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PROPOSAL OF RETROFITTING PROMOTION SYSTEM FOR LOW EARTHQUAKE-RESISTANT STRUCTURES IN EARTHQUAKE PRONE COUNTRIES

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SUMMARY

Recent damaging earthquakes have clearly revealed that retrofitting low earthquake-resistant structures is the key issue for earthquake disaster reduction. In this paper, a new system and policies that could serve as driving forces for the promotion of retrofitting of weaker structures are proposed. The main concept of the Retrofitting Promotion System (RPS) is that the government guarantees a portion of the building repair and reconstruction expenses if retrofitting is implemented by the owner following guidelines before the earthquake and in spite of this, the structure is damaged. The effect of applying the RPS to Istanbul in Turkey was investigated on the basis of the recovery activity data after the 1999 Kocaeli earthquake, Istanbul building stock data, and a hypothetical earthquake ground motion. The effectiveness of the RPS was verified and several advantages for both governmental and citizen sides were identified.

INTRODUCTION

Recent damaging earthquakes have clearly revealed that retrofitting of low earthquake-resistant structures is the key issue for earthquake disaster mitigation. Seismic retrofitting not only reduces the damage to buildings during earthquakes, but also the costs of rescue and first aid activities, rubble removal, temporary residence building, and permanent residence reconstruction to re-establish normal daily life. Furthermore, considering the fact that it can also sharply reduce the number of dead and injured people immediately after an earthquake and the various disaster response activities carried out later, a system that could effectively contribute to encouraging seismic retrofitting could be the most important to provide earthquake protection. Unfortunately, retrofitting is not wide-spread, especially for non-public use structures in almost all the seismic prone areas in the world. Generally, there are three main reasons that make retrofitting of residential buildings difficult to be implemented; insufficient retrofitting techniques, unawareness for structural damage due to an earthquake and lack of proper laws and system by which retrofitting activities become popular among the population. Seriousness among these three reasons may be different according to the situation of the countries. Focusing on the lack of proper laws and system for

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promoting retrofitting, we have proposed a new system, Retrofitting Promotion System (RPS) that could serve as driving forces for promoting retrofitting of weaker structures in Japan. With the system, the government guarantees a portion of the building repair and reconstruction expenses of the damaged and/or collapsed buildings under the condition that the owners have retrofitted their buildings following guidelines before the earthquake.

In this paper, as the first step for proposing global model of retrofitting promotion system for low earthquake-resistant structures, promotion strategies using the RPS are discussed in Istanbul in Turkey, one of the earthquake prone areas. Firstly, current system related to retrofitting activities in Turkey is compared with that in Japan and problems with the existing system are identified. Secondly, the effects of applying the RPS to 10,000 residences under different hypothetical earthquake ground motions in Istanbul are verified according to the degree of the system acceptance on the basis of the recovery activity data after the 1999 Kocaeli earthquake, Istanbul building stock data and fragility curves. Moreover, the balance between system design and development of retrofitting techniques is also analyzed. As the results, the effectiveness of the RPS is verified and several advantages for both governmental and citizen sides are identified.

IDENTIFICATION OF CURRENT SYSTEM PROBLEMS

Hypothetical Earthquake Ground Motion and Building Distribution

Geologically, Turkey is located at the boundary area where the Arabian Plate and African Plate are moving north towards the Eurasian Plate. Many strong earthquakes have historically occurred along the Northern Anatolia Fault (NAF) that is more than 1,000km long from east to west in the northern area. The 1999 Kocaeli earthquake with the magnitude 7.4 caused tremendous damage to human lives and structure. Recently, seismologists are paying much attention to the phenomena that the epicenters of latest earthquakes are migrating from east to west along NAF. They are pointing out the possibility of another big earthquake hitting Istanbul which is located at the western edge of NAF. Japan International Cooperation Agency (JICA) and Istanbul Metropolitan Municipality (IMM) published the study on a disaster prevention / mitigation basic plan in Istanbul including seismic microzonation in September 2002. Among four scenario earthquakes at Istanbul considered in this report [1], the fault model as shown in Fig.1 was chosen as a most probable model. The moment magnitude (Mw) for this case is estimated as

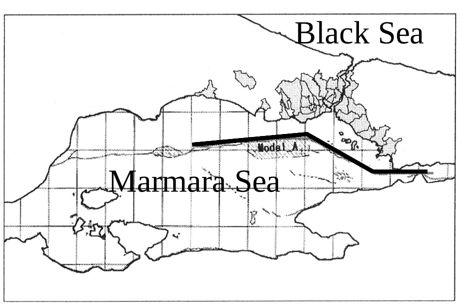


Figure 1: Fault Model

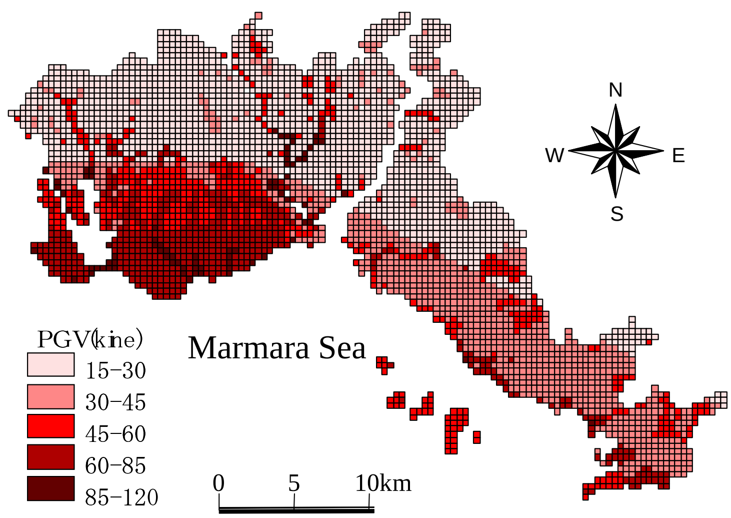


Figure 2: Hypothetical PGV in Istanbul

7.5 and the corresponding hypothetical Peak Ground Velocity (PGV) distribution is shown in Fig. 2. Figure 3 shows the classification of building in Istanbul according to the building types and the number of stories. 543,622 RC frame brick infill residences and 168,100 masonry residences account for 75% and 23.2% of the total, respectively. Figure 4 shows the distribution of buildings according to the building types, the number of stories, and the hypothesized earthquake ground motion at the building location. It can be seen that many buildings are located in the regions with PGV ranging from 20 to 80 kines (cm/s).

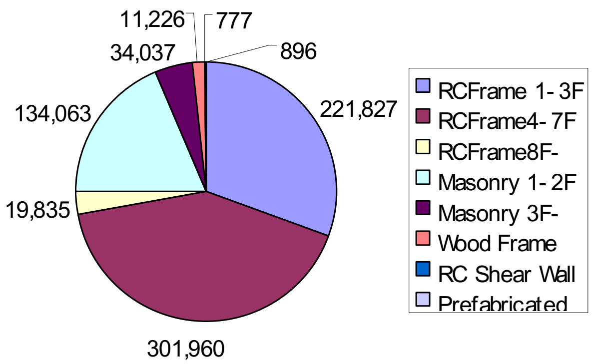


Figure 3: Classification of Buildings According to the Building Types and the Number of Stories

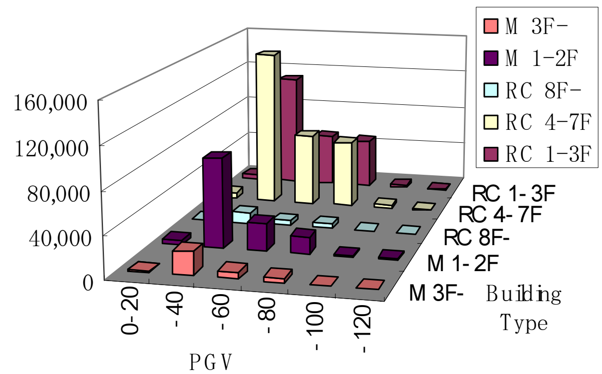


Figure 4: Distribution of Buildings According to Building Types, the Number of Stories, and the Hypothesized Ground Motion

Building Code and Building Strength

The first set of explicit legal provision for earthquake resistance in Turkey appeared in 1944. This was in reaction to a series of severe earthquakes that started with the Erzincan Erarthquake in 1939 with the magnitude 7.9. Buildings were regulated with a set of construction requirements and a map defining the different seismic regions. The most recent earthquake code went into effect in 1998. Between 1944 and 1998, the building code was revised in 1961, 1968 and 1973. Figure 5 shows the fragility curves by JICA•IMM [1]. The damage ratio is represented by a logarithmic normal distribution. These are the fragility curves of RC frame brick infill residences with 1 to 3 floors and masonry residences with 1 to 2 floors constructed before 1970.

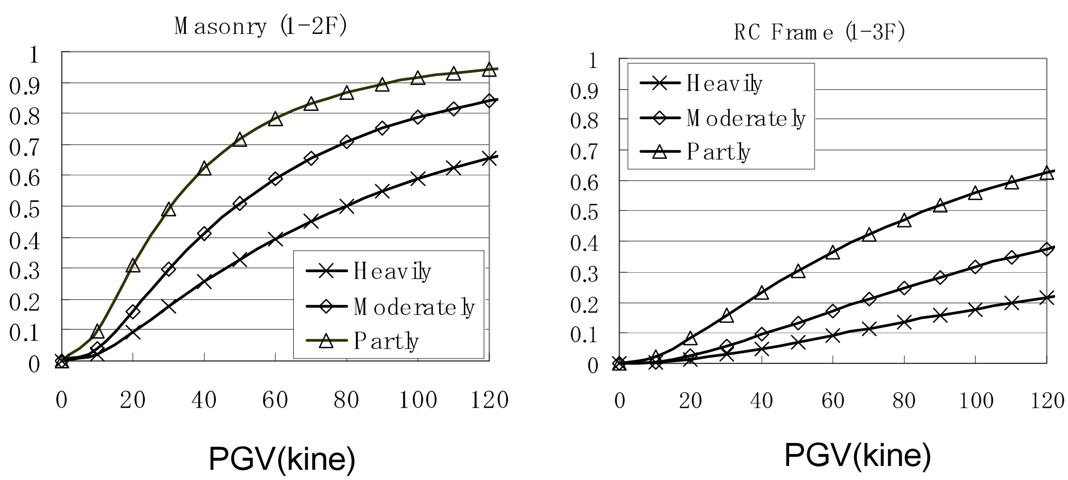


Figure 5: Building Damage Fragility Curves

Social Conditions Resulting from Building Damage

According to JICA•IMM [1], the numbers of heavily, moderately and partly damaged buildings due to a hypothetical earthquake were estimated to be 51,477, 113,535 and 252,370, respectively. In this part of the study, problems with the present system were clarified by foreseeing the social situation in case an earthquake occurs under the present system.

Whenever an earthquake occurred in Turkey, the support that the government provided to the owners of damaged residences during the emergency recovery phase included setting up of tents, constructing temporary residences, and cleaning up rubble. The cost for supplying temporary residences was calculated referring to the provision of temporary residences following the 1999 Kocaeli Earthquake and is equal to US$4,717 per dwelling. On the other hand, the cost of cleaning rubbles after Kocaeli Earthquake was US$28,758,170 for 60,503 demolished houses or approximately US$1,163 per building. During the recovery and restoration phase, new permanent residences are constructed, and house owners of heavily damaged residences can obtain those residences with long-term low interest loans. Following the Kocaeli Earthquake, permanent residences were constructed by the government at a cost of US$42,000 (including the cost of utility connections and other infrastructure) and provided to the people at a price of US$12,000. The government provides financing for purchasing permanent residences. According to Nakabayashi [2], those money are repaid within 20 years at an extremely low interest rate and no payments during the first two years1). However, considering an economy in Turkey with a high inflation rate, these conditions resemble more a donation than a loan.

The government expenditures after residences are damaged include the cost of temporary residences, the rubble removal, and permanent housing construction. A study team for the Japan Bank for International Cooperation (JBIC) calculated the total economic damage in Istanbul area following the building damage due to a hypothetical earthquake described in Fig.1 and Fig.2. JBIC [3] reported that the total economic amounts to US$30.4 billion that corresponds to 15.2% of Turkey's US$199.9 billion GDP for 2000. Moreover, the total government expenditure after residential damage is estimated to be US$7.3 billion, which amounts to 3.6% of Turkey's GDP. This shows that the current aid for the owners of damaged residences is excessive. It is not realistically possible for the Government of Turkey to provide this level of assistance to disaster victims following an earthquake. Moreover, this system acts as a force that discourages ordinary citizens to retrofit their buildings. It is essential to improve the seismic performance of buildings in advance and to review the existing system.

Retrofitting Cost

The interview survey in Turkey revealed that the cost of seismic retrofitting buildings in Turkey is extremely high because the current building strength is very low. The US$30/m2 cost for seismic retrofitting is equal to 3/4 of the US $40m2 cost of constructing the structure of a new masonry building. The situation is Japan is quite different. The costs of retrofitting wooden and RC buildings are 1/10 and 1/8 of the cost of constructing a new house. The high cost of seismic retrofitting in Turkey discourages people to retrofit. Therefore, it is necessary to lower the retrofitting cost by improving retrofitting technologies and adopting a system of government support for retrofitting.

PROPOSAL OF RETROFITTING PROMOTION SYSTEM (RPS)

On 27th Oct 1995 after the Kobe earthquake, Japanese government established the Retrofitting Promotion Law. The objective of this law is the promotion of retrofitting of the structures that are constructed before 1981 with the previous revision of seismic design code, in order to make them compliant with the latest code revision. Because its target are only large structures such as schools, hospitals, hotels, markets etc, retrofitting activities are not carried out seriously especially for non-public structures i.e. private houses. However, the problem with these buildings is more severe than with public buildings. To overcome these difficulties, some municipalities or local governments have proposed laws to promote retrofitting activities such as, the assistance system, and the low interest loan for seismic evaluation or retrofitting of structures.

Unfortunately, so far, there is no municipality in which the retrofitting activities have been successfully carried out in Japan. There are many reasons for this, however, the most important is the difficulty that ordinary people have to understand the effects of structure retrofitting. If this problem is solved by explaining the citizens the advantages of retrofitting, the next problem encountered will be budgetary. Namely, if the number of people who want to retrofit their structure suddenly increases, it will be practically impossible for the local government to prepare such a huge fund.

In order to solve this problem, we have proposed a new Retrofitting Promotion System (RPS) as a driving force to promote the retrofitting of the existing pre-code revision structures in Japan. Under this system, the government bears a portion of the building repair and reconstruction expenses if retrofitting is implemented by the owner following the guidelines before an earthquake and in spite of this the structure is damaged. The flow of money under RPS is described in Fig.6. The RPS can creates an environment that encourages retrofitting by providing incentives to citizens to retrofit without causing budgetary problems for the government before the earthquake. For this system to be fully and successfully operational, it will be necessary to establish an autonomous body to judge whether structures have been adequately retrofitted according to appropriate structural strengthening standards. Money should be paid to this entity to get its certification. This fund can be later used for incentive money, or the money paid to the owners whose houses were damaged in spite of having strengthened them.

As a result of the case studies [4] applying RPS hypothetically to some earthquake prone area in Japan, it was verified that this system can contribute to reduce the earthquake damage and the governmental cost burden after the earthquake. Moreover, it gives the residents economic advantages. Based on these studies, we propose to apply the RPS to Istanbul. It is a part of the study for expanding the RPS to a global model for promoting retrofitting that can be applicable to the earthquake prone area in the world.

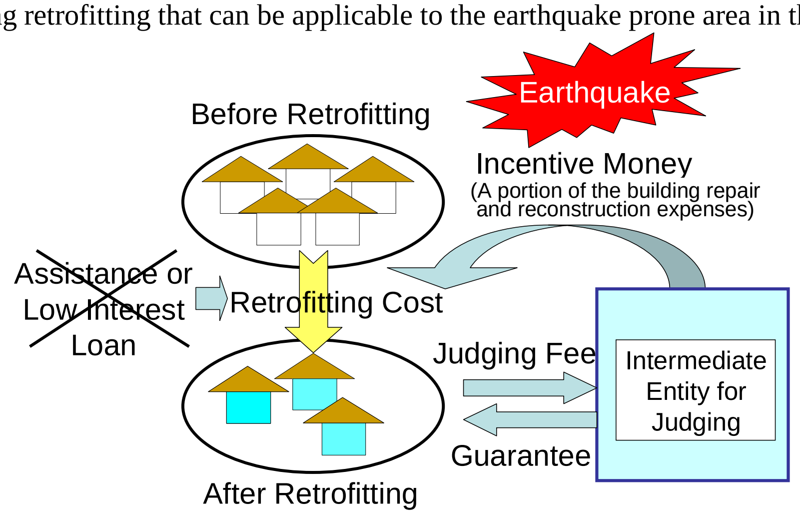


Figure 6: Money Flow under RPS

ANALYSIS OF THE EFFECTIVENESS OF RPS APPLIED TO 10,000 RESIDENCES

The effects of applying the RPS to 10,000 residences under different hypothetical earthquake ground motions in Istanbul were verified according to the degree of the system acceptance. As pointed out in the study of the conditions resulting from a hypothetical earthquake, the present system of supplying permanent residences gives house owners no incentive to retrofit their own houses. It also forces the government to bear a heavy burden when earthquakes occur in the future. One way of resolving these two problems is the abolition of supplying permanent residences. However, because the current system is beneficial for citizens, they will surely oppose the abolition of the current system. Taking this into consideration, as a first step, the effectiveness of the RPS while maintaining the current system was studied. Then, an ideal RPS was explored.

Change in the Cost Burdens for Both the Government and Citizens

Table 1 summarizes the changes in the cost burdens for both the government and citizens after the introduction of the RPS based on current system. In order to offer greater incentives to citizens, money will be given to cover a part of the cost of repairing buildings moderately or partly damaged. As for demolished buildings, providing permanent residences in the past will be expanded to include incentive money to cover part of the cost of re-establishing their lives. This is an extremely generous system that will, in turn, encourage the public to seismically retrofit their buildings.

The incentive money paid for a home that was destroyed even though it had been retrofitted was set at twice the cost required for seismic retrofitting. It was also assumed that the incentive money paid for a moderately damaged home and a partly damaged home is equivalent to half and 1/3 of the amount paid for a destroyed home. Table 2 shows the payment of incentive money in case of a masonry residence with 1 to 2 floors based on the cost for retrofitting obtained by the interview survey.

Table 1: Changes in the Cost Burdens under the RPS Based on Current System

Before Introduction of RPS	Various Costs	After Introduction of RPS
House owners	Seismic retrofitting	House owners
House owners	Structural and equipment damage	House owners
Government	Cost of removing rubble	Government
Governments	Constructing temporary residences	Government
House owners	Repairing moderately and partly damaged residences	House owners + Government (Incentive money)
Government (Permanent residences)	Reconstructing demolished residences	Government (Permanent residences + Incentive money)

Table 2: Incentive Money in case of a masonry residence with 1 to 2 floors

		Cost According to the Damage Type		
Various Cost	Unit	Demolished	Moderately	Moderately
Floor Area	m^2	200		
Seismic Retrofitting	$/$m^2$	30		
Construction of Structural Part	$/$m^2$	40		
Construction of Equipment Part	$/$m^2$	60		
Repair of Damage	$/$m^2$		13	8
Incentive Money				
Based on Current System	$	12,000	6,000	4,000
Under Ideal System	$	20,000	6,000	4,000

Table 3: Changes in the Cost Burdens Following Introduction of the Ideal RPS

Before Introduction of RPS	Various Costs	After Introduction of RPS
House owners	Seismic retrofitting	House owners
House owners	Structural and equipment damage	House owners
Government	Cost of removing rubble	Government
Governments	Constructing temporary residences	Government
House owners	Repairing moderately and partly damaged residences	House owners + Government (Incentive money)
Home owners	Reconstructing demolished residences	Government (Incentive money)

Under the ideal RPS, supplying permanent residences is abolished as shown in Table 3. Instead of this, the incentive money for the owners of heavily damaged residences is set at the amount that enables the owners to construct a new house (Table 3).

Building Strength after Retrofitting

The improvement of seismic performance of buildings through retrofitting is represented by changes in the shape of fragility curves. Specifically, on the fragility curves, retrofitting increases the mean value of logarithmic normal distribution to a degree equal only to the standard deviation. Figure 7 shows the fragility curve of masonry residences with 1 to 2 floors before (described as thick lines) and after (thin lines) retrofitting. The building strength improvement by retrofitting was determined from the interview survey with the experts in Turkey and the difference between the fragility curves of pre and current building –code reported by Murao and Yamazaki [5] in Japan.

RPS Effectiveness Based on Current System

The effect of applying the RPS based on current system was investigated from the viewpoint of both government and citizens. Here, a case in which 10,000 masonry residences with 1 to 2 floors located in different regions and therefore exposed to different hypothetical earthquake motions is introduced. This is the building type with the lowest earthquake-resistance among the building types shown in Figure 3. Figure 8 shows how the number of demolished residences changes according to PGV and the acceptance of the RPS. The RPS is assumed to spread with the acceptance ratio of 0, 25, 50, 75, and 100% among 10,000 residences. In case that the citizens bear the cost of retrofitting, in regions where the earthquake motion is 60 kine or less, the more retrofitting is performed, the higher the overall burden on citizens is (Figure 9-a). The arrow on the figure shows the trends as the RPS spread. This trend is because the increase in the cost of retrofitting resulting from the spread of the RPS will exceed the reduction in the citizens' burden in case that the citizens bear the total retrofitting cost. Considering that 87% of the masonry residences with 1 to 2 floors are in the region with the PGV less than 60 kine, bearing the full cost of seismic retrofitting will not provide an incentive to all the citizens under the present circumstances. Then, the citizens' profit by obtaining permanent residences is taken into account for estimating the cost burden on citizens. The higher the earthquake ground motion is, the more profit the citizens gain instead of losing their asset, because the obtained asset value exceeds the expenditure due to an earthquake (Figure 9-b). This clearly reveals that the current system that promises providing a permanent residence to the owner of a destroyed home eliminates incentives for ordinary citizens to retrofit their own buildings.

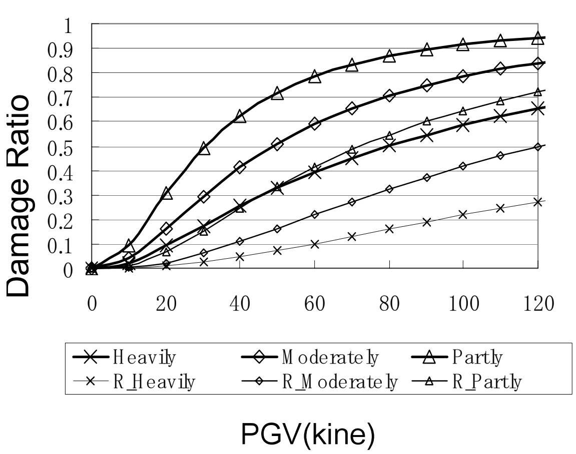


Figure 7: Fragility Curves Before and After Retrofitting

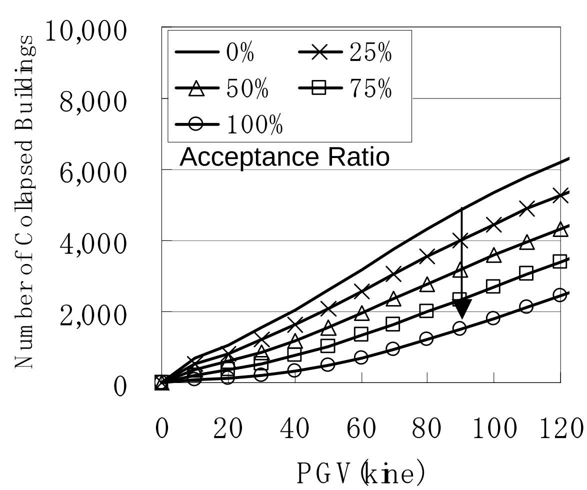
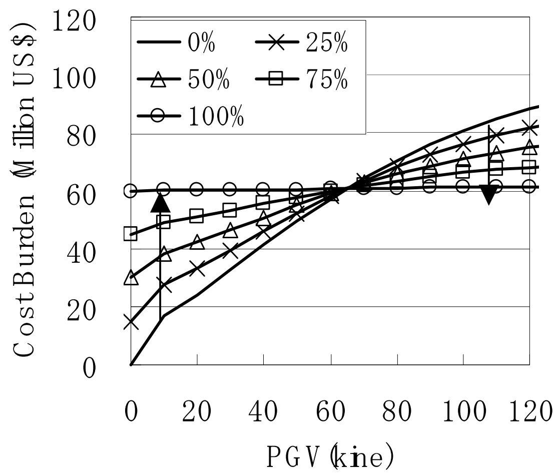
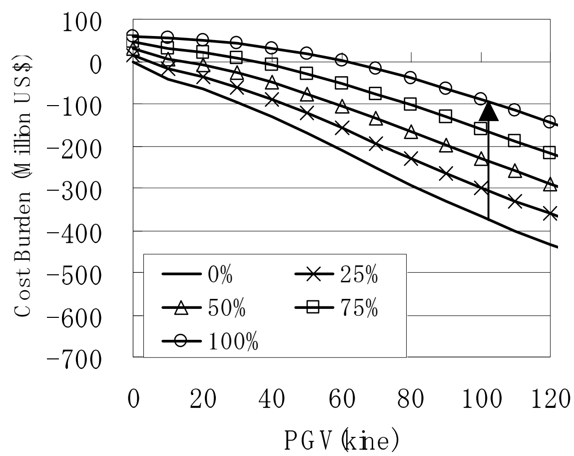


Figure 8: Number of Demolished Residences

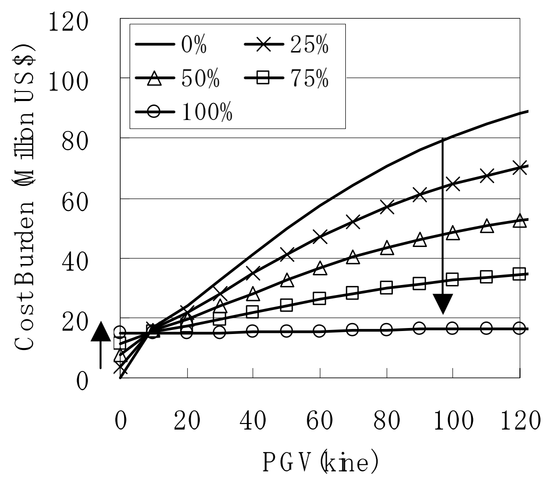
If the retrofitting cost is assumed to be US$7.5/m2 that is 1/8 the cost of constructing the building structure, as it is in Japan, the cost burden on citizens falls in the region with the PGV more than 10 kine as the system spreads (Figure 9-c). Considering that all the masonry residences with 1 to 2 floors are in the region with the PGV more than 10 kine, this shows that all the citizens will benefit from the RPS if new low cost retrofit techniques are available. It is extremely important to support the improvement of the retrofitting technology to enhance the effectiveness of the RPS.
Focusing on the government's cost burden, in case that the citizens bear the entire cost of retrofitting, the greater the RPS acceptance, the lower the cost burden on the government is (Figure 10). This shows that because the costs of temporary residences, permanent residences, and rubble removal are all sharply reduced due to the building strengthening, the total cost burden will be reduced even if incentive money is paid to owners of damaged residences. The reduction in cost burden proves to be the advantage of introducing the RPS for the government.



(a) Cost Burden on Citizens



(b) Cost Burden on Citizens (Including Obtained Profit by Permanent Residences)



(c) Cost Burden on Citizens (Low-cost Retrofitting)

Figure 9: Cost Burden on Citizens in Case of the RPS Based on the Current System

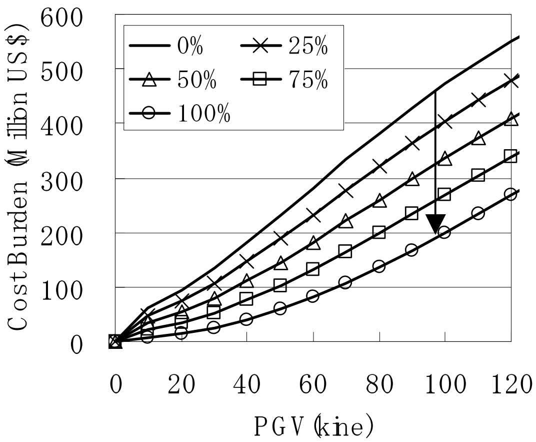


Figure 10: Cost Burden on Government in Case of the RPS Based on the Current System

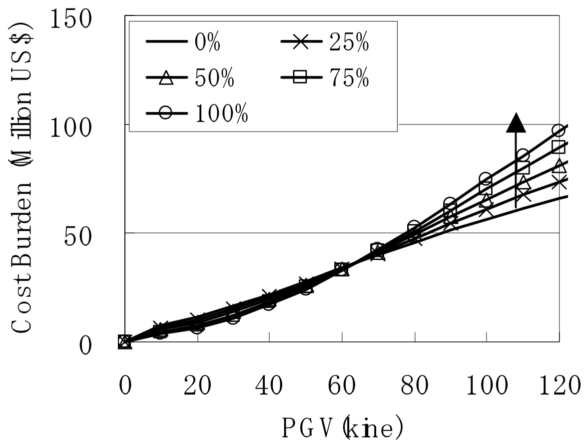


Figure 11: Cost Burden on Government in Case of the Ideal RPS

Effectiveness of the Ideal RPS

Next, the effect of applying the ideal RPS to 10,000 masonry residences with 1 to 2 floors located in different regions was investigated. The government's burden increases with the system spread, because high incentive money for demolished residences imposes huge expenditures on the government (Figure 11). However, comparing the government cost burden under the system based on the current system and under the ideal RPS, it can be observed that its cost is drastically reduced due to the abolishment of the system of supplying permanent residences. This ideal system is strongly recommended in order to prevent the bankruptcy of the Turkish Government due to the excessive burden that the government should bear to supply permanent residences to the citizens that lost their houses.

CONCLUSIONS

In this paper, we propose new Retrofitting Promotion System (RPS) that could serve as driving forces for the promotion of retrofitting of weaker structures. The RPS was hypothetically applied to Istanbul in Turkey and its effectiveness was evaluated on the basis of the recovery activity data during the 1999 Kocaeli earthquake, Istanbul building stock data and hypothetical earthquake ground motion. The analysis confirmed the advantages of the RPS for both governmental and citizen sides. The RPS will be more effective if new low cost retrofit techniques are available. In order to effectively apply the RPS, not only its introduction and presentation through educational campaigns are necessary, but also the study of methods to improve seismic retrofitting techniques.

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