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FORCED VIBRATION TEST AND ITS ANALYTICAL STUDY FOR EMBEDDED FOUNDATION SUPPORTED BY PILE GROUP

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SUMMARY

A forced vibration test on an actual embedded foundation supported by a pile group was carried out for the purpose of obtaining basic data to execute analyti-cal investigation. And then simulation analysis was performed by the analytical method based on Thin Layer Method (hereafter TLM ; Ref.1,2,3). The analytical results showed a good agreement with the test results and it was confirmed that this analytical method is efficient for estimating dynamic behavior of soil-pile-structure systems.

INTRODUCTION

The dynamic behavior of a structure on pile-foundation is strongly influenced by the dynamic soil-pile-structure interaction effect. In the study of a structure on pile-foundation, it is important to estimate precisely the effect of the dynamic characteristics of the soil-pile-structure system. However, only a few analytical studies exist regarding the problem of dynamic interaction of embedded foundations supported by pile groups because of analytical difficulty and the amount of computational time required. The authors also developed the analytical method based on TLM, and verified its usefulness by a simulation analysis of a forced vibration test on a full-scale unembedded pile-foundation(Ref.4). In this paper, an improved method taking account of the effect of embedment is introduced, and its adequacy is discussed using the simulation analysis.

FORCED VIBRATION TEST

OUTLINE OF THE FORCED VIBRATION TEST The tested structure is a foundation supported by pile group for a 24 story building which is under construction. As shown in Fig.-1, the high-rise section is supported by 69 cast-in-place reinforced concrete piles of ϕ1500 and the low-rise section by 15 piles of ϕ1100, whose length is 12.5m. Soil profile at the test site, shown in Fig.-2, can be idealized as layered strata. Also, the supporting soil at the pile tip is a gravel layer with shear wave velocity of 490m/sec, at G.L.-19m depth. The forced vibration test was conducted using two units of vibration generator (maximum excitation load of 3ton per unit) installed on the 1st floor, after fabricating the column reinforcement in forms of the same floor.

OUTLINE OF TEST RESULTS Examples of the test results are: the resonance curves and phase lag curves in Fig.-3 and Fig.-4, the vibration mode at 2.4Hz in Fig.-5, and the soil stiffness derived from the average displacement in the test with the assumption of rigid foundation in Fig.-6 and Fig.-7. The test results shown are only of the longitudinal excitation. The dynamic characteristics that can be judged from above results are as follows:

i) Regarding the horizontal resonance curves of the basement floor, a remarkable peak near 3~4Hz can be seen. The amplitude becomes smaller in the high frequency range because of radiation damping(See Fig.-3).
ii) The rocking motion of the foundation is not so large compared with other motions, while the amplitudes of horizontal motion of both the 1st floor and the basement floor are about the same(See Fig.-5).
iii) Both the horizontal and rotational stiffness obtained from the test results indicate that the real part decreases like a curve of second order as the excitation frequency becomes higher and the imaginary part increases in a straight line manner in proportion with the excitation frequency. This is a general tendency of radiation damping(See Figs.6-7).

ANALYTICAL METHOD

OUTLINE OF ANALYTICAL METHOD The outline of the analytical method is summarized below. As shown in Fig.-8, the total stiffness of the embedded foundation supported by the pile group is approximated as the combination of following three stiffnesses, *K1~K3*. *K1* represents the stiffness of the embedded foundation without piles, *K2* represents the stiffness of a foundation supported by the pile group resting on the artificial ground surface, and *K3* represents the stiffness of a foundation without piles resting on the artificial ground surface. The analysis is based on TLM, and the foundation is assumed to be rigid and massless. It is assumed that the stiffness of the pile group can be estimated as the difference between the stiffness *K2* and *K3*. The total stiffness is calculated by adding the stiffness of pile group *K2-K3* to the stiffness *K1*.

COMPARISON STUDY WITH FEM In order to examine the appropriateness of the proposed method, a comparison of total stiffness is made, using a simple model shown in Fig.-9, with FEM(Ref.5). As an analytical model, a circular embedded rigid foundation supported by pile group is employed. Then the dynamic soil stiffness is calculated. Fig.-10 shows each dynamic stiffness, i.e. the embedded rigid foundation (*K1*;full line), the rigid foundation supported by pile group (*K2*;dashed line), and the rigid foundation on the artificial ground surface (*K3*;dotted line). The difference between the dashed line and the dotted line indicates the additive stiffness of the pile group, and it is evident that the piles greatly influence the rotational stiffness. Also the difference between the full line and the dotted line indicates the effect of embedment. Fig.-11 shows the total dynamic stiffness. In this figure the full line indicates the result of the proposed method, and the dotted line the FEM analysis. The two are in good agreement.

SIMULATION ANALYSIS

ANALYTICAL MODEL Simulation analysis is performed by using the actual pile arrangement shown in Fig.-1. The soil profile for the simulation analysis is the same as shown in Fig.-2. The pile tip is assumed to be pinned, and a half-space condition(Ref.6) is applied to the bottom of the thin layer model. Moreover, the foundation is assumed as a rigid block considering the test result. The frequency range of calculation is up to 10Hz.

EXAMINATION OF ANALYTICAL RESULTS In Fig.-12, the horizontal and rotational dynamic stiffness obtained by the proposed method are compared with test results. They are in good agreement although there are some differences regarding the real part of the rotational stiffness. Fig.-13 shows the horizontal and vertical displacement of the basement floor respectively in comparison with test results. Regarding the horizontal displacement, it shows a good agreement in that a peak exists at 3~4Hz, the amplitude gradually decreases after the peak, and there is little difference between the amplitude of the analytical results and that of test results in all frequency range. Regarding the vertical displacement which is much smaller than the horizontal displacement, the value of the analytical result is about the same as the average value of the test result although the scattering which appears in test results is not naturally represented because of the assumption of the rigid foundation. The phase lag curves of both horizontal and vertical displacement are in good agreement.

CONCLUSION

A forced vibration test on an actual embedded foundation supported by a pile group was carried out. And then simulation analysis was performed by using the proposed method taking account of the effect of both embedment and pile group, based on TLM. From the foregoing results of simulation analysis, it is confirmed that the dynamic characteristics of structures supported by pile group with embedment, though extremely difficult to analyze, can be comprehended at the practical level by using the method reported herein.

REFERENCES

1. Kausel, E. and Peek, R., "Dynamic Loads in the Interior of a Layered Stratum ; An Explicit Solution", Bull. Seis. Soc. Am. vol.72 p1459-p1481 (1982)
2. Tajimi, H., "A Contribution to Theoretical Prediction of Dynamic Stiffness of Surface Foundation", Proc. of 7th World Conf. on Earthq. Eng., Istanbul, Turkey, p105-p112 (1980)
3. Tajimi, H., "Predicted and Measured Vibration Characteristics of a Large-Scale Shaking Table Foundation", Proc. of 8th World Conf. on Earthq. Eng., San Francisco, U.S.A., p873-p880 (1984)
4. Masuda, K., Sasaki, F., Urao, K., Ueno, K., and Miyamoto, Y., "Simulation Analysis of Forced Vibration Test for Actual Pile Foundation by Thin Layer Method", Proc.of Reliability and Robustness of Engineering Software, Como, Italy, p243-p256 (1987)
5. Tyson, T. R. and Kausel, E., "Dynamic Analysis of Axisymmetric Pile Groups", M.I.T. Research Report R83-07 (1983)
6. Hull, S. and Kausel, E., "Dynamic Loads in Layered Halfspace", Proc. of 5th EM Division Specialty Conference, ASCE (1984)

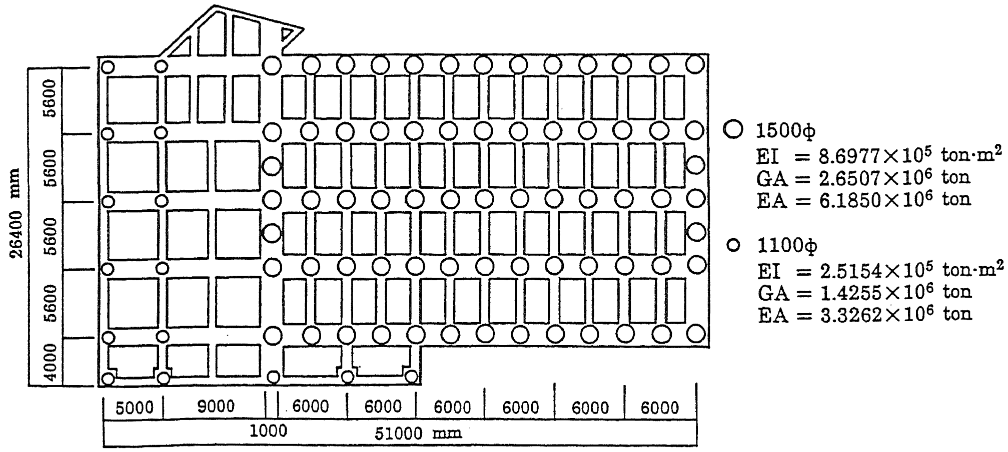


Fig.-1 Pile Arrangement

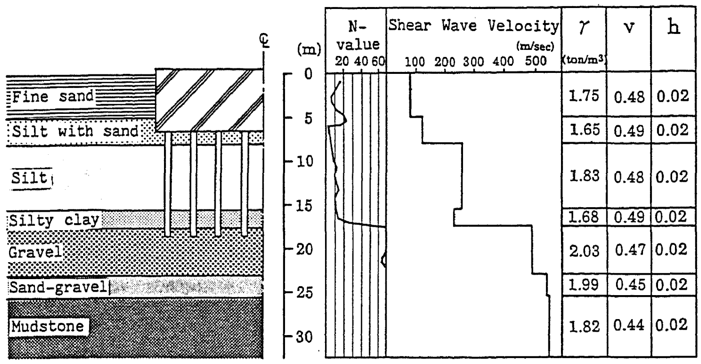


Fig.-2 Soil Profile

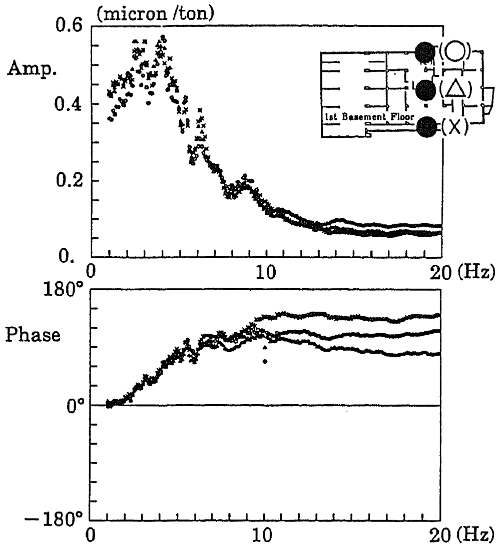


Fig.-3 Test Results (Horizontal Motion)

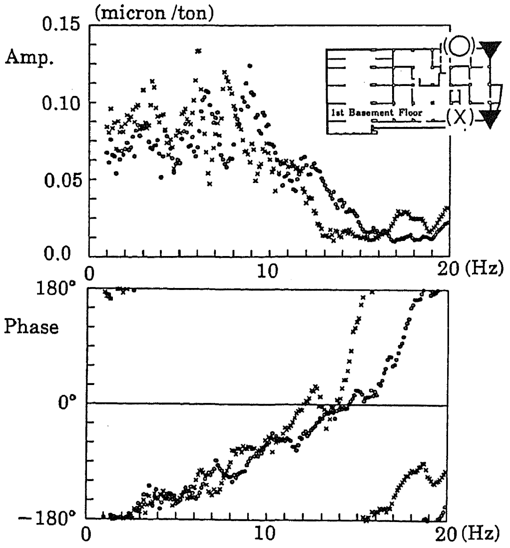


Fig.-4 Test Results (Vertical Motion)

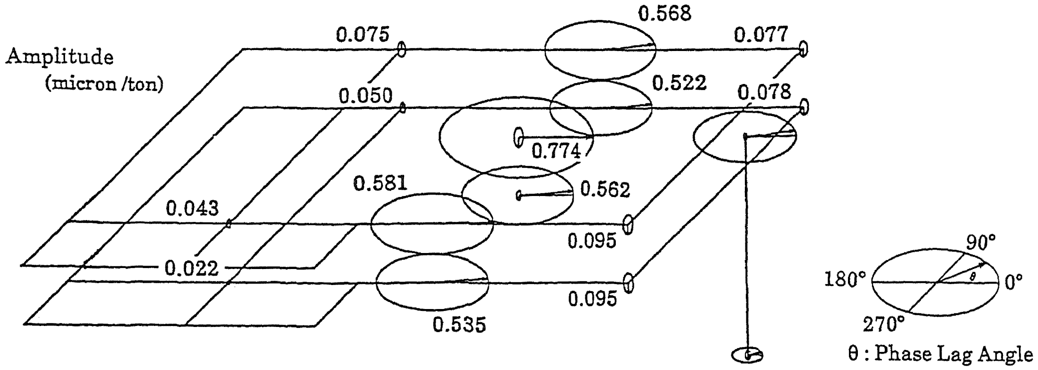


Fig.-5 Test Results (Vibration Mode 2.4 Hz)

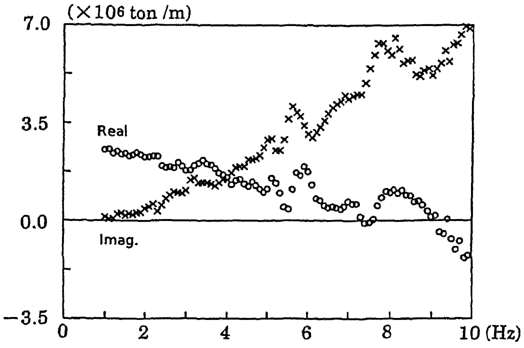


Fig.-6 Test Results
(Horizontal Stiffness)

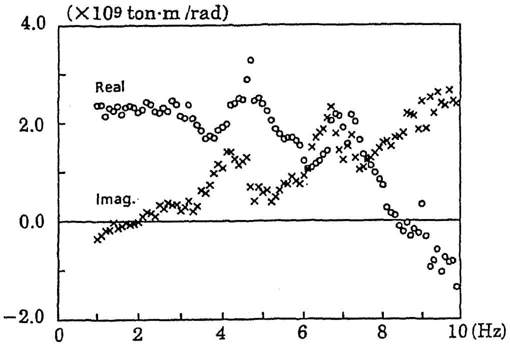
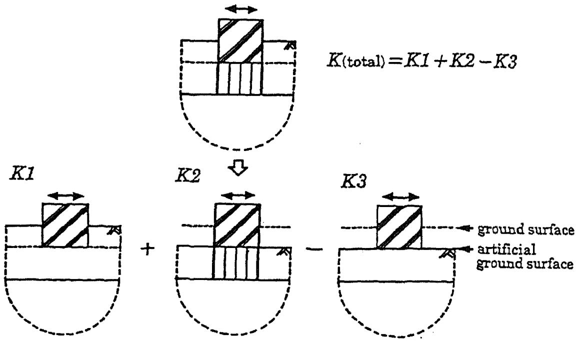


Fig.-7 Test Results
(Rotational Stiffness)

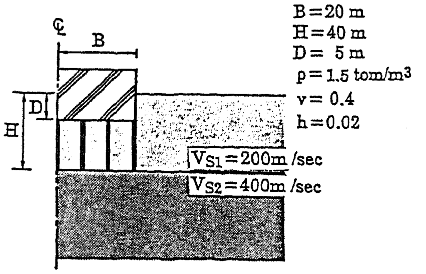


K1 ; the stiffness of the embedded foundation without piles

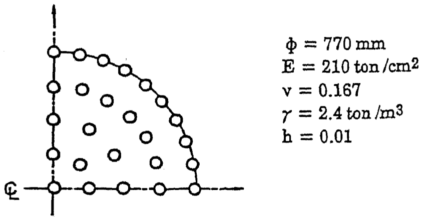
K2 ; the stiffness of the foundation supported by pile group

K3 ; the stiffness of the foundation resting on the artificial ground surface

Fig.-8 Analytical Method



(a) Soil Profile



(b) Pile Arrangement

Fig.-9 Analytical Model for Comparison Study with FEM

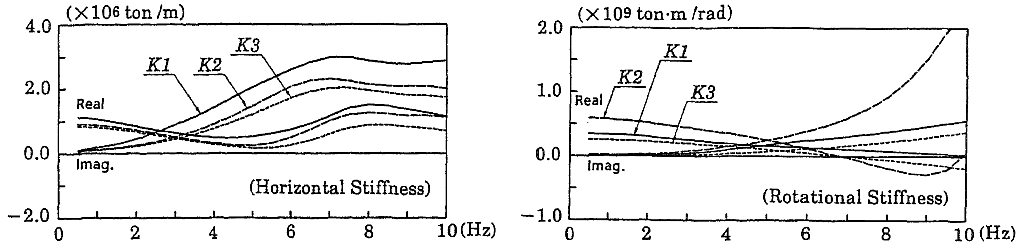


Fig.-10 Each Stiffness of K1,K2 and K3

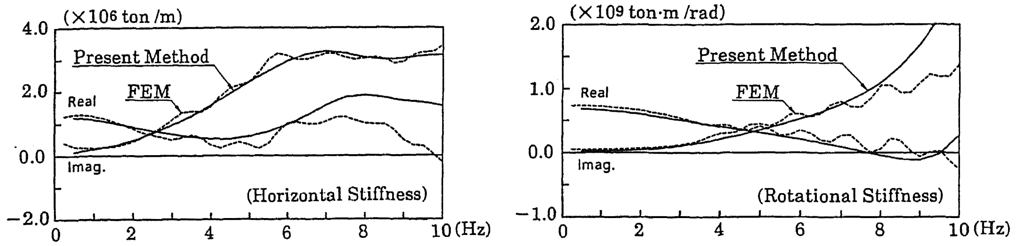
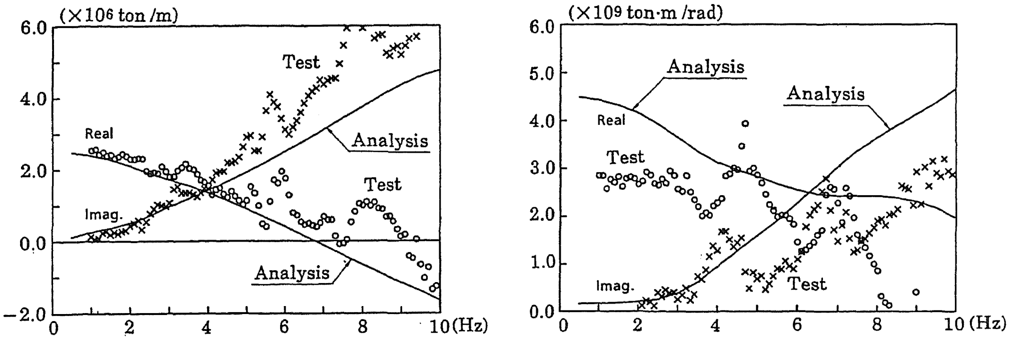
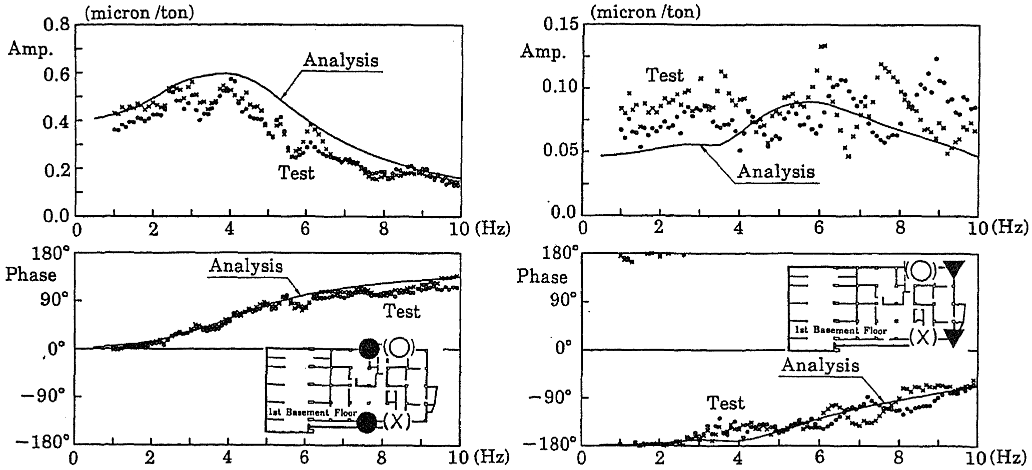


Fig.-11 Comparison of Total Stiffness between Two Analytical Methods



(a) horizontal stiffness (b) rotational stiffness

Fig.-12 Comparison of Stiffness between Test and Analysis



(a) horizontal displacement (b) vertical displacement

Fig.-13 Comparison of Resonance Curves and Phase Lag Curves between Test and Analysis