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VARIATION OF NON-LINEAR RESPONSE OF REACTOR BUILDING CONSIDERING UNCERTAINTIES OF DYNAMIC PROPERTIES

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1 Introduction

Study on advanced seismic design for LWR has been carried out by the Nuclear Power Engineering Corporation(NUPEC), under the sponsorship of the Ministry of International Trade and Industry(MITI) of Japan.

Recently, a lot of efforts to estimate the safety integrity of a reactor building have been made by many researchers. When we evaluate the safety integrity, it is important to estimate the variation of the seismic response that is associated with the uncertainties of the dynamic properties. The object of this study is to evaluate the variation of non-linear seismic response of the reactor buildings. In this study, several non-linear variation analyses are carried out on two typical types (BWR type and PWR type) of reactor buildings in Japan, focusing on two points. One is to use statistical data based on laboratory tests and field tests to simulate the real phenomena and second is to deal with the maximum variation of the non-linear response nearby the second yield point of the tri-linear restoring force curve.

2 Sensitivity analysis

2.1 Outline of analysis

First, sensitivity analyses are conducted using several factors that are considered to affect the seismic responses of a reactor building, in order to investigate contributions of these factors in the variations of the responses. The analytical model for the sensitivity analysis is sway-rocking (S-R) stick model representing a BWR type MARK- II reactor building. The random factors of this model are shown in Table 1. The fluctuation of the random factor is due to both systematic (or modeling) uncertainty and random uncertainty. All the coefficient of variation(C.O.V.) of these random factors are assumed as shown in Table 1 considering both uncertainties. The fluctuation of the input motion is defined as that of its power spectrum. The first order perturbation method is used for the sensitivity analysis assuming these random factors to be independent each other and to have a normal distribution respectively.

2.2 Results

Contributions of each random factors to the variation of the maximum seismic responses are as follows:

(1) Maximum response acceleration

Fig.1 illustrates contributions of each random factor to the variation of the maximum response acceleration for two ground conditions which have the shear wave velocity(Vs) of 500m/s and 1500m/s respectively. The results in the case of Vs=500m/s shows that real part and imaginary part of horizontal impedance function and the power level of input motion affect the variation of the maximum response acceleration, and the other factors do not affect. The contribution of the impedance functions in the case of Vs=1500m/s is smaller than that in Vs=500m/s. In addition to these factors, mass, Young's modulus, shearing area and damping factor have little contribution in Vs=1500m/s.

(2) Maximum response displacement

Fig.2 shows contributions of each random factor to the variation of the maximum response displacement for two ground conditions. The tendency of the contributions of each random factor to the variation of the maximum response displacement is similar to that of the maximum response acceleration.

3 Non-linear variation analysis

3.1 Selection of randam factors

The results of the sensitivity analysis indicate that the fluctuations of impedance functions at the base mat and the power level of input motion have the greatest influence on the seismic responses. On the other hand, the restoring force characteristics of structural components play the important role for non-linear response. Therefore, the impedance functions and the restoring force characteristics are selected as random dynamic properties in non-linear variation analysis. As it is difficult to treat the input motion as random variable in an analysis, we use three kinds of input motions so that we may investigate their influences on the variation of the seismic responses.

3.2 Analysis model and input motion

Non-linear variation analysis are carried out on two typical types (BWR type MARK-II and PWR type 4LOOP) of the reactor buildings in Japan. Fig.3 shows analysis models that have the floor springs and the sway and rocking springs as impedance functions. The damping factor of structural components of reinforced concrete is 3.0%.

Three seismic motions (EQ No.1, No.2 and No.3) whose dominant frequency differs from each other are used as input motion(Fig.4). In this study, each input motion is magnified so that the non-linear response reaches nearby the second yield point of the tri-linear restoring force curve that is used on design stage in Japan in order to investigate the maximum values of the variations of the responses.

3.3 Outline of analysis

Fig.5 explains how to fluctuate the impedance functions and the restoring force curve. Real parts and imaginary parts of the horizontal and rocking impedance functions fluctuate at the primary frequency that the motion of the base mat is dominant. $\tau - \gamma$ relationship skeleton curve has the tri-linear curve whose first, second and ultimate points of τ and ultimate point of γ are treated as the random variables. The non-linear monte-carlo simulation (MCS) is carried out using 25 samples from these distributions.

In order to simulate the real phenomena, statistical data that are obtained in other studies[1, 2] using results of laboratory tests and field tests, are used in these analyses. As these statistical data have not only first and second order moments but also coefficient of correlation, 25 MCS samples are generated after making each random variables independent using a coordinate transformation. One Sample of the skeleton curve and the impedance function are shown in Fig.6.

3.4 Results

In many cases, a limit state of shearing wall is defined using shear strain. On the other hand, a seismic design of equipments of nuclear facilities demands floor response spectra (FRS). The variations of both maximum of response shear strain and FRS are evaluated through 25 non-linear MCS for each input motion.

(1) Maximum response shear strain

Fig.7 shows the variations of maximum response shear strain. In the case of BWR type reactor building, the range of its C.O.V. is 0.06～0.47 for EQ No.1, 0.09～0.46 for EQ No.2 and 0.08～0.48 for EQ No.3. On the other hand, in the case of PWR type reactor building, its rang is 0.05～0.90 for EQ No.1, 0.08～0.66 for EQ No.2 and 0.05～0.85 for EQ No.3. Both types of reactor building have such a tendency that the stress concentrates the components whose response reaches the range of non-linear, so that the variations of these components are great.

(2) Floor response spectrum

In the case of BWR type, the variation of 5% damped floor acceleration response spectra at the operation floor is illustrated in Fig.8(a). The C.O.V. of FRS tends to be greater in the range of high frequency than in the range of low frequency and not to have any apparent peaks for each input motion. The maximum value of the C.O.V. is about 0.2. On the other hand, in the case of PWR type, Fig.8(b) shows the C.O.V. of FRS at the operation floor of I/C, whose value is about 0.3 at most. The peaks of the C.O.V. at the dominant frequencies of each input motion could be found.

4 Conclusions

Conclusions in this study are as follows:

- The results of the sensitivity analysis using first order perturbation method indicate that the fluctuations of impedance functions and the power level of input motion have the greatest influence on the seismic responses.
- The non-linear Monte-Carlo simulations are carried out under the following conditions. One is to use statistical data based on laboratory tests and field tests to simulate the real phenomena. The other is that the input motion is magnified so that the non-linear response reaches nearby the second yield point in the tri-linear restoring force curve in order to investigate the maximum values of responses. The results indicate that the coefficient of variation (C.O.V.) of maximum response shear strain in the case of BWR type reactor building is about 50% at most, in the case of PWR type, about 90% at most, while maximum C.O.V. of floor response spectra of BWR type is 20% and that of PWR type, 30% at most.

5 Acknowledgement

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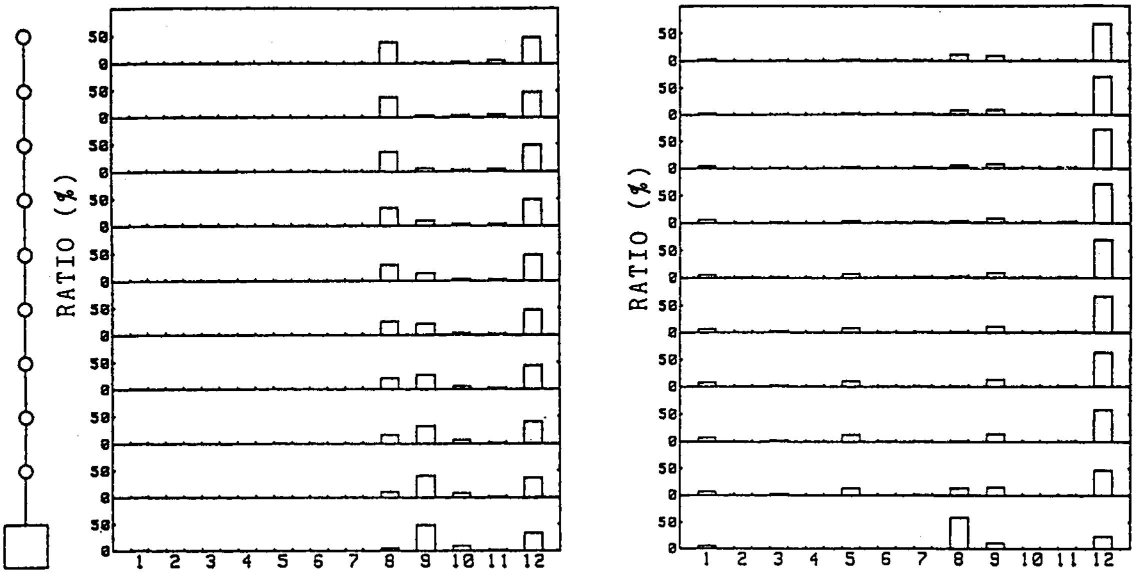
REFERENCES

1)R.SHOHARA et al.(1993),'Estimation of Uncertainty of Impedance Function of SSI system based on Existing Comprehensive Block-Shacking Test Data',Proc. 12th SMiRT,K03/2.

2)Y.KAI et al.(1993),'Uncertainty of Restoring Force Characteristics of Shear Walls and its Effect on Seismic Response',Proc. 12th SMiRT,K09/2.

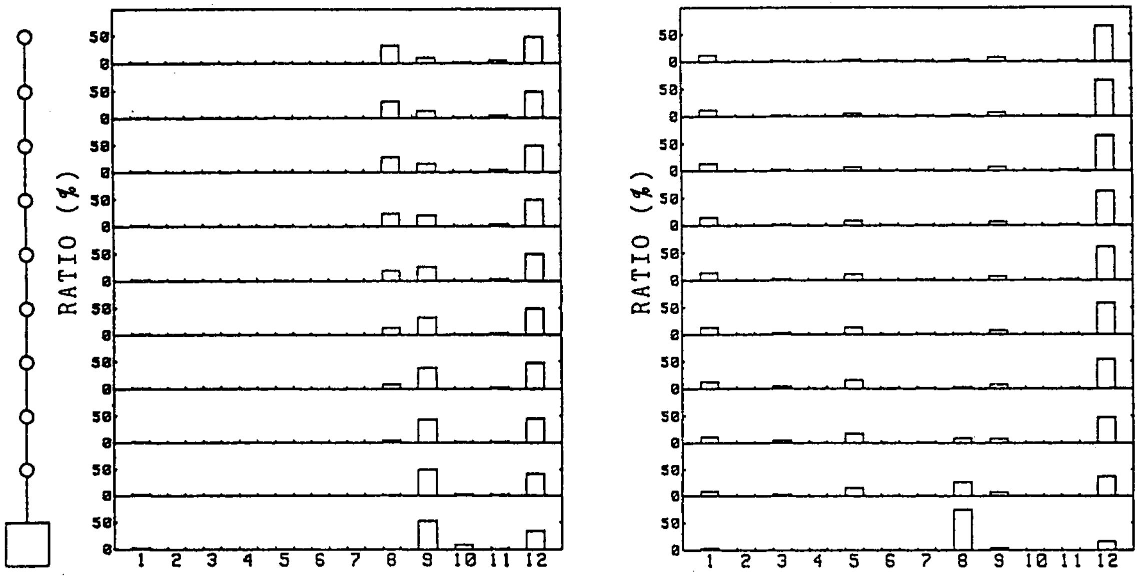
Table 1 Random factors and their C.O.V.

factor	C.O.V.	factor	C.O.V.
1. Mass	0.10	8. Real part of horizontal impedance	0.20
2. Rotational inertia	0.10	9. Imag. part of horizontal impedance	0.20
3. Young's modulus	0.05	10. Real part of rocking impedance	0.20
4. Poisson's ratio	0.05	11. Imag. part of rocking impedance	0.20
5. Shearing area	0.10	12. Input power level	0.20
6. Geometrical moment of inertia	0.10		
7. Damping factor	0.10		



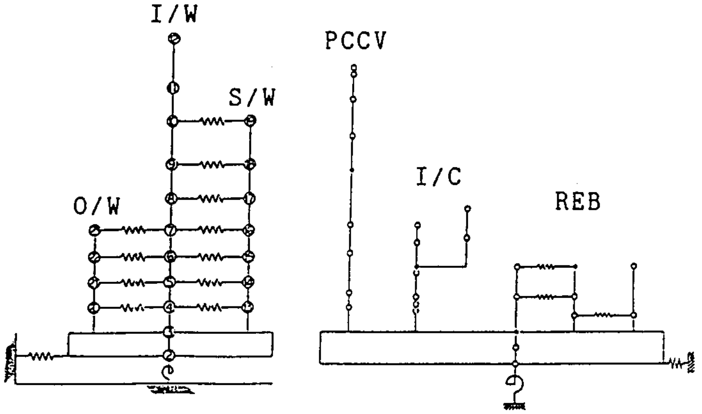
(a) Vs=500m/s (b) Vs=1500m/s

Fig.1 Contributions of random factors in variation of maximum response acceleration.



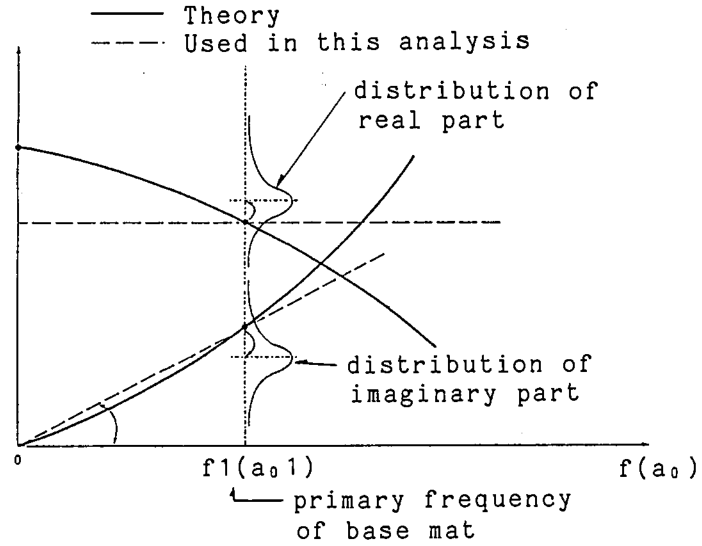
(a) Vs=500m/s (b) Vs=1500m/s

Fig.2 Contributions of random factors in variation of maximum response displacement.

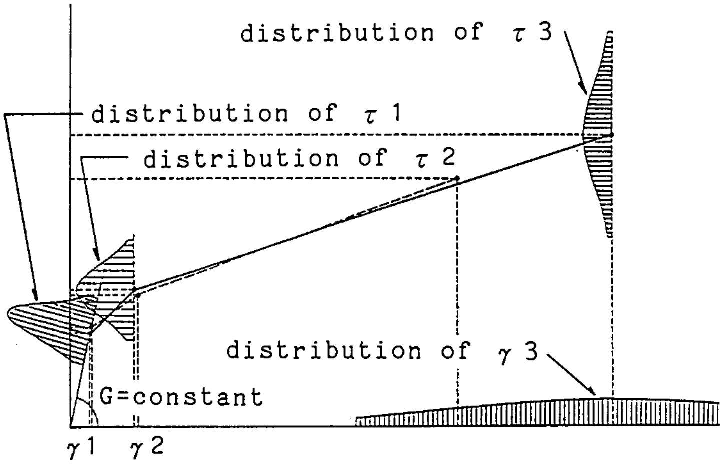


(a) BWR type (b) PWR type

Fig.3 Analysis models

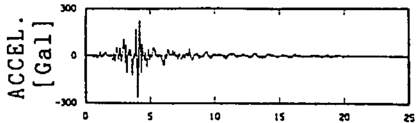


(a) Impedance function

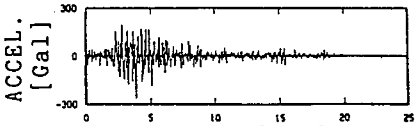


(b) Skeleton curve

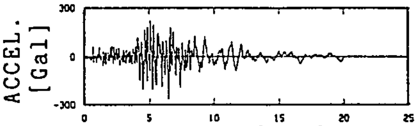
Fig.5 How to fluctuate random factors



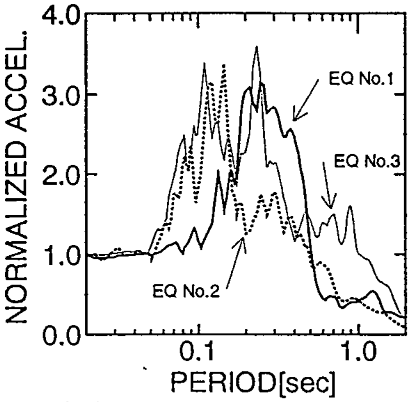
(a) EQ No.1



(b) EQ No.2

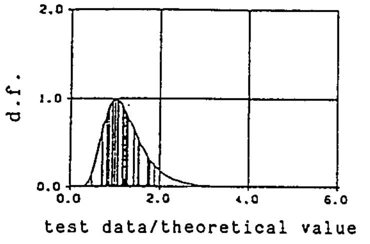


(c) EQ No.3

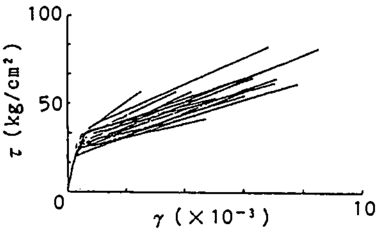


(d) Response spectra

Fig.4 Input motion

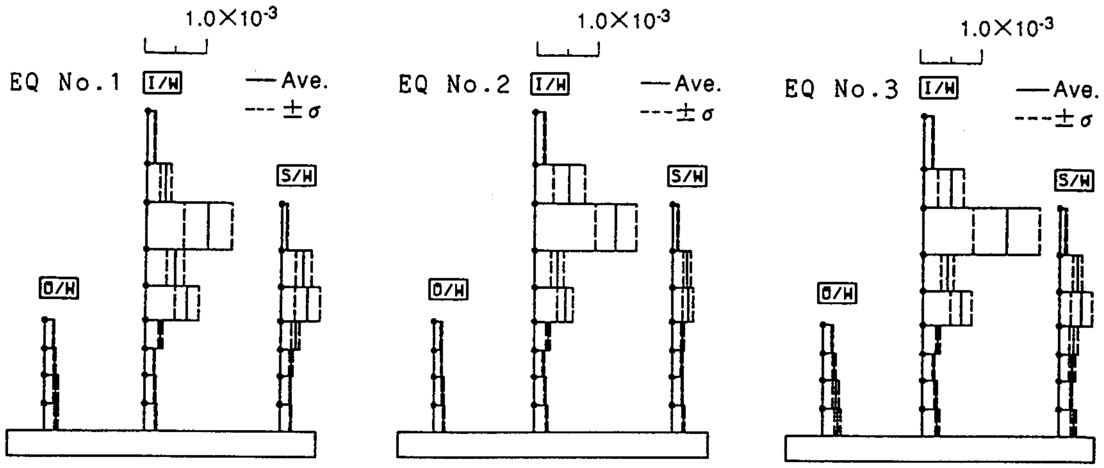


(a) Impedance function

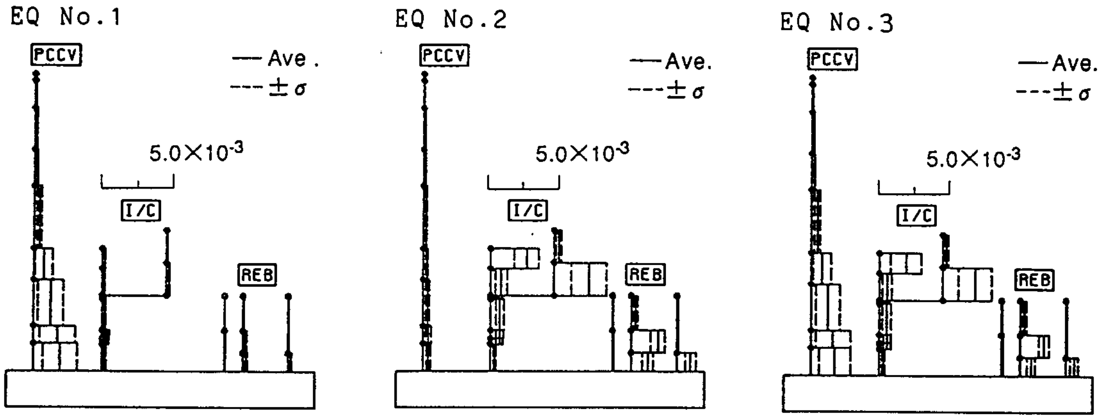


(b) Skeleton curve

Fig.6 One sample of MCS

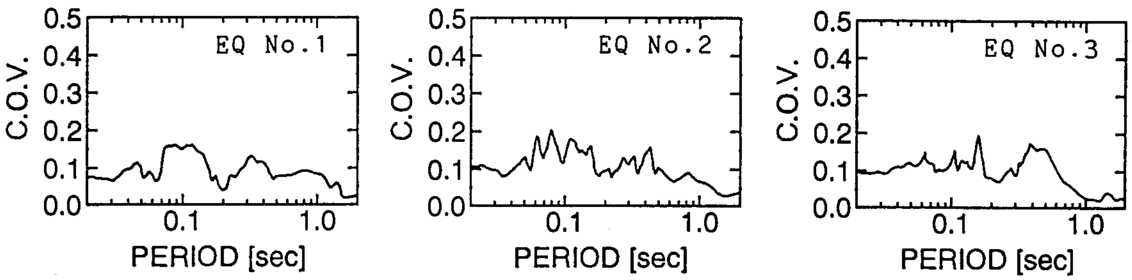


(a) BWR type

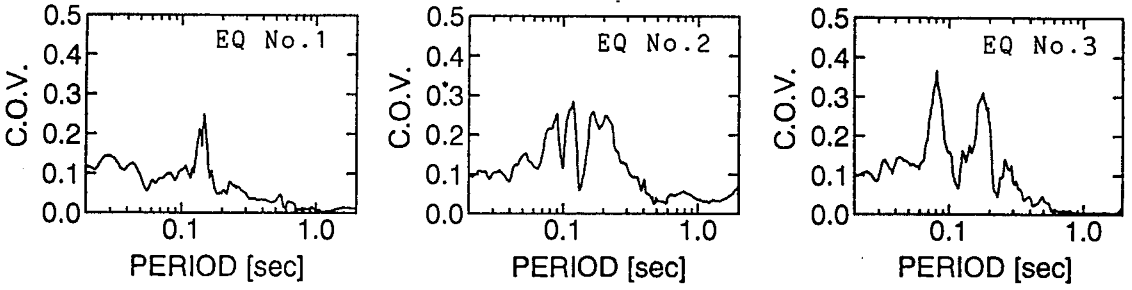


(b) PWR type

Fig.7 Variation of maximum response shear strain(γ)



(a) BWR type (at operation floor)



(b) PWR type (at operation floor of I/C)

Fig.8 Variation of FRS (h=5%)