echo method in field experiments to inspect installed soil nails. Liao et al. (2008) evaluated the installed lengths of soil nails using the sonic echo and impulse response methods. It has been demonstrated that non-destructive methods using elastic waves are effective tools for inspecting installed lengths of soil nails. However, Gong (2006) mentioned that the maximum detectable length of elastic waves is dependent on the grout quality and interaction between grout and surrounding materials. Cheung and Lo (2001) applied electromagnetic waves to inspect the installed length of the soil nail by installing the copper wire alongside the soil nail. However, this method is not applicable for preinstalled soil nails. Thus, a new method for evaluating lengths of preinstalled soil nails is needed.

The purpose of this study is to develop soil nail length evaluation system using electromagnetic waves that can be applied to preinstalled soil nails. In this study, experimental studies were conducted with soil nails with different lengths. The electromagnetic waves were generated and detected using a time domain reflectometer. The measured electromagnetic waves were analyzed using travel time and velocity.

2 EXPERIMENTAL STUDY

2.1 *Measurement system*

A schematic diagram of the measurement system is shown in Fig. 1. Parallel two soil nails are used to configure transmission line. The spacing between two soil nails is set to be 1 m. For generation and detection of electromagnetic waves, a time domain reflectometer (TDR, HL1101, Hyperlabs) is used. The TDR and soil nails are connected using a coaxial cable (RG-58A/U) of which characteristic impedance is 50 Ohm. The inner and outer conductors of the coaxial cable are connected to each head of two soil nails. The length of the soil nail is evaluated by estimating the time difference (Δt) between the initial inflection and final inflection points.

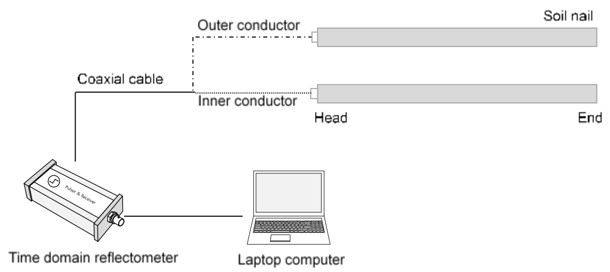

Figure 1. Schematic diagram of measurement system.

2.2 *Experimental specimens*

Soil nails with different lengths of 1 m, 2 m, 3 m, 4 m, and 5 m were prepared. Figure 2 shows 1 m and 5 m long soil nails. Soil nails of lengths of 4 m and 1 m were combined using the coupler to produce 5 m long soil nail. The coupled 5 m long soil nail was used as return path, while the other soil nails were used as signal paths. The steel bars were epoxy-coated reinforcing steel bars of 29 mm in diameter. The grout material was a mixture of cement and water at a weight ratio of 1:0.45 (w/c = 45%). The external diameter of the grout was set as 100 mm. The soil was dense silty sand. The wet unit weight of the soil was 19 kN/m^3. The internal friction angle of the soil was 33° and Poisson's ratio were 0.32. The dielectric constant of the soil was 16.67.

Figure 2. Soil nails of lengths of 1 m and 5 m.

2.3 *Experimental results*

The measured electromagnetic waves for soil nails of lengths of 1 m, 2 m, 3 m, 4 m, and 5 m are shown in Fig. 3. For 1 m long soil nail, the travel time of electromagnetic waves appears at 28.3 ns. For 2 m, 3 m, 4 m, and 5 m long soil nails, travel times of electromagnetic waves appear at 46.3 ns, 66.8 ns, 90.7 ns, and 106.8 ns, respectively.

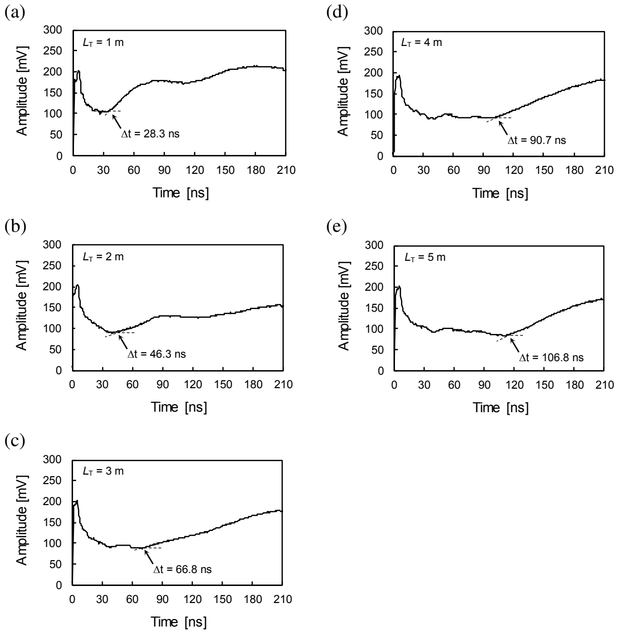

Figure 3. Measured electromagnetic waves for soil nails of lengths of: (a) 1 m; (b) 2 m; (c) 3 m; (d) 4 m; (e) 5 m.

The travel time according to the length of soil nail is presented in Fig. 4. The travel time of the electromagnetic wave linearly increases with an increase in the length of soil nail without a significant effect of the coupler on the travel time. In addition, the linear relationship between the length and the travel time is very high: the coefficient of determinations (R^2) soil nail is 0.9941. The average velocity of electromagnetic waves along soil nails is approximately 0.86×10^8 m/s. The velocity of electromagnetic waves along soil nails is much smaller than electromagnetic wave velocity in vacuum (3.0×10^8 m/s). Note that the electromagnetic wave velocity is inversely proportional to square root of a dielectric constant of the material. The dielectric constant of vacuum is 1. The dielectric constant of the grout (w/c = 45%) is approximately 4.2 ~ 4.5 (Solak, 2011). The dielectric constant of the soil is 16.67. The soil nail is composite material of steel, grout, and soil. Thus, the dielectric constant of soil nail is affected by the dielectric constant of grout and soil. As the dielectric constant of grout and soil is much smaller than vacuum, the velocity of electromagnetic waves along soil nails is smaller than the electromagnetic wave velocity in vacuum.

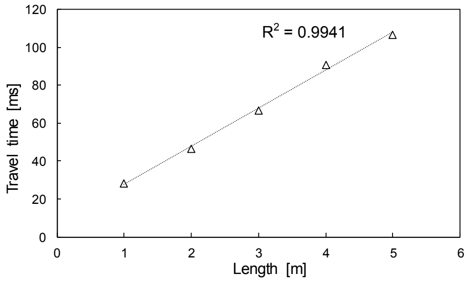

Figure 4. Variation of travel time according to the length.

3 SUMMARY AND CONCLUSION

The experimental study to evaluate lengths of soil nails were conducted with different lengths of 1 m, 2 m, 3 m, 4 m, and 5 m using electromagnetic waves. The generation and detection of electromagentic waves were carried out using the time domain relfectometer. The measured electromagnetic waves were analyzed using travel time and velocity. The experimental results show that the electromagnetic waves linarly increases with an increase in length of the soil nail. This study demonstrates that electromagnetic waves may be an effective tool for evaluating lengths of soil nails.

4 ACKNOWLEDGEMENTS

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (NRF-2017R1A2B3008466)

5 REFERENCES

Cheung, R.W.M., Lo, D.O.K., 2011. Use of time-domain reflectometry for quality control of soil-nailing works. *Journal of the Geotechnical and Geoenvironmental Engineering*, ASCE, 137 (12), 1222-1235.

Gong, J., Jayawickrama, P. W., Tinkey, Y., 2006. Nondestructive evaluation of installed soil nails. Transportation Research Record: *Journal of the Transportation Research Board*, 1976, 104-113.

Lazarte, C.A., Robinson, H., Gómez, J.E., Baxter, A., Cadden, A., Berg, R., 2015. Soil nail walls - reference manual. Technical report, FHWA-NHI-14-007, Federal Highway Administration.

Liao, S.T., Huang, C.K., Wang, C.Y., 2008. Sonic echo and impulse response tests for length evaluation of soil nails in various bonding mediums. *Canadian Geotechnical Journal*, 45 (7), 1025-1035.

Pernica, G., Law, T., Glazer, R., Lee, C.F., Tham, G., Yue, Q., 2002. Development of a non-destructive procedure to determine the length of in-situ soil nails. *Proceedings of the 55th Canadian Geotechnical Conference*, Niagara Falls, Ontario, Canada, 1-8.

Salloum, T., 2003. Using the impulse response technique to estimate the length of in-situ soil nails. M.S. Thesis, Carleton University, Ottawa, Ontario, Canada.

Singla, S., 1999. Demonstration project 103: Design and construction monitoring of soil nail walls. Project summary report, FHWA-IF-99-026, Federal Highway Administration.

Solak, I.C., 2011. Determination of the dielectric constants of hydrated cement paste and cement mortar using a contact coaxial probe. M.S. Thesis, University of Massachusetts Lowell, Massachusetts.

Yu, J.D., Bae, M.H., Lee, I.M., Lee, J.S., 2013. Nongrouted Ratio Evaluation of Rock Bolts by Reflection of Guided Ultrasonic Waves. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 139 (2), 298-307.

Yu, J.D., Hong, Y.H., Byun, Y.H., Lee, J.S., 2016. Non-destructive evaluation of the grouted ratio of a pipe roof support system in tunneling. *Tunnelling and Underground Space Technology*, 56, 1-11.