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SEISMIC PERFORMANCE LEVEL OF BUILDINGS CONSIDERING RISK FINANCING

Sei'ichiro FUKUSHIMA[1] and Harumi YASHIRO[2]

SUMMARY

Seismic risk is of concern for enterprises, since it brings pure risk that is very complicated to estimate and handle. This study examines the seismic performance of buildings from the viewpoint of minimizing the life cycle cost including the risk financing such as insurance and/or securitization. After evaluating the seismic risk of 25 buildings in the Kanto district, the followings are obtained; combination of risk control and risk financing reduces the life cycle cost significantly, life time has a large effect on the selection of risk management scheme, and the trends of risk aversion has also affect on it.

INTRODUCTION

Enterprises are surrounded by a lot of risks such as human-induced risks, accidents and natural disaster risks. In particular, seismic risk is of concern for Japanese enterprises since it brings pure risk that is very complicated to estimate and to handle.

After 1995 Kobe earthquake, the concept of performance-based design has been introduced. Though the previous seismic design standard is still valid as the minimal requirement, it is not preferable for company owners to design their buildings with the minimal requirement since they are requested to expose the seismic risks to stock holders as well as to contribute to the sustainable society. Therefore, they are requested to evaluate their seismic risk and cost for the countermeasures such as risk control and risk financing, and to select the best countermeasure from the viewpoint of cost-benefit optimization. For example, the risk control measure includes the increment seismic design requirement, retrofitting and so on, on the other hand, the risk financing measure means earthquake insurance and catastrophic bond and so on. Authors think it important to combining those measures since seismic risk itself is very complicated.

In this paper, seismic risk of the model enterprise that owns 25 buildings in the Kanto district is evaluated with some countermeasures, followed by establishment of selecting the seismic performance level including the risk financing method.

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[1] Tokyo Electric Power Services Co., Ltd.
[2] Tokio Marine and Fire Insurance Co., Ltd.

QUANTIFICATION OF SEISMIC RISK OF PORTFOLIO

Seismic Risk Analysis of Portfolio

Authors constructed the seismic risk analysis of the group of buildings (hereinafter called portfolio) based on the seismic hazard analysis [1]. Figure 1 shows the concept of the analysis, which carries out the numerous loss estimations for the given scenario earthquakes generated based on the seismic source characteristics that are the relationship between magnitude and annual frequency of occurrence, and that between magnitude and shape of rupture plane in source zone. In the figure, $l(j,i)$ is a loss of building j by scenario earthquake i and N is the number of buildings. $l(p,i)$ is a loss of portfolio by scenario earthquake i, which is given by the sum of $l(j,i)$ for j = 1 to N. It must be noted that $l(j,i)$s and $l(p,i)$ have the annual frequency of occurrence corresponding to the scenario earthquake i.

By arranging $l(j,i)$s and $l(p,i)$ in the order of magnitude of loss, risk curves are obtained. Risk curves show the relationship between the loss and annual frequency of exceedence. Using risk curve, some indices of loss are derived as shown in Fig.2. For example, the area surrounded by risk curve, x-axis and y-axis corresponds to annual expected loss (hereinafter called AEL), and the loss for the given annual frequency of exceedence is called probable maximum loss (hereinafter called PML). In this study, the annual frequency of exceedence to assign PML is set to 1/475.

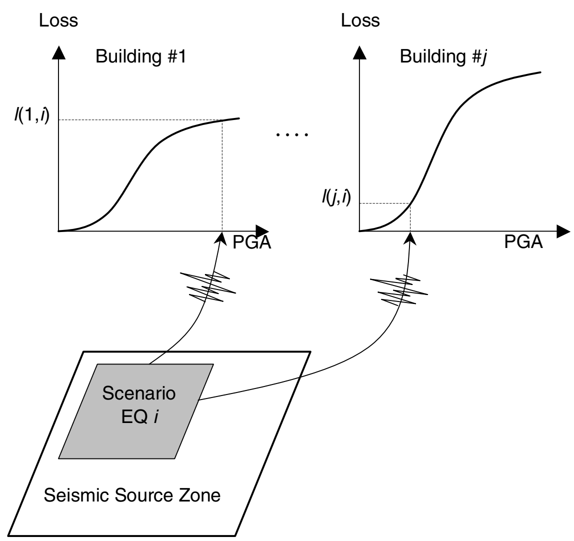

Fig.1 Concept of Portfolio Analysis

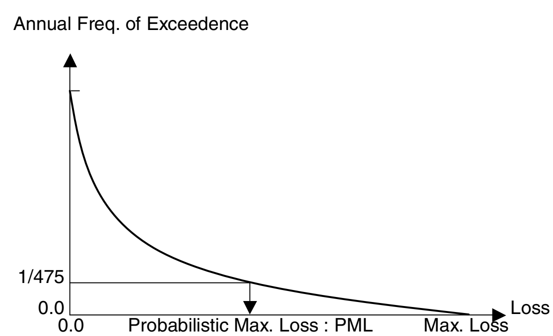

Fig.2 Risk Curve and Loss

Inclusion of Risk Financing in Risk Analysis

The procedure of risk analysis including risk financing are illustrates in Fig. 3. Basic concept for evaluate the effect of risk finance is to modify $l(p,i)$ according to the given scheme [2]. Risk curve of portfolio is obtained based on $lh(p,i)$ instead of $l(p,i)$, where, $lh(p,i)$ is calculated by following equation,

$$lh(p,i) = l(p,i) - lt(i)\,. \tag{1}$$

$lt(i)$ is a loss transferred to risk taker such as insurance company, and calculated in various manner. In case of earthquake insurance, $lt(i)$ is evaluated by loss $l(p,i)$ as shown by following equations,

$$lt(i) = \min(le, f[l(p,i)]) - la \qquad , l(p,i) > la\,, \tag{2a}$$

$$lt(i) = 0 \qquad , 0 \le l(p,i) \le la\,, \tag{2b}$$

where, *la* is deduction and *le* is a limit. *f*[ ] is a function to relate the loss and payment. On the other hand, in case of catastrophic bond, *lt*(*i*) is evaluated by a parameter other than loss. Magnitude in JMA scale is employed in this study as shown by following equations,

$$lt(i) = g[m(i)] \times C \qquad , m(i) \geq ma \, , \tag{3}$$

where, *m*(*i*) is a magnitude of scenario earthquake *i*, *g*[ ] is a function to relate the *m*(*i*) and payment and *C* is a capital. It must be noted that risk curve can be obtained for *lt*(*i*), which is the risk of risk taker. So, Insurance companies can estimate the insurance fee by the product of their AEL and risk premium.

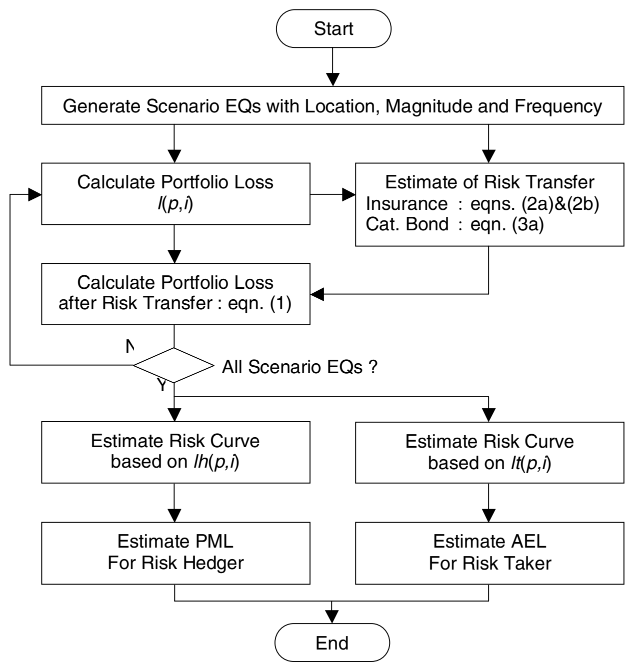

Fig.3 Procedure of Risk Analysis including Risk Financing

DTERMINATION OF SEISMIC PERFORMANCE LEVEL

Framework

Life cycle cost (hereinafter called LCC) includes all the cost for the building through its life as expressed by the following equation,

$$C(x,t) = I(x) + M(x,t) + R(x,t) + D(x) - B(x,t) \, , \tag{4}$$

where, *C*(*x*,*t*) is LCC, *I*(*x*) is the initial construction cost, *M*(*x*,*t*) is the maintenance cost, *R*(*x*,*t*) is the seismic risk, *D*(*x*) is the cost for demolishment, and *B*(*x*,*t*) is the benefit, respectively. *x* is the design base shear coefficient corresponding to the seismic performance and *t* is the building life.

The performance level that gives the lowest LCC is called the optimal performance level in this study. In order to obtain the optimal base shear coefficient, the terms considered as constant can be neglected. The initial cost and the seismic risk are affected by the design base shear coefficient *x*, since increment of *x* brings the higher initial cost and lower seismic risk. On the other hand, *x* has less affect on maintenance cost ,demolishment cost and benefit. Reflecting those fact and introducing the cost for risk transfer *T*(*x*,*t*) and risk aversion factor *u*, the following equation is obtained,

$$C(x,t) = I(x) + uR(x,t) + T(x,t) \, . \tag{5}$$

The factor u is introduced to express the trend of risk aversion of the decision makers and/or to include indirect loss. Therefore, it can be concluded that minimizing the above equation is to optimize the decision maker's utility function.

Moreover, assuming the *Poisson*'s process for the occurrence of earthquakes, seismic risk within the building life can be obtained by the following equation,

$$R(x,t) = t \times R1(x) \,, \tag{6}$$

where, $R1(x)$ is the annual seismic loss evaluated by seismic hazard source model possessing the annual occurrence frequency of each source zone. The cost for risk transfer is also expressed by the product of building life and annual cost as follows,

$$T(x,t) = t \times [T1(x) + T2(x)] \tag{7}$$

where, $T1(x)$ is the annual insurance fee given by the product of AEL of the insurance company and risk premium. $T2(x)$ is the annual interest paid to investors. In this study, $T2(x)$ is considered as constant since the annual interest is determined by capital and interest rate, which are not the function of x.

Procedure to Obtain the Optimal Risk Management Scheme

For some combinations of risk financing method and design base shear coefficients, LCC can be obtained using the equations described above. Among them, the combination that gives the least LCC is selected to find out the optimal risk transfer method and the corresponding optimal design base shear coefficient. Figure 4 shows the flowchart to obtain the optimal risk management scheme.

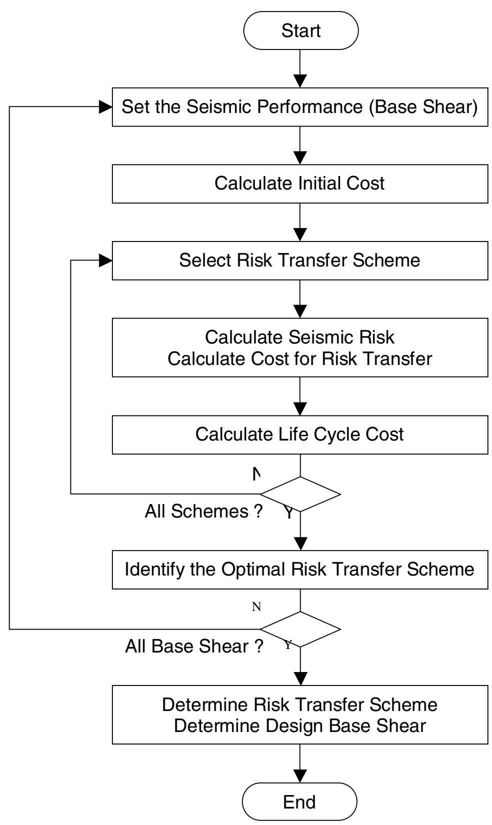

Fig.4 Procedure to Obtain the Optimal Risk Management Scheme

APPLICATION

Condition Setting

Model Portfolio
Portfolio consisting of 25 buildings in Kanto district is employed in the application. Figure 5 shows the arrangement of the buildings. It is noted that 10 buildings within the broken line is selected as targets of the risk control measure, which is the increment of design base shear coefficient.

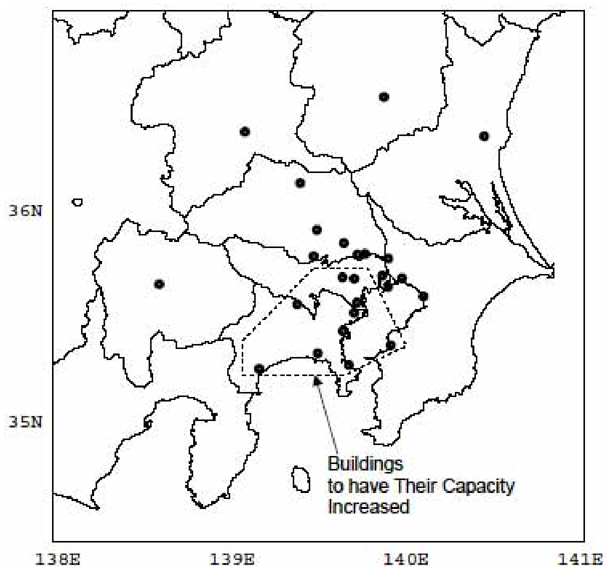

Fig.5 Arrangement of Buildings

Fragility and Damage cost of Each Building
Log-normal distribution is applied to express the building capacity. Therefore, building capacity can be assigned only by 2 parameters, which are the median and the log-normal standard deviation of the capacity acceleration. Fragility of buildings varies corresponding to damage mode as well as damage cost. So, 4 damage modes are selected in the application, which are “slight”, “moderate”, “severe” and “collapse”.

Table 1 summarizes the fragility parameters and cost for each building designed assuming $x = 0.2$ that is ordinary design level. Initial cost and damage cost are affected by the design base shear coefficient, so that the factor k is applied to these costs. Based on the existing research, k is given as follows,

$$k = 1 + \frac{1.2 - 1}{0.4 - 0.2} \times (x - 0.2) \equiv 0.8 + x\,. \tag{8}$$

Table 1 fragility parameters and cost for $x = 0.2$

Damage Mode	Fragility Parameter		Cost	
	Median (cm/s/s)	Log-normal SD	Initial Cost	Damage Cost
Slight	160	0.4	100	5
Moderate	480			10
Severe	800			30
Collapse	1120			100

Also, the median capacity acceleration is multiplied by (x/0.2) that means median capacity is in proportion to design base shear coefficient. On the other hand, the log-normal standard deviation remains constant.

Seismic Source Model

Seismic source models are determined based on Annaka & Yashiro [3]. Seismic source models in which large earthquakes occur, are the regions where earthquakes with magnitude of 7.0 or greater occur in land and those with magnitude of 7.5 or greater in sea bottom. The relationship between magnitude and frequency is modeled as characteristic earthquake. On the other hands, the regions where small earthquakes, occur are set along the plate and in the cluster. The relationship between magnitude and frequency for these earthquakes is modeled by Gutenberg and Richter equation whose parameters are obtained from the observation records from January 1926 to July 1977.

Figure 6 shows the seismic source models employed in the analysis. Table 2 shows the specification of each source model.

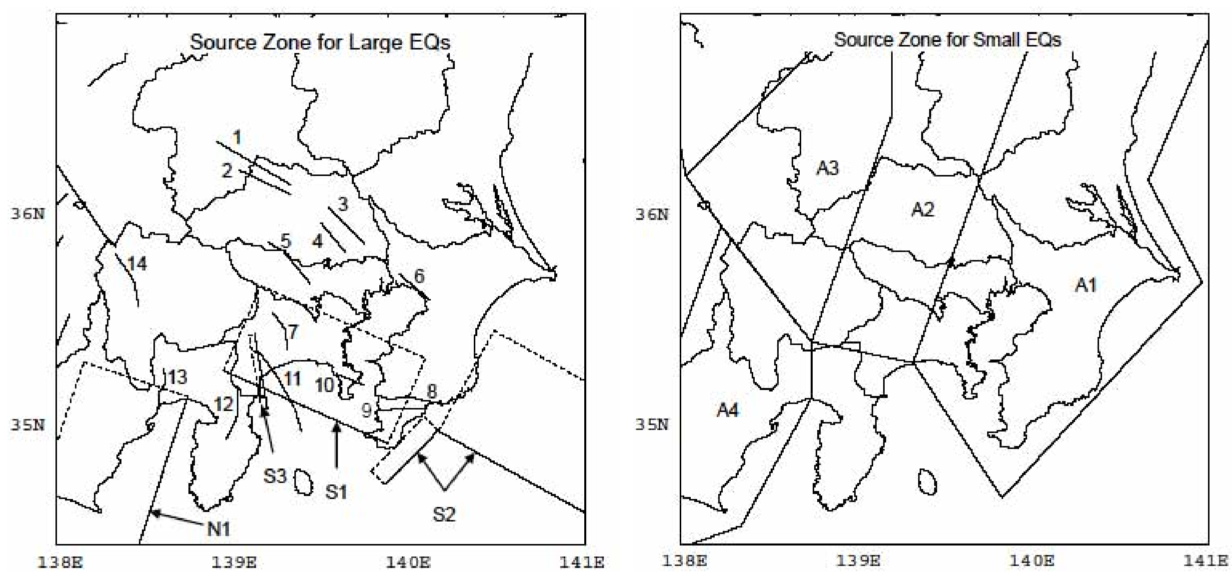

Fig.6 Seismic Source Models

Table 2(1) Specification of Each Source Model for Large Earthquakes

#	Range of *M*	Return Period (yr.)	#	Range of *M*	Return Period (yr.)	#	Range of *M*	Return Period (yr.)
1	7.0-7.6	1182	7	6.9-7.3	7239	13	6.8-7.2	1917
2	6.9-7.3	5212	8	7.1-7.5	2842	14	7.1-7.5	2851
3	7.0-7.4	79283	9	7.0-7.4	2639	S1	7.8-8.2	200
4	6.8-7.2	5931	10	6.6-7.0	1365	S2	7.8-8.2	1000
5	7.1-7.5	8710	11	7.5-7.9	1625	S3	6.8-7.2	73
6	6.8-7.2	5676	12	7.1-7.5	877	N1	7.6-8.0	130

Table 2(2) Specification of Each Source Model for Small Earthquakes

#	Maximum M	*A*-Value	*b*-value	#	Maximum M	*A*-Value	*b*-value
A1	7.0	2.344	0.9	A3	7.0	1.645	0.9
A2	7.0	4.235	0.9	A4	7.0	3.344	0.9

Also based on Annaka & Yashiro[2], following attenuation relation is used in the analysis,

$$\log A = 0.61M + 0.00501h - 2.203\log(r) + 1.377\,, \tag{9a}$$

$$r = \sqrt{(d^2 + 0.45h^2} + 0.22\exp(0.699M)\,, \tag{9b}$$

where, A is a peak ground acceleration, M is a magnitude, h is a focal depth and d is a epicenter distance, respectively. The standard deviation expressing the uncertainty of attenuation relation is 0.5 in natural logarithm.

Risk Financing Method

Earthquake Insurance

In case of the earthquake insurance, both deductive and limit must be determined. The latter is often determined considering PML. In order to examine the effect of increment the seismic design base shear coefficient on PML, 3 cases of analysis are carried out, followed by the risk curves shown in Fig. 7. In case “x = 0.2”, all the buildings have the same seismic capacity as indicated in Table 1. In case “x = 0.25” and “x = 0.3”, 10 buildings within the broken line have their capacity increased by 1.25 times and 1.5 times. Table 3 summarizes the condition setting for the earthquake insurance.

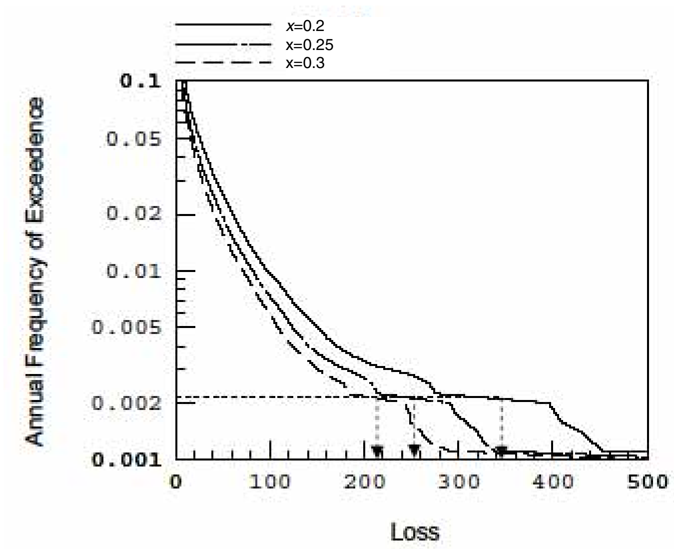

Fig. 7 Risk Curve of Model Portfolio

Table 3 Condition Setting for Earthquake Insurance

Insurance Parameters	Analysis Case (Base Shear Coefficient for Target Buildings)		
	x=0.2	x=0.25	x=0.3
Deductive	50	50	50
Limit	350	250	200

Catastrophic Bond

In case of the catastrophic bond, 3 parameters need to be determined; capital, the function $g[\ ]$ to relate the magnitude and payment and the grid to define the area of occurrence of earthquakes that are considered in the payment. The capital is set to 300, which is compatible to the case “x = 0.2” in the case of the earthquake insurance.

The grid is determined so that it covers the buildings in south Kanto area and the seismic source corresponding to Kanto earthquake. It is noted that these conditions are derived from the viewpoint of the contribution to the loss of portfolio. Figure 8 shows the grid employed in the analysis.

The function $g[\ ]$ is determined so that the forfeiture starts at M=7.0 and reaches to maximum at M=8.0, since the large earthquakes in the grid described above possess the magnitude of 7.0 to 8.0. Figure 9 shows the function employed in the analysis.

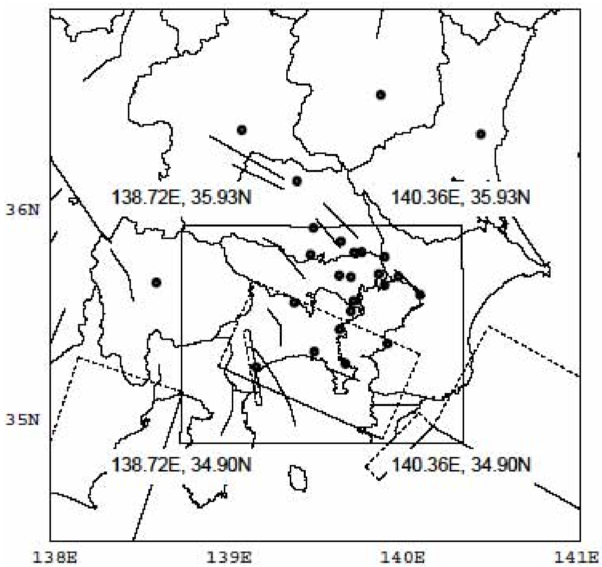

Fig. 7 Grid for Catastrophic Bond

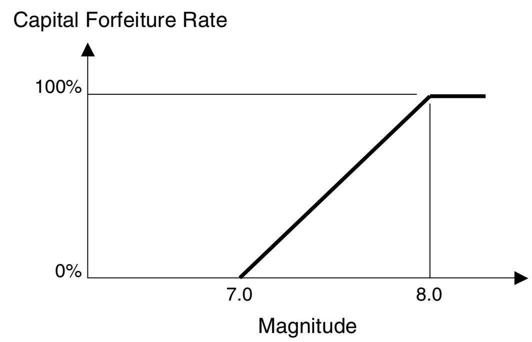

Fig. 8 Function of Capital Forfeiture

Relationship between Performance Level and Costs

Initial Cost

The initial cost of a building for x = 0.2 is assumed to be 100. Therefore, by applying eqn.(8), the initial cost for the arbitrary x is given by the following,

$$I1(x) = k \times 100 = 80 + 100x\,. \tag{10}$$

Remembering that the 10 buildings may have their capacity increased, the initial cost of the portfolio can be calculated as follows,

$$I(x) = 10 \times (80 + 100x) + 15 \times 100 = 2300 + 1000x \tag{11}$$

Seismic Risk

Table 4 summarizes the annual expected loss of the risk hedger for each combination of seismic performance level and risk financing scheme; "no risk transfer", "insurance", and "cat. bond". Moreover, the relationship between the design base shear coefficient x and AEL of risk hedger is estimated as shown in Fig. 10, followed by equations listed below,

$$R1(x) = 1.11x^{-1.043} \quad \text{for "no risk transfer",} \tag{12a}$$

$$R1(x) = 1.16x^{-0.846} \quad \text{for "insurance",} \tag{12b}$$

$$R1(x) = 1.20x^{-0.671} \quad \text{for "cat. bond".} \tag{12c}$$

Table 4 Annual Expected Loss of Risk Hedger

Risk Transfer Scheme	Analysis Case (Base Shear Coefficient for Target Buildings)		
	x=0.2	x=0.25	x=0.3
No Risk Transfer	6.00	4.63	3.94
EQ Insurance	4.55	3.71	3.23
Catastrophic Bond	3.57	3.01	2.72

Cost for Risk Transfer

Table 5 summarizes the annual expected loss of the risk taker for each combination of seismic performance level and risk financing scheme; "no risk transfer", "insurance", and "cat. bond". Moreover, the relationship between the design base shear coefficient x and AEL of risk taker is estimated as shown in Fig. 11, followed by equations listed below,

$$T1(x) = T2(x) \equiv 0 \quad \text{for "no risk transfer",} \tag{12a}$$

$$T1(x) = pr.\times 0.0965x^{-1.707} \quad \text{for "insurance",} \tag{12b}$$

$$T2(x) = in.\times 300 \quad \text{for "cat. bond",} \tag{12c}$$

where, *pr.* is a risk premium and *in.* is a interest rate.

Table 5 Annual Expected Loss of Risk Taker

Risk Transfer Scheme	Analysis Case (Base Shear Coefficient for Target Buildings)		
	x=0.2	x=0.25	x=0.3
No Risk Transfer	0.00	0.00	0.00
EQ Insurance	1.52	1.01	0.76
Catastrophic Bond	2.42	1.62	1.21

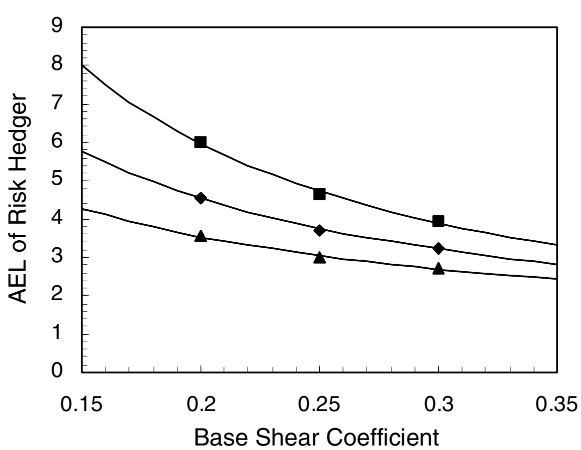

Fig 10 Relation of x vs. Risk Hedger's AEL

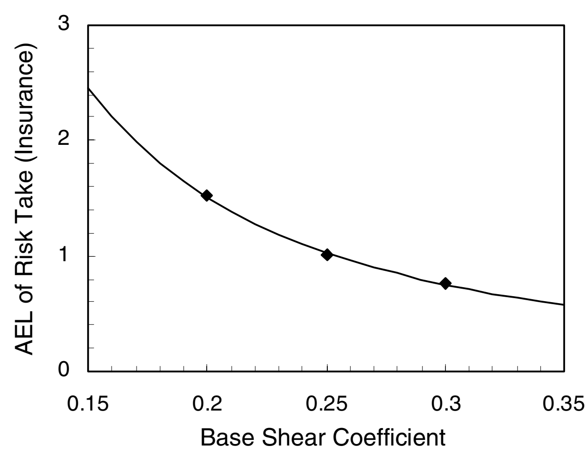

Fig 11 Relation of x and Risk Taker's AEL

Results

Effect of Risk Control on LCC

Figure 12 shows the LCC for the fixed value of $x = 0.2$. Figure 13 shows the minimal LCC when varying x from 0.2 to 0.3. From the comparison of these 2 figures, it can be seen that the difference in LCC appears for large risk aversion factor u and long return period t.

The ratio of LCC in Fig.13 to that in Fig. 12 is shown in Fig. 14 as well as the optimal base shear coefficient. From the viewpoint of reducing the LCC, the effectiveness of increment of design base shear coefficient appears for larger values of u and t, since the contribution of seismic risk to LCC increases with u and t. This also suggests that increasing of seismic capacity is not adequate for the temporary structure with short life.

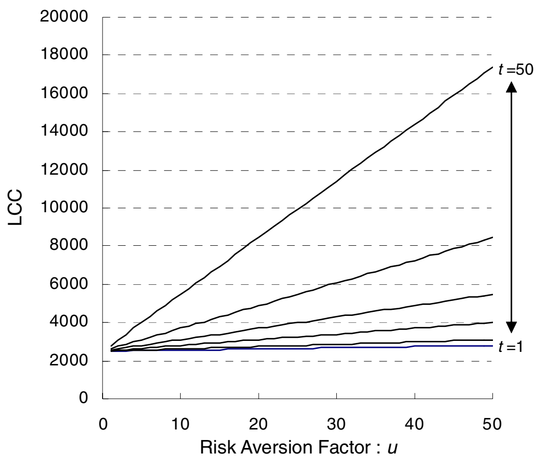

Fig.12 LCC for the Fixed Value of $x = 0.2$

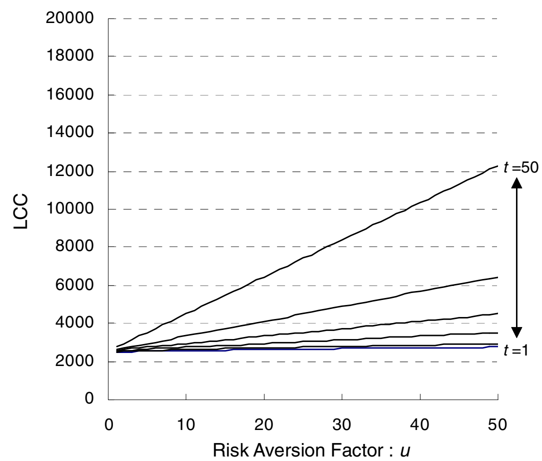

Fig.13 Minimal LCC for $x = 0.2$-0.3

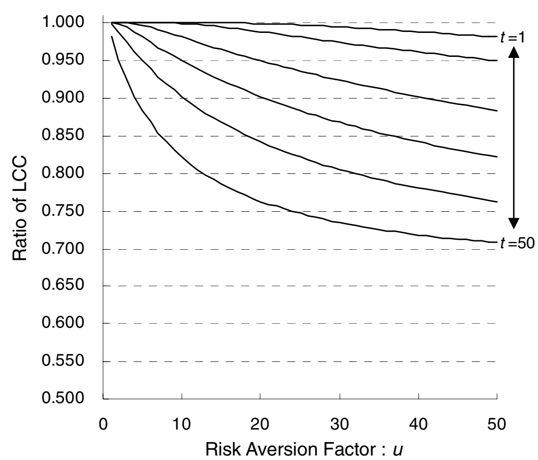

Fig.14(1) Ratio of LCC

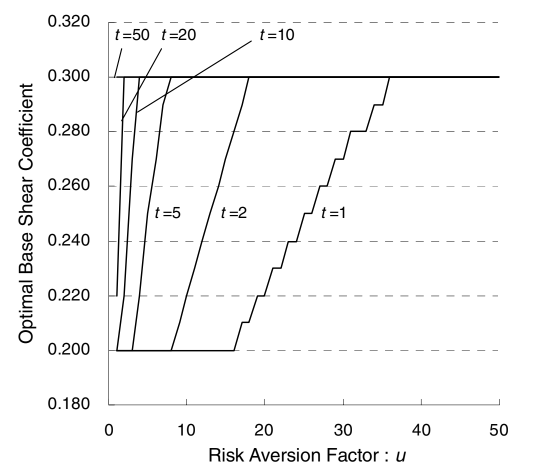

Fig.14(2) Optimal Base Shear Coefficient

Effect of Risk Financing on LCC

In order to examine the effects of insurance and catastrophic bond, the following assumptions are employed that the risk premium is 6 and the interest rate is 5.5%. These figures are determined based on the existing data. In this case, the base shear coefficient is fixed at 0.2. Figure 15 shows the ratio of LCC with risk transfer to that without risk transfer. In the case that the ratio is unity, no risk transfer is carried out.

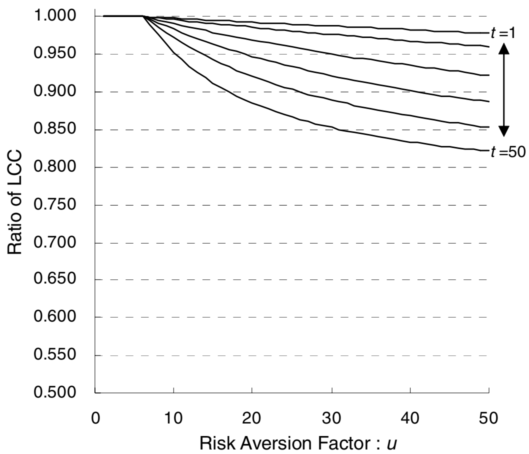

Fig.15(1) Ratio of LCC

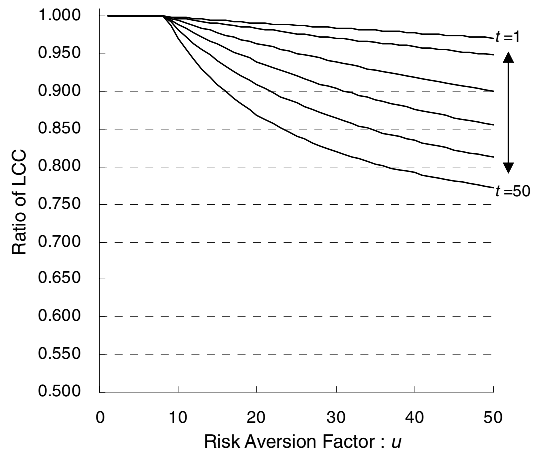

Fig.15(2) Optimal Base Shear Coefficient

Effect of Combination of Risk Control and Risk Financing on LCC

The ratio of LCC in case when both risk control and risk financing are considered, to that in Fig. 12 is shown in Fig. 16 as well as the optimal base shear coefficient. From this figure, it is seen that LCC is significantly reduced comparing with other cases.

Figure 17 shows the optimal risk management scheme. In case of long building life, risk control is effective since its cost per year reduced. On the other hand, risk financing is effective for the buildings of short life, such as temporary buildings. This tendency may also be helpful when determining the retrofitting plan for existing buildings.

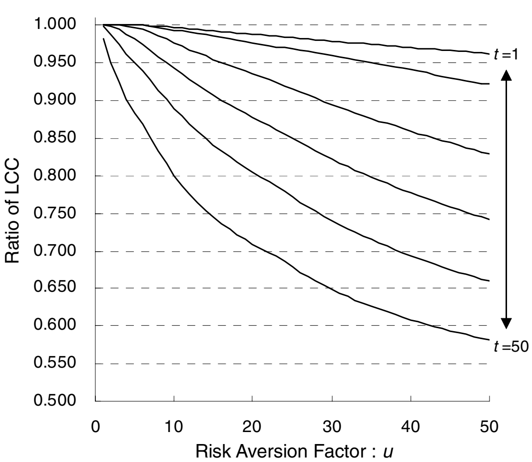

Fig.16(1) Ratio of LCC

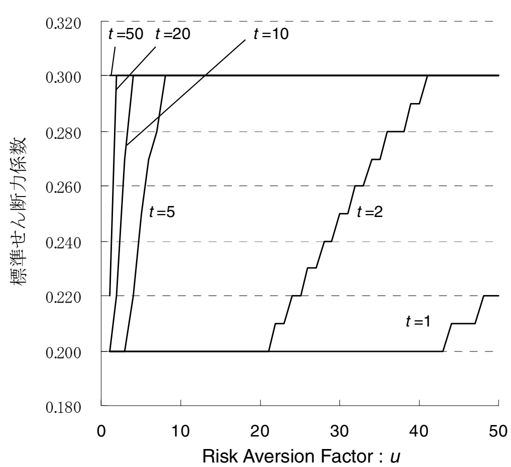

Fig.16(2) Optimal Base Shear Coefficient

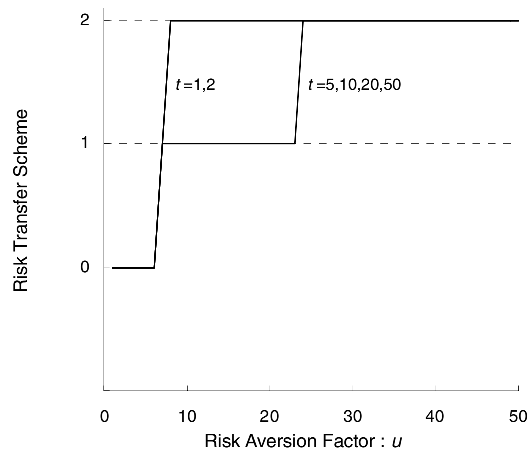

Fig.17 Optimal Risk Management Scheme when Considering Risk Control and Risk Financing

CONCLUSION

In this paper, the outline to obtain LCC of portfolio ob buildings considering the risk financing is proposed. Also proposed is a procedure to determine the seismic risk management procedure from the viewpoint of optimization of LCC. This procedure is applied to the model portfolio consisting of 25 buildings in Kanto district. Though the example employed is very simple, the concept and the framework are robust and applicable to the real risk management.

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