ROAD BRIDGES IN MINAMI-SANRIKU WASHED AWAY IN THE MARCH 11th 2011 GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

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On March 11th, 2011, Minami-Sanriku, located in the northeastern coast of Japan was severely inundated by the tsunami that followed the Great East Japan Earthquake on March 11, 2011. Road bridges near the coastlines in this area have been extensively damaged with their decks being overturned or carried over long distances. An attempt was made to deduce as rational scenarios as possible before remaining debris was cleaned up. Though the reasons for the washout of bridges can be many and complex, it is to be noted that bridge decks have hollows for the optimum light-weight solution, which fact eventually allowed the bridge decks to be carried over remarkable distances. Poor connection details and cavities, hollows between deck beams, are considered to have facilitated overturning due to uplift forces.

Key Words: Great East Japan Earthquake, Road bridges, Tsunami, optimum light-weight solution, tsunami wave/floating debris/ bridge interaction

1. INTRODUCTION

Minami-Sanriku, located in the northeastern coast of Japan, was one of the areas severely inundated by the tsunami that followed the Great East Japan Earthquake on March 11, 2011. Tsunami waves had engulfed extensive areas of the town resulting in 343 missing and 558 dead as of Sept. 28, 2011¹⁾, and had caused widespread significant damages to properties. Tsunami run-up heights reportedly reached 13.1m, 15.8m and 13.5m at Utatsu Oiso (38.709977, 141.559074), Utatsu Baba (38.714682, 141.554718) and Hiraiso Shizugawa (38.681289, 141.469778) respectively²⁾ (See Fig.1).

Bridges near the coastlines and waterways in this area have been extensively damaged with their decks being displaced or overturned^{3), 4)}. Every bridge was left in a chaotic mess indicating complexity of the tsunami wave, possible failure

Fig.1 Locations of surveyed bridges in Minami-Sanriku town

Fig.2 Oritate Bridge and tsunami engulfed Oritate area (imagery from Google map)

Fig.3 Shape and configuration of Oritate Bridge Deck

sequence based on prevailing condition of bridge details and evidences of floating debris. All the more because of the complexity, every detail fragment of information is to be compiled and analyzed for rational discussion of possible remedial measures. Among the many damaged bridges on the Minami-Sanriku area, three bridges were taken herein as case studies. These are the Oganeyama and Oritate Bridges, spanning the small stream of Oritate River and Utatsu Bridge for the National Route 45 (See **Fig.1**). The Oritate Bridge is made up of pre-stressed concrete box girder deck. The Oganeyama Bridge is a 40-year-old H-girder steel bridge. Lastly, the Utatsu Bridge is a newly

seismically retrofitted bridge with decks having lattice pattern due to the crossways of longitudinal concrete I-beams and transverse beams. These bridges represent those of different times, authorities and therefore both good and poor conditions of maintenance. The distinctness of the attributes of the three bridges taken into study is a good platform for investigation of various faces of possible failure mechanisms due to tsunami waves. Analyses of possible scenario of damages are described in detail in the following chapters.

Fig.4 Displaced Deck 2 of Oritate Bridge (Date & location: May 4th, 2011, 38.647134, 141.436868)

Fig.5 Bent dowel pins at abutment 2 (Date & location: May 4th, 2011, 38.647134, 141.436868)

Fig.6 Bent dowel pins at pier 1 and abutment 1 (Date & location: May 4th, 2011, 38.647156, 141.436973)

Fig.7 Eroded backfill at abutment 1 (Date & location: May 4th, 2011, 38.646771, 141.437469)

Fig.8 Displaced Deck 1 of Oritate Bridge (Date & location: May 4th, 2011, 38.646589, 141.439437)

Fig.9 Damaged railing at west side of span1 (Date & location: May 4th, 2011, 38.646611, 141.439671)

2. ORITATE BRIDGE

Pre-stressed concrete deck spans of Oritate Bridge were found washed out away from their original locations (see the pier and abutments in **Fig.2**, Location of pier: 38.647021, 141.437044). Deck No. 1 was seen approximately 250m east downstream of abutment 1 whose backfill had been scoured, while Deck No. 2 was seen approximately 11m west upstream of the abutment 2 (See **Fig.2**).

Originally, the road bridge is composed of 2 spans. Each is approximately 17.5m long with the double lane roadway of approximately 8.5m width and pedestrian carriages on both sides, each with 2.0m width (See **Fig.3**). The decks are composed of

16 precast pre-stressed concrete box beams aligned parallel with one another. Each beam is tapered along its axis in terms of beam height with its thinner and thicker sides for the abutment and the wall-type pier, respectively. The bridge is simply supported having steel dowel pins connecting the superstructure and substructure.

A possible scenario for the damage to the bridge is that when tsunami inundated the area, the strong wave was on the abutment 2 side as manifested by the gentle downward-curving river banks in northern part of the bridge. This centrifugal force had caused super-elevation of the water surface, and Deck No. 2 was carried approximately 11m west and upstream of the abutment No. 2 and was rotated

Fig.10 Overturned Oganeyama Bridge and its configuration

approximately 90 degrees counterclockwise (See **Fig.4**). This caused the dowel pins at the abutment No. 2 to bend towards the west/upstream side of the bridge (See **Fig.5**) while dowel pins at pier No. 1 toward the coastline (See **Fig.6**).

Not long after, the tsunami began surging back to the ocean. The flow was strong on the abutment No. 1 side, manifested by the upward-curving southern river bank. This flow, which scoured the backfill for the abutment No. 1 (See **Fig.7**), was strong enough to carry Deck No. 1 over an about 250m distance towards the coastline as manifested by the dowel pins all bent toward the coastline and heavily damaged pedestrian railing at the west side of the deck (See **Figs. 8 and 9**).

3. OGANEYAMA BRIDGE

Oganeyama Bridge, spanning a small stream of Oritate River at, 38.646808, 141.426649, was a single-span steel girder bridge, 18.4m long and

Fig.11 Line bearings on the right abutment: A rusty bolt for the RB/DS bearing was remaining on the lower flange of I-beam indicating that the friction between the anchor and the concrete had been loosened already. (Date & location: May 4th, 2011, 38.646726, 141.42659)

Fig.12 Broken line bearing on the upper stream side of the left abutment (LB/US) and scratches remaining on the left river wall (Date & location: May 4th, 2011, 38.646726, 141.42659)

Fig.13 Aseismic retrofit plan for Utatsu Bridge⁵⁾

Fig.14 Decks of Utatsu Bridge carried inland (Satellite imagery from Google Map)

4.75m wide with reinforced concrete (RC) slab casted on two I-beams. The face plate of the bridge says that the construction of the bridge was completed in October, 1968, more than 40 years ago. The bridge was lying upside down and diagonally across the stream (See **Fig.10**).

The rusty surface of the exposed bolt remaining on the lower flange of I-beam (RB/DS side) indicates that the friction between the anchor and

the concrete had been loosened and deteriorated already. Therefore, it is deduced that the right end of the bridge (RB / DS) was detached first in the tsunami surge (See **Fig.11**). Both the lateral drag from tsunami and buoyancy from the air instantaneously entrapped between two girders and beneath the slab were probably large enough to break the thin pinching plate of the remaining line bearing on the upstream-right bank (RB / US) side.

Fig.15 Remaining piers with steel brackets (Date & location: May 4th, 2011, 38.716373, 141.522153)

Fig.16 Bridge deck lying upside down showing lattice work of beams (Date & location: May 4th, 2011, 38.716373, 141.522153)

On the left bank (LB) side however, the bearing for the upstream side girder (LB / US) had gripped the lower flange until the right end of the bridge was carried about 15m upstream, and the entire bridge was turned over. In this movement of this bridge, the anchor bolt for LB / US bearing was pulled up and bent in an arc towards upstream, and finally the LB / US bearing was ripped off causing the left end of the bridge to fall on the river bed leaving scratches on the left abutment (See **Fig.12**).

4. UTATSU BRIDGE

Utatsu Bridge for National Route No. 45 (Location of its east-end abutment: 38.716687, 141.524194) is a 304m long bridge made up of 5 east and 2 west decks over waters and 5 middle decks over land (See **Fig.13**). The bridge was retrofitted in 2004 and 2005 in such a way that steel brackets were fixed to pier tops to be interlocked with main pre-stressed concrete beams of the bridge,

Fig.17 Configuration of Utatsu Bridge Deck

thus confining the beams' transverse movements^{4),5)}, and yet 8 decks of total 12 were found carried over several tens meters distances inland as shown in **Fig.14**. These steel brackets were remaining almost intact on pier tops except for the northernmost ones on the inland side (See **Fig.15**). Some bridge decks were lying upside down showing all their lattices of main and cross concrete beams about full of water (See **Fig.16**). This fact indicated that the watertight lattices of main and cross concrete beams may have entrapped airs giving some remarkable buoyancy to bridge decks. The cross-section of the bridge deck shown in **Fig.17** indicates that the hollow volume among the lattice beams of about 223 m^3 is about 2.2 times as large as the entire volume of the bridge deck of 100 m^3 . Considering that the relative density of concrete is around 2.3, this volume of the hollow in the beam lattice may have been large enough for the weight of the deck to be almost canceled in water.

The process of inundation of this bridge was videotaped by an evacuee, who was on a cut slope of excavated east approach to the bridge. Moving up

the slope for higher and safer location, he was unable to videotape the complete process of inundation. But the followings were seen on the video clip:

- (1) Tsunami water was flowing at the velocity of about 4 m/s or faster just before the bridge deck was immersed. This was determined by observing the time elapsed for a debris flow to traverse between two established reference points from the video clip. These two points are referred from the Google earth to get the distance and subsequently determine the velocity.
- (2) Some small fish boats were being stopped on the ocean side of the bridge. But beside them, no large floating object was seen.
- (3) Water that ran up the east closest bay flowed through the excavated east approach of the bridge (See **Fig.14**).

The above are all witnessed fragments of reality. Further investigations will be necessary to see the whole picture of the destruction in focus.

5. SUMMARY

Possible scenarios for road bridges washed away by tsunami in Minami-Sanriku were deduced from what the authors observed on the spots. Though the reasons for the washout of bridges can be many and complex, it was to be noted that bridge decks have hollows for the optimum light-weight solution, which fact eventually allowed the bridge decks to be carried over remarkable distances as seen in the cases of three bridges. The Oritate Bridge deck, made up of tapered prestressed concrete box girders were displaced transversely by the lateral tsunami waves. The boxy and compact configuration of beams of this bridge deck allowed it to be dragged laterally upright. On the contrary, the cavity created by the space between beams in the cases of the H-girders of Oganayama and the lattice deck of the Utatsu bridge allowed the entrapped water underneath it to exert buoyant force, thus uplifting and in turn, overturning it in addition to the displacement caused by lateral force of the tsunami wave. Moreover, the 40-year old Oganeyama Bridge had rusted bearings indicative of inherent problems of maintenance. The poor connection details facilitate readily detachment of the deck from the substructure, having its deck easily overturned by the uplift force and be displaced. This bridge case, for example, indicated that tsunami waves can pinpoint the weakest point of a bridge, thus determining the sequence of its collapse. Newly seismically retrofitted bridges such as the Utatsu Bridge show that even if they are capable to withstand strong ground motions, they do not necessarily perform the same in restraining the decks against tsunami waves. It would still be unwise to conclude that it is needed to design bridge

decks that are unlikely washed away, because a bridge is just a part of a long traffic route, and tsunami water can breach the weakest points of embankments first. Moreover, tsunami is not a pure water wave, but can carry a huge amount of debris. Compiling really accurate records of the entire picture of the tsunami-induced devastation will be mandatory for rational measures for mitigating tsunami disasters.

The above scenarios are nothing more than a deduction from fragments that the authors observed. To move one step further, quantitative description of the deduced scenario will be necessary.

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