A STUDY ON THE RISK MANAGEMENT DESIGN METHOD BY CONSIDERING OF BOTH LCC AND $LCCO_2$

Kaneko Takeshi [1] and Kazutoshi Tsutsumi [2]

ABSTRACT

The enhancement of the useful life of buildings is an important issue with regard to global environmental problems. The aim of this study is to evaluate the optimum useful life of buildings so that the synthetic evaluation, which considers both the cost and the CO_2 emission, becomes minimum during a given evaluation period. In order to achieve this objective, the quantitative evaluation of the damage risk due to earthquake and $LCCO_2$ is conducted by using the seismic risk management method (e.g., Masaru HOSIYA 2002).

KEY WORDS

bearing-force increase ratio, useful life of building, seismic risk management method

INTRODUCTION

In Japan, many buildings have been built during periods of high economic growth, and many of these buildings have been dismantled and rebuilt after about 30 years. This lifetime is shorter than that of buildings in other developed countries. In recent years, the concern with regard to global environmental problems that have surfaced due to the use of a large amount of resources and increased waste generation has become widespread. Further, the importance of buildings with longer lives and improved durability has been widely recognized. With regard to the global environmental problems, in December 1997, the Architectural Institute of Japan reported that life cycle carbon dioxide ($LCCO_2$) of buildings must be reduced by 30%, the life of a building must be extended threefold (for 100 years). It is essential to ensure a longer life of buildings in order to limit carbon dioxide emission. By making buildings long lives, the possibility of a major earthquake increase and great damage is caused. Therefore, it is necessary to estimate both the cost and the CO_2 emission for the repair of the damage to a building due to an earthquake. In this study, a seismic risk management method was formulated and used as a method for evaluation.

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PURPOSE

The aim of this study is to evaluate the optimum useful life of buildings so that the synthetic evaluation, which involves a comprehensive evaluation of both the cost and the CO_2 emission, becomes minimum during a given evaluation period.

ANALYSIS METHOD AND RESULT

The bearing-force increase ratio, based on a useful life of 50 years, is estimated so that the calculated response value becomes lower than the designated value. Next, by considering the uncertain factors-earthquake wave, building strength, and eigen period-in the seismic risk management method, the quantitative damage risks due to earthquakes are evaluated against the maximum earthquake motion during the useful life of a building. The optimum useful life of buildings is evaluated so that the synthetic evaluation, which involves a comprehensive evaluation of both LCC and $LCCO_2$ emission, may become minimum during a given evaluation period.

BEARING-FORCE INCREASE RATIO FOR EACH USEFUL LIFE

Seismic response analysis by considering the qualitative dispersion of an earthquake wave, building strength, and eigen period, is performed with respect to the maximum earthquake motion during the useful life of a building. The probability of the analyzed story displacement angles is calculated by response analysis by changing the bearing-force increase ratio in steps of 0.2. The optimum bearing-force increase ratio for the safety of human life is defined so that the probability of the analyzed story displacement angles less than 1/50 becomes greater than or equal to 95%.

The conditions for analysis are set out as follows;

- object area： Tokyo, Japan
- structure type： reinforced concrete structure
- number of stories： 7
- analysis method：1 mass system response analysis method(e.g., Kazutoshi TSUTSUMI 1999)
- useful life： 50-200 years for every 25 years
- number of samples： 27,000 samples
- building dispersion： 25% for building eigen periods and 7% for bearing-force increase ratios

The number of both samples is each 30 and both samples are generated by normal random numbers. However, the average value of the bearing forces is set at 7% higher than the designated value.

- qualitative dispersion of earthquake wave ：The 30 artificial earthquake waves are generated by software(e.g., AIJ 1996, KOZO SOFT 2002).

  The earthquake waves are created as follows

The maximum earthquake motion during the useful life increases with the life of the buildings. Therefore, it is necessary to appraise the design earthquake force for each useful life. Further, the design reappearance period is calculated so that the non-excess probability may be 80%, and then the design earthquake acceleration is calculated from the seismic hazard curve of the site. The relationship between the useful life and the design earthquake acceleration is shown in Table 1.

The target response spectrum for each useful life is defined as the acceleration response spectrum, which will occur rare on open engineering base defined by Building Standard Law. The envelope function of the artificial earthquake waves is similar to that of the L2 earthquake defined by the Building Center of Japan. The phase characteristics are defined by uniform random numbers. The earthquake waves are created by defining these three elements and changing the initial random numbers of the phase characteristics.

In Figure 1, the target response spectrum for a useful life of 50 years is shown as an example. The adopted envelope function is shown in Figure 2. The response spectrum of an artificial earthquake wave is shown in Figure 3.

Table 1: The relationship between the useful life and the design earthquake acceleration

useful life(year)	5	10	25	50	75	100	125	150	175	200
design recurrence period(year)	23	45	113	225	337	449	561	673	785	897
design earthquake acceleration(gal)	164	226	339	443	512	561	601	635	664	688

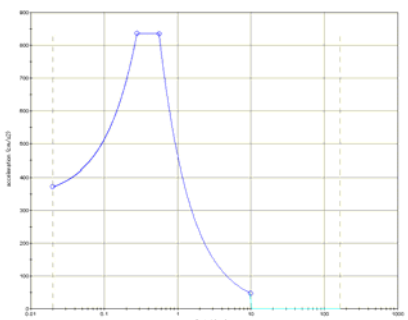

Figure 1:
The target response spectrum for a useful life of 50 years

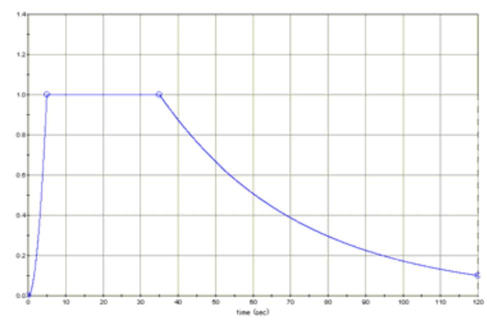

Figure 2: The adopted envelope function

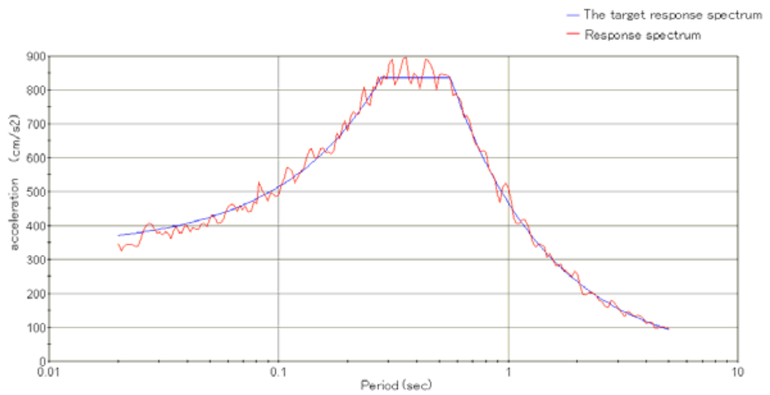

Figure 3: The response spectrum of an artificial earthquake wave

The results of the probability of the response story displacement angles for each bearing-force increase ratio with respect to each useful life are shown in Figure 4 to Figure 10. The optimum bearing-force increase ratio is shown in Figure 11.

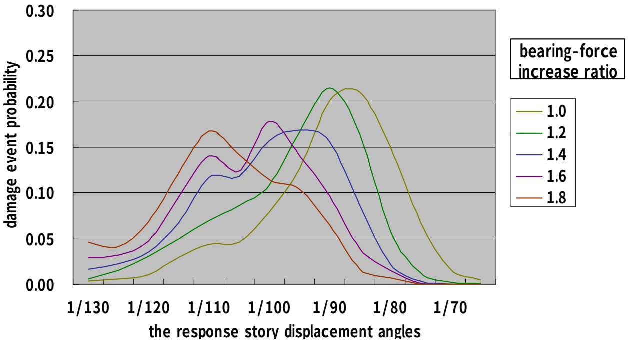

Figure 4: Useful life of 50 years

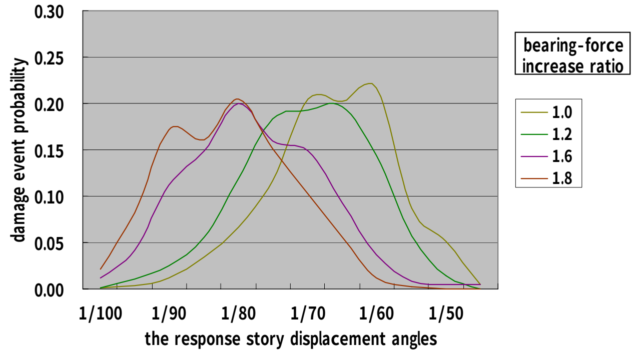

Figure 5: Useful life of 75 years

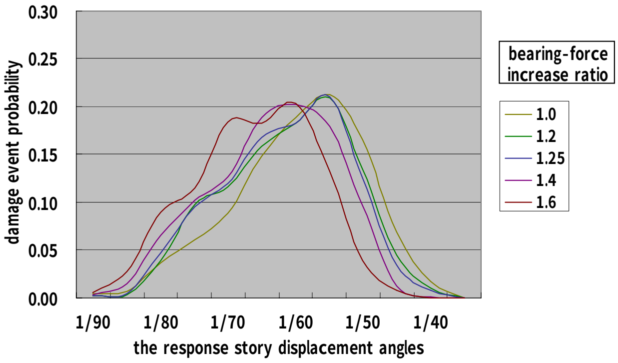

Figure 6: Useful life of 100 years

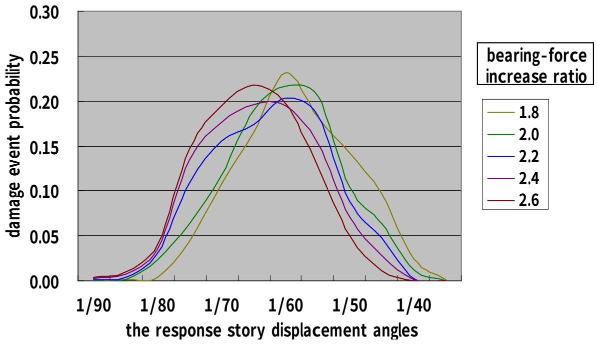

Figure 7: Useful life of 125 years

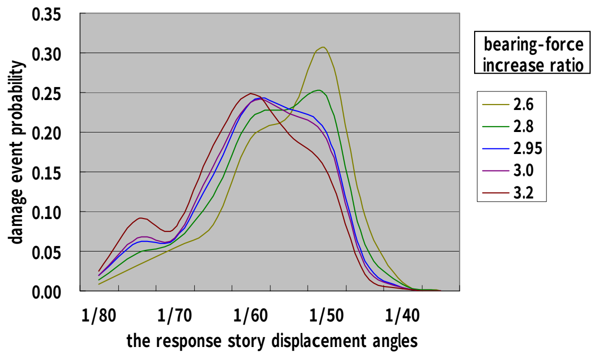

Figure 8: Useful life of 150 years

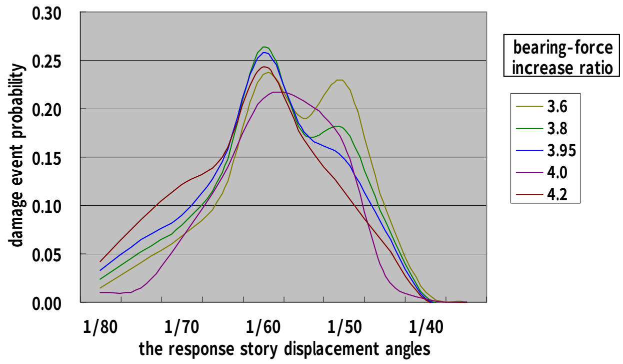

Figure 9: Useful life of 175 years

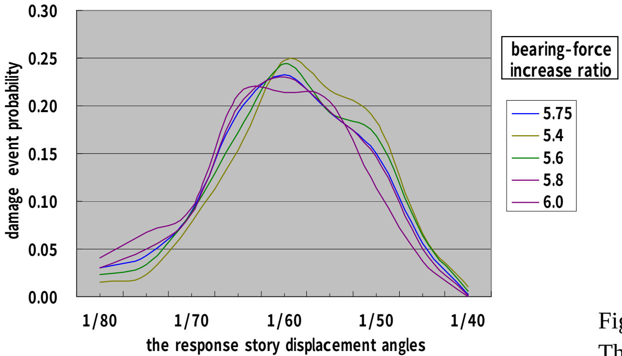

Figure 10: Useful life of 200 years

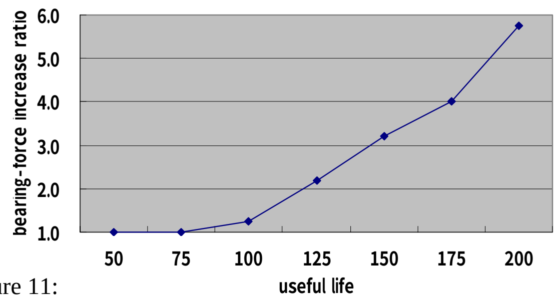

Figure 11:
The Optimum bearing-force increase ratio to each useful life

CALCULATION OF COST AND CO_2 FOR REPAIR

The repair cost is the cost involved in repairing the damage to buildings due to earthquakes, and repair CO_2 emission is the quantity of CO_2 emitted during the repair work. These values are evaluated by using the seismic risk management method.

First, a seismic response analysis is performed by using the optimum bearing-force increase ratio and the maximum earthquake acceleration for each useful life. Then, the seismic fragility curve is expressed as the probability of the story displacement angles.

The seismic fragility curves for each useful life are shown in Figure 12 to Figure 17.

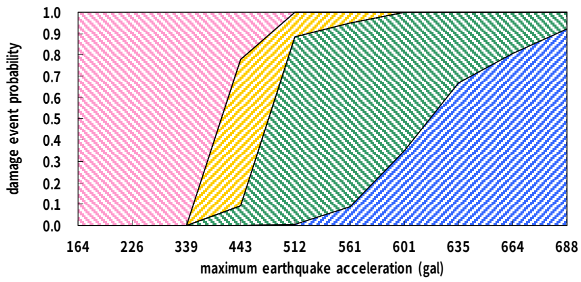

Figure 12: Useful life of 50 and 75 years

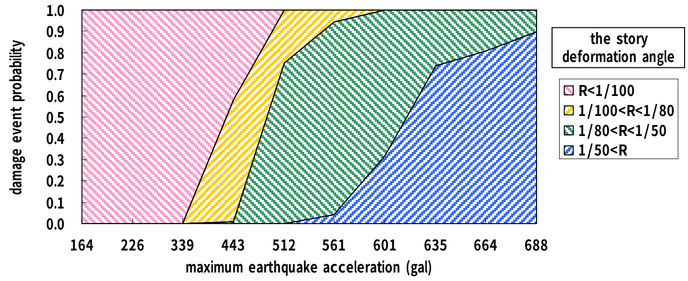

Figure 13: Useful life of 100 years

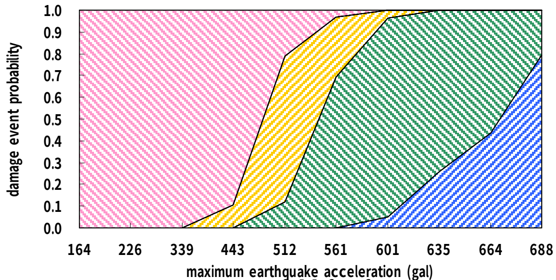

Figure 14: Useful life of 125 years

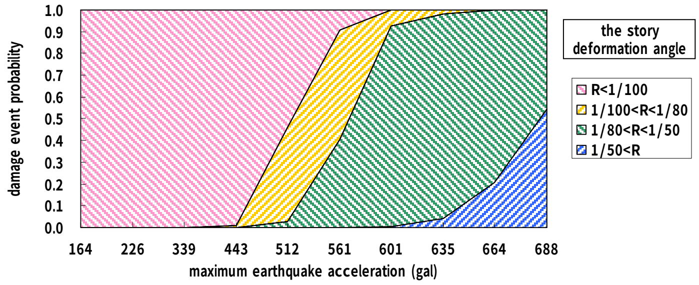

Figure 15: Useful life of 150 years

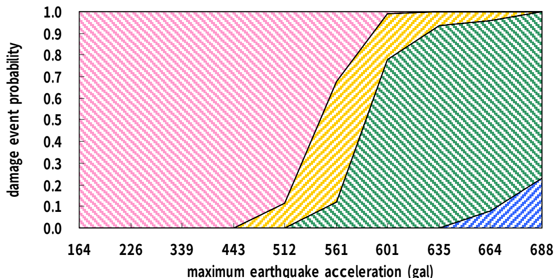

Figure 16: Useful life of 175 years

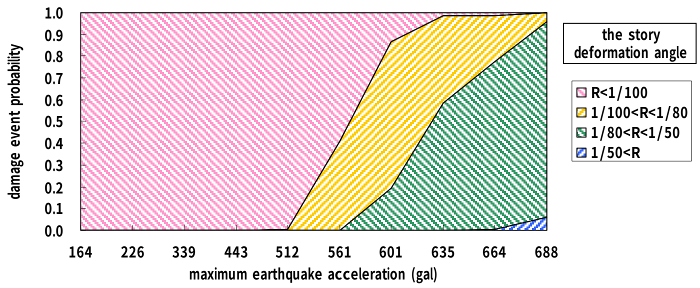

Figure 17: Useful life of 200 years

Next, the seismic loss function, which expresses the relationship between the damage loss expectation and the maximum earthquake acceleration for each useful life, is calculated from the relationship of the repair cost and repair CO_2 emission to the story displacement angles. The relationship between the story deformation angle and the repair cost ratio of the structural members is shown in Figure 18.

The relationship between the story deformation angle and the repair cost ratio of the nonstructural members is shown in Figure 19. However, the repair cost ratio is the ratio of the repair cost to the initial cost of the structural or nonstructural members (e.g., Kazutoshi TSUTSUMI 2002, Akira WADA 1998). The items of the initial cost (e.g., Akira WADA 1998) are shown in Figure 20. The initial cost and the initial CO_2 emission are calculated by designing the member sections based on the optimum bearing-force increase ratio and by estimating both the cost and CO_2 emission (e.g., Takeshi KANEKO 2005). The relationship between the bearing-force increase ratio and the increase ratio for the initial cost and the initial CO_2 emission is shown in Figure 21. The CO_2 emission ratio is the ratio of the repair CO_2 emission to the initial CO_2 emission (e.g., Jyun KANDA 2000). The relationship between the story deformation angle and the CO_2 emission ratio is shown in Figure 22. The seismic loss function of the cost is shown in Figure 23. The seismic loss function of the CO_2 emission is shown in Figure 24. Next, the probability density function is calculated by differentiating the seismic hazard curve. The annual seismic risk density is calculated by multiplying the probability density function with the seismic loss function. The area of this curve yields the annual loss expectation. The reduction in the area results in an increase in the earthquake-proof performance. The seismic hazard curve is shown in Figure 25. The probability density function is shown in Figure 26. The annual seismic risk density of the cost is shown in Figure 27, and the annual seismic risk density of CO_2 emission is shown in Figure 28.

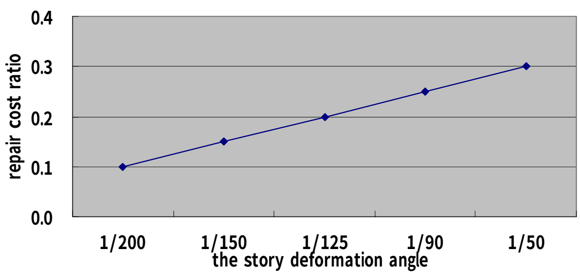

Figure 18: The relationship between the story deformation angle and the repair cost ratio of the structural members

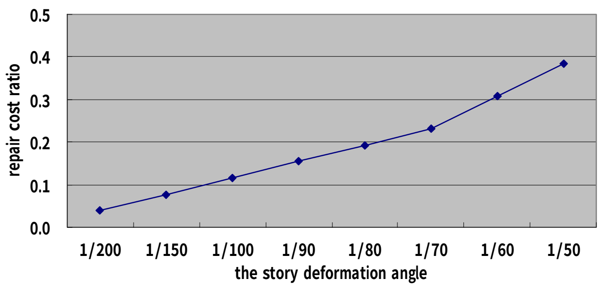

Figure 19: The relationship between the story deformation angle and the repair cost ratio of the nonstructural members

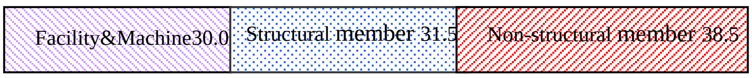

Figure 20: The items of the initial cost (%)

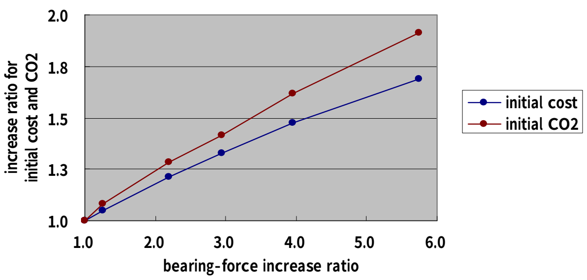

Figure 21: The relationship between the bearing-force increase ratio and the increase ratio for the initial cost and the initial CO_2 emission

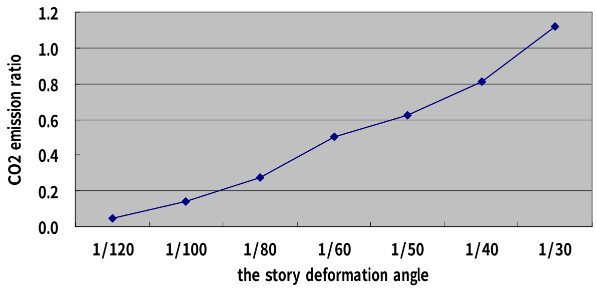

Figure 22: The relationship between the story deformation angle and the CO_2 emission ratio

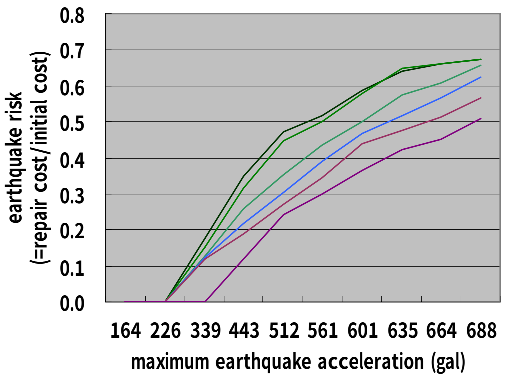

Figure 23: The seismic loss function of the cost

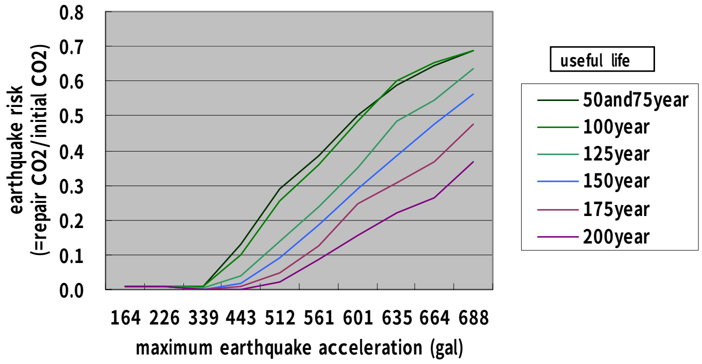

Figure 24: The seismic loss function of the CO_2 emission

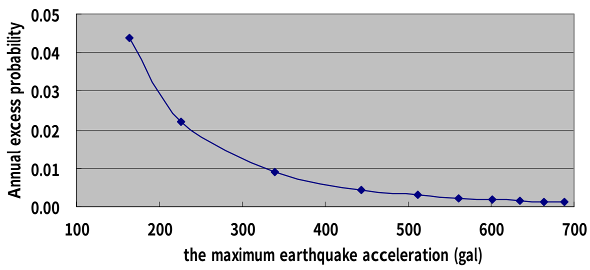

Figure 25: The seismic hazard curve

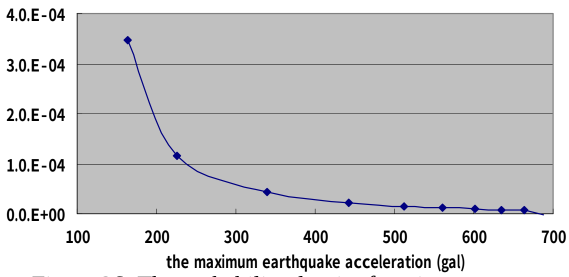

Figure 26: The probability density function

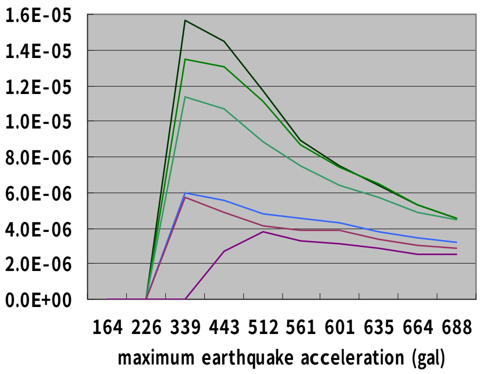

Figure 27: The annual seismic risk density of the cost

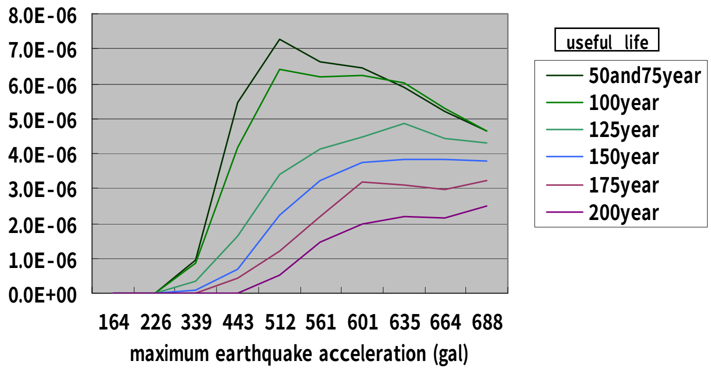

Figure 28: The annual seismic risk density of CO_2 emission

CALCULATION OF LCC AND $LCCO_2$ DURING THE EVALUATION PERIOD

With regard to LCC, the ratio of the operational cost (electrical power, gas, water system, equipment control, cleaning) for one year with respect to the initial cost for each useful life is 0.03. Further, the ratio of the demolition cost is 0.13. With regard to $LCCO_2$, the ratio of the operational CO_2 emission (electrical power, gas) for one year with respect to the initial CO_2 emission for each useful life is 0.04. Further, the ratio of demolition CO_2 emission is 0.06 (e.g., Kenya OKA 2000).LCC and $LCCO_2$ are calculated for an evaluation period of 250 and 500 years, respectively. The items of LCC and $LCCO_2$ for each evaluation period are shown in Table 2 to Table 5 and in Figure 29 to Figure 32. As a standard, for a useful life of 50 years, the value of the initial cost and initial CO_2 emission is considered as 1 each. The repair cost and the repair CO_2 emission are calculated by multiplying the area of the annual seismic risk density with the evaluation period. The initial cost and initial CO_2 emission and the demolition cost and demolition CO_2 emission are calculated by multiplying the number of new constructions and demolitions, respectively, during the evaluation period. The optimum useful life for each evaluation period is shown in Figure 33.

Comprehensive Evaluation Method For Both LCC And LCCO$_2$

It is difficult to compare both LCC and LCCO$_2$ because of different dimension. This paper proposes a new evaluation method, TLCC that employs a refund tax of x% for the initial cost based on the ratio of LCCO$_2$ reduction.

TLCC is calculated by using LCC and LCCO$_2$ for each useful life. Here, LCCO$_2$ (50) represents LCCO$_2$ for a useful life of 50 years, LCCO$_2$ (t) represents LCCO$_2$ for a given useful life t, LCC (t) represents LCC for a given useful life t, and TLCC (t) represents LCC considered along with LCCO$_2$ for each useful life.

The calculation results of TLCC for evaluation periods of 250 and 500 years are shown in Figure 33 and Figure 34, respectively.

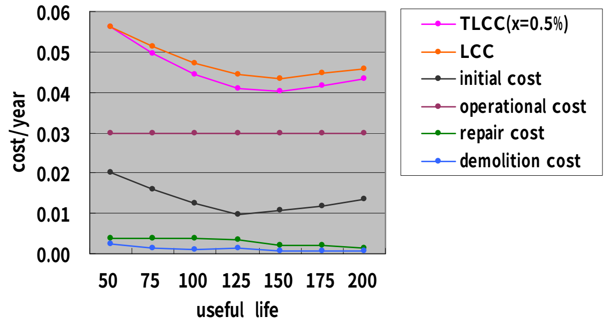

Figure 29: The items of LCC for evaluation period of 250 years

Table 2:
The items of LCC for evaluation period of 250 years

useful life(year)	50	75	100	125	150	175	200
initial cost/time	1.0	1.0	1.0	1.2	1.3	1.5	1.7
number of times	5	4	3	2	2	2	2
initial cost	5.0	4.0	3.1	2.4	2.7	2.9	3.4
initial cost/year	0.020	0.016	0.013	0.010	0.011	0.012	0.014
operational cost/year	0.03	0.03	0.03	0.03	0.03	0.03	0.03
operational cost	7.5	7.5	7.5	7.5	7.5	7.5	7.5
repair cost/year	0.0038	0.0038	0.0037	0.0036	0.0022	0.0022	0.0015
repair cost	1.0	1.0	0.9	0.9	0.6	0.6	0.4
demolition cost/time	0.13	0.13	0.13	0.16	0.17	0.19	0.22
number of times	5	3	2	2	1	1	1
demolition cost	0.6	0.4	0.3	0.3	0.2	0.2	0.2
demolition cost/year	0.003	0.002	0.001	0.001	0.001	0.001	0.001
LCC	14.1	12.8	11.8	11.1	10.9	11.2	11.4
LCC/year	0.0563	0.0513	0.0472	0.0445	0.0434	0.0446	0.0458
TLCC/year(x=0.5%)	0.0563	0.0496	0.0445	0.0409	0.0401	0.0417	0.0435

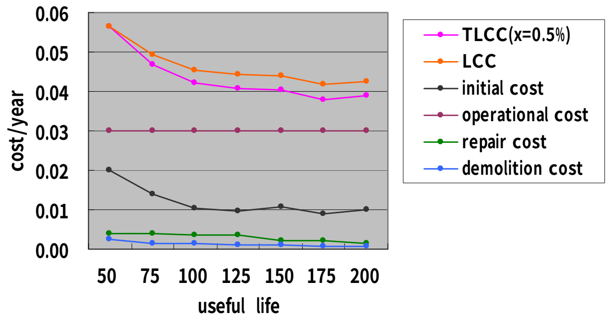

Figure 30: The items of LCC for evaluation period of 500 years

Table 3:
The items of LCC for evaluation period of 500 years

useful life(year)	50	75	100	125	150	175	200
initial cost/time	1.0	1.0	1.0	1.2	1.3	1.5	1.7
number of times	10	7	5	4	4	3	3
initial cost	10.0	7.0	5.2	4.9	5.3	4.4	5.1
initial cost/year	0.020	0.014	0.010	0.010	0.011	0.009	0.010
operational cost/year	0.03	0.03	0.03	0.03	0.03	0.03	0.03
operational cost	14.9	14.9	14.9	14.9	14.9	14.9	14.9
repair cost/year	0.0038	0.0038	0.0037	0.0036	0.0022	0.0022	0.0015
repair cost	1.9	1.9	1.9	1.8	1.1	1.1	0.8
demolition cost/time	0.13	0.13	0.13	0.16	0.17	0.19	0.22
number of times	10	6	5	4	3	2	2
demolition cost	1.3	0.8	0.7	0.6	0.5	0.4	0.4
demolition cost/year	0.0026	0.0015	0.0013	0.0012	0.0010	0.0008	0.0009
LCC	28.1	24.6	22.7	22.2	21.9	20.9	21.2
LCC/year	0.0563	0.0493	0.0454	0.0445	0.0438	0.0417	0.0424
TLCC/year(x=0.1%)	0.0563	0.0469	0.0421	0.0409	0.0404	0.0380	0.0391

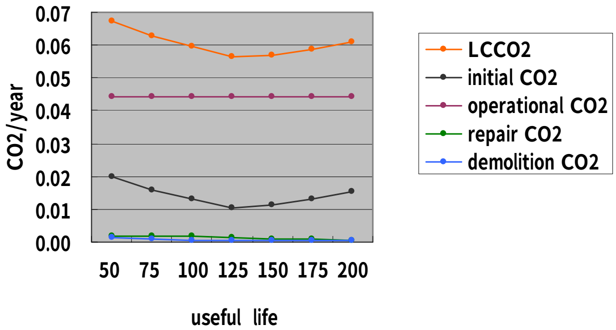

Figure 31: The items of LCCO$_2$ for evaluation period of 250 years

Table 4:
The items of LCCO$_2$ for evaluation period of 250 years

useful life(year)	50	75	100	125	150	175	200
initial CO2/time	1.0	1.0	1.1	1.3	1.4	1.6	1.9
number of times	5	4	3	2	2	2	2
initial CO2	5.0	4.0	3.2	2.6	2.8	3.2	3.8
initial CO2/year	0.020	0.016	0.013	0.010	0.011	0.013	0.015
operational CO2/year	0.04	0.04	0.04	0.04	0.04	0.04	0.04
operational CO2	11.1	11.1	11.1	11.1	11.1	11.1	11.1
repair CO2/year	0.0019	0.0019	0.0018	0.0013	0.0011	0.0009	0.0006
repair CO2	0.47	0.47	0.45	0.33	0.26	0.22	0.15
demolition CO2/time	0.06	0.06	0.07	0.08	0.09	0.10	0.12
number of times	5	3	2	2	1	1	1
demolition CO2/time	0.31	0.19	0.13	0.16	0.09	0.10	0.12
demolition CO2/year	0.001	0.001	0.001	0.001	0.000	0.000	0.000
LCCO2	16.9	15.7	14.9	14.2	14.3	14.6	15.2
LCCO2/year	0.067	0.063	0.060	0.057	0.057	0.059	0.061

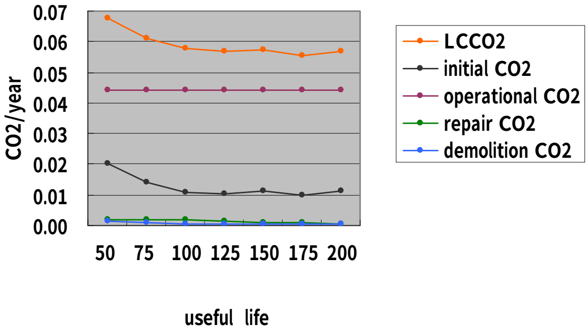

Figure 32: The items of $LCCO_2$ for evaluation period of 500 years

Table 5:
The items of $LCCO_2$ for evaluation period of 500 years

useful life(year)	50	75	100	125	150	175	200
initial CO2/time	1.0	1.0	1.1	1.3	1.4	1.6	1.9
number of times	10	7	5	4	4	3	3
initial CO2	10.0	7.0	5.4	5.1	5.7	4.8	5.7
initial CO2/year	0.020	0.014	0.011	0.010	0.011	0.010	0.011
operational CO2/yea	0.04	0.04	0.04	0.04	0.04	0.04	0.04
operational CO2	22.2	22.2	22.2	22.2	22.2	22.2	22.2
repair CO2/year	0.0019	0.0019	0.0018	0.0013	0.0011	0.0009	0.0006
repair CO2	0.9	0.9	0.9	0.7	0.5	0.4	0.3
demolition CO2/time	0.06	0.06	0.07	0.08	0.09	0.10	0.12
number of times	10	6	5	4	3	2	2
demolition CO2/time	0.62	0.37	0.34	0.32	0.26	0.20	0.24
demolition CO2/year	0.001	0.001	0.001	0.001	0.001	0.000	0.000
LCCO2	33.7	30.5	28.8	28.3	28.6	27.7	28.5
LCCO2/year	0.067	0.061	0.058	0.057	0.057	0.055	0.057

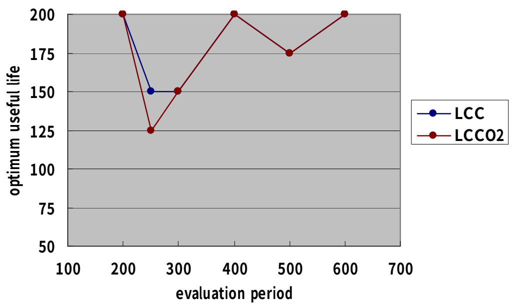

Figure 33: The optimum useful life for each evaluation period

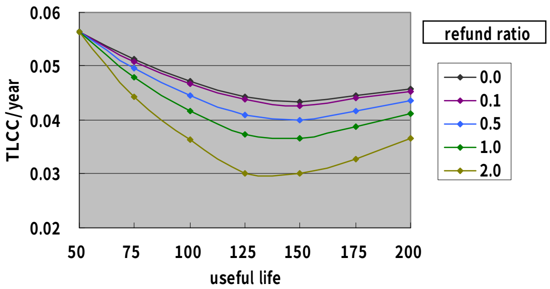

Figure 34: The calculation results of TLCC for evaluation period of 250 years

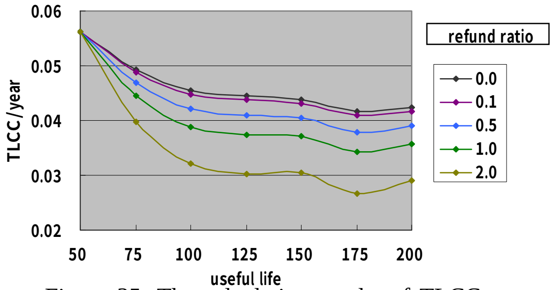

Figure 35: The calculation results of TLCC for evaluation period of 500 years

CONCLUSIONS

The magnitude of the cost and CO_2 decrease in the following order of the life cycle: operational, initial, repair, demolition. In order to reduce quantity of LCC and $LCCO_2$, the measurements in operational stage are effective. For example, the measurements are improvements in the airtightness and heatproofing of the building and energy conservation. Both the cost and CO_2 emission have comparable values that are independent of the useful life in the operation, repair and demolition stages. On the other hand, the initial cost and initial CO_2 emission exhibit a parabolic behavior with respect to the useful life. Therefore, the initial cost or the initial CO_2 emission has a significant effect on LCC or $LCCO_2$. These values change considerably up to a useful life of 100 years. The change gradually becomes smaller after 125 years, and then, it remains almost constant. If the useful life is short, the frequency of rebuilding increases, and both repair cost and repair CO_2 emission increase because buildings are designed to withstand small earthquakes. The optimum useful life is different for each evaluation period. However, if the useful life is 175 or 200 years, a large amount of LCC and $LCCO_2$ can be reduced.

In this paper, the cost and CO_2 emission during repair and demolition are calculated based on the ratios for the initial cost and the initial CO_2 emission without considering each difference for the useful life. Therefore, the optimum useful life of LCC and $LCCO_2$ are almost similar. Hence, the optimum useful life of TLCC calculated from (A) is similar to that of LCC. In the future, it is expected that a more detailed study on LCC and $LCCO_2$ for ascertaining the useful life would reveal the difference between TLCC and LCC in greater detail, and the evaluation of TLCC would prove to be more effective. In order to improve the precision of LCC and $LCCO_2$, earthquake response analysis should be performed with a shorter interval for the useful life. If the useful life is greater than or equal to 150 years, the initial cost increases with respect to the bearing-force increase ratio. Therefore, other seismic design methods (seismic isolation structure, damping structure, braced framing structure, and so on) should be introduced, and the cost and CO_2 emission require re-estimation.

In this study, the safety of human life is considered as the objective; however, in the future, it is also necessary to study about preserving the functionality of the building.

REFERENCES (All in Japanese except Kazutoshi Tsutsumi (2002))

Masaru HOSIYA and Takaaki NAKAMURA (2002). “Seismic Risk Management of Building”, SANKAIDO

Kazutoshi TSUTSUMI (1999). “A Response Displacement Estimation Method for One Lumped Mass RC Models by Identifying Hysteresis Energy Coefficient”, Journal of Structural Engineering, AIJ, pp.157-161

AIJ (1996). “Recommendations for Loads on Buildings”

KOZO SOFT (2002). “BUILD.WAVE2000”

Kazutoshi TSUTSUMI (2002). “A Development of the Seismic Performance Evaluation System by Utilizing Fuzzy Theory”, The Ninth International Conference on Computing in Civil and Building Engineering, April 2002, Taipei, Taiwan, pp.91-96

Akira WADA and Mamoru IWATA (1998) “A Design Method of Control Damage of Buildings”, MARUZEN

Takeshi KANEKO and Kazutoshi TSUTSUMI(2005)“A Study on the Optimum Member Section Design Method in consideration of CO_2 Emissions in Building Design” Summaries of Technical Papers of Annual Meeting, AIJ.Japan, A-2,497-498

Jyun KANDA (2000) http://ssweb.k.u-tokyo.ac.jp/indexe.htm

Kenya OKA (2000) "Method of Calculation of $LCCO_2$” KENTIKU GIJYUTU.JAPAN, pp.110-116