Damage to Highway Bridges Caused by the 2011 Tohoku-Oki Earthquake

– JAPAN BRIDGE ENGINEERING CENTER –

1. Introduction

In the 2011 Tohoku-Oki Earthquake (magnitude 9.0; also known as the 2011 Great East Japan Earthquake) on March 11, 2011, damage extending over a large area occurred due to seismic ground motion and the tsunami which followed the quake. Japan Bridge Engineering Center (J_BEC) surveyed damage to highway bridges, mainly on National Route 45 (Rte. 45), which passes through the coastal area from Miyagi Prefecture to Iwate Prefecture.

The survey does not provide a total grasp of the damage to highway bridges, as it was carried out focusing on a limited route and sections. The following presents examples of the main types of damage observed in the survey.

2. Outline of the Survey

Site surveys were conducted on three occasions. On March 28-29, 2011, 16 bridges on Rte. 45 in the area from Ofunato City to Kamaishi City, Otsuchi Town, and Yamada Town in southern Iwate Prefecture were surveyed; on April 13-14, 15 bridges on Rte. 45 from Minamisanriku Town to Kesennuma City in northern Miyagi Prefecture were surveyed; and on April 25-26, one bridge on Rte. 4, four bridges on Rte. 45, one bridge on Rte. 398, and one bridge on a principal local road were surveyed in Sendai City, Natori City, Ishinomaki City, and Tome City in Miyagi Prefecture. In these areas, seismic intensities of 5-upper to 6-upper on the Japan Meteorological Agency Scale were generally observed. Inspections (visual inspection and photography) were carried out on foot at the sites of each of the surveyed bridges.

3. Examples of Damage by Seismic Ground Motion

The main damage to highway bridges caused by seismic ground motion occurred in bearings and neighboring parts of the superstructure and substructure, expansion joints, bridge approaches, and members supporting horizontal loads (pier column, lateral bracing, etc.).

(1) Damage to superstructures

· Cracking in main girder ends (supporting point) (Photo–1)

Cracking occurred at the main girder supporting point of a simple PC post-tensioned T-girder bridge. It is estimated that cracking occurred due to the support reaction against the inertial force of the superstructure at the ends of the main girder.

· Buckling/fracture of upper lateral bracing (Photo–2)

Buckling and fracture of the upper lateral bracing occurred at a steel Langer bridge. The estimated cause of this buckling/fracture was the seismic load on the lateral bracing, which is a member that resists horizontal loading.

· Displacement at the center hinge of rigid-frame bridge (Photo–3)

Relative displacement of 4cm occurred perpendicular to the bridge axis at the center hinge of a rigid-frame box girder bridge. It is considered necessary to clarify the cause after inspecting deformation of the bearing

and substructure.

Photo–1 Cracking of ends of main girders (supporting point) (principal local road, Shiogama-Watari Line; Yuriage Bridge, Natori City, Miyagi Pref.)

Buckling　　Fracture

Photo–2 Buckling/fracture of upper lateral bracing (Rte. 45, Tennoh Bridge, Ishinomaki City, Miyagi Pref.)

Photo–3 Displacement at the center hinge of rigid-frame bridge (principal local road, Shiogama-Watari Line; Yuriage Bridge, Natori City, Miyagi Pref.)

(2) Damage to substructures

· Cracking, spalling of concrete and buckling of reinforcement of RC pier (Photo–4)

Cracking occurred at the joint between the column and beam of an RC pier, and the concrete spalled and reinforcing bars buckled in some parts. It is estimated that the column of the pier escaped damage because RC lining reinforcement had been carried out, and as a result, damage occurred at the joint between the column and beam. If the lining reinforcement had not been carried out, there is a possibility that the damage to the column would have been more severe.

Photo–4 Cracking of RC pier, spalling of concrete, and buckling of reinforcement (Rte. 4, Natori Bridge, Natori City, Miyagi Pref.)

· Cracking of abutment (Photo–5)

Cracks slanting downward from the bearing occurred in the abutment wall. It is estimated that this crack occurred due to the inertial force of the superstructure acting on the abutment wall by way of the bearing.

Photo–5 Cracks in abutment (Rte. 45, pedestrian bridge at Tennoh Bridge, Ishinomaki City, Miyagi Pref.)

(3) Damage to bearings

The following types of damage occurred in bearings, which are positioned in between the superstructure and substructure. Because bearings are parts which connect the superstructure and substructure, they are considered to be particularly susceptible to damage during earthquakes.

- Deformation/fracture and abnormal expansion gap of upper shoe stopper (Photo–6)
- Deformation of anchor bolts (Photo–7)
- Fracture of set bolts (Photo–8)
- Cracking and loss of shoe seat mortar (Photo–9)
- Dislodgment of expansion joint protector (Photo–10)

Deformation　　Fracture　　Abnormal gap (movable bearing)

Photo–6 Deformation/fracture and abnormal expansion gap of upper shoe stopper (Rte. 45, Omosegawa Bridge, Kesennuma City, Miyagi Pref.)

Photo–7 Deformation of anchor bolts (Rte. 45, pedestrian bridge at Tennoh Bridge, Ishinomaki City, Miyagi Pref.)

Photo–8 Fracture of set bolts (Rte. 45, Tennoh Bridge, Ishinomaki City, Miyagi Pref.)

Photo–9 Cracking/loss of shoe seat mortar (Rte. 45, pedestrian bridge at Tennoh Bridge, Ishinomaki City, Miyagi Pref.)

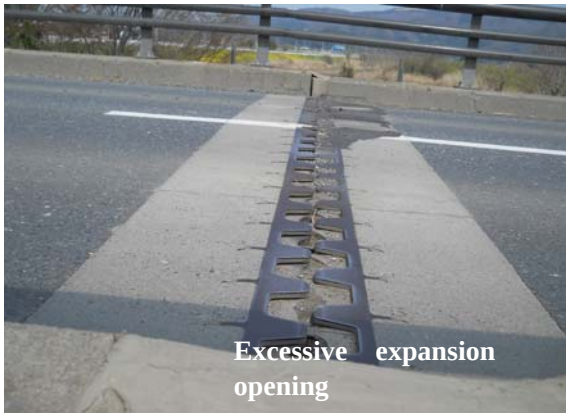
Photo–10 Dislodgment of expansion joint protector (Rte. 45 (Sanriku Expressway), Shin-Tennoh Bridge, Ishinomaki City, Miyagi Pref.)

(4) Damage to expansion joints

Damage to expansion joints took the forms of vertical misalignment (difference in level) and abnormal expansion gap. In expansion joints where vertical misalignment, etc. was observed, there is a possibility that deformation occurred in the bearing, substructure, etc. under the expansion joint.

- Vertical misalignment of expansion joint (Photo–11)
- Abnormal expansion gap of expansion joint in bridge axial direction (Photo–12)
- Abnormal expansion gap of expansion joint perpendicular to bridge axial direction (Photo–13)

Photo–11 Vertical misalignment of expansion joint (principal local road, Shiogama-watari Line; Yuriage Bridge, Natori City, Miyagi Pref.)



Photo–12 Abnormal expansion gap of expansion joint in bridge axial direction (Rte. 45, Tennoh Bridge, Ishinomaki City, Miyagi Pref.)

Photo–13 Abnormal expansion gap of expansion joint perpendicular to bridge axial direction (principal local road, Shiogama-watari Line; Yuriage Bridge, Natori, Miyagi Pref.)

(5) Damage to bridge approaches

A difference in the level of the bridge and its approach occurred due to subsidence of the abutment backfill at the bridge approach.

· Difference in level of bridge and approach due to subsidence of abutment backfill (Photo–14)

Difference of surface level in roadway section (after emergency repair by construction of ramp)

Difference of surface level in pedestrian section (difference of more than 2 cm)

Photo–14 Difference in level of bridge and approach due to subsidence of abutment backfill (Rte. 45, Shirokizawa Bridge, Ofunato City, Iwate Pref.)

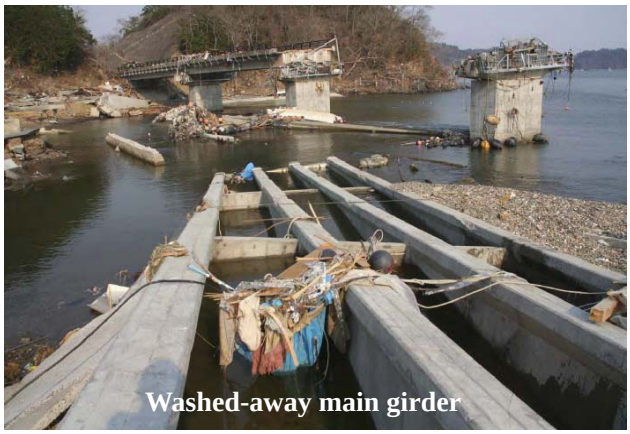
4. Examples of Damage by Tsunami

The giant tsunami triggered by the 2011 Tohoku-Oki Earthquake caused remarkable damage, for example, washing away the superstructures of bridges. In addition to washing away, scouring, etc. caused by the tsunami, damage also occurred as a result of impact by floating debris.

(1) Damage to superstructures

· Washed-away main girders (PCT girders) (Photo–15)

At the Utatsu Bridge on Rte. 45, the main girders (PCT girders) of the 8 central spans were washed away, leaving two spans each on the origin side and terminus side. Damage and deformation of seismic restraints (steel brackets and anchor bars) occurred at the top of the piers where the main girders were washed away.



Photo–15 Washed-away main girders (PCT girders) (Rte. 45, Utatsu Bridge, Minamisanriku Town, Miyagi Pref.)

· Washed-away main girders (steel plate girders) (Photo–16)

At the Koizumi Bridge on Rte. 45, the main girders (steel plate girders) of all spans were washed away. It is estimated that these main girders were washed away as the anchor bolts of the dampers connecting the main girders with the substructure broke, and the attaching portions of the aseismatic connectors also failed. The main girders were carried more than 300 m upstream.

Photo–16 Washed-away main girders (steel plate girders) (Rte. 45, Koizumi Bridge, Kesennuma City, Miyagi Pref.)

· Washed-away main trusses (Photo–17)

Of 7 spans on the Shin-Kitakami Bridge on Rte. 398, the main trusses of 2 spans on the left bank were washed away. The PC cables of the aseismatic connectors failed, and the superstructure was carried upstream.

Photo–17 Washed-away main trusses (Rte. 398, Shin-Kitakami Bridge, Ishinomaki City, Miyagi Pref.)

· Washed-away main girders (PCT girders) of bridge-side pedestrian bridge (Photo–18)

The main girders (PCT girders) of the No.2 to No.4 spans of a pedestrian bridge on the upstream side of the Sodeogawa Bridge on Rte. 45 were washed away.

Photo–18 Washed-away main girders (PCT girders) of bridge-side pedestrian bridge (Rte. 45, pedestrian bridge at Sodeogawa Bridge (outbound side), Kesennuma City, Miyagi Pref.)

· Washed-away main girders (H-shape steel girders) of bridge-side pedestrian bridge (Photo–19)

The main girders (H-shape steel girders) of both spans of a pedestrian bridge on the seaward side of the Namiita Bridge on Rte. 45 were washed away. The pier was also broken in the middle, and the upper half was washed away.

Photo–19 Washed-away main girders (H-shape steel girders) of bridge-side pedestrian bridge (Rte. 45, pedestrian bridge at Namiita Bridge (inbound side), Otsuchi Town, Iwate Pref.)

· Deformation of main girder due to impact by floating debris (Photo–20)

The main girder (steel plate girder) was deformed. The estimated cause was impact by floating debris due to the tsunami.

Photo–20 Main girder deformed by impact of floating debris (Rte. 45, Katagishi Bridge, Kamaishi City, Iwate Pref.)

(2) Damage to substructures

· Washed-away pier (Photo–21)

At the Koizumi Bridge on Rte. 45, where the superstructure of the bridge was washed away, a pier in the the river was also washed away.

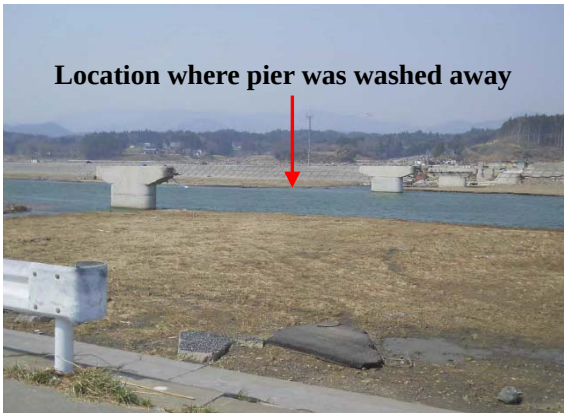


Photo – 21 Washed-away pier (Rte. 45, Koizumi Bridge, Kesennuma City, Miyagi Pref.)

· Damage to pier (Photo–22)

The RC pier column was partially crushed. It is estimated that the beam part of the pier was inclined toward the upstream side by the force of the tsunami acting on the bridge, and as a result, the upstream side of the pier column was crushed.

Photo–22 Damaged pier (Rte. 45, Utatsu Bridge, Minamisanriku Town, Miyagi Pref.)

· Damage to pier due to impact by floating debris (Photo–23)

Part of an RC pier was broken. The estimated cause was impact by floating debris due to the tsunami.

Photo–23 Damage to pier by impact of floating debris (Rte. 45, Kamaishi Viaduct, Kamaishi City, Iwate Pref.)

· Scouring of foundation (Photo–24, Photo–25)

The tsunami caused scouring of bridge foundations.

Concrete placing in the scoured part

Photo–24 Scouring of foundation (Rte. 45, Nijuichihama Bridge, Kesennuma City, Miyagi Pref.)

Abutment of pedestrian bridge showing an exposed foundation pile

Photo–25 Scouring of foundation (Rte. 45, Sodeogawa Bridge, Kesennuma City, Miyagi Pref.)

(3) Damage to bearings

It is estimated that damage occurred in bearings due to the movement of the superstructure caused by the tsunami. In these cases, the damage was limited to the bearings, and the superstructure was not washed away.

· Deformation/fracture of bearing side block (Photo–26)

· Deformation/pulling out of anchor bolts (Photo–27)

Photo–26 Deformation/fracture of bearing side block (Rte. 45, Utatsu Bridge, Minamisanriku Town, Miyagi Pref.)

Photo–27 Deformation/pulling out of anchor bolts (Rte. 45, pedestrian bridge at Osawa No.2 Bridge (inbound side), Kesennuma City, Miyagi Pref.)

(4) Damage to bridge approaches

The tsunami washed away or caused scouring of the approach embankments.

· Washed-away approach embankment (Photo–28)

· Scouring of approach embankment (Photo–29)

Temporary bridges constructed over areas where approach embankment was washed away.

Photo–28 Washed-away approach embankment (Rte. 45, Nijuichihama Bridge, Kesennuma City, Miyagi Pref.)

Photo–29 Scouring of approach embankment (Rte. 45, Toyasaka Bridge, Kamaishi City, Iwate Pref.)

5. Conclusion

In the damage to highway bridges due to the 2011 Tohoku-Oki Earthquake, in addition to damage caused by seismic ground motion, damage caused by the tsunami which followed the earthquake was remarkable. The main damage caused by seismic ground motion which was confirmed in this survey occurred in bearings and neighboring parts of the superstructure/substructure, expansion joints, bridge approaches, and members supporting horizontal loads (pier, lateral bracing, etc.). However, comparatively few bridges collapsed or displayed remarkably reduced load bearing capacity, which appears to show the effects of the seismic countermeasures adopted up to the present.

On the other hand, damage due to the tsunami was more severe than any tsunami-related damage experienced in Japan in the past, and included washing away of bridge superstructures and approach embankments, scouring of foundations, etc., and also damage caused by the impact of floating debris. It appears to be necessary to study future countermeasures for tsunamis as well as seismic ground motions based on the experience of the damage to bridges in the 2011 Tohoku-Oki Earthquake.

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