SYSTEM FOR PROMOTION OF RETROFITTING OF EXISTING PRE-CODE REVISION STRUCTURES

by

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ABSTRACT

Recent damaging earthquakes have clearly revealed that retrofitting of existing pre-code revision structures is the key issue for earthquake disaster reduction in Japan. Unfortunately, this practice is not extended, especially for non-public use structures such as residential buildings. These weak structures will certainly suffer great damage and cause a negative impact when a big earthquake strikes. Why the retrofitting of residential buildings has not been implemented yet? We think that reason for this is the lack of proper law and system by which retrofitting activities become popular among the population. Therefore, in this paper, we propose a new system/measures to promote retrofitting activities. In order to show the efficiency of the proposed system from the government and residents viewpoints, we introduce the results of simulations performed on the basis of the building damage data during Kobe earthquake and building stock data in Nakahara ward of Kawasaki City.

INTRODUCTION

Even if we have a very good disaster response system, it is impossible to reduce earthquake damage without implementing proper mitigation techniques. **Figure 1** and **Table 1** show the number of casualties, death cause and estimated time of death during the Kobe earthquake in Kobe city (by Hyogo prefecture medical examiners). From these figures we can understand that many of the people were killed due to collapse of the structures or the dynamic behavior of the furniture. The main cause may be suffocation, crushing, heavy injury to head/neck or other body parts or shocks. This type of casualty corresponds to 84% of the total number of casualties. When we look at the estimated time of death, 92% of the deaths occured within the first 15 minutes. This ratio becomes 26% if we exclude the casualties due to burns or crashes because in this cases the accuracy to estimate the time of death is low. Ordinary doctors are not specially trained to evaluate the cause and time of death and therefore they noted the death time as the time when the dead body was carried to the place. For this reason, the recorded time is the first day and that's why we should pay much attention to the data prepared by these medical examiners. As the occurrence time of Kobe earthquake was early in the morning, 5:46 am, 97% of people were killed in the their own apartment. Therefore the only way in which they could have saved their lives was retrofitting their houses before the event. Even among the people who were burned (15%), almost all of them were trapped under the debris of damaged structures and they could not escape the fire attack. This is quite different from the 1923 Kanto earthquake. In this case, people could not manage themselves because of bad or no evacuation guidance. They could not escape from the fires. Before discussing fire-fighting problems we should recognise that there was a structure collapse problem. After the Kobe earthquake we heard from

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Table 1 Estimated time of death due to Kobe earthquake (In Kobe city, Hyogo prefecture medical examiners)

Date & Time	Number of casualties: Medical examiner cumulative			Ordinary doctor cumulative			Cumulative total casualties	
1/17 ~ 6:00	2,221	2,2221	(91.9 %)	719	719	(58.2 %)	2,940	(80.5 %)
~ 9:00	16	2,237	(92.6 %)	58	777	(62.9 %)	3,014	(82.6 %)
~ 12:00	47	2,284	(94.5 %)	61	838	(67.9 %)	3,122	(85.5 %)
~ 23:59	12	2,296	(95.0 %)	212	1,050	(85.0 %)	3,346	(91.6 %)
Unknown	110	2,406	(99.6 %)	84	1,134	(91.8 %)	3,540	(97.0 %)
1/18	5	2,411	(99.8 %)	62	1,196	(96.8 %)	3,607	(98.8 %)
1/19		2,411	(99.8 %)	13	1,209	(97.9 %)	3,620	(99.2 %)
1/20	2	2,413	(99.9 %)	8	1,217	(98.5 %)	3,630	(99.4 %)
1/21	1	2,414	(99.9 %)	6	1,223	(99.0 %)	3,637	(99.6 %)
1/22	1	2,415	(100.0 %)	1	1,224	(99.1 %)	3,639	(99.7 %)
1/24		2,416	(100.0 %)	1	1,225	(99.2 %)	3,640	(99.7 %)
1/25	1	2,416	(100.0 %)	1	1,226	(99.3 %)	3,642	(99.8 %)
1/26		2,416	(100.0 %)	2	1,228	(99.4 %)	3,644	(99.8 %)
1/27		2,416	(100.0 %)	1	1,229	(99.5 %)	3,645	(99.8 %)
1/28		2,416	(100.0 %)	1	1,230	(99.6 %)	3,646	(99.9 %)
2/4		2,416	(100.0 %)	1	1,231	(99.7 %)	3,647	(99.9 %)
No date		2,416	(100.0 %)	4	1,235	(100.0 %)	3,651	(100.0 %)
Total		2,416			1,235		3,651	

Mechanical Asphxia	1,967	53.90%
Chest	857	
Chest & Abdomen	435	
Trunk	108	
Head, Neck, Face & Air Way	324	
No mention is made	211	
Others	32	
Crush	452	12.40%
Traumatic Shock	82	2.20%
Head Injury	124	3.40%
Organ Injury	55	1.50%
Cervical Spine Injury	63	1.70%
Burn	444	12.20%
Organ Failure	15	0.40%
Starvation & Hypothermia	7	0.20%
Blunt Trauma Injury	300	8.20%
Unidentified (Including perfectly burnt)	116	3.20%
Others	26	0.70%
Total	3,651	

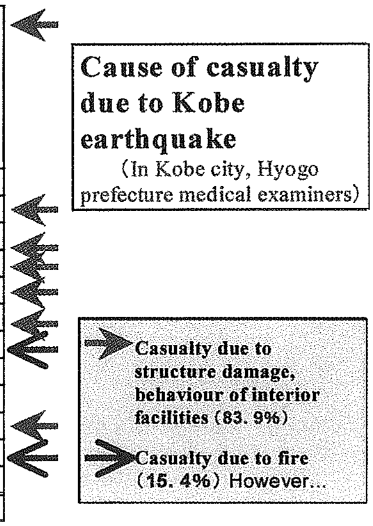

Fig. 1 Cause of casualty due to Kobe earthquake (In Kobe city, Hyogo prefecture medical examiners)

many newspapers that if the damage information could have reached the Prime Minister smoothly or the self-defence force could have responded more quickly or if there have been a system for deciding to move without getting the requirement from the governor of the affected area, many people could have been saved. This information in not correct. Moreover, many problems were generated after the earthquake occurrence, such as temporary shelter problem, community loss people problem, construction problems and its environmental effects, psychological problems (PTSD) and many others during the reconstruction period. These issues were all generated after the earthquake because a huge number of the structures were collapsed or severely damaged. If we had retrofitted these structures before the event, we could have reduced the number of structures that collapsed due to the Kobe earthquake. Totally 100000 structures were completely collapsed and 140000 structures were severely damaged and in consequence 5500 people were killed. If we could reduce this 200000 to 20000 and 5500 casualties to 500, many of the issues that were generated would not have been so severe. This is the main lesson that we should learn from the Kobe earthquake. The software related countermeasures can be functional only under the condition that the hardware is functional. The key issue is that human life can only be saved by hardware.

Based on the actual earthquake damages, the seismic code of structures was revised many times in Japan. The last revision (shin tai shin) was done in 1981 and the structures that were constructed using this code were reported to perform well even under the strong ground motion of Kobe earthquake as shown in **Fig. 2**.

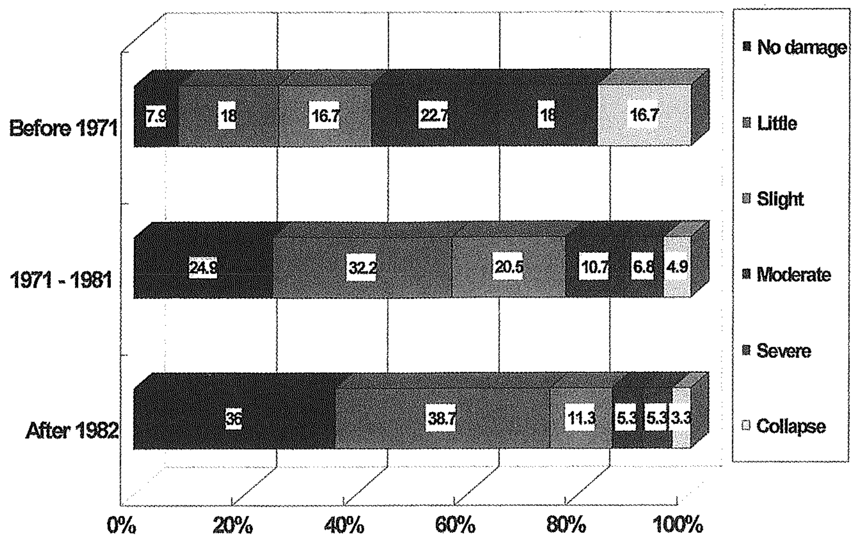

Fig. 2 Characteristics of the structure damage in Kobe city
(based on the observations of Chuo Ward, Kobe city by committee of structure damage investigation)

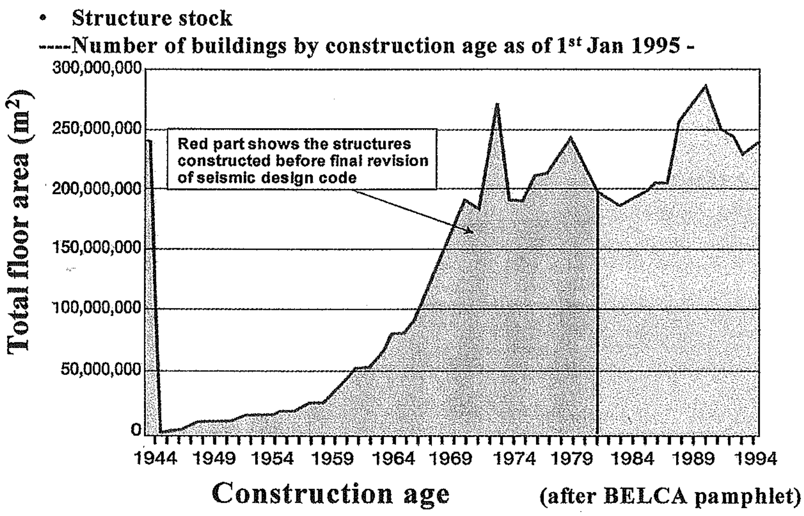

Fig. 3 Building and housing stock in Japan. Among the structures which were constructed before 1981, it is reported that the structures which require seismic evaluation; residential houses 12 million and non-residential houses 2.2 million houses

However, there is a problem because there are many structures constructed before the final revision of the code as shown in **Fig. 3.** These structures are very vulnerable against earthquakes and this is the current critical issue. To reduce the earthquake damage just after the event, there is only one way and that is retrofitting the structures before the next earthquake comes. Namely, evaluate the structure seismic capacity and retrofit them accordingly before the occurrence of the next event. In the current situation, retrofitting activities are not carried out seriously, especially if the structures are not public i.e. private houses. We are sure that these unretrofitted structures will be damaged in future earthquakes and generate many casualties. Why the retrofitting of residential structures is not carried out well? From the authors' viewpoint, this is not because of a technological problem but because of the system or a social environment problem. Therefore in this research, we propose a new system or new laws for promoting the retrofitting of existing pre-code revision structures. With this objective, we

Without Proposed system		With proposed system
Residence owner	Retrofitting cost	Residence owner
Residence owner	Structure damage cost	Residence owner
Government*	Temporary shelter cost	Government*
Government	Demolishing cost	Government
Residence owner	Reconstruction cost	**

*Based on the Kobe earthquake

** Basically owner should pay but the house with proposed; the owner can get some money from the government

Fig. 4 The change of the persons who should pay cost with and without the proposed model

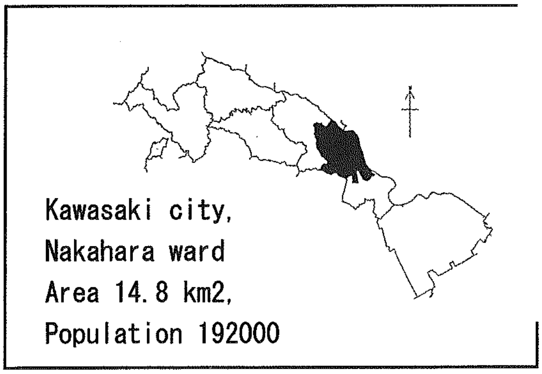

Fig. 5 Study Area (Nkahara Ward in Kawasaki City)

Table 2 Classification of structures in study area

Type of structure	Age of construction	Number	Average floor area (m^2/bldg.)	% of property to the initial value
Timber	Before 1971	14,031	72.3	34.0
	1972-1981	8,416	80.3	53.3
	After 1982	8,317	107.9	75.7
Non-timber	Before 1981	10,490	207.9	64.1
	After 1982	11,703	287.3	85.8

Timber			Non-Timber	
~1971	1972~1981	1982~	~1981	1982~

Case 1 : **Retrofitting of Timber Houses Constructed before 1971** 14,000

Case 2 : **Retrofitting of Timber Houses Constructed between 1972-1981** 8,400

Case 3 : **Retrofitting of Non-Timber structures Constructed before 1981** 10,500

Fig. 6 Number of structures to be retrofitted in different categories

would like to show the effects or benefits of the retrofitting activity from both government and resident side.

NEW IDEA FOR PROMOTING RETROFITTING OF STRUCTURES AND ITS EFFECTS

Proposing a new system

Considering the experiences of the Kobe earthquake disaster, Japanese government enforced the retrofitting promotion law on October 27, 1995. The objective of this law is to promote the retrofitting of the structures that were constructed before 1981 and to make those structures have the same earthquake capability as those that were constructed after the final revision of code i.e. after 1981. Unfortunately, this code is not mandatory. Furthermore, the law targets large structures such as schools, hospitals, hotels, markets etc. Ordinary residential houses are not targets of this law. Paradoxically, the residential house problem is much severe than the public building problem.

For the reasons mentioned in the previous paragraph, some of the municipalities or local governments proposed laws to promote retrofitting activities such as, assistance system, and low interest loan for seismic evaluation of structures or retrofitting of structures. The result is that there is no municipality in which the retrofitting activities are carried out well. The most important reason for this is that it is difficult for ordinary people to understand the effects of retrofitting structures. If we explain the ordinary people the effects of retrofitting, the number of people who start to retrofit their own structures may increase. However, with the system mentioned above a large budgetary problem will arise. Namely, if the number of people who want to retrofit their structure increases, local governments would require large amounts of money, which is practically impossible.

In Japan, there is a principle in natural disasters, people should recover from damaged situation by themselves. Reconstruction of the damage structures and retrofitting of structures should be done by the owner of the houses. But when we look at the real situation, e.g. the Kobe earthquake, if the owner is affected and his damage is severe a lot of governmental money is used in different ways such as rescue operations, preparation of emergency supplies, refugee camps, shelter, demolishing etc., as shown in **Fig. 4.** Most of these costs could be saved if the structures were not damaged. Based on this fact, the new system which we are proposing is, if the owner retrofitted his structure properly and his structure is damaged during the earthquake then the government will pay some money to him. It is obvious that before establishing this system, we should create a neutral organization to evaluate whether the structure is properly retrofitted or not.

This system has lot of advantages from both government and citizen side. Here, using the Nakahara ward of Kawasaki city as a case study area, we would like to simulate the earthquake damage with and without the proposed model to show its usefulness. The case study area adopted in this research, the number of structures of different types and their construction age are very well distributed as shown in **Table 2**.

Database preparation

(a) Estimation of structural damage

We classified the structures by the construction age considering the years when the seismic code was revised, from collapse to no-damage using fragility functions for each code revision. The damage cost is evalu-

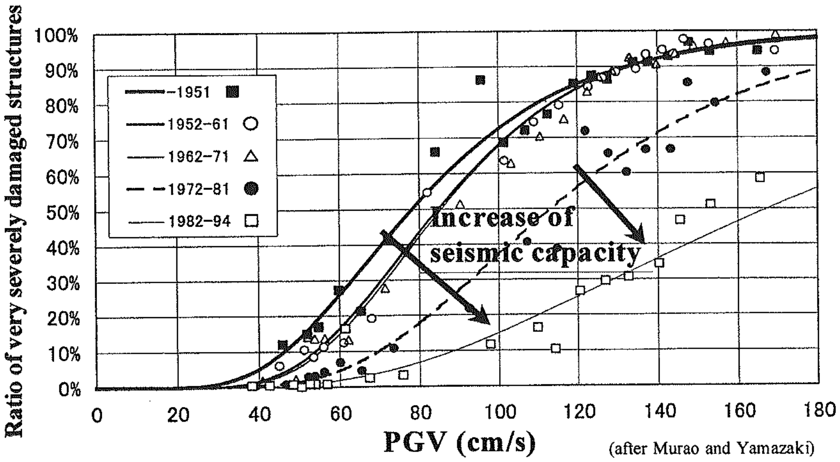

Fig. 7 Fragility function obtained from Kobe damage data

ated proportionally to the floor area in sqm. The structure property was assumed as 150000 and 300000 yen per sqm for timber and non-timber, i.e. RC or steel, structures, respectively. We are considering a property depreciation based on time. In case of timber houses, its value becomes half in 25 years and for non-timber houses its value becomes half in 40 years.

(b) Estimation of damage reduction by the retrofitting activity

Considering the retrofitting activity, we assume an increase of the seismic capacity of the structure and evaluate the decrease of damage for different strong ground motion cases. The cost of retrofitting the structure is calculated using the floor area and different structure categories. Based on the ratio of retrofitting, the numbers of damaged structures become different. By changing the ratio of retrofitting of the structures and by changing the strength of the ground motion, the effects of the proposed new system, efficiency and usefulness are discussed.

(c) Evaluation of the cost for preparation of refugee camps, demolition and treatment of construction waste

Using Kobe earthquake data regarding refugee camps, we assume that city pays 130000 yen for one

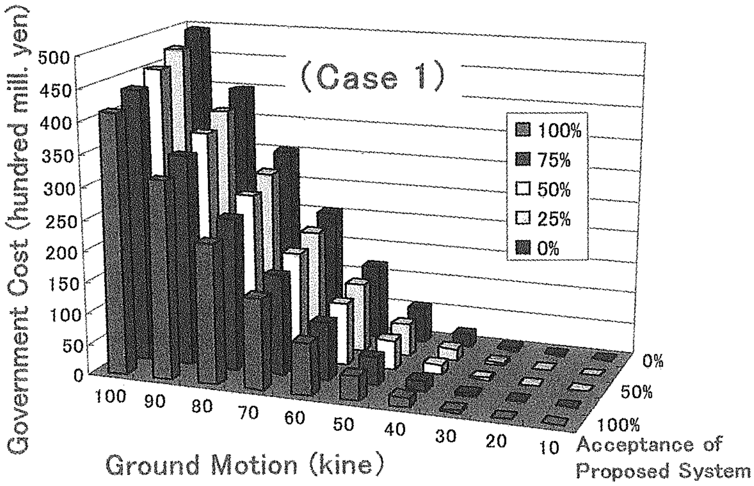

Fig. 8 Changes of the cost of Kawasaki City in different ratio of proposed system and ground motion

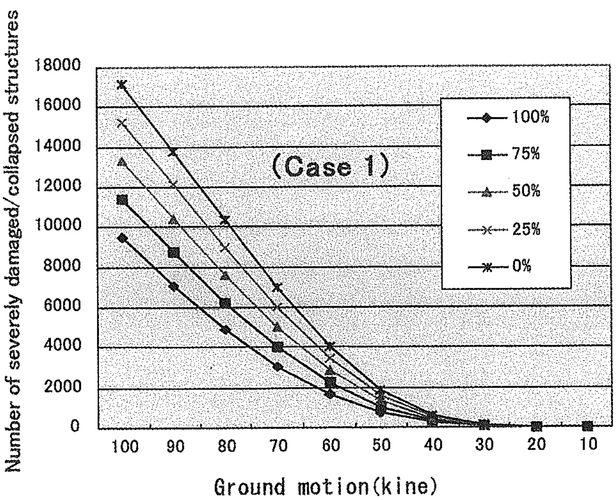

Fig. 9 Change of number of severely damaged/collapsed structures

refugee shelter. Estimated number of shelters is calculated based on number of damaged structures and ground motion level. Although city government pays 130000 yen per refugee shelter, the total cost is 2800000 yen. The latter does not include the additional cost used for modification i.e., steps, air conditioners, etc. The cost of demolishing the construction waste was assumed 3270000 yen for one structure, based on the Kobe case.

(d) Selecting the optimum retrofitting

Figure 6 shows the comparison of the effects of retrofitting different types of structures at different ages. From this we can decide the optimum retrofitting. For this discussion, we use the fragility function shown in **Fig. 8** prepared using earthquake damage data of the Kobe earthquake. This fragility functions were prepared using the data of timber houses of 3 categories and non-timber houses of 2 categories i.e. total 5 categories were used. Note that if we use this fragility function (Murao and Yamazaki, 2000), we are assuming that in the Nakahara ward of Kawasaki city the structure strength characteristics are close to those of Kobe area. This point will be discussed in future when the information of structure strength of the Kawasaki area is available.

We use three different cases of retrofitting as shown in **Fig. 6,** discuss the cost performance of each of them and calculate the optimum retrofitting case. Namely, by retrofitting the structure, the seismic capacity of the old structure become the same as that of the structure built after the final revision of the seismic code. With this effect the structure damage becomes less and the structure damage reduction cost and retrofitting cost are compared and discussed. For this procedure, we assume that the retrofitting cost per 1 sqm is 15000 and 40000 yen for timber houses and for non-timber houses, respectively.

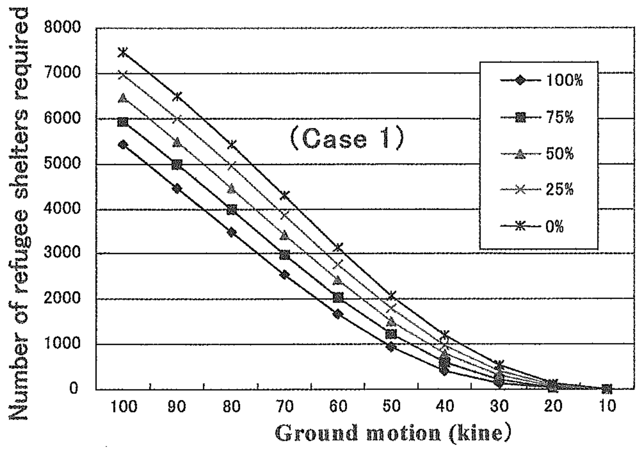

Fig. 10 Changes in number of refugee shelters required

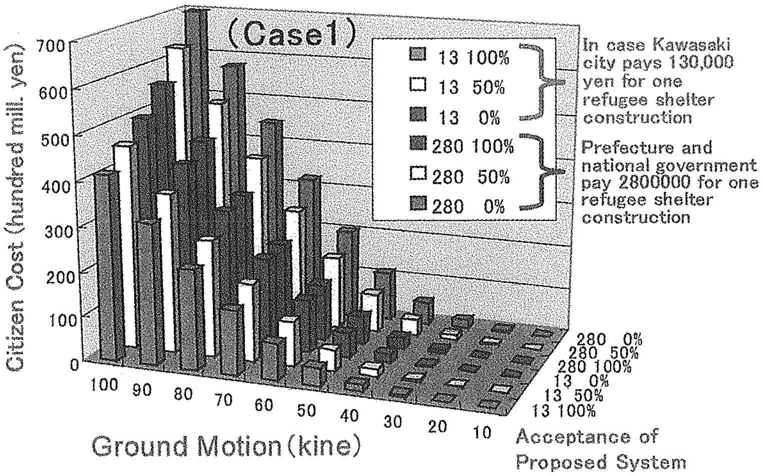

Fig. 11 Changes of the governmental cost

Discussion of the effects of the proposed model

With and without the proposed system, the total cost from the viewpoint of government and residents becomes different. Here, as a first step, we consider the following four items: the structure damage, the cost for temporary shelters, the cost for demolishing construction waste and the house reconstruction cost. We would like to introduce the result of retrofitting the structures which were constructed before 1981 as this retrofitting cost benefit is the highest evaluated. As **Fig. 4** shows, if the owner does not follow the proposed system, the cost of structure damage and reparation should be covered by himself and the government should cover the cost for temporary shelter and demolishing. Repairing cost is assumed based on the data as 1/3 of the new construction, namely in case of timber houses 15000 yen 1 sqm and 100000 1 sqm for non-timber houses. We assumed that owners' following the proposed model because of the retrofitting the cost for temporary shelter demolishing is reduced. As already explained before the earthquake, if the owner retrofitted the structure and that structure is damaged the government will pay some money to that owner. Considering all conditions, the efficiency of the proposed model is discussed.

SIMULATION RESULT AND CONSIDERATION

Simulation result

Here we assume that the retrofitted structure is damaged. In case severely damaged, 3000000 yen per one structure will be paid to the owner, which is same as the cost of the temporary shelter. For partially collapsed houses, the government will pay 1500000 yen which is equivalent to the cost of retrofitting a 100-sqm timber house. This means that the total cost of the retrofitting is paid back after the earthquake by the government. The total cost of the government is supporting money + demolishing cost + refugee shelter cost based on the damage. **Figure 8** shows the changes of the government cost and the % of the proposed system acceptance and the ground motion. In this case, the cost that Kawasaki city may pay is assumed as 5% of the initial construction for temporary shelters, following the Kobe case i.e. 130000 out of 2800000 yen. From **Fig. 8,** the cost to the city government can be reduced, when the proposed system is accepted and the ground motion become severer. When we look at this figure carefully, in case of a ground motion of 50 kine, when we compare the two different cases i.e. proposed model acceptance ratio is 100% and 0%, and we just look at the government cost, there is no big difference. However, because of retrofitting of the houses before the earthquake, as **Fig. 9** shows, the severely damaged structures reduces from 1830 to 750. In case of 60 kine, the number reduced from 4020 to 1640. Based on this result the number of temporary shelters required can be drastically reduced, as shown in **Fig. 10**. In case of 50 kine its number becomes half or less. This point is very important when we consider the earthquake problem in Tokyo area, because it is impossible to find open space for temporary shelter. And when we compare the result in **Fig. 8** with the case of **Fig. 11** which shows the total government cost in the previous case. We just consider 130000 yen per one temporary shelter that was paid by the Kobe city but the initial cost was 2800000 yen. Prefecture government and national government prepared this. From the government view-point, this money was spent as a whole. It means that, proposed system effect becomes much larger.

We can also discuss the merits from the viewpoint of the residents. **Fig. 12** shows the relation of acceptance ratio and the ground motion severeness and the residential damage cost, individual owner cost. From this figure, it can be seen that when the ground motion increases, the total damage cost becomes less if the proposed model is accepted. The ratio of number of people who accepted this new proposed system and this case as the damage cost of individual residence is structure damage cost and retrofitting cost and cost for reconstruction or repairing cost and if the owner made a contract of proposed system then when his or her structure is damaged then that person can get some money from the government based on **Fig. 12** from ground motion of 30 kine. If the ground motion becomes larger then from the individual owner viewpoint retrofitting before the earthquake is economically good. These 30 kine is not so high value, this level of ground motion should be considered even in a normal situation. For instance, in the Kobe case the ground surface maximum velocity was over 150 kine. Based on this fact, from this level of ground motion if the resident can get merit then the system has lot of advantages. We did not consider household goods in the results introduced in **Fig. 12.** But when we consider them, the system's efficiency becomes much better. From **Fig. 12,** the critical value was 30 kine but when we consider household goods this value becomes 20 kine. And with and without proposed system, the total cost of the residential owners becomes very much different.

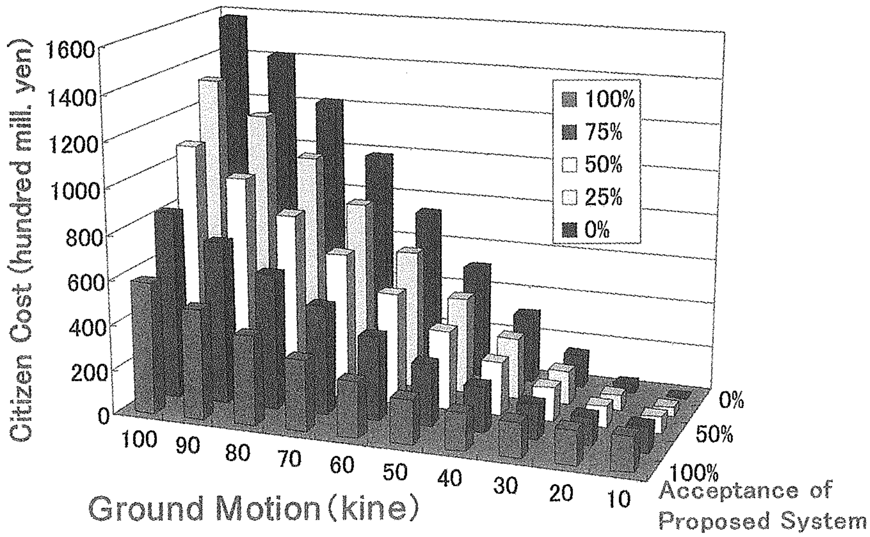

Fig. 12 Changes of cost of people

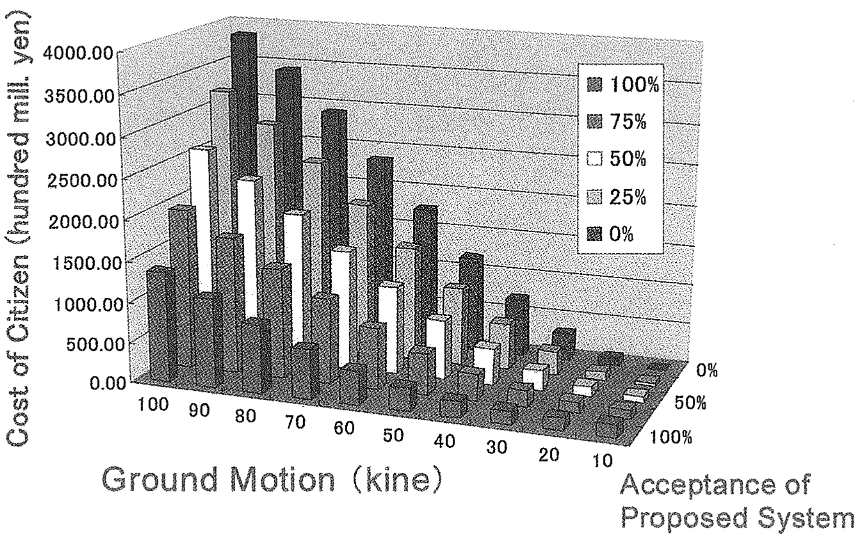

Fig. 13 Changes of the cost of people (household goods are considered)

Considerations

From the results introduced in the previous sections, it is noticed that the proposed system can give huge economical merits from government and resident side. Namely, from the viewpoint of the government, this system will increase disaster prevention potential and reduce the total cost which should be paid after the earthquake. From the viewpoint of governmental money, this way of spending money is by far better. From the resident viewpoint, even for reasonable levels of ground motion, the number of people affected drastically reduces. The strong points are listed below:

1. The proposed system is quite different from the one prepared by the local government i.e. with the current system the government should pay a lot of money before the event. But with the proposed model, the government does not have to pay the money. When we consider the situation of the local government after the

event, the situation becomes much better to receive money from the national government.

2. From the viewpoint of the national government, the proposed system can greatly contribute after the event because the money can be well used. With this method, we break the principle that the damaged people should recover by themselves and government money cannot be used for private property. This system can contribute to reduce the earthquake damage and to use the government money more efficiently.
3. Contribute to reduce the amount of damage and the difficulty of the response. This is important because no matter the amount of preparedness without mitigation, the damage situation cannot be reduced.
4. Within the reasonable ground motion level, comparing the cost that government should pay before and after the earthquake, the proposed system gives the residents an economical merit. When we think about the casualties generated just after the earthquake, besides the economical merit, this system gives very strong merit to the house owner as it prevents human loses.
5. With the current supporting retrofitting system, the government helps only once because it does not have incentives or motivation to take care. On the other hand, with the current proposed model, if the owner argues that he retrofitted his house but does not keep his structure in good condition, once earthquake occurs and the structure is damaged, the government should pay. Therefore, the government should continuously watch the structures and this helps to maintain the quality control of the structures. The current system does not have such advantage even if the government can spare money before the earthquake. The proposed model can maintain the quality of structures stock. This is very important point.
6. There is a big difference between earthquake insurance systems and the proposed model. Even if the earthquake insurance contract changes, the damage faced after earthquake is the same. With the proposed model damage becomes smaller.

CONCLUSIONS

In this paper, we proposed a new method, which may solve our country's most important disaster mitigation issue i.e. retrofitting of the existing pre-code revision structures and discuss its effects. Based on the results there are several issues to be discussed and the proposed model can provide us the driving force. The issues that should be discussed are first, the relation between the magnitude of the ground motion and its occurrence probability. Even if we propose a proper supporting system and the retrofitted structure does not experience a ground motion more than 30 kine, the total retrofitting cost becomes high. This means that in case of a small ground motion even if the structure is not retrofitted, it should be fine. The retrofitting cost is not worthy. For these cases, we are proposing a tax reduction.

In this study we just considered the cost assumed by the government, the cost for temporary shelter and the demolishing cost. In the actual case we should add assistance money or supporting money and cost for public house and rent for affected people and the money which should be lent to residential owner to construct their new houses. The government should spare some money for lending and therefore its income is reduced. When we consider these effects the efficiency becomes higher.

REFERENCES

1) Nishimura, A., Ijiri, G., Ueno, Y., Emergency Medicine –from the autopsy on bodies, Separate volume of emergency medicine, Health publisher, 1995.
2) Building and Equipment Life Cycle Association, BELCA Pamphlet, 1995
3) The Society for the Study of Construction Administration, The Explanation of an Act for Promotion of Retrofitting buildings, Taisei Publishing, 1996.5.
4) Kobe City, Hanshin-Awaji Earthquake Disaster – Record of Kobe City, 1996.1
5) Murao, O., Yamazaki, F., Development of Fragility Curves for Buildings Based on Damage Survey Data of a Local Government After the 1995 Hyogoken-Nanbu Earthquake, *Journal of Structural Consturuction Engineering*, AIJ, No.527, 189-196, 2000
6) Takahashi,K., Meguro,K., Basic Research on the More Effective Earthquake Damage Estimation / Support System – Case study of Kawasaki city – 54th JSCE Annual Meeting, 1st Category(B), 80-81, 1999.9
7) Yamaguchi, N., Yamazaki, F., Estimation of Strong Ground Motion in The 1995 Hyogoken-Nanbu Earthquake Based on Building Damage Data, *Journal of Structural Mechanics and Earthquake Engineering*, No.612/1-46, 325-336, 1999
8) The Yasuda Fire & Marine Insurance Co., Ltd., http://www.yasuda.co.jp/insurance/katei/hokentyo.html