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Dynamic tests of concrete block on gravel deposits

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ABSTRACT: This paper describes the forced vibration tests and the simulation analyses on the concrete blocks specimen, which has a large earth contact pressure similar with actual nuclear reactor building, to confirm the dynamic soil-structure interaction on Quaternary deposits. As the result of dynamic loading test, the effective data was obtained regarding the evaluation of the dynamic soil-structure interaction related to Quaternary deposit. An axisymmetric FEM model was adopted for the simulation analyses of the test results to effectively express the three dimensional phenomena in the dynamic soil-structure interaction. The significance was recognized in confirming adequately the effects of the confining stress and the static strain in the ground because of the excavation of the soil and the construction of the structure, in the evaluation of dynamic soil-structure interaction on Quaternary soil deposits.

1 INTRODUCTION

The basic policy in Japan is to build nuclear reactor buildings on rock. However, in order to cope with the middle and long term siting problems, it has become necessary to promote new siting technology from the standpoint of increasing the range of site selections and effective utilization of land. The large scale field tests were performed on the grounds of Tadotsu Engineering Laboratory, Nuclear Power Engineering Center (NUPEC), Kagawa Prefecture, Japan, in order to verify the seismic stability of soil appertained to the siting technology on Quaternary deposits. For the field tests, two concrete blocks were built on Quaternary deposits. One is weighing 30MN with earth contact pressure equivalent of actual reactor building, and the other is 50MN. The verification of soil-structure interaction were executed by dynamic loading tests. Other aspects of the large scale field tests are described in the companion papers submitted in this conference. The outline of the entire test results is described in the paper by Watabe et al (1991).

2 DYNAMIC LOADING TEST

2.1 *Objective*

The objectives of the concrete block tests are to collect data relevant to the soil-structure interaction under the condition of earth contact pressure of approximately 470kPa, which is similar with actual reactor building. And, by means of the field verification test the adequacy of the evaluation method for seismic safety of the Quaternary soil siting and its rationality is to be confirmed.

2.2 *Selected soil*

For the test deposit, a diluvium sand and gravel layer was chosen, which has high possibility of being the bearing soil when building a nuclear power plant on the Quaternary deposit. There was an overburden of about 10m thick reclamation material on top of the selected test gravel layer, therefore, the ground was excavated to 11m

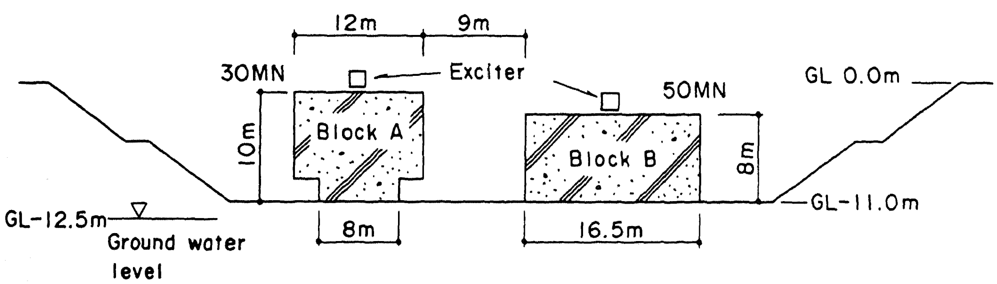

Fig. 1 Concrete blocks A and B

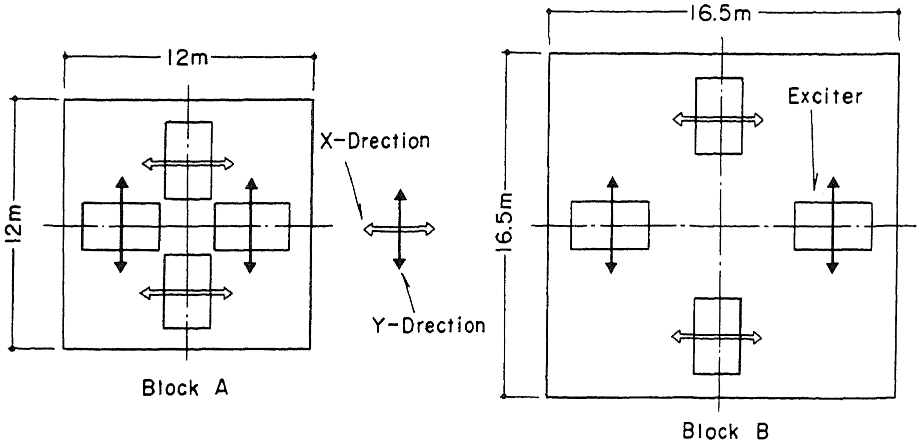

Fig. 2 Location of installed exciters

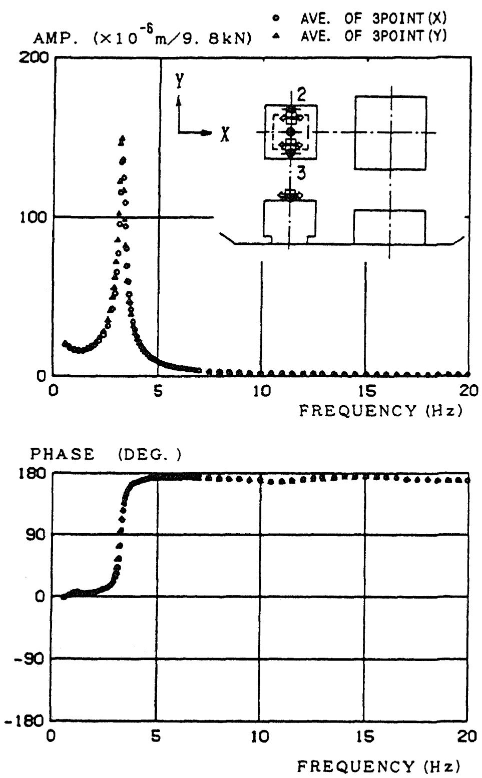

Fig. 3 Resonance and phase lag curve of block A

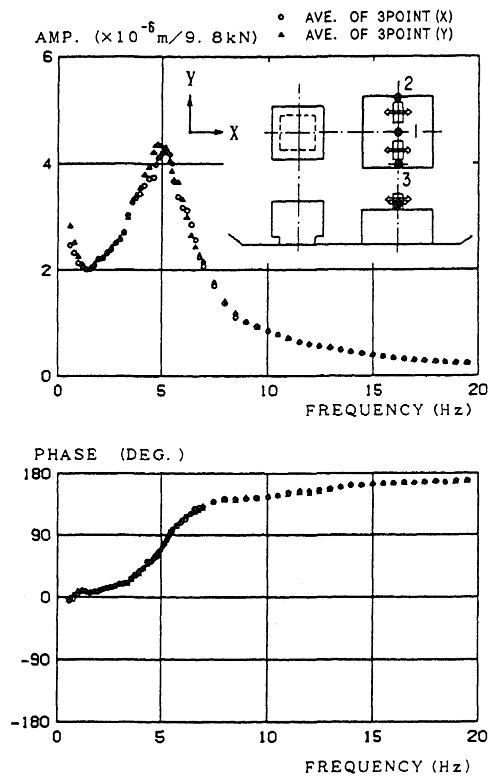

Fig. 4 Resonance and phase lag curve of block B

below the ground surface for constructing the concrete blocks. The ground water level was lowered by using wells and controlled to hold the level of 1.5m beneath the excavated ground surface.

2.3 *Test specimens*

The test specimens consist of concrete blocks A and B as shown in Fig.1. The block A of 10m height was designed to have the plan dimensions of 8m × 8m at the lower part and 12m × 12m at the upper part, so that the contact pressure of approximately 470kPa could be attained. Regarding the soil-structure interaction, in order to assume the correlation with an actual building, because the non-dimensional frequency a_0 of the block A is small at about 0.5, the block B was made to have the plan dimensions of 16.5m × 16.5m and 8m height, so that the non-

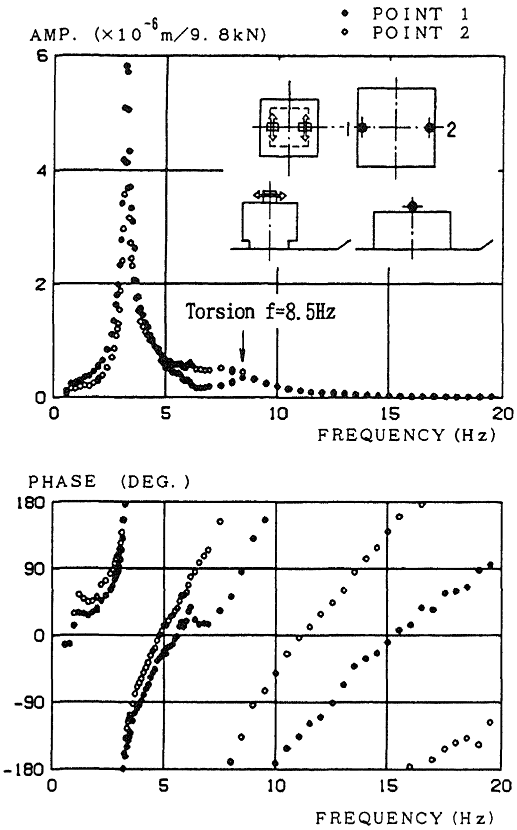

Fig. 5 Resonance and phase lag curve of block B during exciting block A

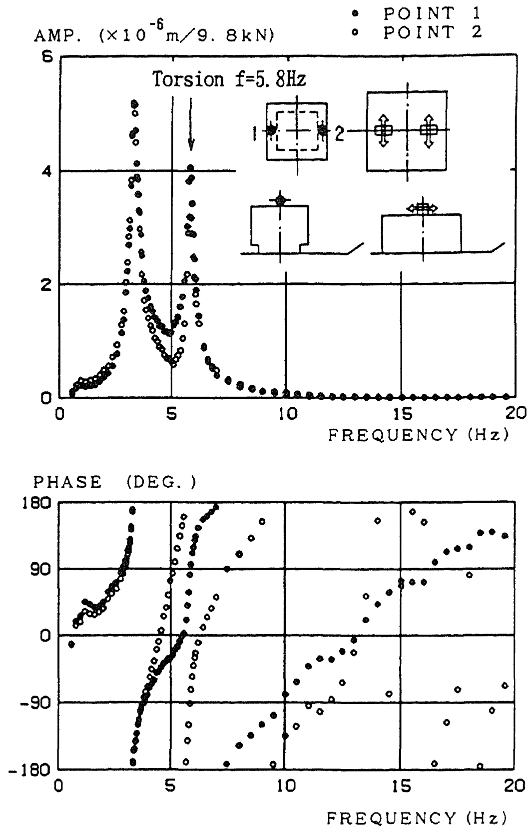

Fig. 6 Resonance and phase lag curve of block A during exciting block B

dimensional frequency would be the same as the actual building at approximately 2.0.

2.4 *Loading and measurement*

The dynamic loading test was performed by installing two sets of exciters on the top of the concrete blocks. The exciters were installed parallel to the excitations in the X direction and Y direction as shown in Fig.2. Each of the selected exciter possessed the capacity; maximum eccentric moment of 6.2kN·m, maximum exciting force of 98kN, excitation frequency of 0.2Hz to 20Hz, and with plan dimensions of 2.2m × 3.7m. The excitation force was determined after confirming of its being sufficiently within the elastic limitation of the ground. Applied forces were; P=19.6kN for the block A, and P=196kN for the block B. The excitations were conducted taking the procedure of increasing frequency, and were carried out by steady state tests.

2.5 *Results of test*

Fig.3 and Fig.4 show the resonance and phase lag curves obtained at the top of the blocks A and B. Each of the curve is an average of three points indicated in the figures. The amplitudes of the resonant curves are normalized to those corresponding to 9.8kN excitation, and the phase lag curves are indicated in term of phase lag from exciting force. Regarding the resonant curves for both blocks A and B, only the fundamental resonant frequency is shown to be predominant in the range of 1.0Hz ~ 20Hz, and the difference between X and Y directions is quite small. The fundamental damping ratios obtained by power method are 5% for block A and 28% for block B in the both directions. In the case of the block B measurement, due to the excitation of the block A in Y direction, the sway mode is predominant at the fundamental frequency 3.20Hz which belongs to block A, and the torsional mode is predominant at 8.5Hz as shown in Fig.5. In the measurement of the block A during the block B excitation in Y direction, the rocking mode is predominant at the fundamental frequency 3.20Hz of the block A, similar to the block A excitation in Y direction, and the torsional mode is predominant at 5.8Hz as shown in Fig.6.

3 SIMULATION ANALYSIS

3.1 *Analytical model*

It is well known that the dynamic characteristics of a rigid structure is influenced significantly by surrounding

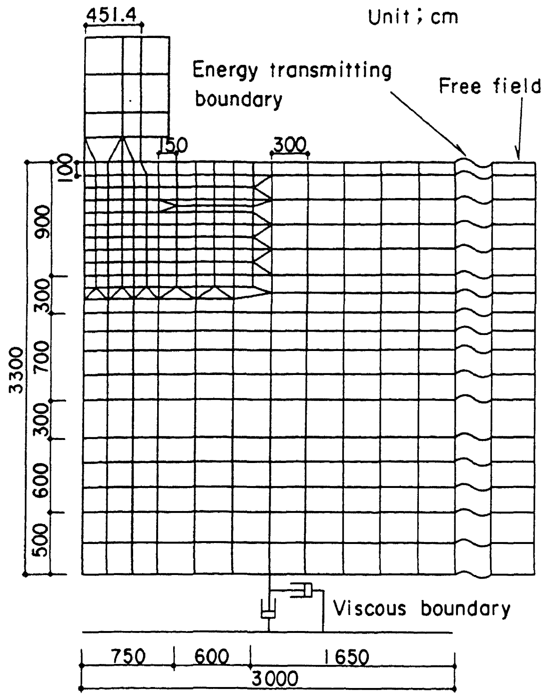

Fig. 7 Axisymmetric FEM model of block A

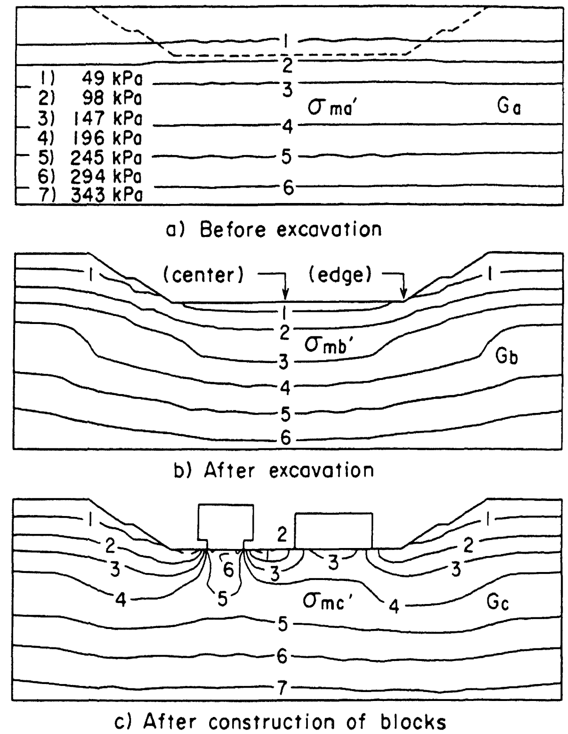

Fig. 8 Distributions of effective confining stress

soil condition. Therefore, an axisymmetric FEM model was adopted for the simulation analysis of the test results. Fig.7 shows the analytical model of the block A, and the block B is also adopted with a similar axisymmetric FEM model. An axisymmetric FEM model is adequate to express the three dimensional phenomena in the dynamic soil-structure interaction and is able to estimate easily the initial stiffness of the soil due to the confining stress and the static strain.

3.2 *Initial stiffness of soil*

Fig.8 shows the distributions of the mean effective confining stress σm′ in three different situations, before excavation, after excavation and after construction of the concrete blocks. Based on the results of the elastic wave tests which were carried out before the excavation of the soil, the determination of the dynamic soil properties was performed considering variation of confining stress in the ground according to the excavation and the construction of the concrete blocks. The initial stiffness of soil is estimated by the effective confining stress.

The initial shear modulus G_a is determined by the elastic wave test before excavation. G_b and G_c in the Fig.8 are calculated by the following formulas.

$$G_b = G_a \left(\frac{\sigma_{mb}'}{\sigma_{ma}'}\right)^n \qquad (1)$$

$$G_c = G_a \left(\frac{\sigma_{mc}'}{\sigma_{ma}'}\right)^n \qquad (2)$$

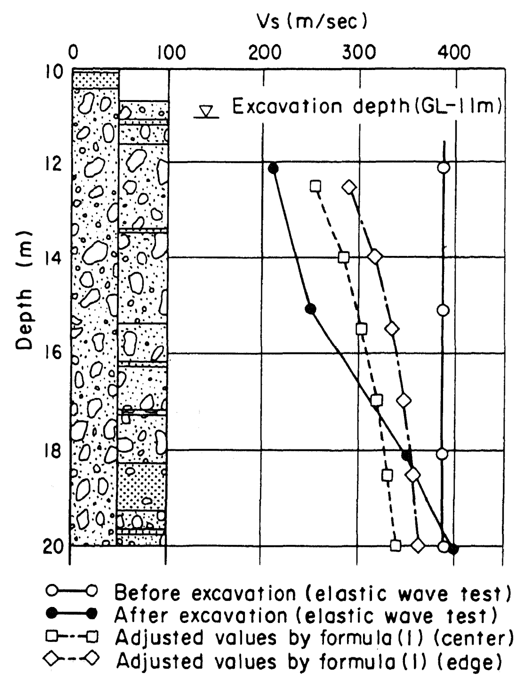

Fig. 9 Effect of confining stress on shear wave velocity

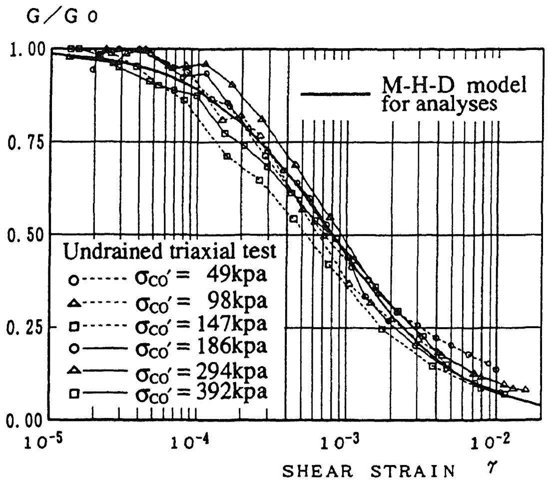

Fig.10 G/Go ~ γ relationship

In these formulas, σma', σmb' and σmc' are computed by static analyses of two-dimensional FEM model considering the gravity of the soil and the concrete blocks.

The constant n is obtained by cyclic undrained triaxial test which gives the relation of the shear modulus Go at small strain $\left(\gamma = 10^{-5}\right)$ and the confining stress. The value n obtained by in-situ frozen sample of the gravel is about 0.8 which, is larger than the value of 0.5 commonly known for the sand.

Fig.9 shows the shear wave velocities before and after excavation obtained by the elastic wave tests. The shear wave velocity Vs decreases from 380 m/sec to about 200m/sec at GL-12m level in the ground due to the excavation. Computed shear wave velocity adjusted by the formula (1) at the center and the edge of the bottom of the excavated level shown in Fig.8 b) shows well the tendency of the test result influenced by excavation. In this paper G_c obtained by formula (2) is adopted as the initial stiffness of the soil for the simulation analysis.

3.3 *Linear analytical results*

Fig.11 compares the analytical and the test results in regard to the resonant curves. Case 1 shows the analytical results when the adjusted value by the formula (2) is used as the initial stiffness of the soil, and hysteretic damping 2% is used for the soil and block. The initial stiffness of the soil is estimated to be too hard due to a large contact pressure of 470kPa. Fig.10 shows the relationship between the stiffness of the soil and shear strain. The authors assumed that the initial stiffness of the soil decrease, with the effect of the static shear strain which is assumed to occur due to the construction of the concrete blocks. Case 2 shows the analytical results when all of the soil shear strain contributes to the decrease of the soil stiffness according to $G/G_o \sim \gamma$ relationship shown in Fig.10. The initial soil stiffness is estimated to be too soft. Therefore, 90% of soil shear strain is considered to work effectively to the decrease of the soil stiffness as shown in Case 3. The analytical results of the resonant curves of the block A have a good agreement with the test results. However the initial stiffness of the soil has a tendency of being estimated as being hard slightly in the analysis of the block B compared with the block A.

3.4 *Non-linear analytical results*

After the excitation with 19.6kN load was finished, additional tests were performed with P=49kN and 98kN load just near the vicinity of the fundamental resonant frequency of the block A in Y direction to confirm the non-linear properties. Fig.12 shows the analytical results by means of the equivalent linear method comparing with the test results. As the exciting force increased, the peak of the fundamental resonant frequency shifted toward the side of lower frequency and the amplitudes also increased. Although the difference between 19.6kN and 49kN is small, the difference between 49kN and 98kN is especially large. From these results, non-linear properties are simulated well by the equivalent linear method.

4 CONCLUSION

As a result of the dynamic loading tests which were directed at the actual diluvium sand and gravel soil deposits, an effective data such as resonance and phase lag curves were obtained for both the blocks A and B. It was found out to be significant to confirm adequately the effects of the confining stress and static strain in the ground due to the excavation of the soil and the construction of the structure in the evaluation of soil-structure interaction on the Quaternary soil deposits.

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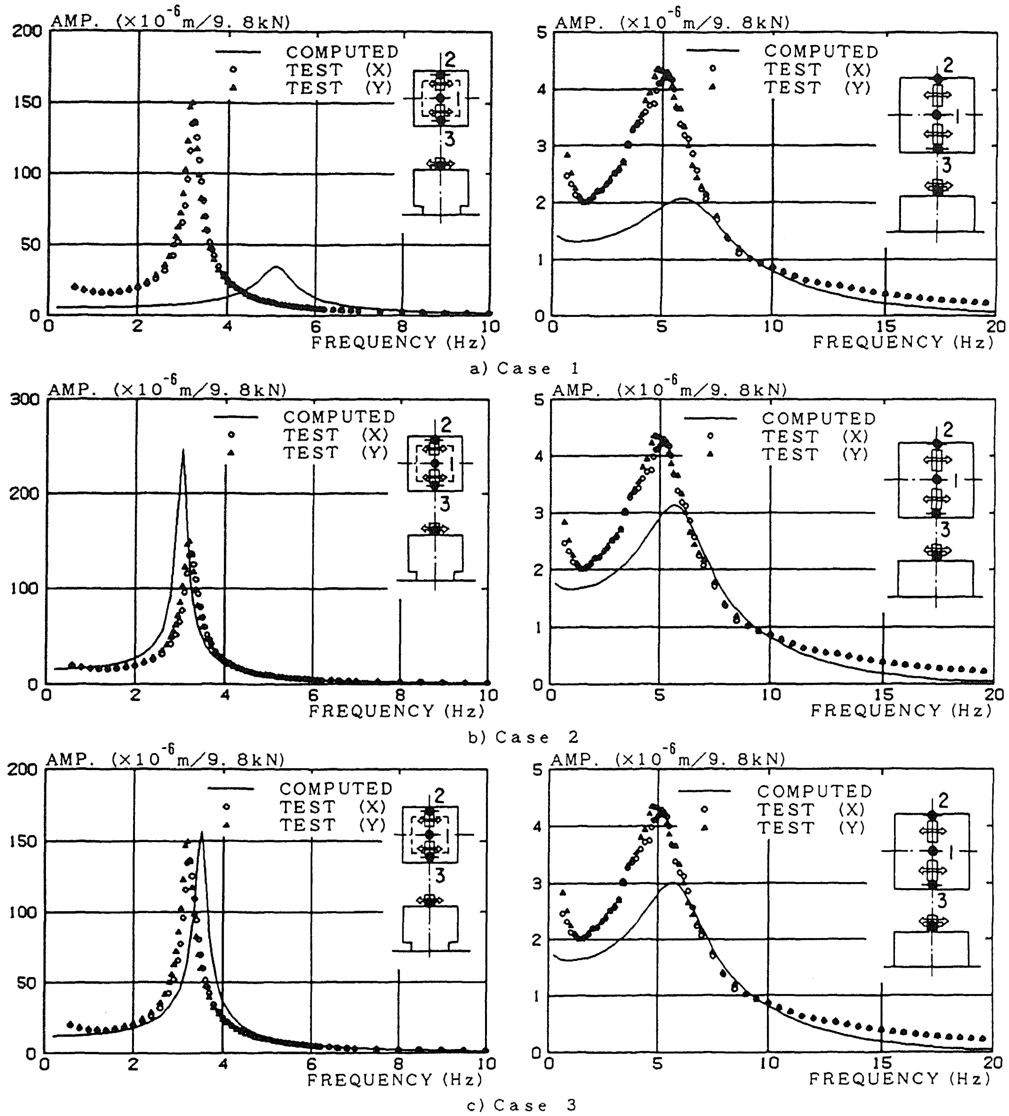

Fig. 11 Comparison of analytical results with tests

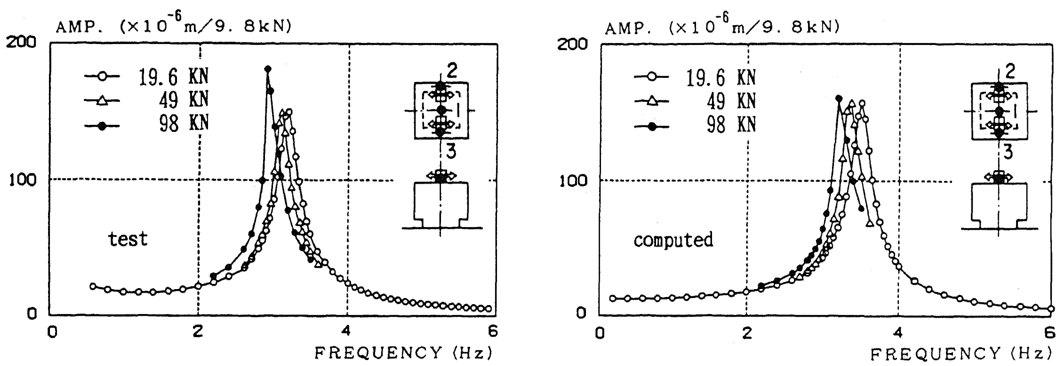

Fig. 12 Resonant curves as exciting force increase (P=19.6kN, 49kN, 98kN)