Development and field application of static cone penetrometer combined with dynamic penetration

Développement et application sur le terrain du pénétromètre à cône statique associé à la pénétration dynamique

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ABSTRACT

New type static cone penetration equipment called combination cone was developed for more appropriate evaluation of housing land bearing capacity. The combination cone penetration equipment installs dynamic penetration mechanism to increase cone penetration power, but does not attach the pore water pressure measurement function to promote the efficiency of the work. To establish the bearing capacity evaluation method with high reliability from the combination cone penetration test result, the in-situ experiment of combination cone penetration test, plate loading test, three-component cone penetration test and Swedish weight sounding test was executed on a lot of sites in Kanto and Kansai district in Japan. An empirical formula of the bearing capacity was proposed based on this correlation. On the other hand, a good correlation was not obtained between number of half turn N_{sw} of Swedish weight sounding test result and cone resistance q_c. Some problems when the bearing capacity was calculated from Swedish weight sounding test result were confirmed. To be obtained higher additional values, the surface wave exploration can be combined with the combination cone penetration test. The surface wave exploration can be obtained the cross section of *S*-wave velocity corresponding to soil stiffness. The surface wave exploration combined with the combination cone penetration test is very useful in-situ investigation approach for the estimation of the bearing capacity of housing land.

RÉSUMÉ

Un nouveau type de pénétromètre à cône statique appelé cône combinatoire a été développé pour évaluer de manière plus appropriée la capacité portante de terrains d'habitation. Le pénétromètre à cône combinatoire est doté d'un mécanisme de pénétration dynamique permettant d'accroître la puissance de pénétration du cône, mais, afin de renforcer l'efficacité des travaux, il n'inclut pas la fonction de mesure de la pression de l'eau interstitielle. De manière à établir avec une haute fiabilité la méthode d'évaluation de la capacité portante à partir des résultats d'essai de pénétration à cône combinatoire, une série d'essais, à savoir l'essai in-situ au pénétromètre à cône combinatoire, l'essai à la table, l'essai de pénétration au cône de trois composants, et l'essai au pénétromètre à cône suédois, a été réalisée sur un lot de sites dans les régions du Kanto et du Kansai au Japon. Une formule empirique de la capacité portante a été proposée sur la base de cette corrélation. Toutefois, une bonne corrélation entre le nombre de demi-tours N_{sw} des résultats d'essai au pénétromètre à cône suédois et la résistance du cône q_c. n'a pas été obtenue. Lors du calcul de la capacité portante à partir des résultats d'essai au pénétromètre à cône suédois, des problèmes ont été confirmés. Pour obtenir des valeurs complémentaires plus élevées, l'exploration des ondes de surface a été associée à l'essai de pénétration à cône combinatoire. L'exploration des ondes de surface peut être effectuée avec la coupe transversale de célérité d'ondes S correspondant à la rigidité du sol. L'exploration des ondes de surface associée à l'essai de pénétration à cône combinatoire est très utile dans l'approche des essais in-situ pour l'estimation de la capacité portante des terrains d'habitation.

Keywords : static cone, plate loading test, bearing capacity, Swedish weight sounding

1 INTRODUCTION

Recently, a number of Swedish weight sounding tests (WST) have been used in Japan to evaluate a bearing capacity of housing land. The WST is a test method which is simple, easy and efficient procedure owing to a mechanical advance for automatic penetration. As for a test results using WST, however, there are such problems in particularly soft grounds that the testing data contain a not negligible effect of friction resistance of extension rods, and a penetration showing no turn of rotation is frequently taken place (Toyota et al. 2003). On the other hand, as for a piezocone penetration (CPTU) test, test results have a high repeatability and so many experienced data for design parameters have been obtained (Lunne et al.1997). But the CPTU test has a relatively troublesome preparation procedure on a measurement of pore pressure and then is inferior to the WST in terms of efficiency of field works.

From the view points of reliability and efficiency for site investigation of housing land, a new static cone penetration test equipment, called the Combination Cone Penetration equipment (CPTC) installed a dynamic penetration mechanism, was developed. The CPTC test is used to evaluate a bearing capacity of housing land mainly composed of unsaturated embankment soil using cone penetration resistance, q_c. The CPTC is not equipped with pore pressure measuring part so that an efficiency of testing work may promote. This paper presents details of the CPTC, a calculation method of a bearing capacity of housing land using the CPTC result, a comparative study of results between the CPTC test, the CPTU test and the WST test, and an applicability of the CPTC test in combination with a surface wave exploration method.

2 DEVELOPMENT OF THE COMBINATION CONE PENETRATION EQUIPMENT

For the purpose of improving a precision on estimating a bearing capacity of housing land, a combination cone penetration equipment (CPTC) was developed in 1991. In a field operation, a dynamic penetration by hammer (10kg in mass and 200mm in falling height) is carried out to a given depth first and followed by a static cone penetration test. This sequence of alternate penetration is performed every given

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depth. A cone tip is a single cone having 60° apex angle and base area of both 642mm^2 and 314mm^2. However a penetration capacity of this CPTC was founded to be less than that of the WST.

In 2005, a new type of CPTC furnished with an automatic penetration mechanism, an automatic recording system and a self-propelled system was developed (Figure 1). This new equipment can provide three types of penetration testing such as quasi-statistic penetration, dynamic penetration and static-dynamic combined penetration (Rito et al. 2005). These types of penetration testing can be selected based on types of ground. In a soft ground, a continuous quasi-penetration is conducted, and in a stiffer ground condition a continuous dynamic penetration is used. In an alternation layer condition combined with soft soils and stiff soils, an alternate procedure of static-dynamic combined penetration is applied. The dynamic penetration capacity of the new type of CPTC was promoted by improving a hammering energy such as hammer mass of 30kg and falling height of 500mm which corresponds to the DPM (medium) from the ISO International Standard.

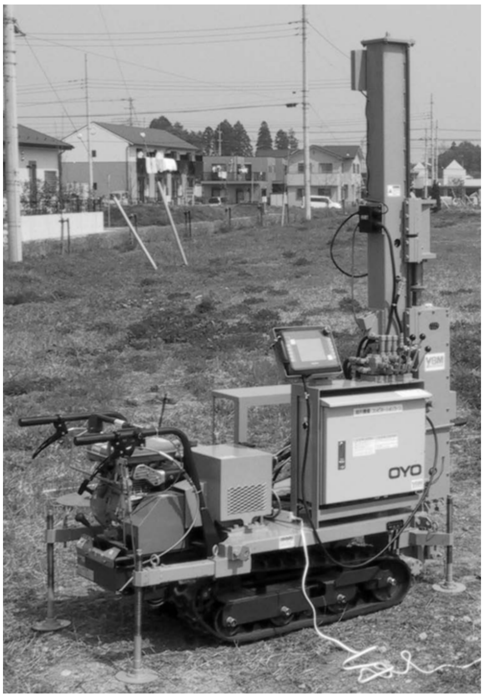

Figure 1. New combination cone penetration equipment.

3 CALCULATION METHOD OF BEARING CAPACITY USING THE CPTC TEST RESULTS

A comparative study between the CPTC test and a plate loading test was carried out in 24 sites of the Kanto district and in 4 sites of the Kansai district. In the Kanto district, embankment soils mainly consisted of Kanto Loam (i.e. volcanic ash clay) are distributed. On the other hand, in the Kansai district, embankment soils of argillaceous deposits from the Osaka formations are distributed. Figure 2 shows a correlation between a yield pressure, p_y, obtained from a plate loading test and a cone resistance, q_c. Similarly, Figure 3 shows a correlation between unconfined compression strength, q_u, and a cone resistance, q_c. Although those correlations indicate some amount of scattering, they are related by the following equations:

$$p_y = 0.15\, q_c \qquad (1)$$

$$q_u = q_c / 15 \qquad (2)$$

From Equation (1), a long term allowable bearing capacity of an individual footing foundation with zero embedded depth can be given in the following equation:

$$q_a = p_y/2 = 0.15\, q_c/2 = 0.075\, q_c \qquad (3)$$

And also, considering a continuous footing foundation as a form, and substituting a shape factor α=1.3 for individual footing foundation and α=1.0 for continuous foundation, the Equation (3) is rewritten as follows:

$$q_a = 0.075 q_c/\alpha = 0.075\, q_c/1.3 = 0.058\, q_c \qquad (4)$$

And since cohesion, c, is given in the following equation:

$$c = q_u/2 = q_c/30 \qquad (5)$$

A long-term allowable bearing capacity for a continuous foundation using Equation (5) and a bearing capacity factor N_c=5.3 is given as follows:

$$q_a = 1/3 \cdot \alpha \cdot c \cdot N_c = 1/3 \cdot 1.0 \cdot (q_c/30) \cdot 5.3 = 0.059\, q_c \qquad (6)$$

Since Equation (6) and (4) are almost the same, the correlative relationship between Equation (1) and (2) are conformable with each other.

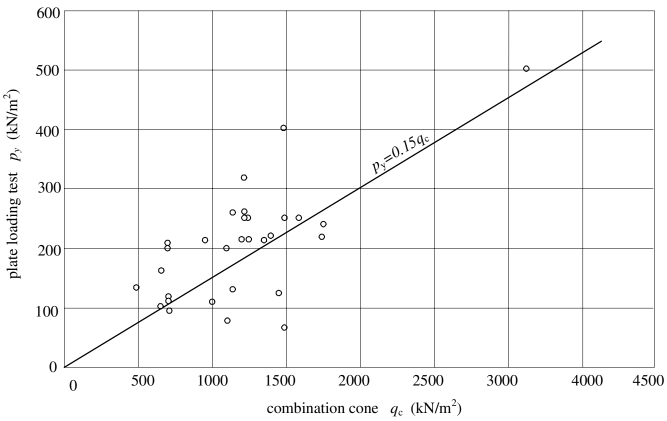

Figure 2. Relationship between p_y and q_c.

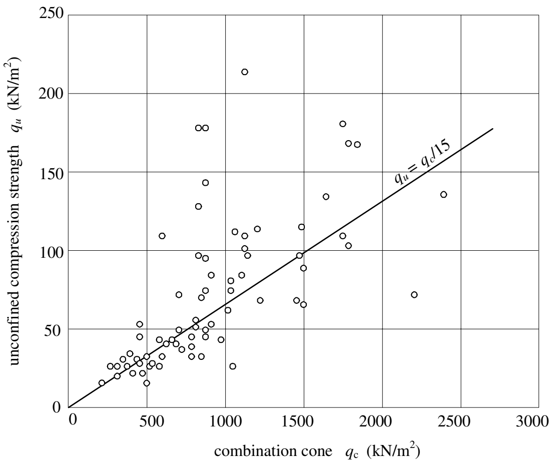

Figure 3. Relationship between q_u and q_c.

4 COMPARATIVE FIELD STUDY OF THE RESULTS BETWEEN THE WST, THE CPTC AND THE CPTU

Comparative field tests using three types of penetration test including the WST, the CPTC and the CPTU were performed in the embankment soils, called Loam of Kanto district (Rito et al. 2006). The Loam consists of about 40～60% fines (clay and silt), and about 40～60% coarse material (sand and gravel), containing the water content of about 25～35%. Figure 4 shows the results of these testing obtained at the almost same points. And also Figure 5 shows a correlation of the cone resistance, q_c, between the CPTC and the CPTU and Figure 6 shows a correlation between q_c from the CPTC and number of half turns, N_{sw}, from WST.

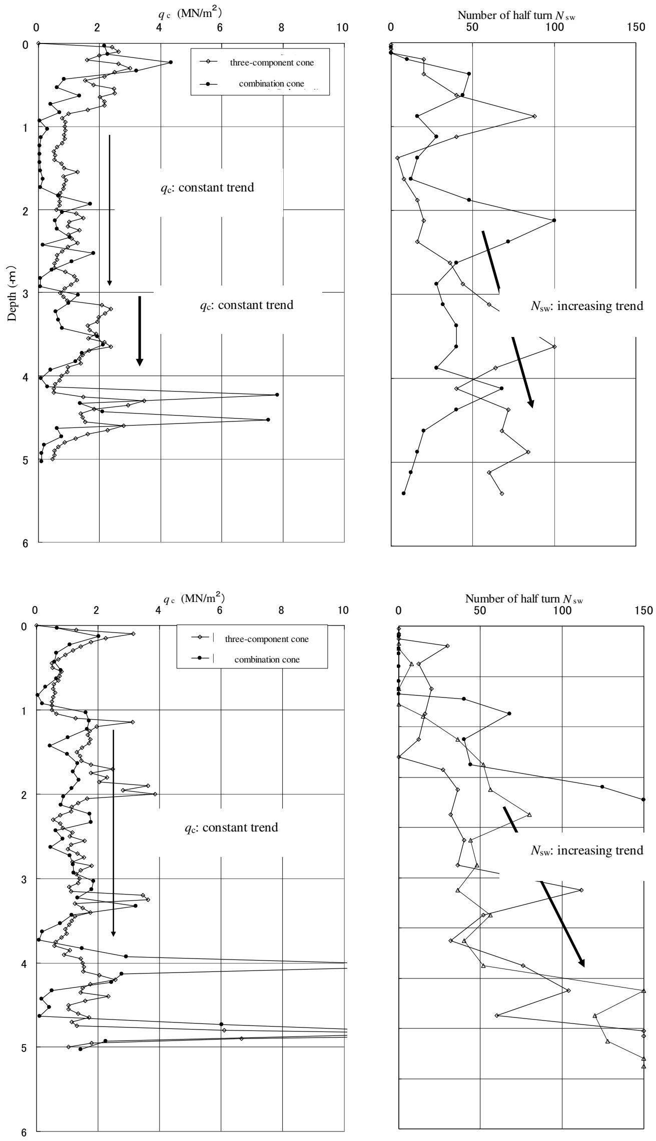

Figure 4. Depth distribution of q_c and N_{sw}

The profiles of the cone resistance, q_c, obtained from the CPTC and the CPTU show a certain values in depth and this values closely agree with each other. In addition, the pore pressure during the CPTU penetration showed a slightly negative value which was negligible small compared with a value of cone resistance. It is concluded from the field comparative study that the results from the CPTC gives almost the same level as that from the CPTU without a correction of cone resistance due to a pore pressure during penetration.

There is a different trend of testing results between the CPTC and the WST. The values of cone resistance, q_c, from the CPTC develop almost constant level with increasing depth, while N_{sw} from the WST tend to develop increases as penetration depth increases. And the correlation between q_c and N_{sw} shows significantly scattering. It is considered that the reason why the correlation between q_c and N_{sw} shows scattering is mainly that a excess resistance of surface friction of extension rod is added to the N_{sw} which gets increase with penetration depth. So the N_{sw} show excess values compared with q_c from the CPTC. Then it can be indicated that a results from the WST does not give a reasonable estimation of strength at a given depth in such a clayey soil as Loam.

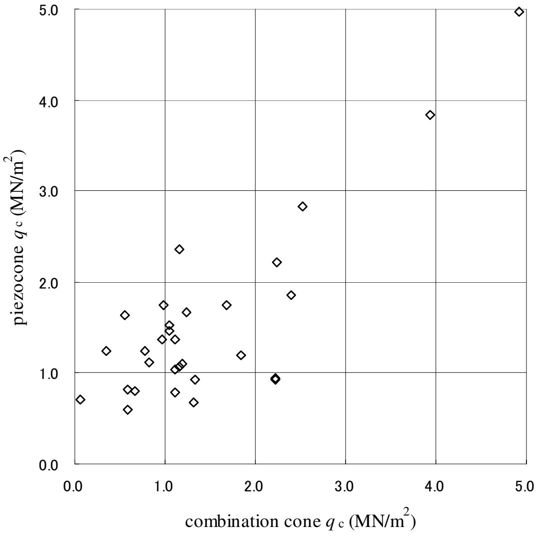

Figure 5. Relationship of q_c between combination cone and piezocone

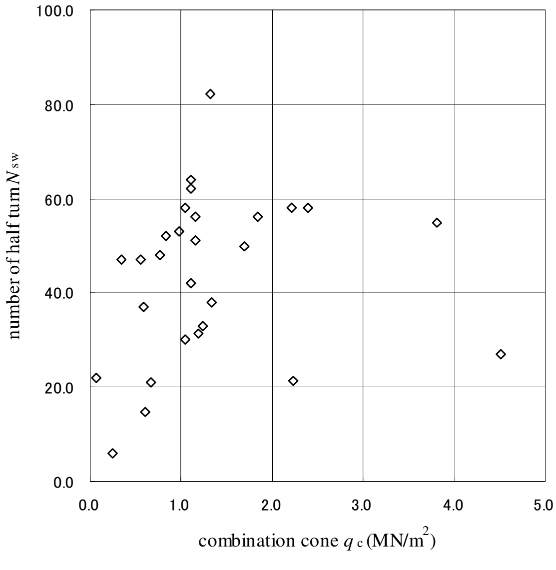

Figure 6. Relationship between q_c and N_{sw}

5 APPLICATION OF AN INVESTIGATION PROCEDURE BY COMBINING THE CPTC WITH A SURFACE WAVE EXPLORATION

A surface wave exploration (SWP) was carried out in the comparative study site mentioned above (Rito et al. 2007). The SWP is a method to obtain a distribution of S- wave velocity by analyzing a surface wave (Rayleigh wave) which transmits a

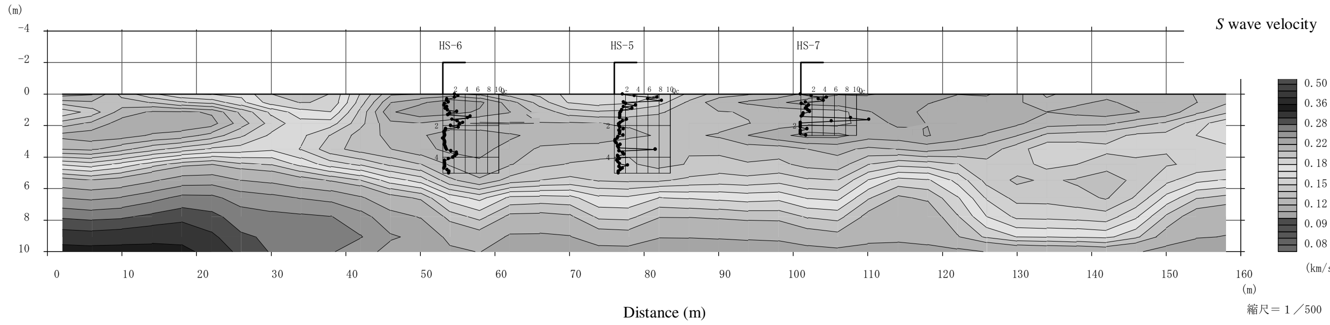

Figure 7. Cross-section of S wave velocity.

surface of the ground. A transmission velocity of the surface wave mainly reflects S-wave velocity of the ground to depth equivalent to a wave length. Since S-wave velocity correlates closely with N-value from the Standard Penetration test (SPT), it is evidently considered that the S-wave velocity should be correlated to the q_c obtained from the CPTC.

Figure 7 shows a cross section showing the distribution of S-wave velocity, containing the q_c profiles from the CPTC. From this figure, it can be seen that the S-wave velocities are not necessarily uniform and indicate the amount of scatter from 100m/s to 180m/s. The test results by the CPTC only show the one at a point area. But using the SWP information, the ground information of the section can be seen visually.

Figure 8 shows a correlation of q_c from the CPTC to S-wave velocity. From the figure, a following regression equation can be obtained:

$$V_s=11.26q_c+122 \quad (7)$$

where V_s: S-wave velocity (m/sec)
q_c: cone resistance from the CPTC (MN/m^2)

Combining Equation (7) and (6), a long-term allowable bearing capacity of a continuous footing foundation (q_a) using V_s can be obtained in the following equation:

$$q_a=0.0052V_s-0.639 \quad \text{provided that } V_s>122\text{m/s} \quad (8)$$

Using Equation (8), a diagram of cross-section related to a long term bearing capacity of housing land can be described based on the combined results of the CPTC with the SWP.

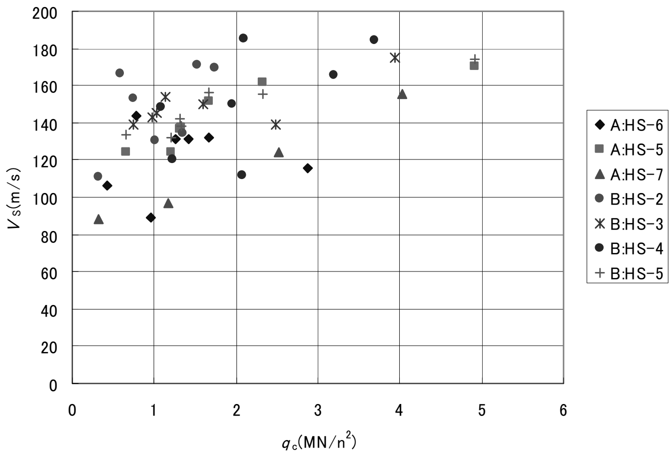

Figure 8. Relationship between V_s and q_c.

6 CONCLUSIONS

From an international point of view, it is not found except Japan that the Swedish weight sounding (WST) is used so frequently as in Japan. The WST at the beginning to be introduced was used as a supplementary tool for a site investigation method mainly in a soft ground, but recently is being abused improperly. The Combination Cone Penetration equipment (CPTC) was started developing application for estimating a bearing capacity of embankment soils in housing land using a static cone penetration which is known as a main current practice in the world. In recent years, the surface wave exploration (SWP) has been come into wide use as a more promising investigation method to survey shear strength of planar section of a ground. The authors have confidence that the CPTC is more excellent investigation method replacing the WST.

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