Damage to Structures in Rikuzentakata Region Due to Tsunami

Graduate School of Kyushu Institute of Technology Student Member Yulong ZHENG
Kyushu Institute of Technology Member Kenji KOSA
Nippon Engineering Consultants Co., Ltd Member Hideki SHIMIZU
Graduate School of Kyushu Institute of Technology Student Member Li FU

1. Introduction

The 2011 Tohoku earthquake, known as the 2011 Great East Japan Earthquake, with a magnitude 9.0, occurred at 14:46 (JST) on 11 March 2011. Due to the great tsunami triggered by earthquake, areas along eastern Japan suffered tremendous destructions.

Soon after the great earthquake, several field investigations to the disaster areas were conducted. In this paper, the authors will analyze the damage conditions of structures (buildings and bridges) in Rikuzentakata (Iwate Prefecture), which has suffered great tsunami with the inundation height as about 15m. The tsunami affecting area is illustrated in Fig. 1. Total 26 bridges over the main rivers and original 628 residential buildings in most severely damaged area will be analyzed. Secondly, the reasonability of using β ratio between girder resistance and tsunami impact force to judge the girder outflow will be conducted. Thirdly, the tsunami velocity in Rikuzentakata area will be estimated based on which the characteristics of velocity distribution will also be analyzed.

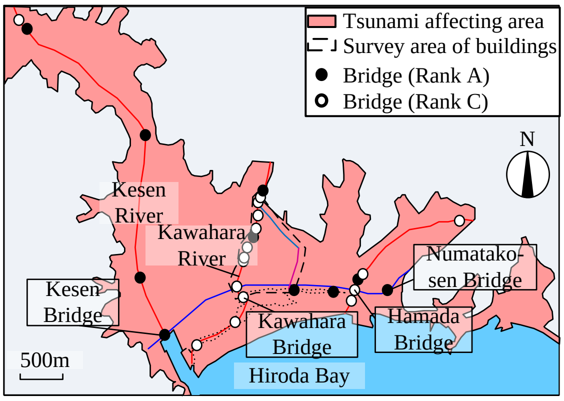

Fig. 1 Research Region for Rikuzentakata

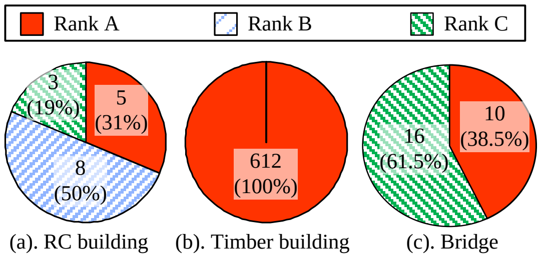

Fig. 2 Investigation Results

2. Damage to Structures

The survey area for buildings, (Fig. 3) being flat and close to the coastline, suffered great damage. Among total 16 RC buildings (Fig. 2 (a)), proportion is 31%, 50% and 19% for Rank A (structural elements damaged), B (non-structural elements damaged) and C (slight damage), respectively. Around 70% of RC buildings suffered non-structural damage (sum of Rank B and C). While 100% of all 612 timber buildings are washed away (Rank A, Fig. 2 (b)). Thus, RC buildings have greater resistance to tsunami impact. Fig. 3 presents the distributions of RC buildings in survey area. There is the trend that Rank A buildings are in smaller size inducing smaller stiffness to resist tsunami impact. Further, Rank A buildings are mainly distributing in regions relatively closer to the coastline.

For bridges, damage conditions of 26 bridges can be referred from Fig. 1. Rank A (girder flowed out) occupies 38.5% (Fig. 2 (c)) while Rank C (girder survived with slight damage) takes 61.5%. In Fig. 1, it is found 80% bridges in the Kesen River suffered Rank A (4 in 5); while only 18% in the Kawahara River (2 in 11). Using distance measurement of Google Earth, Kensen River has greater size (width about 120m) than Kawahara River (width about 15m). Direct run-up of tsunami in the greater size river is considered the reason for more serious damages to the related bridges.

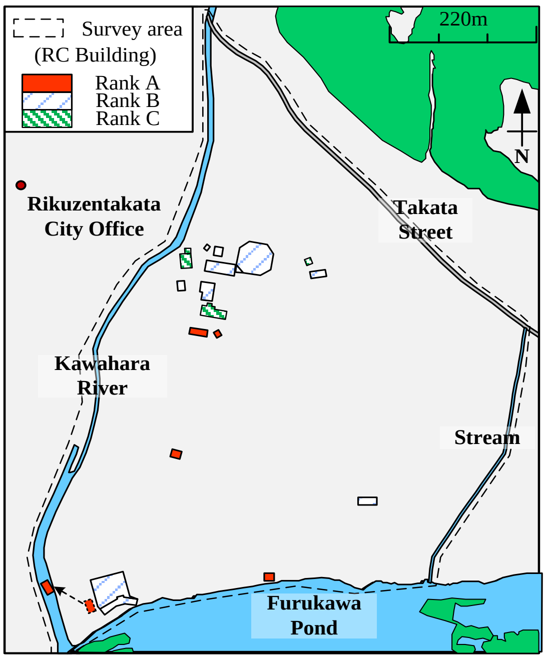

Fig. 3 Survey Area to Buildings

3. Judgment for Bridge Loss

Authors define the indicator β (S/F) to judge outflow of girder. S ($S=1/2\rho_w C_d v^2 A_n$, v uses 6.0m/s as average of velocities from recorded videos in entire Tohoku area) is the resistance of girder. F

(F=μW) is tsunami impact force. Fig. 4 illustrates β ratios for four bridges in Rikuzentakata (refer from Fig. 1). β ratios of two Rank C bridges are all greater than 1.0 with average as 3.47, inferring resistance is greater than tsunami impact force. Thus, their girders survived. β ratio of Rank A bridges is in small level (avg. 1.17). Average β ratio of Rank C bridges is 2.97 times of Rank A bridges. β ratios for 29 bridges in entire Tohoku area are presented in Fig. 5 (Rikuzentakata included). Average β ratio of Rank A bridges with girders outflowed is 0.94. Average β ratio of Rank C bridges with girders survived is 2.11 (2.24 times of Rank A). Further, PC girders have relatively greater β ratios and 53% have survived (9 in 17, Rank C); all steel girders have relatively small β ratios and flowed out, inferring small resistance to tsunami impact.

From Fig.4 and Fig. 5, difference of β ratios between Rank C and Rank A bridges are obvious. Thus, β ratio is considered as an effective indicator to judge outflow of girder. As velocities in all areas probably not uniform to be 6.0m/s as authors used. Some β ratios of Rank A bridges are greater than 1.0 (like Numatakosen Bridge, Fig. 4) while some of Rank C bridges are smaller than 1.0.

4. Tsunami Velocity in Rikuzentakata

Two methods will be used for estimation of velocity. From recorded videos, velocity can be calculated by checking the floating distance of debris and the time. Also, based on study of Mr. Matsutomi, equation $v=0.58(gh_f)^{1/2}$ is derived. (h_f: tsunami depth front of building, values obtained from 2011 Tohoku Earthquake Tsunami Joint Survey Group). Estimated velocities are plotted in Fig.6. Focusing on velocities from videos, average value is around 7.0m/s. This is greater than 6.0m/s of entire Tohoku area (Chap.3). Velocities from equation can roughly coincide with those from video. Tsunami velocity in river area ((b), 8.50m/s) is 29% greater than land area (avg. of (a), (c), (d) and (e), 6.61m/s). From former study, tsunami energy can be partly weakened by friction of land and plants. Further, from video screens and height differences between tsunami and structures (Fig. 7), wave shapes can be drawn (positions in Fig. 6). Except for wavefront part (A, B of Fig. 7), entire tsunami is in shape with relatively small slope. Tsunami heights also do not have great difference between river and land area. However, based on wavefront (A, Fig. 7 (a)), wave of river is considered as Breaker Bore with greater velocity. For land area, slope angle (around 9°, B, Fig. 7 (b)) is relatively small, probably inducing the smaller velocity.

5. Conclusions

(1) In Rikuzentakata, 70% of the total 16 RC buildings suffered non-structural damage; while 100% of all 612 timber buildings are washed away.

(2) 60% of 26 bridges in Rikuzentakata have survived (Rank C). Average β ratio of Rank C bridges is 2.97 times of Rank A for Rikuzentakata and 2.24 times for Tohoku area. Thus, β ratio is effective to judge outflow of girder.

(3) From videos, tsunami velocity in Rikuzentakata is estimated as 7.0m/s, being greater than 6.0m/s of the entire Tohoku area.

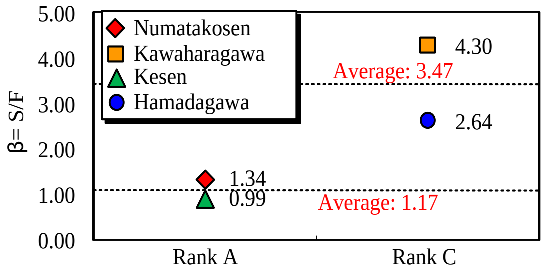

Fig. 4 β Ratios for Rikuzentakata Area

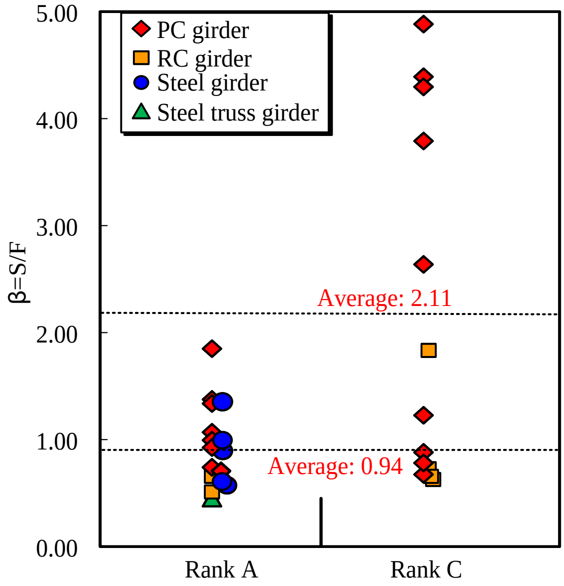

Fig. 5 β Ratios for Tohoku Area

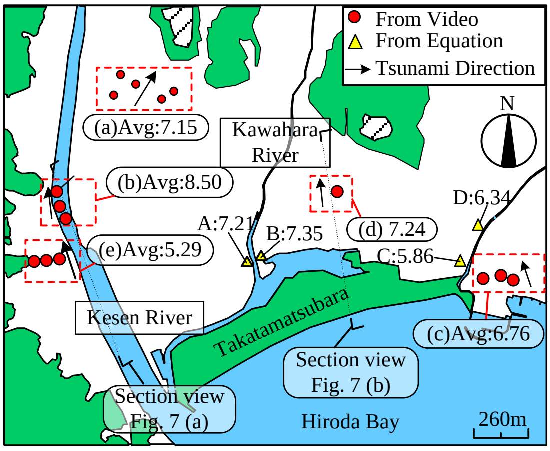

Fig. 6 Distribution of Tsunami Velocities

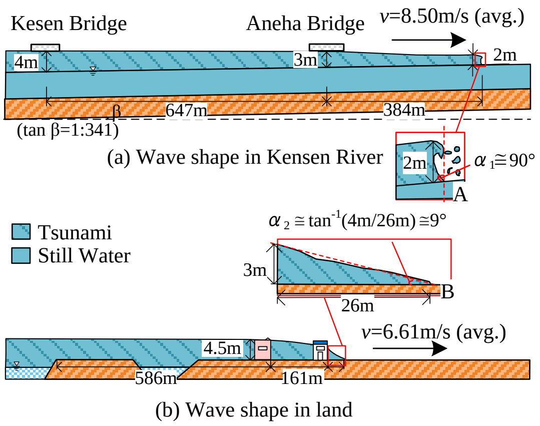

Fig. 7 Different Wave Shapes