EVALUATION OF PORTFOLIO SEISMIC RISK DUE TO DIFFERENT ALLOCATIONS OF MULTIPLE BUILDINGS

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Abstract : The purpose of this paper is to develop a method for evaluating portfolio seismic risk through a set of scenario earthquakes in and around Japan, and to compare with seismic risk of several portfolios, the contents of which are mutually different. It is quantitatively verified that value at risk such as PML is to be different because of the degree of correlation.

1. INTRODUCTION

In recent years, seismic risk analysis of building has been widely carried out in Japan for the purpose of due diligence business for real estate investment trust and so on. Seismic risk curve for a single building, which can be obtained through both seismic hazard curve at construction site and seismic loss curve of building, has been generally calculated. However, from the standpoint of risk dispersion, portfolio seismic risk, which indicates the seismic risk with respect to multiple buildings located at scattered construction sites, is to be evaluated among property insurance companies etc. Seismic hazard curve can not be used for calculating portfolio seismic risk, because this curve is only defined with respect to a single construction site. As a single earthquake may have an influence on seismic damage of multiple buildings, it is necessary to add up the seismic loss of each building due to a specific earthquake on condition that the geographical relationship between hypocenter location and each construction site is appropriately considered. Therefore the analytical method by making use of numerous scenario earthquakes, which can equivalently represent probabilistic seismic hazard at a specific construction site, is needed in order to evaluate portfolio seismic risk. The purpose of this paper is to evaluate portfolio seismic risk through a set of scenario earthquakes in and around Japan, and to quantitatively compare with seismic risk of several portfolios, the contents of which are mutually different.

2. ANALYTICAL METHOD FOR EVALUATING PORTFOLIO SEISMIC RISK

The flowchart for evaluating portfolio seismic risk curve is shown in Fig.1. It is denoted that ‘n’ is the order of a scenario earthquake and ‘m’ is the order of a building respectively. A set of scenario earthquakes in and around Japan [1] is adopted in order to calculate probabilistic seismic hazard at a construction site. The exceedance loss curve of m-th building due to n-th scenario earthquake can be obtained through integrating the seismic loss distribution of building multiplied by each small occurrence probability of seismic intensity. By repeating this calculation with respect to other buildings M times, the exceedance loss curve of multiple buildings due to n-th scenario earthquake is calculated. Moreover, by repeating this procedure with respect to other scenario earthquakes N times, the exceedance loss curve of multiple buildings due to all selected scenario earthquakes is calculated. Portfolio seismic risk curve can be evaluated through this exceedance loss curve. The detail of these procedures is

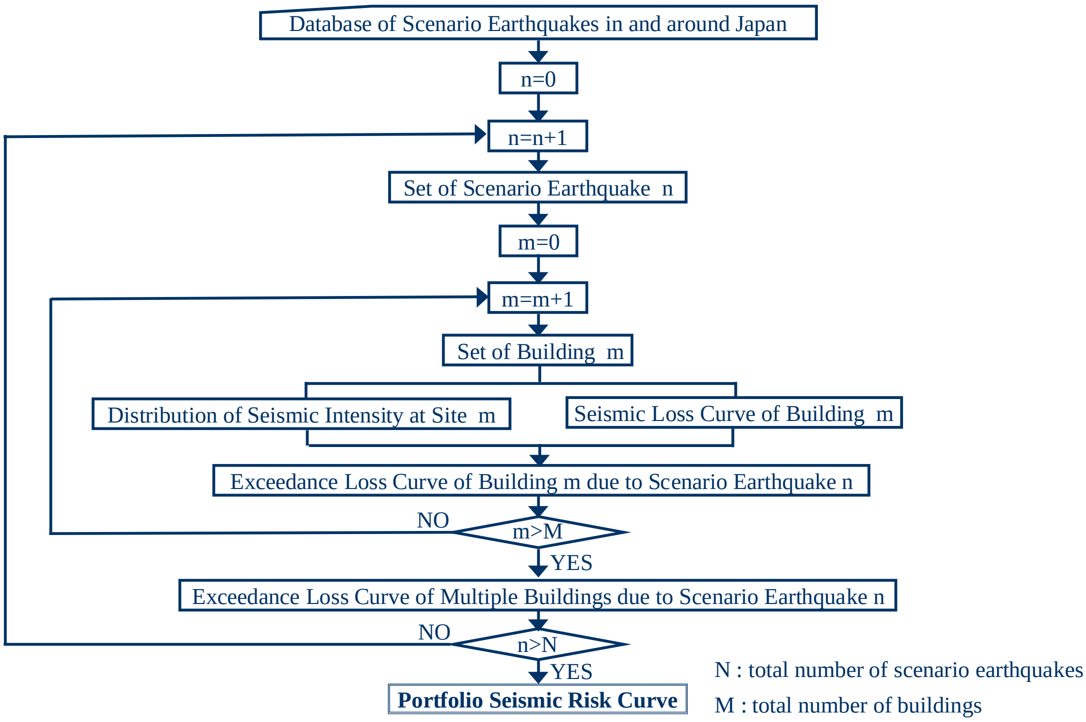


Fig.1 Flowchart for Evaluating Portfolio Seismic Risk Curve

described as follows.

2.1 A Set of Scenario Earthquakes

For seismic source model, many earthquakes which are located at inland and sea are considered. The model consists of three type seismic sources, which are plate boundaries, inland active faults and background earthquakes. For the plate boundary source, the Pacific Ocean Plate and the Philippine Sea Plate are considered. For the fault source, several major tectonic lines are considered as vertical plane sources, and others are considered as line sources. The background source is considered to explain historical earthquakes which are not related with plate boundaries or active faults.

A set of scenario earthquakes, which appropriately represent the characteristic of the above mentioned seismic source model, is developed. A scenario earthquake consists of a set of information including a name of source, a location of source, a distribution of magnitude and its annual occurrence rate. The number of scenario earthquakes should be reduced in order to make it rapid to calculate portfolio seismic risk. In this study, about twenty-eight thousand scenario earthquakes, which are located at 20km grid-points throughout Japan, are generated. The accuracy of this reduced model has been confirmed by comparing these results with the probabilistic seismic hazard curve at several principal cities.

2.2 Seismic Intensity at Construction Site

Seismic intensity at a construction site is calculated through the attenuation model, representative parameters of which are magnitude of a scenario earthquake and shortest distance from a hypocenter. The uncertainty of attenuation is modeled by lognormal distribution.

2.3 Seismic Fragility Curves of Buildings

For structural type of buildings, R/C buildings, which are modeled by shear lumped mass system, are selected in this study. In order to obtain the relationship between seismic intensity and response relative story displacement for each story, earthquake response analysis due to several simulated seismic

Table1 Parameters of Limit Drift Angle for Seismic Fragility Curve

	Minor	Intermediate	Major	Collapse
Median	1/200	1/100	1/75	1/40
Lognormal Standard Deviation	0.4	0.4	0.4	0.4

waves is carried out. Semi-continuous relationship of them is calculated by changing the level of peak ground acceleration at several points, and the relationships may be modeled by the following regression equation.

$$\delta = d_1 \times a^{d2} \tag{1}$$

a : *peak ground acceleration* δ : *response relative story displacement*

d_1, d_2 : *coefficient of regression*

Minor damage, intermediate damage, major damage, and collapse are considered for the level of damage. The shape of seismic fragility curve is modeled by lognormal distribution, and its parameters are determined as follows. The median of limit drift angle with respect to each level of damage is given through the damaged database of buildings suffered from several historical earthquakes. The lognormal standard deviation is assumed to be 0.4 for all levels of damage based on damaged ratio curves in terms of many buildings in 1995 Hyogo-Ken-Nanbu earthquake [2]. The median and lognormal standard deviation of limit drift angle with respect to each level of damage is shown in Table 1. Because the relationship between seismic intensity and response relative story displacement can be obtained from Eq.(1), the lognormal expectation and lognormal standard deviation of seismic fragility curve, in which peak ground acceleration is selected as the index of seismic intensity, are evaluated respectively from the following equation.

$$\lambda_R = \frac{1}{d_2} \times \left(\lambda_\delta - \ln d_1 \right) \quad ; \quad \zeta_R = \frac{1}{d_2} \times \zeta_\delta \tag{2}$$

λ_R, ζ_R : *parameters of seismic fragility curve*

$\lambda_\delta, \zeta_\delta$: *parameters of limit relative story displacement*

2.4 Repair Costs of Buildings due to Hyogo-Ken-Nanbu Earthquake

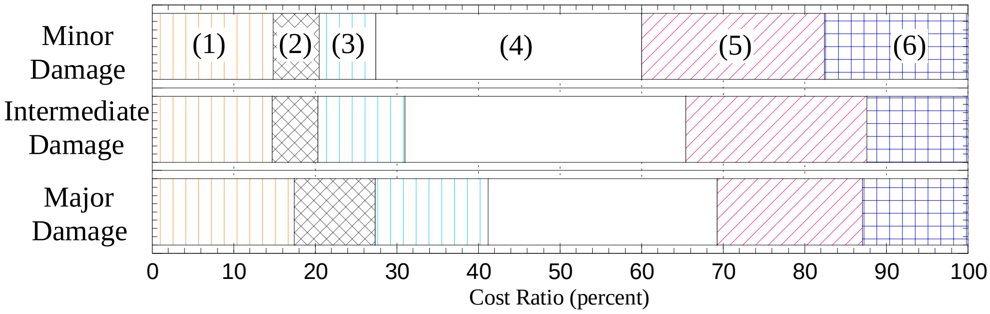
We investigated the repair cost of buildings suffered from the 1995 Hyogo-Ken-Nanbu earthquake, and made out the database of repair cost . The total number of investigated buildings are twenty-seven, and this database consists of eighteen R/C buildings, in which this number includes steel encased reinforced concrete buildings, and nine steel buildings. On the other hand, this database consists of fourteen minor damaged buildings, ten intermediate damaged buildings, and three major damaged buildings respectively. Repair costs per unit area, which are defined by repair cost of whole building over total floor area, are calculated with respect to each building. Expectations of repair cost per unit area, which are obtained through these repair costs of each building, are shown in Table 2. The cost ratios of each building work, which are normalized by sum of repair costs of each building work, are shown with respect to each level of damage in Fig.2. It is found that the cost ratio of skeleton work is around ten percent, that of finishing work is approximately thirty percent, and that of equipment work is about twenty percent regardless of the difference of level of damage. Therefore, it is significant to enhance seismic performance of finishing materials in order to decrease seismic loss effectively.

2.5 Modeling of Numerous Damaged Modes Through Event Tree

Including the level of no damage, there are five kinds of the level of damage at each story. In the case of L story building, the total combination K of damaged mode for all stories is to be 5^L . Therefore event tree analysis is adopted in order to calculate many consequences as efficiently as possible. For example, schematic diagram of event tree analysis for five story building is shown in Fig.3. At that

Table2 Expectation of Repair Cost per Unit Area (yen)

Minor	Intermediate	Major
38,800	87,400	119,000



(1) : temporary work, (2) : demolition work, (3) : skeleton work, (4) : finishing work, (5) : equipment work, (6) : other work, content of which consists of general overheads and design fee etc.

Fig.2 Cost Ratio of Each Building Work

time, the occurrence probability and the repair cost of k-th damaged mode is given in the following equations respectively.

$$P_k = \prod_{i=1}^{L} \{SF_{ik}(a)\} \quad ; \quad C_k = \sum_{i=1}^{L} C_{ik} \tag{3}$$

$SF_{ik}(a)$: *damaged probability of i-th story with respect to k-th damaged mode on the condition that peak ground acceleration is a*

C_{ik} : *repair cost of i-th story with respect to k-th damaged mode*

At that time, newly built cost is used for repair cost if any story collapses. As this procedure is carried out K times, the occurrence probability and the repair cost of all kinds of damaged mode can be calculated.

2.6 Evaluation of Exceedance Loss Curve of Each Building

Through the event tree analysis, the seismic loss distribution is obtained. By using Eq.(3), the expectation and standard deviation of this distribution is calculated by the following equations respectively.

$$\mu_C = \sum_{k=1}^{K} (P_k \times C_k) \quad ; \quad \sigma_C = \sqrt{\sum_{k=1}^{K} \{P_k \times (C_k - \mu_C)^2\}} \tag{4}$$

The occurrence probability P_0, in which no story is damaged, and the occurrence probability P_M, in which any story collapses, are calculated in advance, and the rest distribution of seismic loss is modeled by lognormal distribution. At that time, the exceedance probability of seismic loss, in which seismic loss C is greater than c when peak ground acceleration is ‘a’, is formulated as follows.

$$P(C > c|a) = P_M + \{1 - (P_0 + P_M)\} \times \Phi\left(-\frac{\ln C - \lambda_C}{\zeta_C}\right) \tag{5}$$

λ_C, ζ_C : *lognormal expectation and lognormal standard deviation of seismic loss distribution*

$\Phi(\bullet)$: *standard normal probability distribution function*

As the uncertainty of seismic intensity at construction site is defined by lognormal distribution, the exceedance probability of seismic loss of each building due to a specific scenario earthquake can be formulated by using Eq.(5).

$$P(C > c|E) = \int P(C > c|a) \times f(a|E) da \tag{6}$$

$f(a|E)$: *conditional probability density function of seismic intensity due to a specific scenario earthquake*

2.7 Evaluation of Portfolio Seismic Risk Curve

In order to calculate the exceedance loss curve of all buildings with respect to a specific scenario earthquake, the amount of seismic loss distribution of each building is needed. This distribution can be obtained by the following equation.

$$C(E) = \sum_{m=1}^{M} C_m(E) \tag{7}$$

$C_m(E)$: *seismic loss distribution of each building due to a specific scenario earthquake*

$C(E)$: *seismic loss distribution of all buildings due to a specific scenario earthquake*

Annual occurrence ratio of seismic loss for all buildings due to a specific scenario earthquake is calculated by using both annual occurrence ratio of a specific scenario earthquake and Eq.(7).

$$\nu(C > c|E) = \nu \times P(C > c|E) \tag{8}$$

ν : *annual occurrence ratio of a specific scenario earthquake*

$P(C > c|E)$: *exceedance probability of seismic loss for all buildings*

The annual occurrence ratio of seismic loss of all buildings due to all scenario earthquakes is given by using Eq.(8).

$$\nu(C > c) = \sum_{n=1}^{N} \nu(C > c|E_n) \tag{9}$$

Assuming that the occurrence of each scenario earthquake is modeled by stationary poisson process, the annual exceedance probability of seismic loss for all buildings is calculated.

$$P(C > c) = 1 - \exp[-\nu(C > c)] \tag{10}$$

According to Eq.(10) , portfolio seismic risk curve can be obtained.

3. ANALYTICAL CONDITIONS

3.1 Analytical Conditions for Calculating Seismic Intensity

The scenario earthquakes, the magnitude of which is greater than five, are selected from a set of scenario earthquakes. The seismic intensity at engineering bedrock is calculated through Annaka's attenuation model [3]. The uncertainty of its model is given by lognormal distribution, in which the lognormal standard deviation is assumed to be 0.5.

The response spectrum at engineering bedrock is defined by that of AIJ recommendations [4]. The acceleration response spectrum in terms of soil type one is selected. The method, which fits response spectrum due to simulated seismic waves for this target response spectrum, is adopted. Several simulated seismic waves are generated by the following method, which is defined by multiplying the waves fit for the target spectrum by the Jennings type enveloped function in proportion to the level of magnitude. In addition, the level of seismic intensity of simulated seismic waves is variously changed. As a result, thirty nine simulated seismic waves at engineering bedrock are generated. In order to calculate simulated seismic waves at ground surface, equivalent linear responses through SHAKE program are carried out by using the specific soil profile in Table 3.

3.2 Analytical Model for Buildings

The five story R/C building, in which first natural period is about 0.42sec, and yielding base shear coefficient is 0.5, is assumed for the analytical model. The vertical distribution of yielding shear coefficient is given based on the Ai distribution, which indicates the vertical distribution of seismic

Table3 Soil Profile for Surface Layer

Thickness of Layer (m)	Velocity of S Wave (m/s)	Weight per Unit Volume (kN/m^3)	Type of Soil
5	120	14.0	Cohesive Soil
1	180	18.0	Cohesive Soil
6	260	20.0	Sandy Soil
10	395	20.0	Sandy Soil

Table4 Analytical Model

Story	Height of Story (m)	Floor Area (m^2)	Weight (kN)	Cracking Strength (kN)	Yielding Strength (kN)	Yielding Displacement (m)	Second Ratio of Stiffness	Third Ratio of Stiffness
5	3.5	800	9800	2215	6645	0.023	0.22	0.01
4	3.5	800	9800	3667	11002	0.023	0.22	0.01
3	3.5	800	9800	4845	14535	0.023	0.22	0.01
2	3.5	800	9800	5794	17383	0.023	0.22	0.01
1	3.5	800	9800	6533	19600	0.023	0.22	0.01

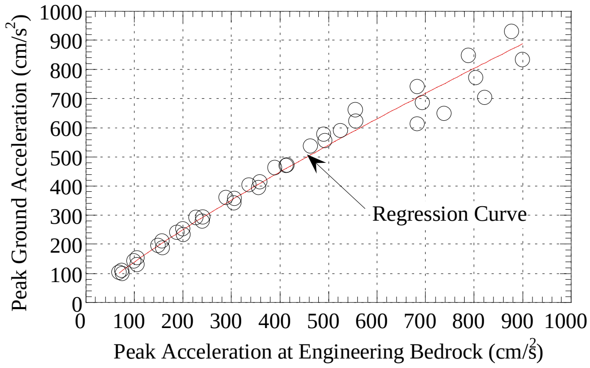


Fig.3 Relationship between Peak Acceleration at Engineering Bedrock and Peak Ground Acceleration

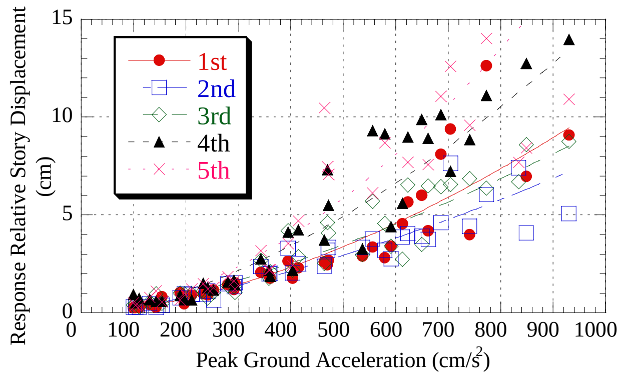


Fig.4 Relationship between Peak Ground Acceleration and Response Relative Story Displacement

shear coefficient defined by Japan building code. Takeda model is used as hysteresis restoring force characteristic. Some parameters concerning building model is shown in Table 4. The repair costs per unit area for minor damage, intermediate damage, and major damage are given through Table2. Moreover, the repair cost of collapse is given by newly built cost, in which 250,000 yen is assumed for a standard newly built cost.

3.3 Analytical Cases for Portfolio Seismic Risk

Result of portfolio seismic risk is influenced by both allocation of buildings and correlation of seismic loss. Portfolio seismic risk is generally calculated on condition that correlation of seismic loss among buildings is assumed to be independent. However, correlation of seismic intensity among multiple construction sites might exist because of a way of allocation. In order to investigate the extreme combinations, correlation of seismic loss is assumed to be independent or fully correlated. As shown in Table 4, three cases of portfolio are set to evaluate the difference due to previously mentioned factors. At that time, total number of buildings is ten, the analytical model of which are all the same. The degree of influence due to correlation may tend to be higher in Case1 rather than other cases.

4. ANALYTICAL RESULTS

4.1 Some Results

Based on the analytical condition in chapter 3.1, the relationship between peak acceleration at engineering bedrock and peak ground acceleration is obtained in Fig.3. The relationship between peak

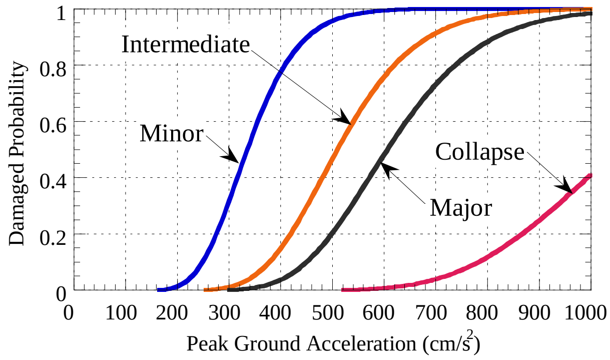


Fig.5 Seismic Fragility Curves at First Story

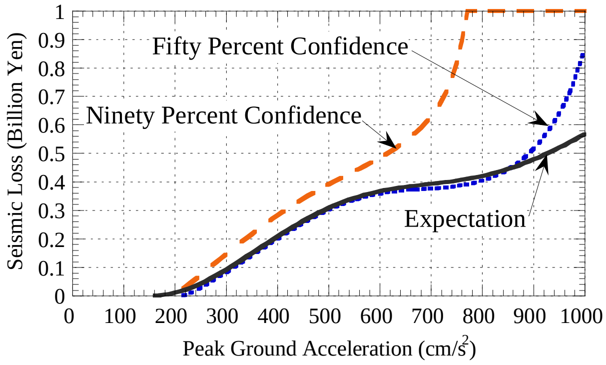


Fig.6 Seismic Loss Curve of Building

Table5 Analytical Cases of Portfolio

	Influence due to Correlation	Region	Construction Sites
Case1	High	Urban Area	Tokyo, Shinjuku, Shinagawa, Ueno, Ikebukuro, Shibuya, Meguro, Ochanomizu, Yotsuya, Komagome
Case2	Medium	Metropolitan Area	Tokyo, Shinjuku, Shinagawa, Mitaka, Hachioji, Kawasaki, Yokohama, Funabashi, Chiba, Saitama
Case3	Low	Whole Country Area	Tokyo, Kawasaki, Yokohama, Shizuoka, Nagoya, Kyoto, Osaka, Kobe, Sendai, Niigata

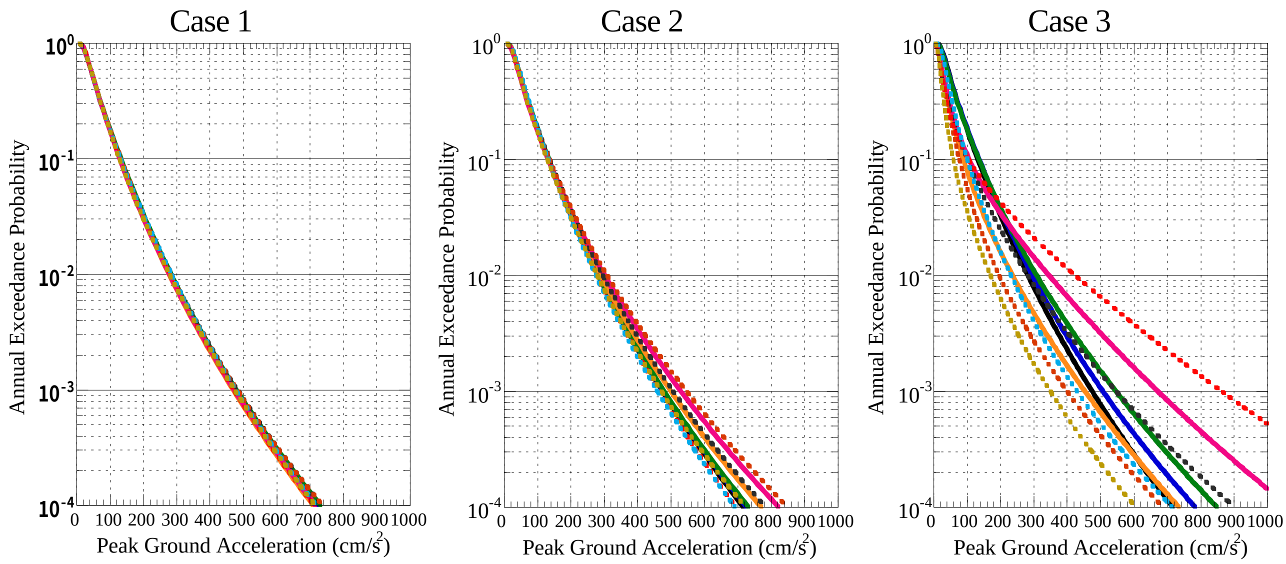


Fig.7 Seismic Hazard Curves at Each Construction Site

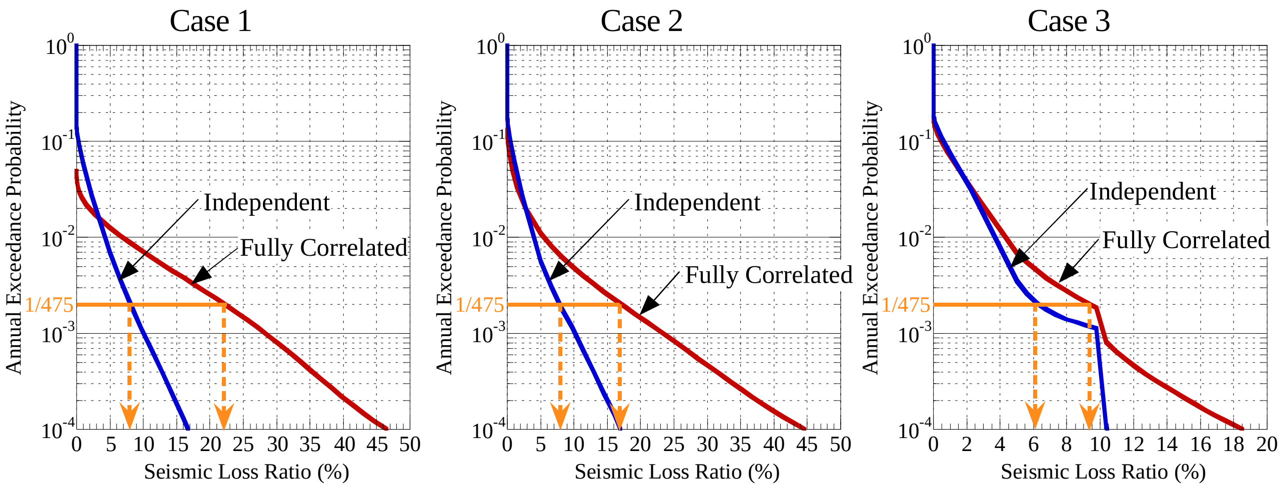


Fig.8 Comparison of Portfolio Seismic Risk Curves

Table6 Comparison of Portfolio PML (%)

	Independent	Fully Correlated
Case1	8.2	22.4
Case2	7.8	16.2
Case3	6.2	9.2

ground acceleration and response relative story displacement for each story is shown in Fig.4. In this figure, five curves denote regression equations through Eq.(1). Seismic fragility curves of first story, which denote the conditional damaged probability with respect to peak ground acceleration, are shown in Fig.5. Seismic loss curve, which denotes the relationship between peak ground acceleration and seismic loss of building, is shown in Fig.6. The seismic loss curves with respect to fifty percent confidence and ninety percent confidence, as well as expectation of it, are denoted in this figure. It is noted that the fifty percent confidence curve is relatively similar to the expectation curve until the value of peak ground acceleration is within about 900 cm/s^2. However beyond this value, the fifty percent confidence curve is considerably larger than the expectation curve, because the occurrence probability P_M is defined that any story collapses.

4.2 Comparison of Portfolio Seismic Risk

Seismic hazard curves at each construction site are shown in Fig.7. Seismic hazard curves in case 1 almost correspond with each other. On the other hand, seismic hazard curves in case 3 are mutually different with respect to a construction site.

Portfolio seismic risk curves with respect to each case are shown in Fig.8. The seismic loss ratio, which is normalized by the total cost of ten buildings, is used for the representation of seismic loss. It is found that portfolio seismic risk cures are different with respect to degree of correlation in all cases. In due diligence, probable maximum loss (PML) has been conventionally adopted as the checking level of seismic loss. In this study, PML is defined such that the annual exceedance probability of seismic loss is equal to one over four hundred and seventy-five. Portfolio PML with respect to each case is shown in Table 6. It is verified that as the area of allocation of multiple buildings is gradually narrow, the difference between PML of independent and that of fully correlated gets to be larger. It is likely that correlations of seismic intensity among construction sites might be high in smaller area. Therefore, annual expectation of seismic loss, the definition of which is to integrate the probability density function multiplied by seismic loss, is very useful index for representing seismic risk as well as PML.

5. CONCLUSION

From the standpoint of risk dispersion, an analytical method, which can evaluate portfolio seismic risk through a set of scenario earthquakes in and around Japan, is developed. Seismic risk of several portfolios, the contents of which are mutually different, is compared numerically through this method. As a result, it is confirmed that value at risk such as PML is to be different because of the degree of correlation. Therefore, annual expectation of seismic loss as well as PML is useful index for representing seismic risk of buildings.

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