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Simulation analysis of reactor buildings on Niigataken Chuetsu-oki earthquake at Kashiwazaki-Kariwa Nuclear Power Plant

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1 ABSTRACT

Simulation analyses were carried out on reactor buildings using observation records at Kashiwazaki-Kariwa nuclear power plant during the Niigata-ken Chuetsu-Oki Earthquake, which occurred on July 16, 2007. Based on the analysis model employed in the design, the simulation analysis utilized the most realistic conditions at the earthquake. Accordingly, the simulation analysis results relatively showed well agreement with the earthquake observation records. It was confirmed that the maximum stress and strain of the shear walls of the reactor buildings, which were the main structural members, were generally within the elastic range and the structural elements have adequate structural integrity.

2 INTRODUCTION

Observation records were obtained at the reactor buildings of Kashiwazaki-Kariwa nuclear power plant during the Niigata-ken Chuetsu-Oki Earthquake, which occurred on July 16, 2007. These records were used to carry out simulation analyses on representative reactor buildings. This report presents the framing of the analyses and the analysis results for reactor buildings Unit 1 and Unit 6.

3 METHOD OF ANALYZING EARTHQUAKE RESPONSE

Observation records (acceleration time history) on the base mat slab were input to the earthquake response analyses for the reactor buildings specifically where such records were available. In the analysis, linearity was assumed for both the building and the soil spring. Two horizontal directions (North-South and East-West) were analyzed independently.

The simulation analysis method was as follows.

First, the dynamic responses of the ground at the embedded part of the building were calculated from the analysis based on the one dimensional wave propagation theory.

Second, the dynamic responses were applied to the building for the simulation analysis in the horizontal direction as the input motions. As a result, the responses of the building were evaluated taking into account the soil structure interaction. The transfer functions between each floor and the base mat slab were obtained from the building responses.

Third, the earthquake responses of the building's individual parts were obtained by multiplying the transfer function calculated as above by the Fourier spectrum obtained from the Fourier transform of the observation records for the base mat slab.

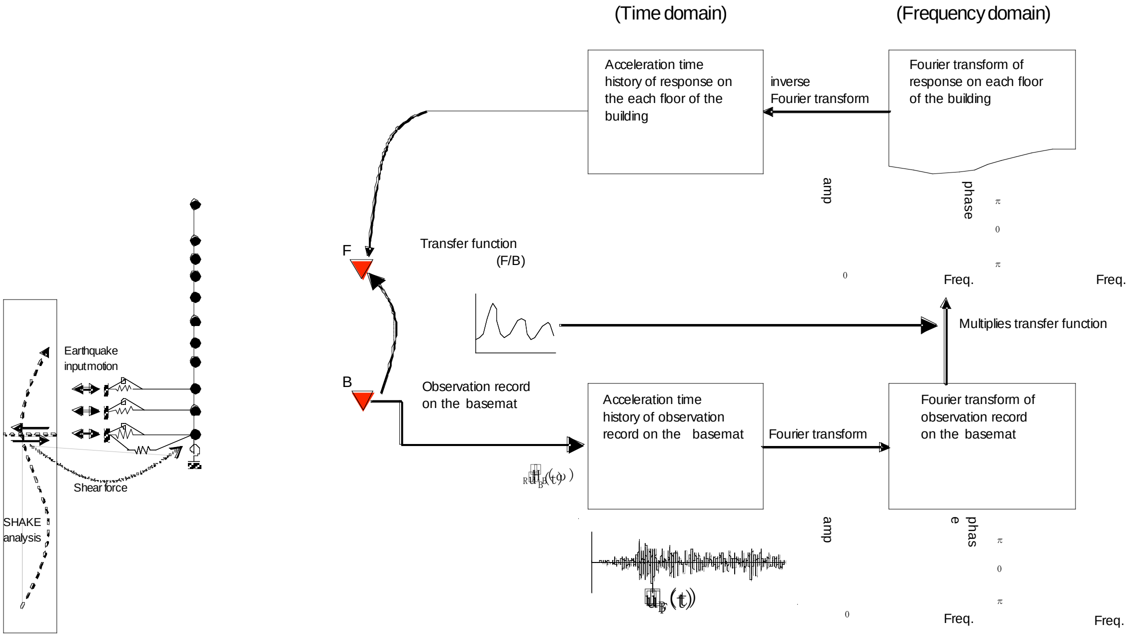
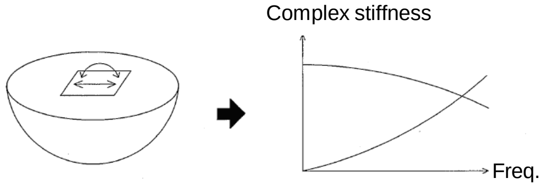
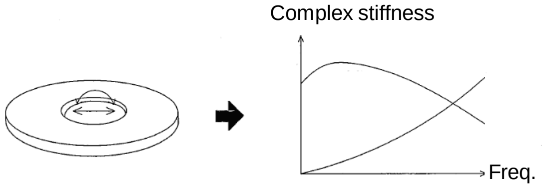


Figure 1 Simulation analysis method



Soil spring underneath the base mat (based on Vibration admittance theory)



Soil spring beside the embedded side wall (based on Novak's method)

Figure 2 Soil springs

Table 1 Analysis conditions

Analysis conditions for structure		
Stiff-ness	Young's modulus of concrete Ec	Based on material testing Unit 1 : Ec=2.90 × 10^4N/mm^2 (44.1N/mm ^{2}) Unit 6 : Ec=3.13 × 10^4N/mm^2 (49.0N/mm ^{2}) ( ) : compressive strength
	Stiffness	Shear walls and auxiliary walls
damping		5%

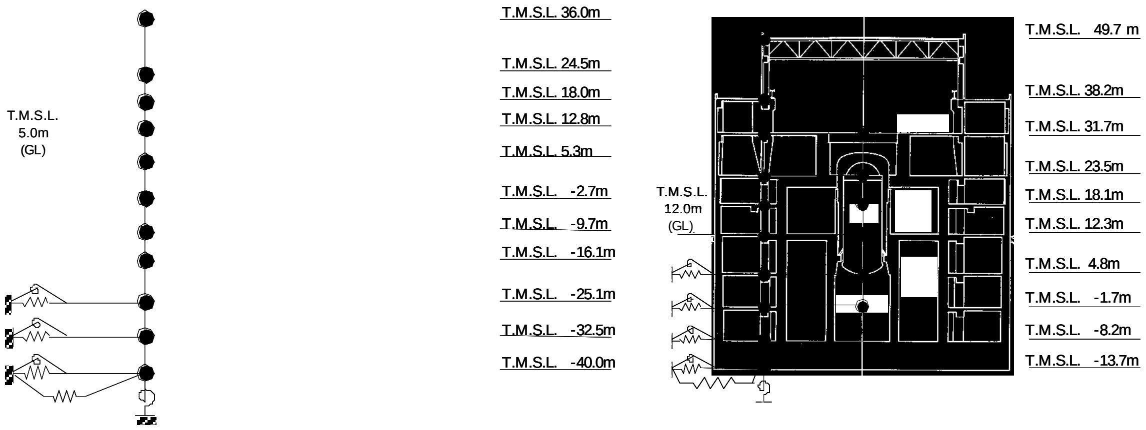
Analysis conditions for soil -structure interaction		
Soil spring	Underneath the basemat	Based on Vibration admittance theory (horizontal and rotational)
	Beside the embedded part	Based on Novak's method (horizontal and rotational)
Soil properties		Stiffness and damping factors based on maximum strain levels
Uplift of basemat		linear

4 EARTHQUAKE RESPONSE ANALYSIS MODEL

The analysis model using soil structure interaction for the earthquake response analysis was determined to be an embedded sway-rocking model consisting of a lumped mass system for the building and the ground spring.

The building model is described as a lumped mass model with weight concentrated at mass points located at each floor, taking into account bending and shear stiffness. In the building model, auxiliary walls that were thought to increase stiffness during an earthquake were taken into account in addition to the main shear walls considered in the initial design. Concrete stiffness was evaluated from the measured compressive strength of test pieces sampled from actual building walls. The model also took into account the stiffness estimated in accordance with the design code for reinforced concrete structures in Japan (Young's modulus and shear modulus).

The building's damping constant was determined to be 5%. The soil springs for the base mat slab employed a constant spring (horizontal and rotational) based on Tajimi's vibration admittance theory. The soil springs for the side plane of the building's embedded part employed a constant spring (horizontal and rotational) based on Novak's method. The ground properties took into account the strain dependency of the stiffness and damping based on laboratory tests. Building-specific decreasing stiffness and damping factor were provided in accordance with the strain level of the ground.



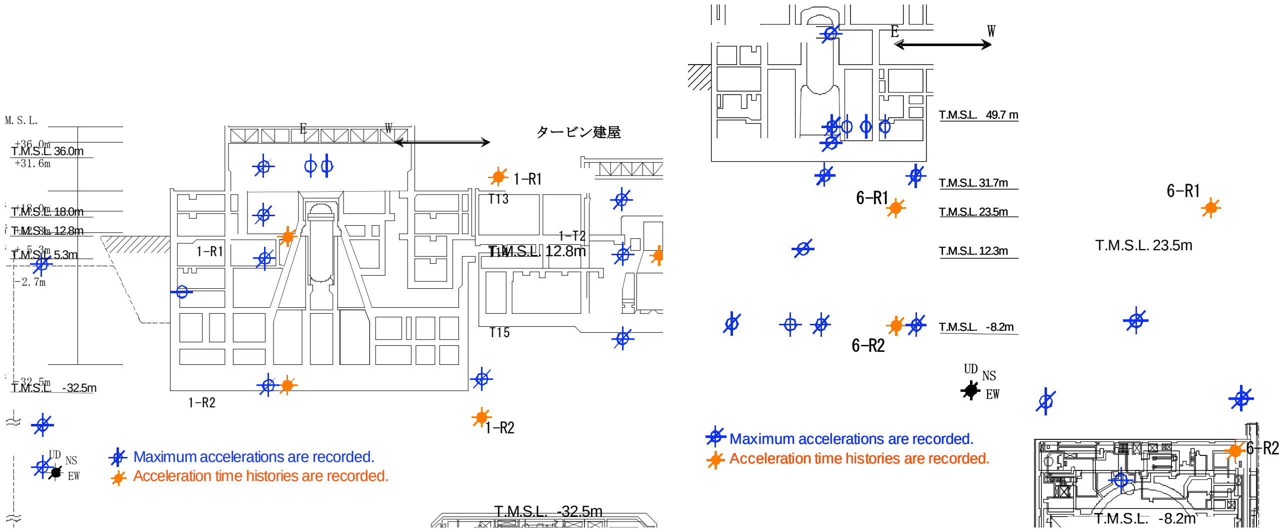
Unit 1 Unit 6

* T.M.S.L.: Tokyo Mean Sea Level

Figure 3 Analysis models

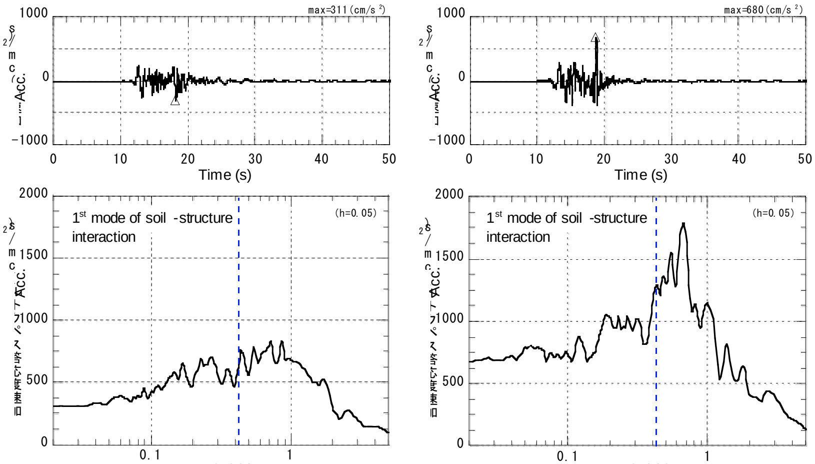
5 OUTLINE OF EARTHQUAKE OBSERVATIONS

Seismometers were installed on the base mat slab of each building's lowest floor and on an intermediate floor of each building's upper portion. The seismometers recorded the acceleration time histories as observation records. Sampling frequency was 100Hz. A sufficient number of observations were acquired for the earthquake response analysis.



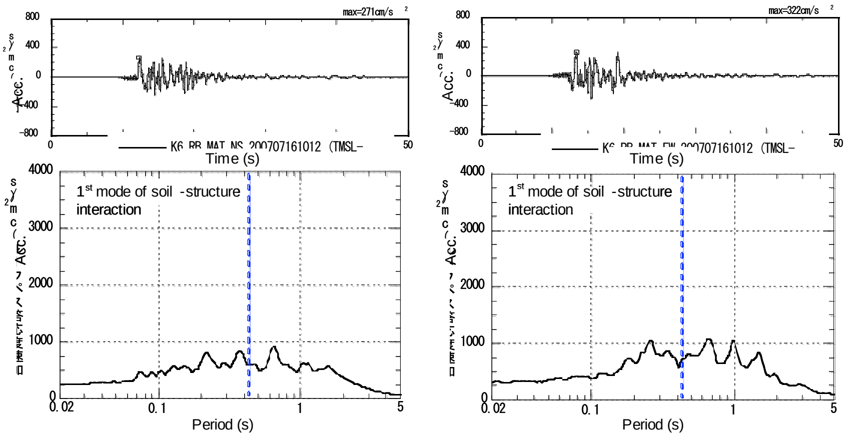
Unit 1 Unit 6

Figure 4 Locations of seismometers in the reactor buildings



NS direction EW direction

Figure 5 Acceleration time histories and response spectra of the observation records on the base mat slab (Unit 1)



NS direction EW direction

Figure 6 Acceleration time histories and response spectra of the observation records on the base mat slab (Unit 6)

6 RESULTS OF SIMULATION ANALYSIS

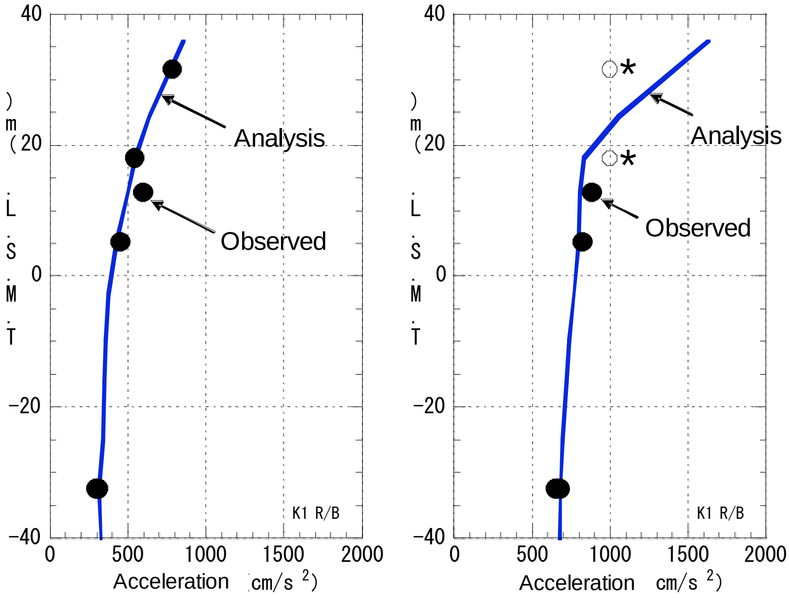
Simulation analysis was carried out using the acceleration time histories observed at the reactor buildings of Unit 1 and Unit 6 as input motions.

Figure 7 shows the distribution of maximum response accelerations for Unit 1 in the building's height direction obtained from the analysis. Figure 8 compares the analysis results with the observation records of the acceleration time histories and the acceleration response spectrum for Unit 1 at the second floor above ground of the building (T.M.S.L. 12.8m). These results indicated that simulation analysis was able to represent fairly well the earthquake observation records.

Figure 9 shows the average shear stress and shear strain of the walls of individual floors obtained from the simulation analysis for Unit 1. As shown in the figure, shear stress generated in the walls during the earthquake became smaller than the allowable stress that could be resisted only by design reinforcing bars. Also, the shear strain generated in the wall at each floor during the earthquake was about 0.2 x 10^{-3} at maximum, which was below the reference value for crack occurrence.

Figure 10 compares the analysis results with the observation records for Unit 6 for the distribution of maximum response accelerations in the building's height direction. Figure 11 compares those for the third floor above ground of the building (T.M.S.L. 23.5m) for the acceleration time histories and the acceleration response spectrum. These results indicate that simulation analysis for Unit 6 incorporating realistic earthquake conditions was able to represent fairly well the seismic observation records.

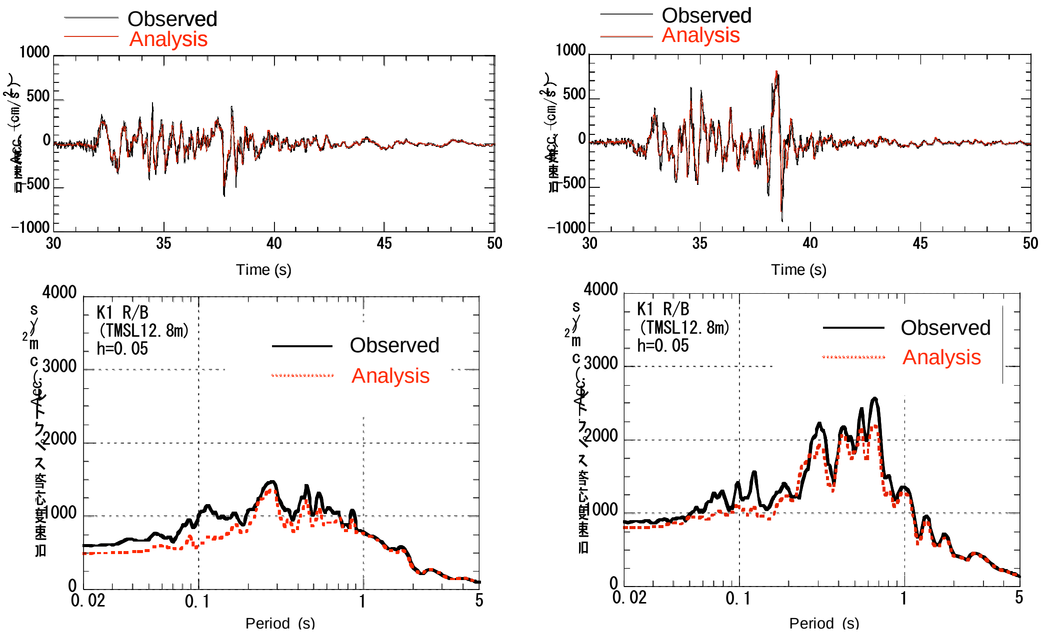
Figure 12 shows the average shear stress and shear strain of the walls of individual floors obtained from the simulation analysis for Unit 6. As shown, shear stress in the shear walls during the earthquake became smaller than the allowable stress that could be resisted only by design reinforcing bars. Also, the maximum shear strain at each floor during the earthquake was about 0.15 x 10^{-3}, which was below the reference value for crack occurrence.



NS direction EW direction

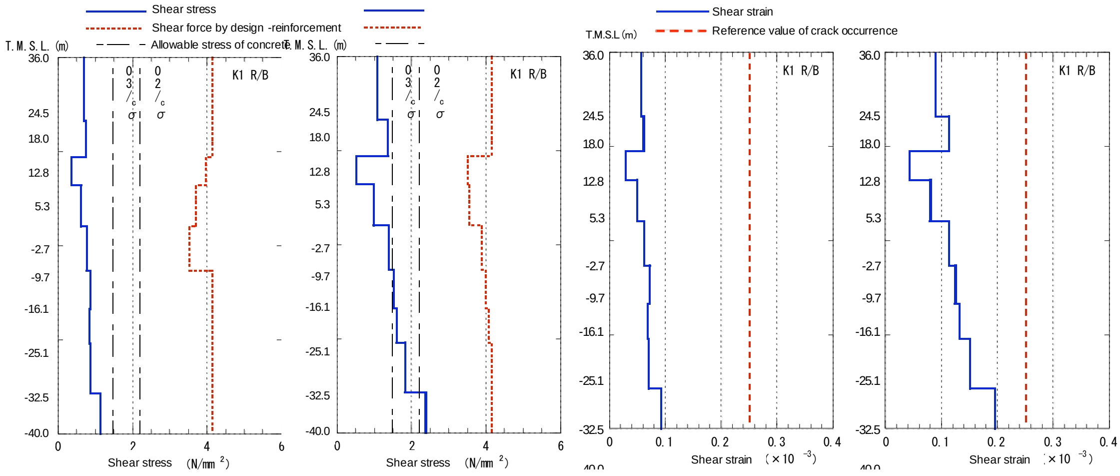
* Maximum acceleration was larger than maximum range of the seismometer.

Figure 7 Maximum accelerations (Unit 1)



NS direction EW direction

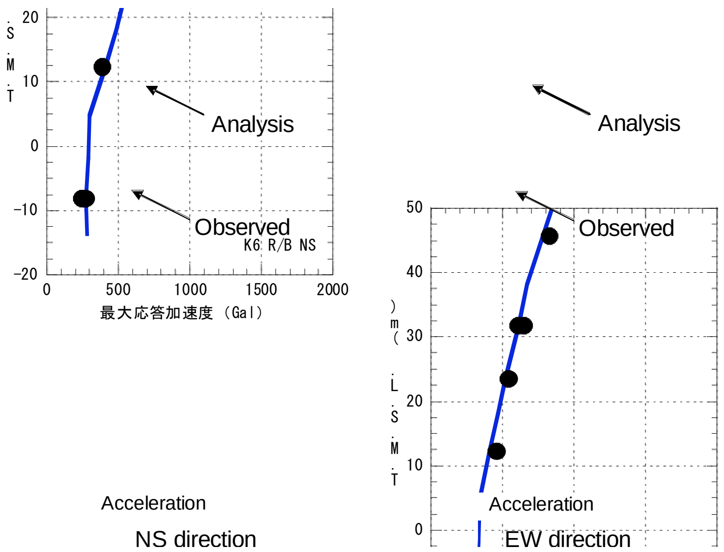
Figure 8 Acceleration time histories and response spectra of the observation records (Unit 1)



NS EW NS EW

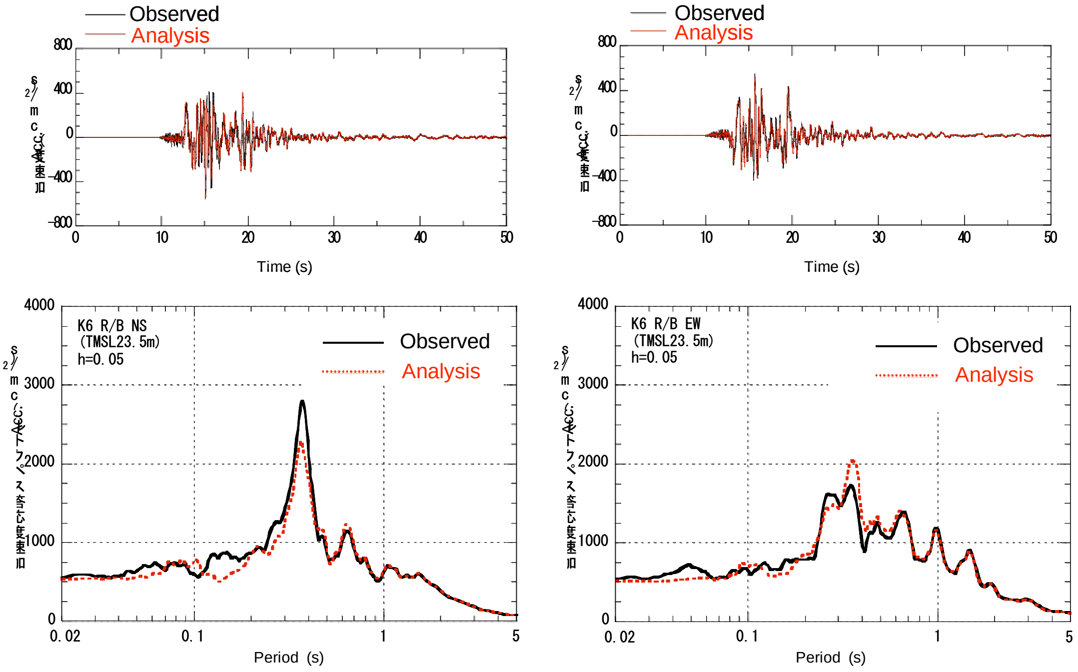
Shear stress Shear strain

Figure 9 Maximum shear stress and strain of shear walls (Unit 1)



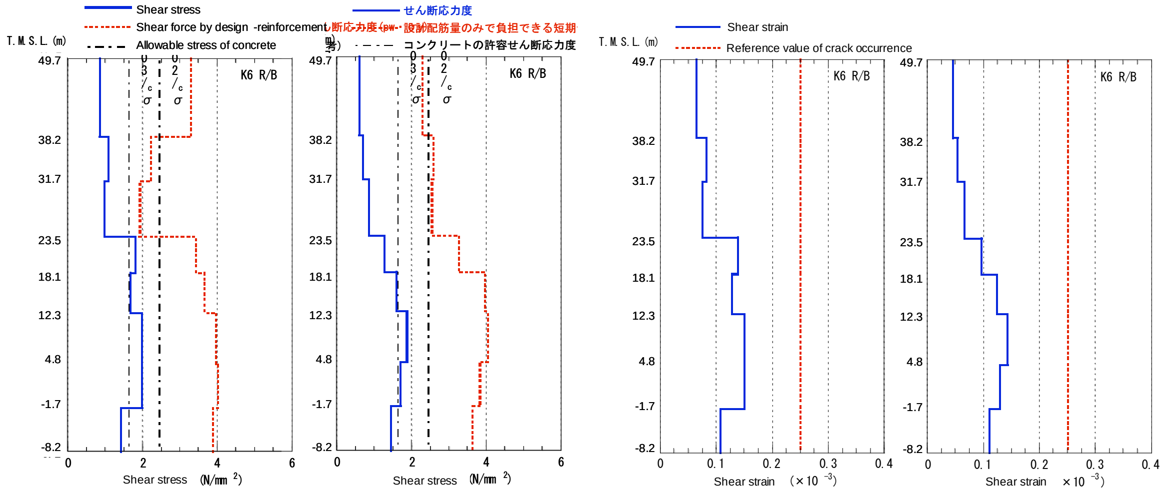
NS direction EW direction

Figure 10 Maximum accelerations (Unit 6)



NS direction EW direction

Figure 11 Acceleration time histories and response spectra of the observation records (Unit 6)



NS EW NS EW

Shear stress Shear strain

Figure 12 Maximum shear stress and strain of shear walls (Unit 6)

7 CONCLUSIONS

Simulation analyses were carried out on the reactor buildings using observation records at Kashiwazaki-Kariwa Nuclear Power Plant obtained during the 2007 Niigata-ken Chuetsu-Oki Earthquake, which occurred on July 16, 2007.

Simulation analysis models for the reactor buildings were based on the design models. They employed sway rocking models incorporating realistic conditions of building and ground. It also utilized observation records on the base mat slab. As a result, the following items were found.

The simulated distribution of the maximum response acceleration closely followed the trend of observation records and showed well agreement.

The simulated floor response spectrum of intermediate floors in the reactor buildings closely followed the frequency characteristics of the observation records.

The simulated maximum shear stress of each floor was within the range of allowable stress that could be resisted only by design reinforcing bars.

The simulated maximum shear strain of each floor was smaller than the reference value for crack occurrence 0.25×10^{-3}.

The simulated maximum stress and strain of the shear walls of the reactor buildings, which were the main structural members, were generally within the elastic range and the structural elements have adequate structural integrity.

REFERENCES

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