Damage Analysis of Utatsu Bridge due to Tsunami

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1. Introduction

The 2011 Tohoku Earthquake occurred at 2:46 p.m. (JST) on March 11th 2011, with a magnitude 9.0. The earthquake caused a destructive tsunami. Many bridges in Tohoku region suffered damage by tsunami. The authors conducted a field survey to the coast of Tohoku region and observed the damage of coastal bridges.

The Utatsu Bridge, at the coast of Minamisanriku Town, is a 304m long, 8.3m wide, 12-span, prestressed concrete bridge. From field survey, it is observed that 8 middle girders were washed away while 4 end girders survived. Two-dimensional numerical analysis is conducted at Utatsu Bridge. From the numerical result, the tsunami landing characteristics is understood and the outflow mechanisms on girders are evaluated by the ratio (β) to girder resistance and wave force.

2. Outflow Condition of Utatsu Bridge

Utatsu Bridge is made of 3 types of girders (S1~S2: 40.7m long; S3~S7: 14.4m long; S8~S12: 29.9m long). The 12 girders and 11 piers of Utatsu Bridge are numbered from S1 to S12 and P1 to P11.

Based on the field survey, as shown in Fig. 1, it is observed that S3~S10 were washed away while S1, S2, S11 and S12 survived. Besides, S8 suffered greatest displacement 41m. It is also noted that S3~S4 and S5~S7 moved off together while S8~S10 were inverted by wave uplift force. Further, S3~S4 rotated after tsunami.

3. Numerical Analysis for Tsunami

On purpose of studying for tsunami characteristics at Utatsu Bridge, and researching the reason why only 8 girders flowed out, two-dimensional numerical analysis was conducted. The Fujii•Satake Model (Ver.4.6) is used as the model of seismic wave source. 8 numerical regions (A~H) were set and the mesh size from A to H decreases by three times. The smallest Region H (mesh size: 2m) is plotted in Fig. 2.

The numerical result of 4 areas (A, B, C, D) are focused for analyze the outflow of S1~2, S3~7, S8~10 and S11~12. For each area, average numerical wave height and velocity histories of 8 points are applied to study the tsunami characteristics.

The wave height and velocity histories of B, C and D are illustrated in Fig. 3. It is defined as time span 1 (called T1 in following) from tsunami height reached girder bottom to tsunami height reaches road surface, and it is defined as time span 2 (called T2 in following) from tsunami height reaches road surface to max wave height occurs. The max wave velocities for B, C and D in T1 or T2 almost happen at the same time. Among B, C, D the max velocity 4.48m/s happens to B at 41min.. No matter for T1 or T2, the max velocities of B, C are more than 3 times greater D. The

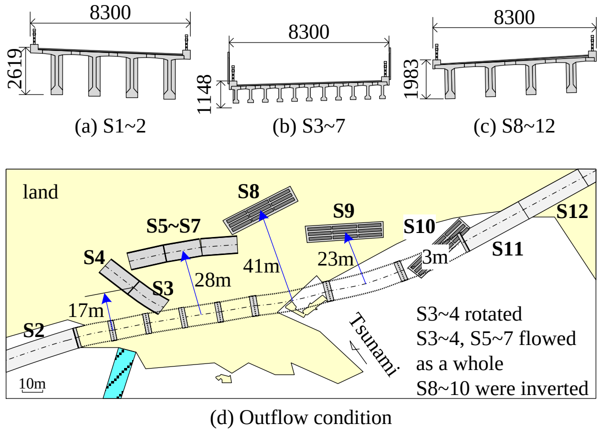

Fig. 1 Outflow Condition of Utatsu Bridge

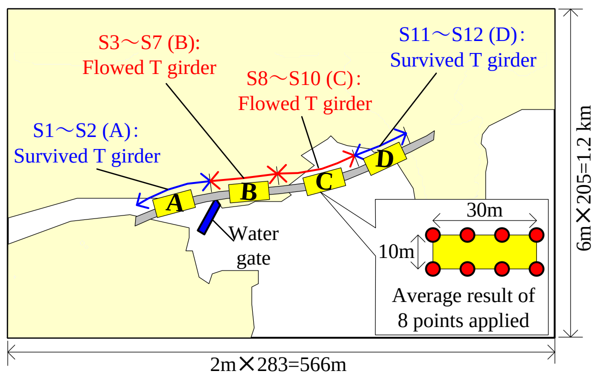

Fig. 2 Division of Numerical Area and Objective Points

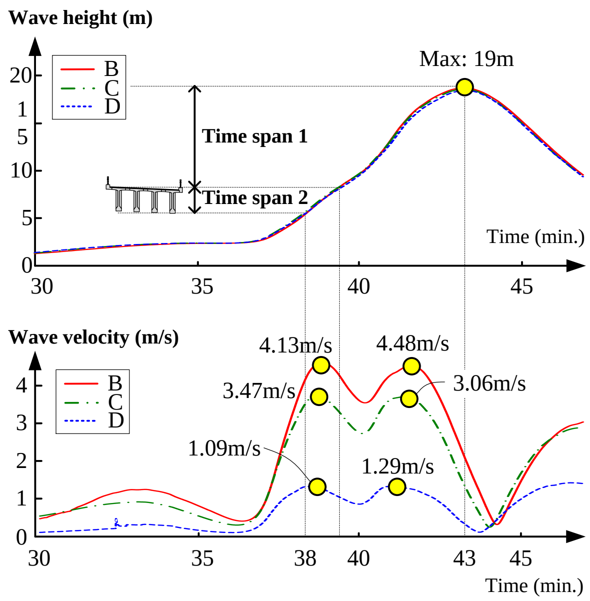

Fig. 3 Variations of Wave Height and Velocity

tsunami height touched girder bottom at 38min. from earthquake occurred, and then reached max height 19m at 43 min..

The distribution of wave velocity at Utatsu Bridge, when max velocity of T2 occurs, is given in Fig. 4. Generally, the wave flows to northwest. For B and C, the wave flows to girder with acute angle while for D, the wave flows to girder vertically. And the angles between flow and girder axis are 36.69°, 44.36°, 90.63° for B, C, D respectively. Due to the blocking effect of mountain, the velocity at D is smaller than B, C.

4. Evaluation of Outflow Mechanism

The different mechanisms on girder are proposed. The tsunami acting force on girder is estimated by Eq. 1 while the friction resistance on girder is calculated by Eq. 2. According to different flooding condition, 3 cases are found for resistance (Fig. 6). When tsunami height reaches girder bottom (case1, girder is not submerged), buoyancy is not considered for computing resistance. After girder is submerged, buoyancy occurs and 2 possibilities are considered. In case2, the buoyancy caused by girder volume is considered for computing resistance (U_1). In case3, besides the buoyancy caused by girder volume, the buoyancy from air between girders is considered as well ($\sum U_{2i}$).

$$F = \frac{1}{2}\rho C_d v^2 A \qquad (1)$$

$$S = \mu(W - U_1 - \sum U_{2i}) \qquad (2)$$

Corresponding to case1~3, the max velocities are applied to compute tsunami force for evaluation of outflow. From Fig. 3, the relation between wave height and velocity before and after girder submerged (T1: before submerged, T2: after submerged) is drawn in Fig. 5. The effective max velocities (V_a) revised by acting angles (θ) for B, C, D of T1, T2 are applied to compute tsunami force.

At last, the ratio (β) to friction resistance and tsunami force is computed (Fig. 6). When ratio is greater (smaller) than 1.0, it means girder is difficult (easy) to flow out. From video, wave height first reached to girder bottom (case1), this time β of S3~12 are greater than 2.0, so it is observed girders can resist tsunami. With time going, it is noted wave submerged girders. This time, considering girder buoyancy only (case2), β of S3~12 reduce but still greater than 1.5. In channel experiment for estimating tsunami force on girder by PWRI, the authors found when girder was submerged, about 1/2 volume of air between girders might be locked and cause buoyancy (case3), in this condition, β of S3~10 reduces under 1.0 while β of S11~12 still keeps great (3.74). Thus after tsunami S3~S10 flowed out while S11~12 survived.

5. Conclusions

(1) Based on field survey of Utatsu Bridge, S3~S10 displaced from their supports while S1~S2 and S11~S12 survived.

(2) Based on numerical result, the max wave velocities at S3~7 and S8~10 (B and C, 4m/s) are more than three times greater than S11~12 (D, 1m/s).

(3) It is found that after submerged, considering the effect of buoyancy caused by girder volume and 1/2 air volume between girders, the outflow condition of S3~S12 can be evaluated by β ratio to friction resistance and tsunami force.

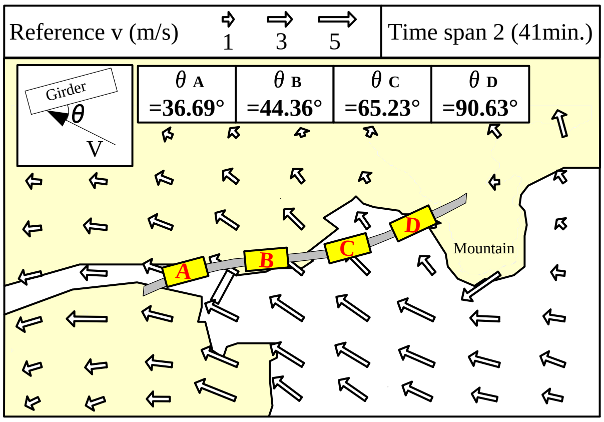

Fig. 4 Distribution of Wave Velocity

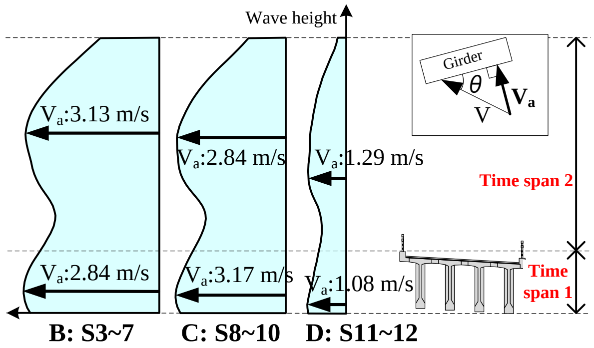

Fig. 5 Relationship between Wave Height and Velocity

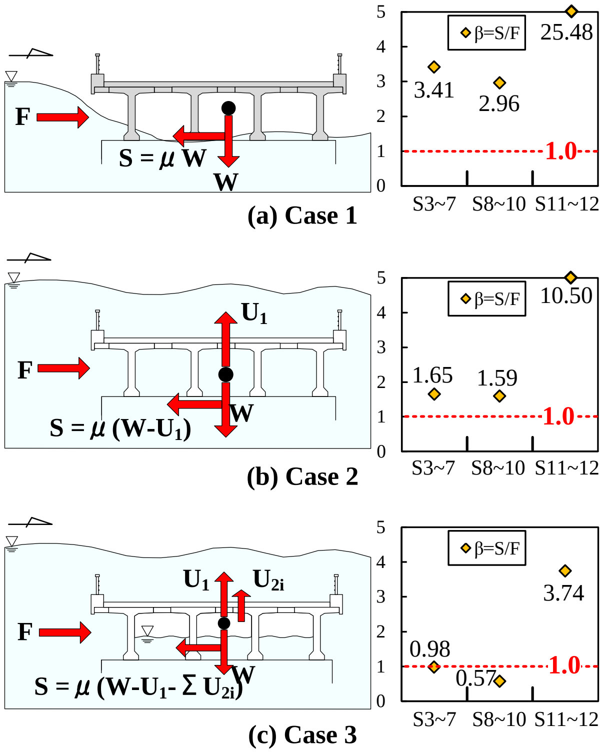

Fig. 6 Mechanisms on Bridge