Lifecycle Cost Concept of Existing Buildings Based on The Seismic Performance

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LIFECYCLE COST CONCEPT Of EXISTING BUILDINGS BASED ON THE SEISMICPERFORMANCE

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Abstract : In Japan, almost all of buildings were considered as "consumables". However steel products will run short in these 40 years in the world. The giant industrial waste will break out when reinforced concrete buildings are pulled down. Considering such conditions the new concept of durability of existing buildings is proposed here. This paper is discussed about the life cycle cost and asset management of existing reinforced concrete buildings based on the seismic performance. Extending the life of existing buildings to more than one hundred years, the occurrence possibility of giant earthquake is discussed and the installation of the base isolation system to existing buildings is proposed. Through the case analytical study of dynamic response to the buildings due to giant earthquake inputs the damage grade was evaluated among three cases of buildings; non-strengthened building, seismic strengthened building and base isolation building. The cost evaluation for such seismic device and running cost was discussed. The ratio of the initial construction cost to running cost of building showed that the building with high construction cost is much smaller than total life cycle cost to the building with cheaper initial construction cost from the viewpoint of the concept of asset management. Such running cost is composed of reconditioning, administration, effective management and preservation.In Japan usually the initial cost (construction cost) occupies around thirty percent of total life cycle cost (initial cost + running cost) Through the analytical process, following recommendations were proposed.

(1) The installation of base isolation system to existing building is much effective to the viewpoint of asset management of existing buildings.

(2) The damage of existing building which was based on the old seismic design code due to earthquake caused additional disadvantageous situation such as repair works and business loss during the repair works.

KEYWORDS office buildings ,life cycle cost, earthquake damage ,seismic approach,

1. INTRODUCTION

Up to now seismic design concept of buildings is based on the concept that buildings don't collapse and never cause human damage against giant earthquakes according to the Japanese design code. This means that severe damage will be allowed against giant earthquakes.

However many owners of buildings have started to think that at least the buildings would keep their functions against giant earthquakes since 1995 Kobe earthquake.

Hereupon it was important to consider that buildings should be the target of asset management including earthquake damages. The example showed here is general office building. However required performances will be changed in case of buildings; governmental office buildings, hospitals, school buildings so on in case of the building owners menu.

2. LIFE CYCLE COST APPROACH TO OFFICE BUILDINGS IN JAPAN

If required seismic performance of the building is raised up in the Fig.1. The initial cost will be also expensive. However the repair cost of the building will be much more expensive if the great earthquake will occur. In such case, the running cost includes repair and renewal cost against earthquake damage. On the

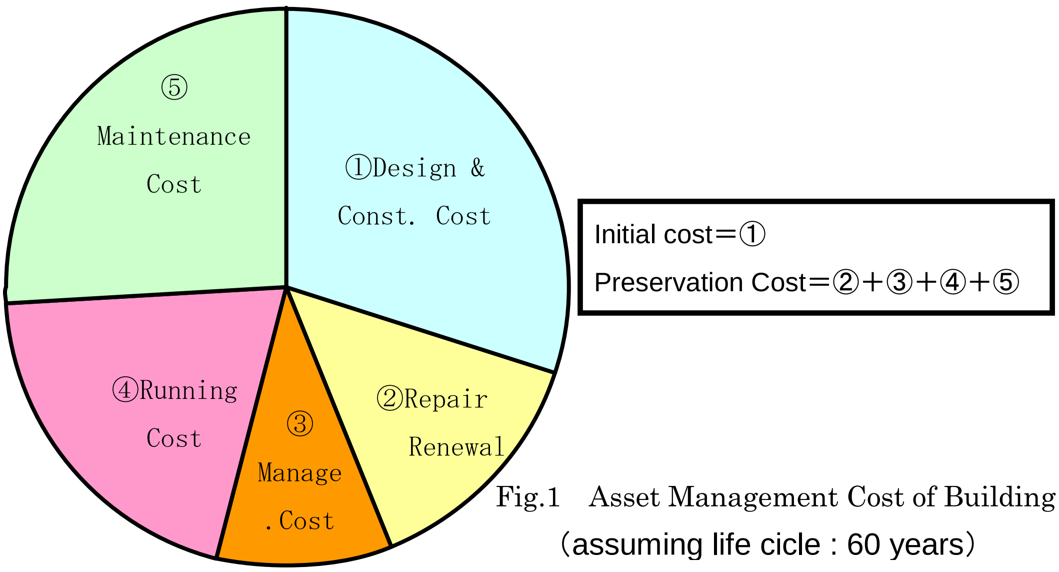

Fig.1 Asset Management Cost of Building
(assuming life cicle : 60 years)

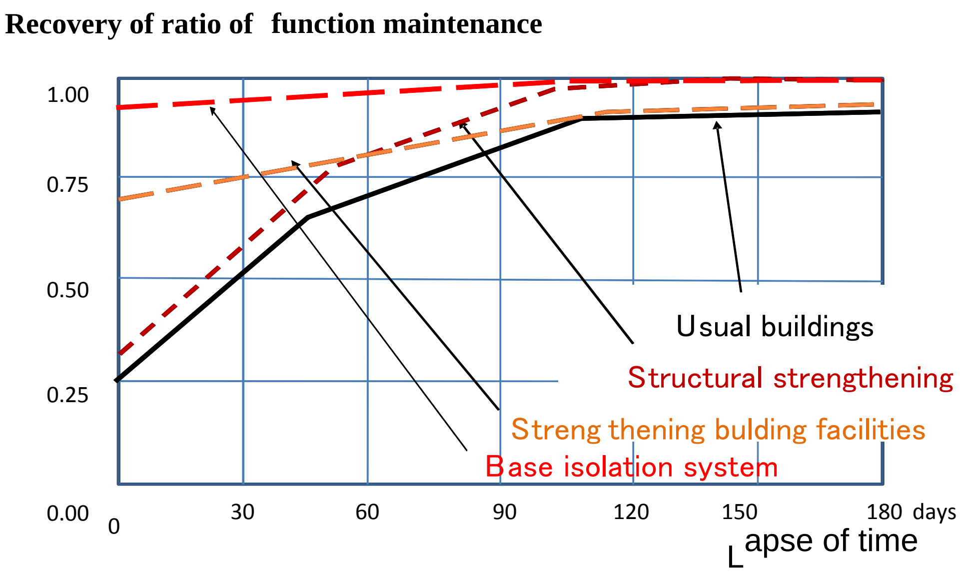

Fig.2 Recovery Curves after Earthquakes

other hand the total life cycle cost will be reduced if the seismic device is installed in the initial cost even if the initial cost will be expensive.

Until now the almost of all owners of buildings in Japan have focused the concept that initial construction cost ①. If the total cost of the building is tried to be minimized, the initial cost will be expensive because of higher grade of seismic performance. However the preservation cost (②③④⑤) can be minimized because the repair cost and the economic loss due to suspension of business during repair work.

Controlling seismic damage of buildings has strong connection to the asset management. Therefore the total asset management for building should be focused considering earthquake damage in Japan.

Business companies request strongly the never interruption of business works due to the damages of earthquakes. If they have some level of damage, they wish to reopen as soon as possible.

The Central Disaster Prevention Council, Japan Government reported the guidelines of the Business Continuity Plan against earthquake damage.

In this report, the recovery curves were shown as the concept of business continuity plan with the lapse as shown in Fig.2.

This recovery curves show the conditions of business activity and are not same as the recovery of building itself. However this Figure can be the good indicator for the preservation of business buildings.

In this Figure, four story reinforced concrete office building is the subject of analysis. The physical damage due to earthquake and building function after earthquake are evaluated. Supposed damage grade of structure is three level; medium, severe and collapse. The damage level of interior and exterior materials were supposed to be two patterns; slight or severe. If the building was damaged, it can not to be used during rehabilitation working days.

Table 1 Establishment of Repair Cost Based on the Damage Level

Damage level	Limit stage	Damage grade	Story drift angle R= δ /h	Repair cost (¥/m²)
Ⅰ	serviceability	Slight or none	1/200	0～10000
Ⅱ	Repair limit Ⅰ	Small	1/100	10000～29000
Ⅲ	Repair limit Ⅱ	Medium	1/75	29000～60000
Ⅳ	Safe limit	Severe	1/50	reconstruction
V		Collapse	—	

Table 2 Strengthening Cost of Each Method

Installation of Steel Brace System	250～300 million yen / portion
Carbon windings of column	0.8～1.0 million yen / post
Slit setting	30000～50000 yen/ m

For the evaluation of each facility of the building, the influence factors on electric supply and air conditioning were expressed numerically. If electric function ceased, office work was supposed to be stopped. If the function of air conditioning stopped, the business work supposed to be continued.

From this Figure, the grade of the recovery ratio of building function is base isolation building shows the minimum functional damage and the usual building show the largest amount of damage.

For the drawing the recovery curves in Fig. 2, the damage occurrence probability is considered with respect to the weight function from several severer situations

The base isolation building mostly never cause function stop.

In case of the building which is seismically strengthened, the amount of time elapsed for the recovery is shortened. In case that the building facilities are strengthened, the elapsed days for the recovery can be less than 90 days and such elapse days is much improved.

3. EARTHQUAKE DAMAGE AND REPAIR COST

Existing buildings are based on the old design code and caused severe damage due to Kobe earthquake (giant earthquake). The approximate calculation was done for the strengthening of such buildings in order to shut out collapse.

At the same time the cost of the restitution work after earthquake damage was estimated. During such work, the commercial pursuit will stop and it causes business loss which is calculated. The dynamic response analys shows maximum response story drift. From such response the damage grade of building can be evaluated.

Such setting up of damage degree was referred to "Seismic Performance Evaluation Standards of Reinforced Concrete Buildings", Architectural Institute of Japan.

The establishment of repair cost is shown in Table 1. Such cost is evaluated in each damage level. The damage level is judged from dynamic response analysis.

At the same time the cost of the restitution work after earthquake damage was estimated. During such work, the commercial pursuit will stop and it causes business loss which is calculated.

The approximate figure for business loss during such repair works is calculated based on the damage grade. In this case study, business loss is assumed to be ¥2200.

According to the Japan market cost of the seismic strengthening, the following Table 2 is recommended.

The building which is seismically strengthened was also evaluated its damage grade through the dynamic

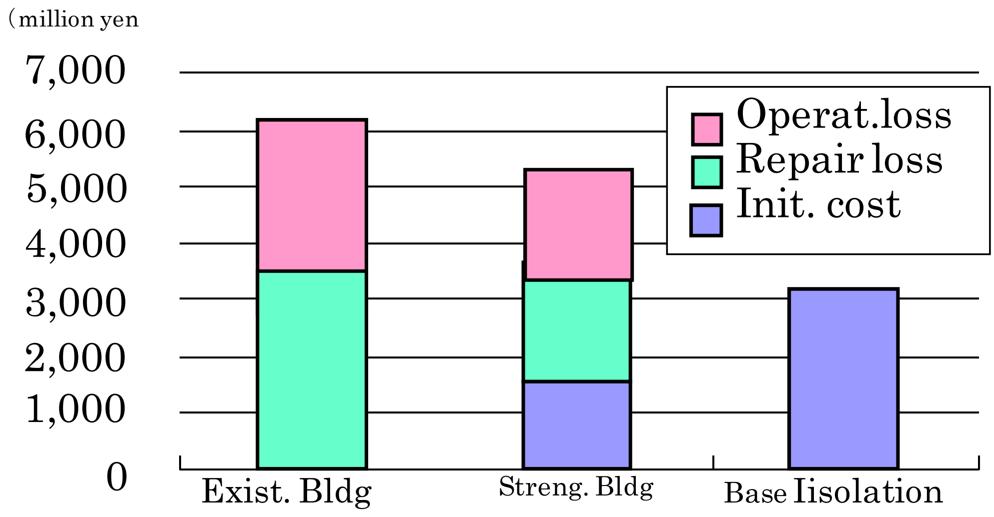

Fig.3 Approximate Costs Results in Each Case of Building

response analysis.

Earthquake response story drift of the strengthened building decreases comparing with that of existing building and accompanying with this effect, the amount of building damage and the operating loss were decreased.

For the base isolation building, additional construction cost were considered following items; the members of base isolation parts, construction cost for base isolation and additional structural device members. The rough estimate is adopted as 30,000¥/ m^2 .

The base isolation buildings never cause any damage. Recently such buildings were proved none damage through the real giant earthquake. Therefore in this case we need not consider repair cost and operating loss. This is the tremendous appeal.

Fig.3 shows that the base isolation building is the minimum total cost and the second is the strengthening building ,the third is existing building as such total cost ranking. In the existing building the repair cost and operating loss is the highest due to the severe damage. In the strengthened building, the strengthening added as the initial cost. However additional damage loss and operating loss become smaller by strengthening.

If the servicing year of the buildings is shorter, the ratio of the encounter of earthquake will be lower and such initial cost will not be needed.

4. EXPECTED DAMAGE AMMOUNT SUPPOSING EARTQUAKE OUTBREAKING PROBABILITY

The occurrence probability of Nankai earthquake is assumed to be 10 % in 10 years from now, 50 % in 30 years and 90% in 50 years. Such graph is shown in Fig.4. Other Tokai earthquake and Tounankai earthquake show much higher probability than our Nankai earthquake.

It is very important that the owners of building which is tried to be newly constructed, have to be considered the minimum investment for not only new construction project but also its strengthening and repair against earthquakes during its life span.

In this research, the calculation method for the expected amount of total damage reduction of buildings was proposed as following equations.

$$\sum_{t=1}^{50}\left(\prod_{i=1}^{t-1}(1-Pi)Pt\right)\times B$$

$$R_{total}=\sum_{t=1}^{T}\frac{\prod_{1}^{t-1}(1-P_i)\cdot P_t\cdot R_t}{(1+r)^{t-1}}$$

P_i : probability of earthquake occurrence at the year of i

P_t : probability of earthquake occurrence at the year of t

B : amount of earthquake damage

(1 －Pi): probability of no earthquake to the (t-1)th year

R_{total}: total amount of R_t up to the year of t

P_t: probability of Earthquake the year of t

R_t: Expected Reduction of Damage at the Year of t if the earthquake occurred then

r : Discount rate of net present values (lapse of rime)

If we know the probability of earthquake occurrence at each year, and the expected reduction of earthquake damage with anti-seismic countermeasures, the expected amount of total damage reduction up to the year of t is derived with the formula below.

$$\prod_{i=1}^{t-1}(1-P_i)$$

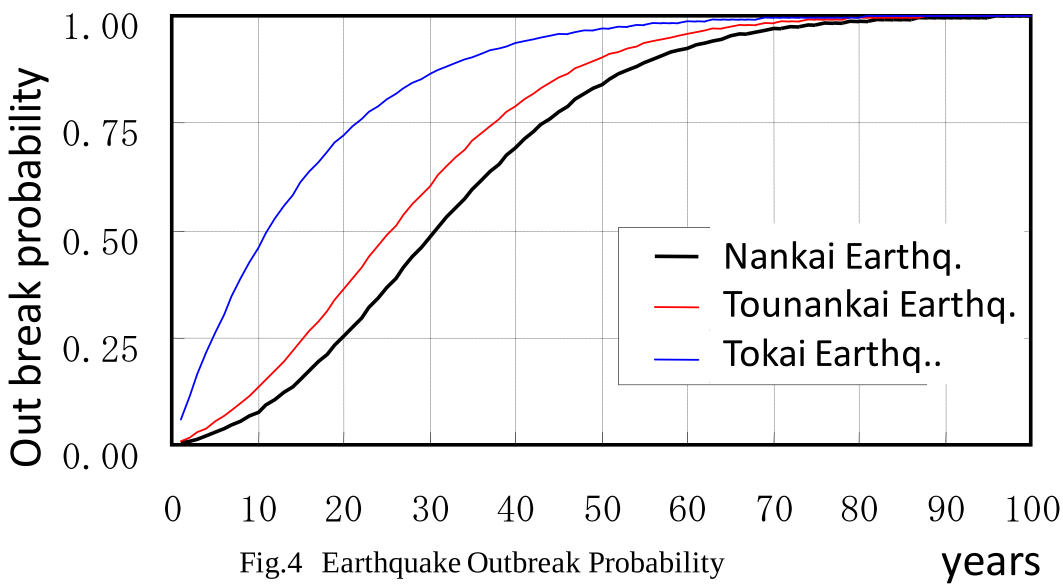

Fig.4 Earthquake Outbreak Probability

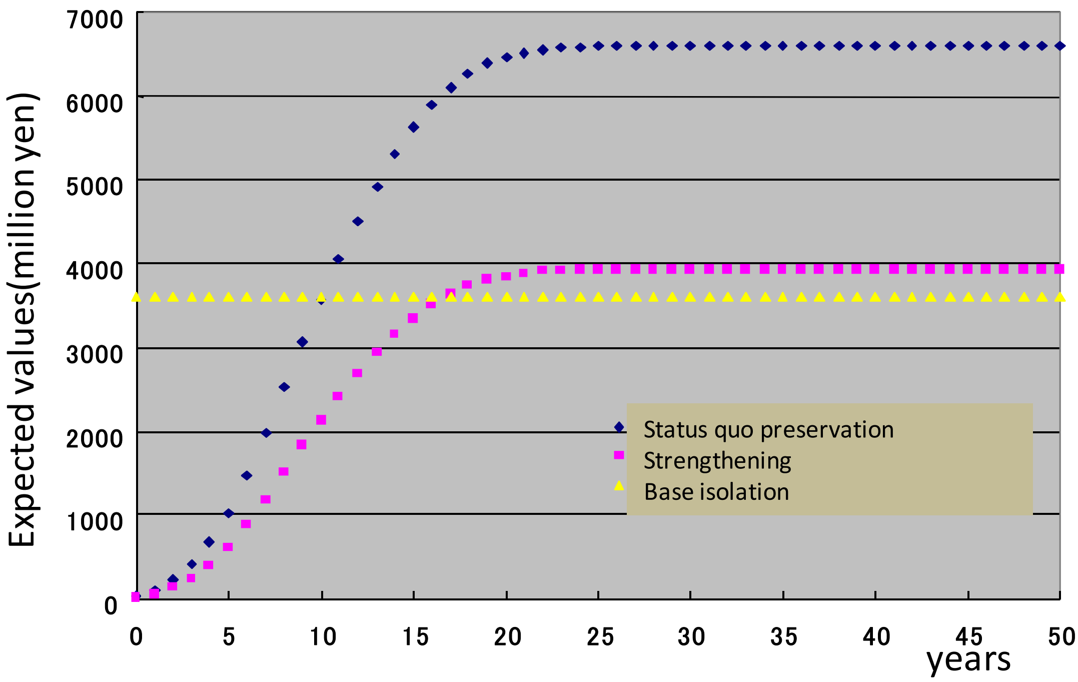

Fig.5 Expected Damage Values Earthquake Outbreak Probability

Suppose earthquake occurs at the year of t, that means from 1st year to (t-1)th, earthquake dose not occur. The formula above is the multiplication of each year probability of which earthquake does not occur up to the (t-1)th year, so that the formula means the probability that no earthquake occur up to (t-1)th year.

Multiplying the probability of earthquake occurrence at the year of t to probability of which earthquake dose not occur up to the (t-1)th year, the probability of which at the year of t the earthquake occurs can be described.

$$\prod_{i=1}^{t-1}(1-P_i)\cdot P_t\cdot R_t$$

Multiplying the amount of damage reduction with anti-seismic countermeasures at the year of t to the probability of which at the year of t the earthquake occurs, the expected amount of damage reduction at the year of t can be described.

$$\frac{\prod_{i=1}^{t-1}(1-P_i)\cdot P_t\cdot R_t}{(1+r)^{t-1}}$$

The formula above describes the net present value (NPV) of the expected amount of damage reduction with anti-seismic countermeasures in case the earthquake occurred at the year of t. Here NPV is a discounted value with the discount rate “r”.

As shown in Fig.5, the expected amount of total damage with lapse of years considering the authorized probability of earthquake occurrence was the different tendency comparing the case that is based on the earthquake occurrence fixed after five years.

In case of the base isolation building, the expected amount of total damage of buildings does not change for fifty years. This case shows only the initial cost for base isolation. On the other hand, the buildings of maintenance of the status quo, and the buildings of seismic strengthening show that such expected amount of total damage of buildings increase in curved lines year by year.

Both of these two types of buildings show the peak after 40 years when the occurrence probability of giant earthquakes reached to 80 %. In Fig.5, these two types of buildings show the loose rate of change after around twenty years. At this year the occurrence probability of giant earthquakes was about 50 %. The results of this statistical analysis will be useful for the risk analysis to the owners of buildings.

After ten years, the base isolation building will be advantageous comparing other two types of buildings.

Thus if the owners can decide how long do they use their buildings, such selection of building device will be selected knowing the occurrence probability of giant earthquake.

5. CONCLUSIONS

1) The installation of base isolation system to existing building which is not enough seismic strength, is much economically effective in the viewpoint of asset management of existing buildings.
2) The damage of existing building which was based on the old seismic design code due to earthquake caused additional disadvantageous situation such as repair works and business loss during the repair works
3) The relationships among the business loss, the physical damage and the initial cost are much depended on each other.
4) The preciseness of this types of analysis will be much effected the soil layer conditions where the building is located. In very near future, the accurate multiplying factor of input earthquake considering soil conditions for the building will be applicable. Then we can evaluate more correct analysis.

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