The Collapse Mechanism and the Temporary Restoration of Omori Bridge Damaged by the Storm Surge of Typhoon No.18 in 2004

Shinya OKADA*, Hiroshi MITAMURA**, Hiroyuki ISHIKAWA***

*Independent Administrative Institution, Civil Engineering Research Institute of Hokkaido, Researcher
**Independent Administrative Institution, Civil Engineering Research Institute of Hokkaido, Senior Researcher
***Independent Administrative Institution, Civil Engineering Research Institute of Hokkaido, Director

Abstract
Omori Bridge, Hokkaido, Japan was damaged by Typhoon Songda. This paper reports the conditions of bridge failure, which were estimated based on hydraulic tests and weather and tidal conditions obtained from observation data. The situation of temporary bridge construction is explained. The hydraulic model tests found that the bridge was subjected to lateral and vertical forces from standing waves formed by interference between progressive waves and wave reflected from the cliff. The vertical and lateral forces acting on the girder caused the four spans to dogleg and fail. Both ends of the girder hit the mountain side of the remaining girders and damaged piers and hinges.

Keywords: bridge failure, standing wave, hydraulic model test

1. Introduction

Omori Bridge on National Highway 229 in Kamoenai Village, Hokkaido, Japan was damaged by Typhoon Songda (Typhoon 18), which passed along the west coast of Hokkaido on September 8, 2004. Kamoenai Village is on the west coast of the Shakotan Peninsula, and it was isolated by the collapse of the bridge. The Hokkaido Regional Development Bureau, which administers the highway, took emergency measures such as constructing temporary bridges to restore road traffic.

2. Outline of Typhoon Songda

Typhoon Songda formed in the South Pacific near the Marshall Islands on August 28, 2004, and approached the west coast of the Oshima Peninsula (Hokkaido, Japan) at around 1 a.m. on September 8. The typhoon headed north along the coast, arriving at Omori Bridge shortly after 5 a.m. The forward speed then decreased to 35 km/h, and the typhoon slowly started to leave Hokkaido from 2 p.m. (Figure 1).
The typhoon brought southwesterly winds that blew perpendicular to the coastline. The storm remained in the vicinity of the bridge for a long period of time, and the sea was very rough.
As the typhoon approached the area, the highway over the bridge was closed on September 8 because of wave overtopping.
During the typhoon, a record-breaking maximum wind velocity of 44.2 m/s was recorded at Otaru City at 11:20 a.m. on September 8, and a maximum 60 cm sea level rise from normal was observed at Otaru Harbor. Also, a maximum wind velocity of 42.1 m/s was recorded at Iwanai Harbor, which is close to Omori Bridge , at 11 a.m. on September 8.

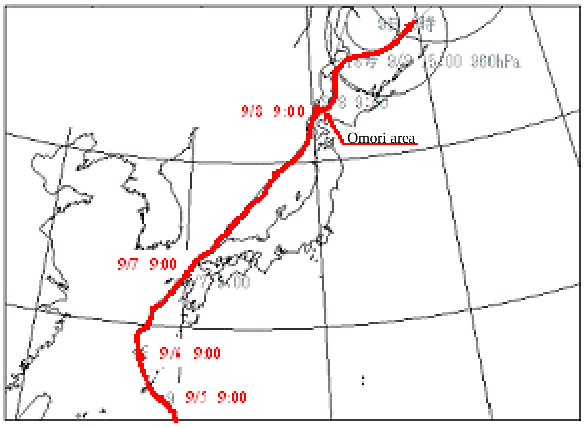

Figure 1: Course of Typhoon Songda

3. Features of coast around bridge

Omori Bridge is built on a rocky reef (Photo 1), whose elevation is about +0.5 m. The elevation drops abruptly to -10 m beyond the offshore end of the reef, where wave dissipating concrete blocks are installed. On the mountain side of the bridge, there is a sheer cliff that embays the reef (Figure 2 and Photo 4).

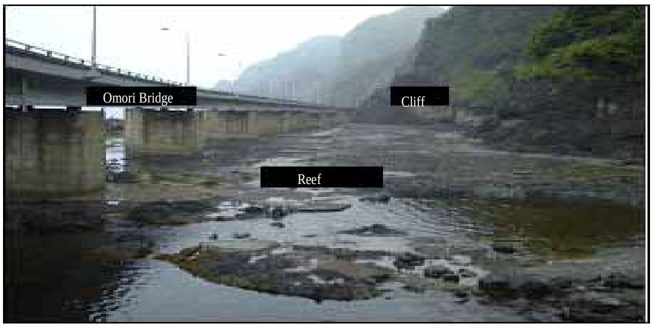

Photo 1: Local topography (reef and cliff) at Omori Bridge

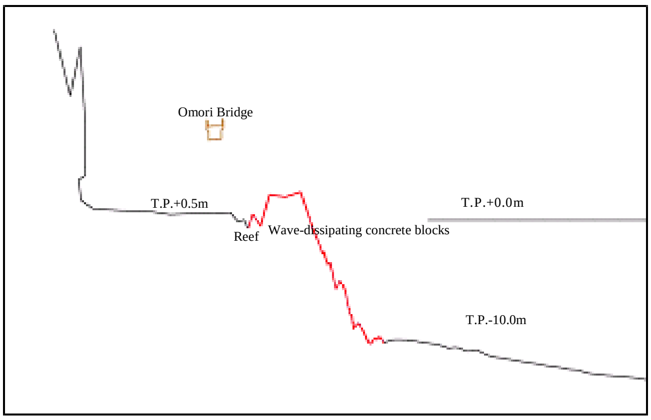

Figure 2: Topographic profile of Omori Bridge site

4. Damage to bridge

The major damage to Omori Bridge is as follows (Figure 3 and Photo 2):
(1) collapse of four spans of PC girders (Photo 3),
(2) diagonal cracks about 0.7 mm in width on pier P2,
(3) bending-shear failure of pier P3, which has a tilt of about 30 cm (Photo 4), and
(4) bending cracks about 2.0 mm in width on pier P8.

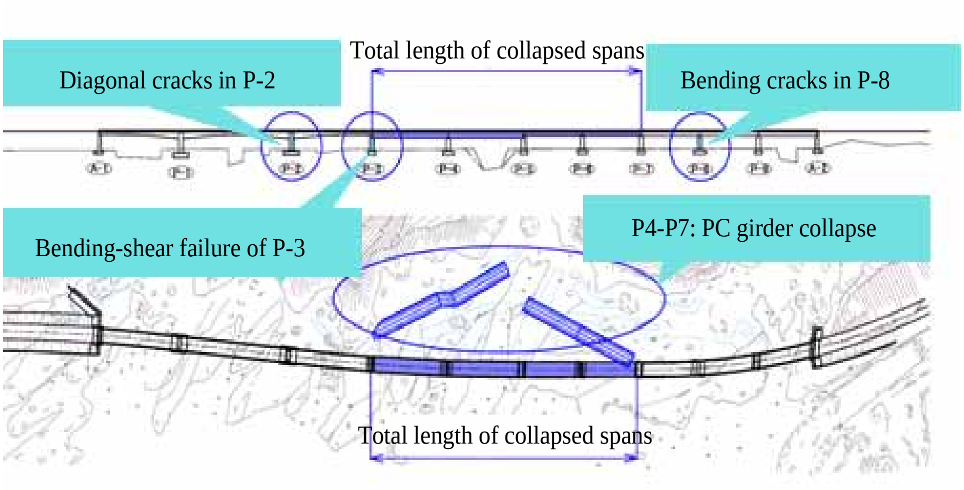

Figure 3: Damaged portions of bridge

Photo 2: Collapsed bridge

Photo 3: Fallen spans

Photo 4: Damage to pier P-3

5. Estimated state of sea during collapse

A barometric pressure of 989 hpa and a maximum average wind velocity of 34.1 m/s were recorded at 1:40 p.m. on September 8 by a telemeter near Omori Bridge. The sea level rise at the time, caused by the drop in barometric pressure and strong winds from the sea, is estimated to be 94.8 cm (Figure 4). Also estimated are a significant wave height of 7.6 m and a wave period of 12 sec.

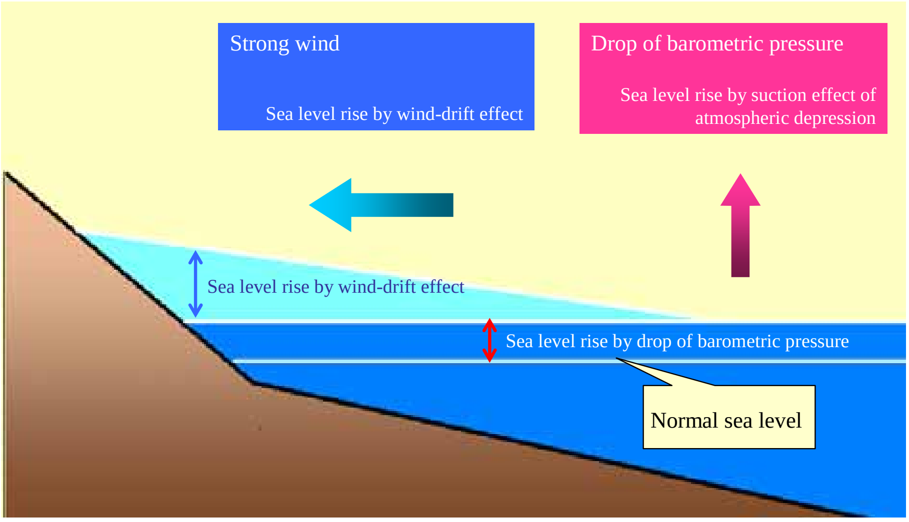

Figure 4: Model showing mechanism of sea level rise

6. Hydraulic model test

The Port and Harbor Engineering Division of the Civil Engineering Research Institute of Hokkaido conducted a hydraulic model test to investigate the state of the sea during the collapse of the bridge. The topography of the site was modeled in detail in a two-dimensional wave flume 22 m in length, 2 m in depth, and 0.8 m in width, and the test was videotaped. A 1/25 model was used, and Froude similitude was applied. The test results showed that the girders were subjected to lateral and vertical forces at the bridge piers because of standing waves formed by interference between progressive waves and wave reflected from the cliff

7. Inferred mechanism of collapse

It is inferred that Omori Bridge collapsed under peculiar circumstances.

7.1 Unusual rise of sea level: The sea level at the bridge saw an unusually great rise because of the drop in barometric pressure and strong winds from the sea.

7.2 Particular topography: Because of the reef below the bridge and the sheer cliff that embays the reef (Photo 5), the waves reflected from the cliff concentrated around the bridge. The wave-dissipating concrete blocks created a pool on the reef, causing a further rise of sea level.

Photo 5: Aerial photo of site

7.3 Standing wave: As the sea level rose, the progressive waves rose higher on the reef. Standing waves of higher height were produced as a result of interference between the progressive waves and waves reflected by the cliff. The girders were subjected to buoyancy and uplift pressure (Figure 5).

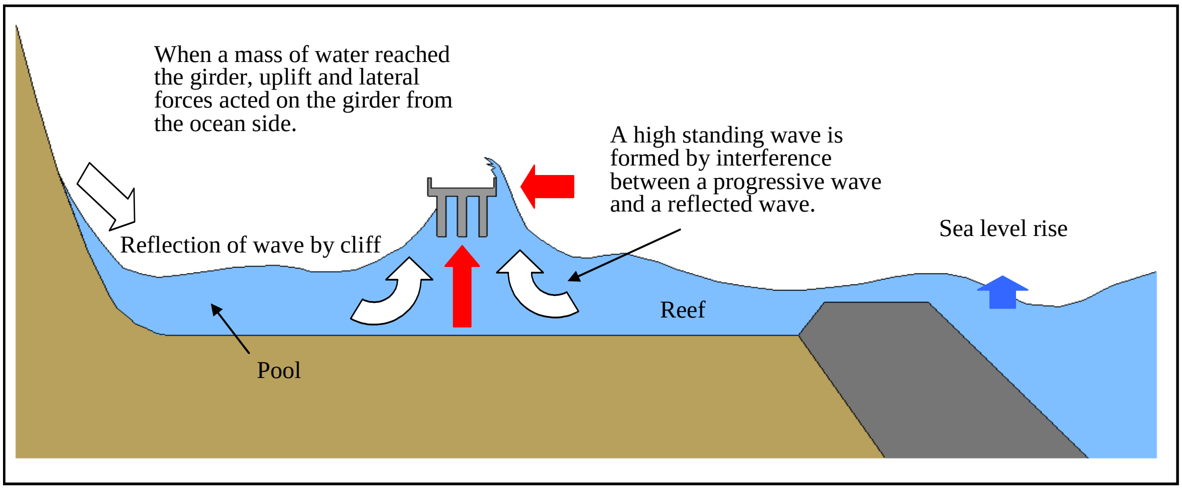

Figure 5: Collapse of bridge by wave action

8. Process of collapse inferred from damage

Bearings on the ocean side of the piers were damaged by uplift force, and those on the mountain side of the piers were damaged by lateral force. Damage was also found at the mountain-side shoulder of the substructure. It is inferred from the above observation that the fall of the bridge proceeded in the following manner. The ocean side of the girder was first lifted, and then the girder itself was laterally displaced toward the mountain side while scratching the shoe surface (Figure 6).

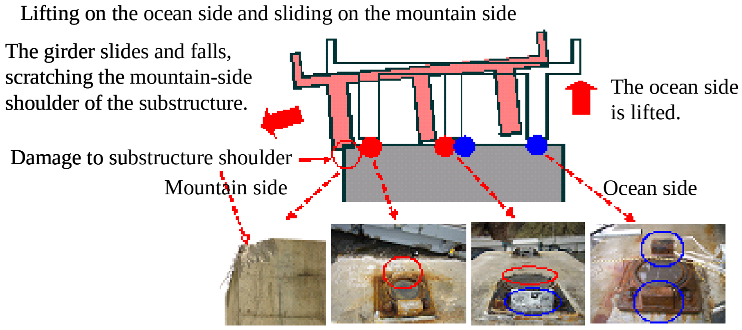

Figure 6: Inferred process of bridge collapse

During the fall of the main girders, it is thought that the doglegged girders hit the adjacent girders on the Otaru and Hakodate (Iwanai) sides and that this impact damaged piers P2, P3, and P8 (Figure 7).

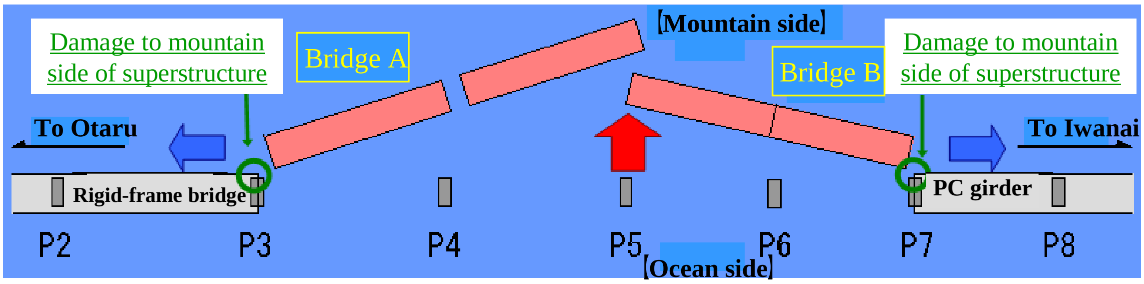

Figure 7: Postulated process of girder fall

9. Temporary restoration

Temporary truss bridges were selected in view of economy, ease of construction and maintenance, and ready availability of materials, and because such bridges have been used many times. Side views of the temporary bridges are shown in Figures 8 and 9 and Photo 6.

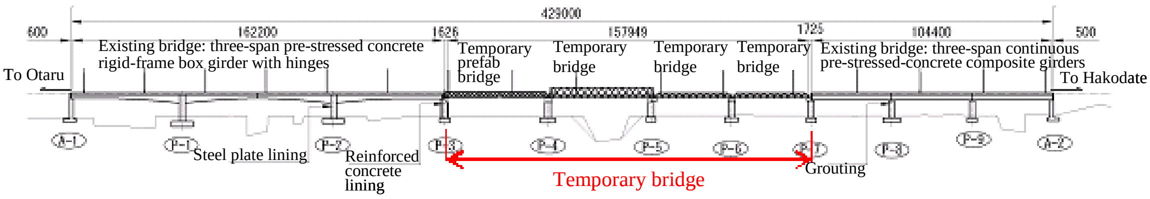

Figure 8: Outline of bridge restoration

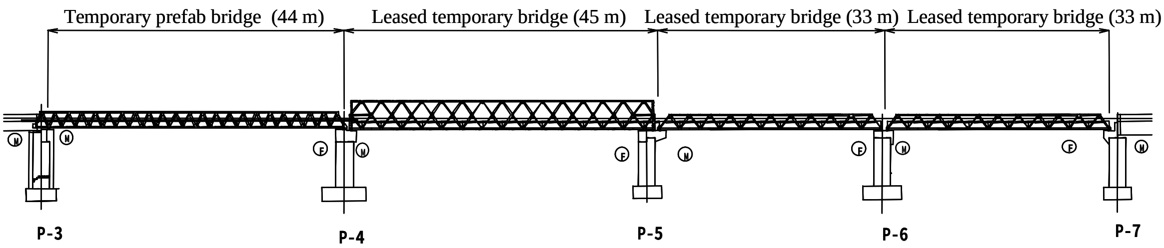

Figure 9: Side view of temporary bridges

Photo 6: Construction of temporary bridge

The substructure was repaired based on the initial design criteria in *The Design Manual for Highway Bridge Substructures* issued in 1968 (seismic design was based on the seismic coefficient method). The repair work included the steel jacketing of pier P2, (2) reinforced concrete lining to pier P3 (Photo 7), and (3) crack grouting to pier P8.

Photo 7: Repair of pier P-3

10. Final remarks

After the collapse, Omori Bridge was quickly restored and was returned to service on December 8, 2004 (Photos 8 and 9).

Photo 8: Restored bridge in service (1)

Photo 9: Restored bridge in service (2)