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The Role of Buildings in Disaster Risk Reduction: Focusing on the Great East Japan Earthquake

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Abstract

As a result of unprecedented tsunami happened 11 March 2011, in the coastal Tohoku area of Japan, around 126,000 buildings were destroyed. Some of the buildings withstood the strong tsunami, though the number of such buildings is small. Obviously the strength of the waves was the strongest determinant of the destruction or endurance, some other factors such as inundation height, depth of the building parallel to the tsunami direction and opening ratio have also been understood as the factors supporting the survival. This paper investigates Sendai sewage purification center which survived the GEJE and tsunami in the context of its endurance.

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Keywords: GEJE, inundation height ; Miyagi Prefecture ; reinforced concrete structures ; Sendai sewage purification centre

1. Introduction

The role of existing buildings on disaster mitigation is paid attention after the Great East Japan Earthquake (GEJE). Tsunami fully destroyed around 126,000 buildings, and the number of half-destroyed buildings was counted as 272,000. It is understood that the large buildings had sometimes served to reduce the impact of tsunami while giving the temporary shelter to the affected inhabitants.

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Meanwhile, there is a plan for constructing the future coastal buildings in Japan which are resistive to tsunami. However, there are no guidelines for constructing such buildings. Therefore, precise understanding of damaged and undamaged buildings by GEJE is essential for establishing the future guidelines.

Matsutomi et al. (2012) have investigated the damages of buildings exited from Kuji seashore in Iwate prefecture to Minamisoma seashore in Fukushima prefecture. The period for the surveys was from March to November in 2011. The surveyed factors were locations and position of buildings, geometry of the building (width, depth, height, area of windows and doors), depth of embedment, having or not having pile foundations and paving around buildings, the inundation height, having or not having land liquefaction, and the damage situations of the building. Matsutomi et al. (2012) have concluded that the survivability of reinforced concrete (RC) buildings depended on locations and arrangements of buildings, the inundated vertical sectional area, opening ratio of the front and back of buildings, depth of embedment, having or not having pile foundations and paving around buildings, land liquefaction, and the easiness of air transfer in buildings.

The purpose of this study is to investigate the role of existing buildings against the tsunami through previous literature and extensive field surveys; and to analyse the disaster mitigation mechanism of existing buildings quantitatively and qualitatively.

Previous literature surveys, field surveys and analysing the statistical parameters were the methodologies mainly used in this research. Field surveys were mainly carried out in Miyagi Prefecture in order to understand the services of existed buildings in wave strength mitigation. Aerial photos provided by the Google Earth and Geospatial Information Authority of Japan were extensively used to classify the damage of buildings into 2 classes such as washed-away and survived. Damages to the buildings were identified by one by one through visual inspection. Well detailed aerial photos of some specific targets were taken from a helicopter. Those aerial photographs were used in photogrammetry surveys. A statistical analysis was done to clarify the relationship among the survival rate, inundation height and physical/structural parameters of buildings.

Due to the space limitations this paper reports only the set of survived buildings in Sendai sewage purification centre in Miyagi Prefecture. However, the authors acknowledge that the buildings washed-away should also be reported, in order to understand the boundary condition of washed-away and survived. Hence, this paper refers to boundary parameters given by Matsutomi et al. (2012) and Ogata (2014). Figure 1(a) and (b) show aerial views of Sendai sewage purification centre, and Figure 1(c) is a view of purification centre on 11 March, 2011.

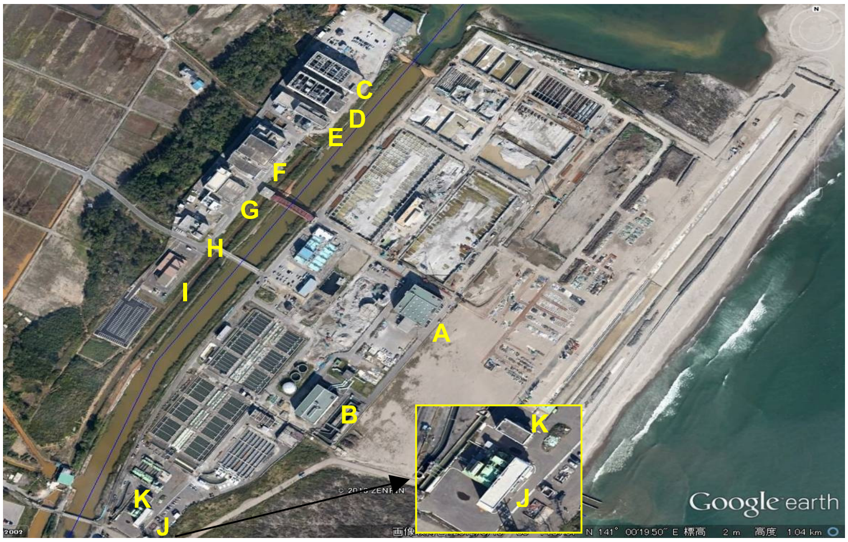

Figure 1(a). An aerial view of Sendai sewage purification center

Figure 1(b). An aerial view of purification center used for photogrammetry surveys

Figure 1(c). A view of purification centre on March 11, 2011 (source: Sendai City)

2. Methodology

Eleven buildings (named A to K in Figure 1(a)) were analyzed according to the methodology given by Matsutomi et al. (2012). All of those buildings were located at a distance of 325-637 m from the coastline on the site of Sendai sewage purification center in Miyagi Prefecture. Despite of close proximity to the sea, this series of buildings survived and they were praised by the neighbors for the role of protecting their lives.

The authors collected the following data for each building:

Height of the tsunami, inundation height, altitude, width and depth of the building, distance to the building from the sea, height of building, inundated vertical sectional area, inundated sectional area, opening ratio, opening ratio difference, and the structure of the building.

In depth details of methods of data accumulation have been given elsewhere (Ogata, 2014). A brief introduction to those methodologies is given below.

- Height of the tsunami is acquired from the database of the 2011 Tohoku Earthquake Tsunami Joint Survey (TTJS) Group (2013). The height of wave which is the nearest to a given building was considered as the height of tsunami of the building.
- The inundation height was obtained by subtracting altitude of the location of building from height of tsunami.
- Width and depth of the building, and the distance to the building from the sea were obtained from a map of "aerial photos around the areas affected by the tsunami" provided by Geospatial Information Survey Authority of Japan.

- The heights of objective buildings were obtained through photogrammetry survey methods using aerial photos taken by the authors, pictures of Google earth, and aerial photos provided by Geospatial Information Survey Authority of Japan.
- Inundated vertical sectional area is the product of inundation height (P) multiplied by the depth of the building (D) which is parallel to the tsunami direction (see Figure 2(a)).
- Inundated sectional area is an area of a building which faces the tsunami. It is the product of inundation height (P) multiplied by width (W) of the building right-angled to the tsunami direction (see Figure 2(b)).
- The opening ratio was obtained by dividing the area of openings in the inundated sectional area by inundated sectional area.
- Opening ratio difference was obtained by subtracting landward opening ratio from seaward opening ratio of the building.

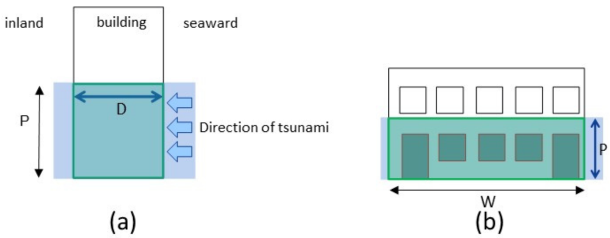

Figure 2. Inundated vertical sectional area and inundated sectional area

3. Results and Discussion

Table1 indicates the measured and calculated values for each building, which was located in the premises of Sendai sewage purification centre. All of them are reinforced concrete structures except two, which are the combination of reinforced concrete and steel. Data has shown that any of them have not been fully inundated by tsunami. All of the buildings survived while surroundings were severely damaged by tsunami.

Table 1. The measured and calculated values for each building.

Objective Building			Sendai Sewage Purification Center										
Sign			A	B	C	D	E	F	G	H	I	J	K
Structure*1			RC	RC	RC+S	RC+S	RC	RC	RC	RC	RC	RC	RC
Height (m)			18.4	14.7	25.7	25.7	20	27.8	9.7	12.3	10.5	10.8	10
Width (m)			47	47	27.5	27.5	17	71	28	22	47.5	28	7
Depth (m)			43	29	77	77	77	44	27	35	13	7	15
Inundated Vertical Sectional Area (m²)			499	328	293	293	293	167	103	132	50	54	118
Distance from the sea (m)			325	360	600	600	600	623	630	637	631	463	472
Height of the tsunami (m)		Seaward	14.7	14.7	6.8	6.8	6.8	6.8	6.8	6.8	6.8	10.1	10.1
		Inland	7.2	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	10.1	10.1
Altitude (m)			3.1	2.2	3	3	3	3	3	3	3	2.4	2.4
Inundation Height (m)		Seaward	11.6	12.5	3.8	3.8	3.8	3.8	3.8	3.8	3.8	7.7	7.7
		Inland	4.1	4.6	3.8	3.8	3.8	3.8	3.8	3.8	3.8	7.7	7.7
Inundated Sectional Area (m²)	Seaward	All	545	526	105	105	65	270	106	84	181	216	54
		Opening	41.5	24.2	2.2	6.0	0.0	0.0	3.6	0.0	36.1	29.3	11.0
	Inland	All	193	216	105	105	65	270	–	84	181	216	54
		Opening	30.0	17.9	5.5	0.0	0.0	29.5	–	6.0	35.4	11.6	2.4
Open Ratio (%)		Seaward	7.6	4.6	2.1	5.7	0.0	0.0	3.4	0.0	20.0	13.6	20.3
		Inland	15.6	8.3	5.3	0.0	0.0	10.9	–	7.2	19.6	5.4	4.5
Open Ratio Difference (%)			–8.0	–3.7	–3.2	5.7	0.0	–10.9	–	–7.2	0.4	8.2	15.8

*1 RC: Reinforced Concrete Structure S: Steel Structure SRC: Steel Framed Reinforced Concrete Structure

3.1 Relationship between the inundation depth and the height of the building

Figure 3 shows the relationship between the inundation height (h) and the height of the building (H). All the buildings indicated in the graph withstood tsunami. The results imply that all buildings which were not fully submerged withstood tsunami. Matsutomi et al. (2012) has found that all buildings which moved and/or toppled were fully submerged, however, some of the fully submerged buildings have survived.

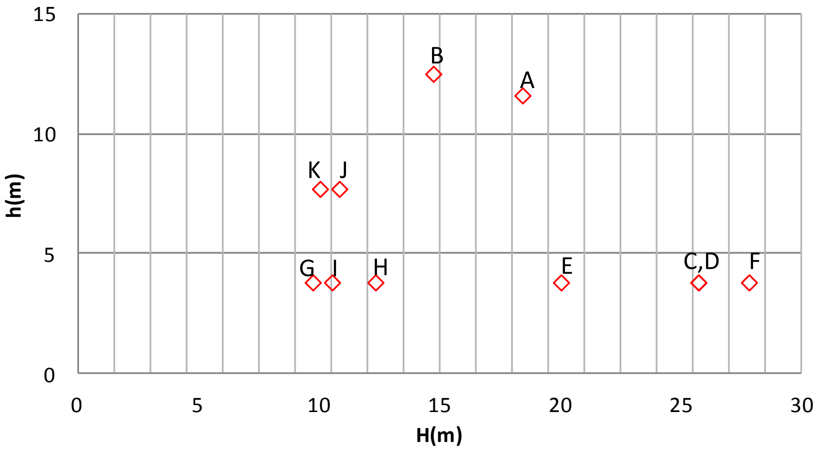

Figure 3. Relationship between the inundation height (h) and the height of the building (H)

3.2 Relationship between the inundation height and the inundated vertical sectional area

Figure 4 shows the relationship between the inundation height (h) and the inundated vertical sectional area (A_c). All the buildings indicated in the graph withstood tsunami. The building J indicates a critical value, which has a higher inundation height while having a lower inundated vertical sectional area. The depth of this building is 7m (see Table 1), the lowest of the eleven buildings. It is justifiable to say that the depth of a building should be more than 7 m to remain undamaged by a tsunami like 11 March 2011.

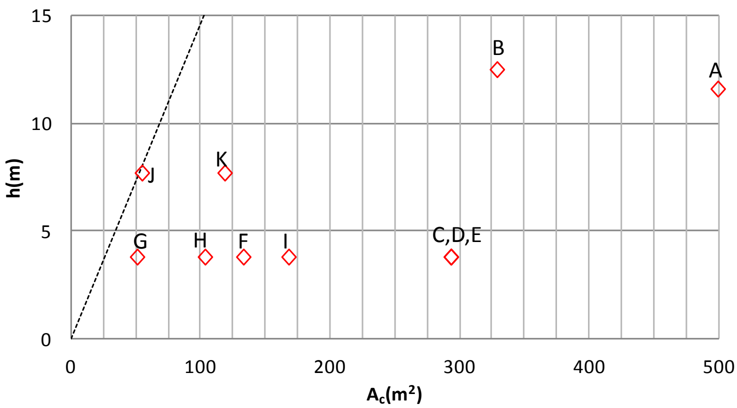

Figure 4. Relationship between the inundation height (h) and the inundated vertical sectional area (A_c).

3.3 Relationship between the inundation height and the opening ratio of buildings

Figure 5 shows the relationship between the inundation height and the opening ratio of buildings. According to the previous studies the buildings those opening ratio is high, especially over 14 per cent, tend to withstand. Meanwhile, buildings whose opening ratio is low or under 10 per cent tend to move and/or topple. Some buildings whose opening ratio was 17 to 38 per cent withstood even though they were fully submerged (Matsutomi et al. (2012) and Ogata (2014). In despite of this theory, the opening ratio of buildings A to G was under 8 per cent, but they survived. It is assumed that the buildings survived due to their large vertical sectional area.

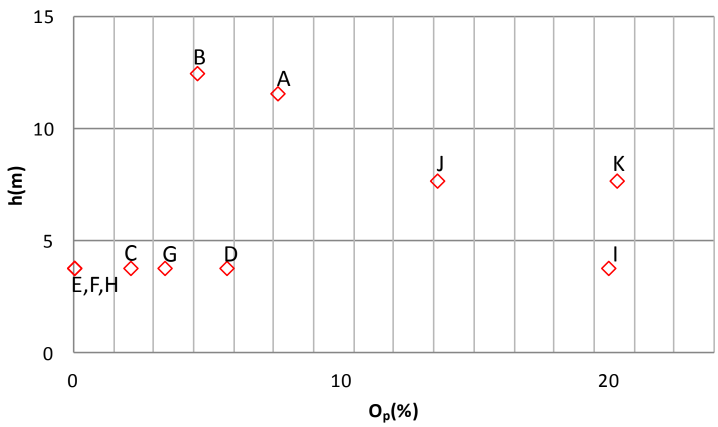

Figure 5. Relationship between the inundation height (h) and the opening ratio (O_p) of buildings

4. Conclusion

According to the analyses given above the authors have drawn following conclusions.

- Buildings whose depth was over 7 m withstood.
- The possibility of moving and/or toppling of buildings will be low if the opening ratio of buildings is high.
- All buildings which were not fully submerged withstood tsunami.
- In the case that buildings are fully submerged, the possibility of moving and/or toppling of buildings will be low if the opening ratio and/or inundated vertical sectional area are high.
- In the case that buildings are fully submerged, the possibility of moving and/or toppling of buildings is very high if the opening ratio and inundated vertical sectional area are low.
- In the case of buildings which were fully submerged but did not move and/or topple, the opening ratio was 17 to 38 per cent.

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