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TECHNOLOGICAL AND SOCIAL APPROACHES TO ACHIEVE EARTHQUAKE SAFER NON-ENGINEERED HOUSES

K. MEGURO[1]

[1]*Director/Professor, International Center for Urban Safety Engineering,*
Institute of Industrial Science, The University of Tokyo, Japan
Email: meguro@iis.u-tokyo.ac.jp

ABSTRACT :

Masonry structures are widely used due to its low cost and construction easiness especially in developing countries. In spite of the efforts to provide guidelines for the construction of sound earthquake resistant houses, every year casualties due to collapsing masonry houses during earthquakes are reported. To overcome this situation, retrofitting techniques applicable for both existing and new constructions involving inexpensive materials available in remote regions and low-skill labor as well as social retrofit promotion system are needed. To solve this problem, the author's research group has developed polypropylene band (PP-band) method. PP-band, which is commonly used for packing, is resistant, inexpensive, durable and worldwide available and PP-band retrofit method is a simple, cheap, easy and local acceptable retrofitting method. However, in spite of low retrofitting cost of PP-band method (about \$30-\$70/house for materials), it is still unaffordable for the very low income people. The author's research group has proposed some social retrofit promotion systems – "two-step incentive system" and "new micro-earthquake insurance system" – to solve this problem. Based on the study results carried by the author's research group, by the combination of our proposed technology and social promotion system, it could have been possible to prevent more than 85% of the fatalities due to the 2003 Bam, 2005 Kashmir and 2006 Java earthquakes. Furthermore, the cost borne by the government could have been reduced by at least 75%. With this system, the house owner has to prepare no money and the number of damaged houses could be drastically reduced.

KEYWORDS: Masonry, Seismic Retrofitting, PP-band, Retrofitting Promotion System, Non-engineered Buildings, Developing Country

1. INTRODUCTION

Damage due to past and recent earthquakes, such as the 2003 Bam, 2005 Kashmir and 2006 Java earthquakes, has shown that the collapse of vulnerable houses is the main cause of casualties. These vulnerable houses are mainly masonry structures consisting of adobe, brick masonry, stone masonry, RC frames with masonry infill, among others. Even if a good disaster response system, including rescue operations, and a recovery/reconstruction plan are conceived, earthquake damage, especially human casualties, cannot be reduced unless structural collapse is prevented. Therefore, it is vital to guaranty the seismic strength of new constructions as well as to upgrade the resistance of existing ones. In the former case, "good construction codes", i.e. codes that are complied, are necessary. Complicated codes which are difficult to interpret and put into practice are inappropriate. In addition, an efficient system to ensure the code application should also be established. For existing constructions, technical solutions which emphasize local availability, applicability, and acceptability are required. These should be accompanied by a social system which encourages retrofitting among the general population. Such system should aim at increasing people's disaster awareness and at giving incentives to house owners for retrofitting.

In this paper, I introduce a very efficient retrofit technique and some social systems that promote retrofitting weaker houses, and also show the great effects of their combined approaches.

2. PP-BAND MESH RETROFIT METHOD

Adobe and masonry are the most used construction materials worldwide and also very vulnerable during earthquakes. Considering the key points, a technical solution for retrofitting based on polypropylene band (PP-band) meshes has been developed by the author's research group [1, 2, 3]. PP-band, which is commonly used for packing, is resistant, inexpensive, durable and worldwide available and PP-band retrofit method is a simple, cheap, easy and local acceptable retrofitting method The installation process is very simple and can be performed by the house owner him/herself [1), 2)].

2.1 Performance of PP-band mesh retrofitted masonry structure

In order to verify the effects of PP-band mesh retrofit method, a number of experimental and numerical studies have been done using wallets and wall structures and 3-dimensional miniature and real scaled structures with static and dynamic loading conditions [1, 2), 3)]. Due to space limitation, this paper shows one example of shaking table experiment using unreinforced masonry and PP-band retrofitted masonry houses. The model houses used in the experiment are popular and typical single-storied houses with wooden frame roof.

Sinusoidal motions of frequencies ranging from 2Hz to 35Hz and amplitudes ranging from 0.05g to 1.4g were applied to obtain the dynamic response of the structures. The numbers given in the Table 1 shows the loading sequence used in the tests. General trend of loading was from high frequency to low frequency and from lower amplitude to higher amplitude. Higher frequencies motions were skipped towards the end of the runs. The highlighted numbers in the Table 1 are the last input motion that specimen could withstand.

Table 1 loading sequence and the last run that specimen could withstand

Amplitude (g)	Frequency							
	2Hz	5Hz	10Hz	15Hz	20Hz	25Hz	30Hz	35Hz
1.4		50						
1.2	54	49						
1.0		48						
0.8	53	47	43	40	37	34	31	28
0.6	52	45	42	39	36	33	30	27
0.4	51	44	41	38	35	32	29	26
0.2	46	25	24	23	22	21	20	19
0.1	18	17	16	15	14	13	12	11
0.05	10	09	08	07	06	05	04	03
Sweep					01,02			

A-4-RE-P → 54; A-4-RE-X → 52; A-4-NR-P → 46; A-4-NR-X → 45

B-R-P-S
Brick type: A- unburned brick, B- burned brick
Roof Condition: 0- no roof, 2- roof connected to two walls in direction of shaking, 4- roof connected to all four walls
Surface finishing: X- Paste not applied, P- Paste applied (7.5 mm)
Retrofitting condition: NR- Non retrofitted, RE- Retrofitted

From the table, improvement of performances of masonry house by PP-band mesh retrofit and surface finishing material on the walls can be clearly seen. Figure 1 shows the performances of non retrofitted model A-4-NR-P and retrofitted model A-4-RE-P with different Japan Meteorological Agency (JMA) intensities. Total collapse of the non-retrofitted model A-4-NR-P was observed at the 47th run with intensity JMA 5+ while retrofitted model A-4-RE-P performed moderate structural damage level at 47th run. Moreover, moderate structural damage level of performance was maintained until 48th run, leading to intensity JMA 6-. It should be noted again that this model survived 7 more shakings in which many runs were with higher intensities than JMA 5+ at which the non-retrofitted building collapsed before reaching to the final stage at the 54th run.

When we applied the surface finishing to above house model, due to improve bond connection between PP-band and brick wall, surface plaster kept well with wall. This is not observed in non-retrofitted model. Because of this, brick unit confined effect inside the PP-band mesh is improved and it improves the overall earthquake resistant performance of the structure.

Index	JMA ~4	JMA 5-	JMA 5+	JMA 6-	JMA 6+	JMA 7

D0: No damage - No damage to structure	D1: Light structural damage - Hair line cracks in very few walls.
D2: Moderate structural damage - Small cracks in masonry walls, falling of plaster. The structure resistance capacity is partially reduced.	D3: Heavy structural damage - Large and deep cracks in masonry walls. Failure in connection between two walls.
D4: Partially collapse - Serious failure of walls. Partial structural failure of roofs.	D5: Collapse - Total or near collapse

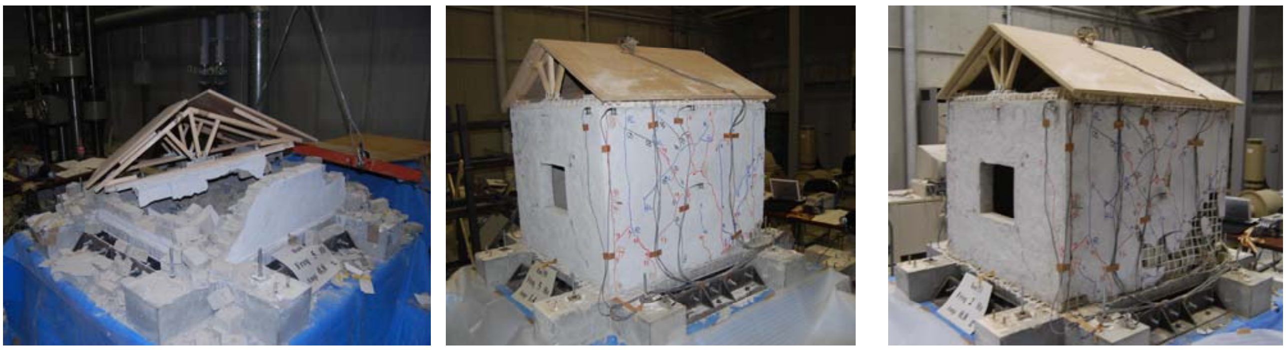
Amplitude (g)	*Frequency (Hz)*							
	2	*5*	*10*	*15*	*20*	*25*	*30*	*35*
1.4								
1.2								
1.0								
0.8		D5	D3	D3	D2	D2	D1	D1
0.6		D5	D3	D2	D2	D2	D1	D1
0.4		D4	D3	D2	D2	D1	D1	D1
0.2	D5	D0	D0	D0	D0	D0	D0	D0
0.1	D0	D0	D0	D0	D0	D0	D0	D0
0.05	D0	D0	D0	D0	D0	D0	D0	D0

(1) Non-retrofit model (A-4-NR-P model)

Amplitude (g)	*Frequency (Hz)*							
	2	*5*	*10*	*15*	*20*	*25*	*30*	*35*
1.4		D3						
1.2	D4	D3						
1.0		D2						
0.8	D4	D2	D2	D2	D1	D1	D0	D0
0.6	D3	D2	D2	D1	D1	D0	D0	D0
0.4	D3	D2	D2	D1	D1	D0	D0	D0
0.2	D2	D0	D0	D0	D0	D0	D0	D0
0.1	D0	D0	D0	D0	D0	D0	D0	D0
0.05	D0	D0	D0	D0	D0	D0	D0	D0

(2) PP-band retrofit model (A-4-RE-P model)

Figure 1 Performance and damage levels of specimen during the experiment



(1) A-4-NR-P after run 47 (JMA 5+)

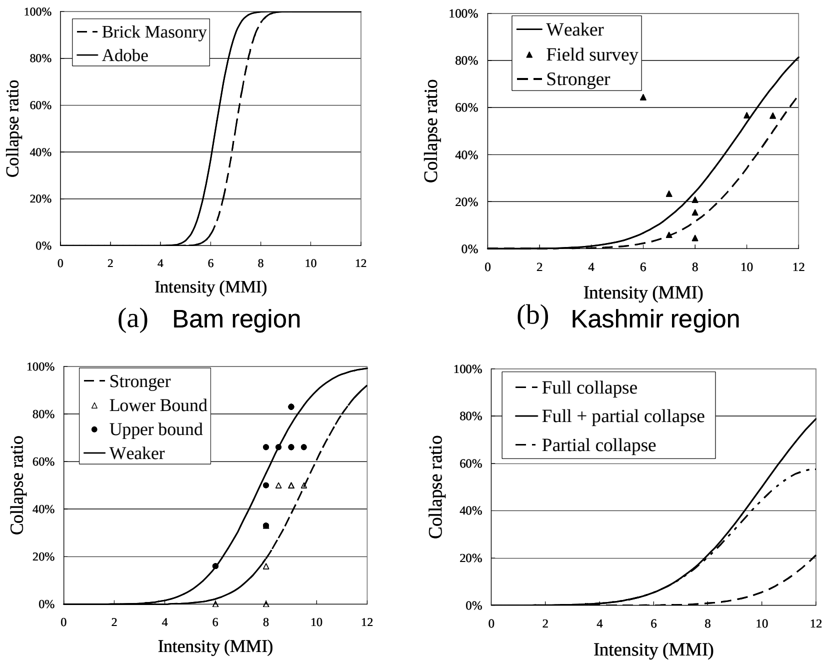
(2) A-4-RE-P after run 48 (JMA 6-)

(3) A-4-RE-P after run 53 (JMA 6+)

Figure 2 Photos of damaged specimen during the experiment

3. THE EFFECT OF RETROFITTING

The effectiveness of retrofitting was quantitatively calculated and is exhibited 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. Figures 3(a) to 3(c) show the fragility functions of masonry houses in the regions affected by the recent earthquakes obtained from field surveys [6, 7, 8, 9, 10]. 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 3(b), 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.



(a) Bam region (b) Kashmir region

(c) Java region (d) P-band mesh retrofitted one

Figure 3 Fragility functions of houses in different regions

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 percentage of damaged houses and fatalities when retrofitting is implemented.

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 3(d)).

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.

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. In non-retrofitted cases, falling blocks of masonry hitting people are the major cause of death. However, in houses retrofitted by PP-band mesh, this phenomenon is prevented. 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 expected 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.

3. PROMOTION SYSTEM FOR SEISMIC RETROFIT

Even if technically attractive retrofit method is developed, if people's disaster imagination capability is poor, retrofit of weaker houses cannot be popular. It is impossible for human to prepare well for unimaginable situation. We should pay much attention to increase disaster imagination of the people to understand the importance of seismic retrofit of weaker houses that is the main cause of casualty and to create some social systems by which house owners are encouraged to retrofit their own weaker houses by themselves. In this chapter, some research activities related to promotion of seismic retrofit are introduced.

3.1 Demonstration of PP-band mesh retrofit construction and shaking table failure test at the affected site due to the 2005 Kashmir Earthquake

Two approaches are considered for the social system to promote retrofitting. The first is to increase people's disaster awareness. For this purpose, demonstrations at earthquake affected areas have been carried out. As an example, I introduced my research group activities in Musafrabad, one of the most affected areas by the 2005 Kashmir Earthquake. One local standard house retrofitted with PP-mesh was constructed to show the people how to built earthquake-resistant houses. Retrofitting material cost for the house was about 30US$ and the installation cost was less than 5 % of the total construction cost for the first trial by the local masons under the supervision of PP-band method experts. As part of the demonstration, two 1/6 scale models, with and without retrofitting, were shaken with an improvised shaking table in order to increase earthquake risk awareness. This event was attended by politicians, local practitioners, mass media people, NGO/NPO representatives, and the general public. All participants could clearly understand the importance of structural strength, ease of installation, and the great effect of PP-band retrofit.

3.2 Proposal of the retrofitting incentive system

As retrofit promotion social system, the author's research group has developed some interesting and efficient models such as the "2-step incentive system" and the "new micro-earthquake insurance system." Due to space limitations, only the "2-step incentive system" is presented in this section.

Figure 4 shows the structure of the "2-step incentive system" proposed by the author's research group[5)]. 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 (54 m^2 and 2 rooms) were used for the assessment with an assumption that each ten-thousand 1-story houses are located at the same MMI area. 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.

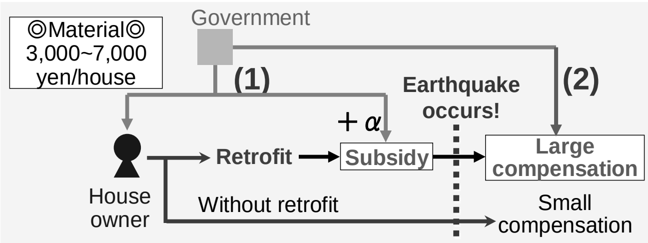


Figure 4 Scheme of 2-step Incentive system

Table 3. Unitary 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

Figures 5 and 6 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 1st-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 rebuild their collapsed houses. Because the incentive money and PP-band cost are relatively low, there is no much difference between Figures 5 and 6. Consequently, the money that the government should prepare for the first step incentive is not so large.

Let us now consider the cost borne by the government due to the 2nd-step incentive (i.e. compensation after the earthquake occurs). Figures 7 and 8 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 9 and 10 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.

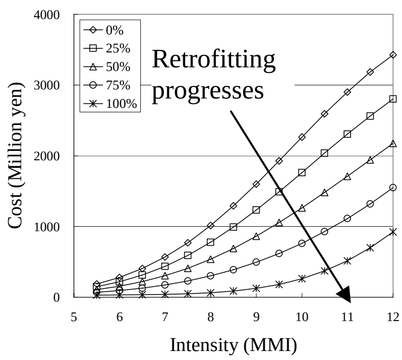


Figure 5 House owner borne cost if all works are done by him/herself and there is no incentive

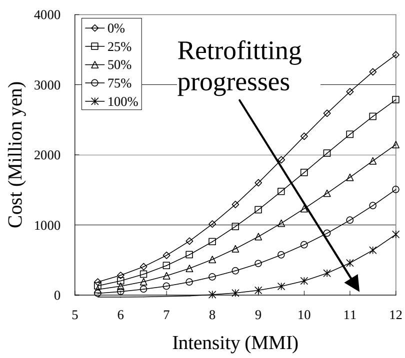


Figure 6 House owner borne cost if all works are done by him/herself and there is incentive

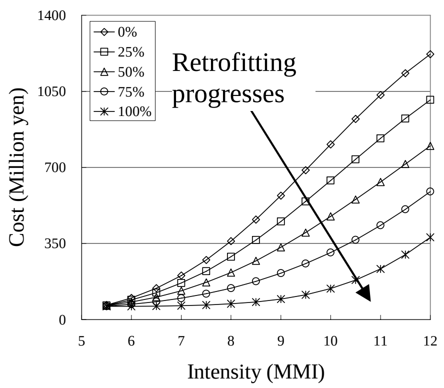


Figure 7 Government borne cost if compensation is same for all house owners

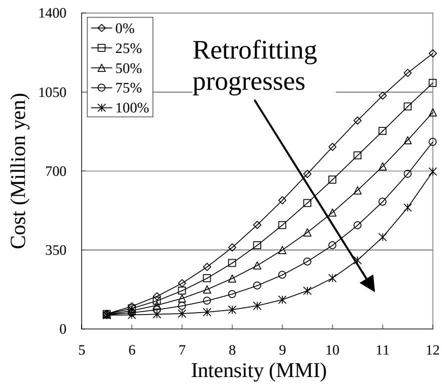


Figure 8 Government borne cost if compensation is double for house owners who retrofitted their houses

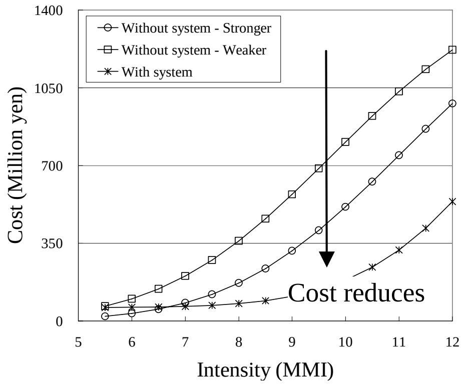


Figure 9 Total government borne cost (Kashmir)

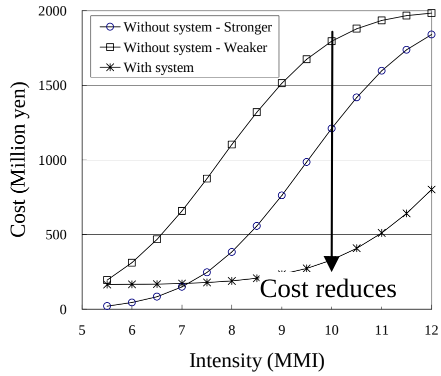


Figure 10 Total government borne cost (Java)

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 lower intensities and relatively small areas subjected to higher intensities. If this is taken into account, the costs borne by the government and the house owner can be more realistically calculated.

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 11) and house owners (Figure 12) 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.

6. 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. For implementation of safer housing, it is important to approach by both technical and social solutions. In this paper, I have introduced the PP-band mesh retrofit method which is local available, applicable, and acceptable as one of best technical solutions, and also, 2-step incentive system as a social system that encourages retrofitting among the general population.

It is found that with the PP-band mesh retrofit method, both new construction and existing low earthquake resistant structures can be strengthened drastically using local available and cheap material and without requiring high skills and any change of life stile of the area. And with a 2-step incentive 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.

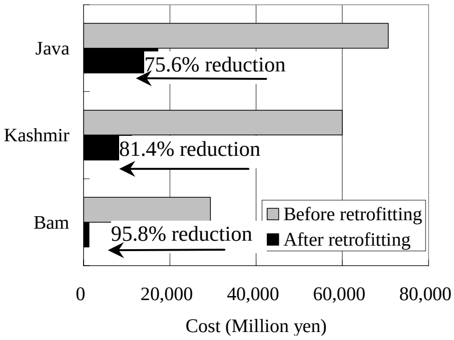


Figure 11 Total government borne cost considering the conditions during the events

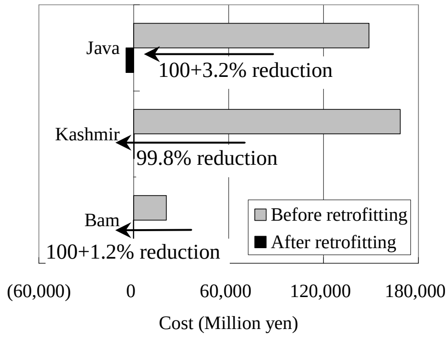


Figure 12 Total house owner cost considering the conditions during the events

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