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Study on probabilistic response by Monte Carlo method

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ABSTRACT: In probabilistic seismic safety assessment based on safety factor method, it needs to get probabilistic seismic response considering uncertainty for material properties of soil and structure in order to obtain response factor. So, considering Young modulus of concrete (E), damping factor of structure (h) and shear velocity of soil (Vs) as main properties of soil and structure, influence on elastic seismic response of reactor building caused by uncertainty of those properties is studied based on Monte Carlo method. As the results of analyses, it is found that uncertainty of shear velocity of soil has large influence on elastic seismic response of structure. And it is cleared that response value calculated by the seismic design method for nuclear power plants in Japan hearafter reffered to as "design value" seems to have a sufficient seismic safety margin compared with average of variational response analyzed by probabilistic method considering uncertainty of those properties.

1. OBJECT

The usual seismic response method for reactor building of nuclear power plant gives only a part of seismic response characteristics of structure, because properties of structure and soil are assumed to be constant. But those properties are actually recognized to have uncertainty. So to get "real seismic response of structure", it is important to consider uncertainty of those properties in probabilistic seismic safety assessment of reactor building.

The object of this paper is to study the influence on vibrational characteristics and seismic response of reactor building caused by uncertainty of material properties of soil and structure. And simultaneously, the seismic safety margin for reactor building is cleared by investigating the relation of design values and variational response values analyzed by probabilistic method considering uncertainty of properties. And moreover, the seismic safety margin obtained from this study is available as one of data for the estimation of response factor used for probabilistic seismic safety assessment of reactor building based on safety factor method.

Uncertainty as to input earthquake motion for structure is one of the important issues in probabilistic assessment. But in this paper, it is taken for deterministic value, because this paper is only focussed on the influence of uncertainty of properties such as soil and structure. In the same way, the purpose of this paper is to grasp the variation of the basic vibrational characteristics and seismic response for reactor building, so plastic properties of structure and soil are not considered in this paper.

There are Monte Carlo method and probabilistic finite element method as probabilistic analytical method, and this study adopts the former method.

2. METHOD OF ANALYSIS

From among the input constants of structure and soil, Young modulus of concrete, damping factor of structure, and shear velocity of soil are considered as typical properties. Then the influence on elastic seismic response of structure caused by uncertainty of above constants is investigated with probability based on Monte Carlo method. The seismic response is calculated for the analytical model of soil-structure interaction vibration system with constants which are specified according to the assumption that the uncertainty of those constants has normal distribution on the basis of the references and actural survey.

Table 1 shows the averages and standard deviations assumed as uncertainty of respective constants (Sakamoto 1987, AIJ standard specification). Those distributions are assumed to be independent completely each other.

Fig. 1 shows the histograms of each constant prepared according to the assumption of normal distribution. Total appearance number is one hundred respectively for each constants. And the averages and standard deviations of probabilistic density functions computed by prepared one hundred values for each constant, which are also shown in Fig. 1, have good agreement with the assumed values in Table 1.

There are four cases of analyses. Namely in three cases of them, one kind of uncertainty is considered from among three kinds of uncertainty concerning Young modulus of concrete, damping factor of structure and shear velocity of soil, and one case of them, three kinds of uncertainty of the above are considered at the same time. One hundred seismic calculations are practices per one case.

In those cases, it is likely that the case considering uncertainty of three constants at the same time can give the result to simulate actual phenomena. On the other hand, in the former three cases, it is possible to grasp influence of uncertainty of one constant on the variation of seismic response. And besides, in the case considering three kinds of uncertainty at the same time, one hundred eigen value analyses are carried out and the variation of eigen value in investigated.

In the cases considering only one kind of uncertainty, the other two constants are supposed to be the average as deterministic value.

In this study, one hundred calculations are regarded to be appropriate as statistical sample number judging from the result of two hundreds calculations.

Fig. 2 shows the analytical model of reactor building used for this study. As shown in Fig. 2, the lumped mass corresponding to the floor, on which the important equipments are settled, is selected to estimate the variation of seismic response.

The normalized acceleration spectrum of input earthquake motion, which is treated to be fixed value, is shown in Fig. 3.

3. RESULT OF ANALYSIS

3.1 Result of eigen value analysis

Fig. 4 shows the variational distributions of the first and the sixth natural periods, which are dominant vibrational mode of the analytical model calculated on the basis of undamped eigen value analyses, in the case of considering three kinds of uncertainty at the same time.

Fig. 5 shows the correlation between the natural periods and the shear velocity of soil, Young modulus of concrete respectively. The straight lines in this figure respresent the regression lines obtained by method of minimum square deviation.

It is found in Fig. 5 that the first natural period has strong correlation with shear velocity of soil, and weak correlation with Young modulus of concrete. On the contrary, the sixth has weak with shear velocity of soil and strong with Young modulus of concrete. Considering these correlations, the range of uncertainty for shear velocity of soil corresponding to variation of ± 10% from the average of the first period is estimated to be from $856\text{-}0.86\sigma$ m/s to $856+1.01\sigma$ m/sec by Fig. 5. 856 m/s and σ mean the average and the standard deviation of uncertainty for shear velocity of soil respectively as shown in Fig. 1. In the same way, as for the sixth natural period, it is from $307\text{-}1.21\sigma$ t/cm to $307+1.45\sigma$ t/m. 307 t/m and σ mean the average and the standard deviation for Young modulus of concrete as also shown in Fig. 1.

Namely, under the condition of this study, the uncertainty for shear velocity of soil has strong correlation with variation of the first natural period in which rocking and sway vibrations of the structure are dominant. The uncertainty on the order of $\pm 1\sigma$ for shear velocity of soil causes variation about ±10% for the first natural period. And similarly the uncertainty for Young modulus of concrete has strong correlation with variation of the sixth natural period in which vibration mode due to elastic deformation of the structure is dominant, the uncertainty on the order of $\pm 1.5\sigma$ for Young modulus of concrete causes variation about ±10% for the sixth natural period.

3.2 Result of response analysis

Fig.6 shows the variational distributions of the maximum response accelation ratio to the maximum accelation of the input earthquake motion in the case of considering one kind of uncertainty respectively and three kinds of uncertainty at the same time. In the case of considering three kinds of uncertainty at the same time, the variation coefficient of response acceleration is 11.7%, which is larger than 3.6%, 0.9% and 11.3% in the cases of considering one kind of uncertainty respectively. And among variation coefficients derived from the cases considering one kind of uncertainty respectively, it is cleared that the degree of influence on response acceleration is reduced in order of shear velocity of soil, Young modulus of concrete, and damping factor of structure. Especially, it should be emphasized that shear velocity of soil has more influence on variation of response than another two constants have.

Now, it is tried to presume the variational distribution of response considering three kinds of uncertainty at the same time by means of variational distributions of response considering one kind of uncertainty respectively.

First, it is assumed that the variational distributions of response acceleration considering one kind of uncertainty respectively are similar to lognormal distributions. Under this assumption, the variational distributions of response accelation caused by uncertainty of respective constants are assumed to be independent each other.

Next the deterministic maximum response accelation for the analytical model defined with the median of uncertainty given to each constant (Vs = 847 m/s, E = 304 t/m, h = 2.9%, see Fig. 1) is calculated. Resultantly the maximum response accelation ratio (a_0) at the specified floor is obtained to be 2.12. The medians of maximum response accelation ratio (m_E, m_h, m_{Vs}) obtained from the case of considering one kind of uncertainty respectively are normalized by a_0 = 2.12. Then variational distribution of response in the case of considering three kinds of uncertainty at the same time is presumed by the following expression.

$$m_{E,h,Vs} = a_0 \cdot \frac{m_E}{a_0} \cdot \frac{m_h}{a_0} \cdot \frac{m_{Vs}}{a_0}$$

$$\beta_{E,h,Vs} = \sqrt{\beta_E{}^2 + \beta_h{}^2 + \beta_{Vs}^2}$$

where

$m_{E,h,Vs}$: median of maximum response acceleration ratio obtained from the case of considering three kinds of uncertainty at the same time

m_E, m_h, m_{Vs} : median of maximum response acceleration ratio obtained from the cases of considering one kinds of uncertainty

$\beta_{E,h,Vs}$: logarithmic standard deviation of maximum response acceleration ratio obtained from the case of considering three kinds of uncertainty at the same time

β_E, β_h, β_{Vs} : logarithmic standard deviation of maximum response acceleration ratio obtained from the cases of considering one kind of uncertainty

$m_{E,h,Vs}$ and $\beta_{E,h,Vs}$ estimated by the above expression are 2.38, 0.019 respectively. These values are very similar to $m_{E,h,Vs}$ = 2.26, $\beta_{E,h,Vs}$ = 0.018 obtained from the case of considering three kinds of uncertainty at the same time as shown in Fig. 6(4). Particularly it is found that the logarithmic standard deviation shows good agreement. The result gives suggestion that, under the analytical conditions used for this study, variational distribution of response acceleration caused by three kinds of uncertainty at the same time can be presumed by respective variational distributions of response caused by one kind of uncertainty independently, so increase of variation of response acceleration caused by added uncertainty can be estimated by the above expression.

Under the analytical conditions used for this study, in the case of considering three kinds of uncertainty at the same time, it is not so large problem to assume that the variational distribution of response acceleration is similar to the lognormal distribution as shown in Fig. 6 (4), but it is necessary to notice that in the case of considering one kind of uncertainty independently, the shapes of lognormal distributions does not give so good agreement with the histogram of response value as shown in Fig. 6 (1) ~ (3). Particulary in the case of considering only the uncertainty of Young modulus of concrete, the appearance frequency of small response value is dominant.

3.3 Comparison between design value and probabilistic response value

Investigated approximately in this section is the relation between design value and the variational distribution of probabilistic response value. Table 1 also shows the values of constants adopted for calculation of design value. The analytical model and input earthquake motion is the same condition of probabilistic method.

Table 2 shows the design value as differences from the average of natural periods and maximum response acceleration ratioes in the case of considering three kinds of undertainty at the same time. Those design values are plotted in Fig. 4 and Fig. 6 (4).

As for the eigen values, the design value of the first natural period makes small difference of $+0.33\sigma$ from the average of probabilistic values, but the sixth does $+2.33\sigma$ from the average. As for the response acceleration value, the design value is $+2\sigma$ over more than the average of probabilistic value, so judging from variational distribution of response by probabilistic method, under the analytical conditions of this paper, the design value seems to have a sufficient safety margin.

4. CONCLUSION

The influence on elastic seismic response of reactor building caused by uncertainty for properties of soil and structure is studied based on Monte Carlo method. Under the conditions in this study, the followings are the main items which are obtained from the analyses.

① Uncertainty for shear velocity of soil has large influence on elastic maximum response acceleration of reactor building in comparison with uncertainty for Young modulus of concrete and damping factor of structure.

② It is suggested that the variational distribution of response caused by some kinds of uncertainty at the same time can be estimated by respective variational distributions of response caused by one kind of uncertainty independently, provided that variational distribution of response is assumed as lognormal distribution.

③ Response value calculated by seismic design method for nuclear power plants in Japan seems to have a sufficient seismic safety margin compared with average of variational response obtained from probabilistic method considering uncertainty of properties of soil and structure.

And besides, correlation between variation of natural periods of reactor building and uncertainty of respective properties are studied.

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Table 1 Uncertainty of constants

Constant	Normal Distribution for Uncertainty		
	Average	Standard Deveation	Variable Coefficient
Young Modulus of Concrete	308 t/cm^2 (210)*1	46 t/cm^2	15%
Damping Factor of Structure	3% (5)*1	1%	33%
Shear Velocity of Soil	850 m/s (850)*1	130 m/s	15%

*1 for calculation of design value

Table 2 Relation between results of probabilistic method and design value

		Design value	Probabilistic Method*1
Natural Periods (sec)	1st	$\mu + 0.33\sigma$	μ = 0.27 σ = 0.03
	6th	$\mu + 2.33\sigma$	μ = 0.082 σ = 0.006
Maximum Response Acceleration /Maximum Input Acceleration		$\mu + 2.44\sigma$	μ = 2.27 σ = 0.27

*1 Considering Uncertainty of Three Constants Simultaneously

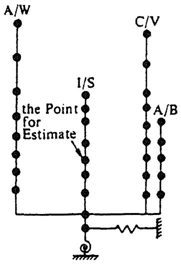

Fig. 2 Analytical model

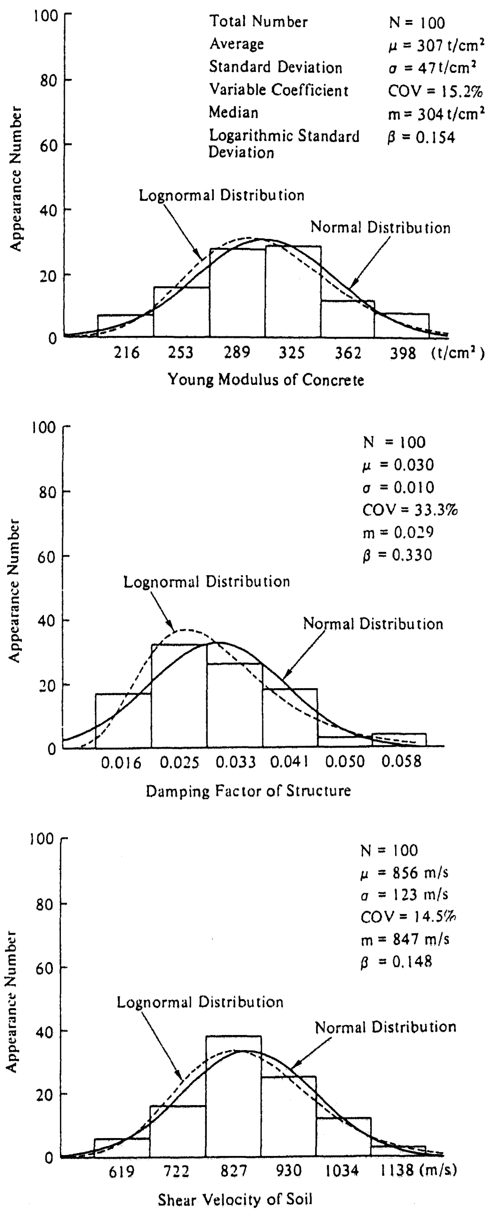

Fig. 1 Histograms and probability density functions of constants

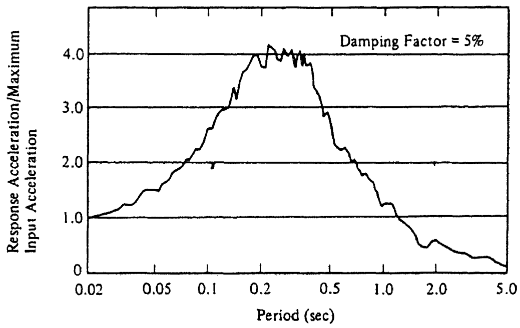

Fig. 3 Normalized response acceleration spectrum of input earthquake motion

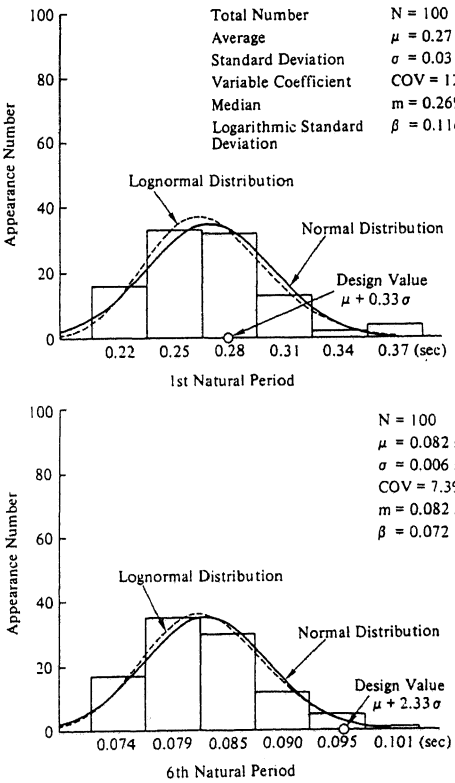

Fig. 4 Histograms and probability density functions of natural periods considering young modulus of concrete, damping factor of structure, shear velocity of soil

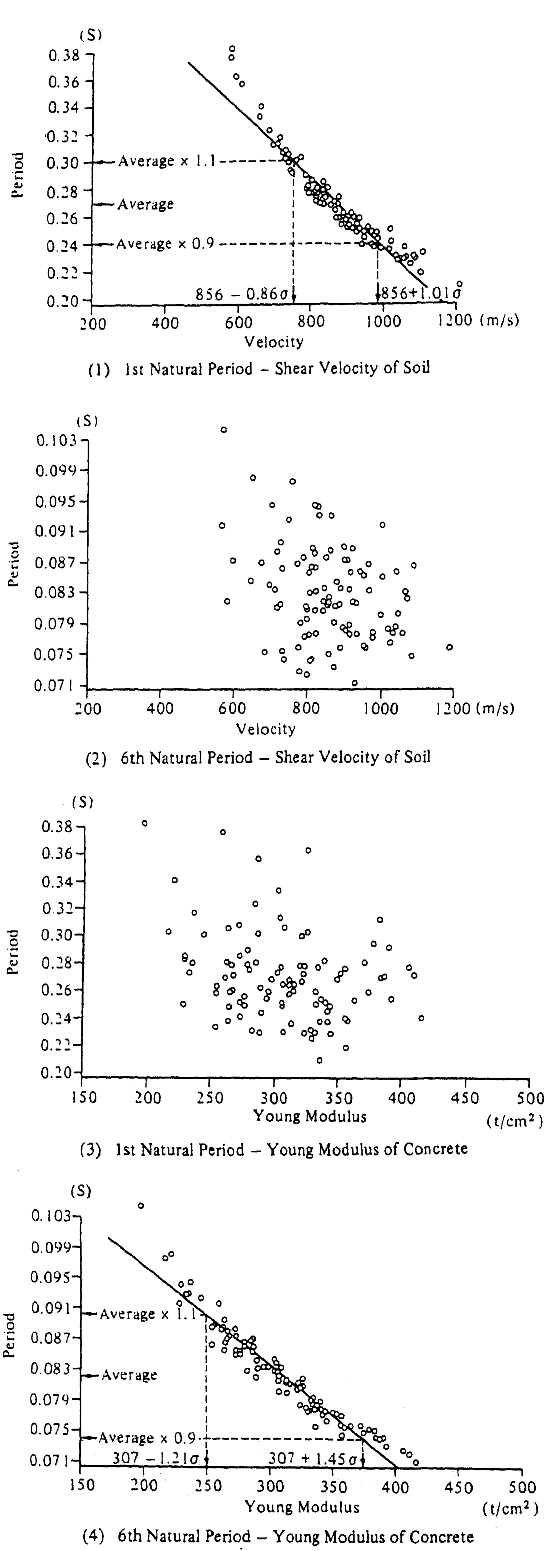

Fig. 5 Correlation between eigen natural periods and shear velocity of soil, young modulus of concrete

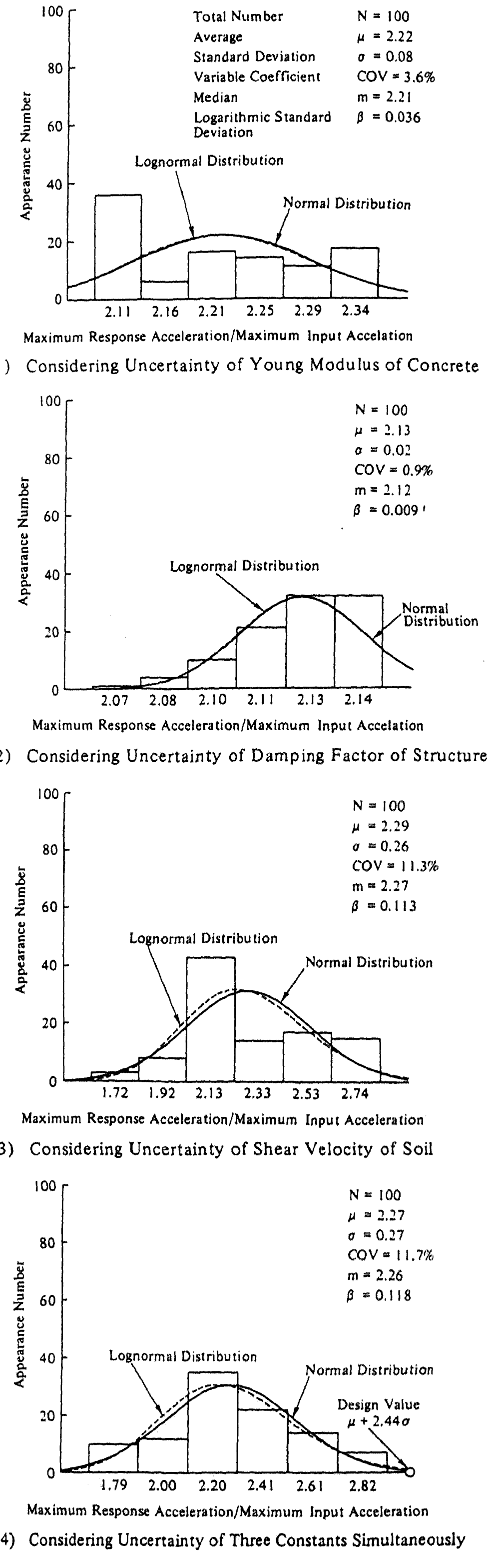

Fig. 6 Histograms and probability density functions of maximum response acceleration ratio