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LESSONS OF RECENT GIGANTIC EARTHQUAKE DISASTERS IN JAPAN

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1. Introduction

In the last 100 years, there are three gigantic earthquake disasters in Japan which caused tremendous loss of human life: the 1923 Great Kanto Earthquake Disaster (hereinafter referred to as **1923 Kanto Earthquake**), the 1995 Great Hanshin-Awaji Earthquake Disaster (hereinafter referred to as **1995 Kobe Earthquake**) and the 2011 Great East Japan Earthquake Disaster (hereinafter referred to as **2011 Tohoku Earthquake**). Figures 1 shows the epicenters and Table 1 summarizes the disasters.

1923 Kanto Earthquake　　1995 Kobe Earthquake　　2011 Tohoku Earthquake

Figure 1 Epicenters of earthquakes (figures are cited from Wikipedia)

Table 1 Three gigantic earthquake disasters in Japan after 1900

	1923 Great Kanto Earthquake	1995 Great Hanshin Awaji Earthquake	2011 Great East Japan Earthquake
Date	1923.09.01	1995.01.17	2011.3.11
Time	11:58	05:46	14:46
Magnitude	7.9	7.2	9.0
Death & missing	Around 105,000	6,434	19,312 (*2)
Main cause of death	Fire 85%	Building Collapse 75% Fire 12% (*1)	Tsunami 92% (*2)
Major building damage	- Wooden houses - Brick buildings adopting western style	- Old type buildings designed before 1981 - RC buildings with Soft first story	- Minor damage for shaking - Tsunami damage

*1 from statistics of Kobe city
*2 from Japanese National Police Agency (as of 22 Dec. 2011)

The cause of loss is different in each disaster. Roughly, it can be categorized as "Fire (1923 Kanto Earthquake)", "Shaking (1995 Kobe Earthquake)" and "Tsunami (2011 Tohoku Earthquake)". Even Japan has learnt severe lessons from earthquake disasters and has improved knowledge and technology for countermeasures, the 2011 Tohoku Earthquake reveals the fact that our effort is not still enough. This paper summarizes lessons of each disaster and efforts which have been taken, especially focusing on the structural design of buildings.

2. Earthquake intensity

Figure 2 shows the sizes of earthquake fault including the 1960 Chile Earthquake which is known as the largest earthquake in the world.

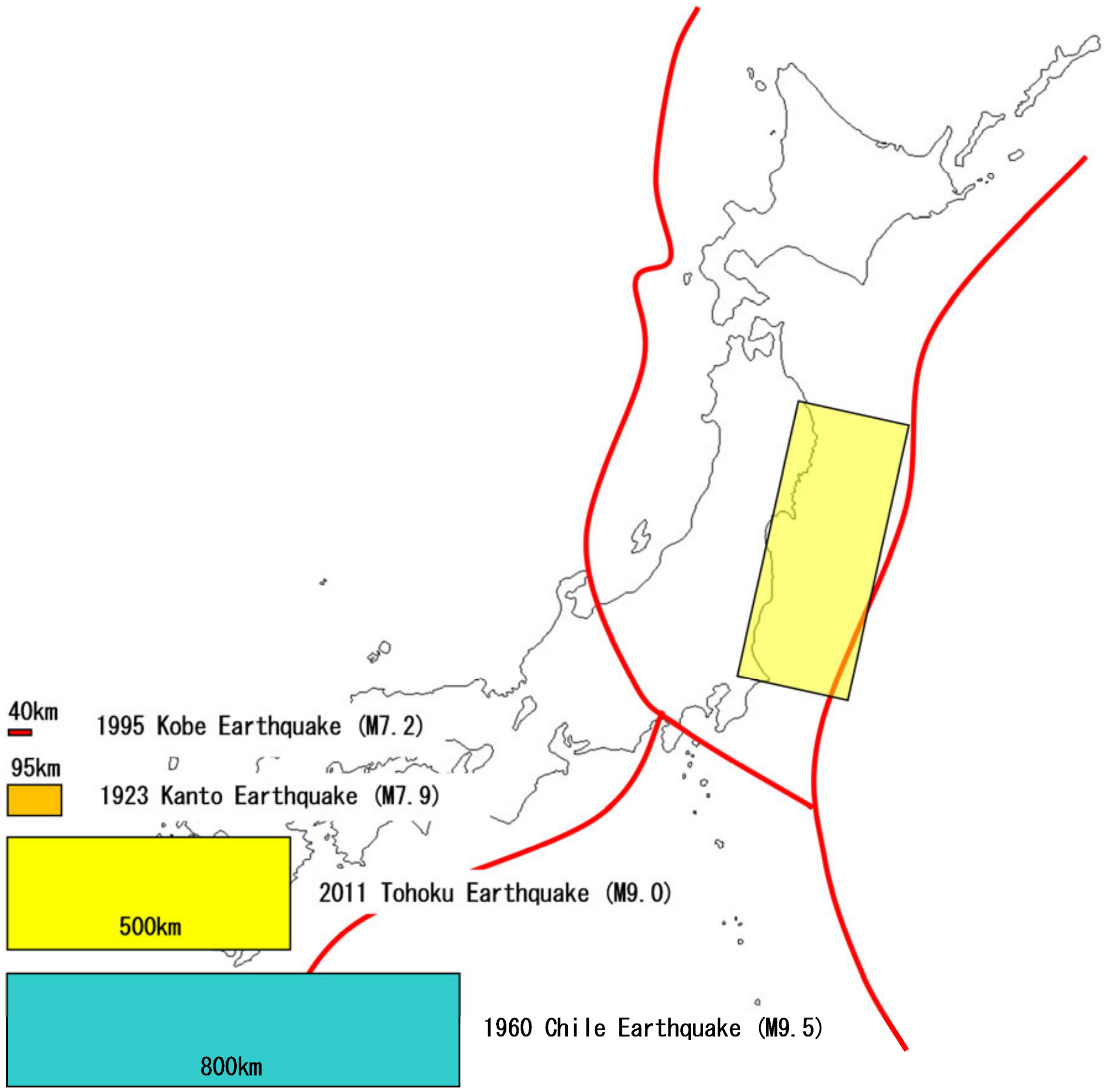


Figure 2 Size of earthquake fault

The 2011 Tohoku Earthquake is known at the largest earthquake in the history of Japan from the size of magnitude. However, comparing other two earthquakes, the epicenter was relatively far from the land. In general, intensity of earthquake ground shaking is getting reduced as the distance from the epicenter increases (as shown in Figure 3). This could be the reason that building damage due to the 2011 Tohoku Earthquake was relatively minor. However, the maximum accelerations of earthquake ground motions recorded at the 2011 Tohoku Earthquake are quite large as shown in Figure 4. Question still remains why the building damage was minor even earthquake ground motion has such a high acceleration value.

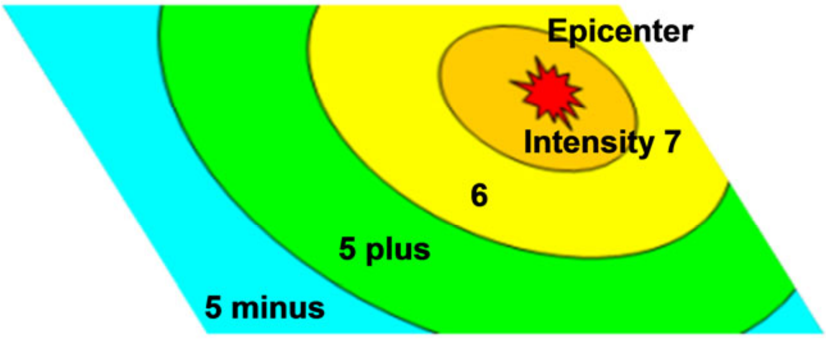
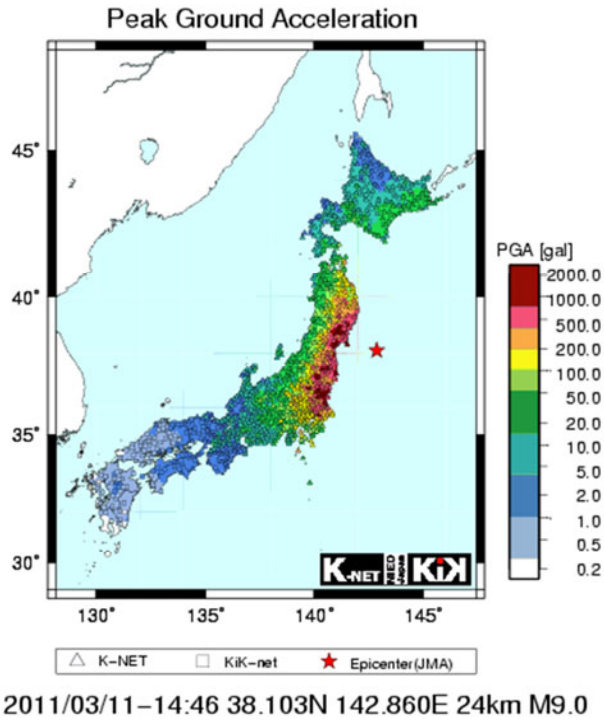


Figure 3 Intensity of earthquake



No	Name of station	The maximum acceleration
1	K-NET筑馆(MYG004)	2933gal
2	K-NET盐灶(MYG012)	2019gal
3	K-NET日立(IBR003)	1845gal
4	K-NET仙台(MYG013)	1808gal
5	K-NET鉾田(IBR013)	1762gal
6	K-NET今市(TCG009)	1444gal
7	K-NET白河(FKS016)	1425gal
8	KiK-net西乡(FKSH10)	1335gal
9	K-NET大宫(IBR004)	1312gal
10	KiK-net芳贺(TCGH16)	1305gal

(data from National Research Institute for Earth Science and Disaster Prevention)

Figure 4 List of large earthquake ground motions at the 2011 Tohoku Earthquake

Figure 5 shows the comparison of pseudo velocity spectrums between the 1995 Kobe Earthquake and the 2011 Tohoku Earthquake. The 1995 Kobe Earthquake occurred just beneath the city of Kobe and produced intensive shaking with high frequency around 1 to 2 Hz as shown in the spectrum. On the other hand, it is seen that the power of the 2011 Tohoku Earthquake in this frequency range is relatively small. Generally wooden houses and low rise reinforced concrete buildings are affected by the shaking with the frequency component around 1 to 2 Hz; this could be the explanation of minor building damage at the 2011 Tohoku Earthquake.

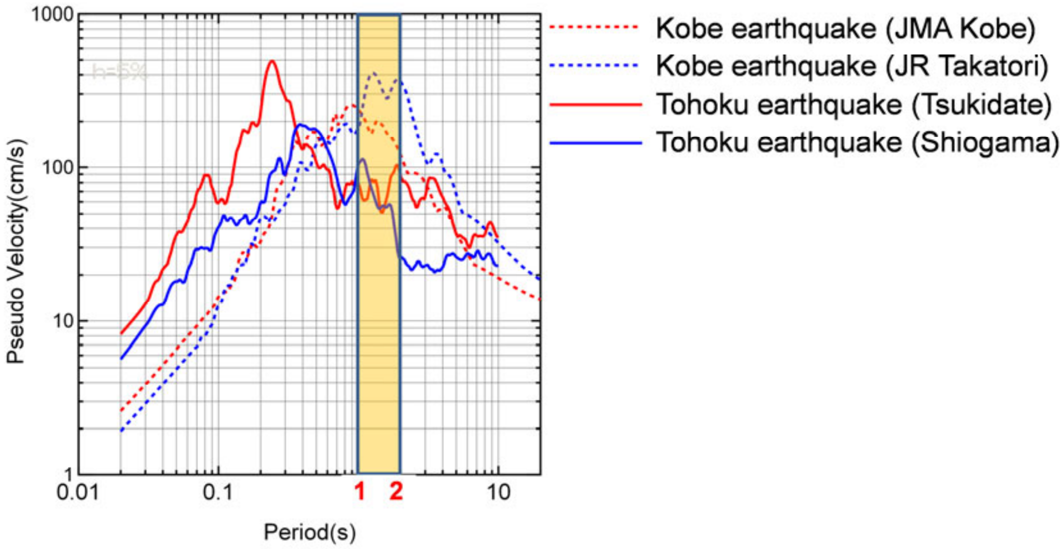


Figure 5 Pseudo velocity spectrums with 5% damping

3. Seismic capacity of buildings

3-1. 1923 Kanto Earthquake --- from brick to reinforced concrete

There was no seismic design code in Japan before the 1923 Kanto Earthquake. As that time, Japanese Government decided to introduce Western culture and technology to catch up Western countries. Fire resistance was the main concern in urban areas since the most buildings were constructed by wood. Therefore, Government recommended buildings made of brick instead of wood.

At the 1923 Kanto Earthquake, brick buildings were severely damaged. The Ginza Brick Street, the symbol of Western style town, destroyed completely. Ryou-unkaku, the highest brick tower in Japan with 12 stories, also the landmark of Asakusa district, has collapsed. On the other hand, reinforced concrete buildings showed excellent performance both against fire and earthquake shaking. Reinforced concrete has jumped to the leading role in building the city of Japan. The first seismic design code was enacted next year of the 1923 Kanto Earthquake.

There are unique structures became popular after the 1923 Kanto Earthquake. One is the steel encased concrete structures (so called SRC) and another one is the reinforced concrete shear walls.

3-2. 1995 Kobe Earthquake --- start promotion of seismic retrofit

Japanese seismic design code has been revised many times based on the lessons of earthquake disasters. The 1968 Tokachi Earthquake caused severe damage to reinforced concrete buildings. The Architectural Institute of Japan (AIJ) revised design guideline of reinforced concrete buildings in 1971, requiring more stirrups to increase shear resistance and ductility of buildings.

The biggest revision of seismic design code was made in 1981 after the 1978 Off Miyagi Earthquake. The code adopted two level design procedures as shown in Figure 6; one is the serviceability limit design for moderate earthquakes with a base shear capacity of 20 percent of total weight of a building, another one is the safety limit design for strong earthquake with a base shear capacity of 100 percent of total weight of a building.

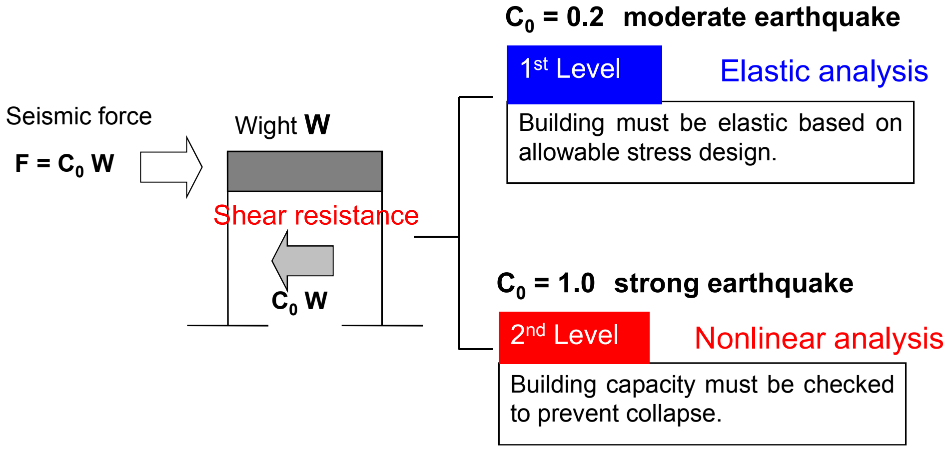


Figure 6 Concept of the two level design procedure at 1981 revision

The effect of this revision was proved at the 1995 Kobe Earthquake. As shown in Figure 7, the ratio of collapse buildings designed after 1981 was very small. The minor revision was made after the earthquake to prevent collapse of soft first story buildings. After the earthquake, Japanese Government issued a law to promote seismic retrofit of existing buildings design before 1981, providing subsidy and other benefits.

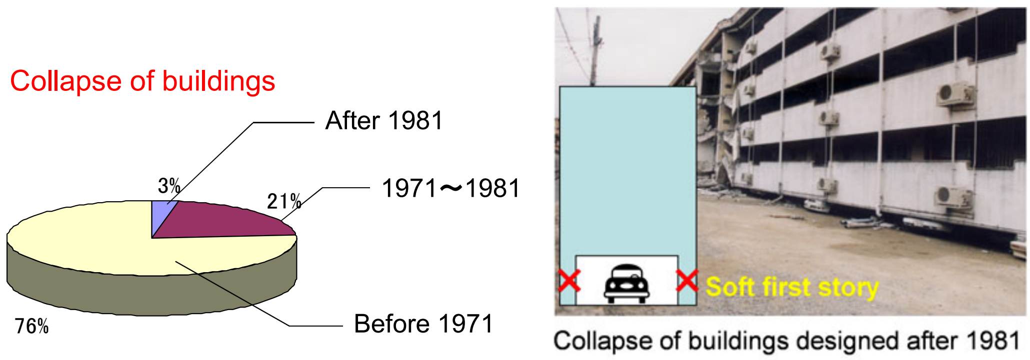


Figure 7 Building damage at the 1995 Kobe Earthquake

3-3. 2011 Tohoku Earthquake --- need to consider Tsunami force in building design

Tsunami induced by the 2011 Tohoku Earthquake struck the Pacific coast of eastern Japan including prefectures of Iwate, Miyagi, Fukushima, Ibaraki and Chiba. In some areas, tsunami height reached over 10 m and washed away the houses and buildings in the areas.

The earthquake shaking was also strong in wide area of Japan; however, the damage of buildings due to shaking was limited. Extensive liquefaction of sandy soil occurred in Kanto area.

In tsunami disaster site, overturning was observed in 4-story or lower reinforced concrete buildings with relatively small size of openings as shown in Figure 8. In all overturned buildings, the maximum inundation depth exceeded their height. Most of the overturned buildings are of mat foundation. In some overturned buildings on pile foundation, piles were pulled out from the ground.

Figure 8 Overturning of a reinforced concrete warehouse in Onagawa city

Consideration of the tsunami effect on buildings is not mandatory for the structural design and there is no regulation to define the tsunami force in the Building Standard Law in Japan. However, the Cabinet office, government of Japan released official guideline on the structural design of buildings for vertical evacuation from tsunamis in 2005. This guideline provides the simplified method to calculate tsunami wave pressure affecting a building using design water depth (see Figure 9). The guideline was revised in 2011 to change the run-up height of tsunami using the parameter α which ranges from 1.5 to 3.0 depending on the distance from the coast and the existence of shielding fence of tsunami.

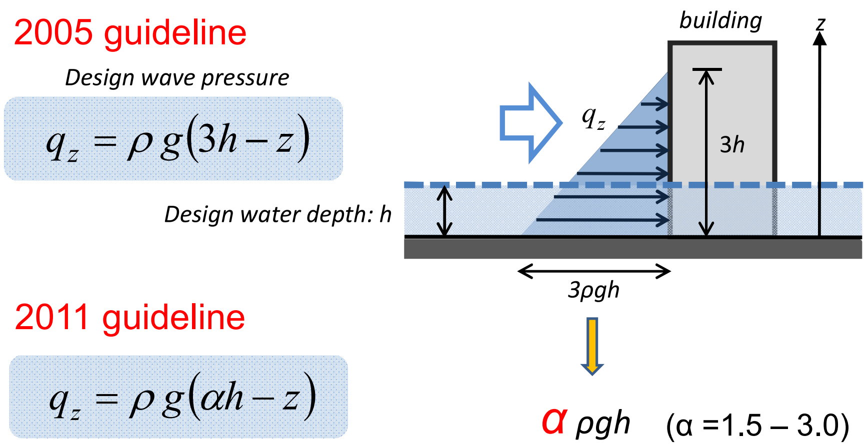


Figure 9 Guideline on the structural design of tsunami evacuation buildings

4. Conclusions

Tsunami has attacked Tohoku regions repeatedly. However, people forgot such lessons and started living again in dangerous areas near the ocean. A gigantic earthquake like the 2011 Tohoku Earthquake is supposed to occur every 1,000 years. The 1995 Kobe Earthquake is also expected to occur every 2,000 years. The return period of the gigantic earthquake is too large for human to keep awareness of disaster prevention. Therefore, it is important to change regulations or make the new ones reflecting the lessons as soon as possible. Also, sharing such experience with other countries is important.

Acknowledgement

The author would like to express his deepest condolences to those who lost their families and those who are suffering from the disaster. Alos, he would like to express his heartfelt appreciation to people from around the world for their warm support.