Improvement of Fragility Curves by Classifying Building Category

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Abstract

We investigated the method to improve the accuracy of the fragility curves by classifying buildings, in order to estimate damage immediately after earthquakes. Specifically, we tried to change the explanatory variables in the fragility curves according to the building age and subdivide building categories. First, we examined the period bands used in the fragility curves. Previous studies have shown that the 1-1.5 sec. response has close relationship with heavy damage to buildings. This is because 1-1.5 sec. response corresponds to the equivalent period when wooden houses or low-rise non-wooden buildings are damaged. However, the period which has close relationship with damage to buildings may be different between the new buildings with high strength and the old ones with low strength, because the natural period and the strength depend on each other. We investigated the correlation between the response acceleration of various periods and the rate of damage to wooden houses by the age of construction. We found that the period which has close relationship with damage to buildings differs depending on the age of construction. Then we improved the accuracy of the fragility curves compared to the conventional one, by creating the fragility curves based on the response acceleration of different period bands according to the age of construction. Since the strength of buildings declines due to aging, the strength may be different depending on when the earthquake occurred even if the age of construction is the same. We created simple aging curves of the strength and organized the damage rate of the buildings by the strength at the time of the earthquakes. Then we modified the fragility curves by considering the aged deterioration of strength. Next, we examined the classification of buildings. We classified the buildings based on the parameters that affect the strength of buildings such as roofing materials, number of stories and purpose. We attempted to improve the accuracy of the damage estimation by changing the period bands of response acceleration used in the fragility curves according to the building categories. Finally, we weighted the damage rate obtained from the fragility curves classified based on the building age and category by the existence rate of buildings in each age and category around the seismic stations. As a result, we confirmed that the accuracy of the fragility curves considering the building age and category is improved compared with the conventional fragility curves not considering the building age and category.

Keywords: Building damage estimation, fragility curves, period band, aging, building category

1. Introduction

We use fragility curves to estimate damage to buildings immediately after earthquakes. Various fragility curves have been proposed e.g. [1]~[3] since the Southern Hyogo Prefecture Earthquake where many strong motion records and building damage data were obtained. The authors also created a fragility curve using a 1-1.5 sec response[4] acceleration that correlates with heavy damage to buildings, using data collected from building damage surveys around seismic stations conducted in past various earthquakes[5]. 1-1.5 second response has a clearer causal relationship with building damage than the maximum ground speed PGV used in many fragility curves, because 1-1.5 sec corresponds to the equivalent period when wooden houses or low-rise non-wooden buildings are damaged. On the other hand, in making this fragility curve, we did not take into account the differences in the building age, as in Hasegawa et al.[2] and Murao et al[3]. In this study, we tried to improve the accuracy of damage estimation by finely classifying buildings by parameters such as age and number of floors.

2. Fragility curves classified by the age of construction

Previous studies have shown that the 1-1.5 sec. response has close relationship with heavy damage to buildings[4]. This is because 1-1.5 sec. response corresponds to the equivalent period when wooden houses or low-rise non-wooden buildings are damaged. However, the period which has close relationship with damage to buildings may be different between the new buildings with high strength and the old ones with low strength, because the natural period and the strength depend on each other. We investigated the correlation between the response acceleration of various periods and the rate of damage to wooden houses by the age of construction. Table 1 shows the strong motion records and the damage rates by age. Figure 1 shows that the peak of the correlation coefficient becomes shorter as the building age becomes newer. The periods which has close relationship with building damage are 1.5-2 seconds in the 1960s, 1-1.5 seconds in the 1970s, and 0.5-1 seconds in the 1980s.

Table 1 – Building damage around seismic stations

strong ground motion records			Dw[%]			
earthquake	station	code	1960s	1970s	1980s	total
1995 Southern Hyogo Prefecture Earthquake	Osaka Gass Fukiai	hnbfki	33.6	4.5	0.0	25.8
	JMA Kobe	hnbkma	6.9	0.0	0.0	4.1
	Motoyama Daiichi Elementary School	hnbmty	6.4	4.0	0.0	4.2
	NTT Kobe	hnbntt	6.4	0.0	0.0	6.0
	JR Takatori	hnbtkt	69.6	33.3	5.6	54.7
Mid Niigata Prefecture Earthquake in 2004	Kawaguchimachi Kawaguchi	ngckgk	37.1	9.4	4.2	18.7
	JMA Ojiya	ngcojj	0.0	0.0	0.0	0.0
Noto Hanto Earthquake in 2007	JMA Wajima	nthjwj	8.6	0.0	0.0	4.4
	K-NET Anamizu	nthkan	44.4	13.4	4.2	22.1
	K-NET Wajima	nthkwj	3.8	4.5	0.0	3.1
The Niigataken Chuetsu-oki Earthquake in 2007	K-NET Kashiwazaki	ncokzk	22.2	2.1	1.7	3.5
	Kashiwazaki City Chuo Cho	ncokzs	42.9	6.3	1.6	8.0
The 2011 off the Pacific coast of Tohoku Earthquake	K-NET Ogawa	ttokog	0.0	0.0	0.0	0.0
	JMA Osaki City Furukawa	ttojfr	2.3	5.3	0.0	3.3
The 2016 Kumamoto Earthquake (4/16)	KiK-net Mashiki	kkmsk2	8.3	10.3	7.4	8.4

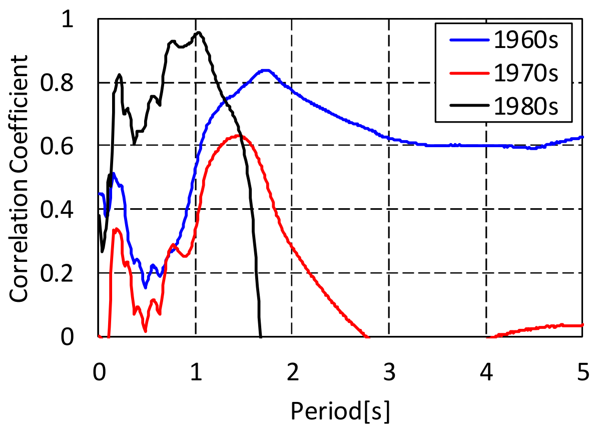


Fig.1 – Periods correlated with building damage

We created fragility curves based on the response acceleration of different period bands according to the age of construction. Equation (1) shows the relationship between the acceleration response ACC and the damage rate D.

$$D = \Phi(\alpha \log Acc + \beta) \tag{1}$$

where, Φ is the cumulative probability of the standard normal distribution.
Table 2 shows the coefficients α and β that correspond to the actual damage rates. Figures 2 and 3 show the correspondence with the actual damage rates. Figure 2 shows graphs by building age. Figure 3 shows the overall damage rate by weighting the number of buildings in each building age. ERR in the Figures represents the average of the absolute value of the error, and COR represents the correlation coefficient. In both cases of estimating the damage rate by building age and estimating the total damage rate, the accuracy of the fragility curve classified by age is higher than that of the conventional method.

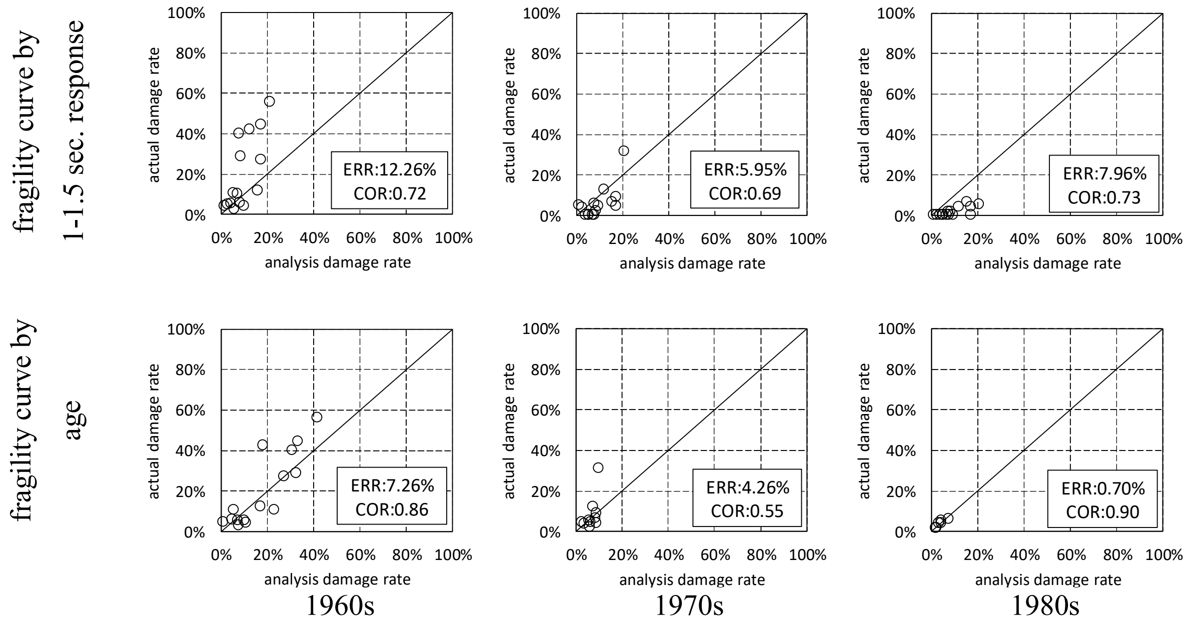
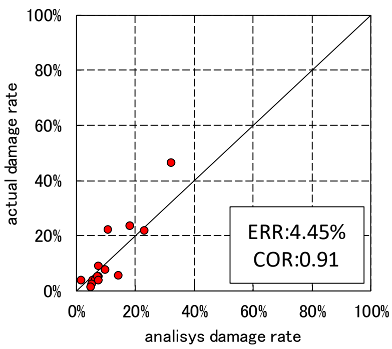


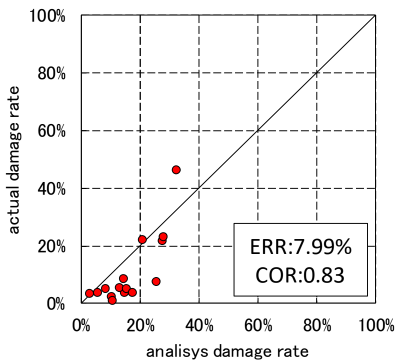
Fig.2 – Correspondence with actual damage rate

Table 2 – parameters for fragility curves classified by age

	1960s	1970s	1980s
α	3.73	1.28	2.10
β	−11.22	−5.22	−8.49
period of acceleration	1.5−2 sec.	1−1.5 sec.	0.5−1 sec.



(a) fragility curves by age



(b) conventional fragility curve (1-1.5 sec. response)

Fig.3 – Correspondence with actual damage rate

3. Fragility curves classified by strength at the time of earthquake

We could estimate the building damage more accurately than the conventional fragility curve by constructing the fragility curves based on the response acceleration of different period bands according to the age of construction. Since the strength of buildings declines due to aging e.g. [6], the strength may be different depending on when the earthquake occurred even if the age of construction is the same. We tried to classify the fragility curves not by the building age but by the strength at the time of the earthquake. Specifically, we classified the buildings into eight categories, considering the parameters that affect the strength of the building, such as the number of floors, the type of roofing material, and the presence of large openings. Then, we estimated the strength of buildings in each category at the time of the earthquake by considering the deterioration of strength due to aging.

First, we determined the difference in strength between building categories with Hayakawa's method[7]. The difference in the strength caused by the difference between the number of floors and the roofing material is assumed to be equal to the wall-length ratio quantity used in the earthquake resistance diagnosis. In order to investigate the effect of the large opening on the strength, Hayakawa examined how much the wall-length differs with and without the large opening in the buildings around the observation point shown in Table 3. It is found that the wall-length of buildings with large openings is 0.42 times that of buildings without large openings. Hayakawa examined the relationship between the wall-length ratio of the outer wall and that of the total wall from literatures of shaking table tests using full-scale models of wooden buildings[9]~[13]. As shown in Fig. 4, the wall filling ratio of the outer wall is 0.54 times the total. The wall-length ratio of outer wall is 0.54 times that of whole, and the outer wall of houses with large openings is 0.42 times as long as that of houses without large openings. Therefore, the wall-length ration of a house with large openings is 0.69 times that of a house without large openings. Table 4 shows the strength ratio for each category determined by the above method.

Table 3 – Number of buildings classified by opening size

	rate of area occupied by openings		small opening			large opening		
			1/4	1/3	1/2	2/3	3/4	1
number of buildings	The Mid Niigata Prefecture Earthquake in 2004	Kawaguchimachi Kawaguchi	12	25	42	10	16	9
		JMA Ojiya	25	15	42	10	9	14
	The Noto Hanto Earthquake in 2007	JMA Wajima	42	49	87	21	28	29
		K-NET Anamizu	23	28	54	7	19	34
		K-NET Wajima	53	65	45	4	23	12
	The Niigataken Chuetsu-oki Earthquake in 2007	K-NET Kashiwazaki	69	47	28	2	3	5
		Kashiwazaki City Chuo Cho	16	11	11	0	5	7
	The 2011 off the Pacific coast of Tohoku Earthquake	K-NET Ogawa	37	39	19	5	10	7
		JMA Osaki City Furukawa	70	26	44	10	20	26
	The 2016 Kumamoto Earthquake	KiK-net Mashiki	103	61	42	2	3	1
		Mashiki-machi Miyazono	47	29	26	1	3	2
	The 2018 Hokkaido Eastern Iburi Earthquake	K-NET Mukawa	56	17	14	2	7	6
	summary		553	412	454	74	146	152

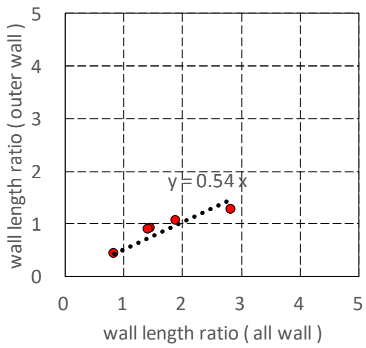
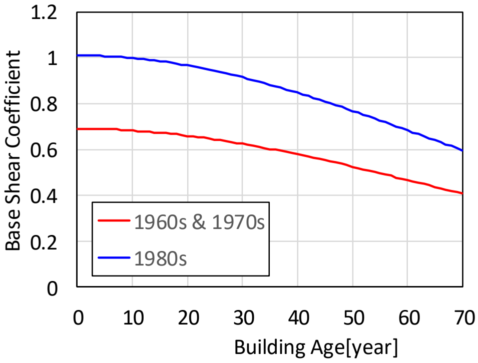


Fig. 4 - comparison of wall length ratio

Table 4 – Strength ratio of each category

	small opening		large opening	
	heavy roof	light roof	heavy roof	light roof
2 Stories	1.00	1.28	0.71	0.91
1story	2.65	3.79	1.88	2.69

In order to calculate the strength at the time of the earthquake considering aging deterioration, we used a strength reduction model by Miki[14] shown in fig 5. This model is not based on a specific category because it was created based on the damage rate by building age. Since most wooden houses in Japan have two stories and heavy roofs[15], this model represents a category 1 buildings. Strength of buildings classified into other categories is obtained by multiplying the strength of buildings of category 1 by the ratio in Table 4. Strength of buildings classified into other categories is obtained by multiplying the strength of buildings of category 1 by the ratio in Table 4. In the case of the Southern Hyogo Prefecture Earthquake, the information necessary for classifying buildings was insufficient. Therefore, we estimated the strength of the building at the time of the earthquake at the observation points in Table 1 other than the Southern Hyogo Prefecture Earthquake.



$$f(T) = C_{Age}\frac{exp\left(-\frac{T^2}{\beta}\right)+\gamma}{1+\gamma}$$

$$\beta = 8192, \gamma = 0.1$$

$$C_{1960} = 0.69$$

$$C_{1970} = 0.69$$

$$C_{1980} = 1.01$$

Fig. 5 – strength deterioration model[14]

Table 5 – Strength of each category at the time of earthquake

(a) 1960s

1960s		category 1	2	3	4	5	6	7	8
ngckgk	Dw	78.0%		43.0%	50.0%	0.0%		29.0%	
	Cy	0.56		0.71	0.33	2.11		0.42	
	N	9		14	6	2		14	
ngcojj	Dw		0.0%			0.0%			0.0%
	Cy		1.48			2.11			1.25
	N		1			9			7
nthkan	Dw	20.0%	0.0%	33.0%	60.0%	50.0%	50.0%	100.0%	40.0%
	Cy	0.54	1.44	0.69	0.32	2.05	0.85	0.41	1.21
	N	15	4	3	25	2	2	1	5
nthjwj	Dw	5.0%	33.0%	0.0%	18.0%		33.0%	0.0%	0.0%
	Cy	0.54	1.44	0.69	0.32		0.85	0.41	1.21
	N	80	6	2	33		3	4	1
nthkwj	Dw	0.0%	0.0%	0.0%	8.0%		29.0%	0.0%	
	Cy	0.54	1.44	0.69	0.32		0.85	0.41	
	N	34	10	5	13		7	1	
ncokzk	Dw	50.0%		0.0%	0.0%				
	Cy	0.54		0.69	0.32				
	N	8		5	1				
ncokzs	Dw	80.0%	0.0%	0.0%	40.0%			0.0%	
	Cy	0.54	1.44	0.69	0.32			0.41	
	N	5	2	2	10			1	
ttokog	Dw	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Cy	0.52	1.38	0.66	0.31	1.97	0.81	0.39	1.16
	N	5	6	8	2	10	2	2	2
ttojfr	Dw	17.0%	0.0%	10.0%	0.0%	0.0%		0.0%	0.0%
	Cy	0.52	1.38	0.66	0.31	1.97		0.39	1.16
	N	6	4	21	1	16		18	8
kkmsk2	Dw	9.0%	18.0%				0.0%	0.0%	
	Cy	0.49	1.30				0.77	0.37	
	N	11	11				2	1	

(b) 1970s

1970s		category 1	2	3	4	5	6	7	8
ngckgk	Dw	0.0%		5.0%	0.0%	0.0%		33.0%	0.0%
	Cy	0.61		0.78	0.36	2.30		0.46	1.36
	N	2		21	2	2		6	1
ngcojj	Dw		0.0%			0.0%	0.0%		0.0%
	Cy		1.61			2.30	0.95		1.36
	N		7			28	3		5
nthkan	Dw	8.0%	0.0%	27.0%	17.0%	0.0%	0.0%	0.0%	0.0%
	Cy	0.59	1.57	0.76	0.35	2.25	0.93	0.45	1.33
	N	36	3	11	12	1	1	7	1
nthjwj	Dw	0.0%	0.0%	0.0%	0.0%			0.0%	
	Cy	0.59	1.57	0.76	0.35			0.45	
	N	60	3	2	11			3	
nthkwj	Dw	2.0%	12.0%	0.0%	7.0%	0.0%	0.0%	50.0%	0.0%
	Cy	0.59	1.57	0.76	0.35	2.25	0.93	0.45	1.33
	N	45	8	4	14	3	2	2	1
ncokzk	Dw	3.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Cy	0.59		0.76	0.35	2.25	0.93	0.45	1.33
	N	29		9	6	2	1	2	1
ncokzs	Dw	4.0%	0.0%	12.0%	7.0%			0.0%	
	Cy	0.59	1.57	0.76	0.35			0.45	
	N	24	2	8	15			6	
ttokog	Dw	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Cy	0.57	1.52	0.73	0.34	2.17	0.90	0.43	1.28
	N	8	1	11	6	9	2	3	5
ttojfr	Dw	0.0%		0.0%	17.0%	0.0%		12.0%	0.0%
	Cy	0.57		0.73	0.34	2.17		0.43	1.28
	N	4		41	6	14		24	2
kkmsk2	Dw	4.0%	0.0%	33.0%	50.0%	0.0%	0.0%		
	Cy	0.55	1.45	0.70	0.32	2.07	0.86		
	N	25	14	3	2	2	1		

(c) 1980s

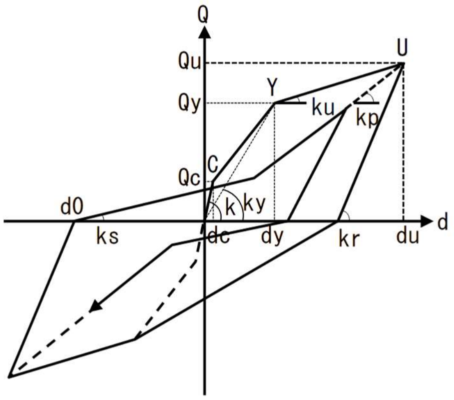
1980s		category 1	2	3	4	5	6	7	8
ngckgk	Dw	0.0%		0.0%	50.0%	0.0%		0.0%	0.0%
	Cy	0.95		1.21	0.56	3.59		0.72	2.12
	N	1		17	2	1		2	2
ngcojj	Dw		0.0%			0.0%	0.0%		0.0%
	Cy		2.51			3.59	1.48		2.12
	N		4			19	1		7
nthkan	Dw	0.0%		0.0%	25.0%			0.0%	0.0%
	Cy	0.93		1.19	0.55			0.70	2.08
	N	12		5	4			3	1
nthjwj	Dw	0.0%		0.0%	0.0%			0.0%	
	Cy	0.93		1.19	0.55			0.70	
	N	30		3	1			1	
nthkwj	Dw	0.0%	0.0%	0.0%	0.0%			0.0%	
	Cy	0.93	2.47	1.19	0.55			0.70	
	N	27	4	4	11			1	
ncokzk	Dw	3.0%	0.0%	0.0%	0.0%			0.0%	
	Cy	0.93	2.47	1.19	0.55			0.70	
	N	30	4	16	6			3	
ncokzs	Dw	0.0%		0.0%	0.0%			25.0%	
	Cy	0.93		1.19	0.55			0.70	
	N	45		8	8			4	
ttokog	Dw	0.0%	0.0%	0.0%		0.0%	0.0%	0.0%	
	Cy	0.91	2.41	1.16		3.44	1.42	0.69	
	N	6	7	5		9	2	2	
ttojfr	Dw	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	0.0%
	Cy	0.91	2.41	1.16	0.54	3.44		0.69	2.03
	N	3	1	22	1	3		7	1
kkmsk2	Dw	3.0%	0.0%	11.0%	50.0%	0.0%			
	Cy	0.88	2.32	1.12	0.52	3.32			
	N	33	6	19	2	3			

(d) Parameters of each category

category	parameters: story	roof	opening in wall
1	2	heavy	normal
2	1	heavy	normal
3	2	light	normal
4	2	heavy	large
5	1	light	normal
6	1	heavy	large
7	2	light	large
8	1	light	large

Table 5 contains many categories with less than 10 buildings. It is not appropriate to treat such categories equally as those that have a sufficient number of buildings, and the categories with more buildings should be given more weight. Therefore, we determine the parameters of the fragility curves by using "weighted correlation analysis"[16], which weights the data based on the number of buildings around the seismic station.

Conventionally, we could only empirically determine the seismic intensity used for the fragility curves based on the correlation with the actual damage. However, since the proposed method estimates the strength at the time of the earthquake, we can theoretically determine the seismic intensity from the strength. Specifically, the equivalent period corresponding to the strength of a building with nonlinear hysteresis characteristics is calculated by the equivalent linearization method. The response acceleration at the equivalent period and damping is the theoretical ground motion intensity. As a nonlinear skeleton curve, we used a modified Takeda-Slip model[17] (Fig. 6) that can reproduce the behavior of wooden buildings during an earthquake.



$$k_y = k\alpha_y$$

$$k_u = \beta \frac{Q_y}{d_y}$$

$$k_r = \frac{Q_c}{d_c}\left|\frac{d_u}{d_y}\right|^{-\alpha}$$

$$k_s = \frac{Q_u}{d_u - d_0}\left|\frac{d_u}{d_u - d_0}\right|^{\gamma}$$

$$k_p = \delta \frac{Q_u}{d_u}$$

Fig.6 – Modified Takeda-Slip model

Equation (2) shows the elastic period of wooden buildings, using the parameters of the modified Takeda-Slip model.

$$T = 2\pi\sqrt{\frac{h \cdot \alpha_y \cdot R_y}{C_y \cdot g}} \tag{2}$$

where, h is 4.5m, which is the equivalent height when a two-story wooden building is represented by one mass point system, ay is the stiffness reduction ratio at the yield point, R_y is the interlayer deformation angle corresponding to yielding, 1/120 rad, C_y is the base shear coefficient at the yield point, and g is the gravitational acceleration.

In this study, the secant period is treated as the equivalent period. Equation (3) shows the relationship between the equivalent period T_e and the elastic period T of the modified Takeda-Slip model.

$$T_e = \sqrt{\frac{\mu}{(\beta\mu - \beta + 1)\alpha_y}}T \tag{3}$$

where, μ is the plasticity factor corresponding to collapse, and β is the stiffness reduction coefficient after yielding.

Equations (4) to (6) show the equivalent viscous damping constant h_e of the modified Takeda-Slip model using the parameters in Fig. 6.

$$h_e = \frac{B + B^2 + \frac{A}{(1 - A)\mu}}{2\pi\mu} \tag{4}$$

$$A = \left(\frac{\mu}{\mu + B}\right)^{\gamma - 1} \tag{5}$$

$$B = \mu - \frac{\{(\mu - 1)\beta + 1\}^{d_c/d_y}}{Q_c/Q_y}\mu^{\alpha} \tag{6}$$

The value of the plasticity factor μ corresponding to collapse is 8 from the interlayer deformation angle 1/15 rad[18] corresponding to collapse and the interlayer deformation angle 1/120 rad corresponding to yielding.

Table 6 – parameters for Modified Takeda-Slip model and equivalent linearization technique

	1960s	1970s	1980s
αy	0.13	0.13	0.19
β	0.25		
μ	8		
α	0.5		
γ	3.0		
δ	1.0		
Qc/Qy	1/3		

We calculate the elastic acceleration response spectrum with the damping constant h_e, and use the average of the 0.5-second-wide spectral values around the equivalent period T_e as the equivalent period response. Since the range of the base shear coefficient between 0.3 and 1.3 contains a sufficient number of data to create fragility curves, we created fragility curves for this range. We grouped the data in Table 5 by the value of Cy and determined the parameters of equation (1) for the data in the same group using the damage rate and the equivalent periodic response. The group of Cy0.7-0.9 added one data of 0% damage at 0 cm/s^2 in order to prevent the parameter from decreasing the damage rate as the acceleration response becomes larger. Table 7 shows the coefficients α and β that correspond to the actual damage rates. Table 6 shows the parameters of each group. Fig. 7 shows the correspondence of the fragility curves classified by strength to the actual damage rate compared to the case of using the fragility curves classified by age. Categories with less than 20 buildings are indicated by colorless circles, and categories with more than 20 buildings are indicated by colored circles. In any group, the correspondence with the actual damage rate is not good. Even if categories with less than 20 buildings are ignored, the correspondence with the actual damage rate is improved only for the group Cy0.3-0.7.

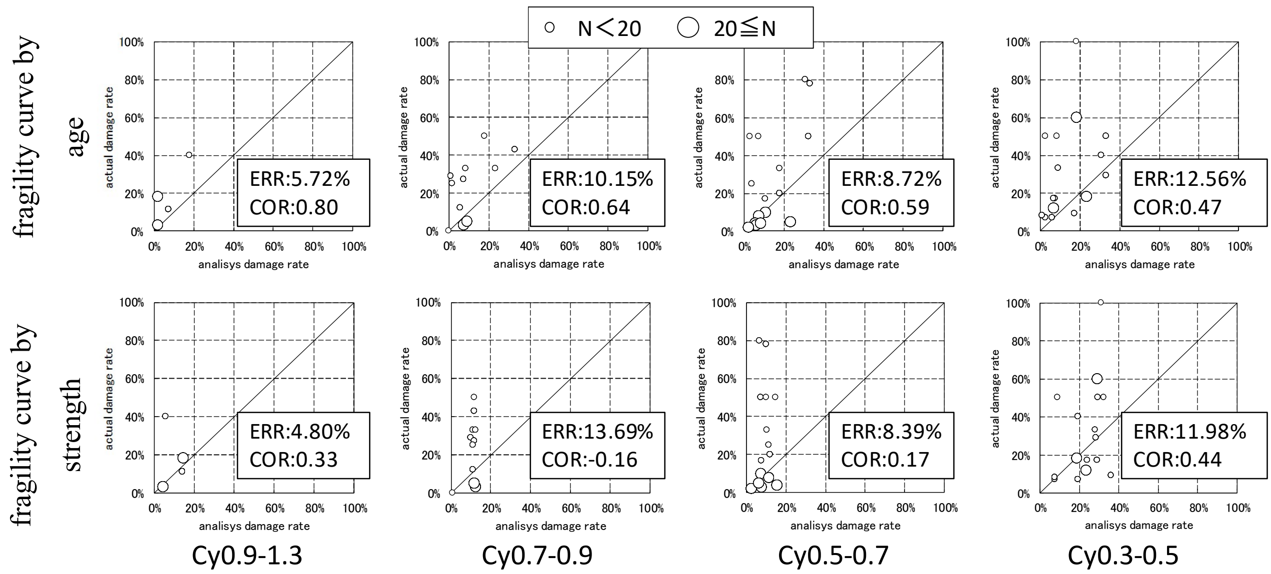


Fig. 7 – Correspondence with actual damage rate

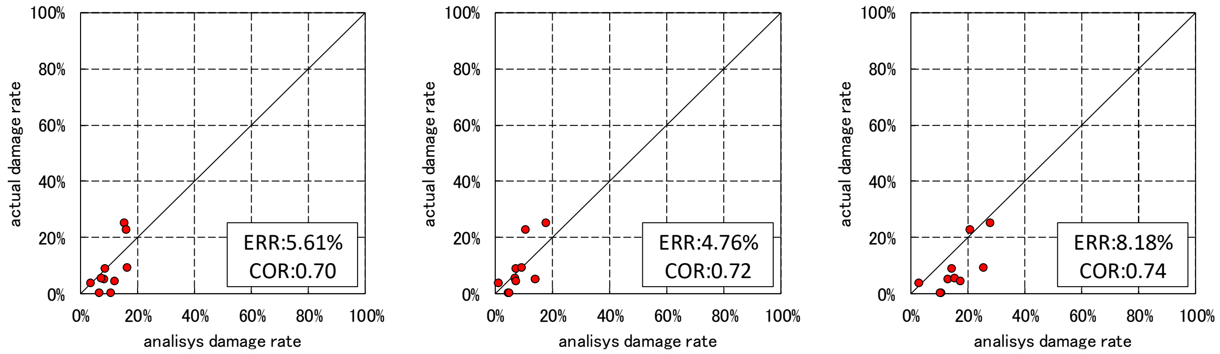
Table 7 – parameters for fragility curves classified by base shear coefficient

	0.9≦Cy<1.3	0.7≦Cy<0.9	0.5≦Cy<0.7	0.3≦Cy<0.5
α	2.54	0.28	1.83	1.95
β	−1.66	−1.21	−1.38	−0.71

The reason why the ERR does not decrease in Fig. 7 may be that there is a problem in the accuracy of building categorization and the validity of the parameters of the equivalent linearization method. If we ignore the data with less than 20 buildings in the Cy0.5-0.7 group, the ERR is 6.13% for the fragility curve classified by age and 1.83% for the fragility curve classified by strength. The accuracy is greatly improved by creating a fragility curve using only data with a sufficient number of buildings. Therefore, the use of data with a small number of buildings seems to be one of the factors that reduce the accuracy. However, if we ignore data with a small number of buildings, there is not enough data left to create a fragility curve, so we have to include data with a small number of buildings. The following is an example of how to use the Cy-specific fragility curve to estimate the damage of a category 3 building when an earthquake occurs in 2020.

1) The strength Cy1 of the standard buildings (category 1) built in 1960s is calculated using the proof strength reduction model. Cy1 is 0.49.
2) Multiply Cy1 by the coefficient shown in Table 4 to obtain the strength Cy2 of category 3 buildings. Cy2 is 0.62. So, we use the fragility curve of Cy0.5-0.7.
3) When Cy2 is 0.62, the equivalent period is 0.6 seconds from Equations (2) to (6). The average value of the 0.5 second width spectrum centered on 0.6 second of the elastic acceleration response spectrum of the damping constant h_e is substituted into the fragility curve.

For other categories, the damage rate is calculated by the same procedure. By weighting by the existence ratio of each category, we obtain the total damage rate. Fig. 8 shows the correspondence between the estimated damage rate obtained by weighting and the actual damage rate. The average of the absolute value of the error of the fragility curve classified by strength at the time of the earthquake is about 1% larger than that of the fragility curve classified by age.



classified by strength　classified by age　1-1.5 sec. response

Fig.8 - correspondence with actual damage rate

We confirmed that the accuracy of damage estimation was improved by classifying buildings by age of construction or category. However, the accuracy of the fragility curve by strength, which classifies the building more finely than the classification by the building age, conversely decreased. This may be due to the fact that data containing a sufficient number of buildings has been reduced due to the detailed classification of buildings. Also, when the fragility curve is further classified, the number of buildings for which damage can be estimated decreases, for example, damage to buildings since the 1990s cannot be estimated. In addition, there is a problem that the amount of required information increases as the fragility curve is further classified. We don't need any information of buildings to use 1-1.5 sec response fragility curve. We need the age distribution of buildings to use fragility curves classified by age. We need the number of stories, the roofing materials, opening in the wall and the age distribution of buildings to use fragility curves classified by strength. According to the results of this study, it is considered that the fragility curve by building age is superior to the fragility curve by strength in terms of both accuracy and practicality.

5. Conclusion

We have created fragility curves classified by building age and building category, in order to improve the accuracy of earthquake damage estimation using fragility curves. First, we examined periodic bands correlated with building damage by building age. It was found that the peak of the correlation coefficient became shorter as the building age became newer. Then we improved the accuracy of the fragility curves compared to the conventional one, by creating the fragility curves based on the response acceleration of different period bands according to the age of construction. Since the strength of buildings declines due to aging, the strength may be different depending on when the earthquake occurred even if the age of construction is the same. We created fragility curves classified by the strength at the time of the earthquake, considering the deterioration of the strength due to aging and the parameters that affect the strength such as the number of stories, roofing materials and openings in the walls. As a result, we could determine the seismic intensity measure logically from the equivalent period corresponding to the strength at the time of the earthquake, without empirically determining the seismic intensity measure from the correlation with the damage rate as in the conventional method. The accuracy of the damage estimation was slightly lower than the age-specific fragility curve. This is probably because we had to use data with a small number of buildings to determine the parameters of the fragility curve.

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