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Appraisal Research on Rayleigh Wave Method for Gravel Piles Composition Foundation

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Abstract: Rayleigh wave method is a relative new in-situ method to the evaluation of low-amplitude shear wave velocity V_s in soil as a function of depth. The method is investigated to appraise the treatment effects of gravel piles anti-liquefaction. The appraisal results of the shear wave velocities measured by Rayleigh wave method are consistent with SPT's. The relative formula of shear wave velocities with $N_{63.5}$ is presented based on the regression analysis. Rayleigh wave method is applied to determine the shear wave velocity of soils in a simple, nondestructive way.

Key words: rayleigh wave, SASW, liquefaction foundation, SPT

Seismic methods most often used today to profile near-surface soils are the cross-hole and down-hole methods. Those methods involve body wave measurements and thus require the installation of one or more bore-holes. Bore-hole installation is generally time consuming and costly. The Rayleigh wave method, on the other hand, involves measurement of surface wave of Rayleigh type to evaluate shear wave velocity and shear modulus profiles. The spectral analysis of surface wave (SASW) is used in Rayleigh wave method. So, Rayleigh wave method is called SASW. In the Rayleigh wave method both the source and receivers are placed on the ground surface. Rayleigh waves generated by applying vertical loading to the ground surface are monitored. The propagation velocity and stiffness profile of the site is typically calculated through a forward modeling and inversion process.

Any significant velocity or stiffness changed due to a soil improvement, for instance, or a construction phase can be directly determined without recourse natureof Rayleigh wave method and the fact that it is based on stress wave propagation makes it ideal for evaluating purpose. Rayleigh wave method has been proved to be a valuable tool for determining shear wave velocity profiles, effectiveness of soil improvement techniques and evaluation of soil liquefaction potential from surface measurements results in substantial time and cost savings compared to other seismic methods, such as cross-hole and down-hole techniques. In the paper, Rayleigh wave method is investigated to evaluate the treatment effects of gravel piles anti-liquefaction.

1 SASW Method

The spectral analysis of surface wave (SASW) method is a testing procedure for determining shear wave velocity profile of soil layers in-situ. The test is performed from the ground surface without bore-holes. Measurements are made at low strain levels (strain levels below 0.001%), where elastic properties of soil are considered independent of strain amplitude. Key elements in SASW testing are the generation and measurement of Rayleigh waves. The method has been used to date for a number of applications including design of foundations for dynamic loads, nondestructive pavement evaluation of the integrity of a concrete dam and as a diagnostic tool for determining effectiveness of soil improvement technique. The SASW method is proven to be a valuable tool for determining shear wave velocity profiles.

A number of publications in recent years have described the SASW method in detail[2-4]. Current practice calls for locating several vertical receivers on the ground surface, a known distance apart and a wave containing a large range of frequencies is generated in the soil by means of a hammer, vibrator, or energy source. Testing is usually conducted in both the forward and reverse direction by placing the source on either side of the centerline. Surface waves are detected by the receivers and recorded by using a Fourier spectrum analyzer. The spectral analysis function of interest here are the phase of the cross power spectrum and the coherence function. Knowing

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the distance and relative phase shift between the receivers for each frequency, the velocity of the surface wave (phase velocity) associated with that frequency is calculated. This relationship is known as the dispersion curve. The final step is application of an inversion process that constructs the shear wave velocity profile from the dispersion information.

Numerous investigations have been reported in which the reliability of the SASW method has been assessed. However, most reliability assessments have concentrated on accuracy (bias) of the test results, typically by compared results from SASW with results from other established testing methods such as the cross-hole technique.

2 Characteristics of Soil Layers in Site

The site locates on a sillation valley flat of Yangzi River in Nanjing of China. The soil profile is given in Tab.1. Tab.1 shows that the site belongs to liquefaction foundation. It is of disadvantageous factor for the anti-seismic area because Nanjing area is 7° earthquake intensity area. So, anti-liquefaction treatment must be taken for the building of industry and civil construction in the site and gravel pillars are adopted to treat the liquefaction foundation according to engineering design.

Tab.1 The soil profile in the site

Soil layer	Soil name	Depth range/m	Colour	Soil component	$N_{63.5}$	I_P	Liquefaction potential	Designing treatment method
①-1	Miscellaneas fill	0.0 – 1.2	Yellow, grey	Silty clay	4	15.3		Excavation
①-2	Plain fill	0.1 – 2.0	Yellow, grey	Silty clay	3	16.1		Excavation
①-3	Muck fill	1.8 – 2.1	Grey, black	Mucky soil	4	23.1		Excavation
②-1	Silty fine sand	2.1 – 7.4	Grey	Silty sand, Silty fine sand	4	6.2	Serious liquefied	Anti-liquefaction
②-2	Silty clay	7.1 – 9.6	Grey	Silty fine sand	6	9.4	Medium liquefied	Anti-liquefaction
②-3	Silty fine sand	8.8 – 20.1	Grey	Silty clay, silty fine sand	12	12.6		

3 Rayleigh Wave Measurement and Evaluation

3.1 Rayleigh wave measurement

Rayleigh wave measurement uses the multiple traces surface wave equipment — SWS-1A. In the test, we use 12 traces (i.e. 12 receivers used in the test) to receive Rayleigh wave signal (See Fig.1). The purpose of multiple traces receiving is to increase sign-to-noise ratio of Rayleigh wave and distinguish effectively Rayleigh wave. The spacing interval of traces (Δx) is 2?m, offset is 8?m in the measurement. The whole measurement is divided into two steps. The first step is for original foundation, the second step is for gravel piles composite foundation.

3.2 Evaluation of liquefaction potential

Evaluation of liquefaction potential is basic of liquefied ground improvement. In the past, SPT was used as the major tool to evaluate liquefaction potential, however, it was costly and in-situ construction consumed a lot of time. SASW method was used to detect liquefaction potential and the contrastive tests with the SPT method were made.

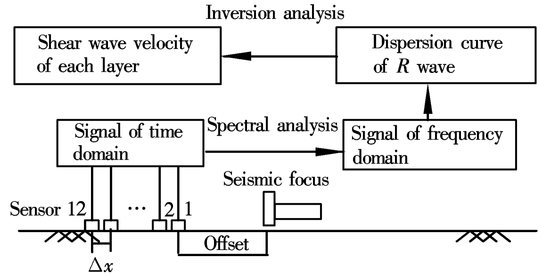

Fig.1 Principle chart of Rayleigh wave measurement

The critical shear wave velocity V_{scr} is adopted by the formula provided by *Geotechnical Engineering Code* (GBJ0021—94, in Chinese).

$$V_{scr} = k_s \sqrt{(d_s - 0.01 d_s^2)} \text{ (for sands)} \quad (1)$$

$$V_{scr} = k_s \sqrt{(d_s - 0.013?3 d_s^2)^2} \text{ (for silt)} \quad (2)$$

where d_s is depth; k_s is the empirical coefficient, when the measured shear wave velocity V_s is less than V_{scr}, ground is then evaluated as liquefied.

The recommended formula for the SPT method is adopted from *Structure Anti-Seismic Design Code*

(GBJ11—89, in Chinese)

$$N_{cr} = N_0[(0.9 + 0.1(d_s - d_w)]\sqrt{\frac{3}{\rho_c}} \qquad (3)$$

where d_s is depth of SPT; d_w is the depth of groundwater level; ρ_c is the content of clayey particle; N_0 is reference value of the SPT blow number.

When measured SPT blow number N is less than N_{cr}, then ground is evaluated as liquefied. The liquefaction grade is further judged according to the liquefaction index number.

Fig.2 gives the measuring results of shear wave velocities by Rayleigh wave method. The measuring results show that the shear wave velocities of the composite foundation of gravel piles treatment are obviously increased compared to the original foundation and evidently larger than critical shear wave velocity of liquefaction foundation. Simultaneously, the results are consistent with SPT's, the gravel piles treatment realized the purpose of dispelling liquefaction.

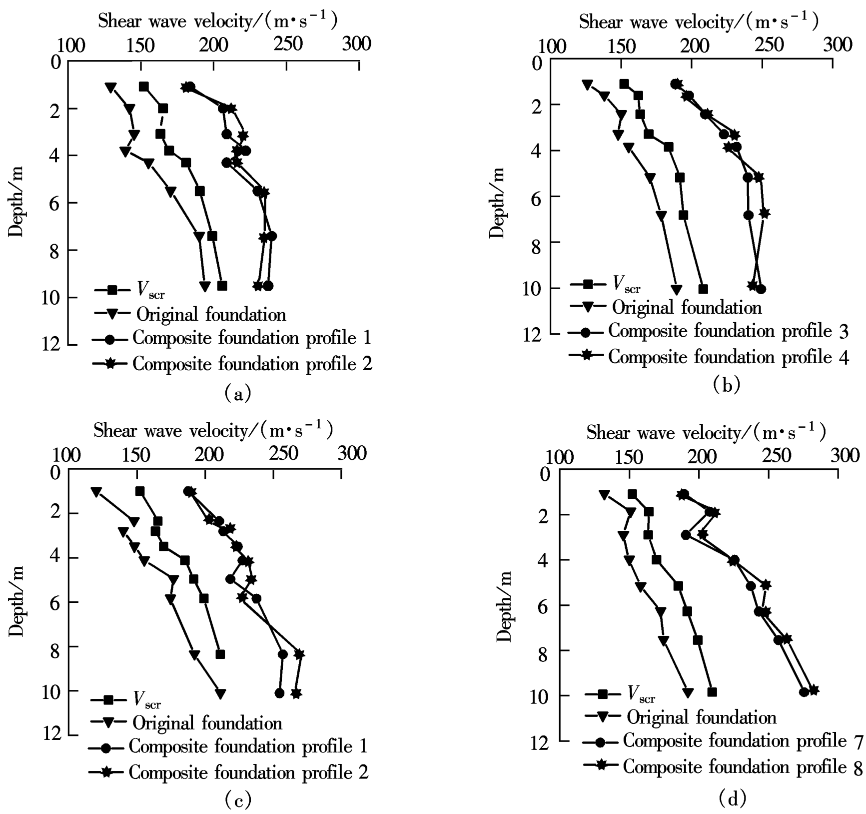

Fig.2 Shear wave velocity profiles of SASW

Fig.3 gives the results of shear wave velocity versus SPT number of gravel piles composite foundation. On behave of popularizing Rayleigh wave method to evaluate liquefaction potential of liquefaction foundation, we take regression analysis for the shear wave velocity and SPT blow number. The regressive equation is given as follows:

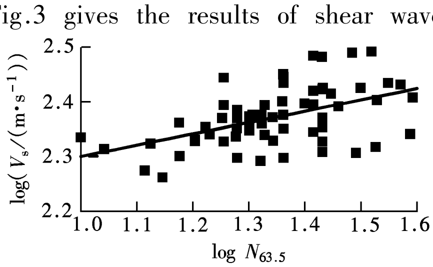

Fig.3 Shear wave velocity versus $N_{63.5}$

$$V_s = 123.3N_{63.5}^{0.21} \qquad (4)$$

4 Conclusions

1) SASW method is confirmed to be a rapid, nondestructive and reliable new tool for the evaluation of the ground improvement, especially for the large-scale ground improvement;

2) SASW can be used to evaluate liquefaction potential of liquefied ground;

3) SASW can be used to evaluate improvement of gravel pile composite foundation;

4) The shear wave velocity measured by SASW conforms well on the result of SPT. There is a good relationship between the shear velocity V_s and the SPT.

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碎石桩复合地基瑞雷波评价研究

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摘　要　低振幅的剪切波速 V_s 是土层深度的函数，瑞雷波法对剪切波波速的评价是一种新的原位测试方法. 本文研究了瑞雷波法，并对碎石桩法加固液化地基的处理效果进行了评价，瑞雷波法检测结果与标准贯入试验结果对比相一致，根据对剪切波波速与标贯击数相关分析，提出了相关的关系式，瑞雷波法是一种简便、无损评价方法.

关键词　瑞雷波，面波频谱分析，液化地基，标准贯入试验

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