

Damage Analysis of the Great East Japan Earthquake

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Abstract: This paper tries to comprehensively summarize the reasons of damages at the Great East Japan Earthquake on March 11, 2011 and what are the lessons in terms of earthquake and tsunami safety of building and cities. The paper examines the damage of tsunami affected areas and analyses the damage to extract lessons in order to safely reconstruct the affected areas from the view point of building regulations such as “Disaster Risk Area” provided by the Article 39 of the Building Standard Law and the Urbanization Control Area and UPA (Urbanization Promotion Area) provided by the Article 8 of the Ordinance of the City Planning Law of Japan.

Key words: Great east Japan earthquake, tsunami, UPA (urbanization promotion area), building standard law, city planning law.

1. Introduction

Both of the BSL (Building Standard Law) and the CPL (City Planning Law) in Japan lay down several Articles related to recovery processes after disasters. However, the term of “tsunami” appears only once in the BSL and in the case of CPL, it does not contain the term of “tsunami” in the law itself, because most of recovery processes were prepared against urban fire. The Japanese history of urban disaster has focused on spread of fire in the city since Edo era and large-scale urban fire also occurred recently in Kobe city in Jan. 1995 at the Great Hanshin-Awaji (Kobe) Earthquake. Therefore, current urban planning system in Japan seems to deal with tsunami disaster management not so clearly. It means that the devastated tsunami that occurred on March 11, 2011 represents the first huge tsunami disaster in the history of both legal systems.

Within the three most affected prefectures by the Great East Japan Earthquake, Miyagi prefecture and Iwate prefecture are now taking different recovery methods and processes especially for restriction of building and urban reconstruction. This paper reviews the processes of both prefectures in terms of building and urban reconstruction and summarizes key issues from April 2011 up to November 2012 in order to

avoid future problems of middle and long term recovery.

2. Damaged Areas by the 2011 Great East Japan Earthquake and Tsunami in Tohoku

Fig. 1 shows all the regions that were affected by the tsunami in Miyagi and Iwate prefectures at the 2011 Great East Japan Earthquake and location of Figs. 2 and 3 in Sendai Plain of Miyagi prefecture. The tinted areas represent the tsunami inundated areas.

Sendai Plain has formed agricultural land. The city area has been designated as “UPA (Urbanization Promotion Area)” in 1970 in Sendai and Ishinomaki areas. Because Sendai city has not designated UPA except surrounding areas of Sendai Port and because the old city area of Sendai is mainly located inland area, there were not so much damages even in the coastal areas of Sendai city except some existed villages and few new developments such as Arahama in Wakabayashi ward.

3. Damage Analysis of the Great East Japan Earthquake by Municipality

Firstly, the damage of the 2011 Great East Japan Earthquake is analysed in this section. Fig. 4 shows ratio of casualties per population in the inundated area

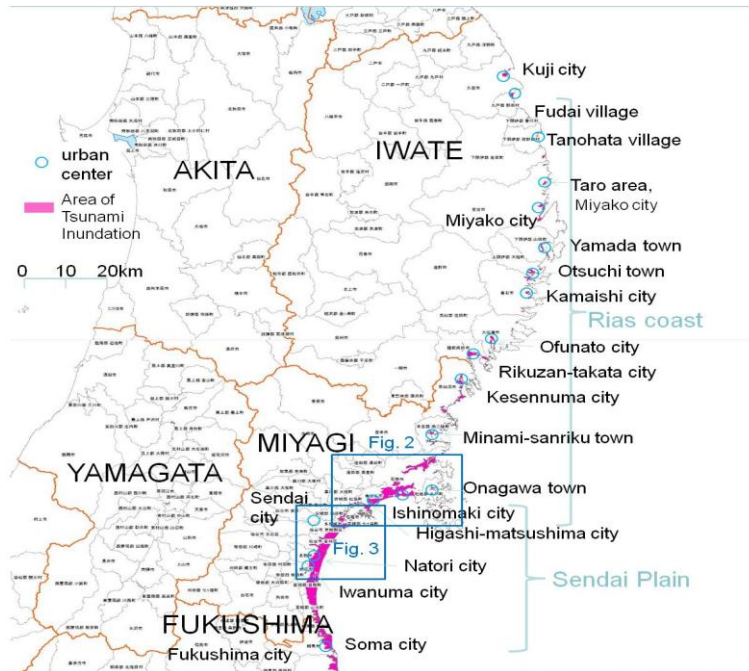


Fig. 1 Affected areas by the great east Japan Eq. and location of Fig. 2 and Fig. 3 in Sendai Plain.

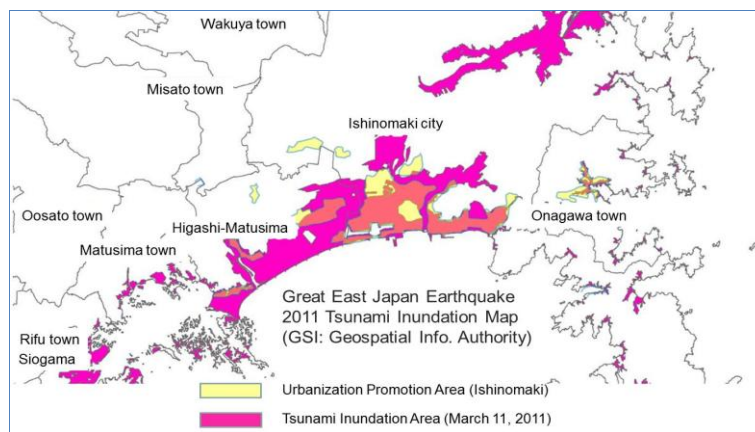


Fig. 2 Ishinomaki urban planning area.

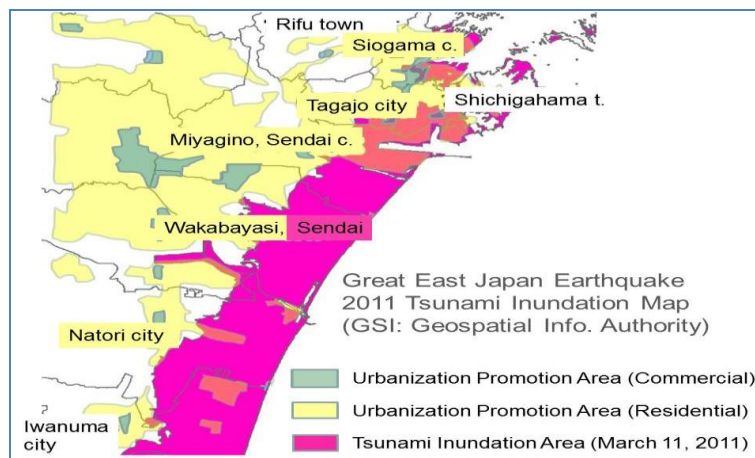


Fig. 3 Sendai-Siogama urban planning area.

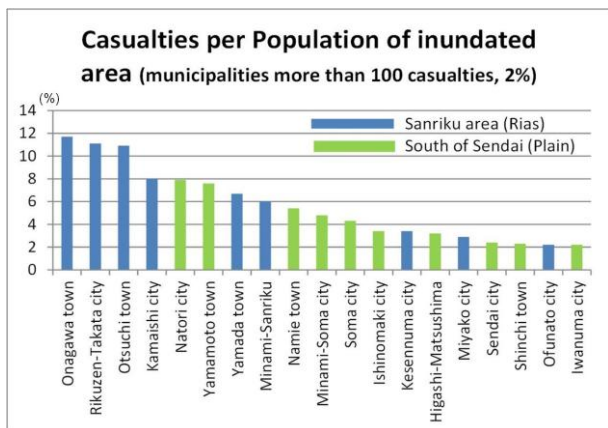


Fig. 4 Ratio of casualties by municipality.

by affected municipality including dead and missing persons as of 30 Dec., 2011. Blue columns in the figure indicate Sanriku area where main geographical condition is “ria coast” (deeply indented coastline i.e. coasts with several parallel Rias extending far inland and alternating with ridge-like promontories) that was suffered from severe damages, while green columns imply plain area in Sendai Plain and the south regions.

3.1 Characteristics of Damage by Tsunami

The characteristics of damage by tsunami are as following (reference [1], [3] and [4]):

(1) The maximum ratio of human damage including death and missing per population of the inundated areas by municipality is recorded as 12% in Onagawa town. Fig. 4 shows Otsuchi town and Rikuzen Takata city also claimed the following large ratio of human damage per population in the inundated areas;

(2) Since no damage by tsunami can be observed outside of inundated areas, Figs. 4 and 5 represent human damage and physical damage per inundated area respectively. The density of human and physical damages in Otsuchi town and Onagawa town are the severest. The third concentrated damage was seen in Yamada town. Kesennuma city and Kamaishi city follow them as the areas of collective and massive damages both in human and physical aspects;

(3) Fig. 6 shows that the gravity of physical damage can be measured by the totally collapsed ratio. The density of houses and population of inundated areas in

Kesennuma city and Kamaishi city was lower than in Onagawa and Otsuchi town. If the ratio of unknown (missing) per human damage will represent severity of human damage, Onagawa town reached 39% as the highest ratio and Otsuchi town, Minami Sanriku town follow the high ratio. They are the municipalities that are ranked in Fig. 5 as the heavily damaged areas;

(4) Figs. 6 and 7 show the severity of damage of each municipality by classifying the characteristics of regions. Fig. 8 represents characteristics of damage and will help to compare with other disasters. The proposed indicator is calculated as “number of human damage per totally collapsed houses” by municipality. Coburn, Spence and Pomonis defined similar ratio as Lethality Ratio in 1992 (reference [2]). The following data is formulated after extracting less damaged municipalities that have large fluctuation because of their smaller denominator;

(5) The ratio varies almost double figures (from 60 to less than 2) under this indicator. Rikuzen-Takata city recorded approximately 60 persons’ human damage per 100 totally collapsed houses, while Sendai city’s indicator shows around one or two persons. Fig. 7 tries to classify the damages however not so clear difference was observed from above mentioned data according to the characteristics of the region type;

(6) The Figs. 8 and 9 show the comparison of disasters in different areas using a proposed indicator.

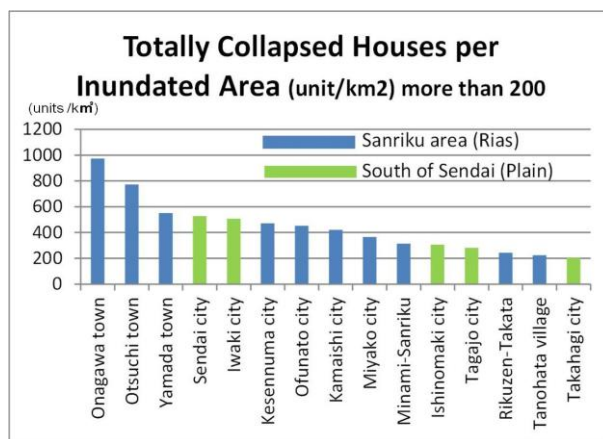


Fig. 5 Totally collapsed units per inundation area.

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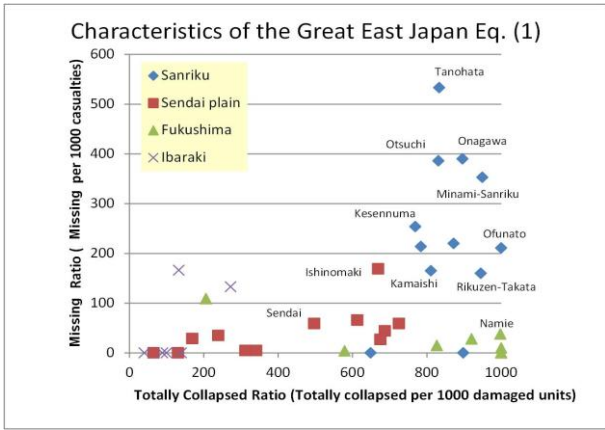


Fig. 6 Missing ratio and totally collapsed ratio.

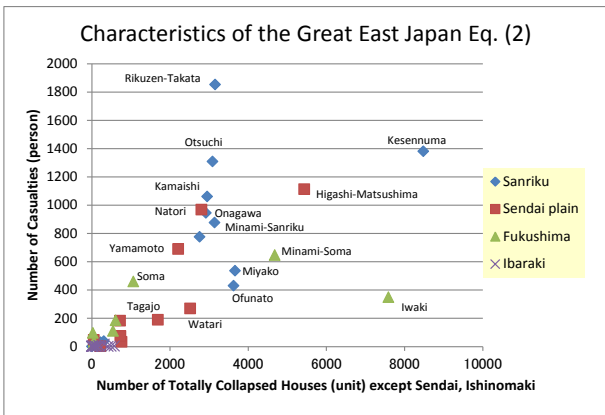


Fig. 7 Totally collapsed houses and casualties.

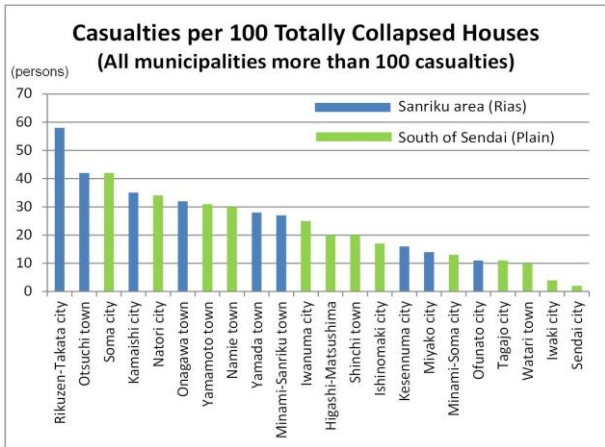


Fig. 8 Casualties per collapsed houses (Tohoku)

From the indicator that sets forth number of casualties per 100 totally collapsed houses, the range of numbers varies from 60 to 2 in both figures. Fig. 8 shows difference among municipalities in the Great East Japan Earthquake affected areas and Fig. 9 indicates difference of recent huge disasters in the world from Bam, Iran in 2000 to Haiti in 2010

including Japanese cases of Kobe in 1995 and the Great East Japan Earthquake. (reference [6] and [8])

The following observation can be pointed out from above-mentioned figures and field visits.

3.2 Analysis of Human and Physical Damages

Analysis of human and physical damages are as following:

(1) Number of Fig. 8 represents the “inclination” of Fig. 7. Although there may exist slight difference of judgment and definition of a “totally collapsed house” among municipalities, large difference of value in Fig. 8 cannot be explained. The difference of prefectures may be analyzed, although the highest casualties in Iwate prefecture in the Fig. 8 cannot be explained from the Table 1 and/or Fig. 10 that indicates the awareness of risk in Iwate was the highest;

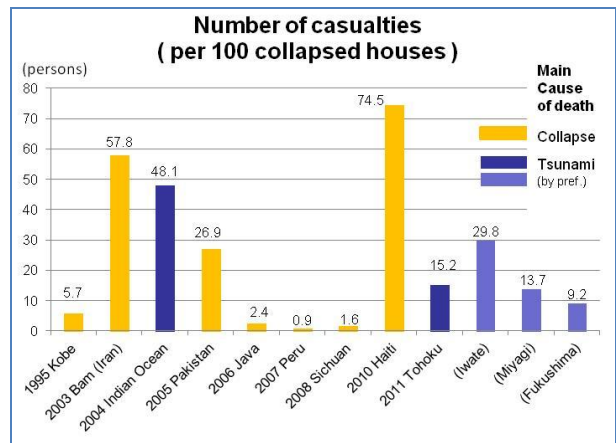


Fig. 9 Casualties per collapsed houses (World)

Reasons of Evacuation on March 11, 2011

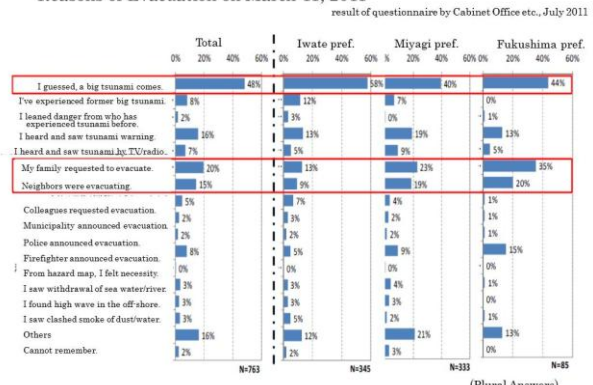


Fig. 10 Reasons of evacuation by prefecture.

Table 1 Damage / Response of Miyagi and Iwate Prefectures in case of the Great East Japan Earthquake.

	Miyagi prefecture	Iwate prefecture
Inundated area	326 km ²	49 km ²
Death	9,506 persons (2011/12/30)	4,667 persons (2011/12/30)
Missing	1,861 persons (2011/12/30)	1,368 persons (2011/12/30)
Totally collapsed	82,754 houses (2011/12/30)	20,184 houses (2011/12/30)
Half collapsed	129,212 houses (2011/12/30)	4,552 houses (2011/12/30)
Partially collapsed	211,305 houses (2011/12/30)	7,316 houses (2011/12/30)
Temporary house	22,042 units (2011/12 MLIT)	13,984 units (2011/12 MLIT)
Temporary rental	24,751 units rented (Miyagi)	Approx. 4,500 units (Iwate)
Public housing	12,000 units planned (Miyagi)	4,000~5,000 units (Iwate)

(2) Fig. 8 shows lower “casualty (mortality) ratio” in Ofunato city even though it is located in Sanriku. The reasons why the ratio in Soma city, Natori city and some other plain areas resulted in higher ratio compared with average of Iwate or Sanriku region may also provide social or historical reasons of the damages. Since this paper focuses on institutional aspect, further research is executed;

(3) Fig. 9 indicates also the wide range of difference of casualty ratio in the recent huge disasters. In general, tsunami disasters claimed rather higher ratio than the other cases. One of the reasons may be the frequency of a disaster (Huge tsunamis occur every thousand years while huge earthquakes can be experienced once per several hundred years, as it is said “disaster comes when it is forgotten”);

(4) Fig. 9 also suggests that the large difference of casualty ratio between the higher cases such as Iran and Pakistan (and in the case of Haiti, the casualty ratio became over 70 persons by official statistics) and lower cases in China 2008, Peru 2007 and Java 2006. The case of Kobe in 1995 set forth the middle level. Two lessons below can be learned from Fig. 9;

(5) Not only in Indonesia 2006 but also in Peru 2007 and China 2008, people usually construct one story house with light roof materials and thin wall, especially in rural regions. Traditional construction systems proved less human damage against shake;

(6) In Iran and Pakistan people adopted modern construction methods. In case of Iran people uses steel frame brick infill structures. As the damage of pure (dried) brick houses was severer than the steel frame type, many reconstructed buildings adopted the steel frame structure. In the case of Pakistan in 2005, reinforced concrete buildings like schools, hospitals and apartment houses were collapsed and caused many casualties. It means that even modern structure, it causes severe damage, if the structure was not properly designed and constructed.

4. Damage and Urban Planning

Based on the data on damages of the Great East Japan Earthquake from the view point of building control and urban planning, i.e. from Figs. 11-13, further observations can be pointed out as follows:

(1) Fig. 11 clearly indicates the characteristics of urban planning with UPA (by Area Division). The damaged houses include collapsed, half collapsed and partially damaged one. That means in UPA especially in the Sendai plain, housing damage in inundated areas turned out large number, while human damage was not so severe if compared with Sanriku rias coast areas where there is no UPA except Onagawa town;

(2) Fig. 12 shows two exceptionally large damaged cities in terms of physical damage. Both Sendai city and Ishinomaki city are classified as the area of “Urban Planning with Area Division”. That means the

pressure of development and increase of population is expected in these cities. Therefore it is required to effectively invest resources into the UPA without investing into UCA (urbanization control area);

(3) Fig. 13 shows the same data as Fig. 8 with

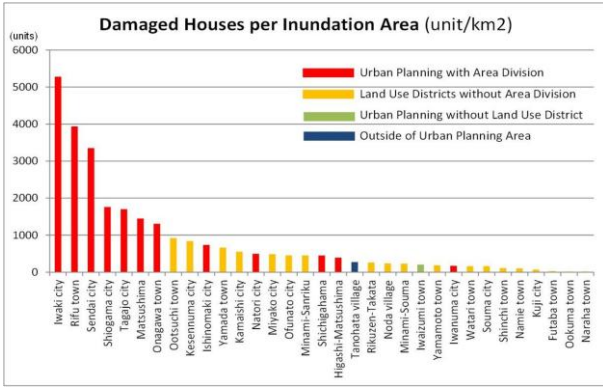


Fig. 11 Totally collapsed houses by municipality.

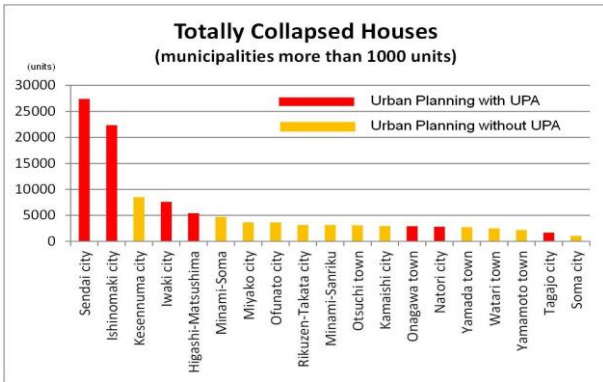


Fig. 12 Damaged houses per inundation area.

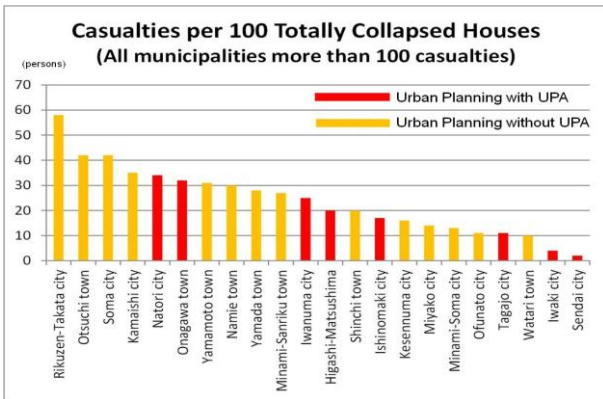


Fig. 13 Casualties per 100 totally collapsed units.

classification by urban planning type. As same as the Fig. 12, all municipalities in Fig. 13 established urban planning. That means heavily damaged areas to houses (Fig. 5) and human (Fig. 4) were basically

controlled under urban planning system that can apply rather strict building control.

5. Past Damages and Recovery in Tohoku

Tohoku especially the Pacific coast areas suffered from many tsunami disasters in the past. Even within recent 100 years history, four big tsunamis attacked the areas shown in the Table 2. Number of casualties of Meiji Tsunami exceeded the case of the 2011 Great East Japan Earthquake, though number of collapsed houses seems less than one tenth. (reference [9])

Recovery efforts have made after each disaster. However in case of tsunami, people often forgot the former case and encountered the same disaster when the next generation manages the society. A concrete example of affected area can be seen in Fig. 14. Taro area of Miyako city is famous for its ten meter-high doubled sea-walls that were constructed after Showa tsunami in 1933. There was no damage at the Chile tsunami in 1960, however almost of all urban areas of Taro were collapsed by the 2011 Great East Japan Earthquake and tsunami because the height of tsunami was more than 15 m and exceeded height of sea-walls.

As seen in the Fig. 14, after 1933 Showa tsunami, reconstruction of Taro area was limited within the doubled sea-wall (green area). Though southern area between two sea-walls of Taro remains as agricultural or factory areas, north-east area between two sea-walls became residential zone because of expansion of its population and heavily affected by last year’s tsunami.

Reference pictures (left side) show the damage and recovery situation of Taro area with its former photo.

6. Japanese Urban Planning against Disaster

Urban planning and building control systems that are prescribed in the CPL and the BSL are expected to play significant roles to prevent tsunami and earthquake disasters. However, before the Great East Japan Earthquake, a few cases of the “DRA (disaster risk area)” under the Article 39 of BSL were applied to prevent tsunami disasters. The reason why DRA

has not been so popular in the case of tsunami can be explained as follows: (reference [5])

(1) DRA aims to prevent disasters utilizing locally applicable control codes through designation of the area. There exist approximately 17,800 DRA in Japan (2007 MLIT). However most of them were designated against land slides to restrict housing construction in the steep slope areas. DRA against tsunami risk was not established except a few cases as the frequency of occurrence is quite rare and residents do not agree to prohibit from building their houses. There is no national financial support;

(2) As shown in the Table 3, DRA provides permanent restriction while other building control system in the disaster affected area like the building control based on the Article 84 of BSL, sets normally two months' limitation or in the case of the Great East Japan Earthquake maximum eight months' control. DRA controls will not be necessary for the area without any development pressure;

(3) DRA was sometimes used in the recovery projects after damaged disasters. In the case of Aonae area of Okushiri town after a big tsunami of the off coast of South-West of Hokkaido earthquake in 1993, DRA was introduced to the high risk area in the old residential zone after the new hilly safe area was developed utilizing "Collective Removal Project (CRP) against Disasters" with subsidies from national

government (former Ministry of Construction (MOC), current Ministry of Land, Infrastructure, Transport and Tourism (MLIT)). This was the unique case after tsunami under DRA. Characteristics of CRP and other major project system are introduced in the Table 4.

(4) As shown in the Table 3, Iwate prefecture requested all affected municipalities to set DRA to the heavily tsunami affected area in April 2011. However Kamaishi city decided not to use DRA in July 2011 and other municipalities are also reluctant to apply DRA. On the contrary, Miyagi prefecture set building control in large areas using the Article 84 of BSL as well as DRA to apply CRPs. Sendai city and Yamamoto town utilized DRA to control building construction in tsunami hazardous areas.

As shown in the Table 3 and Table 5, the basic direction toward reconstruction of Miyagi pref. and Iwate pref. seems to select different way as the case of building restriction in early stage. It seems that Miyagi pref. aims to improve urban structure using this opportunity especially in the coastal zones, while Iwate pref. seems to be struggling to maintain population in the tsunami affected areas and then restriction of building construction in Iwate pref. is not so strict compared to Miyagi pref. because the population decrease trend is expected severer in the remote regions from big cities. (reference [7])

Table 2 Large Tsunamis before 2011 in Tohoku Region (1896, 1933, 1960 tsunamis, Cabinet Office).

Earthquake	Year	Mg.	Outline of Damage		
			Tsunami height max.	Human Damage (persons)	Physical Damage (units)
Meiji-Sanriku Eq. / Tsunami	1896	8.5	Ryori: 38.2 m	Death: 21,915 Missing: 44 Injured: 4,398	Flowed: 9,878 Collapsed: 1,844
Showa-Sanriku Eq. / Tsunami	1933	8.1	Ryori: 28.7 m	Death: 1,522 Missing: 1,542 Injured: 12,053	Flowed : 4,885 Collapsed: 7,009
Chile Eq. / Tsunami	1960	9.5	Sanriku: 5 – 6 m	Death + Missing: 142 Injured: 872	Flowed: 1,474 Collapsed: 1,500
2011 Tohoku Eq. / Tsunami <small>(Great East Japan Eq.)</small>	2011	9.0	Aneyoshi: 40.5 m <small>(Ryori: 40.1m) (Onagawa43m)</small>	Death: 15,875 Missing: 2,725 Injured: 6,120 <small>(as of Dec.5, 2012 by NPA)</small>	Flowed+ Collapsed: 129,656 <small>(as of Dec.5, 2012 by NPA)</small>

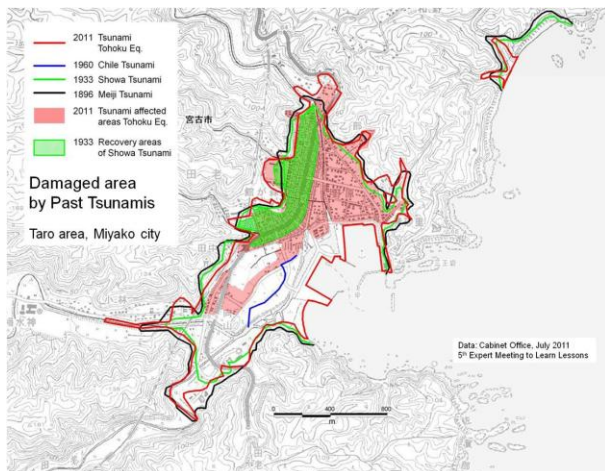


Fig. 14 Map of Inundated areas of Taro, Miyako.

However, it may be caused simply because of the difference of urban planning settings of both prefectures, i.e. Miyagi pref. sets UPA and UPC and most of coastal areas are prohibited to construct buildings. (reference [5]) However, in Iwate pref., construction of buildings is not so strictly controlled in the coastal cities and towns.

7. Conclusions

Concentration of population into urbanization area and rapid improvement of social infrastructures due to the economic growth mostly in emerging countries would be common now in the world economy. As frequent earthquake and tsunami disasters proved such demands for disaster management. In each on-site observation, the collapse of buildings caused major damages in the earthquake related disasters. Therefore, quality of new houses and in the case of tsunami location of new urban area is the key. Moreover seismic retrofit became popular in Japan especially after the 1995 Great Hanshin-Awaji Earthquake, while there are few cases of retrofitting of existed buildings in many developing countries as shown in the other paper of the author in the *Journal of Engineering and Architecture* (Vol. 6, No. 4, Apr. 2012, Evaluation of the Policies for Seismic Retrofit of Buildings).

A Comparison of prefectures and cities provide lessons on the reconstruction process under the

different urban planning settings and conditions, and will be helpful to improve urban planning systems. One sided control mechanism for implementation of building cannot solve the problems. Building control has to be integrated with socio-economic, institutional, technical and other tools to achieve safety of buildings and built-environment.

Awareness creation is instrumental for building culture of safety and demands for intervention in disaster mitigation. The demands ultimately help in creating policy intervention, in realizing institutional mechanism of code enforcement and land use control for the municipal authorities and in creating demand for competent professionals. (reference [10])

After the Great East Japan earthquake, officers and experts are now tackling the challenge to secure future safety of society in Tohoku region and they will find new ways and systems through operation of recovery projects and discussions.

Acknowledgments

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Author moved from IISEE of Building Research Institute to a professor of National Graduate Institute for Policy Studies (GRIPS) in Tokyo from April 2013 and is serving as a director of its Disaster management Policy Program.

Table 3 Building control based on BSL after disaster.

Building Standard Law	Article 39 (Disaster Risk Area: DRA)	Article 84 (Control in Affected Area)
Designation of area	Based on bylaw of local governments	By Specialized Admin. Authority *1
Duration of control	Permanent measures	Max. two months *2
Construction control	Prohibit housing, limit other building (no national intervention)	Prohibit / limit building construction in the project planned area
Application to Great East Japan Earthquake	Iwate: Urge municipality to set bylaw Miyagi: Pref. started to plan to apply	Iwate pref.: No application Miyagi: Applied to 5 municipalities
Response of municipalities	Iwate: Mayors are prudent (negative) Miyagi: Part of Minami-sanriku town	Miyagi: Enterprises were embarrassed then try to permit some construction
Applied cases	Hokkaido, Okushiri town, Aonae area	Great Hanshin-Awaji Eq. (Kobe etc.)

Table 4 Major project systems for reconstruction.

Basic Projects	Collective removal project against disasters (CRP)	Recovery Base project against Tsunami (new system after 2011)	Project on land readjustment for urban recovery
Subsidies	Cost for public works incl. land development except sell land	Total mounding cost, Development of evacuation building and public works etc.	Cost for public works incl. land, totally mounding (40 persons/ha)
Area	No relation to urban planning	Principally within urban planning area	Within urban planning area
Scale	More than five (usual 10) houses	Principally 2 projects per urban, and approx. 20 ha per project	No condition
Condition	Designation of disaster risk area is requisite	Define area for land purchase, Step by step extension will be possible	Consolidated area to develop road system. Division of project area
Process	Agreement of MLIT minister on removal plan	Planning decision as urban facility, project approval of prefecture (or MLIT)	Urban planning procedures are needed (from planning decision to liquidation)
Aid ratio	All costs will be covered (special case by national grant + special tax).		

Table 5 Comparison of Miyagi and Iwate Pref.

(2005-2040)	Miyagi pref.	Iwate Pref.
Total population	2,360,218 persons	1,385,041 persons
Estimated pop. (reference [7])	1,894,000 persons	962,000 persons
Ratio(2040/2005)	-19.8% (affected area—46.8%)	-30.5% (affected area—48.8%)
Aged ratio(05-40)	20.0% (2005) → 34.3% (2040)	24.6% (2005) → 38.0% (2040)
Basic concept for reconstruction (part of land use and development)	<u>Miyagi pref. recovery plan:</u> Recovery focusing on tsunami disaster management of coastal areas applying removal to high land, separation of work and home, multiple protection against tsunami from the lessons	<u>Iwate pref. recovery basic plan:</u> Based on agreements with residents, improvement of residential area for safety and development connected with land use plan considering tsunami disaster management
Current situation (building control)	Pref. set building control based on City Planning Law etc. after BSL Article 39. Article 39 (DRA) is also used in many areas in Sendai, Kesenuma, Minami-Sanriku etc. order to apply CRPs	City Pref. recommended municipalities to use BSL Article 39 (DRA) in planning to apply BSL Article 39 (DRA) in Kamaishi and Miyako cities, Yamada town and Noda village as of Sep. 2012

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Reference Photos: March 11, 2011 (by Building Research Institute, IISEE)

Recovery situation of Taro area, Miyako City, Iwate Pref. Recovery situation of Onagawa Town, Miyagi Pref.



(May 2007, IISEE / BRI)



Apr. 2011



(April 2011)



Sept. 2011



(November 2011, IISEE / BRI)



2011 Onagawa, Miyagi (IISEE/BRI)
Onagawa April 2011



2011 Miyako, Iwate (IISEE/BRI) 1
Taro area April 2011



2011 Onagawa, Miyagi (IISEE/BRI)
Onagawa April 2011