

# ROAD BRIDGES IN MINAMI-SANRIKU WASHED AWAY IN THE MARCH 11<sup>th</sup> 2011 GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

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On March 11<sup>th</sup>, 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.

**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, 2011<sup>1</sup>, 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), respectively<sup>2</sup>.

Bridges near the coastlines and waterways in this area have been extensively damaged with their decks being displaced or overturned<sup>3</sup>, <sup>4</sup>. Every bridge was left in a chaotic mess indicating complexity of the tsunami wave/ floating debris/ bridge interaction sequence. All the more because of the complexity, every detail fragment of information

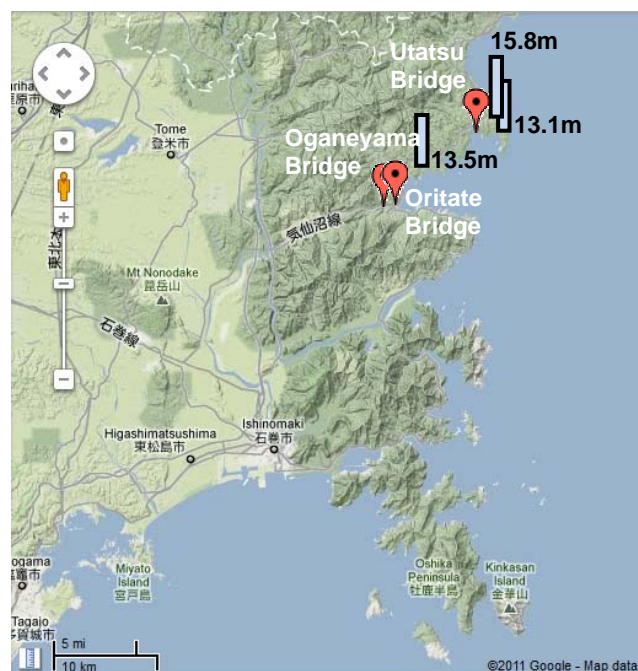


Figure 1. Locations of surveyed bridges in Minami Sanriku Town

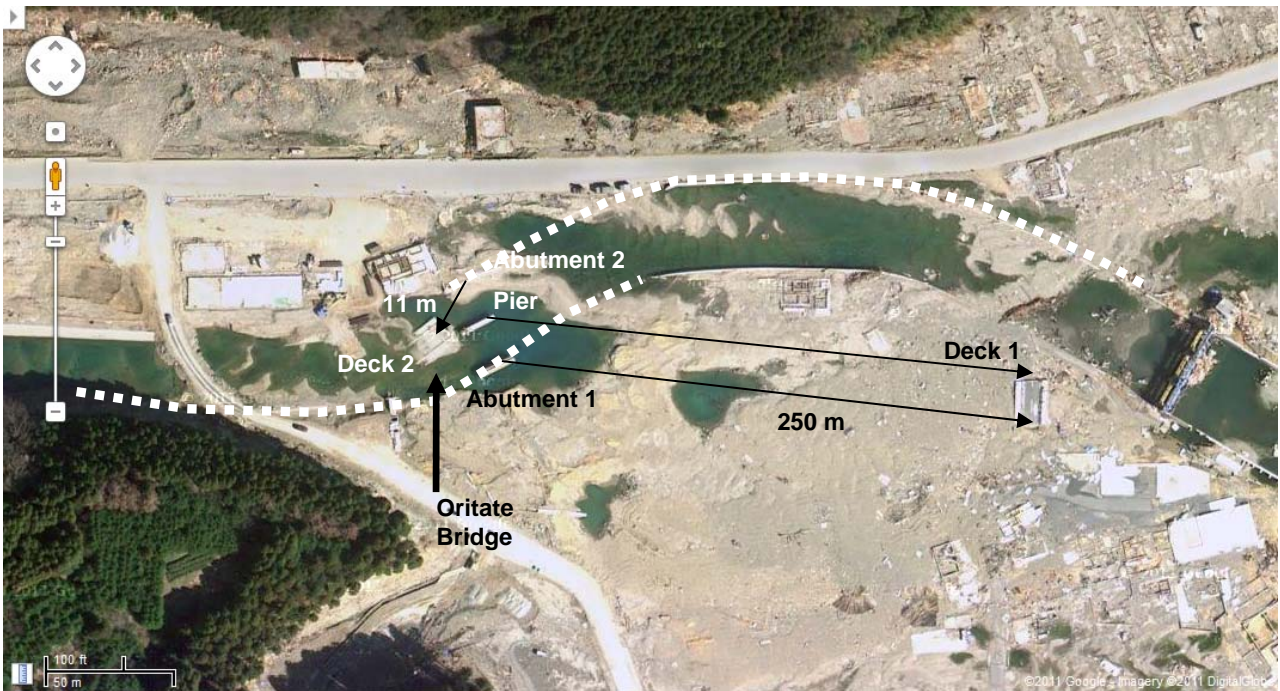


Figure 2 Oritate Bridge and tsunami engulfed Oritate area (imagery from Google map)

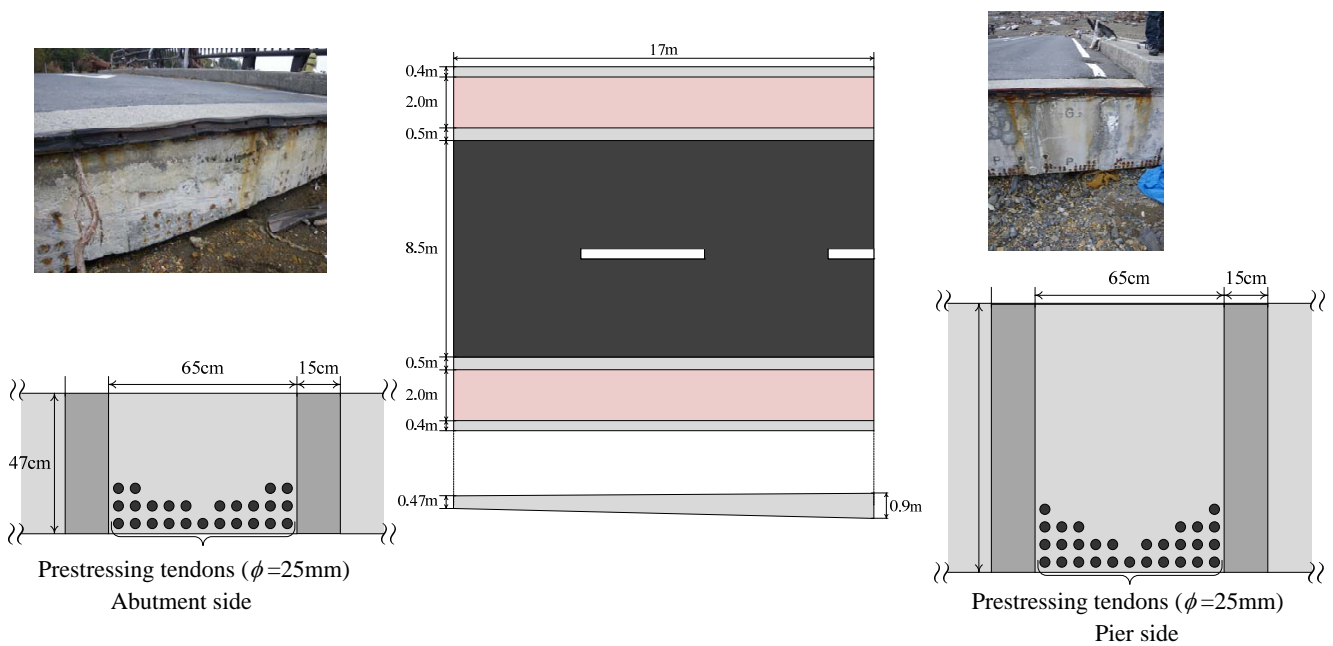


Figure 3 Shape and configuration of Oritate Bridge Deck

is to be compiled and analyzed for rational discussion of possible remedial measures. Three bridges, namely the Oganeyama and Oritate Bridges, spanning the small stream of Oritate River and Utatsu Bridge for the National Route 45 were taken herein as case studies to analyze the possible scenarios for the damage (see Figure 1).

## 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 Figure 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 (Figure 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 (Figure 3). The decks are composed of 16 precast pre-stressed concrete box beams aligned parallel with one another. Each beam is tapered



**Figure 4** Displaced Deck 2 of Oritate Bridge  
(Date & location: May 4<sup>th</sup>, 2011, 38.647134, 141.436868)



**Figure 5** Bent dowel pins at abutment 2  
(Date & location: May 4<sup>th</sup>, 2011, 38.647134, 141.436868)



**Figure 6** Bent dowel pins at pier 1 and abutment 1  
(Date & location: May 4<sup>th</sup>, 2011, 38.647156, 141.436973)



**Figure 7** Eroded backfill at abutment 1  
(Date & location: May 4<sup>th</sup>, 2011, 38.646771, 141.437469)



**Figure 8** Displaced Deck 1 of Oritate Bridge  
(Date & location: May 4<sup>th</sup>, 2011, 38.646589, 141.439437)



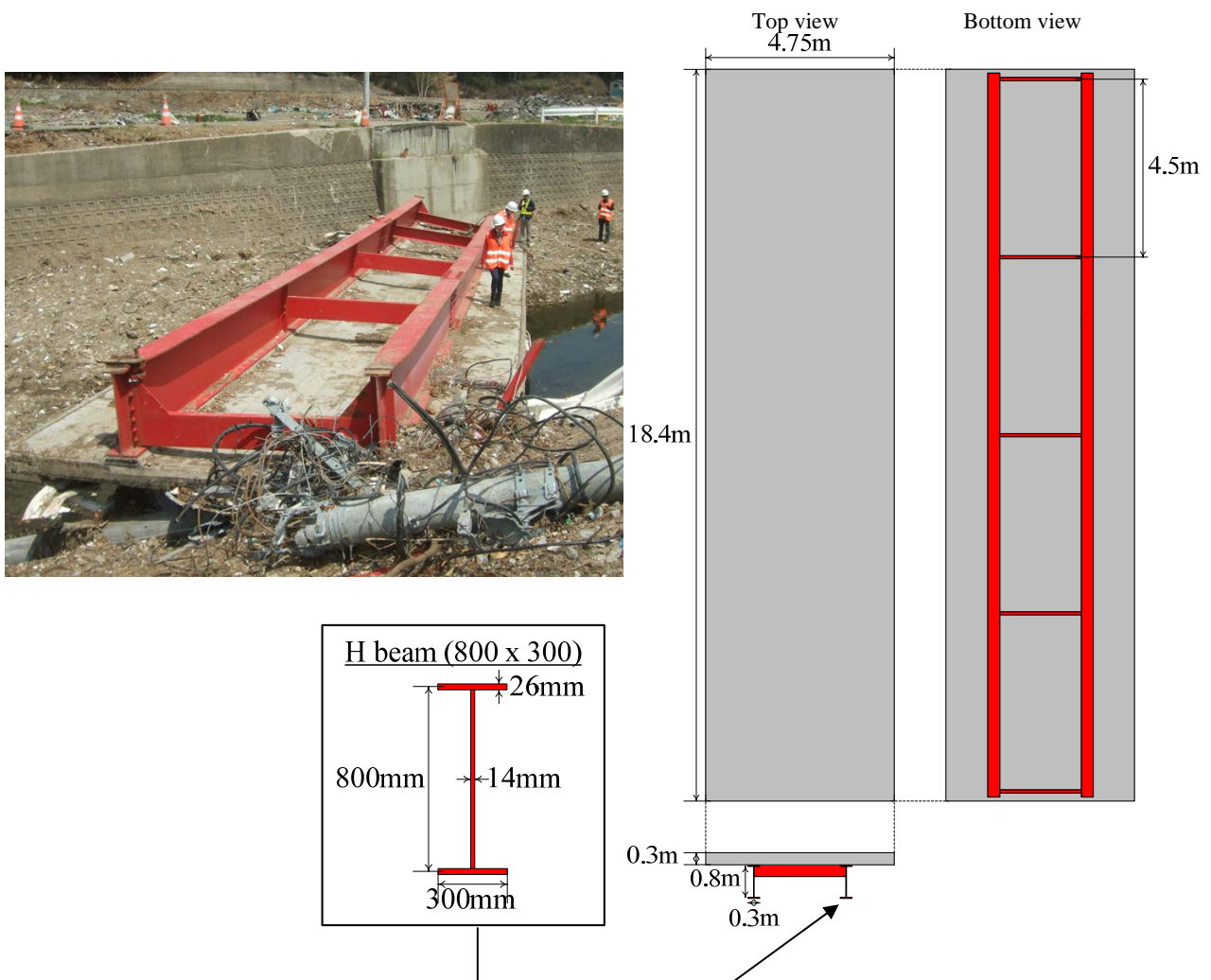
**Figure 9** Damaged railing at west side of span 1  
(Date & location: May 4<sup>th</sup>, 2011, 38.646611, 141.439671)

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

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



**Figure 10** Overturned Oganeyama Bridge and its configuration

damaged pedestrian railing at the west side of the deck (See **Figures 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 4.75m wide with RCC 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 **Figure 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 (**Figure 11**). Both the lateral drag from tsunami and buoyancy from the air instantaneously entrapped between two girders and

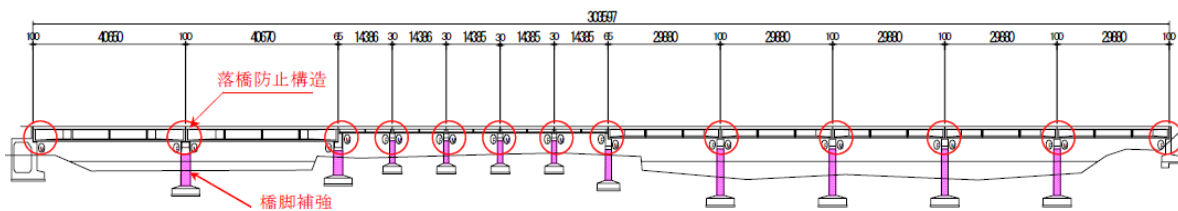


**Figure 11** Line bearings on the right abutment: A rusty bolt for the RB/DS bearing was remaining on the lower flange of I-beam indicating that the friction between the anchor and the concrete had been loosened already.

(Date & location: May 4<sup>th</sup>, 2011, 38.646726, 141.42659)



**Figure 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 4<sup>th</sup>, 2011, 38.646726, 141.42659)



**Figure 13** Aseismic retrofit plan for Utatsu Bridge<sup>5)</sup>



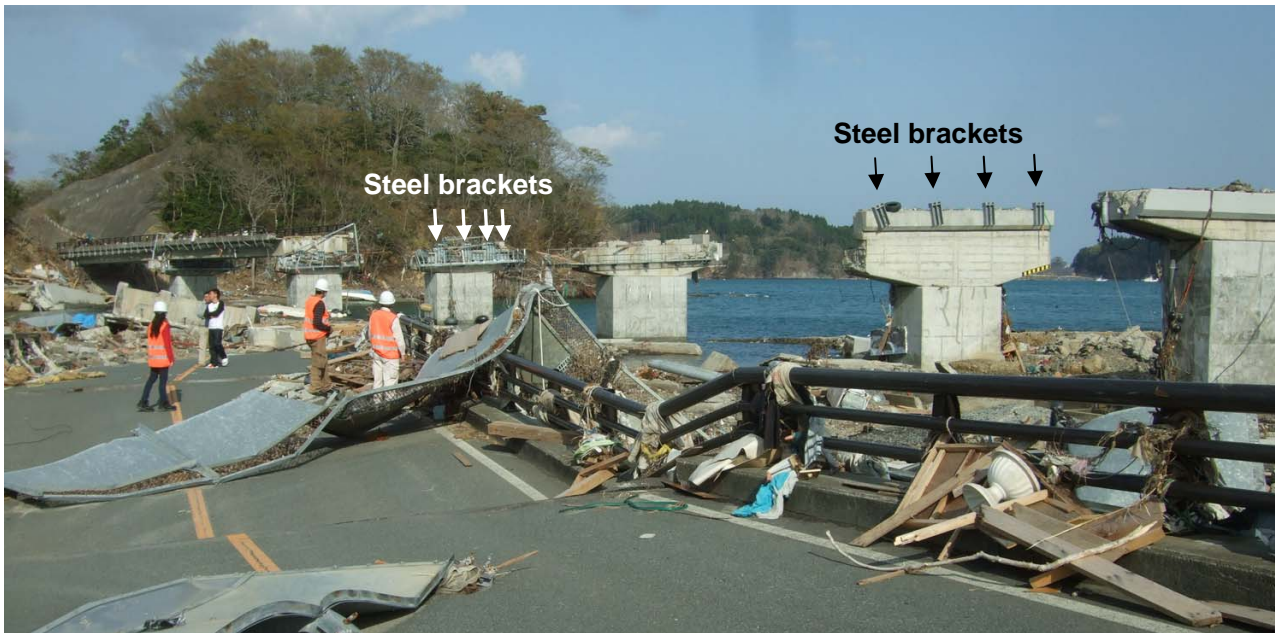
**Figure 14** Decks of Utatsu Bridge carried inland (Satellite imagery from Google Map)

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. 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 **Figure 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



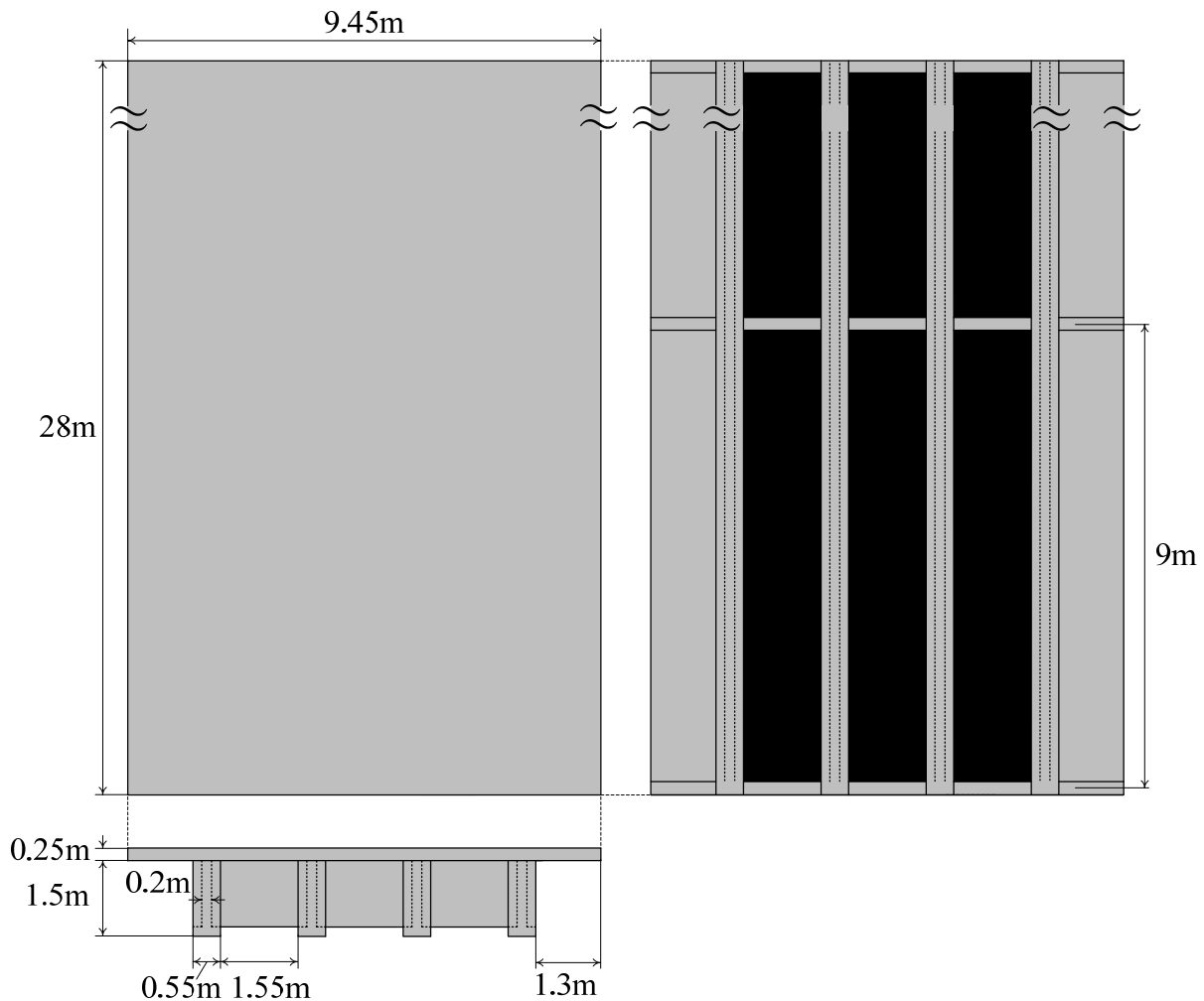
**Figure 15** Remaining piers with steel brackets (Date & location: May 4<sup>th</sup>, 2011, 38.716373, 141.522153)



**Figure 16** Bridge deck lying upside down showing lattice work of beams  
(Date & location: May 4<sup>th</sup>, 2011, 38.716373, 141.522153)

decks over waters and 5 middle decks over land (**Figure 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, thus confining the beams' transverse movements<sup>4, 5</sup>, and yet 8 decks of total 12 were found carried over several tens meters distances inland as shown in Figure 14. These steel brackets were remaining almost intact on pier tops except for the northernmost ones on the inland side (**Figure 14**). Some bridge decks were lying upside down showing all their lattices of main

and cross concrete beams about full of water (**Figure 15**). 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 **Figure 16** indicates that the hollow volume among the lattice beams of about 223 m<sup>3</sup> is about 2.2 times as large as the entire volume of the bridge deck of 100 m<sup>3</sup>. 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



**Figure 16** Configuration of Utatsu Bridge Deck

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 10m/s or faster just before the bridge deck was immersed.
- (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 (**Figure 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. Oganeyama Bridge case, for example, indicated that tsunami waves can pinpoint the weakest point of a bridge, thus determining the sequence of its collapse. It would still be unwise to conclude that we need 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 on, quantitative description of the deduced scenario will be necessary.

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