DAMAGE OF BRIDGE STRUCTURES BY HUGE TSUNAMI AND EVALUATION OF TSUNAMI FORCE ON BRIDGES

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ABSTRACT**:** This paper introduces what damage we had by the huge earthquake and tsunami broken out on 11th March, 2011, and what we have been working for determining the tsunami force having acted on bridge structures. Right after the happening JSCE sent the delegation to survey how serious the damage was. Based on the brief surveying report, JSCE concrete committee decided to set up a research committee (1) to examine what has happened in bridge structures and (2) to study the tsunami force having acted on bridge structures. With help of Internet photo service all bridges within inundation areas were examined whether they were in safe or were washed away. Combined with on site survey the total number of washed away bridges has been determined. Details of bridges have been collected by asking authorities who have been taking care of bridges. Taking the location and dimension of a bridge as well as assumed tsunami velocity, the tsunami force having acted on the bridge is to be studied. Unfortunately, the work does not yet get to the goal.

KEYWORDS: tsunami, damage of bridges, tsunami force

1. INTRODUCTION

Tsunami, following the never experienced huge earthquake (M9.0) broken out on 11th March in 2011 in the eastern part of Japan, caused unbelievable damage in the wide area. Death toll rises up to 15,844 while the number of missing persons remains 3,450 as of 5 January 2012. About 600 thousands houses were destroyed. Many bridges were also engulfed and some of them were swept away. JSCE has set up a research committee with two objectives; (1) to survey the damage of bridges by the tsunami in details and (2) to evaluate the tsunami force acting on bridges for design and for expecting huge tsunamis in the western part of Japan. The committee consists of specialists from several fields, such as hydrodynamics, coastal engineering, bridge engineering, structural engineering as well as concrete engineering.

Survey of the damage of bridges in the first stage was done with use of satellite photo analysis by internet. More than three thousands of bridges which might be soaked during attack of tsunami were checked and more than two hundreds of bridges were supposed to be washed away. Followed by field survey the exact number of bridges which were washed away is determined as 222 including 28 of railway bridge and 40 of relatively large road bridge.

For further study of evaluation of tsunami force on bridges, it is necessary to provide dimensions of both damaged and without damaged bridges. Collecting the copy of drawings of bridges through authorities which maintain their bridges, the database of bridges has been built and the analysis is now being conducted practically and theoretically.

2. OUTLINE OF EARTHQUAKE

As is already known the historically largest earthquake hit the eastern area of Japan on March 11, 2011. The moment magnitude of the earthquake is 9.0 which we have never had in our history of Japan. The characteristics of the earthquake lie in the wide range of fault moved with 500 km long in the north/ south direction and 200 km wide in the east/west direction (Fig.1), and the long duration time of ground shaking in 2 or 3 minutes. In comparison with the Great Hanshin Earthquake in 1995, the duration time is about ten times long (Fig.2). The maximum velocity response spectrum looks similar but the predominant period is shorter as seen in Fig.3.

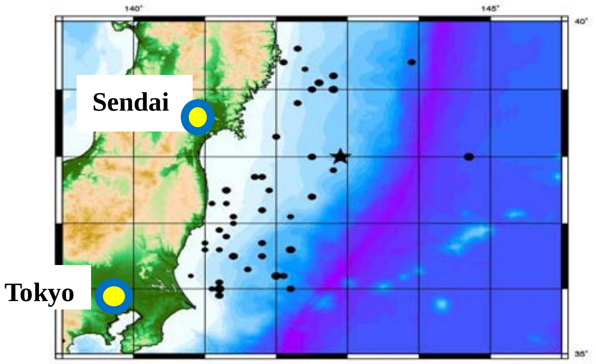

Fig.1 Epicenter of earthquake
(courtesy of Univ. of Tokyo)

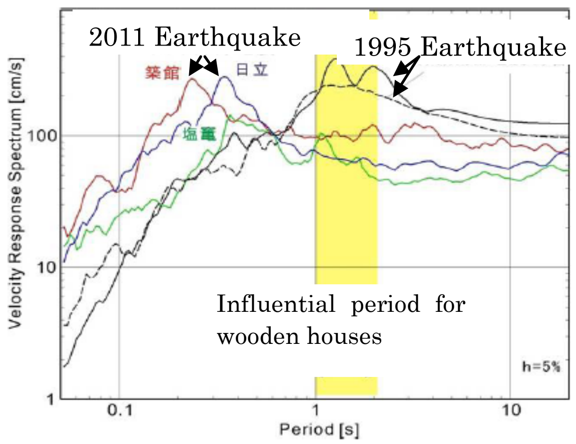

Fig.3 Comparison of velocity response Spectra (courtesy of Univ. of Tokyo)

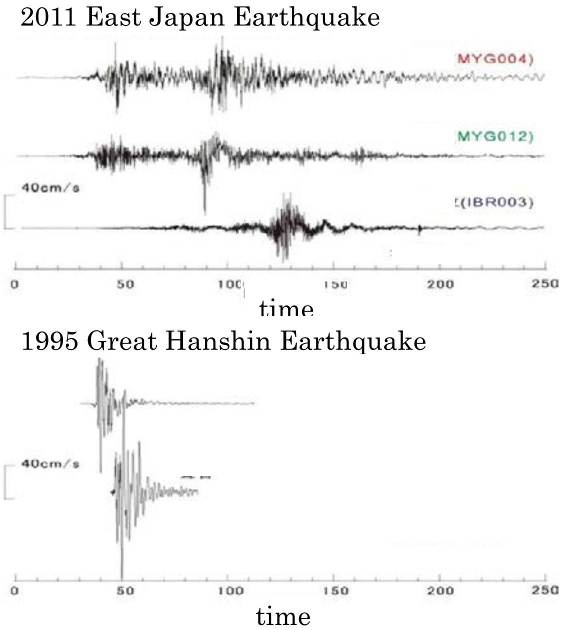

Fig.2 Comparison of duration time
(courtesy of Univ. of Tokyo)

3. OVERALL VIEW OF DAMAGE

In spite of large magnitude of earthquake, the damage of structures was not so severe as to be expected. In particular almost all concrete structures which have been strengthened against severe earthquakes were observed without damage. This fact should be attributed to what we have been working to develop the seismic strengthening technology as well as the seismic design of concrete structures after the Great Hanshin Earthquake in 1995. In addition, a short predominant period of response spectra might be good for concrete structures to have less influence.

Although fatal damage was not recognized in concrete structures, some typical damage was observed on concrete bridge piers which were under control of local governments. Such structures were not sufficiently strengthened against sever earthquakes because of the shortage of budget.

Dreadful disaster was caused by the tsunami. It took 15,854 people's lives. More than 3,086 residents are still missing. The number of wooden

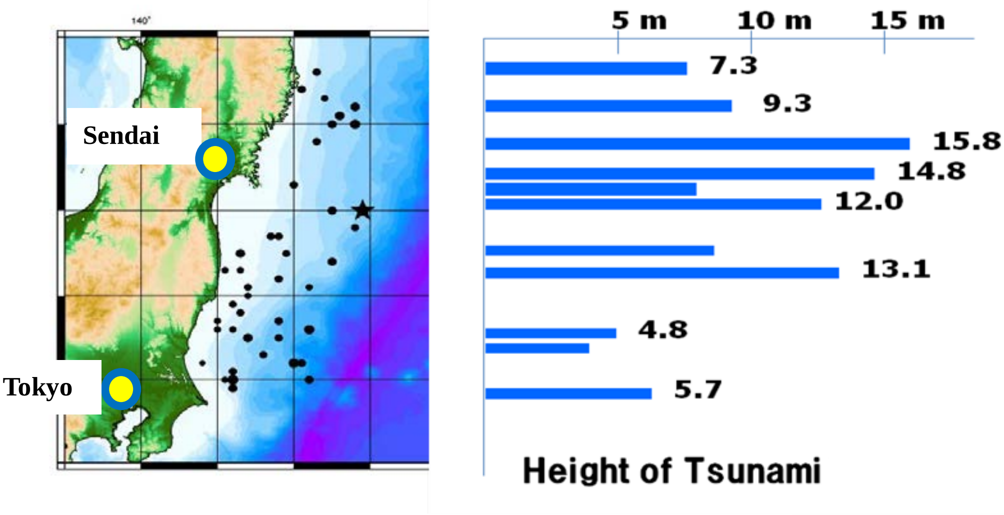

Fig.4 Height of tsunami at each location

houses which were washed away is more than 180,000. Some concrete bridges were also washed away and concrete buildings were overturned. However, in general most concrete buildings were survived though windows and panels of lower stories were broken out and anything inside were washed away. The tsunami height was observed from 5 to 15 m in different coastal area as shown in Fig.4. The scale of tsunami is corresponding to what happened in 869 which called Jogan Tsunami in Japan.

4. DAMAGE DUE TO TSUNAMI

Japan has a large number of active faults both inside the land and near the shore. Big earthquakes and consequent tsunamis have hit the country periodically in the history. In the period of recent one hundred years, major tsunami hit the eastern Japan four times. Table 1 indicates the records of death toll and lost houses by tsunami, respectively. The number of people killed by the latest tsunami in 2011 is about twenty thousands including missing people of more than 3,500. It is comparative to that by the tsunami in 1896. The scale of tsunami in four cases is not identical. Probably the latest case is the largest among them. Even in the old days both government and local governments must has took many countermeasures. The reduction of damage should represent such efforts. The number of death toll in 2011 might look to deny the efforts done so far, but the ratio of death toll to lost houses should be examined carefully.

Table 1 Comparison of damage by tsunami

Date	Death Toll	Lost Houses
1896.6.15	26,360	9,879
1933.3.3	2,995	4,885
1960.5.24	105	1,474
2011.3.11	15,844 (3,450)	>180,000

28 railway bridges were washes away by the tsunami. Figures 5 through 8 represent some cases of damage. Concrete girders were fallen down overturned near piers.

Fig.5 Washed away of concrete bridge

Fig.6 Broken pier at the top

Fig.7 Close-up view of broken pier

Fig.8 Fallen prestressed concrete girder

When special devices were installed on the top of pier to prevent the lateral movement of girder, the pier was broken out at the top by the bending moment produced due to tsunami force acting on the girders (Figs 6 and7). Fig.8 shows the fallen prestressed concrete girder.

Road bridges also suffered from the tsunami (Figs 9 through 12). Devices to prevent fall down of girders during earthquake were useless against tsunami forces as shown in Figs 9 (broken devices for prestressed girders) and 11 (broken devices for steel girders).

Fig.9 Broken anti-fallen device

Fig.10 Bird's-eye view of Tsuya river

Fig.11 Broken anti-fallen device

Fig.10 shows the bird's-eye view of Tsutani river area. Break water structures were completely collapsed. Both a road bridge near the mouth of the river and a railway bridge located upstream were washed away. A truss bridge had damage with two spans of truss member being washed away (Fig.12). The number of major road bridges washed away is 40.

Fig.12 Truss bridge washed away

Although many bridges were washed away by the tsunami, many other bridges were survived. As is discussed in the later section, the ratio of washed away to survived is about 10%. It is not easy to see in Fig.13, but three road bridges are as they used to be. Figure 13 tells another feature that houses located at the higher hill side (seen at the middle portion of

Fig.13 Town attacked by tsunami

Fig.13) escaped from the tsunami disaster while a lot of wooden houses in the lower area were completely washed away.

Fig.14 Broken decks next to water gate

Figure 14 shows a different type of damage of bridge decks. A certain amount of mass of water spilled over the water gate fell down and broke the pre-tensioned prestressed concrete bridge decks.

5. ONGOING ACTIVITIES

After finishing the general survey on the damage of earthquake and tsunami, JSCE has set up necessary committees to support the government and local governments for restoration and reconstruction of the damaged regions. Some of them are, of course, to study new subjects realized by the disaster.

The research committee on the tsunami force to bridges is one of them. The feature of the committee is as follows. Members are university professors, government officials, researchers and engineers in both public and private sectors. Their major fields vary such as concrete engineering, structural engineering, bridge engineering, coastal engineering and hydraulic engineering.

The first target is to collect necessary information on bridges located in the inundation area by the tsunami. The internet is a powerful media for this purpose (Fig.15). Comparing pictures taken before with after March 11, 2011 as shown in Fig.16, the number of bridges washed away as well as that of survived ones was determined. Field survey has been conducted to confirm the details of bridges (Fig.17). The internet survey indicated that the total number of bridges to be surveyed was 3,230 and that the number of washed way bridges was 222, including 28 of railway bridge and 40 of major road bridge. With the field survey the rest were confirmed as small bridges owned by local governments.

Fig.15 Internet image (Google earth pro)

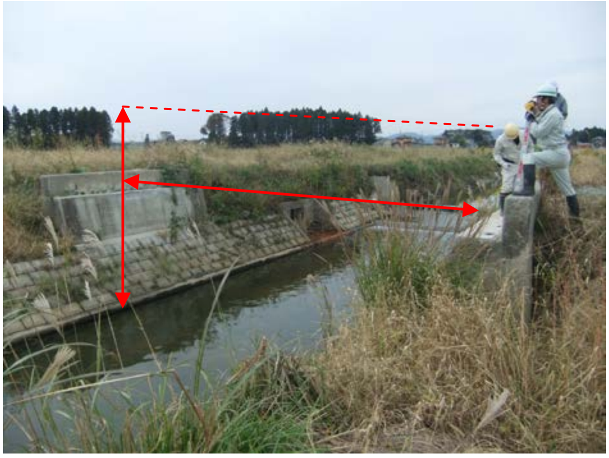

Fig.17 Field survey

The collection of detailed data of bridges was conducted by asking for the authorities, such as MLIT (Ministry of Land, Infrastructure, Transport and Tourism)、local governments and JR (Japan Railway Company). The necessary information for each bridge is the location (distance from the sea), type, dimensions, details of reinforcements, and material properties (if possible). Geographical data are also taken from the Geospacial Information Authority of Japan. The data for more than 400 bridges have been collected and the data base is now processed. Using the data base some trials have started to categorize bridges by their types and dimensions to see what a key is for resisting the tsunami.

Fig.16 Comparison of images taken before and after March 11,

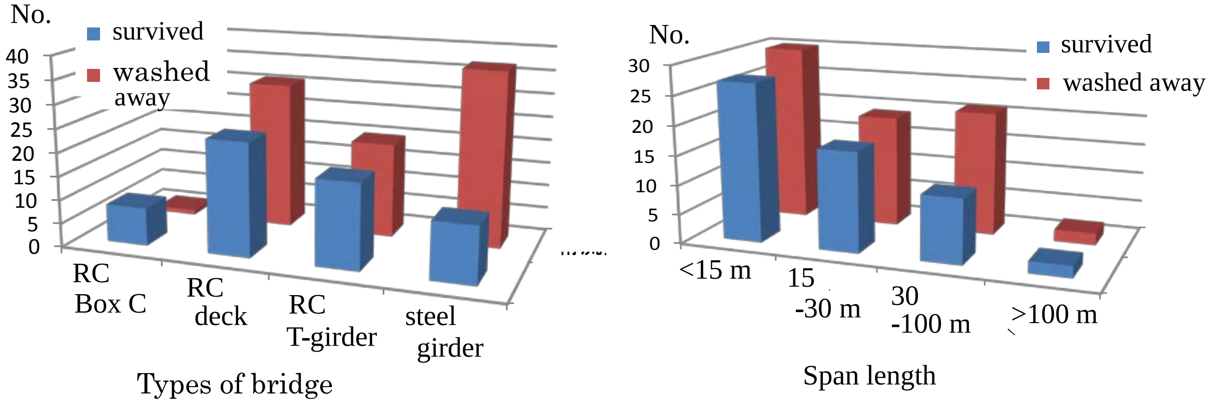

Fig. 18 Category of bridge

Fig.18 shows the number of bridges with or without suffering from washed away in comparison with categorized items, such as type of bridge and span length. In general, the total number of bridges survived in inundation areas is 1,703 while 222 bridges were washed away. In the figure only the survived bridges located near the washed away bridges are selected for comparison.

It is difficult to draw some tendency from Fig.18. This is because no consideration is taken for the velocity and the height of tsunami at the location of bridge. Then, in the next step the weight of girder and the horizontal force caused by tsunami are considered based on the equation proposed by Prof. Kosa. His equation is expressed as equation (1).

$$\beta = \frac{\mu W}{0.5 \rho_w C_d v^2 A} \qquad (1)$$

where, ρ_w :unit density of water (1030 kg/m^3), v : tsunami current velocity (assumed as 6 m/s), A : projected area of girder (m^2), W : weight of girder, μ : coefficient of friction (assumed as 0.6), C_d : coefficient of drag expressed by equation (2).

$$C_d = \begin{cases} 2.1 - 0.1\,(B/D) & (1 < B/D < 8) \\ 1.3 & (8 \le B/D) \end{cases} \qquad (2)$$

where, B is width of girder and D is depth of girder.

The numerator of equation (1) indicates a kind of resistant force, and the denominator represents the hydraulic force. It is expected that when β is less than 1, then a girder should be washed away.

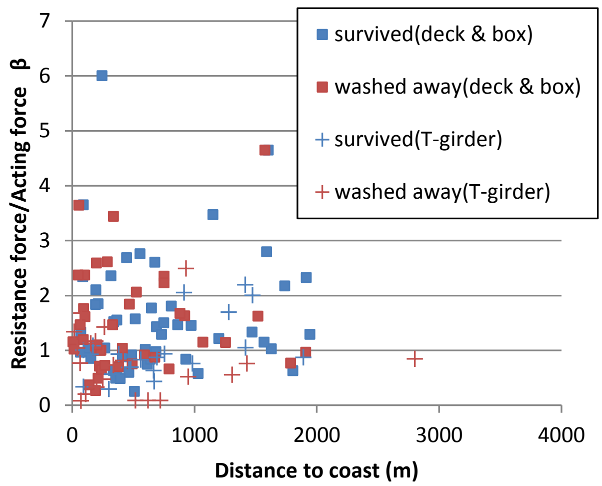

Fig.19 Cases of concrete girder

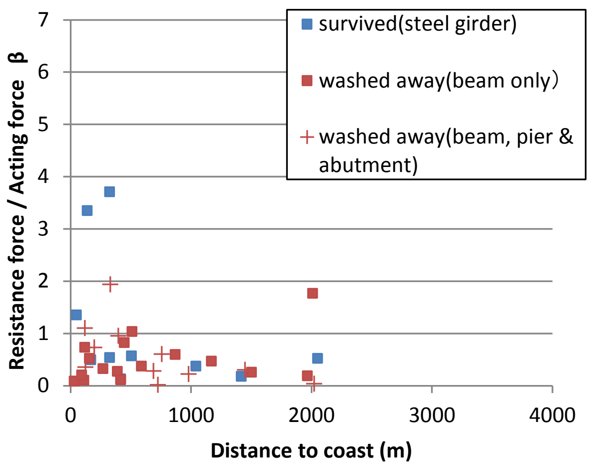

Fig.20 Cases of steel girder

Figs.19 and 20 show the results for cases of concrete (RC and PC) girders and steel girders. Calculation of β was conducted for both bridges whose girders were washed away and whose survived. Blue and red marks represent girders survived and washed away, respectively. It is obvious that the equation (1) is not effective yet to evaluate the bridge behavior or tsunami force on bridges.

It is crucial to conduct the hydrodynamic analyses to get the velocity and the height of tsunami at the targeted bridge locations. Some members of the coastal engineering field in the committee have been working to develop a numerical model to simulate the behaviors of girders during tsunami attacking. Comparing the analytical simulation results with the surveyed ones, the basic formulation of tsunami force will presumably be constructed in near future.

6. CONCLUDING REMARKS

There have been reported in the past that bridge structures were washed away by flood or tsunami. Normally only one or two bridges were suffered at once. Bridge engineers were mostly interested in how to reconstruct, not in what force acted on. On March 11, 2011 a huge tsunami hit in the very wide area caused many bridges washed away. The fact turns bridge engineers to study the force by tsunami. We have already the design formula of tsunami force for breakwaters, tied barriers and levees. The formula is not applicable to bridge girders. Ten months of work in the committee are, of course, not adequate to solve the problem as seen above. We are continuing the work in the committee.

Another huge earthquakes and consequent tsunamis are expected to break out in central and south coastal regions in the Pacific Ocean side of Japan. It is a urgent issue to establish the tsunami force in the design of bridges.

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