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Characteristics of Soil Structure Interaction for Reactor Building of Kashiwazaki-Kariwa Nuclear Power Plant

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1. Introduction

On 16 July 2007, the Nigataken-chuetsu-oki earthquake registering a moment magnitude of 6.8 occurred at a depth of about 15 km. As a result of this earthquake, noticeable shaking exceeding the design ground motion was measured at the Tokyo Electric Power Company (TEPCO) Kashiwazaki-Kariwa Nuclear Power Station (KKN), the biggest nuclear power plant in the world, located at about 16 km away from the epicenter [1]. This earthquake triggered a fire at an electrical transformer and insignificant damage on some parts of facilities [2].

This event gave an impulse to study on the damage and safety margin of nuclear power plant due to the strong earthquake exceeding design basis. As a part of those efforts, KARISMA (KAshiwazaki-Kariwa Research Initiative for Seismic Margin Assessment) benchmark study was launched by the IAEA in terms of an international collaborative research. The main objectives of this research are to estimate the structural behavior and to evaluate the seismic margin of reactor building considering the effects of Soil-Structure Interaction (SSI).

This paper presents verification of structural model developed here and validation of soil foundation characteristics through soil-column analysis. It has also been demonstrated that the spring constants and damping coefficient obtained from impedance analysis represent well the soil foundation characteristics.

2. Analytical Responses and Recorded Data

The reactor building in the KKN was constructed on the soft soil foundation of which shear wave velocity is less than 500 m/s, and thus the effect of SSI should be considered to evaluate the dynamic behavior of structure in an exact manner.

For doing this, 3-D analytical model combined with the spring and damping elements representing soil-foundation has been developed, and soil-column analyses have been performed in this research.

2.1 Modal Analysis with Fixed Base Model

The elaborate 3-D analytical model is developed for the unit 7 reactor building shown in Fig. 1, and it is verified by comparison of its modal analysis results with those obtained with the 2-D stick model used in the design by TEPCO.

In the developed analytical model, the basement and shear walls are modeled with 4-node solid elements, and columns and girders are modeled with 2-node frame elements. The structure is assumed to be fixed at the bottom of building, Tokyo Mean Sea Level (TMSL) -13.7 m. In addition, roof trusses are replaced by rigid frame elements, which have the same mass, to suppress local modes that consume large computational time as compared to the insignificant effect on the results.

As a result of analysis, it is investigated that the resultant force is 2,019 MN, which is 1.4 % larger than the selfweight of 1,992 MN provided by TEPCO. The difference is mainly due to the auxiliary walls which were not considered in the design but implemented in the developed model.

The natural frequencies and modal participation mass ratios are summarized in Table I. The fundamental natural frequencies of the 2-D model provided by TEPCO with fixed boundary condition in X- and Y-direction are 4.84 Hz and 5.11 Hz, respectively.

Table I: Results of Modal Analysis with Fixed Base Model

Mode	Frequency (Hz)	Modal participating mass ratios (%)			Modal participating mass ratios (%)		
		UX	UY	UZ	RX	RY	RZ
1	4.415	56.474	0.063	0.002	0.071	61.081	0.027
2	4.874	0.065	59.275	0.006	58.905	0.070	0.000
3	7.009	0.041	0.016	0.000	0.021	0.005	60.604

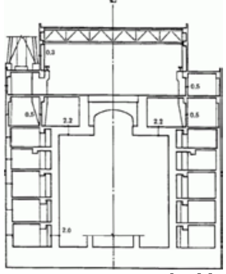
Fig. 1. Unit 7 reactor building.

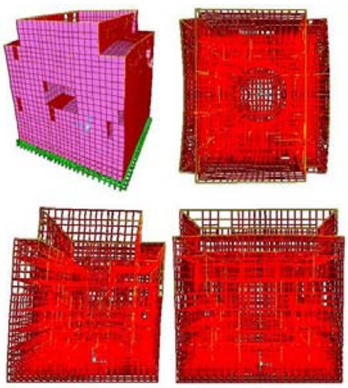
Fig. 2. The first mode shape.

2.2 Soil-Column Analysis

To evaluate the characteristics of surveyed soil foundation in the site, the soil-column analysis has been conducted for soil foundation under the unit 5 reactor building to which ground motions were recorded at the down hole array adjacent. For the analysis, computational software designated for site response analysis, namely EERA [3], has been used.

The maximum thickness of each sub-layer is designed in terms of the shear wave velocity and cut-off frequency as follows [4]:

$$h = \frac{V_s}{5 \cdot f_c} \qquad (1)$$

From equation (1), with f_c = 20 Hz, the total number of sub-layers is calculated to be 83, and the data recorded at the 5G-1 station (TMSL +12.3 m) are used as input ground motions.

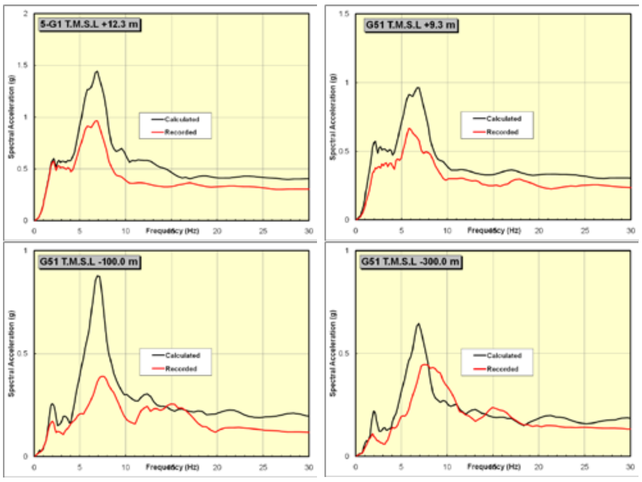

Fig.2. Comparison of acceleration spectra.

Fig. 2 shows the comparison of the spectral accelerations generated from the soil-column analysis with the spectra obtained from the recorded data at each ground level. It can be observed that the analysis generates relatively large spectra, but the difference is small enough to be accepted in the further steps analysis. The discrepancy is due to several reasons such as the uncertainties of soil foundation data and inaccuracy of the analysis scheme.

2.3Soil-Structure Interaction Analysis

One of the main objectives of KARISMA cooperative research is to evaluate the performance of the reactor building considering nonlinear characteristics of material as well as the effect of SSI. However, most programs designated for the SSI analysis cannot take account of nonlinear behavior, and thus spring and damping elements are adopted in lieu of the soil foundation in this study.

The equivalent spring constants and damping coefficients are obtained through impedance analysis using ACS-SASSI, commercial soft oriented to the SSI analysis, and they are compared with those values provided by TEPCO in Table II [5]. It is noteworthy that an excellent match is obtained from the impedance analysis and designed values.

Table II: Comparison of Spring Constants and Damping Coefficients

Model	**Spring Constants (kN/m or kN·m/rad)**					
	Kux	**Kuy**	**Kuz**	**Krx**	**Kry**	**Krz**
KINS	7.35e7	7.22e7	8.18e7	6.78e10	6.37e10	8.51e10
TEPCO	7.30e7	7.26e7	1.22e8	7.78e10	7.23e10	-
Model	**Dashpot Constants(kN·s/m or kN·s·m/rad)**					
	Kux	**Kuy**	**Kuz**	**Krx**	**Kry**	**Krz**
KINS	2.88e6	2.80e6	5.89e6	9.20e8	8.20e8	7.88e8
TEPCO	2.86e6	2.83e6	6.56e6	7.44e8	6.39e8	-

For nonlinear analysis, the spring and damping elements with the constants described in the above table are attached at the bottom center of the 3-D model described in Section 2.1. The analysis results obtained from this combined model will be presented in a future publication.

3. Conclusions

This paper has presented the brief overview of the 1st phase results for the KARISMA benchmark research. According to the modal analysis using 3-D finite element model developed in this study for the unit 7 reactor building, it has been observed that the dominant natural frequencies are similar to those obtained from the TEPCO 2-D models. The effectiveness of the soil foundation characteristics used for the design of reactor building has been demonstrated through the comparison of soil-column analysis results to the recorded data. It has been found that the soil spring constant and damping coefficient obtained from impedance analysis matches the values used in the seismic design conducted by TEPCO almost exactly.

REFERENCES

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