Application of Energy Monitoring Module for Evaluation of Transferred Energy into SPT Sampler

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ABSTRACT: Uncertainty of the transferred energy into the standard penetration test (SPT) sampler leads to erroneous SPT results. In this study, an energy monitoring module is used for the evaluation of the transferred energy into the SPT sampler. The energy monitoring module is connected at the head of the SPT sampler. Inside of the energy monitoring module, a uniaxial accelerometer and four strain gauges are installed to measure the dynamic responses, which can be used for the calculation of the transferred energy via Force-Velocity integration method. For the application of the energy monitoring module, an experimental study is carried out. The experimental result shows that the transferred energy into the SPT sampler is smaller than the transferred energy measured at the head of the driving rod. Therefore, this study demonstrates that the evaluation of the transferred energy into the SPT sampler may be used for the correction of the SPT N-values to obtain a reasonable SPT result.

Keywords: accelerometer; energy monitoring module; standard penetration test; strain gauge; transferred energy.

1. Introduction

For the construction of the infrastructures, ground investigation test should be carried out. Standard penetration test is the most commonly ground investigation method, and SPT N-values are used to estimate the engineering properties of the subsoils. For an accurate evaluation of the ground strength from SPT, N-value is corrected to a reference hammer efficiency of 60% (N_{60}). However, because the hemmer efficiency is measured at the head of the driving rod for the correction of the N-values, it is difficult to consider the effects of energy loss caused by length and joint of driving rods on the N-values.

Therefore, a study on the energy loss of driving rods is necessary for accurate evaluation of the ground strength by SPT. The purpose of this study is to obtain the corrected N-value by measuring transferred energy at the split spoon sampler. First, the background of standard penetration test and correction method are introduced. Then, this paper provides site description, experimental setup and results. Finally, the results of standard penetration test are discussed.

2. Background

2.1. Standard penetration test

In standard penetration test, the driving rod is driven by a drop hammer with a density of 63.5 kg at a drop height of 76 cm (potential energy of drop hammer: 473.5 N·m), and split spoon sampler is penetrated into the ground [1]. The penetration of the split spoon sampler is conducted at three incremental penetration depths. Note that each incremental penetration depth is 15 cm, thus the total penetratipn depth for each target depth is 45 cm as shown in Fig. 1.

During the penetration of the split spoon sampler, the blow counts are recorded, and the blow counts for second and third incremental depths (30 cm) is defined as SPT N-value (blow counts / 30 cm). The N-value is used for estimation of engineering properties of the soils such as relative density, internal friction angle, undrained shear strength and shear modulus[2-5].

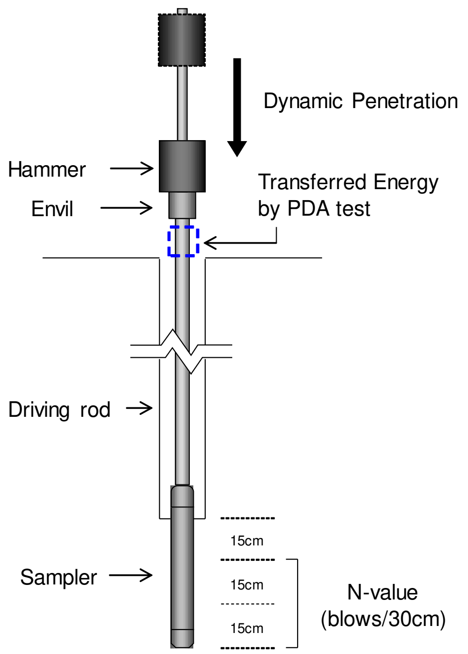


Figure 1. Schematic drawing of standard penetration test

2.2. Correction by transferred energy

For an objective strength characterization of the ground by the standard penetration test, an uniform driving energy is required during the penetration. However, the driving energy can differ according to the hammer type and deteriorated penetration system. Thus, the dynamic responses such as force and velocity are measured at the head of the driving rod by using the pile dring analyzer (PDA) as shown in Fig. 1.

The measured dynamic responses are used for the calculation of the transferred energy from hammer to the driving rod via force-velocity (F-V) integration method [6] as:

$$E = \int F_{Strain} \times V_{Acc} dt \qquad (1)$$

where E is the transferred energy from hammer to the head of the driving rod, and F_{strain} and V_{acc} are the force and velocity measured by PDA test, respectively

The SPT N-value is used for the correction of the SPT N-value to the reference energy efficiency of 60% as:

$$N_{60} = (ER/60)N \qquad (2)$$

where N_{60} is corrected N-value to the reference energy efficiency of 60%, ER is the ratio of transferred energy to the potential energy of the drop hammer (473.5 N·m). In the conventional analysis of N_{60}, the ER is calculated based on the transferred energy at the head of the driving rod as (E_{Head}):

$$ER = E_{Head}/E_{Potential} \qquad (3)$$

However, the actual driving energy at the split spoon sampler can differ according to the weight, length, and the number of the joints of the driving rods. Therefore, the strength characterization of the ground can be conducted with a higher accuracy by correcting the N-value by the transferred energy to the split spoon sampler ($E_{Sampler}$) instead of that to the head of the driving rod as:

$$ER = E_{Sampler}/E_{Potential} \qquad (4)$$

3. Experimental study

3.1. Site description

For the comparison of the transferred energy to the head of the driving rod and the sampler, an experimental study is conducted at a study site located in Pohang, South Korea. According to ground investigation results, the ground of the study site is generally composed of sedimentary layer. SPT N-value of the study site is plotted in Fig. 2. Until the depths of 5.3m, the SPT N-value is less than 10blows/30cm. The SPT N-value is relatively larger at the depths of 6.3m~13.3m, and in paricular the SPT N-value is 108blows/30cm at the depth of 12.3m. Below the depths of 13.3m, the SPT N-value is less than 5blows/30cm, which is very loose ground.The soils composing the ground are classified by sampled soils and laboratory tests. The soils at the depths of 0 ~ 7.3 m, 7.3 ~ 13.3 m, and 13.3 ~ 19.3 m are classified as silty sands, sands, and silty clay, respectively, as summarized in Table 1.

Table 1. Soil classification for depth

Depth(m)	Soil type
0.0~7.3	Silty sand
7.3~13.3	Sand
13.3~19.3	Silty clay

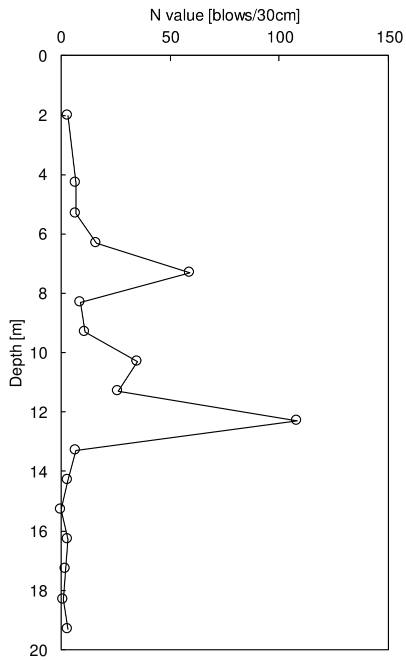


Figure 2. N-values of test site ground

3.2. Experimental setup

In this study, an energy monitoring module is installed at the head of the split spoon sampler for the evaluation of energy ratio by Eq. (4). For the measurments of the dynamic responses, a uni-axial accelerometer and four strain gauges are installed in SPT sampler energy monitoring module. The four strain gauges are connected as the full bridge for the measurement of the force compensated for the temperature effect as shown in Fig. 3.

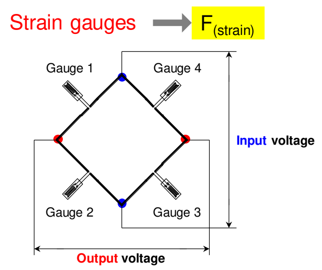


Figure 3. Schematic drawing of full bridge

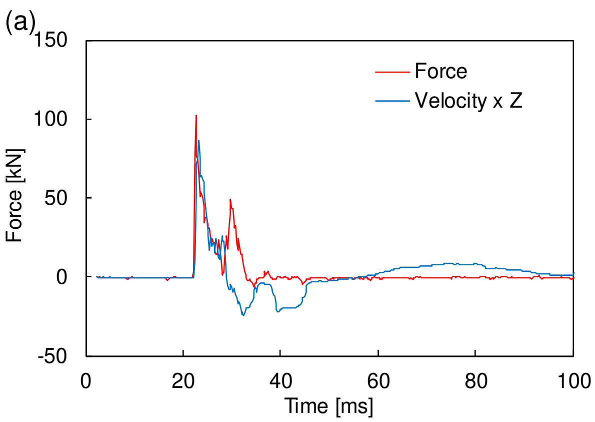
This SPT sampler energy monitoring module measures the force and velocity to calculate the transferred energy to the split spoon sampler via Eq. (1). In addition, PDA test is also conducted for the evaluation of the transferred energy at head of the driving rod. The SPT is conducted at the study site to the depth of 19.3 m with an interval depth of 1 m with measuring the transferred energy to the head of the driving rod and the split spoon sampler.

3.3. Experimental result

In the experimental study, accelerations and forces at the head of the driving rod and the split spoon sampler are measured at each target depth. From measured acceleration, velocity is calculated by integrating the acceleration. And the calculated velocity can be used to estimate the force by multipling the velocity by the impedance (Z) of the energy monitoring module. Impedance (Z) is determined by elastic modulus, cross-section area and longitudinal wave velocity of the energy monitoring module. Therefore, force based on the velocity can be estimated by Eq. (5)

$$F_a = Z \times V_{ACC} = (EA/C) \cdot V_{ACC} \tag{5}$$

where F_a is the force estimated from velocity. E, A and C are elastic modulus, cross-section area and longitudinal wave velocity of the energy monitoring module. Elastic modulus (E), cross-section area (A), and longitudinal wave velocity (C) of the energy monitoring module are 210 GPa, 2.51 cm^2, and 5120 m/s, respectively. The forces measured by the strain gauges and estimated by the velocity at the depth of 12.3 m are plotted with time durations in Fig. 4(a) and Fig. 4(b), respectively.



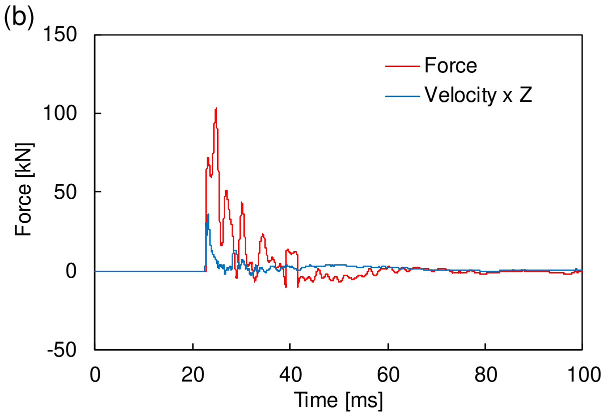


Figure 4. Force-time waveform at 12.3m depth: (a) head; (b) sampler

Based on Eq. (1), transferred energy at the head of the driving rod and the split spoon sampler are calculated by F-V integration method. Fig. 5(a) shows the transferred energy to the head of the driving rod with time. The transferred energy of at the head of the driving rod (E_{Head}) is 341.3N·m. Also, the transferred energy to the split spoon sampler is shown in Fig. 5(b), and transferred energy to the split spoon sampler($E_{sampler}$) is evaluted as 276.1N·m.

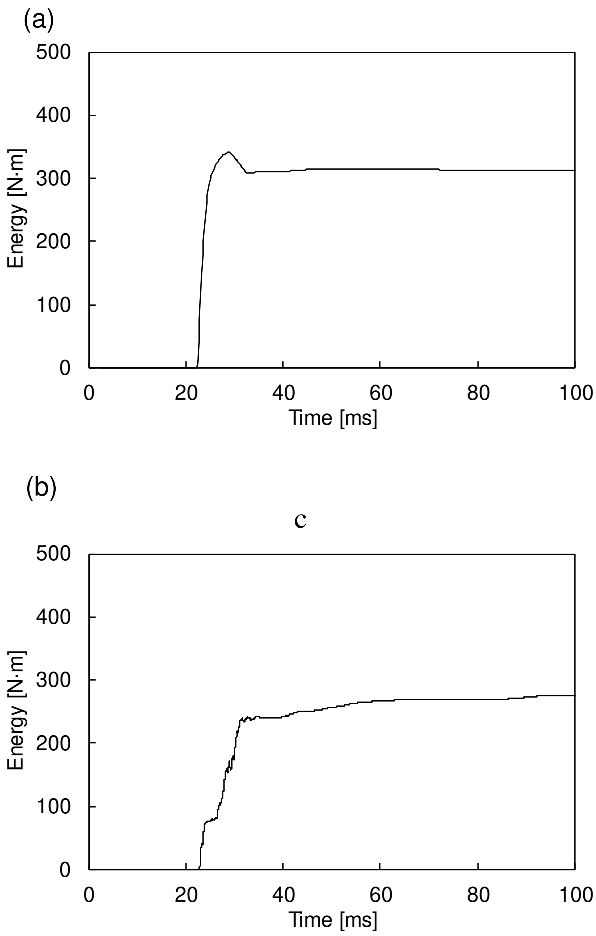


Figure 5. Energy-time waveform at 12.3m depth: (a) head; (b) sampler

4. Discussion

The potential energy of drop hammer used in the SPT is 473.5 N·m, and the transferred energy to the head of the driving rod and the split spoon sampler are 341.3 N·m and 276.1 N·m, respectively, as shown in Fig. 6. The difference in transferred energies at the head of the driving rod and the split spoon sampler is 34.5 N·m, thus the energy ratio (ER) at the head of the driving rod and the split spoon sampler are calculated at 72.1%, 58.3% according to Eq. (3) and (4).

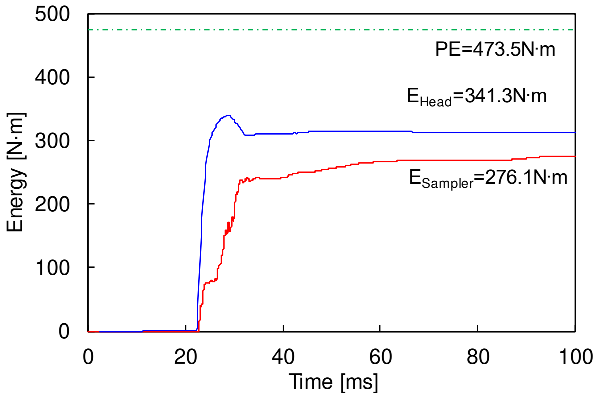


Figure 6. Transferred energy of head and sampler at 12.3m depth

The transferred energy and ER at the split spoon sampler are smaller than those at the head of the driving rod due to the attenuation of the driving energy at the extended driving rods. Therefore, correction of the SPT N-value by the transferred energy to the split spoon sampler is necessary for an abjective ground investigation considering the energy loss at the driving rods.

5. Summary and Conclusion

In this study, standard penetration test (SPT) is conducted with measuring the transferred energy at the head of the driving rod and the split spoon sampler. The transferred energy at the head of the driving rod is measured by PDA test. In addition, the dynamic responses at the split spoon sampler are measured by the energy monitoring module, and the trnasferred energy is calculated by F-V integration method. The main conclusions are as follows:

1. Because energy attenuation occurs in driving rod, the measured energy at the head and split spoon sampler is different.
2. The penetration force of driving rod is caused by the transferred energy at the split spoon sampler. So, the reasonable SPT results may be obtained by correcting the N-value with the transferred energy at the split spoon sampler.

Acknowledgement

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