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CONSTRUCTION OF DAMAGE FUNCTION FOR AN ANALYSIS OF THE ECONOMIC DAMAGE BY EARTHQUAKES WITH A FOCUS ON THE RECONSTRUCTION OF SHARED HOUSING

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ABSTRACT: Conventional economic housing damage estimation methods that quantitatively estimate the damage amount from the structural damage of the building, cannot consider variability in the repair costs due to the decisions made by the victim. Therefore, in the assessment of economic housing damage, there is a concern that a large deviation may occur between the estimated value and the actual value. In this research, we will focus on the types of assessment systems the governments or local governments can employ to ensure the quick rebuilding of damaged houses. Economic housing damage was estimated in line with the actual damage situation, in particular by considering diverse housing reconstruction methods for apartments. We focused on the damage states and restoration examples provided in the Act on Special Measures concerning Reconstruction of Condominiums Destroyed by Disaster, constructed a damage function in line with the actual situation by constructing a restoration pattern model for reconstructing an apartment house. As a result of the earthquake simulation, we quantitatively showed that the variations in reconstruction methods of collective housing make a large variation to the damage amount. In addition, we showed that the current measures and measures that governments and local governments assumed were not sufficient, and pointed out the issues to consider for effective measures in the future.

Keywords: Earthquake, Economic damage Analysis, Damage Function, Housing Reconstruction

1. INTRODUCTION

Many earthquakes that occurred in recent years have been caused by inland active faults, including the Kumamoto earthquake in April 2016, the Northern Osaka Prefecture earthquake in June 2018, and the Hokkaido Eastern Iburi earthquake in September 2018. Earthquakes caused by inland active faults are smaller in scale than trench-type earthquakes. Major local earthquakes that occur near cities are often accompanied by a significant loss of lives and infrastructural damages. For this reason, the government and municipalities implement damage estimation measures in advance in order to take measures for disaster prevention and mitigation [1]. While estimating damage, the number of buildings that can be totally or partially destroyed is determined. This information helps protect the lives of victims. Economic damage is monitored to help survivors of a disaster to restore their lives and to contribute toward the reconstruction of the economy. Economic damage may include losses due to physical damage of the building and the funds required for reconstruction. In this study, economic damage is defined as the funds required for housing reconstruction. Using the number of totally and partially destroyed buildings, the economic damage analysis of the government and municipalities, described in example one, assumes that the rate of economic damage is 100% in the case of total destruction, and 50% in the case of partial destruction. However, according to a recent earthquake damage report in [2], there are reports that buildings that were judged as being totally destroyed were restored, while buildings that were judged as partially destroyed were reconstructed. Since shared housing units have many unit owners, housing reconstruction is carried out based on diverse factors, such as livelihood rehabilitation and asset formation. Accordingly, if economic damage is calculated mainly based on the structural damage of buildings, such as the current damage estimation, it is impossible to properly grasp the extent of funding necessary for the reconstruction of shared housing. The proportion of shared housing, especially in urban areas, is large. The economic forecast that is necessary for the restoration and reconstruction of such buildings may be considered inadequate. Another issue is that the categories of total and partial destruction, which are assumed in the current damage estimation process, are not linked to the categories of damage that are used in various support systems implemented by the government and municipalities. It is not possible to measure the funds required for various support systems quantitatively, because of these differences in the mode of categorizing damage. Funding is necessary for various types of

Table 1 List of building damage survey

No.	Survey name	Purpose	Investigator	Damage category name
1	Damage certification survey	Issuance of disaster certificates	Municipality	Partial destruction, large-scale partial destruction, and total destruction
2	Damage survey	Earthquake insurance	Non-life insurance company	Partial loss, small and partial loss, large loss, and total loss
3	Damage degree classification survey	Understanding the degree of damage, judgment for continuous use	Architect	Insignificant damage, small damage, intermediate damage, large damage, and collapse
4	Act on Disaster-Affected Condominiums	Research for clarifying the causes of disaster	Researcher	Small damage, intermediate damage, large damage, collapse or partial damage, partial destruction, and total destruction
5	Research survey by the Architectural Institute of Japan and the Japan Society of Civil Engineers	Understanding the extent of damage	Municipality	Partial damage, partial destruction, total destruction

Table 2 Classification and criteria of the Act on Disaster-Affected Condominiums

Unit	State	Requirement	Condominium Ownership Act	Act on Disaster-Affected Condominiums Buildings
Total loss	State in which the main part has disappeared, and the overall utility of the building has been lost from a social and economic viewpoint	Reconstruction	Consent of everyone is required	Consent of four-fifths is required
Large-scale partial loss	In cases where the part corresponding to more than half the building price is lost	Reconstruction	Consent of four-fifths is required	
		Restoration	Consent of three-fourths is required	
		Sale of building and site	Consent of everyone is required	Consent of four-fifths is required
		Demolition and sale of site	Consent of everyone is required	Consent of four-fifths is required
Small-scale partial loss	In cases where the part corresponding to less than half the building price is lost	Reconstruction	Consent of everyone is required	Consent of everyone is required
		Restoration	Consent of half of the people	

support. And in the absence of planned reserves, the support system may become bankrupt. For disaster prevention and mitigation measures in the future, it is important to quantitatively analyze the reconstruction costs that may be required by the victims and the funding support that may be necessary for various support systems.

In this study, we focus on the different kinds of economic disaster prevention and mitigation measures that the state and the municipalities can take in order to achieve speedy reconstruction. We review the evaluation of shared housing that creates an element of uncertainty in economic damage and then create a damage function by considering the variability in the approaches toward the reconstruction of shared housing. The damage function should be created in harmony with the classification of various support systems, in keeping with the quantitative evaluation of each of these support systems. We also present an example of an economic damage analysis of an earthquake for Tokyo using the damage function so created.

2. DAMAGE CATEGORY

2.1 Classification of Building Damage

After an earthquake, several surveys are conducted to understand the extent of damage to the building. There are various ways of detecting damage to buildings based on the purpose and the method used in the survey. Table 1 summarizes the main surveys conducted after a disaster and the categories of damage under each. As shown in the

Damage Ratio	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Damage estimation	No Damage	Semi-destruction					Total destruction				
Damage certification survey	No Damage/Insignificant damage			Partial-destruction		Large-scale partial-destruction	Total destruction				
Damage survey	No Damage	Partial damage		Small and partial-destruction		Large-scale partial-destruction	Total destruction				
Damage degree classification assessment	No Damage	Partial damage		Small damage		Intermediate damage		Large damage		Collapse	
Emergency risk assessment	Safety					Attention needed		Danger			
Act on Disaster-Affected Condominiums Buildings	No Damage	Insign-ificant loss	Small-scale partial loss				Large-scale partial loss			Total loss	

Fig. 1 Survey of damage and arrangement of damage category

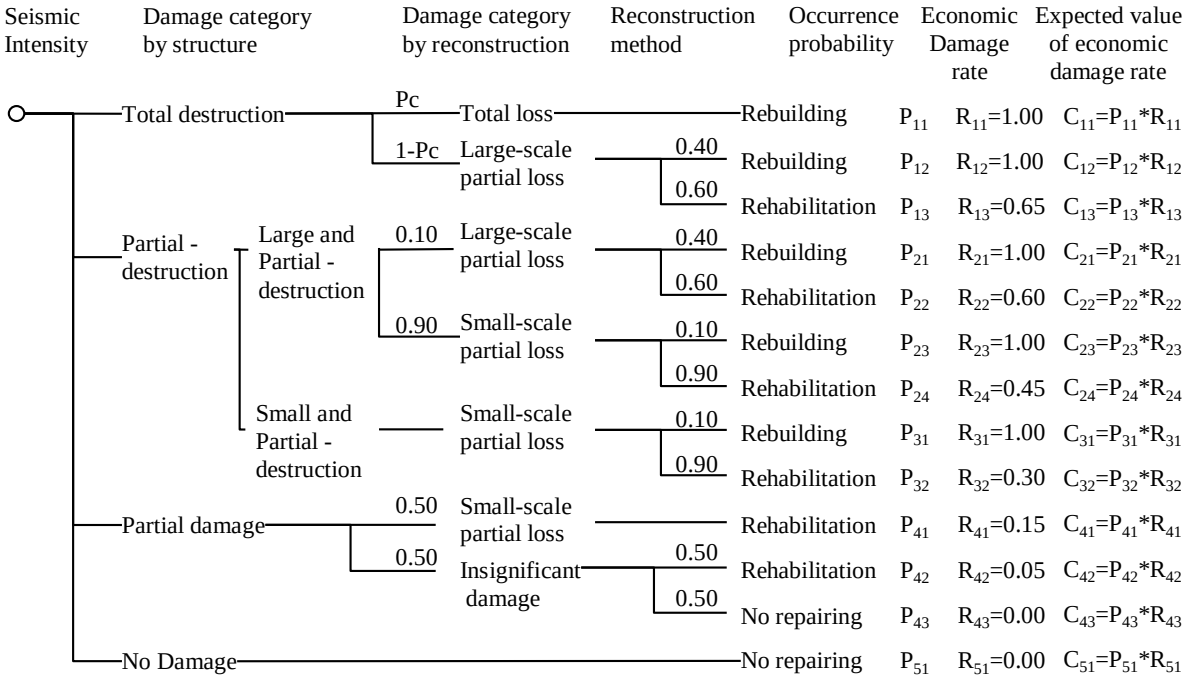


Fig. 2 Event tree related to damages to shared housing

table, there are various categories for each survey, and the names, definitions, and number of categories vary. Number 1 in the table is implemented relying on the Act on the Support for Reconstructing Houses of Disaster Victims and the Emergency Repair System. This legislation covers buildings that suffered total destruction to large-scale partial destruction, and the Emergency Repair System provides funding support in cases of total and partial destruction. Number 2 in the table is implemented while using earthquake insurance. In earthquake insurance cases, the insurance amount is paid for total and partial loss. Number 3 in the table is implemented when shared housing is affected and a resolution of reconstruction methods is carried out. The number of votes necessary to decide upon a reconstruction method and the resolution of reconstruction methods varies based on the category of damage. Numbers 4 and 5 are voluntary surveys of academic societies and municipalities. The survey is conducted in cases of total and partial destruction. The damage function used in the damage estimation by the government and municipalities has been created based on the results of this survey. Even if the degree of damage is the same, the names, definitions, and number of categories vary based on the surveyor. This estimation uses two categories, total and partial destruction, but these categories do not correspond to the categories for the investigations under the Act

on Support for Reconstructing Houses of Disaster Victims, the Emergency Repair System, and the earthquake insurance system. Therefore, it is not possible to quantify funds necessary for these support systems when different assumptions of damages are made. To estimate damage, it is necessary to set categories of damage that are consistent with various support systems.

2.2 Housing Reconstruction Process

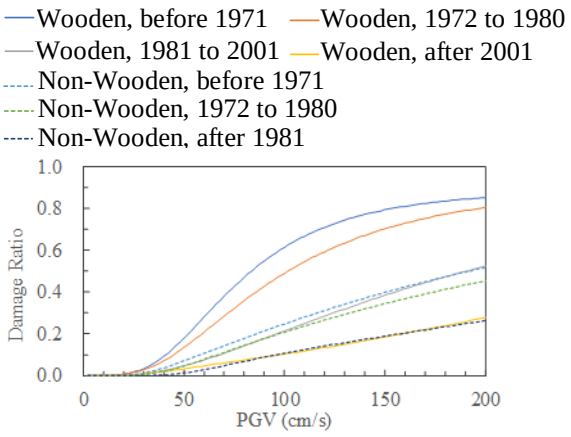
In case of damage to detached houses, decisions are made to reconstruct or restore such houses mainly for the purpose of the rehabilitation of livelihood. This judgment can be made by the owner of the building at his own discretion. However, when shared housing is damaged, the decision on whether to opt for reconstruction or restoration is made not only based on the rehabilitation of livelihood, but also on diverse factors including asset formation. This decision must be determined by the consensus of the unit owners since the building or site is a part of a condominium ownership system. The decision to rebuild shared housing is provided by the Condominium Ownership Act of the Civil Code or the Act on Disaster-Affected Condominiums. Here, the Act on Disaster-Affected Condominiums applies only to shared housing damaged by large-scale disasters as specified by government decree. Table 2 shows the damage categories and criteria based on the Condominium Ownership Act and the Act on Disaster-Affected Condominiums.

As shown in the table, when shared housing is affected, it is divided into four categories: complete loss, large-scale partial loss, small-scale partial loss, and others (minor or no damage). Here, the complete loss means that the entire building has lost its utility, and partial loss means that only some parts have lost their utility, but the building's utility as a whole is maintained. The loss of utility indicates the loss of utilization value and not market price. Among the partial losses, large-scale partial loss indicates a loss of more than half of the building price, and the small-scale partial loss indicates a loss of less than half of the building price. The reconstruction resolution is different for each damage category, and it is necessary to proceed with each resolution according to the method of reconstruction. However, in these resolutions, it is difficult for the unit owners to arrive at a consensus. According to [3], in the case of the Kumamoto earthquake, nearly half of the 18 shared houses that had applied for public funded demolition had difficulties in arriving at a consensus among the unit owners, and the need for demolition was not established sufficiently. In other words, the selection of the building reconstruction method varies widely among the unit owners as well. It is quite possible to take a decision to restore and rebuild when a large-scale partial loss occurs, and to take the decision to rebuild and not restore when a small-scale partial loss occurs.

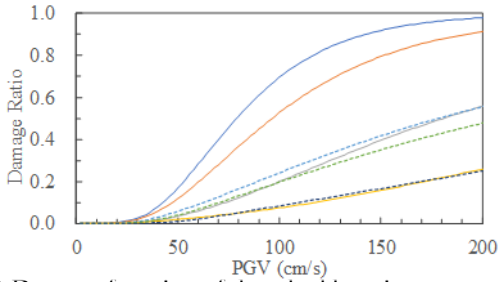
3. DAMAGE FUNCTION FOCUSED ON RECONSTRUCTION OF SHARED HOUSING

3.1 Event Tree

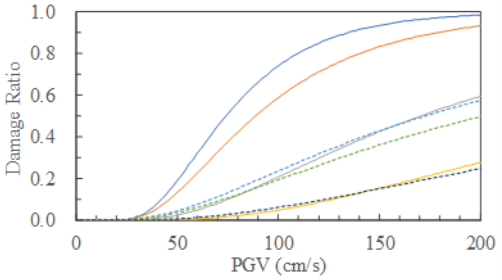
In the previous chapter, we showed the classification of building damage based on the housing damage survey and presented the process of reconstruction of apartment houses. In this chapter, we create a damage function based on the review of damage categories and the reconstruction method based on the Act on Disaster-Affected Condominiums. First, the differences in the economic damage rates of buildings in each damage



(a) Damage function of shared housing



(b) Damage function of detached housing



(c) Damage function of the Cabinet Office

Fig. 3 Damage function

Table 3 Number of households in Tokyo and asset amount data (number of households, 1 billion yen)

Structure		Wooden			Non-wooden			Total
Building Age		Ancient old	Old	New	Ancient old	Old	New	
Number of households	Shared housing	52 558	77 565	627 643	181 667	460 141	2 949 199	4 348 774
	Detached housing	254 013	281 379	1 313 299	5456	7209	53 621	1 914 976
	Total	306 571	358 944	1 940 942	187 123	467 350	3 002 820	6 263 750
Asset amount	Shared housing	1808	2 690	21 753	8194	20 754	132 967	188 167
	Detached housing	6836	7573	35 345	211	279	2077	52 321
	Total	8644	10 263	57 098	8405	21 033	135 045	240 489

Table 4 Number of households damaged by the Tachikawa fault zone

Structure		Wooden			Non-wooden			Total
Building Age		Ancient old	Old	New	Ancient old	Old	New	
Proposed method	Shared housing	33 855	50 334	330 375	106 846	197 996	1 027 438	1 746 843
	Detached housing	164 014	181 057	695 434	2891	3019	17 817	1 064 231
	Total	197 870	231 391	1 025 809	109 736	201 014	1 045 255	2 811 075
Cabinet Office method	Shared housing	25 796	36 374	79 365	37 128	70 374	190 441	439 479
	Detached housing	126 182	131 628	183 611	904	1061	3202	446 587
	Total	151 978	168 001	262 976	38 032	71 435	193 643	886 066

Table 5 Economic damage by the Tachikawa fault zone (billion yen)

Structure		Wooden			Non-wooden			Total
Building Age		Ancient old	Old	New	Ancient old	Old	New	
Proposed method	Shared housing	599	825	2356	1302	2361	8042	15 485
	Detached housing	2449	2420	3605	26	29	98	8627
	Total	3048	3245	5961	1329	2390	8140	24 112
Cabinet Office method	Shared housing	570	770	1563	994	1866	4765	10 527
	Detached housing	2596	2613	3388	25	29	82	8733
	Total	3167	3382	4951	1019	1895	4847	19 261

survey are summarized in Fig. 1. The economic damage rates shown in the figure are organized with reference to [4]. Damage assessment surveys used in damage certification and damage surveys used in earthquake insurance have four damage categories, although the category names are different. The economic damage rates assumed for each category are similar. On the other hand, the damage estimates implemented by the government and municipalities set two categories: total and partial destruction. Partial destruction in damage estimation includes partial destruction and large-scale partial destruction. Partial damage is not considered. The two main systems that can be used for housing reconstruction are livelihood rehabilitation support and earthquake insurance. The damage category set in the current damage estimation is not appropriate while considering the formulation of policies for measures and response for recovery and reconstruction from earthquake damage after the estimation of such damage. Therefore, we set four damage categories in this study: total destruction,

large-scale partial destruction, small-scale partial destruction, and partial damage.

Next, we look at the method of reconstruction of houses. If a detached house is damaged, the reconstruction will be considered first with the goal of returning it to the current status. Therefore, the funds required for housing reconstruction should correspond sufficiently to the degree of structural damage. In this study, following the earthquake insurance payment rate, the economic damage rate is set to 100% for total destruction, 60% for large-scale partial destruction, 40% for small-scale partial destruction, and 5% for partial damage with reference to [5]. In the case of shared housing, it is necessary to determine the reconstruction method through discussions among unit owners. As seen in the previous chapter, in shared housing, various methods of housing reconstruction are selected based on the diverse values held by the unit owners. The funds required for housing reconstruction may show a response different from what the degree of structural damage requires. Therefore, in this study, we created a model of the damage function using the event tree as seen in Fig. 2. After damage categorization based on the structure, we branched out the damage categories based on the Act on Disaster-Affected Condominiums. We also branched out the methods of reconstruction that can be used after the classification of damage based on the Act on Disaster-Affected Condominiums. Based on this, it was set to select reconstruction and restoration even in cases of total destruction. We assumed that the branching probability Pc of total loss and large-scale loss after total destruction is the state where all buildings are lost, and no buildings exist. We adopted the damage grade of [4] and used the ratio of D5 level damage (equivalent to collapse) to D4 level damage or above (equivalent to total destruction.) We set other branching probabilities based on the relationship with the economic damage rate as seen in Fig. 2. However, it may be possible to update the approach using statistical data such as damage results in the future.

3.2 Damage Function

We created a damage function based on the event tree drawn up in the previous section. To create the damage function, it is necessary to define the damage rate function of total destruction, large-scale partial destruction, small-scale partial destruction, and partial damage. In this study, the damage rate function for partial damage uses data from [5,6], partial destruction, and total destruction use data from [1]. Further, while dividing the partial destruction into large-scale and small-scale partial destruction, we use data on the number of damaged buildings for each damage category according to [6]. Using the ratio of the number of damaged buildings that were completely destroyed, largely partially destroyed, and partially destroyed as indicated in the literature, we created a damage function of large-scale partial destruction by combining the damage functions of total and partial destruction. From the above, the damage function obtained is shown in Fig. 3. The damage function used in the damage estimation of the Cabinet Office is also shown as a reference. From the figure, because of the diversity in the methods of reconstruction, the damage function of share housing has a damage rate that is slightly larger than that of the detached houses and the Cabinet Office in areas where the seismic intensity is small, and the damage rate is smaller than that of detached houses and the Cabinet Office in areas where the seismic intensity is large.

4. EXAMPLE OF ECONOMIC DAMAGE ANALYSIS

4.1 Analysis Condition

Using the damage function created in the previous chapter, we try to determine the number of damaged households and the funds necessary for housing reconstruction. We evaluate Tokyo, which is densely populated and has a large number of buildings, many of which are shared housing units. We make predictions assuming that an earthquake was caused by the Tachikawa fault, which has raised concerns of causing significant damage to Tokyo. The analysis model was based on [8]. In the analysis, the source fault model uses [9] and the seismic hazard assessment uses [10,11]. And the evaluation of the number of building assets is set based on [12].

4.2 Result of Analysis

Table 3 shows the number of households and the asset amount as a summary of the asset data for Tokyo. Table 4 shows the number of damaged households after damage estimation and Table 5 shows the prediction of the economic damage. The number of damaged households indicates the number of households affected by such damage. Tables 4 and 5 also show the results of the damage function as adopted by [1] for comparison.

Based on the results, the total number of damaged households in the proposed method is about 2.80 million, which is about 3.1 times more than the results of the Cabinet Office method. The proposed method considers the damage category of partial damage, but the Cabinet Office method does instead considers partial destruction as a category. As a result of this difference, the number of damaged households in the proposed method has significantly increased. While looking at recent earthquake related damages, although non-wooden

buildings rarely suffer complete or partial destruction, there are many cases in which partial damage has occurred. We think that using the proposed method can predict a number of damaged households that is closer to reality.

Next, based on the results, the total economic damage of the proposed method is approximately 24 trillion yen, which is approximately 1.3 times the result of the Cabinet Office method.

The breakdown of the economic damage was approximately 1.30 times for shared housing comprising wooden structures, 1.54 times for shared houses comprising non-wooden structures, 0.99 times for detached houses comprising wooden structures, and 1.13 times for detached houses comprising non-wooden structures. As the main difference between the proposed method and the Cabinet Office method, we can say that takes into consideration the diversity of reconstruction methods and the damage cost because of partial damage for shared housing, and also takes into consideration the damage cost because of partial damage for detached houses. Shared housing is significantly affected when the diversity of reconstruction methods is taken into consideration.

5. CONCLUSION

When a shared housing is affected by a disaster, the mode of housing reconstruction is selected according to the diverse views of unit owners. Therefore, the funds needed for reconstruction do not necessarily coincide with the degree of structural damage. Also, as shown in the case of the Kumamoto Earthquake, resolutions for the reconstruction and restoration of shared housing are complex and such buildings require a lot of time to rebuild. The reconstruction process is complicated when there are many options including large-scale partial loss. It is necessary to take measures in advance to ensure rapid restoration and reconstruction.

In this study, we focused on the damage classification and reconstruction methods that are related to the Act on Disaster-Affected Condominiums, and created a damage function for shared housing by using the event tree of restoration. By using this damage function, economic damage analysis can be performed according to the actual condition of the restoration cost of buildings. We also used damage categories linked to the support system for the subsequent restoration and reconstruction measures and because of this, it was possible to evaluate the costs and effects required for various support systems, and evaluate economic damage. In future studies, we plan to examine the sufficiency of the current support system, as well as effective measures and responses to these economic damages.

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