Improved Ground Vibration from Blast-Induced Liquefaction Testing

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INTRODUCTION

Blasting has been used as an effective soil densification technique since the 1930s. In recent decades, blast technique has also been used as an application of in-situ liquefaction testing to investigate the performance of full-scale foundations and ground improvement in in-situ liquefiable grounds (e.g., van Ballegooy et al. 2014). Ground vibration is a major concern in carrying out blasting safely. This paper reports characteristics of improved ground vibrations measured during the Ground Improvement Trials (GIT) carried out in Christchurch, New Zealand in 2013-2014 (van Ballegooy et al. 2014).

SITE CONDITION

The test site that is the subject of this paper located near the Avon River in Avondale, where the liquefaction and lateral spreading occurred during the 2011 Christchurch earthquake event. Young, loose, and soft sediments depositing in these areas were of relevance to seismically induced ground failures during the earthquake events. Figure 1 shows the subsurface soil conditions of Natural soils (i.e., non-improved soils) at the test site. The targeted soil stratum mainly consisted of medium dense sands with minor silts and silty sands. The surface soil was classified as GP-GM, and the subsurface soils were classified as SP, SM, and ML The ground water table (GWT) located at a depth of 1.0-1.5m from the ground surface.

FIELD EXPERIMENT

During the GIT, a total of eight shallow ground improvements were examined using blasting to compare how they mitigate differential ground surface settlement due to liquefaction. Figure 2 shows an example of the employed blast layouts. Each improved ground was constructed inside of each circle. During the series of blasts, 0.55-2.8kg of gelignite-type explosives were used. The explosives were detonation using 105-550ms delays. 3D geophone receivers were placed at a depth of 1.0m in the center of each circle.

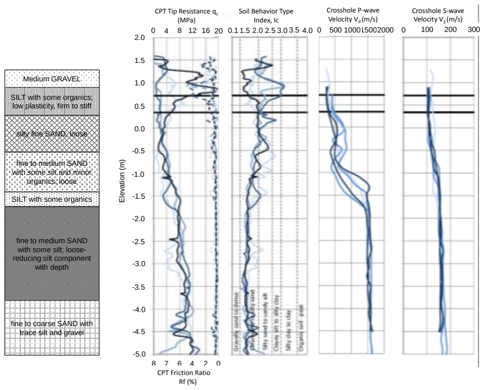

Figure 1. Subsurface soil profile at the test site (Modified from van Ballegooy et al. 2014).

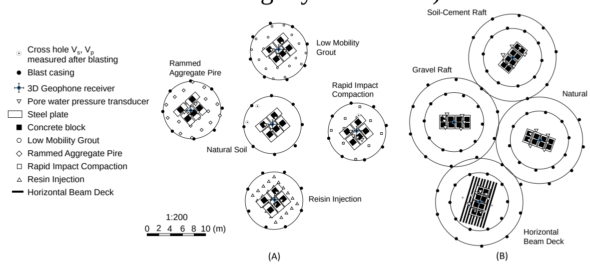

Figure 2. An example of employed blast layouts at the site during the GIT (Modified from van Ballegooy et al. 2014).

Pore water pressure placed in a depth of 4.0-11.5 m and detonated with 105-504ms delays. 3D geophone receivers were placed at a depth of 1.0m around the center of each circle. Pore water transducers were installed at a depth of 2.7-15.8m around the center of each circle.

RESULTS AND DISCUSSIONS

Figure 3 (A) shows the relationship between Scaled distance (SD) and peak particle velocity (PPV) for non-improved and improved grounds. Figure 3 (A) shows that the PPVs decreased with an increase of SD for both non-improved and improved ground. The results show that the maximum PPV are in the range of 0.22-0.26m/s for the natural soil and 0.21-0.26 m/s for the improved grounds, so the results show that the range of the maximum PPV was almost the same regardless of a type of ground improvements. Figure 4 (B) compares the results to the SD-PPV relationships obtained from the other sites. The dot lines are the boundary of the GIT. Figure 4 (B) shows that

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83% of the PPVs fell within the range from the GIT. It can be seen that the tendency of the relationship between PPV and SD from the free fields was the same as the GIT regardless of site condition. The comparison shows that PPVs from blast-induced liquefaction fall within a consistent range for both improved and non-improved grounds, and that range is the same. PPV-SD relationships are usually developed using power model (i.e., $PPV=C\cdot\left(R/\sqrt{W}\right)^{-n}$, where R is radial distance, W is charge mass of explosives, Eq.1). The mean regressive curves from the GIT and the free fields are provided in Eq.2 and Eq.3, respectively.

$$PPV = 2.75\left(R/\sqrt{W}\right)^{-1.46} \qquad \text{Mean} \qquad \text{(Eq.2)}$$

$$PPV = 1.47\left(R/\sqrt{W}\right)^{-1.33} \qquad \text{Mean} \qquad \text{(Eq.3)}$$

Figure 4 shows the relationship between seismic velocities and coefficients in Eq.1. P and S-wave velocities were measured in pre blasting in each improved ground. Figure 4 shows that P-wave velocity has correlated well with the coefficient C and n, however, there is no strong relationship between the coefficients and S, R-wave velocities. That indicates that P-wave velocities are an important attribute for the PPV-SD relationships at a short distance. Also, that indicates that ground vibrations from blast-induced liquefaction are sensitive to soil stiffness, not to a type of ground improvement. The measured P-wave velocity was approximately between 500 and 1,600m/s for both non-improved and improved grounds in the GIT. Because stiffness of unsaturated soils is usually less than water, P-wave velocities of subsurface soils typically fall within the same range as the measured values. The ground vibration collected from the other sites is measured at ground surface so that seismic wave velocities might fall within the same range as the GIT. This is a possible reason why PPVs fall within a certain range regardless of a type of ground improvements and site conditions.

Figure 5 (A) shows that high predominant frequency of 30-45 Hz was induced with PPV of 0.03-0.15m/s, and low predominant frequency of 3-10Hz was induced with PPV of 0.002-0.035m/s. Figure 5 (B) shows that a level of predominant frequency decreases with a decrease of PPVs. Moreover, Figure 5 (B) shows that the high predominant frequency was induced with a small SD, and the small

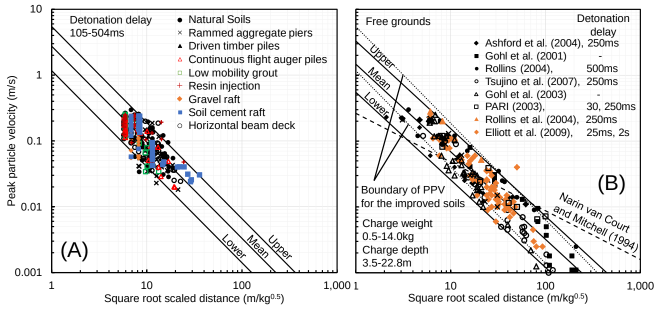

Figure 3. PPV-SD relationships from the GIT and the other sites (from Kato 2017).

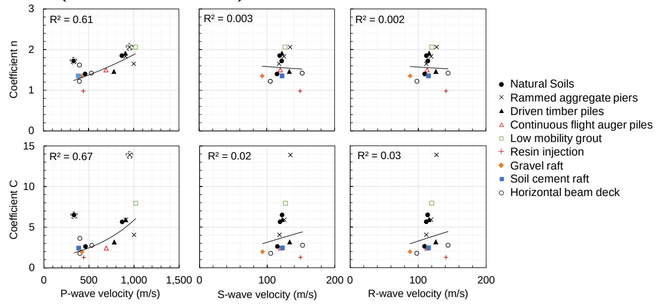

Figure 4. Seismic wave velocities and coefficient C and n (from Kato 2017).

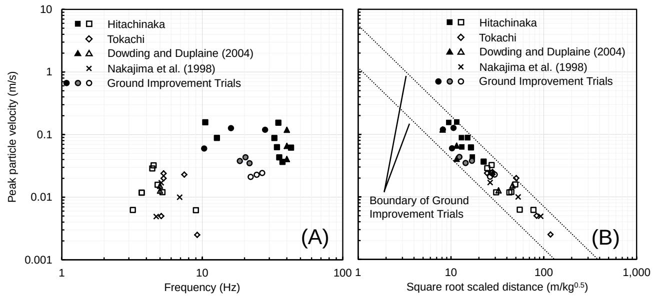

Figure 5. Predominant frequency measured in the GIT and the other sites.

predominant frequency was induced with a large SD. Therefore, the results show that a level of predominant frequency decreases with an increase of SD.

CONCLUSIONS

This paper provides PPV-SD relationships and predominant frequency measured during the Ground Improvement Trials carried out in Christchurch, New Zealand in 2013-2014. The results show that tendencies of improved ground vibration is fairly the same as non-improved grounds.

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