Lessons learned from past big earthquake disasters and comprehensive disaster management for implementation of disaster resilient society

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ABSTRACT

There have been many big earthquakes causing numerous casualties and large economical loss in the world. Even in the 21st century, there are nine earthquake disasters with more than 5,000 fatalities. For minimizing negative impact due to natural hazard, there is a comprehensive disaster management system, which is composed of seven-phase countermeasures. They are three pre-event measures, 'damage mitigation', 'preparedness', and 'disaster prediction and early warning', and four post-event countermeasures, 'damage assessment', 'emergency disaster response', 'recovery', and 'reconstruction'. There are three players for each countermeasure, individuals and companies for self-help effort, community and/or group for mutual assistance, and national to local governments for public support.

Based on the experiences and lessons learnt from past disasters, I have developed a new system that can support making proper regional disaster management plan and this will be a base for making action plans for each player and each phase of countermeasures considering natural and social conditions of the target regions. With the proposed system, ideal and current situation matrixes of disaster countermeasure can be created and by comparing the two, prioritized specific actions for each player can be indicated.

We cannot prevent earthquake occurrence. Earthquake does not kill people but structures do. It is very difficult to save people by post-event countermeasures, such as search and rescue operations. Today's poor-quality structures will be negative inheritance in next generations and attack their society. Today's poor disaster management system will cause more damage in the future. However we can drastically reduce earthquake damage by creating disaster resilient society which is possible by implementing seven-phase structural and non-structural measures, both of which are locally feasible and acceptable, in a well-balanced manner.

Keywords: disaster resilient society, comprehensive disaster management, pre-event and post-event countermeasure, disaster life cycle

1. INTRODUCTION

There have been many large earthquakes causing many casualties and structural damage in the world. Figure 1 shows 21 catastrophic earthquake disasters with over 5,000 fatalities in the last 100 years including nine disasters happened in the 21st century. Excluding four events, collapse of masonry structures was the major cause of damage and accounted for approximately 80 % of all fatalities. Due to the following three reasons, many more people have been killed by the collapse of masonry structures. First, is the failure behavior of masonry structures is brittle and the occupants cannot get enough evacuation time when it collapses, secondly, it is very difficult to keep survival space as the size of structural members and main materials, i.e. bricks, stones, and blocks is small and survival space is filled with these small pieces of materials, and thirdly, during the collapse of masonry structure, heavy dust is generated and the occupants are suffocated even if they survived the collapse.

In this paper, to reduce earthquake damage and implement earthquake disaster resilient society, I will introduce some important points on what we should do.

Year	Location	Fatalities	Magnitude
1915	● Avezzano (Italy)	32,610	7.0
1920	● Haiyuan (China)	200,000	7.8
1923	✸ Kanto (Japan)	105,000	7.9
1927	● Gansu (China)	40,900	7.6
1934	● Bihar, India-Nepal	10,700	8.1
1939	● Erzincan (Turkey)	32,700	7.8
1948	● Asgabat (Tukemenistan)	110,000	7.3
1970	● Cimbote (Peru)	70,000	7.9
1976	● Tangshan (China)	242,769	7.5
1990	● Western Iran	50,000	7.4
1995	○ Kobe (Japan)	6,434	7.3
1999	● Turkey	17,118	7.6
2001	● Gujarat (India)	20,085	7.6
2003	● Bam (Iran)	31,000	6.6
2004	▣ Sumatra (Indonesia)	227,898	9.1
2005	● Kashmir (Pakistan)	86,000	7.6
2006	● Java (Indonesia)	5,749	6.3
2008	● Sichuan (China)	87,587	7.9
2010	● Haiti	316,000	7.0
2011	▣ East-Japan (Japan)	20,896	9.0
2015	● Kathmandu (Nepal)	8,000	7.8

Major cause of damage: ● : Collapse of masonry structures, ✸ : Fires, ○ : Collapse of wooden structure, ▣ : Tsunami

Figure 1 Catastrophic earthquake disasters with over 5,000 fatalities in the last 100 years

2. COMPREHENSIVE DISASTER MANAGEMENT SYSTEM

In order to minimize the negative impact due to natural hazard, there is a comprehensive disaster management system as shown in Figure 2. This management system is composed of seven-phase countermeasures. They are three pre-event measures, 'damage mitigation', 'preparedness', and 'disaster prediction and early warning', and four post-event countermeasures, 'damage assessment', 'emergency disaster response', 'recovery', and 'reconstruction'. All seven-phase countermeasures (six-phase if recovery and reconstruction are considered as one phase) combined is called "Disaster Life Cycle" and information and communication play important roles at all phases.

Followings are brief explanation of each phase of the countermeasures. 'Damage mitigation' consists of two countermeasures i.e. structural mitigation and land use management mitigation measure, resiliency of the site is improved and damage will be reduced. Structural mitigation measure improves structural performance, such as seismic retrofit of weak structures in case of earthquake disaster and increasing height of embankment and breakwater in case of flood and Tsunami disaster. Land use management mitigation measure is the effort by which people are guided to move from high disaster potential areas, such as bad soil condition area and low land with high flood risk to better conditioned area. The aim of 'Preparedness' is to reduce affected area or velocity of propagation of negative impact by preparing before the hazard attacks, i.e. preparation of organizations for disaster response, pre-disaster recovery and reconstruction plan and disaster manual, and also conducting training and drill. 'Disaster prediction and early warning' is that although earthquake prediction is difficult, practically impossible but in case of typhoons and Tsunami disaster, we can predict disaster and give the information before the hazard attack and then we can drastically reduce damage, especially human casualties. After hazard attack, what we should do first is 'damage assessment' that is to assess the amount and kind of damage and their distribution as soon and accurate as possible. Based on the assessment result, what we should do next is 'emergency disaster response' and the main purpose is prevention of secondary damage and to rescue the people, and it does not include the recovery of the affected area. Therefore, 'recovery', and 'reconstruction' should follow. Considering the fact that disaster happened under the condition of what the affected area was, the aim of 'recovery', and 'reconstruction' is not enough to just recover what it was before hazard attacked. Better conditioned area should be created using the disaster as an important opportunity to improve the affected area. This is called 'Build Back Better' that is an important concept included in the statement by Japanese government at the United Nations' World Disaster Conference held in March 2015 in Sendai, Miyagi Prefecture, Japan.

At all seven phases of disaster management, it is necessary to understand that the government is not only the player in disaster management. There are three players for each countermeasure, individuals and companies for self-help effort (SE), community and/or group for mutual assistance (MA), and national to local governments for public support (PS). Also, it is necessary to act based on the idea that one must protect one's own life.

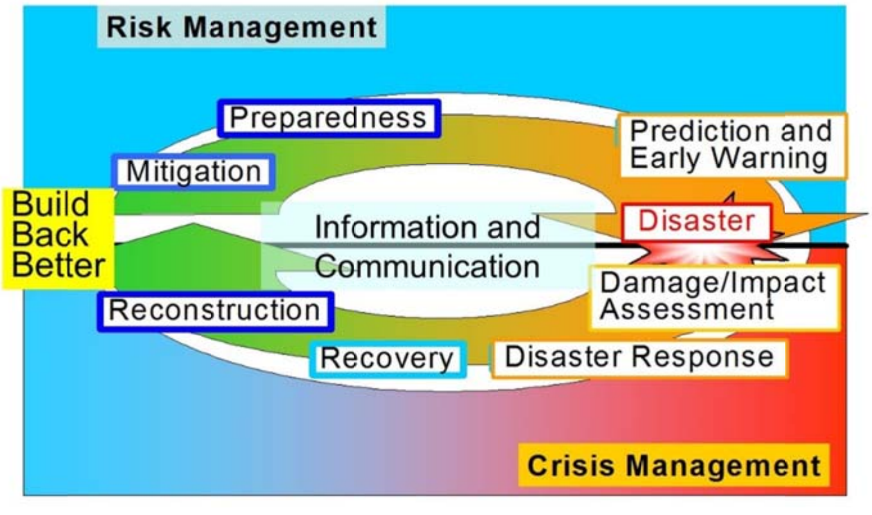

Figure 2 Comprehensive disaster management system for minimizing negative impact

3. DISASTER COUNTERMEASURE MATRIX AND PROMOTION OF COMPREHENSIVE DISASTER MANAGEMENT

3.1 Disaster Countermeasure Matrix

Disaster Countermeasure Matrix (DCM) shown in Figure 3 represents the idea that in all countermeasure phases, there are tasks for three players for PS, MA, and SE. The countermeasure by three players is often complementary to each other and it must be well-balanced. In other words, if the work is concentrated in only PS part, the cost could be enormous while if each individual and company put an effort and cooperate with each other, it could be much more effective with less cost. Therefore, PS should promote MA and SE rather than enhancing people's dependency to PS. In order to realize this situation, disclosure of information about the disaster risk to the general public becomes important.

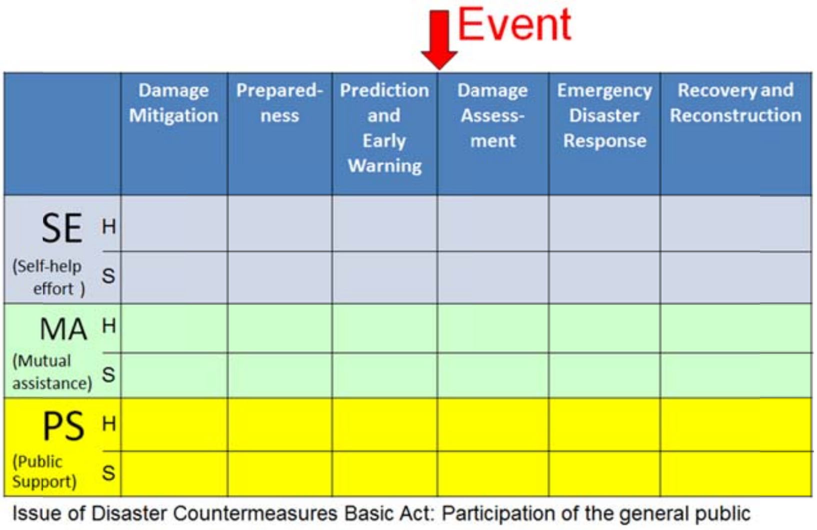

Figure 3 Disaster Countermeasure Matrix (DCM)

3.2 Method for promoting comprehensive disaster management

In order to efficiently conduct disaster management countermeasures, it is important to make appropriate combinations of regional characteristics, target disaster types, available time and budget at each phase. Figure 4 shows the specific procedure. Local government officials in disaster section should start by filling up the matrix with as many countermeasures as possible. This approach can be applied not only for earthquake and Tsunami but also for all other types of disaster. However, the contents will differ based on the type of hazard and thus DCM for each type of disaster needs to be created and all necessary disaster matrixes should be integrated (Figure 5).

1) Describe specific countermeasures as many as possible for each phase and player with structural (H) and non-structural (S) measures. This is called Ideal Situation Matrix (ISM) to achieve goal (G). Then, next describe specific countermeasures that they have done so far in target area. This is called Current Situation Matrix (CSM) to show the present environment (P) in terms of disaster countermeasures.
2) The difference between the "ISM" and "CSM" (G-P) indicates the Action Item Matrix (AIM) that needs to be conducted with priority.

3) For each countermeasure in the "AIM", add the responsible division, necessary time & budget and its effect. It is important to work on this section together with site operators because it is not easy for disaster division officials to evaluate time, budget, and effect.
4) Examine available time and budget with the result of 3) and determine realistic countermeasures that can achieve maximum effect within the given condition. It is easy to understand that even for the same action, necessary time and budget can be different depending on the region and its effect can be also different. Based on the evaluation of each measure using AIM, create project plan by picking up best combination of measures that achieve maximum effects.
5) By practicing this process over several years, PDCA management cycle is put into practice and effective progress management is realized as shown in Figure 6.

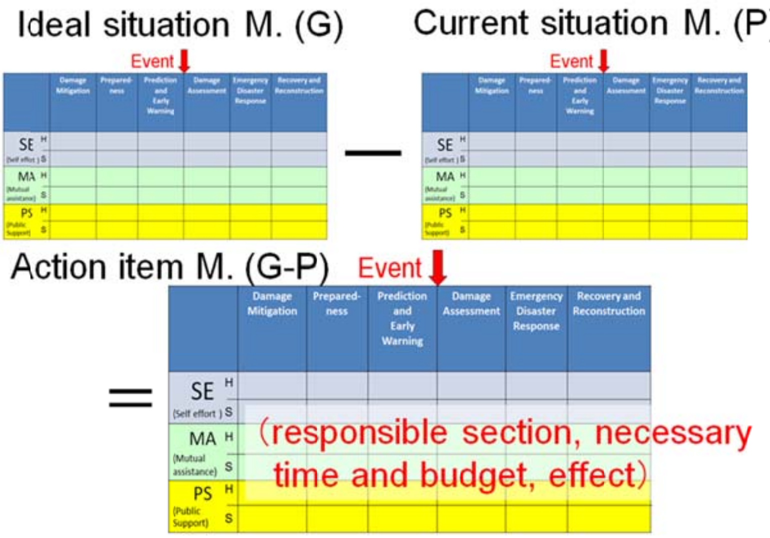

Figure 4 Making of Action Item Matrix (AIM)

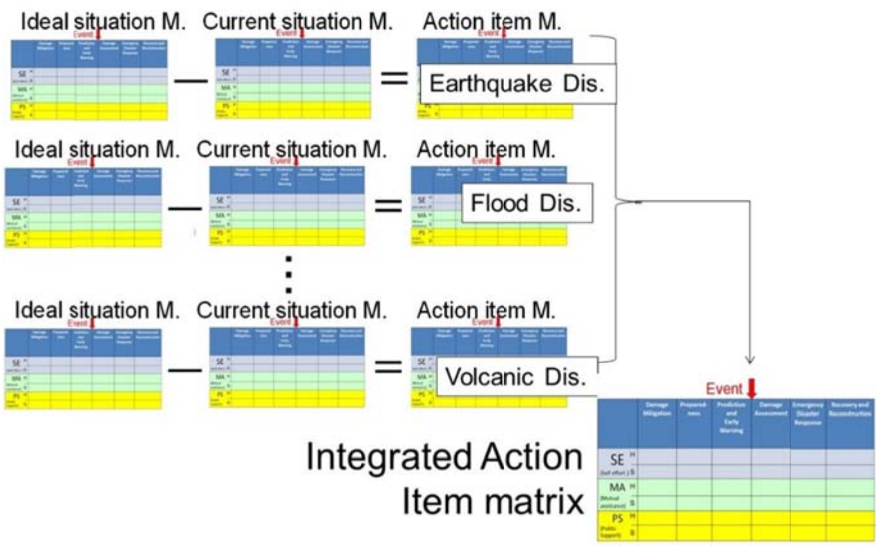

Figure 5 Making of Integrated Action Item Matrix (IAIM)

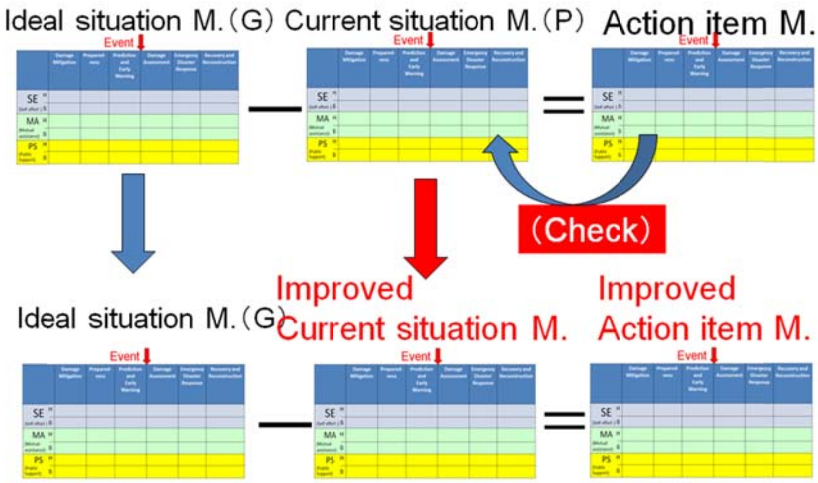

Figure 6 PDCA cycle of making AIM and its implementation

4. REAL SITUATION OF PAST DISASTERS
AND INTERNATIONAL PROJECTS FOR DISASTER REDUCTION

4.1 Real Situation of Past Earthquake Disasters

There was M 7.3 earthquake happened near Kobe City, Hyogo Prefecture in Japan at 5:46 (local time) on January 17, 1995. By this earthquake, till today, total of 6,437 people have been killed and are still missing. But, within the first two weeks, approximately 5.5 thousand people were killed in the entire affected areas and about 70 % of them were in Kobe City. Medical examiners in Hyogo Prefecture checked all the dead bodies carefully and examined direct cause and death time. According to their examination results, 83.3 % of total death toll were killed by structural damage, mainly collapse of old timber houses constructed before the final revision of structural code at that time. Among the rest of the fatalities, which was 16.7 % of total death toll, over 90% of them were found in burn areas. That was 15.4 % of total fatalities and it could be divided into two groups, 2.3 % and 12.2 %. Regarding 2.3 % fatalities, they were burn out perfectly and became born chips, therefore, it was impossible even for professional medical examiners to identify the direct cause. Medical examiners could not judge if people were still alive when the fire attacked them or not. However, regarding 12.2 % fatalities, medical examiners could make clear that people were still alive when the fire attacked and killed them. Therefore, it can be said that over 95 % of the fatalities were killed by the structural damage.

Table 1 shows the time of death evaluated by medical examiners and ordinary doctors. According to the medical examiners, accuracy of the data obtained by ordinary doctors were low as they were not trained to examine the death time. Therefore, ordinary doctor often reported that death time was when the dead body was carried to the hospital or the day of the earthquake. When you see the data obtained by medical examiners, you can clearly understand that within the first 14 minutes, approximately 92 % of the total fatalities were killed.

After the Kobe earthquake, many mass media reported that if information of damage could smoothly reach central part of Japan, such as Kasumigaseki and Nagata-cho, if Prime minister could performed better, and if Self-defense force had had a system by which they had been able to decide by themselves to visit affected areas without waiting for request by the local governors, many fatalities could have survived. But these news were not correct. Even if we had established such a system before the Kobe earthquake, it would have been impossible to save them. There was only one way that could save them which was to retrofit or rebuild weak structures that killed them before the earthquake.

Table 1 Time when the fatalities were killed by the 1995 Kobe Earthquake (in Kobe City)

Time of death		No. of Casualties: by Medical Examiners			by Ordinary Doctors			Total Number	
1/17	~6:00	2,221	2,221	(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 %)
	unidentified	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			2,415	(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 record		2,416	(100.0 %)	4	1,235	(100.0 %)	3,651	(100.0 %)
Total Number		2,416			1,235			3,651	

(after Hyogo Medical Examiners)

We should recognize that the number of people who can be saved by search and rescue operation is very limited. Since the time of the earthquake to the third day, there were about 45 to 50 thousand people who were trapped under the damaged structures in all affected areas by the 1995 Kobe earthquake. Among them, about 8 thousand people were taken out from damaged structures by public support services, such as police, fire fighters and self-defense force. 27 thousand people were rescued by local people and 10 to 15 thousand people came out from the damaged structures by themselves. Survivors' ratio of people who were rescued by public support services was the lowest. Rescue dogs that came from Switzerland, UK and France, could find totally 13 dead bodies and no survivors.

After the 2015 Gorkha earthquake, Nepal, Japanese government dispatched the Urban Search and Rescue team composed of 70 specialists with advanced equipments and rescue dogs by specially chartered airplane. The team left from Japan on the next day (April 26), but on April 27, the team could not land on Kathmandu international airport because of airport operation problem by the earthquake. The team could start search and rescue activities form April 28 and finished May 8. Japanese government, Ministry of Foreign Affairs reported on their Website that Nepal government and people express their appreciation to the team, but result of their search and rescue activities of about 800 man-day was that they could recue no person and find one dead body. We should recognize how difficult it is to save people who are trapped or buried under the damaged structures by search and rescue activities, especially in case of collapse of masonry structures.

4.2 International Disaster-related Projects Conducted in the World

As mentioned already, it is very difficult to save people by search and rescue activities and not many lives can be saved by post-event countermeasures. However, among all international projects carried out during 1990-2010, in both the number of projects and total budget, projects related to ‘emergency response’ was the top as shown in Figure 7. When we see the number of projects, 90 % is ‘emergency response’ projects. Only 10 % is related to ‘mitigation and preparedness’ and ‘recovery and reconstruction’. This is the order of standing out and the number of reports by mass media. Mass media only reported disaster related projects just after a large disaster happened, therefore, the pre-event countermeasure, which is the most important and efficient countermeasure to reduce damage, cannot get attention from the general public and funding organizations.

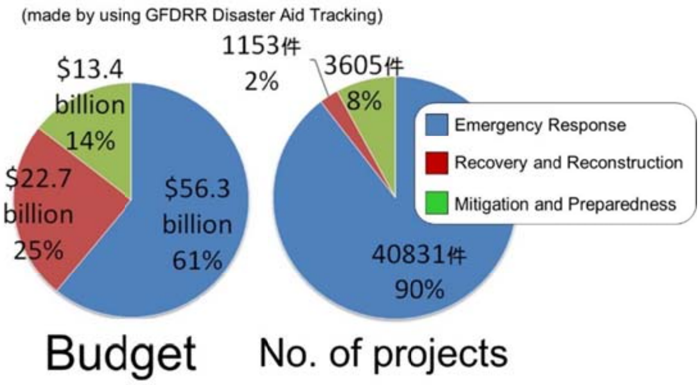

Figure 7 Break down of international projects for disaster reduction (1990-2010)

Among all countries and international organizations, USA is the first and Japan is the 5th top country that have spent the biggest budget for disaster-related projects during 1990-2010 as shown in Figure 8. But between these two countries, there is a big difference. US has spent a lot of money for ‘emergency response’ and Japan has spent more than half of the total budget for ‘mitigation and preparedness’ whose percentage 51 % is the world highest value.

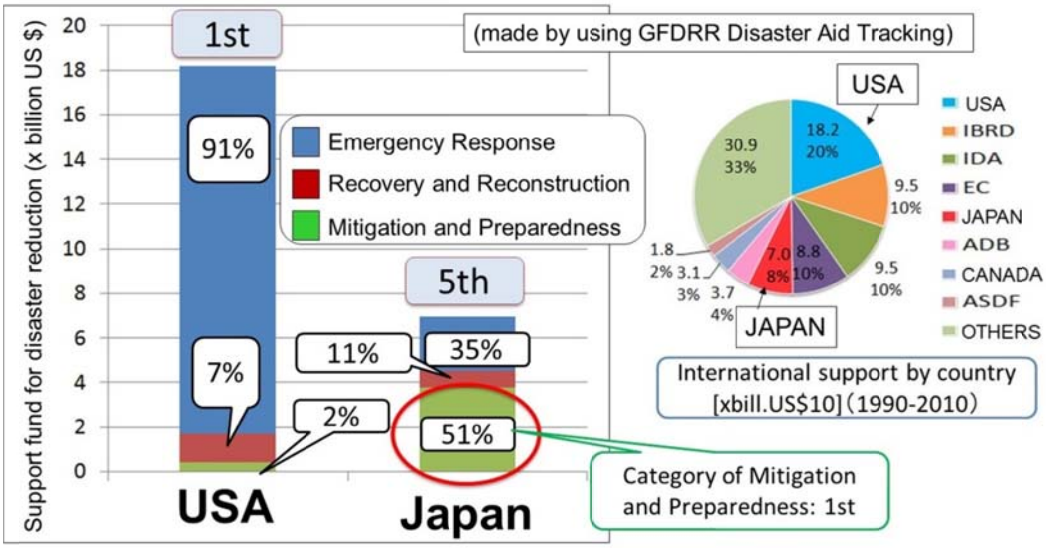

Figure 8 Comparison of budget of USA and Japan for disaster-related projects (1990-2010)

5. IMPLEMENTATION OF DISASTER RESILIENT SOCIETY

There are two important elements to implement disaster resilient society. One is disaster resilient build environment that is guaranteed by resilient infrastructure and buildings, and the other is disaster resilient people with high disaster imagination capability. Regarding resilient structures, especially social infrastructure, revision of seismic code of structure based on the earthquake damage investigation is essential, however, about private buildings and houses, especially in developing countries, revision of seismic code of structure cannot be a solution to the problem because there are many existing and new structures constructed by the local people without any engineering background using locally available materials without following the code. These types of structures are called non-engineered structures. Because of this reason, establishment of quality control system is necessary. This system is a quality check and promotion system by which people are encouraged to retrofit their own houses by proper way.

People who are trained in the engineering field tend to think that engineering issue is the most important to create disaster resilient society, but this is not correct. Engineering issue is important, but that is not all. We should recognize that without integration of technological and social approaches, existing important problems cannot be solved.

5.1 Implementation of Disaster Resilient Structure: Technological Approach and Social Approach

In order to implement earthquake disaster resilient structures, especially non-engineered buildings in developing countries, I have developed several retrofit methods as technological approach. They are all technically feasible and economically affordable methods using PP-band mesh, Bamboo mesh, PET-band mesh, Abacá-rope mesh, FRP+PP-band mesh, and Splint and Bandage+PP-band mesh, etc. PP-band is a polypropylene band, which is normally used for packing. PET band, which is about twice stronger than PP-band, is a recycled material from PET bottle. Abacá is a natural fiber produced from naturally growing plant in tropical regions normally used for making rope.

I have been testing these methods regarding applicability not only for brick and/or adobe single story masonry houses but for other masonry structures, such as shapeless stone masonry and multi-story masonry buildings. Generally speaking, seismic capacity of structures is discussed by three key characteristics of the structure, strength, deformation capability, and energy dissipation capacity. Based on the research results, it has proved that by these methods, deformation capacity and energy dissipation capacity of structures can be improved drastically and by FRP+PP-band mesh and Splint and Bandage+PP-band methods, strength can also be improved. With the PP-band method, retrofitting cost is approximately 30 USD per single-story housing unit with the floor area of 73 m^2 if the house owners retrofit in Pakistan. In case of hiring masons, the cost is no more than 5% of the total building cost.

In the affected area by the 2015 Gorkha earthquake, there is one two-story adobe masonry house with mud mortar, retrofitted by PP-band method by NSET in 2009. There are many severely damaged masonry structures around the retrofitted house and in spite of the fact that adobe masonry house with mud mortar is the world's weakest type structure, damage to this house was very minor. Minor damage was seen at the bottom of the walls showing the effects of PP-band retrofit.

Regarding the social approach for implementation of disaster resilient structures, I have proposed several social promotion systems by which people are encouraged to retrofit their own weak masonry structures. The methods are; 1) Two-step incentive promotion system, 2) Micro earthquake insurance based promotion system, 3) Government micro earthquake reinsurance based promotion system, and 4) Micro-finance based promotion system, etc. With all of these promotion systems, all stakeholders can get benefit by retrofitting weak structures and damage by the future earthquake can be drastically reduced. Due to limitation of the space, I cannot explain the detail of them, but I will introduce them in my lecture.

On the research theme related to seismic retrofit of non-engineered masonry structures and their promotion systems, six PhD students successfully obtained PhD degrees and over 15 Master students got Master degrees under my supervision so far. They carried out from very primitive research to full-scaled dynamic tests using shake table and numerical approaches. Based on their research results, we can say that all of these developed methods can enhance safety of both existing and new masonry buildings. Therefore each method can be one of the optimum solutions for promoting safer building construction in developing countries and contribute earthquake disaster mitigation in future. Now, PP-band retrofit methods are started to be used in Iran, Pakistan, Nepal, Indonesia and China, etc.

5.2 Role of Private Sectors and A New Concept of Disaster Countermeasures from COST to VALUE

As introduced in chapter 2, there are seven phases of disaster management and for each phase, there are three players, individuals and companies for self-help effort (SE), community and/or group for mutual assistance (MA), and national to local governments for public support (PS). For efficient improvement of disaster resilient capacity, strengthening of SE and MA is quite important. Therefore, some social system, which can give strong incentive to the players of SE and MA to promote their disaster management countermeasures, is necessary. As the organizations that establish such a system and make it popular, financial institutions, such as bank and insurance company, and mass media have high potentials.

I would like to introduce a system that my former student working at Development Bank of Japan (DBJ) has established. This is a unique system called BCM (Business Continuity Management) rating project and I have been serving one of the members of its advisory board. Disaster countermeasures have been considered as 'COST' for many years. It is very difficult to keep high level disaster countermeasure when it is considered as 'COST'. And people think that effects of disaster countermeasure can only be appeared when hazard happens. But by some system, if disaster countermeasures can be considered as 'VALUE', it gives incentive to the players of SE and MA to keep high level disaster countermeasure and it gives always benefit to them even without hazard.

With the DBJ BCM rating project, capacity of BCM of client organization is carefully examined by evidence based evaluation method by DBJ and when the score of the evaluation result is high, so that organization is rated as A, highest rate for example. If this organization is a private company, DBJ can consider this company with high BCM rate as reliable business partner that will have less negative impact when some hazard happens. Therefore, DBJ can loan money to the company with lower interest than the other companies with low BCM rate. From the company's viewpoint, continuation of high-level disaster countermeasure will give always benefit even in case that there is no hazard.

6. CONCLUSIONS

For disaster reduction, knowledge on natural science and technological approach are very important. But in many cases, real problems cannot be solved by only knowledge on natural science and technological approach. It is necessary to integrate technological approach based on the knowledge of natural science and social approach based on the knowledge of social science, both of which should be locally feasible and acceptable. Disaster management related issues are typical examples. These problems can be solved by combining both technological and social approaches. We can drastically reduce earthquake damage by seven-phase well-balancing structural and non-structural countermeasures.

Please imagine that you are killed due to an earthquake disaster. What would you like to say to your important persons who could survive? In general, politicians pay attention to the survived victims who can vote, however, this is different from essence of disaster management. Limited resources and energy should be used to reduce the number of people who will be affected before an earthquake rather than to take care of affected people.

We cannot prevent earthquake occurrence. But earthquake does not kill people. Structures kill the people. Among all earthquake disaster measures, 'damage mitigation', structural issue, is the most important and efficient for reducing damage, especially casualties. Today's poor-quality structures will be negative inheritance in next generations and attack their society. And today's poor disaster management system will make that damage worse. But, we can create disaster resilient society by constructing disaster resilient built environment and by educating people of all generations to be disaster resilient with the collaboration of SE, MA, and PS based on understanding that importance of role of private sectors and change of mind on disaster countermeasures from COST to VALUE.