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Hualien forced vibration calculation with a finite element model

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ABSTRACT

The forced vibration tests of the Hualien mock-up were useful to validate finite element models developed for soil-structure interaction. In this paper the two sets of tests with and without backfill were analysed. The methods used are based on finite element modeling for the soil. Two approaches were considered: (1) Calculation of soil impedance followed by the calculation of the transfer functions with a model taking into account the superstructure and the impedance. (2) Direct calculation of the soil-structure transfer functions, with the soil and the structure being represented in the same model by finite elements. Blind predictions and post-test calculations are presented and compared with the test results

1 INTRODUCTION

The Hualien Large-Scale Seismic Test (LSST) is an international research program for the investigation of the soil-structure interaction effects during earthquakes. A 1/4-scale reactor containment model has been constructed at Hualien, a seismically active site in Taiwan [1] (see figure 1). The properties of the soil around and beneath the model structure have been systematically measured by geotechnical field and laboratory tests [2]. Before starting earthquake observation, forced vibration test have been performed to determine the dynamic characteristics of the soil-structure interaction system. These vibration tests were conducted before and after backfill (FVT-1 and FVT-2) [3]. Also, blind predictions and correlation studies were performed by program participants using their own calculation method.

The objective of this paper is to present the results of the dynamic analysis of the test model performed in CEA. Soil spring method and direct method were used in the analysis. Both methods are based on finite element modeling of the near field soil and the use of viscous boundaries. Blind prediction and post-test calculation of the soil-structure sytem transfer functions will be presented and compared with the test results.

2 METHOD OF ANALYSIS

2.1 Soil spring method

In this approach, the first step is to calculate the dynamic impedance functions of the soil under the foundation. For this purpose, the soil is modeled by finite elements and viscous absorbing boundaries. Impedances are obtained by numerical integration in the time domain and by Fourier transform of the time-dependent excitation and foundation response into the frequency domain [4]. In the second step, soil impedances are added to the upper structure as springs and dampers. The analysis is performed by assuming the coefficients for the springs and dampers to be frequency-independent and have the value of the impedance functions at the first fundamental frequency of the interaction system .

2.2 Direct method

In the direct approach, the whole soil-structure system is modeled by finite elements and viscous boundaries. Transfer functions are obtained directly in a similar way as that described above for the computation of the impedance functions. Unlike the soil spring method, the direct approach can take into account the frequency-dependent nature of the dynamic effects of the soil.

3 FORCED VIBRATION TESTS BEFORE BACKFILL (FVT-1)

3.1 Blind prediction

Based on the "Unified model for the ground of FVT-1" proposed by CRIEPI [2], blind prediction analyses were conducted for the test model before backfill using the two methods described above. The structure is modeled by axisymmetric shell elments as shown in figure 2. The finite element soil model is presented in figure 3 and the properties of the soil are listed in table1.

Using the soil spring method, the first fundamental frequencies of the system in the vertical and horizontal directions are found by an iterative method. Transfer functions at different points of the structure are obtained as in the tests. Two of these curves are shown in figure 4. The first corresponds to the amplitude of the vertical base response for unit harmonic vertical base excitation and the second represents that of the horizontal roof response under horizontal roof excitation.

Blind prediction analysis using the direct method was performed by connecting the structure model of figure 2 to the soil model of figure 3. The same transfer functions as these shown in figure 4 , but obtained by the direct method are presented in figure 5. It can be seen that the shapes of the horizontal transfer functions predicted by the two methods are similar, but in the vertical direction, they are rather different. This is due to the hypothesis of constant coefficients of the soil springs and dampers with respect to frequency in this study.

3.2 Correlation study

The forced vibration tests indicate that the dynamic characteristics of the soil-structure system are not axisymmetric and have two orthogonal principal axes named D1 and D2 which are 34° counterclockwise from the NS and EW directions [3]. The experimental transfer functions originally obtained in the NS and EW directions are transposed to the principal axes. Figure 5 shows the comparison between the blind prediction by the direct method and the test results. It is found that the numerical prediction based on the "Unified Model" tends to overestimate the fundamental frequencies of the system. For this reason, post-test calculations were carried out to fit the test results. The modified soil-structure model was obtained by reducing the Young's modulus of the two soil layers just beneath the foundation. The reduction is 31% for the D1 direction and 15% for the D2 direction. Figure 6 shows the results of the correlation analysis by the direct method. A good agreement is obtained for horizontal vibrations. Nevertheless for vertical vibrations, it is found difficult to match the transfer functions.

4 FORCED VIBRATION TESTS AFTER BACKFILL (FVT-2)

4.1 Blind prediction

Blind prediction analysis using the direct method was carried out for the vibration tests after backfill. The finite element model of the whole system is shown in figure 7. The properties of the soil based on the "Unified Model of FVT-2" proposed by CRIEPI as for FVT-1 are listed in table 2. Numerical results for the vertical transfer function of the base and for the horizontal transfer function of the roof are shown in figure 8.

4.2 Correlation study

Transfer functions obtained in the field test of FVT-2 are also presented in figure 8. Comparisons between the prediction and the test results indicate that as in the case of FVT-1, the numerical results based on the "Unified Model of FVT-2" overestimate the fundamental frequencies of the soil-structure system and that for vertical vibrations the predicted transfer function is quite different from the test one.

Using the direct method, correlation analysis was performed by modifying the soil model. For horizontal vibrations, the modification consists of breaking the links between the backfill and the structure wall (0.0 m ~ -2.0 m) and reducing the Young's modulus of the soil beneath the foundation in the same way as in the FVT-1 correlation analysis. For vertical vibrations, the new model is obtained by simply reducing the Young's modulus of all the soil layers and the backfill by 25%. This corresponds approximately to the average reduction ratio for the two principal directions D1 and D2. Furthermore, a much more extensive soil model was used for the calculation of the vertical transfer function. The result of the calculation is presented in figure 8. A good agreement is achieved between the numerical and test results. It can be seen that the calculation of the vertical transfer function has been greatly improved.

5 CONCLUSION

Based on the finite element modeling of the foundation soil, numerical analyses have been carried out for the Hualien forced vibration tests before and after backfill. As blind predictions based on the "Unified Models" of FVT-1 and FVT-2 give fundamental frequencies higher than that measured in the tests, correlation studies have been performed by reducing the Young's modulus of the soil and by assuming no links between the backfill and the containment wall. These modifications of the soil model have led to good agreements between the tests and the calculations. However the study also shows the limitation of the simplified soil spring method, especially for vertical vibrations. Also, the results obtained by the direct method seem to be influenced by the extension of the soil model. This is because the viscous boundary doesn't absorb waves perfectly. Special attention should be paid in using it.

REFERENCES

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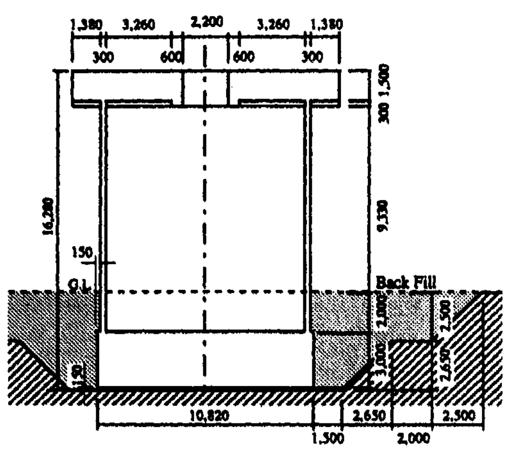
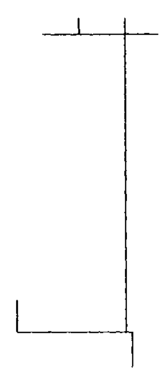


Figure 1. Cross section of the model structure, Ref. [2]



Young's modulus $= 2.822\times10^{10}$ Pa
Mass density $= 2400$ kg / m^3
Poisson' ratio = 0.16

Figure 2. Axisymmetric shell model for the model structure

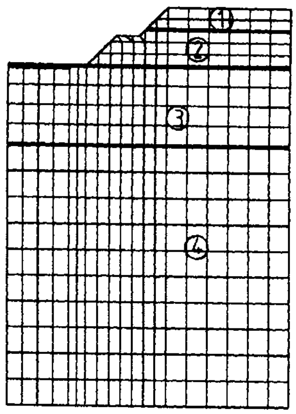
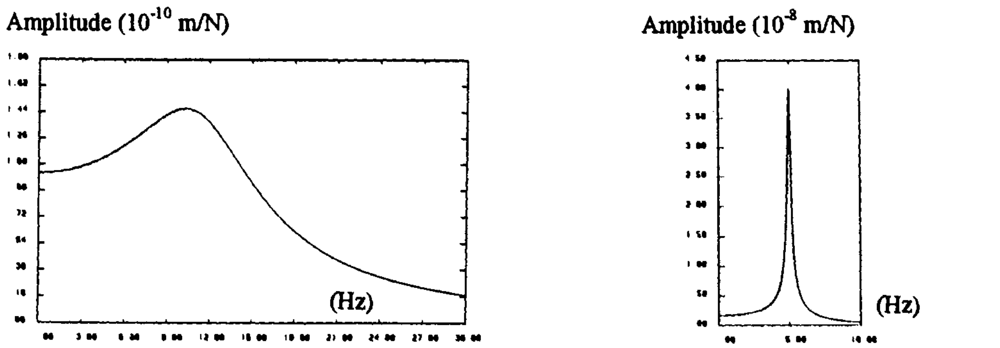


Figure 3. Axisymmetric soil model before backfill (FVT-1)

Table 1. Soil model parameter (FVT-1)

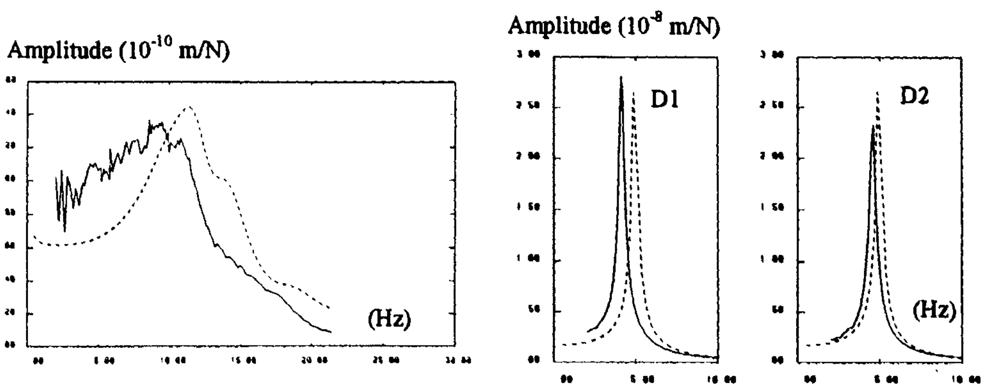
No.	Mass density ρ (kg/m^3)	Shear wave velocity Vs (m/s)	Poisson's ratio ν	Damping factor h (%)
1	1690	133	0.38	2
2	1930	231	0.48	2
3	2420	317	0.47	2
4	2420	476	0.47	2



Vertical base response / Vertical base excitation

Horizontal roof response / Horizontal roof excitation

Figure 4. Prediction of transfer functions for FVT-1, Soil spring method



Vertical base response / Vertical base excitation

Horizontal roof response / Horizontal roof excitation

Figure 5. Transfer functions for FVT-1, ___ Test , ---- Prediction by direct method

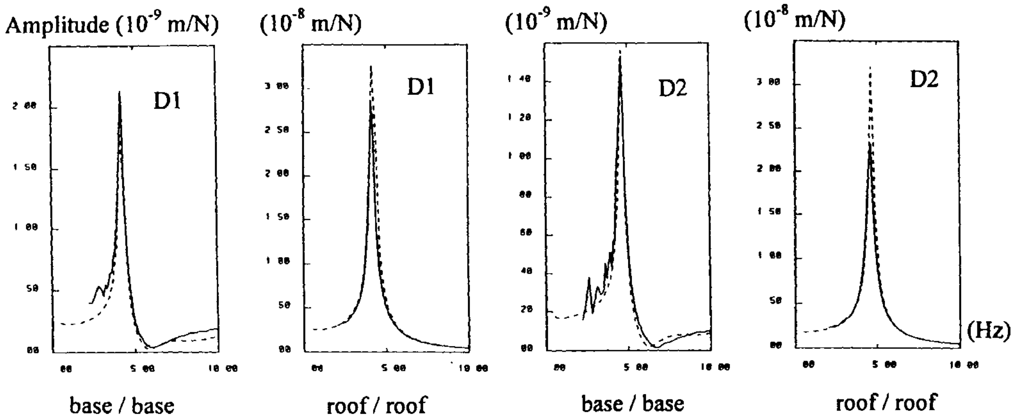


Figure 6. Horizontal transfer functions for FVT-1, ___ Test , ---- Correlation by direct method

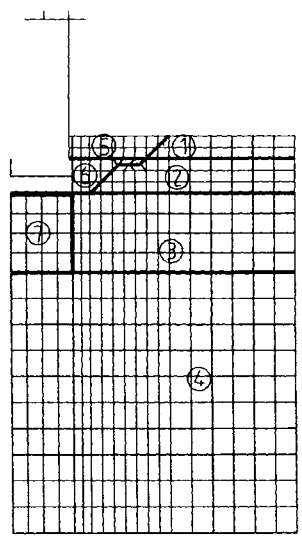


Figure 7. Axisymmetric model for FVT-2

Table 2. Soil model parameter (FVT-2)

No.	Mass density ρ (kg/m^3)	Shear wave velocity Vs (m/s)	Poisson's ratio ν	Damping factor h (%)
1	1690	133	0.38	2
2	1930	231	0.48	2
3	2420	333	0.47	2
4	2420	476	0.47	2
5	2330	400	0.38	2
6	2390	400	0.48	2
7	2420	383	0.48	2

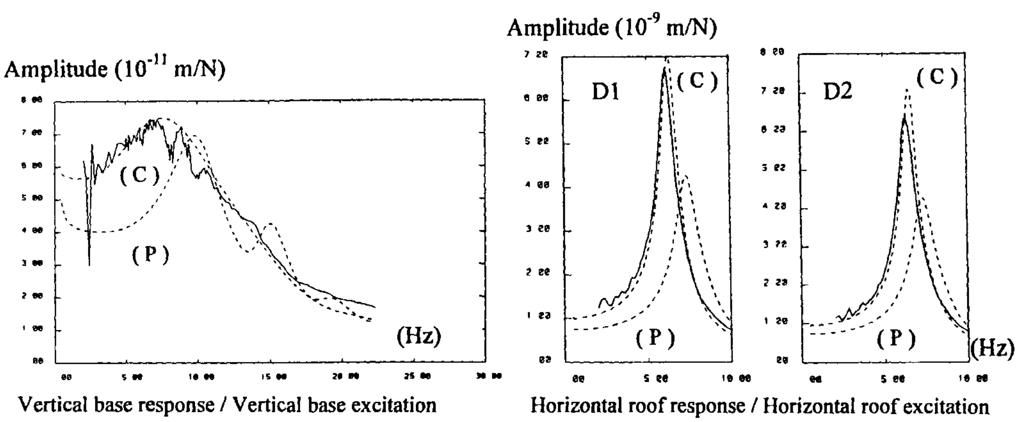


Figure 8. Transfer functions fot FVT-2 , ___ Test , (P) Prediction , (C) Correlation