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QUALITY INVESTIGATIONS ON GROUND IMPROVEMENT IN HIGHWAY ENGINEERING PRACTICE

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ABSTRACT

The constructions of highway often pass through naturally-deposited liquefiable grounds. Anti-earthquake design is essential for highway engineering practice in east China. Gravel column and dynamic compaction are often adopted for the improvements of such problematical grounds. The stability and settlement of the treated grounds depend much on the construction quality. How to investigate the quality of ground improvement is an important issue in highway engineering practice. In this study, the method of Spectral-Analysis-of-Surface-Waves (SASW) is applied to evaluate the construction quality on ground improvements by vibration gravel piles and dynamic compaction technique. The case studies show that the SASW method is a powerful way for investigating the improvement quality in highway engineering practice. The shear wave velocity measured in SASW has a relative good relationship with the N value measured in standard penetration tests.

INTRODUCTION

In east China, the constructions of highway are in the ascendant. Highways often pass through problematical ground, such as soft clayey ground, loose silty/sandy soil ground, expansive soil ground or alternative layers of soft clayey soils and silty/sandy soils etc. For such grounds, ground improvement is essential for satisfying the requirements of stability and settlement of highway structures. The stability and settlement of the treated grounds depend much on the construction quality. How to investigate the quality of ground improvement is an important issue in highway engineering practice.

The method of Spectral-Analysis-of-Surface-Waves (SASW) is non-intrusive and non-destructive technique (Addo and Robertson, 1992; Yuan and Nazarian, 1993). The SASW is based on the dispersive characteristics of surface waves (Tokimatsu et al., 1992; Al-Hunaid, 1994; Gucunski et al., 1996; Kim et al., 2001). Many researchers have devoted many efforts on the application of SASW method in geotechnical engineering (Gucunski and Woods, 1992; Nazarian and Desai, 1993; Kim and Park, 1999). In this study, the SASW method is applied to evaluate the construction quality in engineering practice.

Lian-Xu highway is a main road of Jiangsu Province relating Lianyungang city to Xuzhou City. The construction of Lian-Xu highway encounters the liquefiable ground consisting of loose silty soils. Earthquake often occurs in China. Earthquake-proof design for highway construction is needed. For the liquefiable ground, dynamic compaction and vibration gravel pile are frequently adopted for ground improvement in China (Liu et al., 2000). In this study, field tests are performed on a liquefiable ground with both dynamic compaction technique and vibration gravel pile method. The shear wave velocity is measured by SASW method in the field tests. The case records of shear wave velocity are analyzed for various cases.

NATURALLY SEDIMENTARY LIQUEFIABLE GROUND

The typical physical properties of the soil layers under ground surface are shown in Table 1. It can be seen that the natural water contents are relatively high for silty soils. At the most upper layer, the natural water content is even larger than the liquid limit. This is due to the high underground water table. The water table was about 0.3 *m* under ground surface.

SASW test was performed o the natural ground to evaluate its liquefaction potential at different depths. The measured shear wave velocity for the natural ground Vs is shown in Table 2. According to the Geotechnical Engineering Reconnaissance Standard GBJ0021-94 (Ministry of Construction, 1995), the silty or sandy ground can be judged as liquefiable when the measured shear wave velocity (V_S) is less than the value of critical shear wave velocity V_{scr} calculated by following equations.

Table 1. Typical Physical Properties of Natural Ground.

Soil layer	Depth m	Unit weight kN/m2	Natural water cotent %	Liquid limit %	Plastic limit %
Yellow-brown silty soil	0~4	19.5	28.3	27.5	20.5
Gray silty soil	4~8	19.6	27.3	32.3	18.5
Gray clayey soil	8~11	19.2	24.5	30.0	18.0
Red dilluvial clayey soil	>11	19.0	29.2	39.0	20.0

Sandy soils: $V_{scr}=Kc(d_s-0.01d_s^2)^{1/2}$ (1)

Silty soils: $V_{scr}=Kc(d_s-0.0133d_s^2)^{1/2}$ (2)

Where Kc is coefficient, for sandy soils its value is 92、130 and 184 responsible for earthquake intensity of 7、8 and 9 respectively. For silty soils, the Kc value is 42、60 and 84 responsible for earthquake intensity of 7、8 and 9 respectively. The quantity d_s represents the measured dept (m). The calculated values of V_{scr} are also shown in Table 2. From Table 2It can be known that the upper soil layer ground lying from the ground surface to the depth of about 7m is liquefiable.

Table 2. Shear Wave Velocity for Natural Ground.

Depth (m)	Vscr (m / s)	Vs(m/s) (m / s)	Judgment
1~2	111.8	93.1	Liquefiable
2~3	143.6	99.2	Liquefiable
3~4	171.6	90.1	Liquefiable
4~5	190.7	93.1	Liquefiable
5~6	209.7	111.2	Liquefiable
6~7	226.8	109.6	Liquefiable

The in-situ standard penetration tests were also performed at 8 holes on the investigated natural ground. The measured N values at different depths for 8 holes are shown in Table 3. The liquefaction potential of the ground was judged based on the Anti-earthquake Design Standard of Road Engineering JTJ004-89 (Ministry of Transport, 1990). The results are also shown in Table 3. It can be seen that the upper layer ranging from the ground surface to the depth of about 7*m* is liquefiable. This result is consistent with that evaluated by SASW method. Hence, ground improvement is needed for improving the upper layer soils. Field tests of vibration gravel piles and dynamic compaction were performed on the liquefiable ground.

FIELD TEST OF VIBRATION GRAVEL PILES

The vibration gravel piles are installed in a plum blossom pattern with the diameter of 0.5m and length of 10m. Two types of pile space distances *D* from pile center to pile center are adopted: D=1.4m and D=1.6m. SASW tests are performed on the treated ground after the installation of piles at 2 days、

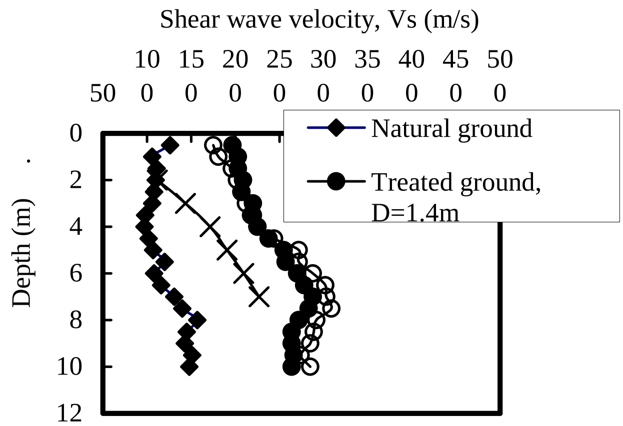

Fig. 1. Shear wave velocity after treatment of 2 days.

15 days and 30 days. Figure 1 shows the measured shear wave velocity Vs by SASW method after the treatment of 2 days. It can be seen that the values of shear wave velocity Vs measured by SASW method after treatment of 2 days are much larger than those the natural ground. For both the treated grounds with the D=1.4m and D=1.6m, the measured values of shear wave velocity Vs are larger than the values of critical shear wave velocity V_{scr} calculated by Equation 2. Hence, the natural ground is much improved. The treated ground is not liquefiable.

Figure 2 shows the increase in the measured shear wave velocity Vs by SASW method with elapsed time t (days) for

Table 3. Liquefaction Potential of Natural Ground (judgment based on JTJ004-89).

Hole	Depth m	Measured N value	Clay content (<0.005mm) %	Anti-liquefaction critical N value (Calculated based on JTJ004-89)	Judgment
G1	2.6~2.9	3	5.5	7.1	Liquefiable
	4.7~5.0	5	5.0	7.8	Liquefiable
G2	2.3~2.6	4	5.6	6.9	Liquefiable
	4.6~4.9	5	5.1	7.7	Liquefiable
	6.3~6.6	8	5.7	7.5	Not liquefiable
G3	2.1~2.4	4	5.2	6.9	Liquefiable
	4.9~5.2	5	5.0	7.8	Liquefiable
G4	2.5~2.8	4	4.5	7.5	Liquefiable
	5.5~5.8	5	4.9	7.9	Liquefiable
	8.5~8.8	12	5.4	7.3	Not liquefiable
	10.0~10.3	16	5.6	7.2	Not liquefiable
G5	1.9~2.2	4	5.1	6.9	Liquefiable
	5.5~5.8	4	5.6	7.6	Liquefiable
	7.3~7.6	7	6.7	7.2	Slightly liquefiable
G6	2.6~2.9	4	5.3	7.2	Liquefiable
	5.2~5.5	4	5.8	7.5	Liquefiable
	7.3~7.6	10	6.7	7.1	Not liquefiable
G7	2.6~2.9	4	6.2	6.8	Liquefiable
	5.3~5.6	4	5.0	7.8	Liquefiable
G8	2.5~2.8	5	5.6	7.0	Liquefiable
	5.4~5.7	4	5.3	7.7	Liquefiable

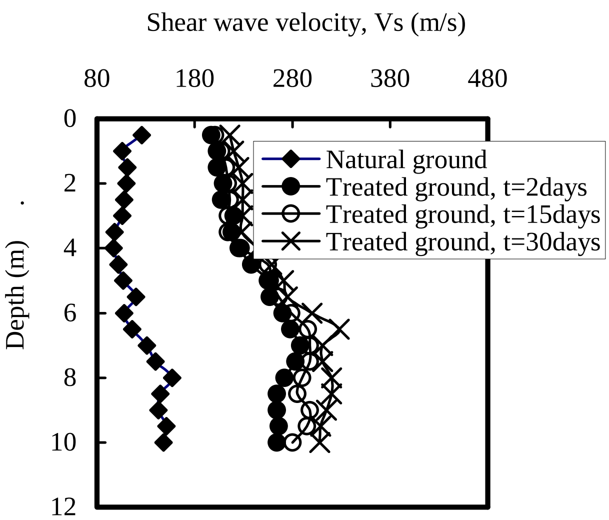

Fig. 2. The effect of elapsed time on shear wave velocity Vs by SASW method for the treated ground by vibration gravel piles with D=1.4m.

the treated ground by vibration gravel piles with D=1.4m. It can be seen that the measured shear wave velocity Vs by SASW method for the treated ground increases with the increase in elapsed time. Figure 3 shows the effect of pile space distances *D* from pile center to pile center on the treated ground. It can be seen that the shear wave velocity Vs for D=1.6m is slightly larger than that for D=1.4m at the relatively deeper soil layers. This phenomenon is most probably caused by the damage of soil structure of the surrounding soils duo to disturbance of pile installation. Hence, the determination of pile space distance should consider the effect of soil structure of the surrounding soils, even silty/sandy soils. The result in Figure 3 indicates that the small pile space distance not only costs more construction budgets, but also may decrease the construction quality.

FIELD TEST OF DYNAMIC COMPACTION

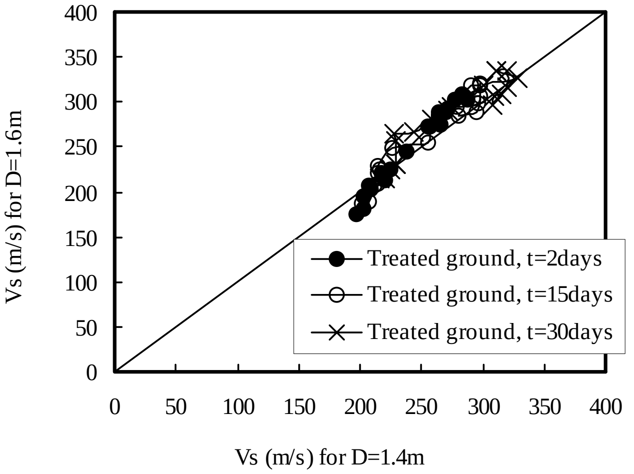

Fig. 3. Effect of pile space distances D from pile center to pile center on the shear wave velocity Vs by SASW method for the treated grounds.

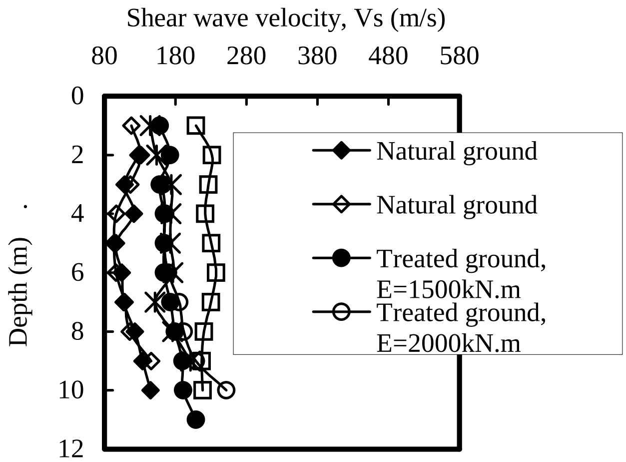

Fig. 4. Shear wave velocity Vs by SASW different single-drop-compaction energy.

Field tests of dynamic compaction were performed on the liquefiable ground with four different values of single-drop-compaction energy E. The values of *E* are 1500*kN•m*、2000*kN•m*、2500*kN•m* and 3000*kN•m* respectively. Figure 4 shows the shear wave velocity Vs of treated ground after the first drop under dynamic impact load with four different single-drop-compaction energies. The shear wave velocity Vs of natural ground is shown in the same figure for comparison. It can be seen that the values of shear wave velocity Vs responsible for the treated ground by the first drop are much higher than those of natural ground. This indicates that the ground is much improved even after only one drop of dynamic compaction. From Figure 4 it can also be seen that the shear wave velocity Vs for the treated ground after the first drop is not big different for the different values of single-drop-compaction energy of 1500*kN•m*、2000*kN•m*、2500*kN•m*. But the single-drop-compaction energy of 3000*kN•m* causes much larger shear wave velocity Vs than other three values of single-drop-compaction energy.

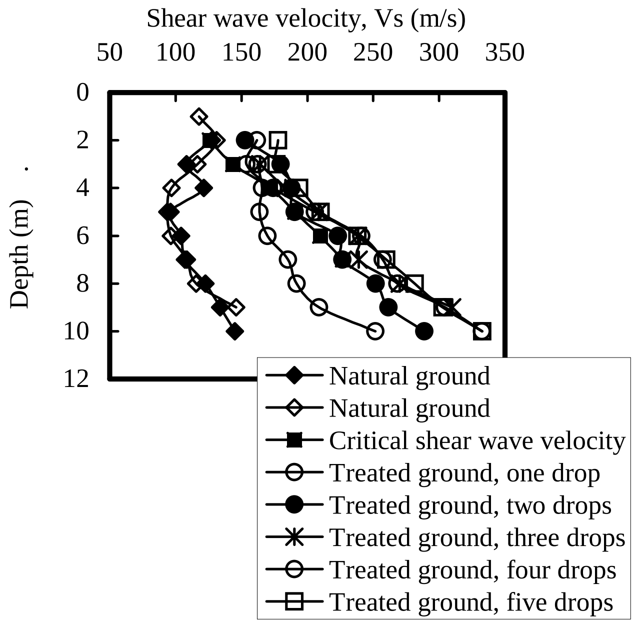

Fig. 5. The typical plot of the change in shear wave velocity Vs with drop numbers under the single-drop-compaction energy of 2000kN•m..

Figure 5 shows the typical plot of the change in shear wave velocity Vs with drop numbers under the single-drop-compaction energy of 2000*kN•m*. The values of critical shear wave velocity V_{scr} calculated by Equation 2 are also shown in the same figure. It can be seen that the shear wave velocity measured by SASW method increases with the increase in drop numbers. After two drops, the measured Vs values are larger than the values of V_{scr}. Figure 6 shows the effect of elapsed time t (days) after treatment by dynamic compaction on ground improvement. It can be seen that the treated ground with elapsed time of 3 days has much high value of shear wave velocity than the treated ground after compacted immediately.

It should be mentioned that standard penetration test (SPT) is routinely performed to investigate the construction quality. While the SASW method is a relatively new technique for quality investigation. Figure 7 shows the relationship between the SPT N value and shear wave velocity Vs measured by SASW method for both the natural ground and the treated ground by dynamitic compaction. It can be seen that the shear

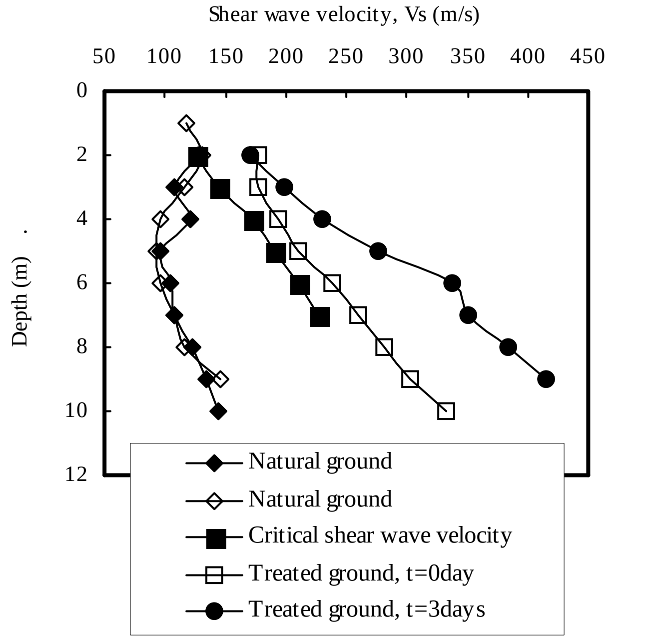

Fig. 6. The effect of elapsed time t (days) after treatment by dynamic compaction on ground improvement.

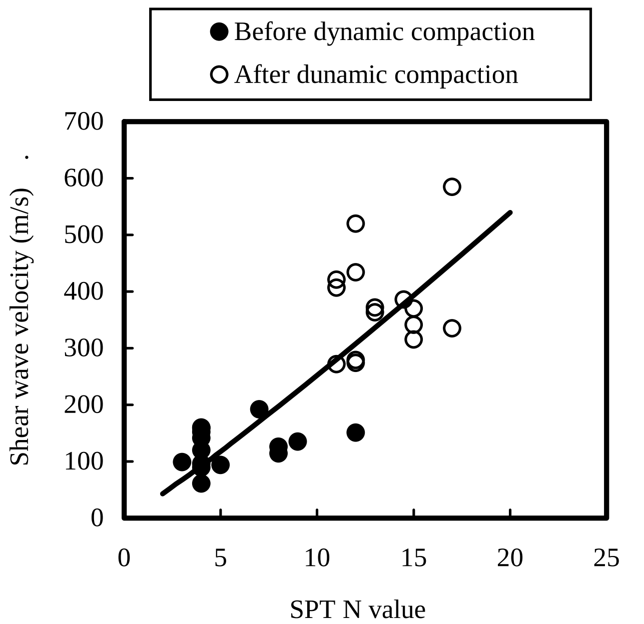

Fig. 7. The relationship between the SPT N value and shear wave velocity Vs by SASW method for both the natural ground and the treated ground by dynamitic compaction.

wave velocity measured in SASW has a relative good relationship with the N value measured in standard penetration tests. Their relationship can be approximately expressed as following equation for both the natural ground and the treated ground by dynamitic compaction.

$$Vs = 20(N)^{1.1} \quad (3)$$

CONCLUSIONS

The main conclusions obtained in this study can be summarized as follows.

1) Field tests of vibration gravel piles and dynamic compaction are performed on a liquefiable silty ground for ground improvement. Both the vibration gravel pile method and dynamic compaction technique can be effectively used for ground improvement on liquefiable ground.
2) The SASW method is a powerful way for investigating the construction quality of the treated grounds by both the vibration gravel piles and dynamic compaction.
3) The shear wave velocity measured in SASW has a relative good relationship with the N value measured in standard penetration tests. Their relationship can be approximately expressed as following equation for both the natural ground and the treated ground by dynamitic compaction : $Vs = 20(N)^{1.1}$.

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