Seismic risk analysis method using both PGA and PGV

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ABSTRACT :

In order to improve the accuracy of risk analysis, authors propose a seismic fragility analysis method using two ground motion intensity measures; peak ground acceleration (PGA) and peak ground velocity (PGV), for which many attenuation relations have been developed. Monte-Carlo simulation is carried out to obtain the fragility planes that show the relationship among PGA, PGV and the conditional probability of failure for model RC building. It is found that PGV is adequate in expressing the fragility for severe damage though both PGA and PGV are adequate for slight damage.

KEYWORDS: Seismic Hazard, Fragility Analysis, Ground Motion Intensity, PGA, PGV

1. Preface

In recent years, seismic risk analysis has been used for many situations, such as earthquake damage estimation, judgment of the real estate investment. In order to improve the accuracy of seismic risk analysis, authors propose a seismic fragility analysis method using two ground motion intensity measures; peak ground acceleration (PGA) and peak ground velocity (PGV), for which many attenuation relations have been developed. Seismic risk analysis for the structure consists of seismic hazard analysis and fragility analysis, so this study consists of two stages. The first one is to conduct seismic hazard analysis using joint probability and correlation between these two intensity measures. We evaluate these parameters from the earthquake observation data. The second one is to conduct dynamic response analysis with Monte-Carlo simulation (MSC). It is carried out to obtain the fragility planes that show the relationship among PGA, PGV and the conditional probability of failure for model RC building.

2. Proposing Seismic Risk Analysis Method

2.1. Risk Analysis Method using by Single Intensity

Seismic fragility curve of some damage levels is expressed by probability distribution function of strength A and seismic hazard intensity a. So damage probability $P(a)$ can be related with seismic hazard intensity a. If A is assume to be log-normally distributed, $P(a)$ is expressed by logarithmic mean λ_A and logarithmic standard deviation ζ_A as below,

$$p(a) = \Phi\left[(\ln(a) - \lambda_A)/\zeta_A\right] \tag{1}$$

where, $\Phi(\cdot)$ is normal distribution function.

On the other hand, response $R(a)$ and strength C are also assumed to be log-normally distributed, so that $P(a)$ is expressed by as below.

$$p(a) = \Phi\left[(\lambda_A(a) - \lambda_C)\Big/\sqrt{\zeta_R(a)^2 + \zeta_C{}^2}\right] \tag{2}$$

If Eqn.(1) and Eqn.(2) are identical with a, λ_A and ζ_A are obtained by following formula.

$$\lambda_A = \lambda_C - \lambda_R(a) + \ln(a) \tag{3}$$

$$\zeta_A{}^2 = \zeta_R(a)^2 + \zeta_C{}^2 \tag{4}$$

Equation(3) shows that setting λ_A as unique $\lambda_R(a) - \ln(a)$ must be constant. And Eqn.(4) shows that $R(a)$ distribution is constant with a, however its adequacy seems to be lack. Therefore this study applies numeric analysis for estimation of fragility, as shown Fig.1.

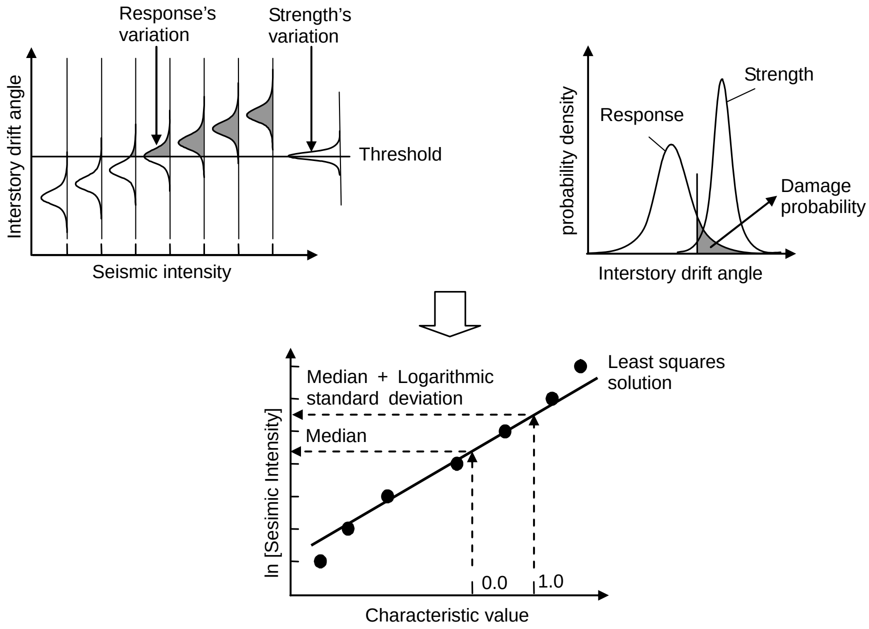

Figure 1 The idea of estimation of fragility using numeric analysis

Obtaining characteristic value s from damage probability using numeric analysis, then if assuming s and $\ln(a)$ to be linear relation, λ_A and ζ_A are settled.

$$\ln a = \zeta_A s + \lambda_A \tag{5}$$

2.2. Extended Seismic Risk Analysis Method using both PGA and PGV

Extending method using single intensity to one using both PGA and PGV, it means setting up conditional damage probability with the use of numeric analysis, which is calculated by seismic wave groups made by given combination of PGA and PGV. a means PGA, v means PGV, respectively. This is illustrated in Fig.2. Therefore, damage probability which consist of two-variable cumulative probability distribution is expressed as fragility planes. However in the case of two-variable, even if obtaining characteristic value s which is from probability $P(a,v)$, a and v are underspecified. Then this study convert Eqn.(5) into Eqn.(6).

$$s = (1/\zeta_A)\ln a - \lambda_A / \zeta_A \tag{6}$$

Equation(6) does not lead to explicit characteristic value of fragility planes, but it lead to characteristic value directly at seismic intensity. Then Eqn.(6) is converted into Eqn.(7).

$$s = (1/\zeta_A)\ln a + (1/\zeta_V)\ln v - \Lambda \tag{7}$$

The inverse of regression coefficient at $\ln a$ means logarithmic standard deviation of PGA, and $\ln v$ means logarithmic standard deviation of PGV. If $S = 0$, constat Λ is shown as Eqn.(8).

$$\Lambda = (1/\zeta_A)\ln a + (1/\zeta_V)\ln v \qquad (8)$$

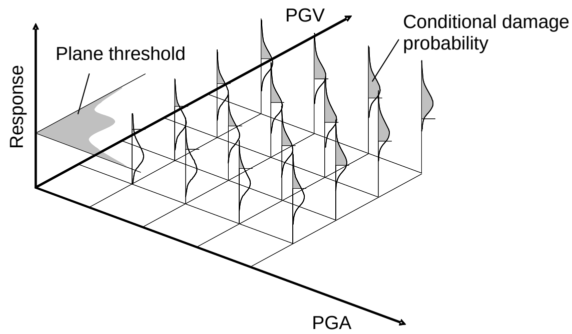

Figure 2 Illustration of fragility carve evaluation using PGA and PGV

3. Making of the Input Seismic Wave Groups

As previously stated, this numeric analysis must have input wave group made by given combination of PGA and PGV. However, the method of making these input wave groups is not obtained now. Therefore this study firstly sets up target spectrum as Eqn.(3) and Fig.3, and makes enormous amounts of waves by given random variables. Secondly this study allocates waves to groups made by given combination of PGA and PGV.

$$S(T) = 1.0 + \frac{X - 1.0}{T_1 - T_{\min}}(T - T_{\min}); \qquad T_{\min} \le T < T_1 \qquad (9a)$$

$$S(T) = X \qquad ; \qquad T_1 \le T < T_2 \qquad (9b)$$

$$S(T) = \frac{X \cdot T_2}{T} \qquad ; \qquad T_2 \le T < T_{MAX} \qquad (9c)$$

The conditions of target response spectrum shape are as below, and probability variable is calculated by Monte Carlo simulation. The duration of seismic waves is 60 seconds, phase characteristic is uniformly random.

① Period T_1 : 0.1 - 1.0 seconds
② Period T_2 : 0.1 - 5.0 seconds (only ,$T_1 < T_2$)
③ Amplification X : 1.0 - 4.0
④ Peak Acceleration : 50 - 5000cm/s/s (at Tmin)

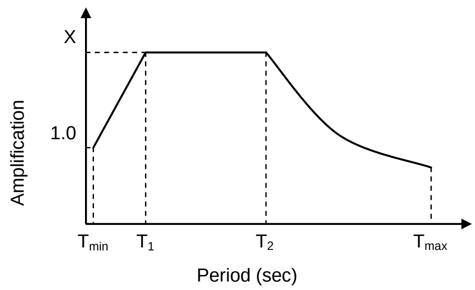

Figure 3 Target response spectrum

Firstly the number of waves after removing no-matching for target response spectrum is 9000. Secondly removing distant waves by standpoint of combinational relation PGA and PGV which number become 5546.

Then for obtaining response probabilistic distribution by input seismic wave groups, classify waves into 441 (21×21) combination of PGA and PGV. For sophistication of the data-analysis, this study takes combinational bin which has at least 10 waves, and limiting maximum to 20 waves in one bin. Finally adopted number of waves is 3551 in this study. The distribution of wave pattern of combination of PGA and PGV is shown in Fig.4.

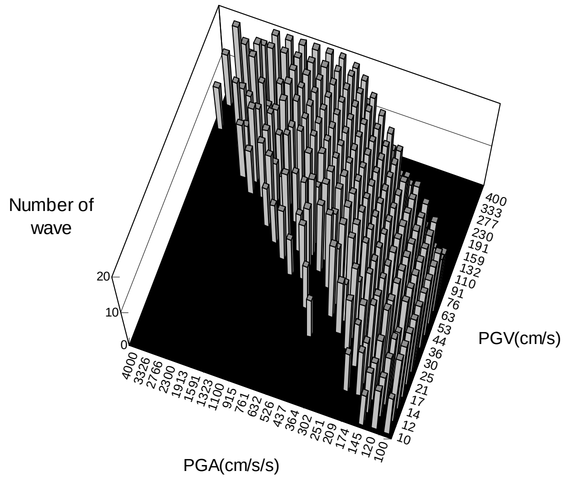

Figure 4 Distribution of wave pattern

4. Building Model

The conditions and attributes of target building model is given as follows;

Table1. Summary of the model building

Structural type	Reinforced concrete
Number of story (N)	7 stories
Surplus capacity rate	Ai distribution
Is-value (Capacity Index)	0.6
Height of story	3.5m
Weight of story	100tonf

The response analysis model is shown in Fig.5, it shows each story is modeled by each lumped mass system and jointed by nonlinear shear spring which has internal damping.
The restoring force characteristics of shear spring adopted in this study is shown in Fig.6. Q_u in Fig.6 is evaluated from seismic index of structural capacity value (Is-value).

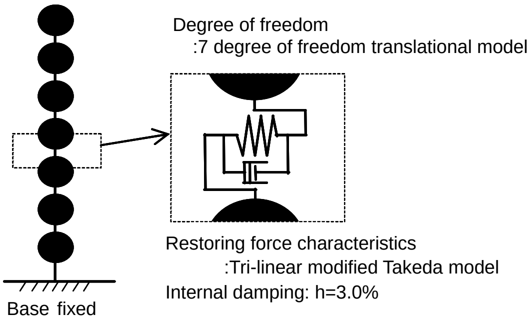

Figure 5 Response analysis model

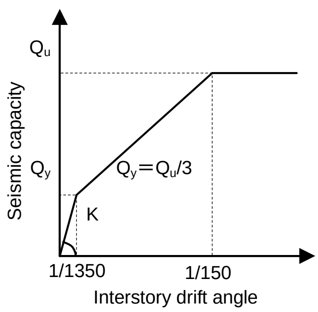

Figure 6 Restoring force characteristics

Table2. Specifications of response analysis model

N	Height (m)	Weight (tonf)	K (t/m)	Q_y (tonf)	Q_u (tonf)
7	24.5	100.0	12668	32.8	98.5
6	21.0	100.0	17395	45.1	135.3
5	17.5	100.0	20820	54.0	161.9
4	14.0	100.0	23991	62.2	186.6
3	10.5	100.0	27000	70.0	210.0
2	7.0	100.0	29653	76.9	230.6
1	3.5	100.0	31780	82.4	247.2

5. Response Analysis Result

In this study damage estimation is judged by response inter-story drift angle value.
The result of response analysis at each combination of PGA, PGV waves is shown Fig.7 and Fig.8. Fig.7 shows median of response inter-story drift angle. It shows increasing tendency when PGA and PGV increase, and PGV is more sensitive for response. Fig.8 shows log-normal standard deviation of response inter-story drift angle. It shows tendency is not always monotone increasing

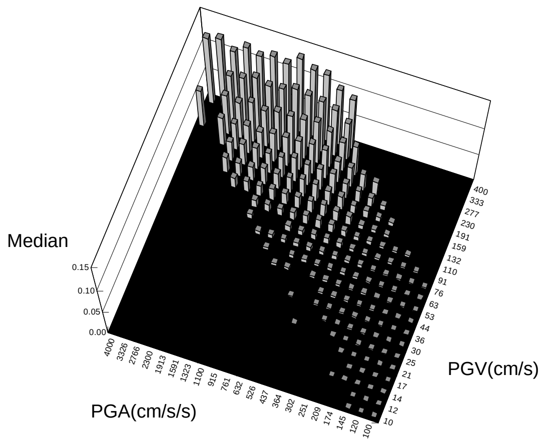

Figure 7 Median of inter-story drift angle

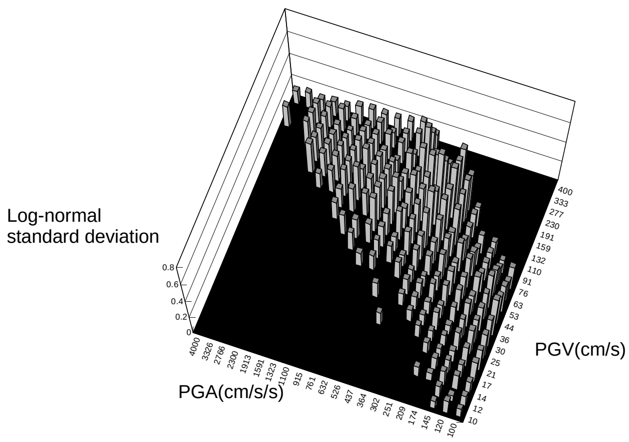

Figure 8 Log-normal standard deviation of inter-story drift angle

6. Seismic Risk Analysis Method

6.1. Conditional Failure Probability of PGA and PGV

Conditional failure probability $p(a,v)$ of given (a,v) is expressed by Eqn.(10),

$$p(a,v) = \Phi\left[\ln\{r(a,v)/\bar{r}\}/\zeta(a,v)\right] \quad (10)$$

where, $r(a,v)$ is median of interstory drift angle, $\zeta(a,v)$ is log-normal standard deviation of interstory drift angle, $\bar{r}$ is threshold of damage condition as Table 3, and $\Phi(\cdot)$ is normal distribution function.

Table 3. Threshold of the damage

Damage condition	Level 1	Level 2	Level 3	Level 4
Internal drift angle	1/240	1/120	1/60	1/30

6.2. Regression Analysis for Damage Distribution

The result of regression analysis for damage distribution is shown Table 4. Coefficient ζ_V value is smaller than ζ_A value at high damage level. It means PGV is more expressive for estimating high damage level for this building.

Table 4. Coefficient obtained from regression analysis

Damage condition	Coefficient		
	ζ_A	ζ_V	Λ
Level 1	0.408	0.401	23.75
Level 2	0.740	0.345	21.32
Level 3	0.884	0.240	27.39
Level 4	0.863	0.214	31.82

For example, damage probability of damage level 1 and 3 are shown at Table 5 and 6

Table5. Damage probability（Level 1）

Damage probability		Velocity (cm/s)		
		20	50	100
Acceleration (cm/s^2)	200	0.000	0.156	0.763
	500	0.146	0.891	0.998
	1000	0.741	0.998	1.000

Table6. Damage probability（Level 3）

Damage probability		Velocity (cm/s)		
		50	100	150
Acceleration (cm/s^2)	500	0.000	0.114	0.686
	1000	0.000	0.338	0.897
	1500	0.002	0.516	0.958

6.2. Making Fragility Planes by PGA and PGV

By using Eqn.(7) and result of regression analysis shown in Table 4, the fragility planes are obtained from failure probability at each damage level, which are shown at Fig.9.

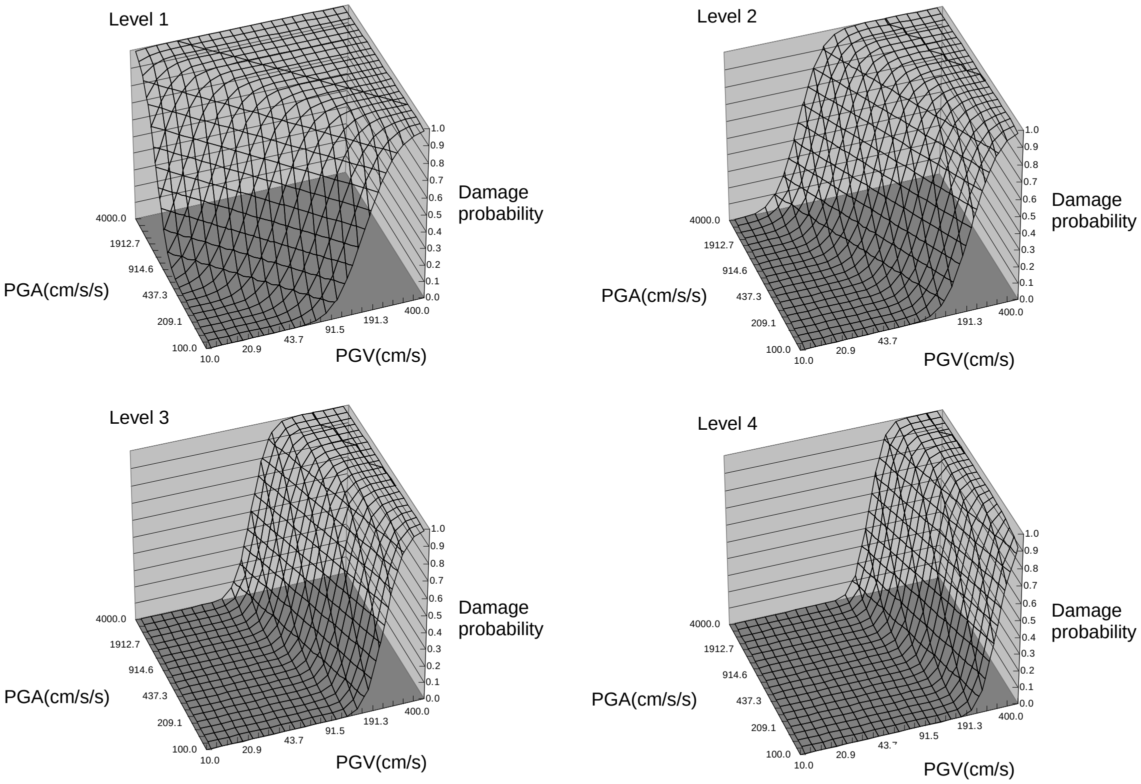

Figure 9 Seismic fragility curve of damage condition

7. Conclusions

In order to improve the accuracy of seismic risk analysis, authors proposed seismic fragility analysis method using two ground motion intensity measures PGA and PGV, and applied to analysis of model RC building. As a result, the followings were obtained.

Fragility plane can be expressed from probabilistic characteristic values which are obtained for PGA and PGV. In the case of model building, it is found that PGV is more adequate in expressing the fragility for severe damage though both PGA and PGV are adequate for slight damage.

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