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RESEARCH ON HOUSING RESTORATION COSTS AND DISASTER RISK MANAGEMENT FOR URBAN EARTHQUAKES

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ABSTRACT: A damage estimation by the Cabinet Office of the Japanese Government examines an earthquake directly beneath the Tokyo as an earthquake disaster that will cause enormous damage. The economic losses are made clear in this damage estimation; however, the effects of financial support systems such as housing restoration funds, support grants for reconstructing the livelihoods of disaster victims, and earthquake insurance payments, which are insufficient throughout the region, are not clarified. In an urban structure such as Tokyo, where there are many apartment buildings, various financial support systems that were established according to lessons learned from previous disasters may not be effective. Therefore, this research performed a stochastic seismic analysis of the Tokyo, and clarified trends in necessary restoration costs and various financial support funds for each category of damage (from partial destruction to complete destruction) according to the housing category. The Average Annual Loss (AAL) and Value at Risk (VaR) for the necessary restoration costs after a disaster were also estimated. To this end, individual building and households were modeled and a damage simulation was performed in order to understand the restoration costs required in the entire disaster area and to examine the effects of various financial support systems for procuring restoration costs. By showing AAL, VaR respectively, the costs required routinely and the costs needed when a major earthquake occurs were clarified. This research also showed quantitatively the extent to which these costs and support funds can be reduced by the ex-ante measure of making buildings earthquake proof.

Keywords: Disaster risk management, Housing restoration costs, Earthquakes in Japan, Stochastic seismic analysis, Ex-post compensation

1. INTRODUCTION

In recent years, numerous earthquakes caused by inland active faults have occurred in Japan, including the Kumamoto Earthquakes in April 2016, the Northern Osaka Prefecture Earthquake in June 2018, and the Hokkaido Eastern Iburi Earthquake in September 2018. These earthquakes caused serious damage to buildings, and many victims were forced to live as evacuees because they were unable to procure housing restoration costs. Even more households are expected to suffer damage as a result of an earthquake predicted to occur directly beneath the Tokyo Metropolis. For rapid restoration, it is necessary to understand the housing restoration costs and implement measures in advance. To address this issue, the national and local governments in Japan have conducted damage estimations to understand the building property damage and economic damage and taken disaster prevention/mitigation measures accordingly. However, there is also an economic loss due to the physical damage of completely or partially destroyed buildings that is not included in the cost required to restore them. These damage estimations are not considered to fully comprehend the restoration costs required in a disaster area. Considering past earthquake damage, in some cases, buildings judged to be completely destroyed were repaired, while in other cases buildings judged to be partially destroyed were reconstructed. Therefore, the cost of the damage is not necessarily consistent with the restoration cost.

Housing restoration is an important component that supports livelihoods, and thus greatly influences the recovery and reconstruction of a disaster area. To plan rapid post-disaster recovery and reconstruction, it is important to understand the housing restoration costs in the entire disaster area and to implement measures on how these costs should be procured.

Among previous research on restoration costs for rebuilding housing in disaster areas, Okada [1] stated that the funds provided through systems of support for reconstructing the livelihoods of disaster victims are insufficient compared to the costs of newly constructing or repairing housing. Okada [1] conducted an earthquake damage estimation in the city of Sapporo and showed that, if the Sapporo City Government were to cover the shortfall in the amount of money required for housing reconstruction, a considerable reserve fund far exceeding the finances of the local government would be required. In addition, Inui [2] compiled housing damage and rebuilding support in Ibaraki Prefecture after the Great East Japan Earthquake. The ratio of the support funds relative to the housing restoration costs was less than 20% for 41.2% of households, showing that the benefits under the current system are extremely inadequate for rebuilding homes. This study suggested that the support funds provided by the various financial support measures are inadequate relative to the necessary restoration costs. However, the targets of this study were the city of Sapporo and one area of Ibaraki Prefecture, as well as that the numbers of households that suffered damage were not high. More households will suffer damage as a consequence of the predicted earthquake directly beneath the Tokyo Metropolis because it is a densely populated area. Accordingly, the necessary restoration costs and financial support systems are expected to be different.

Regarding previous research on restoration costs and measures, Okada et al. [3] and Nakashima et al. [4] identified as an issue the fact that the current framework of housing reconstruction support is uniform throughout the country. By performing damage estimations taking account of regional differences in home rebuilding costs and annual incomes, they showed quantitatively that the difficulty of reconstruction and the economic burden on households differ greatly across regions. They stated that a system of economic assistance that considers regional inequalities will reduce household debt after an earthquake disaster and improve the speed and quality of reconstruction. Nagamatsu et al. [5] presented the problem that all of the housing restoration costs cannot be procured under existing ex-post compensation systems. They proposed linking ex-ante damage mitigation measures and ex-post compensation systems and suggested that reducing housing restoration costs will lead to improved support. These findings are useful as examinations of financial support systems relative to necessary restoration costs. However, in an urban setting such as that of Tokyo, where there are many apartment buildings, existing financial support systems may not be sufficiently effective. Future measures must be implemented after clarifying trends in restoration costs by housing category (apartment, detached house, among others) and damage category.

In Tokyo, seismic retrofitting plans have been drawn up as efforts towards earthquake disaster prevention/mitigation [6]. As of 2003, the earthquake proofing rate was approximately 75%, while as of 2018 this had increased to approximately 80%. However, the question of how to cover the cost, which ranges between several hundred thousand and several million Japanese yen per house, is a major issue. Considering the life of a housing unit of between 30 and 50 years, it is not inevitable that a large earthquake will occur during that time. Therefore, earthquake proofing is not likely to be profitable for many households. Earthquake proofing that is left to the autonomy of households may not progress. In contrast, the US National Flood Insurance Program (NFIP) can be cited as an example of promotion of aggressive ex-ante measures. A characteristic of this program is that it integrates aid for the victims of flood damage and mitigation of flood damage. In addition, by taking ex-ante measures, it reduces destabilization of insurance when a major disaster happens (large insurance payouts leading to destabilization/collapse of the insurance system). Promoting ex-ante measures also makes it possible to reduce compensation amounts and allows a portion of the surplus funds that arise in the ex-post compensation to be invested in ex-ante measures. To implement this type of system linking ex-ante measures and ex-post measures, it is necessary to understand quantitatively the effects of the ex-ante measures. In particular, a quantitative evaluation of the extent to which promoting earthquake proofing will reduce restoration costs and support funds or stabilize support systems is desired.

To address this issue, this study conducts a stochastic seismic analysis of the Tokyo Metropolis and estimates expected values and Value at Risk (VaR) for the necessary restoration costs after a disaster. Trends in necessary restoration costs and various financial support funds are clarified for each category of damage (from partial destruction to complete destruction) according to the housing category (apartment, detached house, among others). By showing the Average Annual Loss (AAL) and VaR, respectively, this study clarifies the costs required routinely and the costs needed when a major earthquake occurs. This study also shows quantitatively the extent to which these costs and support funds can be reduced by the ex-ante measure of making buildings earthquake proof.

2. METHODS: DISASTER RISK MANAGEMENT

With the aim of integrating ex-ante measures and ex-post compensation, this study evaluates the extent to which ex-post compensation can be reduced when the ex-ante measure has been taken. In this study, Seismic reinforcement is assumed as the ex-ante measure. The current earthquake proofing rate of Tokyo is 82% for apartments and 71% for detached houses, and and about 20% to 30% of buildings need seismic reinforcement. In this study, we analyze the earthquake proofing rate by increasing it to 85% and 95% for both apartments and detached houses. AAL and VaR are compared for the necessary restoration costs and various financial support systems at each earthquake proofing rate. The funds required per year can be understood from AAL, and the funds required after a small to medium earthquake and a major earthquake can be understood from VaR. The surplus funds that can be used for ex-ante measures are determined from the extent to which each fund has been reduced compared to the current situation. The following equation is used as an indicator of stabilization of the financial support system.

$$\mathrm{ROR}=\frac{\mathrm{AAL}}{\text{Risk Amount}}=\frac{\mathrm{AAL}}{99\%\mathrm{VaR}-\mathrm{AAL}} \tag{1}$$

Here, ROR represents “return on risk,” and it is an indicator showing the extent to which an annual reserve fund has been maintained relative to the risk amount. The risk amount shows the amount in excess of the annual reserve fund. A higher ROR indicates a more stable system.

3. METHODS: EVALUATION METHOD FOR RECOVERY COST ANALYSIS

To understand the restoration costs required in the entire disaster area and to examine the effects of various financial support systems for procuring restoration costs, individual building and households are modeled and a damage simulation is performed. By accumulating the restoration costs of each household and various financial support funds, trends in restoration costs and various financial support funds are evaluated quantitatively for each category of damage (from partial destruction to complete destruction) and each housing category (apartment, detached house, among others).

The damage simulation used in this study is divided into the following evaluation processes: exposure model evaluation, seismic hazard evaluation, damage function evaluation, and building asset evaluation. The results of the estimation of restoration costs in the entire disaster area are uncertain because there are evaluation errors in each process. However, this study verified the method with property damage caused by the Kumamoto earthquakes and confirmed that the model’s predicted values and the actual damage values show good correspondence. The Kumamoto earthquakes differ from the earthquake directly beneath Tokyo that is considered in this study, and the target regions also differ. However, the accuracy is considered sufficient for examining future measures. The following paragraphs describe each of the evaluation methods in the damage simulation.

3.1 Exposure Model Evaluation

An exposure model is created taking the Tokyo Metropolis as the target evaluation area [7]. Here, the exposure model shows households and buildings exposed to the seismic hazard. First, using census mesh data, data on the number of households by housing type and structure are created in 500-m mesh units. Next, the data on the number of

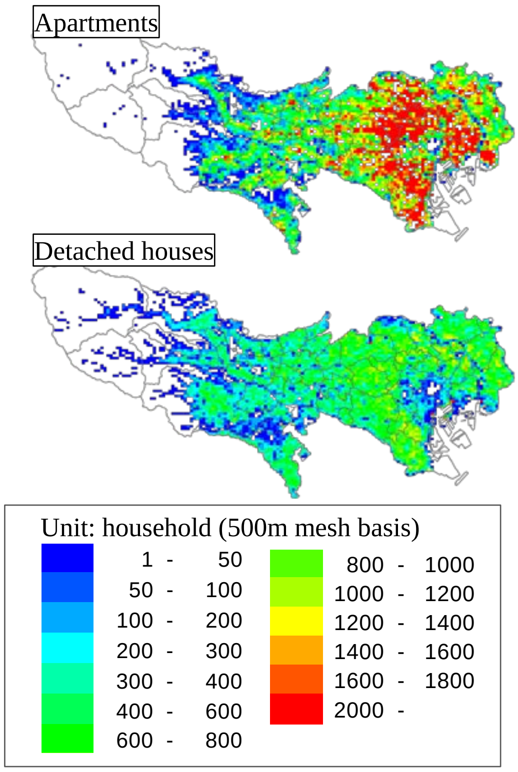


Fig. 1 Distribution of Households

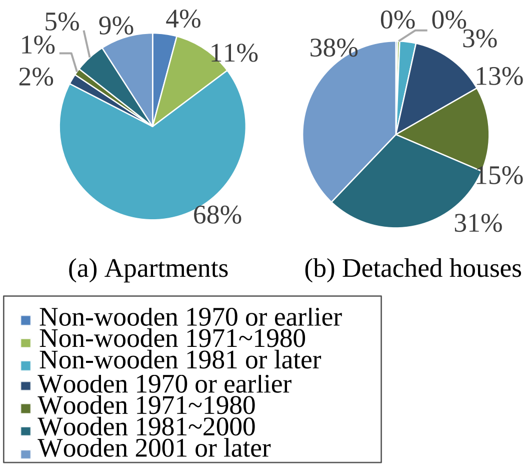


Fig. 2 Proportion of households by building age, and construction material

households are divided proportionally based on Japan’s Housing and Land Survey data on the number of housing units by housing type and construction period according to prefecture or municipal district, in order to create data on the number of households by housing type, structure, and age in 500-m mesh units.

Fig. 1 show the distributions of households by housing type that were created. Apartments are concentrated in the eastern part of Tokyo, while detached houses are distributed evenly across Tokyo. Next, Fig. 2 shows the proportions of households by structure and construction period according to housing type that were created. Sixtyeight percent of the apartments are non-wooden structures built from 1981 onwards, while 69% of the detached houses are wooden structures built between 1981–2000 and from 2001 onwards. Apartments are typified by non-wooden structures and detached houses by wooden structures, and, in both cases, many households reside in buildings with strengths equivalent to new earthquake proofing standards.

3.2 Seismic Hazard Evaluation

The Source model was based on published data from the HARP 2014 [8]. In this study, only inland earthquakes are included in the map. The earthquake prediction equation is adopted from Morikawa et al. [9]. The shallow and deep geotechnical structures are based on the data available in J-SHIS [10]. The distribution of seismic intensity by return period is shown in Fig. 3.

3.3 Damage Function Evaluation for Housing Restoration

Since this study aims to estimate building restoration costs rather than the economic damage to buildings, the necessary housing restoration costs are calculated using the damage function proposed by the authors [11]. This damage function is defined as seismic intensity on the horizontal axis and necessary restoration cost ratio (ratio of restoration cost to replacement cost) on the vertical axis. Fig. 4 shows the damage function used in the analysis. This damage function is categorized into apartments and detached houses, and into wooden and non-wooden structures. The construction period is divided into 1970 or earlier, 1971–1980, and 1981 or later. Wooden structures built in 1981 or later are further divided into 1981–2001 and 2002 or later.

3.4 Building Asset Evaluation

To calculate the cost of restoration, building assets are set using new values rather than market values. The building assets of each household are calculated following Japan's National Tax Agency's "Reasonable Method of Calculating Losses" [12] by multiplying the construction cost per floor area according to structure by the total area of exclusive space per household [13]. However, apartment building assets include both common and exclusive space. Since there is no data available on the total area of common space per household, this is calculated based on the proportion of assets in exclusive and common spaces. Generally, fire insurance for condominium management associations takes the assessed value of common spaces as between 40% and 60% of the building's

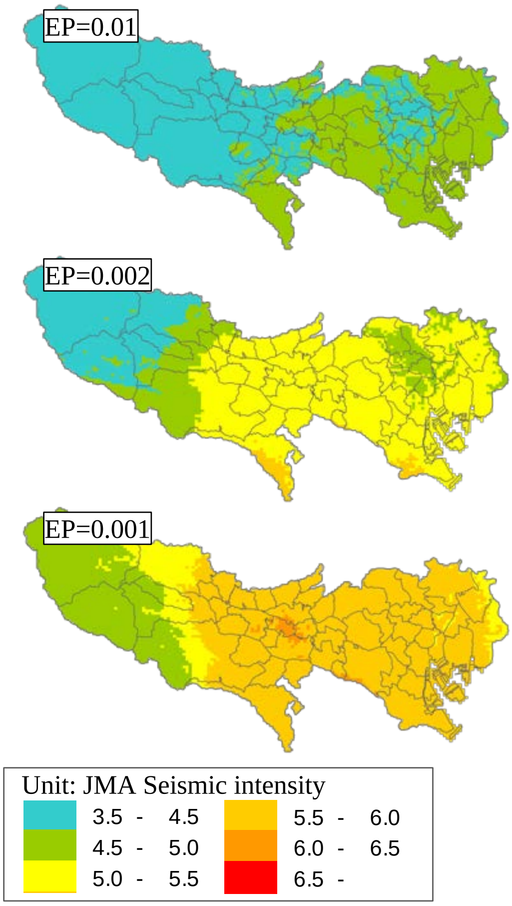


Fig. 3 Distribution of Seismic intensity by EP

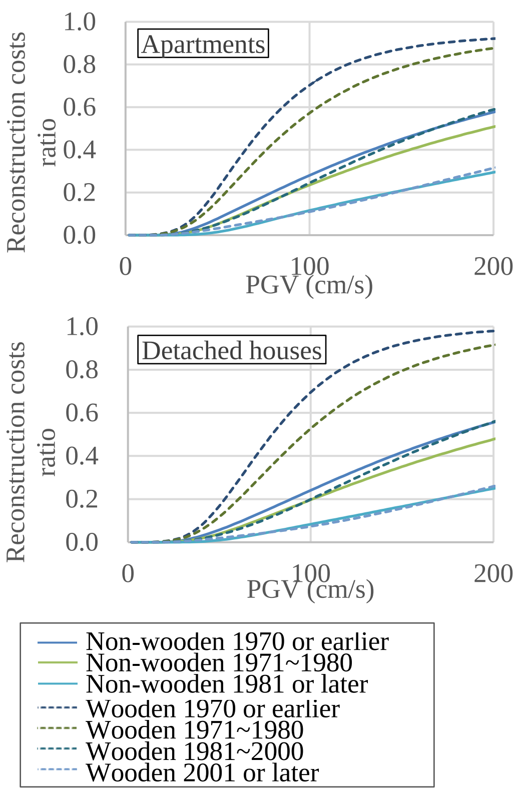


Fig. 4 Damage function of restoration cost

Table 1 Building assets per household

Category		Construction area	Construction cost	Building assets
Apartments	Non-wooden	$51+77m^2$	220K JPY / m^2	28,050K JPY
	Wooden	$39+59m^2$	174K JPY / m^2	16,965K JPY
Detached houses	Non-wooden	$126m^2$	220K JPY / m^2	27,720K JPY
	Wooden	$107m^2$	174K JPY / m^2	18,618K JPY

Table 2 Building assets in Tokyo

Unit: 1M JPY

Category		Non-Wooden	Wooden	Total
Apartments	Pre 1980	18,002,717	2,207,543	20,210,260
	Post 1981	82,725,043	10,647,966	93,373,009
Detached houses	Pre 1980	351,065	9,967,922	10,318,987
	Post 1981	1,486,366	24,450,999	25,937,365
Total		102,565,191	47,274,430	149,839,622

Table 3 Settings for disaster victims' life reconstruction funds

Unit: 1K JPY

Damage State	Reconstruction	Base support	Additional support	Total
Completely destroyed	Rebuilding	1,000	2,000	3,000
	Rehabilitation	1,000	1,000	2,000
Largely destroyed	Rebuilding	1,000	2,000	3,000
	Rehabilitation	500	1,000	1,500
Half destroyed	Rebuilding	1,000	2,000	3,000

Table 4 Settings for earthquake insurance

Damage State	Insurance amount	Payment rate	Total
Completely destroyed	50% of building assets	100%	50%
Largely destroyed		60%	30%
Half destroyed		30%	15%
Partial destroyed		5%	2.5%

total assessed value. In this study, the standard that uses the inner (painted) surface of walls, ceilings, and similar construction elements to determine boundaries between exclusive and common spaces is adopted, and asset value is estimated taking exclusive space as 40% and common space as 60%. On this basis, the total area of common space per household is calculated by multiplying the ratio of assets in exclusive and common spaces by the area of exclusive space. Table 1 show s the value of building assets for each household, and Table 2 shows the total value of building assets in Tokyo. The table reveals that the apartments account for the majority of building assets in Tokyo.

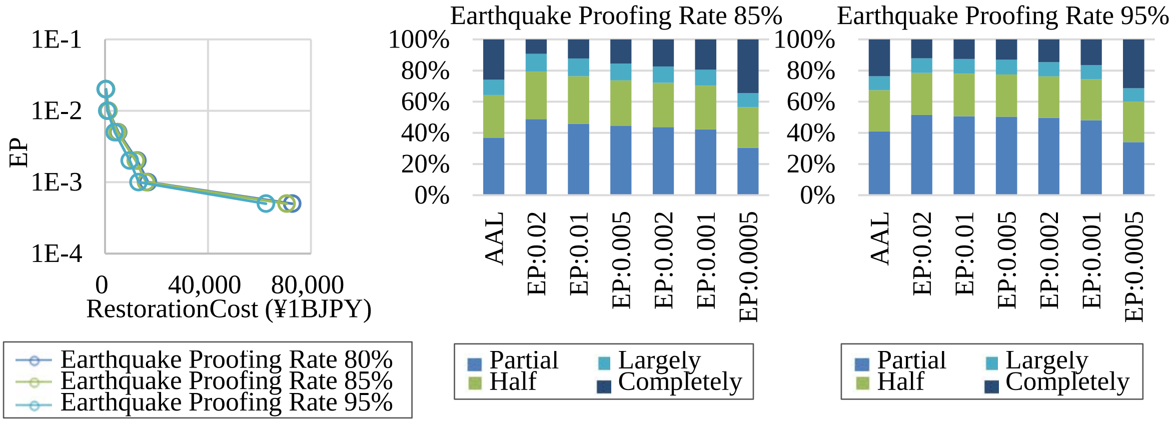
3.5 Evaluation of the financial support system for housing rehabilitation

3.5.1 Housing Reconstruction Assistance Program

Housing reconstruction support programs provide funds to those whose livelihoods have been severely damaged by a natural disaster to help them rebuild their lives. They use funds contributed by the national and prefectural governments from the perspective of mutual aid. The funds set in this study are shown in Table 3.

3.5.2 Earthquake insurance system

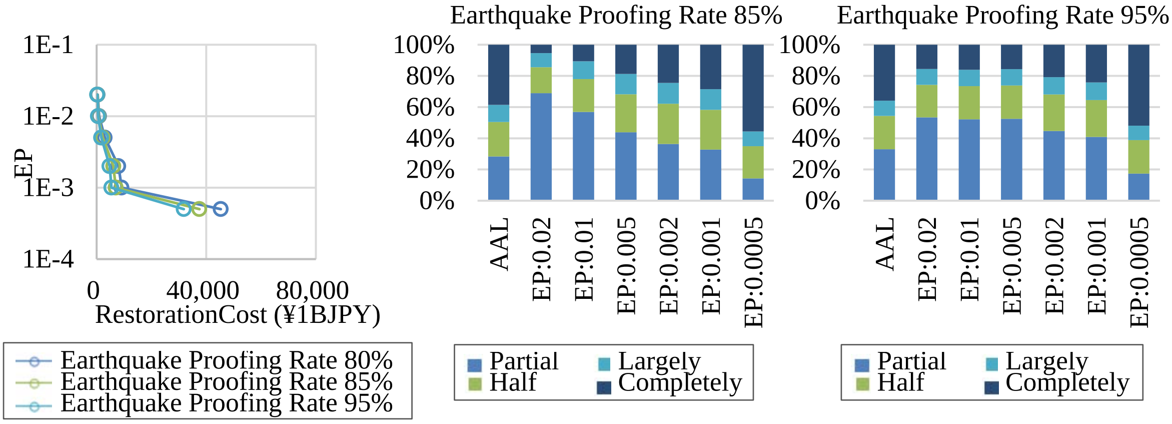
Earthquake insurance is a type of non-life insurance that compensates for losses caused by disasters, such as earthquakes, volcanic eruptions, and tsunamis. It is operated jointly by the government and private non-life insurance companies. Earthquake insurance is purchased together with fire insurance, and the insurance amount is specified as between 30% and 50% of the amount of fire insurance. In 2014, some changes were made to the system, and partial destruction was divided into the two categories of small-scale partial destruction and large-scale partial destruction. The earthquake insurance money set in this study is shown in Table 4. Next, the earthquake insurance take-up rate for each household is set. Here, the take-up rate is the proportion of all



(a-1) EP Curve

(a-2) Proportion of restoration costs by Damage State

(a) Apartments



(b-1) EP Curve

(b-2) Proportion of restoration costs by Damage State

(b) Detached houses

Fig. 5 Necessary restoration costs

households that have earthquake insurance. The earthquake insurance take-up rate for detached houses and exclusive space in apartments is set at 36.7% [14]. Since no data is available for the earthquake insurance take-up rate for common space in apartments, this is set using the attachment rate shown in [15]. Here, the attachment rate represents the percentage of households with earthquake insurance attached to their fire insurance contracted during the relevant financial year. By multiplying the ratio of the attachment rate for exclusive space (71.9%) to the attachment rate for common space (38.1%) in 2015 by the earthquake insurance take-up rate for exclusive space, the earthquake insurance take-up rate for common space is set at 18.2%.

4. RESULTS AND DISCUSSION

4.1 Analysis of the Subject of Evaluation

First, the left-hand side of Fig. 5 shows the necessary restoration costs for each earthquake proofing rate and each return period. The respective graphs show the results for apartments and detached houses. The figure reveals that the necessary restoration costs were reduced at all return periods as a result of promoting earthquake proofing. By promoting the earthquake proofing rate from 80% to 95%, the necessary restoration costs for apartments at a return period of 2,000 years were reduced by approximately 1,019,997 million Japanese yen (from 7,273,176 million to 6,253,180 million Japanese yen). For detached houses, the costs were reduced by approximately 1,350,551 million Japanese yen (from 4,532,159 million to 3,181,608 million Japanese yen). The current earthquake proofing rate for detached houses is low, and therefore there was a large reduction in the necessary restoration costs when earthquake proofing was promoted. Next, the center and right-hand side of Fig. 5 show breakdowns of the extent of damage by return period. The figure reveals that the restoration costs differ for each return period and each damage extent. The shorter the return period, the greater the percentage of partial destruction and the smaller the percentage of total loss. The fact that the damaged households

Table 5 AAL, 99%VaR, ROR by Earthquake Proofing rate

Unit: 1M JPY

	Category	Earthquake Proofing rate	AAL	99%VaR	Risk Value	ROR
Apartments	Necessary restoration costs	82%	13,235	136,214	122,979	10.76%
		85%	12,686	127,117	114,432	11.09%
		95%	10,638	90,676	80,037	13.29%
	Support money from victims' life reconstruction costs	82%	831	6,741	5,910	14.06%
		85%	784	6,157	5,373	14.60%
		95%	605	3,944	3,339	18.12%
	Support money from earthquake insurance	82%	1,293	12,279	10,987	11.77%
		85%	1,234	11,412	10,178	12.12%
		95%	1,015	8,076	7,060	14.38%

Unit: 1M JPY

	Category	Earthquake Proofing rate	AAL	99%VaR	Risk Value	ROR
Detachedhouses	Necessary restoration costs	71%	8,044	90,979	82,935	9.70%
		85%	6,360	68,014	61,654	10.32%
		95%	5,129	53,970	48,841	10.50%
	Support money from victims' life reconstruction costs	71%	656	3,359	2,703	24.26%
		85%	512	2,486	1,974	25.92%
		95%	389	1,814	1,425	27.29%
	Support money from earthquake insurance	71%	1,476	16,695	15,219	9.70%
		85%	1,167	12,481	11,313	10.32%
		95%	941	9,903	8,962	10.50%

requiring restoration funds differ greatly with each return period suggests that the form of the financial support system will also differ depending on the focused return period.

4.2 Effectiveness of earthquake-resistance for necessary restoration costs: the financial support system

In the next section, we evaluate the extent to which the ex-post compensation could be reduced by proceeding with the ex-ante measures. Table 5 shows the results of AAL, 99% VaR, and ROR of various financial support programs, as well as the cost of recovery from the earthquake disaster. It can be seen that the amount of financial assistance provided by the disaster relief and reconstruction assistance and earthquake insurance both decreased as a result of seismic retrofitting. AAL decreases by about 19-24% for both multifamily and single-family dwellings when seismic retrofitting is increased from 85% to 95%. 99% VaR decreases by about 29-36% for multifamily dwellings and 21-27% for single-family dwellings. The impact of seismic retrofitting is greater for VaR than for AAL than for the reduction in aid contributed in the event of a disaster. The effect of seismic retrofitting is to reduce the amount of aid paid out in the event of severe damage. In particular, the Livelihood Reconstruction Assistance Program will reduce the amount of aid paid out in comparison to the earthquake insurance program. The Life Reconstruction Assistance Program for disaster victims includes payments to households that are at least half destroyed, so the number of households whose houses are at least half destroyed is expected to decrease as a result of seismic retrofitting.

Next, promoting earthquake proofing from 85% to 95% increases ROR by between approximately 19% and 24% for apartments and between approximately 2% and 5% for detached houses. ROR is an indicator showing the extent to which an annual reserve fund has been maintained relative to the risk amount, and a higher ROR indicates a more stable support system. In this discussion, earthquake proofing results in a large decrease in 99% VaR. This means that the expenditure after a major disaster is stable relative to the reserve fund. The ROR shows that the system of support for reconstructing the livelihoods of disaster victims and the earthquake insurance system became more sustainable.

5. CONCLUSIONS

With the aim of integrating ex-ante measures and ex-post compensation, this study evaluated the extent to which restoration costs and financial support system funds can be reduced when the ex-ante measure of earthquake proofing has been taken. The study revealed that restoration costs and financial support system funds can be reduced by promoting earthquake proofing. The fund reducing effect was particularly noticeable for major earthquakes, such as 99% VaR, and was shown to contribute significantly to improving ROR. The results of this research will be used to in developing a social system for disaster prevention that combines disaster prevention measures such as seismic retrofitting, systems of support for rebuilding the lives of disaster victims, and financial support measures such as earthquake insurance.

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