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Characterization of Railroad Track Substructures using Dynamic and Static Cone Penetrometer

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ABSTRACT: As deteriorated track substructures cannot produce enough bearing capacity against the load of the train and may lead to serious accidents, an accurate investigation of the track substructures is necessary for proper repair and maintenance. In this study, a dynamic and static cone penetrometer (DSCP) for characterization of track substructures is developed. The DSCP is dynamically penetrated into ballast layer using a 118 N drop hammer and statically pushed into subgrade. The DSCP consists of an outer rod for the dynamic penetration into the ballast layer and inner rod for the static penetration into the subgrade. At the head of the outer rod, an energy-monitoring module is installed to obtain the transferred energy from the drop hammer and two load cells are installed to obtain the cone tip and friction resistances during the static penetration. As a pilot test, track substructures are simulated in a chamber and the DSCP penetration test is conducted and two field tests are conducted in order to investigate the applicability of the DSCP. From the DSCP tests, the energy corrected dynamic cone penetration index for the ballast layer and static penetration resistances (cone tip and friction resistances) are obtained for the subgrade. This study suggests that the DSCP may be a useful tool for the characterization of railroad track substructures.

1 INTRODUCTION

Nowadays, the railroad transportation is recognized as a future-oriented means of transportation and the railway transportation technologies have been actively advanced. Accordingly, the larger wheel load, lateral pressure, and greater starting and breaking forces are acted on the conventional lines. These problems may cause the failure of the railroad track substructures and lead to huge damages for the passengers. For the evaluation of the railroad track substructures, various subsurface investigation methods are suggested aspects on the non-destructive, static and dynamic loading tests.

As a non-destructive method, Al-Qadi et al. (2010) applied the ground penetrating radar (GPR) for the evaluation of fouling depth in the ballast layer. While the GPR is cost-effective and efficiently investigate the large area within a short time, the strength characteristics of the railroad track substructures cannot be evaluated. In addition, the light falling weight deflectometer (LFWD) and the plate bearing test (PBT) can be applied to the railroad track substructures as the static and dynamic loading tests. However, ballast layer should be removed when these methods are applied to the subgrade. In order to evaluate the strength of the railroad track substructures without large removal of ballast layer, a study on the in-situ penetration methods is required. However, the in-situ penetration methods such as cone penetration test (CPT), standard penetration test (SPT), vane shear test (VST), pressuremeter test (PMT), and flat plate dilatometer test (DMT) may cause the significant disturbance in the railroad track substructures due to the large diameter of the penetrometer and the driving rod. In addition, bore holes are necessary in some cases.

In this study, a dynamic and static cone penetrometer (DSCP) is developed for the evaluation of railroad track substructures. This paper shows the overall shape and functions of the DSCP and documents the procedure and the results of the application tests.

2 DYNAMIC AND STATIC CONE PENETROMETER (DSCP)

2.1 *Railroad track substructures*

The railroad system consists of rails, fasteners, ties, and track substructures as shown in Figure 1. Among the components of the railroad system, rails, fasteners, and ties are the parts of the track superstructures and the track substructures consists of ballast and subballast layer with a depth of 500~600 mm, and subgrade. In the ballast and subballast layer, dynamic penetration method is suitable for the characterization due to the large particle size of the gravels. In the subgrade layer, static penetration method is recommended to characterize the subgrade with a high-resolution.

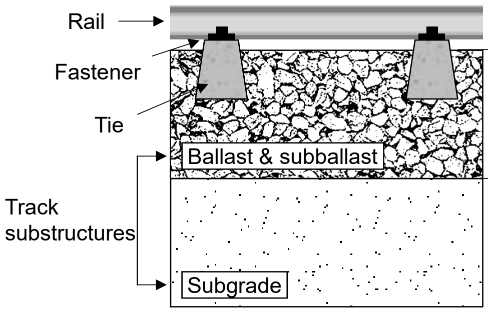

Figure 1. Cross-section of the railroad system.

2.2 *Development*

In this study, a dynamic and static cone penetrometer (DSCP) is developed for characterization of railroad track substructures. The DSCP consists of an outer rod for the dynamic penetration into the ballast and subballast layer, and extendable inner rod with a mini cone for static penetration in the subgrade. In the mini cone, two load cells are installed for measurement of cone tip and friction resistances (q_c and f_s) as shown in Figure 2.

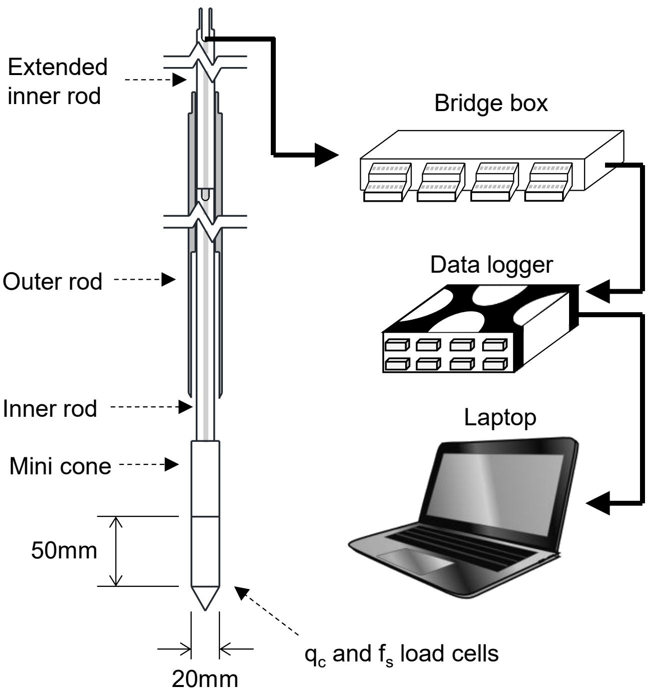

Figure 2. Schematic drawing of DSCP and the measurement system.

In the ballast and subballast layer, the DSCP is dynamically penetrated using a drop hammer with a weight of 118 N and a drop height of 575 mm as a form that the outer rod and inner rod are coupled. During the dynamic penetration, the dynamic cone penetration index (ASTM D6951) is measured along the penetration depth. In the subgrade, static penetration is conducted with a rate of 1 mm/sec as a form that the outer rod and inner rod are uncoupled. Note that the 1mm/sec penetration rate has been used for the miniaturized cone penetration test (Lee et al. 2009; Kim et al. 2010; Yoon et al. 2011). During the static penetration, the static penetration resistances (cone tip and the friction resistances) are measured using a mini cone installed at the front end of the inner rod. The cone tip and friction resistances are gathered through the bridge box and data logger, and monitored by a laptop.

2.3 *Load cells calibration*

In the q_c and f_s load cells, four strain gauges are installed at each load cell and the strain gauges at each load cell are connected as the full bridge which is a kind of Wheatstone bridge. The loads acted on the load cells cause the changes in output voltage of the full bridge circuit. Since the experimental results of the static penetration show the changes in output voltages instead of acted loads, the calibration is conducted to find the correlation factors between the output voltages and the loads acted on the each load cell.

Figure 3 shows the results of the calibration. The relationship between the output voltages (V_{out}) and loads acted on the q_c and f_s load cells show a good linearity with the coefficient of determinant (R^2) greater than 0.99. When 1.25 V is applied to the circuits, the loads acted on q_c and f_s load cells can be converted via Equation 1 and Equation 2.

$$F_{qc}[kN] = 70.3 \times V_{out}[mV] \quad (1)$$

$$F_{fs}[kN] = 84.2 \times V_{out}[mV] \quad (2)$$

where, F_{qc} and F_{fs} are the loads acted on the q_c and f_s load cells, respectively.

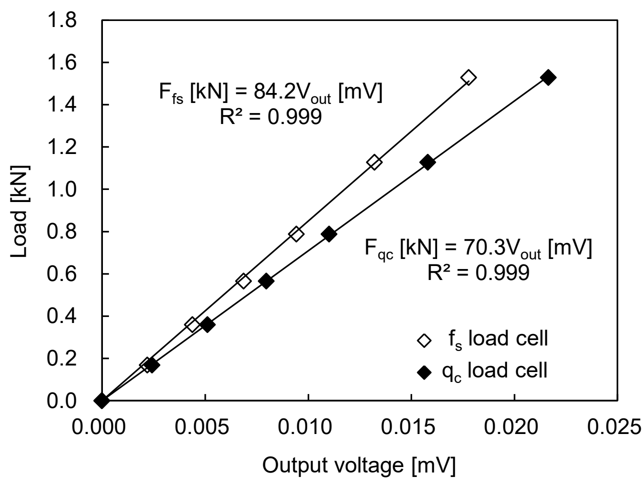

Figure 3. Relationship between the output voltages and the loads acted on the q_c and f_s load cells. F_{qc} and F_{fs} denote the loads acted on the q_c and f_s load cells, respectively.

2.4 *Test procedure*

The characterization of the railroad track substructures using the DSCP is performed as follows:

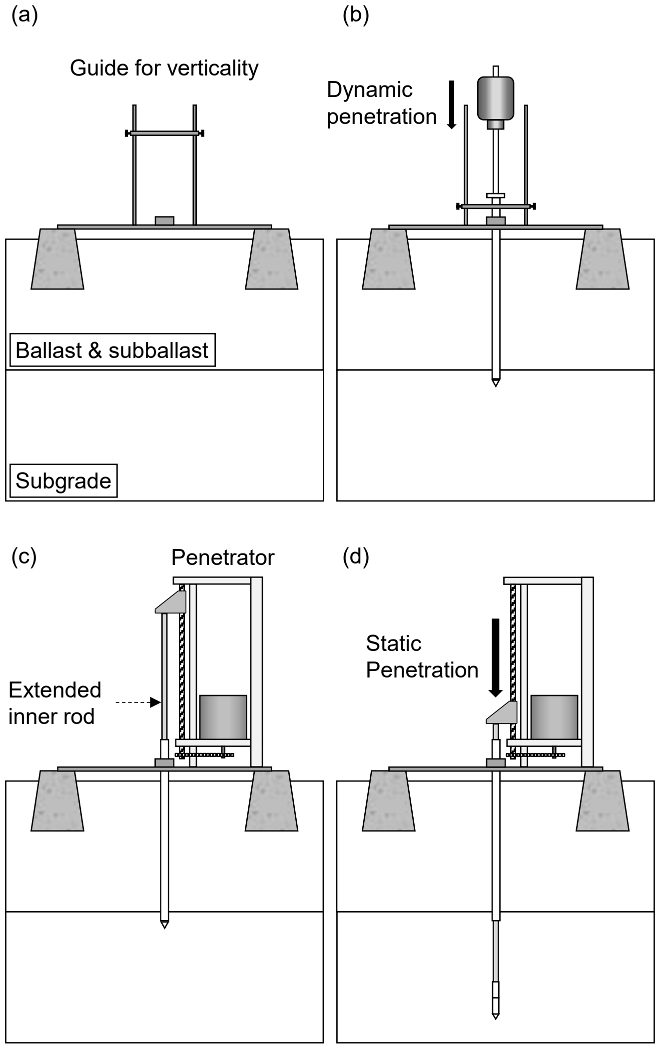

Figure 4. Test procedure of DSCP: (a) installation of a guide for verticality; (b) dynamic penetration of the DSCP; (c) installation of a penetrator; (d) static penetration of the DSCP.

(a) A guide is located on the adjacent ties to maintain the verticality of the DSCP during the dynamic penetration as shown in Figure 4(a).
(b) The DSCP is located on the guide and a hammer guide with a 118 N drop hammer is connected at the head of the DSCP; the dynamic penetration is then performed with 575 mm drop height as shown in Figure 4(b). During the dynamic penetration, the blow counts and the penetration depths are recorded to obtain the DCPI along the depth.
(c) After the completion of the dynamic penetration in the ballast and subballast layer, the hammer and hammer guide are removed, and the inner rod is extended. In addition, a penetrator is installed for static penetration as shown in Figure 4(c).
(d) The inner rod is pushed with a rate of 1mm/sec as shown in Figure 4(d). During the static penetration, static penetration resistances are measured.

3 APPLICATION TEST

3.1 *Site description*

The characterization of the railroad track substructures using the DSCP is performed at a railroad located in Seoul, Korea. Figure 5 shows the photographic image taken during the step of dynamic penetration of the DSCP (Fig. 4(b)).

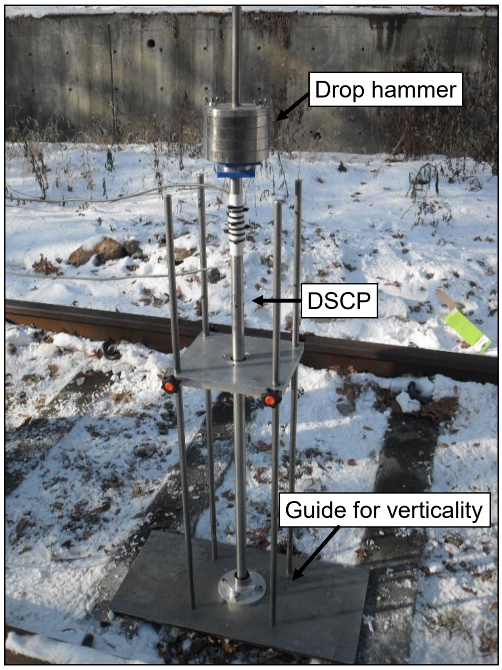

Figure 5. Photographic image of the dynamic penetration of DSCP.

The target railroad had been actually used as an urban railroad for the communication in the Seoul. As a previous study, Byun et al. (2015) investigated the railroad track substructures using a hybrid cone penetrometer and reported that the ballast and subballast layer is distributed to the depth of 400~500 mm from the top of the ties.

3.2 *Experimental results*

In this study, the dynamic penetration of the DSCP is conducted to the depth of 670 mm from the railroad surface and static penetration is performed to the depth of 1400 mm. In the ballast layer, dynamic penetration index (DCPI) is obtained along the depth. Note that the irregularity in DCPI profile may occurs according to the position between the tip of the DSCP and the particles consisting the ballast layer. In order to minimize the irregularity in the DCPI profile, the moving average for three DCPIs is computed with a higher factor in the center (Santamarina and Fratta 1998). In the subgrade, the static penetration resistances are obtained. The static penetration resistances are measured with 5 Hz sampling rate and the penetration rate is 1 mm/sec. Therefore, 5 points of cone tip resistances and friction resistance are gathered per penetration depth of 1 mm.

Figure 6 shows the experimental results of the application test.

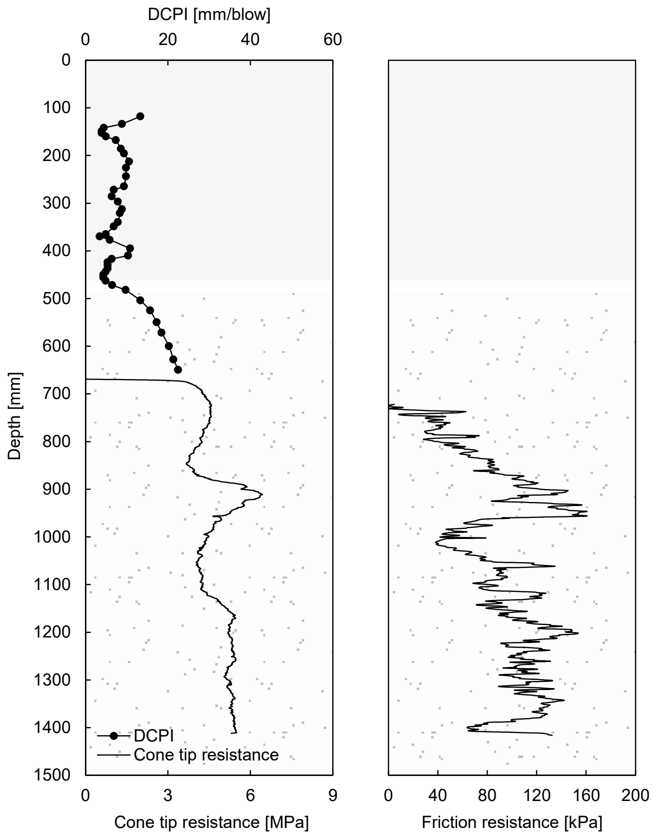

Figure 6. Experimental results.

The DCPI measured near the surface of railroad track substructures shows high values due to the effect of free stress and the DCPI is then converged to 3~10 mm/blow. At the depth of 460 mm, the DCPI rapidly increases which is considered as an interface between the ballast and subballast layer, and the subgrade. In the subgrade layer, the cone tip and friction resistances are measured at approximately 4~7 MPa and 50~150 kPa, respectively. In addition, the friction ratio is calculated as 1~3%. By using the measured cone tip resistance and the calculated friction ratio, the subgrade geo-material is classified as silty sand to sandy silt by soil classification method suggested by Lunne et al. (1997).

4 SUMMARY AND CONCLUSIONS

In this study, a dynamic and static cone penetrometer (DSCP) is developed for characterization of railroad track substructures. The DSCP consists of an outer rod for dynamic penetration in the ballast and subballast layer and an extendable inner rod for static penetration in the subgrade. In addition, a mini cone is installed at the tip of the inner rod for measurement of the cone tip and friction resistances. In order to test the applicability of the DSCP, a field test is conducted at a railroad. The DSCP is dynamically penetrated into the ballast and subballast layer using a hammer with the weight and drop height of 118 N and 575 mm, respectively. In the subgrade, the inner rod with the mini cone is pushed with a rate of 1 mm/sec. As the strength characteristics, dynamic cone penetration index is measured in the ballast and subballast layer, and cone tip and friction resistances are obtained in the subgrade with a high resolution.

The dynamic and static cone penetrometer developed in this study may be a useful tool for the characterization of the railroad track substructures.

5 ACKNOWLEDGEMENTS

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