PROPOSAL OF A SYSTEM TO PROMOTE RETROFITTING OF VULNERABLE MASONRY HOUSES IN DEVELOPING COUNTRIES

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ABSTRACT: There is consensus that retrofitting of existing seismic vulnerable houses is the key to reduce casualties in future earthquakes. In spite of this, few, if any, successful experiences of massive retrofitting campaigns are reported. This is true for both developed and developing countries. Public awareness is without doubt one of the main reasons for this. However, in developing countries, the economic factor is probably one of the most important issues. People living in the most vulnerable houses are usually those with very low income and therefore, it is impossible for them to afford retrofitting costs. In this paper, a system for promoting retrofitting of vulnerable houses through 2-step incentive is presented. To evaluate the effectiveness of the system, three case studies are presented to demonstrate how by implementing the proposed system, damage in terms of human fatalities and economic losses could have been drastically reduced during the 2003 Bam, 2005 Kashmir, and 2006 Java earthquakes [1].

Key Words: Unreinforced masonry, retrofitting promotion system, developing country, PP-band, retrofitting method

INTRODUCTION

Retrofitting low earthquake resistant structures, especially houses, is essential to reduce losses, human and economic, in future earthquakes. Unfortunately, house retrofitting is not swiftly progressing either in developed or developing countries. Lack of public awareness is without doubt one of the main reasons. However, in developing countries, lack of economic resources is probably the most important cause. In these countries, people who live in the most vulnerable houses are those with the lowest income levels. Therefore, a system that provides incentives to them is essential.

Because the economic factor is critical in developing countries, inexpensive locally acceptable retrofitting methods, which consider local availability of materials and do not require highly skilled labor, are necessary. In these countries adobe and masonry construction are the predominant systems. PP-band meshes have been proposed as an alternative solution to this problem [2, 3]. Even though retrofitting by PP-bands can be done with less than US$50 – if installation is done by the house owners –, in many parts of the world, sometimes this amount of money is still unaffordable.

Previous studies have proposed systems for providing incentive for retrofitting [4]. Based on them, this paper presents a two-step incentive system for promoting PP-band mesh retrofitting for adobe/masonry houses. In this study, the government is considered the source of the incentive.

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However, other sources, such as an international funding organization, are also possible. In order to verify the usefulness of the proposal, three case studies were considered: the 2003 Bam, 2005 Kashmir, and the 2006 Java Earthquakes. In these three cases, the situation that was actually faced after the events is compared to the hypothetical scenario in which the proposed system would have been adopted. The comparison is done in terms of human and economic damage.

THE EFFECT OF RETROFITTING

There is no doubt that retrofitting low earthquake resistant houses before an earthquake will reduce human and economic losses when it actually hits. However, how much reduction may be expected? It is possible to quantify this using fragility functions for non-retrofitted and retrofitted structures as well as seismic intensities experienced in the three events that are presented in this paper. Table 1 shows the characteristics of the earthquakes considered.

Table 1. Facts related to the earthquakes considered in the present study

	2003 Bam	2005 Kashmir	2006 Java
Date	December 26, 2003	October 8, 2005	May 27, 2006
Mw	6.6	7.6	6.3
Hypocenter depth (km)	10	10	12
Death toll	43,200	75,035	5,699
Injured	15,000	69,260	37,027
Estimated loss (US$M)	No data	Approx. 3400	Approx. 3700

Figures 1 to 3 show the fragility functions of masonry houses in the regions affected by the earthquakes obtained from field surveys [5, 6, 7, 8 and 9]. It can be seen that the weakest houses were found in Bam area whereas the strongest ones were located in the Kashmir region. In Figure 2, one of the points corresponding to the field survey data falls far from the observed trend. This point corresponds to Batagram where site effects reportedly caused strong ground amplification leading to high intensity shakes which were not reflected in the spatial intensity distributions used in this study.

As mentioned earlier, PP-band meshes were considered for retrofitting of masonry houses because they are affordable and notably improve the structure seismic behavior. Fragility functions for PP-band mesh retrofitted houses were estimated using available experimental data. Because this data is scarce, the curve was defined as the cumulative normal distribution function that best fitted the available data (Figure 4).

Considering the seismic intensity distribution for each event and the corresponding fragility curves for the non-retrofitted and retrofitted masonry houses, the differences in the number of collapse units were calculated as shown in Table 2. Using average house collapse / casualty ratios observed during these events, the number of casualties due to the hypothetically retrofitted houses was estimated. It can be concluded that retrofitting the houses prior to the earthquake could have led to an average reduction of approximately 85% and 80% in the number of fatalities and collapsed houses, respectively.

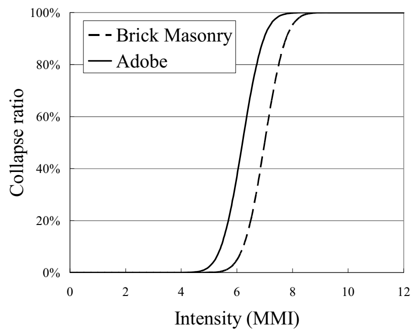

Figure 1. Fragility functions for Bam region

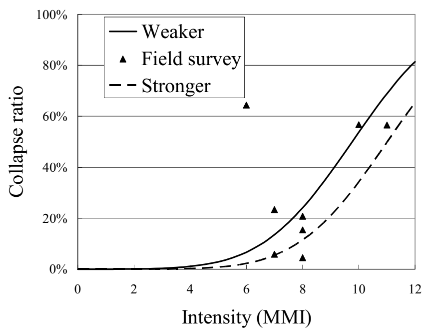

Figure 2. Fragility functions for Kashmir region

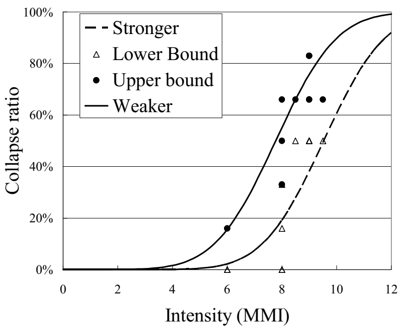

Figure 3. Fragility functions for Java region

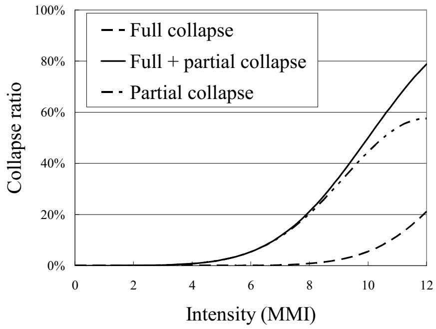

Figure 4. Fragility function for PP-band mesh retrofitted masonry house

Table 2. Comparison of expected losses with and without retrofitting masonry houses

Earthquake → / Item ↓	2003 Bam		2005 Kashmir		2006 Java	
	Without retrofitting	With retrofitting	Without retrofitting	With retrofitting	Without retrofitting	With retrofitting
Totally collapse house / casualty rate	1.13		3.47		33.80	
Partially collapse house / casualty rate			12.01		174.7	
Number of houses (total collapse)	49,000	8,216 (83%)	203,579	5,847 (97%)	154,098	13,080 (92%)
Number of houses (partial collapse)			196,573	67,561 (66%)	199,160	78,550 (61%)
Death toll (from total collapse)	43,200	7,271 (83%)	58,668	1,685 (97%)	4,559	387 (92%)
Death toll (from partial collapse)			16,367	5,625 (66%)	1,140	450 (61%)

*The numbers in parenthesis show the reduction in number of damaged houses and fatalities when retrofitting is implemented.

It is worth mentioning that the partially collapse house / casualty rate should be lower in case of the retrofitted houses because the mechanism of partial collapse is different. Even in the case of total collapse, it takes a longer time for the retrofitted house to fail and therefore fewer casualties are expected. Because there is no data available, the same rates were used to be on the conservative side.

To promote retrofitting in developing countries, the economic factor is very important. It is naïf to expect that the house owners will undertake retrofitting spontaneously when most of them are struggling to procure more urgent basic needs. It is more realistic to recognize that they need some type of subsidy. In the next section, a retrofitting incentive system is introduced and its feasibility is assessed.

PROPOSAL OF THE RETROFITTING INCENTIVE SYSTEM

Figure 5 shows the structure of the two-step incentive system proposed in this study. The first step is providing the house owner with the material for retrofitting plus a subsidy, α, which is given after checking that the house was properly retrofitted. This subsidy is to prevent the house owner from selling the retrofitting material and to give him/her an incentive to retrofit. When the earthquake occurs, the second step incentive is given: those who in spite of having retrofitted their houses face damage, receive larger compensation money than those who have not carried out retrofitting.

The effectiveness of the proposed system was assessed by comparing the difference in costs borne by the incentive given agency (the government for this study) and the house owner if house retrofitting is implemented at different scales. Ten thousand 1-story houses (54m^2 and 2 rooms, see Figure 6) were used for the assessment. The three earthquake scenarios that have been discussed so far were considered. Unit costs for each region are shown in Table 3. To retrofit each house around 4,500 to 5,000m of PP-band, at approximately 3,000yen in Kashimir and 7,000yen in the other regions, were needed. The total cost of retrofitting varies depending on how much of the works are done by the house owner and how much are contracted. In the calculation, other government borne costs resulting from house collapse, such as debris removal, shelter, temporary housing, among others, are not considered. Therefore, the results introduced hereinafter can be considered conservative ones.

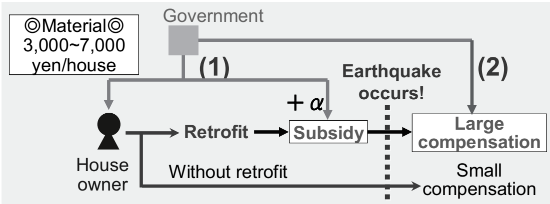

Figure 5. Retrofitting incentive scheme

Table 3. Unit costs used for the analysis

Cost (thousand yen)	Region		
	Bam	Kashmir	Java
New construction	1620	421.2	540
Daily wage	0.96	1	0.45
Compensation (~35% of replacement cost)	600	150	200

Figure 6. Model house considered for the comparative study

Figures 7 and 8 show the cost borne by the house owners (as a group) if they carry out all the works and the government provides or not the 1-step incentive (material cost + α - equal, for example, to the material cost) in case of Kashmir. The different lines represent different levels of system acceptance from 0% (no house is retrofitted) to 100% (all 10,000 houses are retrofitted.) The assumption is that the 10,000 units considered are exposed to a same intensity shake. For example, if 10,000 houses are subjected to an intensity MMI-12 the costs borne by the owners would be approximately 3,500 million yen if retrofitting would not have been done and about 1,000 million yen if it would have been fully embraced. The difference in cost represents the money that the owners have to invest to rebuilt their collapsed houses. Because the incentive money and PP-band cost are relatively low, there is no much difference between Figures 7 and 8. Consequently, the money that the government should prepare for the first step incentive is not so large.

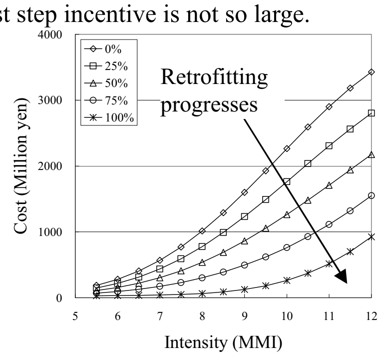

Figure 7. House owner borne cost if all works

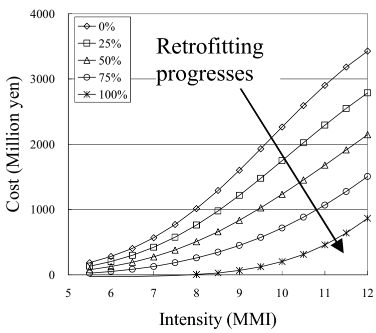

Figure 8. House owner borne cost if all works

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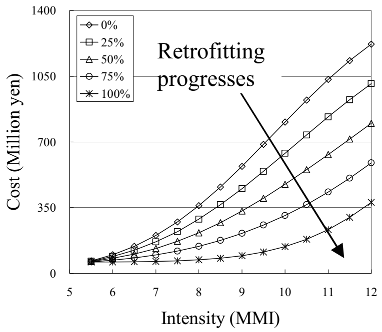

Figure 9. Government borne cost
if compensation is same for all house owners

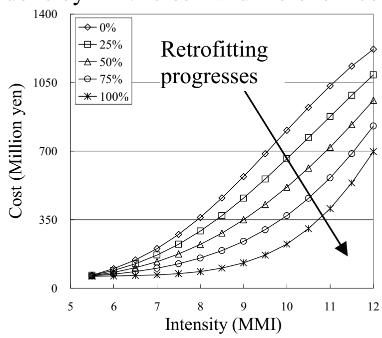

Figure 10. Government borne cost
if compensation is double for house owners
who retrofitted their houses

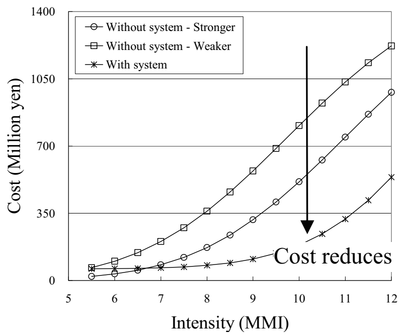

Figure 11. Total government borne cost
(Kashmir)

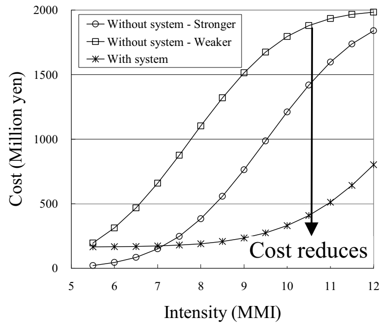

Figure 12. Total government borne cost (Java)

Let us now consider the cost borne by the government due to the 2-step incentive (i.e. compensation after the earthquake occurs). Figures 9 and 10 show the scenarios in which the owner who retrofitted his/her house receives the same or double compensation, respectively, as the owner who did nothing. Although the government expenses increase in the latter, they are still lower than carrying out no retrofitting at all. Therefore, it is concluded that even with the 2-step incentive, the government borne costs decrease if houses are retrofitted. Figures 11 and 12 show the costs borne by the government, including the incentives before and after the earthquake, for Kashmir and Java regions. Retrofitting before the earthquake results in less money spent on the government side.

In the previous calculations, it was considered that all the 10,000 houses were subjected to a single intensity of shaking. However, this is not realistic. In the real situation, there are large areas subjected to low intensities and relatively small areas subjected to high intensities. If this is taken into account, the costs borne by the government and the house owner can be more realistically calculated.

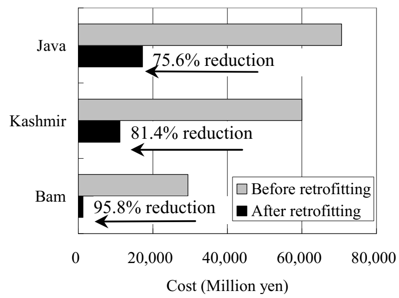

Figure 13. Total government borne cost

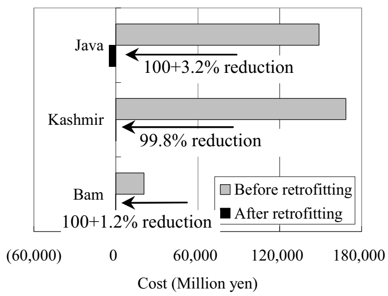

Figure 14. Total house owner cost considering

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For each of the three earthquakes considered in this study, the actual distribution of houses and intensities experienced were used to determine the costs borne by government (Figure 13) and house owners (Figure 14) assuming that the 2-step incentive system was in place before the event. The reduction in government expenses is approximately 95.8%, 81.4% and 75.6% for Bam, Kashmir and Java earthquakes, respectively. On the side of the house owner, the reduction of expenses is even more dramatic and in some cases, the owners profit from adopting the retrofitting promotion system. This is because the government gives the subsidy (α) if retrofitting is satisfactorily carried out before the event.

CONCLUSIONS

Retrofitting of low earthquake resistant houses is fundamental to prevent human fatalities and economic losses in future earthquakes. In spite of this, retrofitting is not progressing smoothly. In developing countries, one of the main reasons is the limitation in economic resources. In this paper, a 2-step incentive system to promote house retrofitting is presented. With this system, house owners are encouraged to retrofit their houses before the event by receiving material for retrofitting and a subsidy upon satisfactorily carrying out the works. If after the earthquake, the retrofitted houses are affected, the owners receive double compensation than the house owners who did nothing. It was found that if this system would have been implemented before the 2003 Bam, 2005 Kashmir and 2006 Java earthquakes, the costs spend by government and house owners could have been dramatically decreased. Consequently, the number of casualties could have been reduced. Although the analysis presented did not include government expenses resulting from structural damage such as debris removal, temporary housing, shelters, etc., the benefits of the retrofitting promotion system for house owners and government were clear. It was demonstrated that by combining technological and social approaches, it is possible to verify the feasibility of implementing weak masonry house retrofitting and consequent drastic reduction of damage due to future earthquakes.

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