Investigation into Seismic Performance of For-Profit Buildings in terms of Economics

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ABSTRACT :

For-profit buildings in cities such as commercial buildings for rent play a significant role in urban economic activities, and their failure would cause enormous economic loss. To reduce such losses in the event of a severe earthquake, it is necessary to clarify the damage limits of for-profit buildings in terms of business continuity.
This paper investigates the seismic performance of for-profit buildings in terms of economics by introducing an economic damage index, and also discusses the following issues: 1) Permissible repair cost for buildings derived from property information such as construction cost, projected revenues and discount rate, and a resulting "damage limit" for failure in business continuity. 2) Upper-bound investment for earthquake resistance derived from a balance between the cost of earthquake resistance and its benefits, and resulting "inevitable damage" in terms of economics. 3) Vulnerability of urban for-profit buildings with low business risk to earthquakes, compared with suburban for-profit buildings with high business risk.

KEYWORDS: Economic damage index, Repair cost, Damage limit, Inevitable damage, For-profit buildings, Economic seismic performance

1. INTRODUCTION

The Great Hanshin-Awaji Earthquake of 1995 caused economic losses totaling 10 trillion yen. Recently, the Japanese government announced that if an earthquake were to hit Tokyo directly, the economic loss could be as high as 112 trillion yen—around 1.4 times Japan's annual budget. In general, seismic designs primarily strives to protect life against the rarely occurring severe earthquakes. Seismic designs rarely set design targets or damage limits explicitly for reducing economic losses. In order to reduce expected economic losses to be suffered from future severe earthquakes, it is necessary to establish a seismic design method that aims at securing the restorability of building structures supporting economic activities.
For-profit buildings in large cities such as commercial buildings for rent play a significant role in urban economic activities, and their failure would cause enormous economic loss. To reduce such losses in the event of a severe earthquake, it is necessary to clarify the damage limits of for-profit buildings in terms of business continuity.

This paper investigates the seismic performance of for-profit buildings in terms of economics by introducing an economic damage index that gives limit repair cost and inevitable repair cost, and discusses the vulnerability of urban for-profit buildings with a low business risk, compared with suburban for-profit buildings with a high business risk.

2. EVALUATION OF SEISMIC PERFORMANCE IN TERMS OF ECONOMICS

2.1. For-profit buildings

Buildings in cities play an important role in economic activities. In particular, earning assets providing fields of economic activities such as commercial buildings for rent (i.e. for-profit buildings) have the following significant features:

1. They support economic activities, and their failure would cause huge economic loss on account of the

ripple effect.

2. The asset value is calculated on the basis of its profitability (Fig. 1). If excessive repair cost resulting from a severe earthquake reduced profitability, the building could fail economically.
3. The number of for-profit buildings has been increasing on account of the recent trend of the securitization of real estate in Japan.

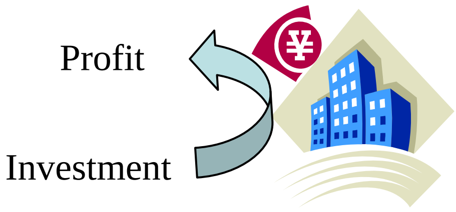


Figure 1 For-profit Building

Table 2.1 Seismic-Performance Evaluation Procedure

	Investigation	Evaluation
Structural	Design Ground Motion ⇨ Damage ⇨ Repair Cost	Economic Severity
Economic	Business Risk ⇨ Profitability	

Seismic evaluation of for-profit buildings in terms of economics is important in order to mitigate economic losses that would be suffered during severe earthquakes.

Recently, the asset values of for-profit buildings are frequently evaluated based on the DCF method. The DCF method calculates the asset values as a summation of annual net profit over a holding period.

$$V = \sum_{i=1}^{n} \frac{a_i}{(1+r)^i} + \frac{1}{(1+r)^n} \cdot Vs \qquad (2.1)$$

Where, n: assumed holding period, Vs: profit at sale in n years, a_i : annual net profit, r: discount rate.
Note that each annual profit is discounted back to the present value at the discount rate.

That is to say, under the DCF method, the value of a building is defined as the total sum of profits generated by the building during its in-service period, including profit at sale. Assuming that the construction cost is "A", if construction cost is considered to be an investment and Eqn. 2.2 is established, this building makes a profit, in other words, it is judged to be a building that has economic existence value.

$$\text{Investment } A < \text{Value } V \qquad (2.2)$$

On the other hand, if an earthquake during the holding period of the building causes economic losses such as repair cost, value V is reduced accordingly. If, as a result, the inequality sign in Eqn. 2.2 is reversed and becomes equivalent to Eqn. 2.3, the building will lose its economic value.

$$\text{Investment } A > \text{Value } V - \text{Economic Loss} \qquad (2.3)$$

2.2. Seismic performance evaluation based on repair cost

The procedure for seismic performance evaluation discussed in this paper is shown in Table 2.1. The evaluation procedure consists of two stages: the investigation stage, and the evaluation stage. In the investigation stage, structural and economic investigations are carried out; i.e., damage provide by design ground motion is predicted and profitability is analyzed based on the expected business risk and profit. In the evaluation stage, predicted earthquake damage is evaluated against economic severity, based on the result of a profitability analysis. Therefore, in the seismic-performance evaluation procedure, damage is converted into economic loss, and evaluated from an economics point of view.

After the Loma Prieta earthquake in 1989 and the Northridge earthquake in 1994 in the United States, Vision2000 and FEMA356 (Federal Emergency Management Agency), which were first-generation guidelines

for performance-based seismic design intended not only to safeguard life safety but also maintain functionality, were documented. They were compiled taking into account the lesson learned that big cities along the West Coast suffered enormous economic losses from these earthquakes.
ACT (Applied Technology Council) and PEER (Pacific Earthquake Engineering Research Center) are currently developing next-generation guidelines for performance-based seismic design. In these guidelines, "repair costs" and "downtime" due to earthquakes are defined as an important index for evaluating the seismic performance of buildings.[1,2]

On the other hand, people in the economic world place great store in a concept referred to as "PML" (Probable Maximum Loss). PML is an index for evaluating the asset value of a piece of real estate against a seismic risk. PML was originally an index used for fire insurance, but has also come to be used in risk evaluations of damage caused by a large earthquake.

Repair costs resulting from earthquakes is important information for decision-makers who need performance descriptions that relate more directly to economic loss. It has become a tendency throughout the world to develop a rational design method including repair costs as one of the seismic performance indices for structures.

The economic damage index presented in the next section is designed to evaluate the economic severity of structural damage against economic failure of for-profit buildings in the evaluation stage shown in Table 2.1. As discussed in Section 2.1, the value of a for-profit building is defined by profitability, and if repair cost is excessive, the building will lose profitability and fail economically.

3. ECONOMIC DAMAGE INDEX

The value of a for-profit building that incurred repair cost "B" at year m, is calculated as follows,

$$V' = \sum_{i=1}^{n} \frac{a_i}{(1+r)^i} + \frac{1}{(1+r)^n} \cdot V_S - \frac{B}{(1+r)^m} \tag{3.1}$$

In Eqn. 3.1, the asset value defined in Eqn. 2.1 is reduced by repair cost B. Note that the repair cost B is also discounted back to the present value at discount rate, r.

On the other hand, the following economic index, "Return on Investment Ratio", is routinely used to analyze the profitability of projects in the business environment.

$$\text{Return on Investment Ratio} = \frac{Profit}{Investment} \tag{3.2}$$

If the index is below 1, the project is deemed to have lost profitability. Assuming construction cost A as an investment, and profit is the value defined by Eqn. 3.1, the following economic damage index is obtained.

$$I = \frac{V'}{A} = \left[\sum_{i=1}^{n} \frac{a_i}{(1+r)^i} + \frac{1}{(1+r)^n} \cdot V_S - \frac{B}{(1+r)^m} \right] \frac{1}{A} \tag{3.3}$$

If repair cost B of a for-profit building is excessive and index I is below 1, the building is deemed to have lost profitability and be an economic loss. Our proposed index introduces the concept of real estate evaluation based on the DCF method that rapidly gained popularity in the wake of the collapse of the economic bubble in Japan, and conforms to the methods for profitability analysis in economics.
The following assumptions has been made for the sake of simplicity:

1. Holding period n is 30 years, which is the average life span of buildings in Japan[3]
2. Each annual net profit stays constant over the holding period ($a_i = a$)
3. Profit at sale Vs is calculated by Eqn. 3.4.

$$Vs = \chi \cdot V_0 \tag{3.4}$$

Where, Vo: value of buildings without social and physical deterioration as defined in Eqn. 3.5, χ:reduction factor resulting from social and physical deterioration, which in this paper has been assumed to be 0.7 in 30 years.[4]

$$V_0 = \sum_{i=1}^{\infty} \frac{a}{(1+r)^i} = \frac{a}{r} \tag{3.5}$$

In the next section, the following economic models are used to calculate "Repair Cost, B", "Construction Cost, A", and "Annual Net Profit, a". It is difficult to calculate these exactly, therefore, simple models, that can demonstrate the characteristics of increase and decrease behavior due to dominant factors, have been adopted.

Economic Models

(1) Repair Cost, B

$$\begin{aligned} B &= 0 & \mu \le 1 \\ B &= (\mu - 1.0) A \times q & 1 \le \mu \le 5 \\ B &= A & 5 \le \mu \end{aligned}$$

$$\mu = \left\{ \left(\frac{1}{C_B} \right)^2 + 1 \right\} \frac{1}{2}$$

(2)Construction Cost , A

$$A = F \cdot k \times \beta$$

$$\beta = p \times C_B + (1 - 0.3 \times p)$$

(3)Annual Net Profit, a

$$a = F \cdot k \times \gamma \tag{3.6}$$

Notations

A:Construction Cost B:Repair Cost,
C_B: Base Shear Coefficient
μ :Ductility Factor, F:Total Floor Area,
k:Unit Price per Unit Area
β : Rate of Increase due to C_B
γ :Coefficient of Profit
q:Rate of Increase of Repair Cost (=0.25)
p:Rate of Increase of Earthquake Proofing Cost (=0.256)

4. INVESTIGATION INTO ECONOMIC SEISMIC PERFORMANCE

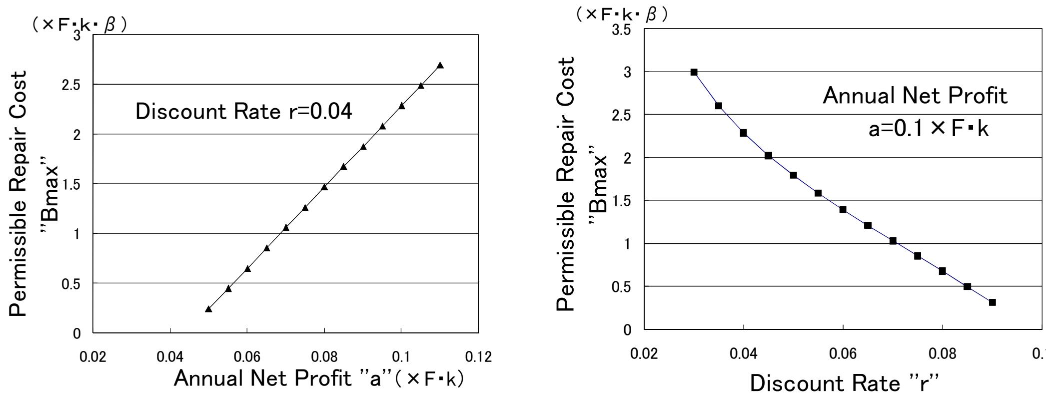
4.1. Permissible Repair cost

We have proposed an index for economic damage and said that a for-profit building would lose its economic value if this index were 1 or less. Repair cost limit is determined by stating that Eqn. 3.3 = 1, so that the permissible repair cost in regard to the loss of economic value can be derived as shown in Eqn. 4.1. A structure that has a small *Bmax* tends to lose its economic value easily, that is, the structure is vulnerable to damage from an economic perspective, not from a structural mechanics viewpoint.

$$B\max = \left[\sum_{i=1}^{n} \frac{a_i}{(1+r)^i} + \frac{1}{(1+r)^n} \cdot V_S - A \right] \times (1+r)^m \tag{4.1}$$

Fig. 2 shows the effect of annual net profit and discount rate on the permissible repair cost. The discount rate is related to business risk. If the business risk is high, the discount rate is set to be large. Fig. 2 indicates that permissible repair cost *Bmax* tends to be large when the annual net profit is high and the business risk is low, in other words, *Bmax* becomes larger when the building is more advantageous from an economic perspective.

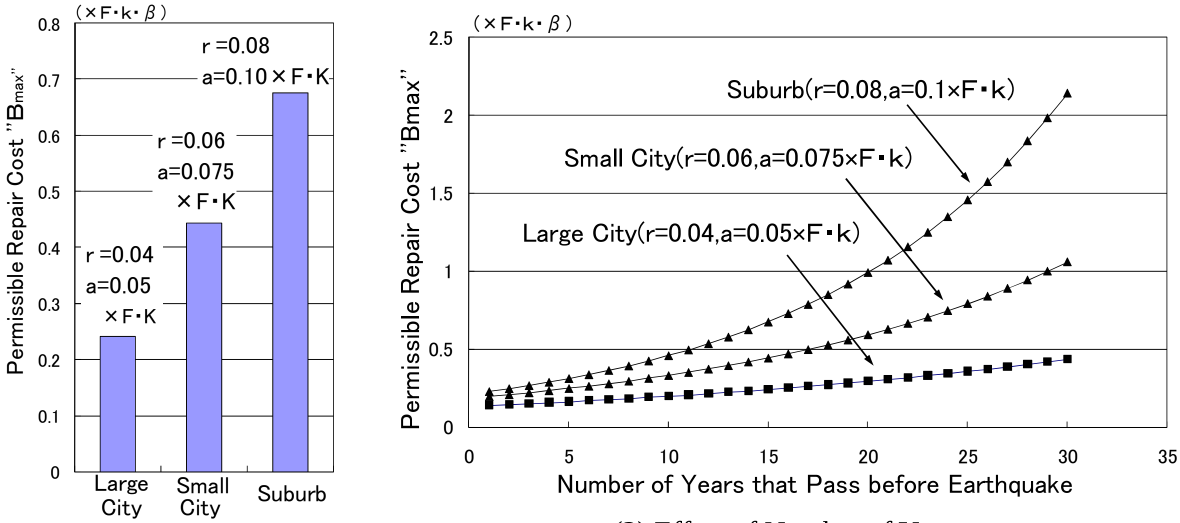
From the principle of high risk-high return, when profit is large, the discount rate is also set to be large, and conversely, when profit is small, the discount rate is also set to be small. In general, in urban areas with a low business risk, the discount rate is set at about 4%, whereas in suburban areas with a high business risk, it is set at about 8% in Japan.[5]



(1)Effect of Annual Net Profit

(2) Effect of Discount Rate

Figure 2 Effects of Annual Net Profit and Discount Rate on Permissible Repair Cost



(1)Comparison between Three Cases

(2) Effect of Number of Years

Figure 3 Permissible Repair Cost for Three Cases with Different Business Risk

Three cases, from a large city, a small city and a suburb, as shown in Table 4.1, are examined here. The discount rate was defined to be small in the large city with a low business risk, and high in the suburb with a high business risk. The annual net profit was set to be small in the large city with a low business risk (low risk and low return) and large in the suburb with a high business risk (high risk and high return), so that value *Vo* of for-profit buildings without social and physical deterioration, as given in Eqn. 3.5, is the same in each of these cases.

Fig. 3 (1) shows the result of permissible repair cost at year 15, as calculated for each case. Permissible repair cost for buildings in the large city is much smaller than that for those in the small city and the suburb. As shown in Fig. 3 (2), the difference becomes more remarkable in relation to the number of years that pass before an earthquake occurs.

The results indicate that urban buildings are considered to be buildings vulnerable to damage when seen economically. If the buildings are damaged by an earthquake, their profitability is reduced and they easily lose their economic functionality. This is because an urban for-profit building provides small business risk and little economic preparedness toward sudden risks such as earthquakes.

Table 4.1 Three Cases with Different Business Risks

		Large City (Low Risk)	Small City (Medium Risk)	Suburb (High Risk)
Discount Rate r		0. 04	0. 06	0. 08
Annual Net Profit a	Eqn.3.6	0. 05×F· k	0. 075×F· k	0. 1×F· k
value $Vo = a / r$	Eqn.3.5	1. 25×F· k		

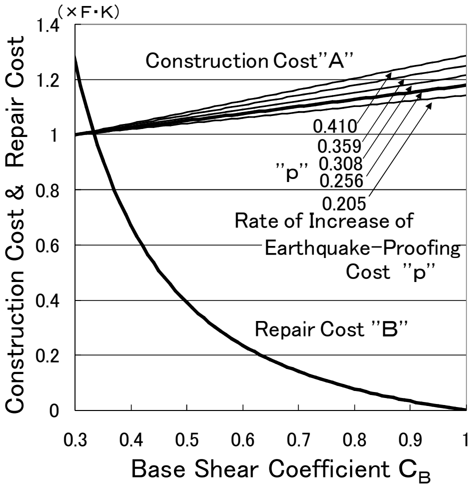
F: Total floor area、k: Unit price per unit area

4.2. Inevitable Repair Cost

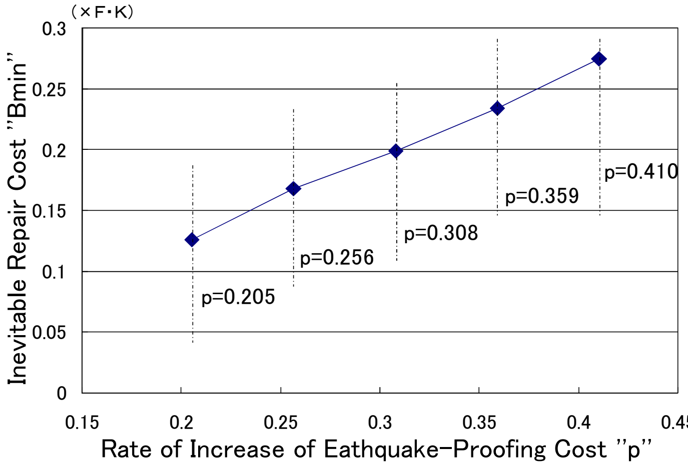
The proposed index defined in Eqn. 3.3, increases with base shear coefficient C_B, but decreases after a certain point. Investment in earthquake-proofing is most suitable when the value of the index is at its highest. Therefore, further investment is an unprofitable action that reduces its value. It is difficult to make any further investment in a financially viable building that attaches greater importance to cost efficiency. In other words, base shear coefficient has an upper limit in terms of economics. On the other hand, repair costs generally decrease with increasing base shear coefficient, thus, repair cost consequently have a lower limit. The limit is referred to as "inevitable repair cost *Bmin*" hereafter. A structure with large inevitable repair cost tends to suffer economic damage easily.

Here, base shear coefficient C_B is changed from 0.3 to 1.0 in increments of 0.01 to calculate *Bmin*, which is the value of repair cost *B* when the value of index *I* is at its highest. For reference, when C_B reaches 1.0 or more at the highest value of index *I,* any higher C_B is unrealistic in any for-profit building, except special buildings. Consequently, we use the value of repair cost *B* when the value of index *I* is at its highest in a range of C_B = 1.0 or less, as that of inevitable repair cost *Bmin*.

Fig. 4 (2) shows the transition of inevitable repair cost *Bmin*, when the rate of increase of earthquake-proofing cost, *p* (the linear gradient in Fig.4(1)), varies as shown in Fig. 4 (1). *Bmin* becomes larger with the increase in the rate, *p*, in other words, *Bmin* becomes larger with the decrease of the investment efficiency in earthquake-proofing.

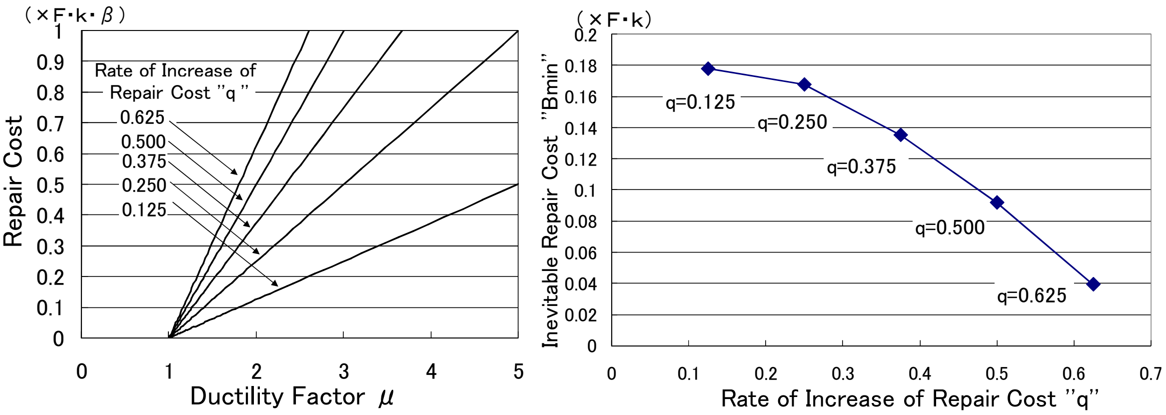


(1) Rate of Increase of Earthquake-Proofing Cost



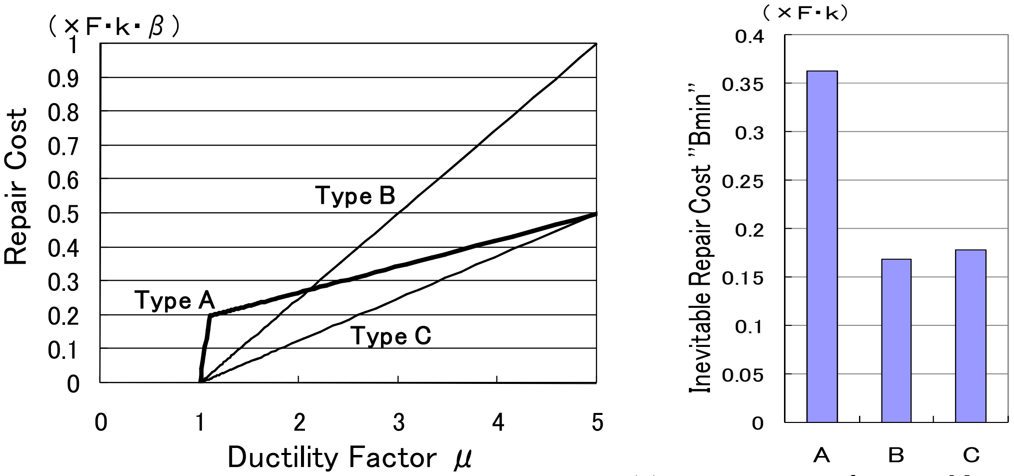
(2) Transition of Inevitable Repair Cost

Figure 4 Effect of Rate of Increase of Earthquake-Proofing Cost on Inevitable Repair Cost



(1) Rate of Increase of Repair Cost (2) Transition of Inevitable Repair Cost

Figure 5 Effect of Rate of Increase of Repair Cost on Inevitable Repair Cost



(1)Three Types of Increase in Repair Cost (2) Comparison of Inevitable Repair Cost between Three Types

Figure 6 Inevitable Repair Cost of Three Types of Increase in Repair Cost

Fig. 5 (2) shows the transition of inevitable repair cost *Bmin*, when the rate of increase of repair cost, *q* (the linear gradient in Fig.5(1)), varies as shown in Fig. 5 (1). *Bmin* becomes smaller with the increase in the rate. *Bmin* can be reduced when there is a high repair cost at the same ductility factor. This result seems to be strange. The increase in the rate, however, leads to the increase of earthquake-proofing investment efficiency, thus resulting in a smaller *Bmin*.

Fig. 6 (2) compares inevitable repair cost *Bmin* among three types of increase in repair cost (see Fig. 6 (1)). Rates of increase for Type B and C are constant, at 0.25 and 0.125, respectively. The repair cost of these types increases proportionally with the ductility factor. On the other hand, the repair cost of Type A instantaneously reaches $0.2 \times F \cdot k \cdot \beta$ at a ductility factor of 1, and subsequently the rate of increase becomes smaller. From Fig. 6 (2), we can see that inevitable repair cost *Bmin* of Type A is significantly larger than that of Type B and C. This suggests that *Bmin* becomes larger when repair work requires a certain cost, regardless of the severity of the damage.

Repairs include costs for direct work, such as repairs to cracks and mortar filling in RC structures, and for preparatory work necessary for repairs (e.g., surveying, temporary construction, removal and restoration work for finishes, works for protection of floors and walls, etc.). An analysis of actual repairs to buildings damaged during the Great Hanshin-Awaji Earthquake reveals that the proportion of costs for preparatory work to total repair costs is by no means small. Preparatory work is required before starting direct work. If the area for repairs is the same size, the preparatory work for it require the same cost, regardless of the intensity of the damage. Type A is considered to represent the upward trend of repair costs with the cost of preparatory work becoming higher.

Cases with increased costs of preparatory works include when temporary scaffolding is needed to repair high-rise structures, when repairs are made during business hours—requiring many temporary partitions, when high-grade finishes necessitate higher costs of removal and restoration for surveys and repairs, and when costs are incurred in ensuring workspace and a material yard in close proximity to the structures being repaired.

The above factors indicate that the inevitable costs of repairing urban buildings, with more constraints to their restoration, tend to be higher.

5. CONCLUSION

An economic damage index was proposed to properly evaluate the economic severity of for-profit buildings damaged by an earthquake. This index is: 1) applicable to structures that have different earthquake resistances and asset values (profitability), 2) enables the economic analysis of seismic performance, such as "ability to withstand damage" and "vulnerability to damage" and, 3) has continuity (linking earthquake engineering and economics), using indexes and measures that are generally used in economics such as the DCF method and profitability analysis.

Based on the proposed index, we have reviewed the amount of allowable damage limit defined from an economic perspective (i.e., permissible repair cost), and the amount of damage limit that cannot be reduced on account of earthquake-proofing investment efficiency (i.e., inevitable repair cost), and have obtained the following findings:

1) For-profit buildings with low business risk and high profit lead to a higher permissible repair cost.
2) The permissible repair cost of an urban for-profit building with low risk and low return tends to be smaller than that of a suburban building with high risk and high return.
3) The inevitable repair cost of buildings with higher earthquake-proofing investment efficiency tends to become smaller.
4) The inevitable repair cost of buildings with more constraints on repair work and with higher costs for preparatory work tends to be larger.
5) From an economic perspective, for-profit buildings in large cities are "buildings vulnerable to damage" that easily reduce their profitability and fail economically, and are considered "buildings that suffer damage easily."

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