Transactions of the **14th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 14), Lyon, France, August 17-22, 1997

K05/4

Simulation analysis of earthquake records observed at Tsuruga unit N° 2 nuclear power plant

Kato A.[1], Oba M.[1], Shirahama K.[2], Imazuka Y.[2], En K.[2]
(1) The Japan Atomic Power Company, Japan
(2) Obayashi Corporation, Japan

ABSTRACT : On January 17, 1995, the Hyogoken-nambu Earthquake (the Great Hanshin Earthquake) was observed at the Tsuruga Nuclear Power Plant Unit No.2 located 160 km north-east of the epicenter. To confirm validity of the analysis model which was proposed after the forced vibration test of the reactor building, authors have conducted simulation analyses for the earthquake records. The simulated results show good agreement with the observed records in maximum response acceleration and acceleration response spectra.

1 INTRODUCTION

In the reactor building of the Tsuruga Nuclear Power Plant Unit No.2 (PWR 4 loop type, 1100 Mwe) and in the ground just beneath the reactor building, seismometers have been installed and observed earthquake motion continuously.

In the early morning on January 17, 1995, the violent shaking of the Hyogoken-nambu Earthquake (the Great Hanshin Earthquake) attacked Kobe city and caused huge disaster in the region. The earthquake was also observed in Tsuruga city and at the plant located almost 160 km north-east of the epicenter. The seismic intensity in Tsuruga city was 4th grade in the Japan Meteorological Agency (JMA) scale. This paper presents the results of simulation analyses for the horizontal observed records using detailed lumped mass models for earthquake response analysis. These models were proposed after the forced vibration test of the reactor building, and the aim of the simulation analyses is to confirm validity of the models.

Locations of the Tsuruga Nuclear Power Plant and the epicenter are shown in Figure 1. The cross sections of the reactor building are shown in Figure 2.

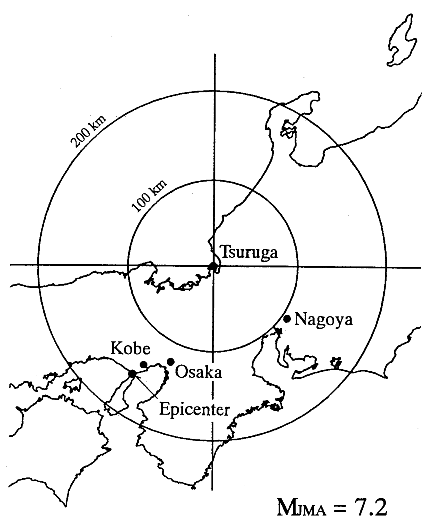

Figure 1. Locations of the Tsuruga Nuclear Power Plant and the epicenter

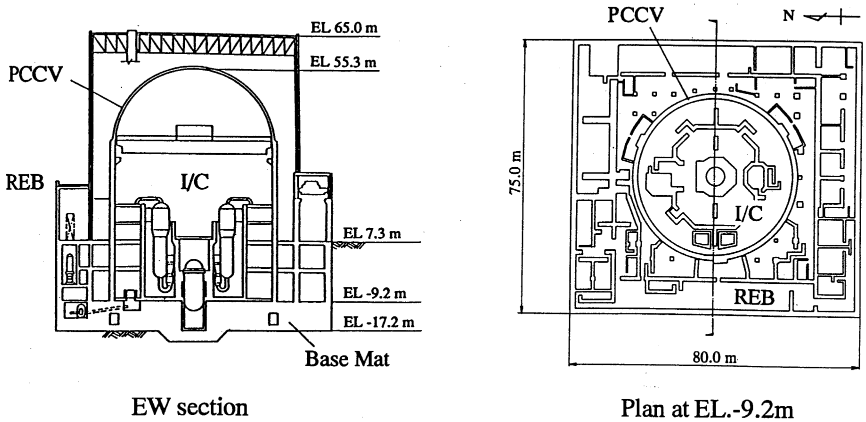

Figure 2. Cross Sections of the Plant

2 OBSERVED EARTHQUAKE RECORDS

The earthquake motion was recorded during 110 seconds at the plant. Then a target time period for the simulation analysis was set to 40 seconds long before and after the main shock part. This has large shaking for 10 seconds following the microtremor of 20 seconds. The maximum accelerations of the observed records were about 10 gal in the ground, 10 to 20 gal on the operating floor (O/F) level of the reactor building and 40 to 50 gal at the top of Prestressed Concrete Containment Vessel (PCCV).

3 ANALYSIS MODEL

In the simulation analysis, we employed the detailed lumped mass models which were proposed after the forced vibration test of the reactor building[1]. They are composed of three-dimensional lumped masses of Reactor External Building (REB) including Enclosure Building (E/B) and two-dimensional lumped masses of PCCV, Internal Concrete structure (I/C) and Steam Generators (S/G) standing on a rigid base mat. Figure 3 and 4 show the analysis models for EW and NS direction respectively. The latter is set as a half model due to geometrical symmetry of the buildings.

With respect to the EW direction model, Pressurizer (P/R) wall and S/G walls of I/C are combined together to form one member below the O/F level, while P/R wall above the O/F level is placed separately from EW axis which goes through the center of the reactor building to account for its torsional effects. As for the NS direction model, P/R wall and S/G walls stand separately on the base mat. At the base of PCCV, a rotational spring is attached to account for elastic sinking of PCCV to the base mat for both directions. Material properties and damping factors of the structures are shown in Table 2. These values were examined through the vibration test.

The soil is modeled as sway and rocking springs incorporating soil-structure interaction. On the basis of the vibration admittance theory, both springs have constant stiffness and frequency-dependent damping. The shear wave velocity of soil is 1600 m/s set from elastic wave tests.

Eigen values of the models are shown in Table 1 and major mode shapes are shown in Figure 5. Note that the mass of the model is modified from the time of vibration test to fit an operating condition on the day.

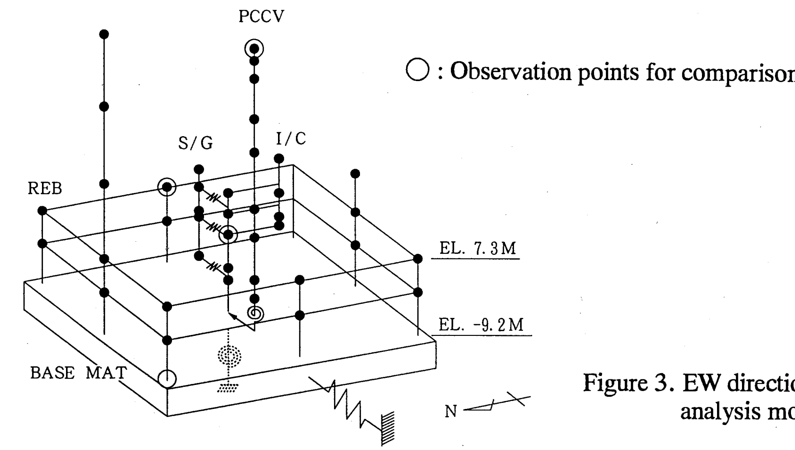

Figure 3. EW direction analysis model

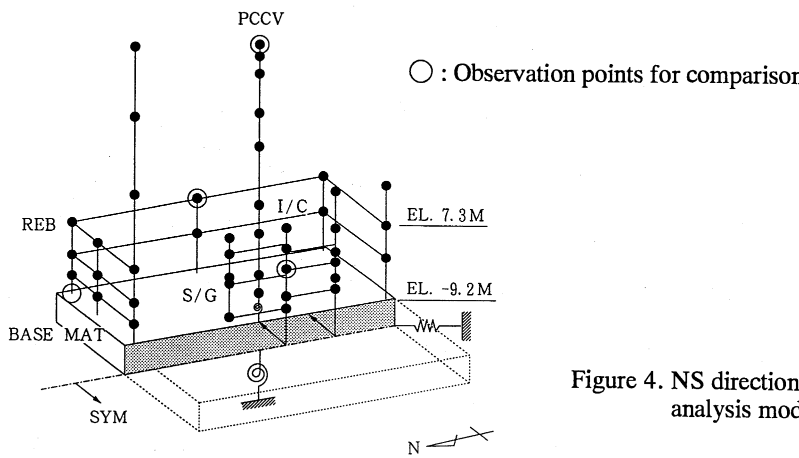

Figure 4. NS direction analysis model

Table 1. Eigen values of the model;
T : Natural period, in sec, f : Natural frequency, in Hz

N	EW		NS	
	T (f)	Excited Building	T (f)	Excited Building
1	0.300 (3.34)		0.313 (3.19)	E/B
2	0.295 (3.39)	E/B	0.202 (4.95)	PCCV
3	0.202 (4.94)	PCCV	0.137 (7.28)	REB
4	0.130 (7.66)		0.132 (7.59)	E/B
5	0.130 (7.69)	E/B, I/C	0.130 (7.66)	I/C
6	0.129 (7.78)	E/B, I/C	0.111 (8.99)	REB, I/C
7	0.110 (9.13)	REB	0.098 (10.2)	REB, I/C
8	0.104 (9.61)	I/C	0.090 (11.1)	I/C
9	0.104 (9.65)	REB, I/C	0.082 (12.2)	REB, I/C
10	0.087 (11.5)	REB	0.077 (13.0)	I/C

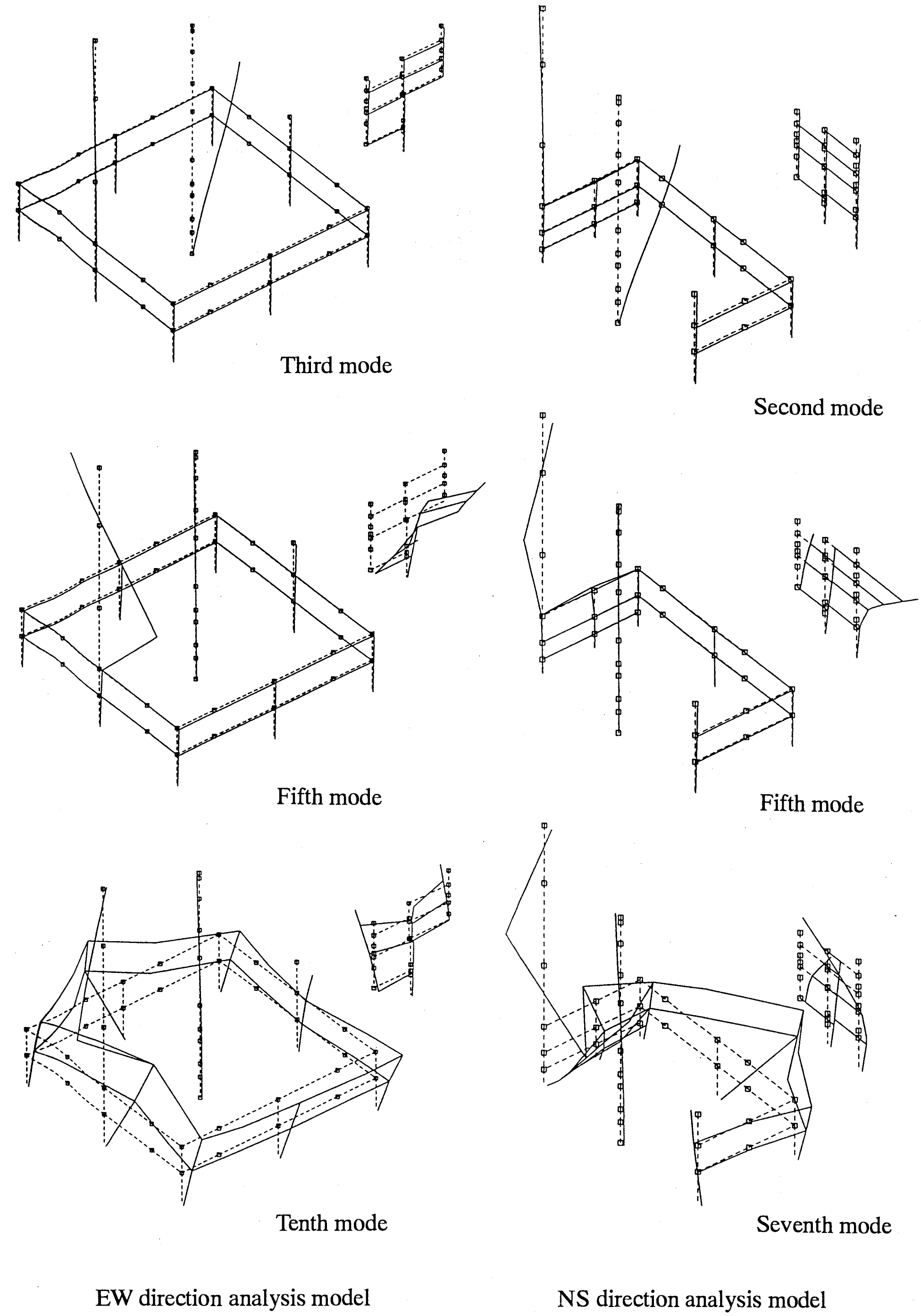

Figure 5. Major mode shapes of analysis models

4 SIMULATION RESULTS

The results of earthquake response analysis are presented comparing with the observed records. The observation points for comparison are at the top of PCCV (EL.55.3m), on the O/F level of I/C and REB (EL.7.3m) and on the base mat (EL.-9.2m). In the analyses, the recorded waves at the bottom of base mat (EL.-17.0m) were used as input ground motions. The waves are shown in Figure 6. Low frequency range less than 5 Hz is dominant in the waves.

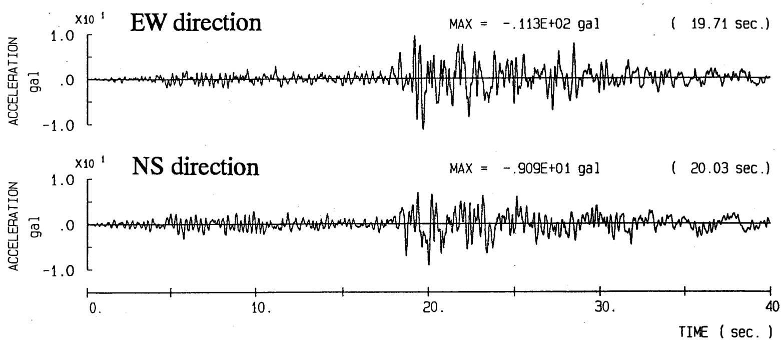

Figure 6. Input Ground Motions (observed records at the bottom of base mat)

4.1 *Maximum acceleration*

The simulated maximum response accelerations are compared with the observed records as shown in Table 3. In EW direction, the analytical values correspond with the observed records well at every point. In NS direction, the analytical values show good agreement with the observed records on the O/F level of I/C and REB. However, the analytical value is almost 40% small to the observed record at the top of PCCV, while 20% larger than the observed record on the base mat.

4.2 *Acceleration time history*

Comparison of acceleration time history is shown in Figure 7 (only for EW direction). The simulated time histories on the O/F level of I/C and REB show good agreement with observed records in their envelope shape. Moreover, both amplitude and phase are quite similar during the main shock. However, simulated time history at the top of PCCV shows larger amplification during the main shock. The difference may be caused by the oval modes of PCCV, which can not be accounted for in two-dimensional stick models.

4.3 *Acceleration response spectra*

Comparison of acceleration response spectra for 5% damping is shown in Figure 8. In general, predominant frequencies of the simulated results correspond with these of the observed records quite well. However, the amplification magnitude is slightly different between the simulated results and the observed records.

At the top of PCCV, a predominant frequency of simulated spectra corresponds with that of the observed record for both directions. Moreover, the magnitude of spectra almost corresponds with the observed record for EW direction. Although a split of peak, which may be caused by a position of the polar crane in the containment vessel on the day, is seen in the observed record for EW direction, the magnitude of the simulated spectra is almost as large as that of the observed record. On the other hand, the magnitude of the simulated spectra is quite small in higher frequency range less than 0.4 second for NS direction.

On the O/F level of I/C and REB, the models can simulate predominant frequencies even in higher modes of response spectrum. However, the magnitude of spectrum shows slight difference between the simulated results and the observed records. These are frequencies at 0.15 second for I/C and 0.10 second for REB for EW direction, at 0.25 second for I/C and between 0.15 to 0.40 second for REB for NS direction respectively.

On the base mat, predominant frequencies correspond well while magnitude differs slightly, too. For this location, spectral acceleration in higher frequency range shows the same difference as in the comparison of maximum acceleration.

5 CONCLUSIONS

Using the observed wave at the bottom of base mat as input ground motion for the analysis, we could obtain good agreement between the observed records and the simulated results except for the results at the top of PCCV for NS direction. Since the model is made up with the results of the forced vibration test, it can simulate even in higher modes of response spectrum at the O/F level of I/C and REB. Accordingly, we could confirm the validity of the models through the simulation analysis.

REFERENCE

Kato, M., Y. Watanabe, A. Kato, T. Takeda, et al. 1988. Simulation analysis on forced vibration tests of Tsuruga Unit No.2 nuclear power station.
Proceedings of 9th WCEE.

Table 2. Material properties and damping factors of the structures

		Young's Modulus E (t/cm^2)	Shear Stiffness G (t/cm^2)	Damping factor h (%)
PCCV	(Concrete Structure)	400	171	2.0
REB, I/C, Base Mat	(Concrete Structure)	270	115	4.0*
E/B	(Steel Structure)	2,100	810	0.5
S/G		1,960	737	1.0

* for steel structure in I/C: h = 2%

Table 3. Comparison of the maximum acceleration, in gal

Location	Observed Records		Simulated Results	
	EW	NS	EW	NS
At the top of PCCV	38.2	47.4	38.9	28.6
On the O/F Level of I/C	13.5	11.1	13.5	13.1
On the O/F Level of REB	17.1	10.8	17.0	10.7
On the Base Mat	13.8	7.9	11.7	9.5

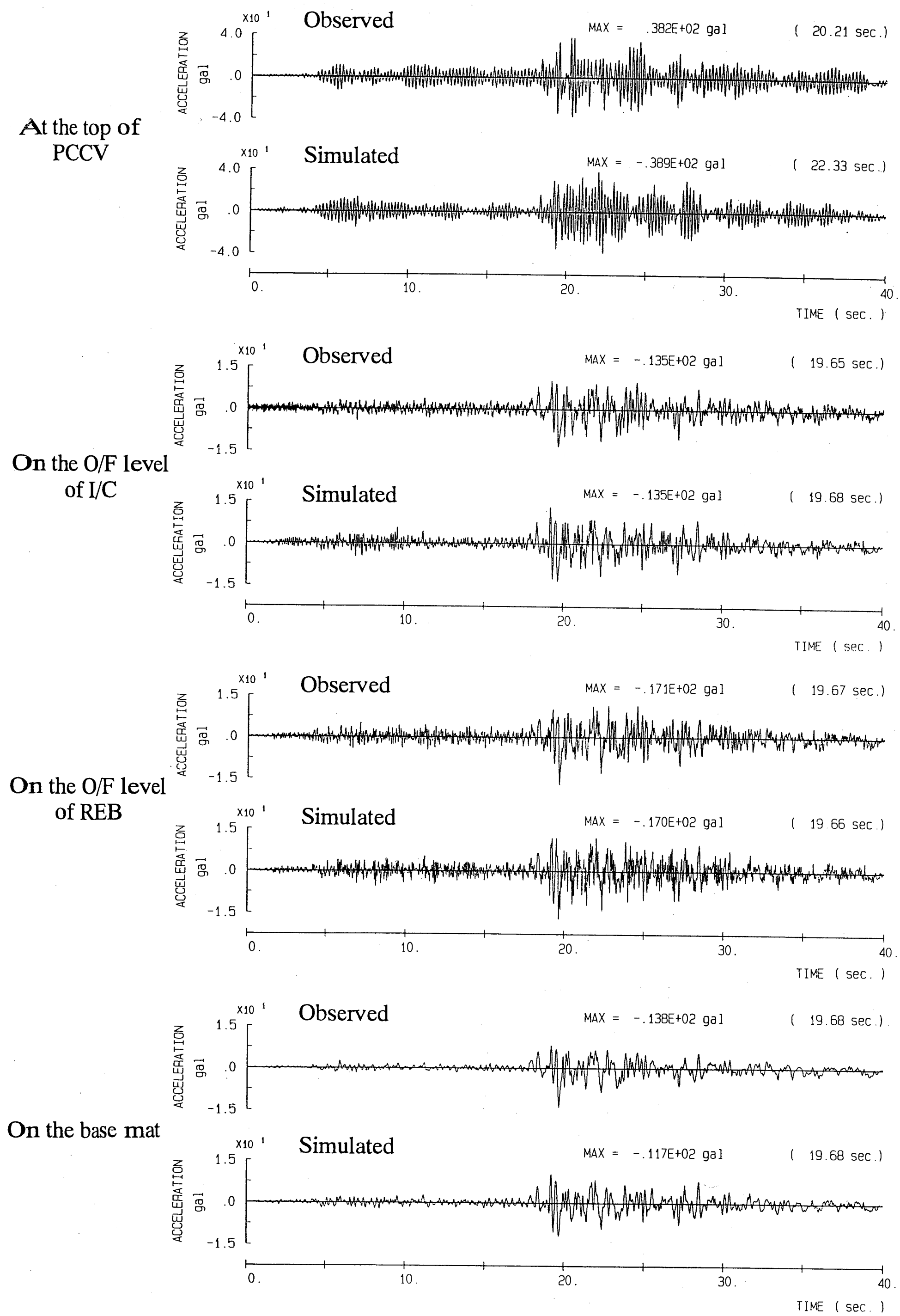

Figure 7. Comparison of acceleration time history (EW direction)

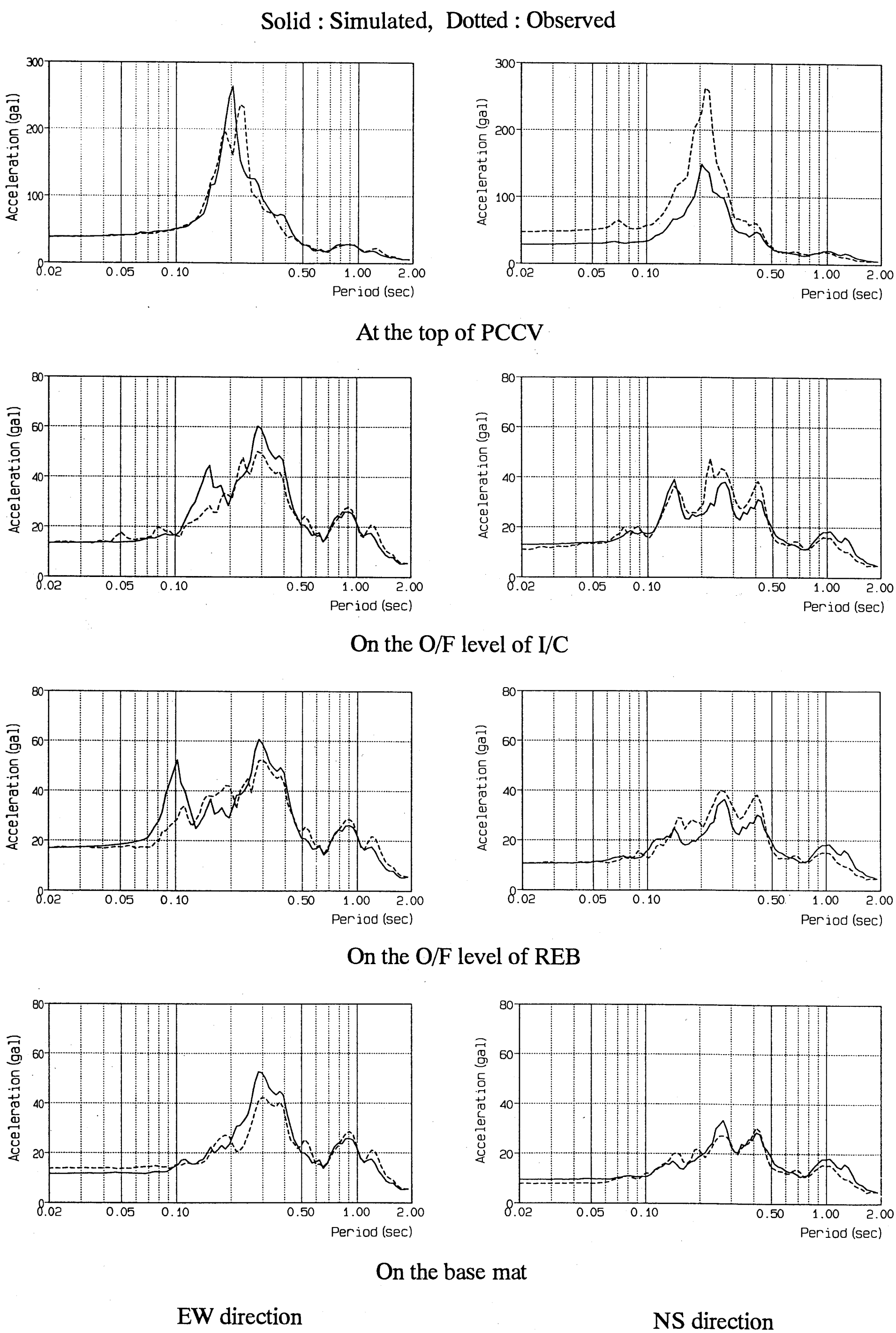

Figure 8. Comparison of acceleration response spectra