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Study on the method of seismic PRA model by utilization of observed earthquake data

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ABSTRACT: The object of this study is to re-evaluate the variations dealt in PRA procedure, which is established by authors, through the earthquake observation data which have been obtained in real buildings such as base-isolated building and ordinary building. Statistical analyses of response spectra of the observed earthquake records and the response spectra obtained from the dynamic response analysis of these records in the time domain, and the response spectra obtained from probabilistic response analyses based on stationary random theory are performed. Comparing these statistical data, it is proposed that the variation of the response of system is mostly occupied by the variation of the input motion. The results represent that there are some room for further improvement in the combination of the hazard analysis and the fragility analysis.

1 INTRODUCTION

The authors have proposed the seismic Probabilistic Risk Analysis (PRA) procedure(Mizutani et al. 1991.) to evaluate the failure probability of Nuclear Power Plant in Japan. The procedure is consist of two major steps of seismic hazard analysis and fragility analysis. In our procedure, the variation included in these two steps is treated as independent each other. In the fragility analysis, the procedure treats the variation of the dynamic characteristics of superstructure and the input motion independently.

The analysis model of the structure includes the effect of soil-structure interaction and the ground motion. Therefore some variation factors in the hazard analysis and the fragility analysis may have the same cause. And also some variation of the structural response characteristics may be caused by the difference of the mechanism of the input motion. Consequently, some variation factors in the dynamic characteristics of superstructure and the input motion in the fragility analysis may not be able to treat as independent.

In this paper we report the result on the study on variation dealt in our seismic PRA procedure through the earthquake observation data which have been obtained in real buildings.

2 OUTLINE OF TEST BUILDINGS AND EARTHQUAKE OBSERVATION

2.1 Test buildings and base-isolated system

Two test buildings were constructed side by side on a relatively hard loam layer with gravel(Izumi et al. 1988.). These buildings are real size 3-story reinforced concrete structures and have exactly same structure, but one has the ordinary foundation, and the other has the base-isolated foundation. Fig.1 shows the plan and elevation of the test buildings.

Base-isolated building has 6-rubber bearings and 12-oil dampers. The dimensions of rubber bearing are shown in Fig.2.

2.2 Earthquake observation

An earthquake observation array system is installed to record the earthquake response of building and ground. In this array, there are 2 observation points on the ordinary building, 5 observation points on the base-isolated building and 4 points in the surrounding ground. Each of 11-points has 2 or 3 components, (X, Y, Z) or (X, Y), and totally 31 components could be observed. Fig.3 represents observation points in the array. Location of the test building and the observation point of ground are shown in Fig.4.

Table 1 Observed earthquake records used in the study

Date	Magnitude	Focaldepth (km)	Hypocentraldistance (km)	Max. Acceleration at G.L.-27m(G1)(gal)
1986/06/24 11:53	6.5	73	387	3.6
1986/10/14 06:17	6.7	53	145	4.3
1986/12/01 05:15	6.0	50	139	5.6
1987/01/09 15:14	6.6	71	208	18.4
1987/01/14 20:04	6.9	115	522	4.1
1987/01/21 08:36	6.5	52	126	7.7
1987/02/06 21:23	6.4	18	174	13.0
1987/02/06 22:16	6.7	31	171	23.9
1987/02/28 15:52	6.5	35	166	2.7
1987/03/10 12:24	5.6	39	169	3.6
1987/04/07 09:41	6.6	37	165	24.4
1987/04/17 04:23	6.0	42	156	5.2
1987/04/23 05:13	6.5	49	156	23.4
1987/05/26 21:08	5.6	25	140	2.7
1987/06/26 16:12	5.5	45	181	1.5

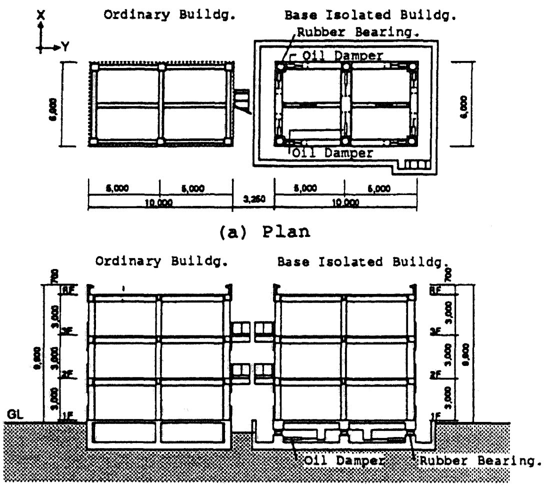


Fig.1 Plan and Elevation of test Building

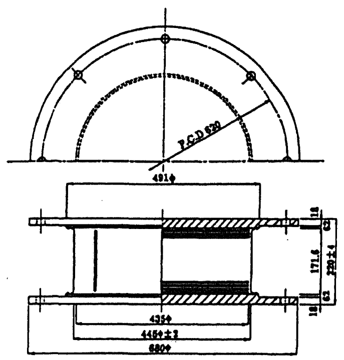


Fig.2 Outline of Rubber Bearing

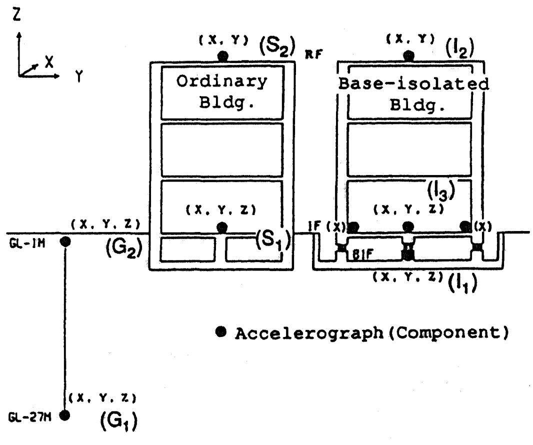


Fig.3 Accelerograph set up

2.3 Statistical analysis of earthquake records

Fifteen earthquake data observed by the array, shown in Table 1, are used in this study. Whole analysis in this study is performed on X .component (transverse direction of building).

These records are normalized by the ground acceleration value of 100 gals at the point of G.L-27m(G1). To grasp the correlation between the variation of input motion and the variation of dynamic superstructural system, the variation of the response of buildings, estimated using the variation data of input motion at G.L.-1m(G2), and the variation data of transfer function between G.L.-1m(G2) and each point of the buildings by several kind of analysis, are compared with observed data.

Fig.5(a) shows the normalized sample data on the point of G.L.-1m(G2), and statistical characteristics of these data are shown in Fig.5(b).

In the following discussion, signs of G1,

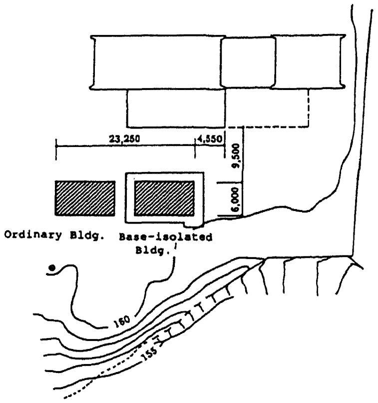
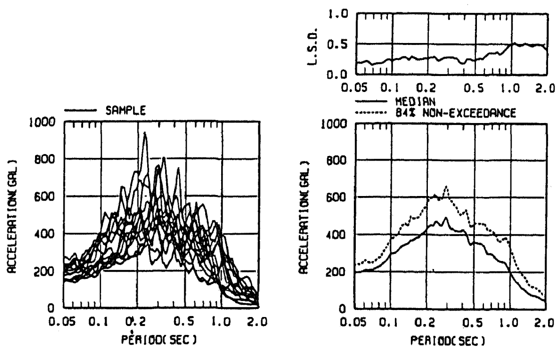


Fig.4 Site Plan



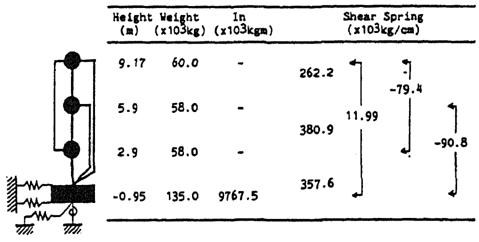
(a) sample spectra

(b) statistical characteristics

Fig.5 Observed response spectra(after normalized)

Specification of isolation device model

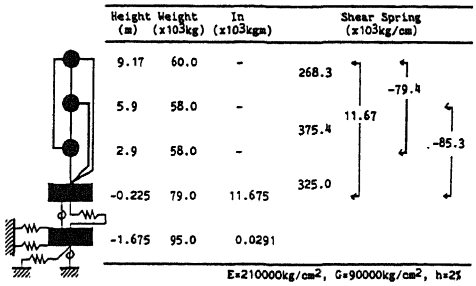
Horizontal	$Kh=4.48\times10^3$kg/cm	C=680kg/cm/sec
Rotational	$Kr=2.65\times10^{11}$kgcm/rad	h=0.02



ground impedance

$Khs_1=2.11\times10^5$kg/cm	$Chs_1=1.50\times10^3$kg/cm/sec
$Khs_2=3.32\times10^5$kg/cm	$Chs_2=1.86\times10^3$kg/cm/sec
$Kh_B=3.34\times10^6$kg/cm	$Ch_B=2.96\times10^3$kg/cm/sec
$Kr_B=3.30\times10^{11}$kgcm/rad	$Cr_B=7.56\times10^7$kgcm/rad/sec

(a) ordinary building



ground impedance

$Khs_1=2.11\times10^5$kg/cm	$Chs_1=3.28\times10^3$kg/cm/sec
$Khs_2=3.32\times10^5$kg/cm	$Chs_2=4.32\times10^3$kg/cm/sec
$Kh_B=4.61\times10^6$kg/cm	$Ch_B=5.62\times10^3$kg/cm/sec
$Kr_B=9.86\times10^{11}$kgcm/rad	$Cr_B=3.51\times10^7$kgcm/rad/sec

(b) base-isolated building

Fig. 6 Analytical model

G2, S1, S2, I1, I2 and I3 represent the observation point of array (see Fig.3).

3. ANALYSIS PROCEDURE

3.1 Analytical model

Sway-Rocking(SR) model is used as analytical model for the simulation of the response of two buildings. The mass has single degree of freedom. In order to count the effect of bending, spanned shear springs are also used. Soil-structure interaction is considered as springs which connect superstructure and ground model. One dimensional ground analysis is used to obtain the input motion to the superstructure. Base isolated devices are modeled as horizontal and rotational springs and dampers. The SR model of two buildings and specifications of the model are shown in Fig. 6.

3.2 Dynamic analysis on earthquake records

Two kind of dynamic simulation analyses in time domain are performed. One simulation is the dynamic analysis using the each input motion sample at G2. The response obtained from the analysis is close to real response except it dosen't take the variation of transfer function into account. The difference between the variation of observed response and this response could be regarded as the variation due to the dynamic characteristics of superstructure. The other represents the procedure in our fragility analysis. At the first, the variation of maximum acceleration of the input motion is estimated and then the variation due to the spectral shape is evaluated. To evaluate this variation, input motion which is normalized by the median of maximum acceleration at G2 is used. Overall variation is obtained by assembling these two variation independentry.

3.3 Probabillistic response analysis on stationaly random process

Probabilistic response analysis based on stationary random theory is also applied to simulate the response of the buildings. The major steps of this procedure are as follows.

1) Expected transfer function of the system and expected response spectral of input motion are expressed by the median value and the 84% non-exceedant value.

2) The variation of response is obtained from the sum of the variations on transfer function and input motion, independently.

3) The median value of transfer function of the superstructure is obtained analytically, but the variation is obtained from the observed data. Parzen's window is applied to the observed transfer function (Band width=0.6). Fig.7 shows the median and variation of the observed transfer function.

4) The response is evaluated through power spectrum under the stationary random process.

4. DISCUSSION ON THE RESULTS

4.1 Median of response spectrum

Fig. 8 shows the median value of response spectra of each point. The response spectra obtained by two kind of analyses in time domain, the response spectra evaluated from probabilistic response analysis, and the observed response spectra are compared in this figure.

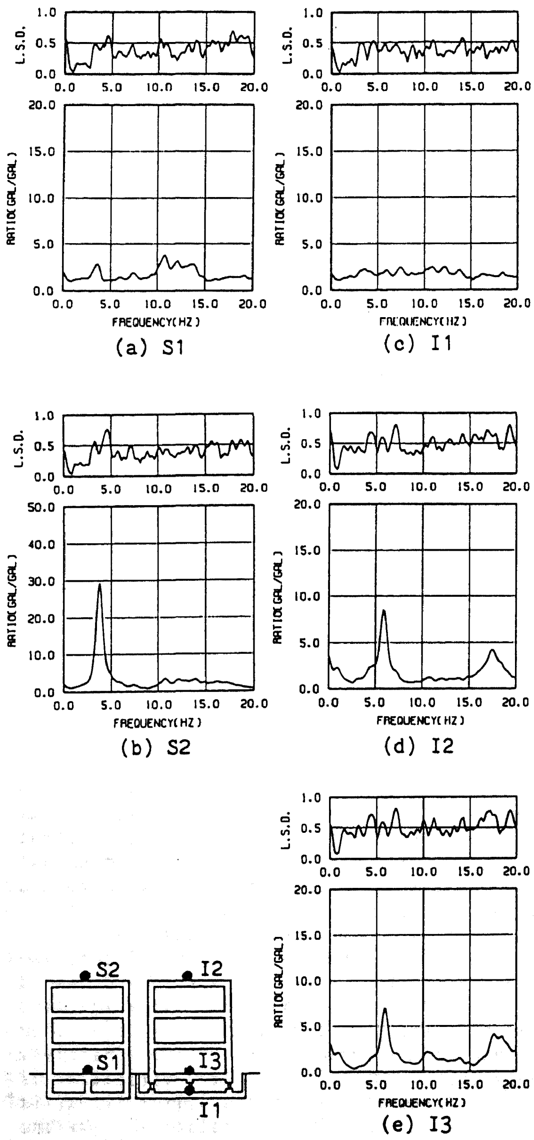


Fig.7 Statistical value of observed transfer function

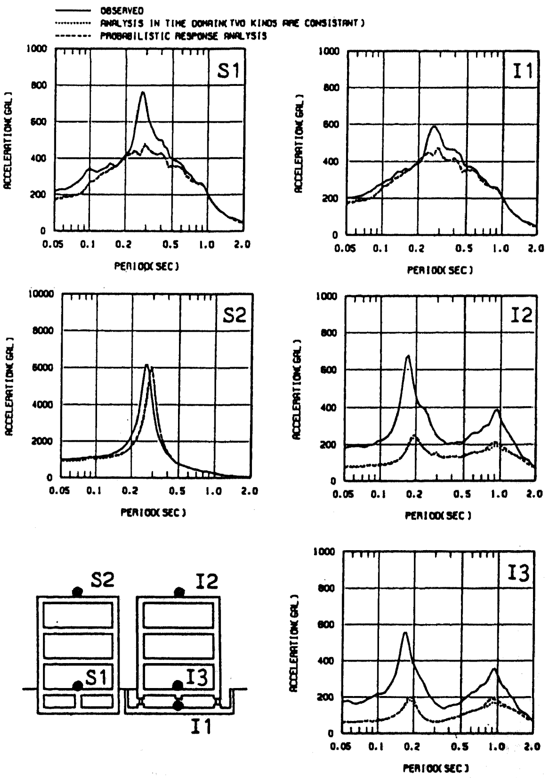


Fig.8 Median value of response spectra

The response spectra obtained from dynamic analyses, and those from probabilistic analysis show a good agreement. However, observed response spectra are different from the result of analyses.

These results point that the evaluation error of response analysis should be considered in evaluation step for median value. As the evaluation technique for the transfer function is improved, the evaluation error would become small.

4.2 Corelation between the variation of input motion and dynamic characteristics of superstructure

In order to investigate the corelation between the variation of input motion and transfer function of superstructure, following two variations are compared,

1)the variation of response evaluated from the observed transfer function using probabilistic response analysis

2)the variation of transfer function evaluated from the observed response spectra and response calculated in time domain

Fig.9 shows the comparison between these variations.

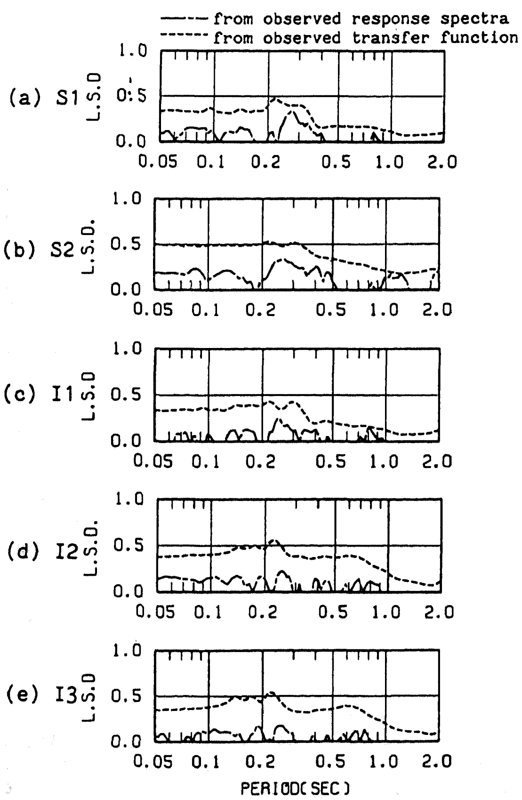


Fig.9 Variation due to the dynamic characteristics of superstructure

The value evaluated from observed response spectra is about 1/5 - 1/4 of the variation of response which is expected from the observed transfer function for both of the ordinary and base-isolated building.

This result means that the statistical characteristics of input motion and that one of dynamic characteristics of superstructure is highly corelated. And the variation of transfer function evaluated from the observed response spectra can be neglect.

4.3 Corelation between the variation of hazard analysis and fragility analysis

In our PRA procedure, hazard analysis and fragility analysis are combined independenyly. The corelation between the variation of hazard analysis and fragility analysis is examined. According to the discussion in the previous section, the variation of transfer function is small and negligible. The result of dynamic analysis, in which the transfer function of superstructure is deterministic, could be utilized for this purpose.

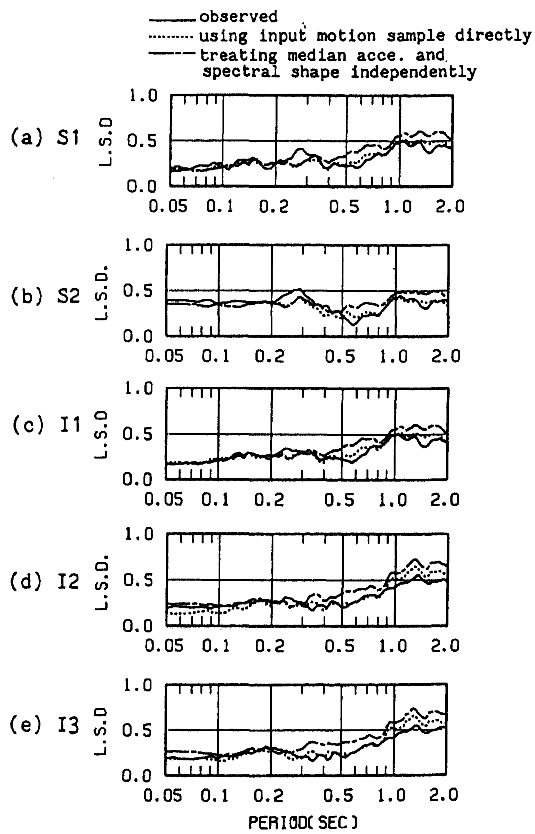


Fig.10 corelation between maximam acceleration and spectral shape of input motion

Fig.10 shows the comparison among the variations of follows,

1) the variation of response spectra of observed records

2) the variation of response spectra of dynamic analysis using the input motion sample at G2 directly.

3) The sum of the variation of spectral shape at G2 and the variation of the maximum acceleration at G2

The variation of 3) is larger than the other two. It implied that to some amounts, the variation in hazard analysis and fragility analysisis are corelated and to treat the variation of hazard analysis and fragility analysis independently causes the total variation overestimated.

4.4 Expression for the variation of the input motion

Fig.11 shows the comparison among the variation of observed response spectra, response spectra evalueted from dynamic analysis and response spectra obtained from probabilistic analysis. These figures explain the features as follows,

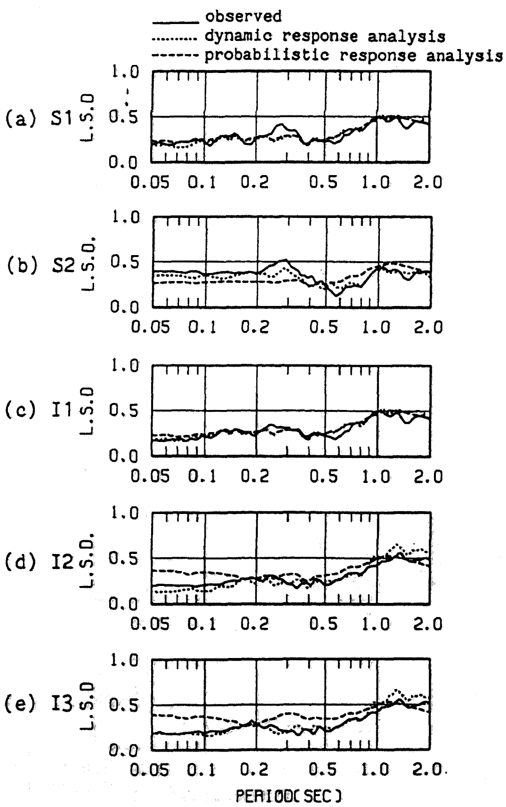


Fig.11 Comparison among the variation of observed spectra, dynamic response analysis and probabilistic analysis

1)the variation of observed response spectra and the variation of dynamic analysis response show a good agreement in all observation point

2)for the ordinary building, the variation obtained from probabilistic analysis makes good estimation

3)for the base-isolated building, the variation obtained from probabilistic analysis is much larger than the other cases. The variation of the response of isolated building is smaller than ordinary building in the observed data. This can be simulated by the dynamic response analysis. But by probabilistic response analysis, these variation are almost same.

The response by the dyanamic resonse analysis and by the probabilistic response analysis were shown to be in good agreement(Kai et al. 1990). The cause of the result such as 3) is considered to be in the treatment of the variation of input motion.

Therefore, the corelation of the variation of input motion through the period axis takes a big role. To express the statistical characteristics of input motion, making monte-carlo samples of input spectrum is better. Expressing by median value and 84% non-exceedance value is insufficient in case of the isolated building.

5. CONCLUSIONS

Statistical analysis of response spectra of observed earthquake records and the simulated response spectra are performed to re-evaluate the variation dealt in PRA procedure. Through this study, following results are obtained.

1)Corelation between the variation of input motion and the variation of dynamic characteristics of superstructure is considerable. To deal these variations independent, the variation of superstructure should be reduced to about one-fifth of the variation of observed response,or could be neglect. Hence, considering only the variation of input motion, the response of the building would be evaluated.

2)To estimate the variation of response of the base-isolated building, the corelation of the variation of the input motion through the period axis should be taken into accout.

3)Hazard analysis and fragility analysis are corelated each other. And these analysis should be considered simultaniously. There are some room for further improvement in the combination of the hazard analysis and the fragility analysis.

4)The improvment of simulation technique and the reduction of evaluation error are important to evaluate the median value precisely.

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