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SEISMIC RISK ASSESSMENT OF HIGH-RISE BUILDING

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SUMMARY

The probabilistic risk assessment technique developed in the nuclear industry (Refs. 1, 2) is applied to estimate seismic safety of a high-rise building. And it is found that annual failure probabilities are sufficiently small. Then the sensitivity study with different model parameters is also carried out to confirm the influence on seismic risk assessment.

INTRODUCTION

Recently, it has been done in the United States to assess the total safety of a nuclear power plant by adopting the method based on probability theory. As a part of the assessment, research and development on seismic risk assessment has been practiced. This paper describes the application of above-mentioned method developed in unclear industry to seismic safety of an usual building with fifteen stories and the calculation results (Ref. 3).

THE METHOD OF ASSESSMENT

The method of seismic risk assessment in this paper consists of the following two kinds of analysis shown in Fig. 1 and Fig. 2 respectively.

Seismic Hazard Analysis To estimate the relationship between the maximum earthquake motion at the site and their annual probability of exceedance, i.e. the seismic hazard curve.

Structural Fragility Analysis To estimate fragility of a structure during an earthquake using probability theory, which is based on the safety factor method applied to Zion nuclear plant in the United States.

And combining seismic hazard curves and structural fragility curves acquired by above analyses, annual frequencies of failure on the following two conditions is calculated. And the probabilities of structural fragility caused by an earthquake is predicted.

Critical damage; The condition that the ultimate deformation occurs at any story of building.

Light damage; The condition that any story of building is gone over elastic limit.

THE SITE AND BUILDING USED FOR ASSESSMENT

The building is located in Tokyo, Japan. The building, as shown in Fig. 3, consists of steel frame structure with fifteen stories above the ground, and a steel-reinforced concrete structure with four stories below the ground. Besides, the foundation of building is supported directly on alluvium with shear wave velocity of 500 m/sec. The structure above ground only is assessed in this paper.

SEISMIC HAZARD ANALYSIS

In seismic hazard analysis, seismic hazard curves are independently calculated based on either data of historical earthquakes or active faults according to analysis flow chart shown in Fig. 1. The main conditions and assumptions for the historical earthquake records model are as follows.

1. Division for seismic zones; Considering observed earthquakes data and some researches, the site and surroundings are divided into sixteen seismic zones as shown in Fig. 4. In each zone, seismic activity is assumed as uniform, and earthquakes occurrence at random, which follows on Poisson Process.

2. Annual occurrence probability of earthquake with magnitude mi(P_k(mi)); P_k(mi) of each zone is calculated by eq(1) written as follows. In eq(1), it is assumed that an earthquake occurrence frequency in each zone is in accordance with Gutenberg-Richter's equation.

$$P_k(mi) = [\beta \exp(-\beta(mi-ml)]/[1-\exp(-\beta(mu-ml)] \quad m \tag{1}$$

where $\beta = b \cdot \ln 10$, mu and ml are the maximum and minimum magnitude, b means Gutenberg-Richter's b value.

3. Attenuation expression for ground acceleration; The maximum ground acceleration is used as intensity scale of earthquake motion, which is given by eq(2) proposed by Kameda et al. It is assumed that eq(2) gives median of the maximum ground acceleration with lognormal distribution.

$$A = C_A \times 349 \times 10^{0.232mi} \times (\quad + 30)^{-0.959} \tag{2}$$

where C_A is a factor depending on ground condition, is an epicentral distance.

In active faults model which follows the method proposed by Tomatsu, Yasuda and Katayama, the seismic hazard curve is estimated by almost same conditions described in the historical earthquake records model, except the seismic sources are replaced by line sources.

Fig. 5 shows the results of seismic hazard curves analyzed on the basis of above conditions and assumptions. According to Fig. 5, the expectancy of maximum acceleration for return period of one hundred years is 215 gal for the active fault model, which is much less than 390 gal based on historical earthquakes records model. This is caused by the fact that few active faults can be found in the site and surroundings.

STRUCTURAL FRAGILITY ANALYSIS

The safety factor method is applied to structural fragility analysis in this research. The safety factor is composed of response safety factor and capacity safety factor which are assumed to have a lognormal distribution respectively. Those factors are estimated as follows.

ESTIMATE OF A RESPONSE SAFETY FACTOR (F_R)

F_R consists of several factors in eq(3) and means the safety margin on response. Eight earthquakes motions recorded near the site with the maximum acceleration more than 30 gal are used to calculate structural response. Table 1 shows the value of factors.

$$F_R = \text{design response value/real response value} = F_{MR} \cdot F_{MC} \cdot F_{SS} \cdot F_{EC} \quad (3)$$

Modal Response Factor (F_{MR}) F_{MR} is composed of spectrum factor (F_{SA}), damping factor (F_H), and model factor (F_M)(= mode shape factor (F_{MS}) x mode frequency factor (F_{MF})), as shown in Fig. 2.

Modal Combination Factor (F_{MC}) F_{MC} is estimated based on the results by both time response analysis method and square root of sum of square method.

Soil Structure Interaction Factor (F_{SS}) F_{SS} is estimated based on the response of both the model considering the effects of interaction and that ignoring the effect as shown in Fig. 6.

Earthquake Component Combination Factor (F_{EC}) F_{EC} is estimated taking the effect of input directions into consideration.

ESTIMATE OF A CAPACITY SAFETY FACTOR (F_C)

F_C is defined by eq(4) and means margin on strength and deformation capacity.

$$F_C = \text{real capacity/design response value} = F_S . Fu \quad (4)$$

Strength Factor (F_S) F_S is defined by eq(5). As to (real strength/calculated strength), strength of steel, section figure of member, strength of member and story are considered. And as to (calculated strength/design response), strength of critical and light damage and response to Elcentro 1940 NS (250 gal) input are considered.

$$\begin{aligned} F_S &= \text{real strength/design response} \\ &= (\text{real strength/calculated strength}) \times \\ &\quad .(\text{calculated strength/design response}) \end{aligned} \quad (5)$$

Inelastic Energy Absorption Factor (Fu) As shown in Fig. 1, Fu is estimated by the result of elastic and inelastic response analyses considering inelastic deformation ability of member and story shown in Fig. 7. Table 2 shows Fu of the first story calculated in the case of critical damage.

ESTIMATE OF SAFETY FACTORS AND FRAGILITY CURVES

Safety factor F is calculated by F_R x F_C. Table 3 shows the calculated factors for critical and light damages. And Fig. 8 shows the fragility curves only for critical damage.

ASSESSMENT OF FAILURE PROBABILITY

From the results of seismic hazard analysis and structural fragility analysis, the annual frequencies of failure for critical and light damages for the building are assessed as shown in Fig. 9.

SENSITIVITY ANALYSIS

As to the parameters for seismic hazard analysis and each safety factor for structural fragility analysis, the degree of their influence on the probability of critical damage at first story is studied. Table 4 and Table 5 show the methods for setting the variation of parameters. Fig. 10 shows the analytical results of their influence.

CONCLUDING REMARKS

1. Median of annual frequency of failure on the building at the first story are 1.17×10^{-9} in the case of critical damage, and 1.14×10^{-3} in the case of light damage respectively, which seem to be sufficiently small.

2. It is cleared that variation of earthquake spectrum shape at the site gives most influence to assessment of damage probability.

The method used in this research is not fully established, besides data are not enough, so it is desirable to get much more data and to improve the method.

ACKNOWLEDGMENTS

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1. ANS/IEEE, "PRA Procedure Guide., NUREG/CR-2300", (1983).

2. Commonwealth Edition Company, "Zion Probablistic Safety Study", Chicago, Illinois, (1981).

3. Ishikawa, Y. at al, "Seismic Risk Assesment of High-Rise Building", AIJ Annual Report, 2015-2018, (1986).

Table 1 Response Factor (First Story)

			F	β_U	β_R
F_{MR}	F_{SA}		2.32	—	0.32
	F_h		1.00	—	0.03
	F_M	F_{MS}	1.00	0.05	—
		F_{MF}	1.00	0.20	—
F_{MC}			1.03	0.15	—
F_{SS}			0.96	0.02*	—
				0.10**	
F_{EC}			1.00	0.20	—
F_R			2.28	0.34	0.32

* : Uncertainty estimated by the ratio between Q_{FIX} and Q_{SSI}.
** : Uncertainty of FEM in itself (Based on engineering judgement).

Table 2 Capacity Factor (Critical Damage at First Story)

Uncertainty Factor		Critical Damage		
		F	β_U	β_U
F_S	1. Strength of Steel	1.03	—	0.08
	2. Error of Member Section	1.00	—	0.01
	3. Calculated Strength of Member and Real Strength of Member	1.03	0.09	— —
	4. Strength of Member and Strength of Story	1.86	0.20	—
F_μ	5. Relationship between Inelasticity and Elasticity	5.50	0.43	—
	6. Calculated Ductility of Member and Real Ductility of Member	0.97	0.23	—
	7. Ductility of Member and Ductility of Story	0.89	0.27	—
F_C		9.37	0.60	0.08

Table 4 Methods of Variation for Parameters (Seismic Hazard Analysis)

Parameters	Standard case	Variation Methods	Remarks
Division for Seismic Zone	O	• 16 Zones • 8 Zones • Single Zone (200km/side) • Single Zone (100km/side)	See Fig.1.
Minimum Magnitude	O	• 5.0 • 4.5	
Maximum Magnitude	O	• Historical Earthquakes Data • above data + 0.2	Parameters are estimated in each zone.
b Value of Gutenberg-Richter's Relationship	O	• Historical Earthquakes Data • above data ± 0.2	
Attenuation expression by Kameda et al.	O	• 0.300 • 0.481 • 0.500 • 0.700	Logarithmic standard deviation.

Table 5 Methods of Variation for Parameters (Structural Fragility Analysis)

Parameter	Variation Methud
Natural Period	• Medians are regarded as 84% exceedance value from median or 84% nonexceedance respectively • Logarithmic standard deviations are not changed.
Damping Factor	• Same as above.
Spectra Response Factor (Fs)	• All logarithmic standard deviations are twice or a half times. • Medians are not changed.
Soil Structure Interaction Factor (Fss)	• Same as Natural Period.
Spectra of Real Earthquake Motions	• Spectra of El-Centro and Taft are assumed as real earthquakes for the building. • Logarithmic standard deviations are estimated from data of 8 earthquakes recorded near the site.
Expression of Inelastic Energy Absorption Factor ($F\mu$)	• Akiyama ex. or Newmark ex. are adopted to calculate $F\mu$

Table 3 Safety Factor (First Story)

Fragility Mode	F	β_U	β_R	Median of Maximum Ground Acceleration (G)
Critical Damage	21.35	0.69	0.33	5.45
Light Damage	3.12	0.41	0.33	0.80

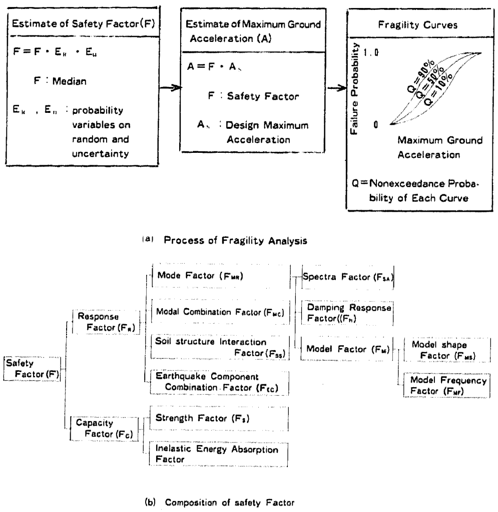

Fig. 2 Structural Fragility Analysis Based on Safety Factor Method

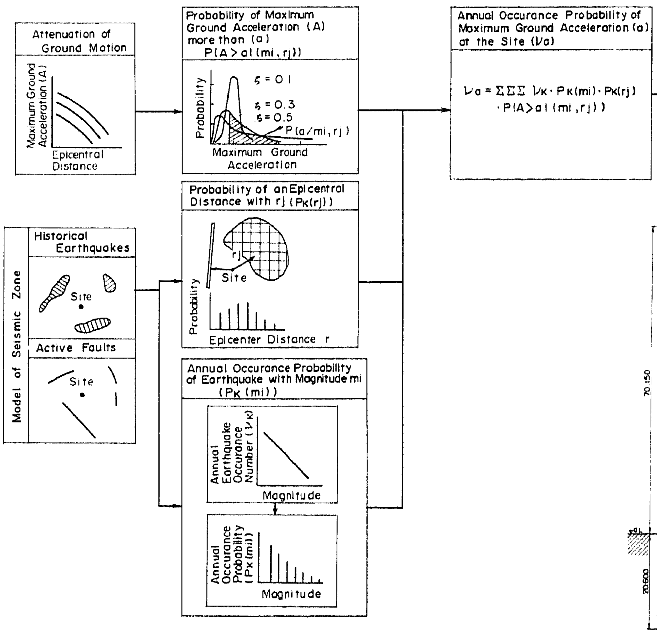

Fig. 1 Seismic Hazard Analysis Flow

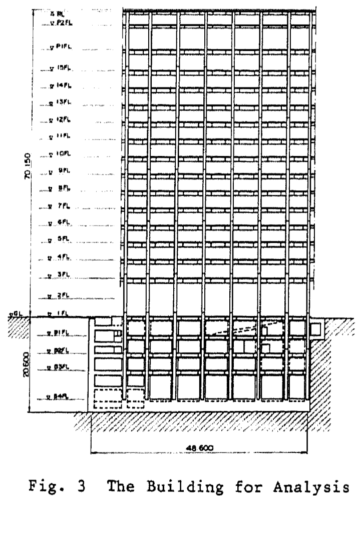

Fig. 3 The Building for Analysis

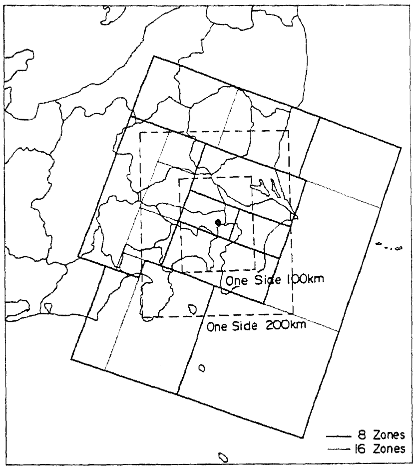

Fig. 4 Seismic Zones

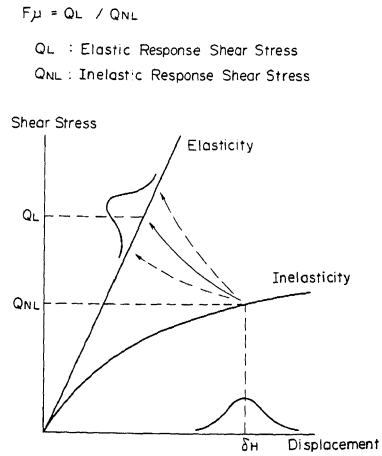

Fig. 7 Estimate Method of Inelastic Energy Absorption Factor (Fμ)

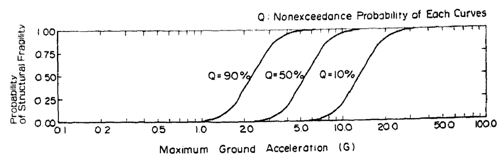

Fig. 8 Fragility Curves (Critical Damage at First Story)

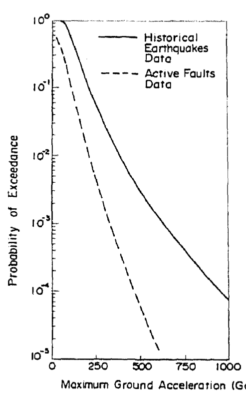

Fig. 5 Seismic Hazard Curves

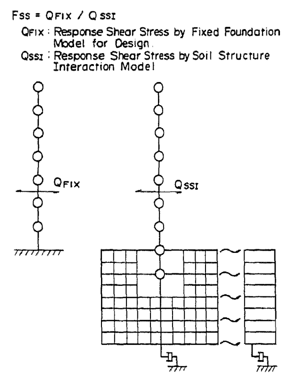

Fig. 6 Estimate Method of Soil-Structure Interaction Factor (F_{SS})

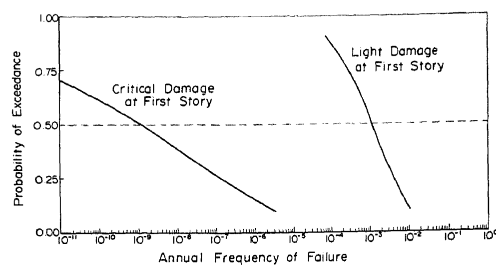

Fig. 9 Probability Distribution for Annual Frequency of Failure

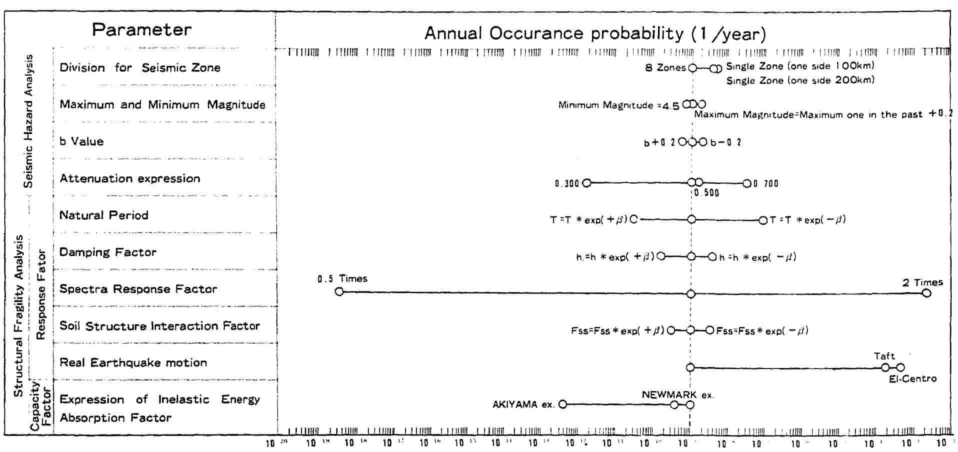

Fig. 10 Results of Sensitivity Analysis