Report by the First Joint Survey Team of the JSCE Concrete and Structural Engineering Committees on the damage caused by the Great East Japan Earthquake

April 5, 2011 (First Report)

1. Survey team members

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2. Survey itinerary

   Date of survey: March 27 and 28, 2011

   Structures surveyed:

   The following railway viaducts and bridges:

   (1) Minami Nagamachi and Naka Nagamachi viaducts between Shiraishi Zao and Sendai Stations on the Tohoku Shinkansen line

   (2) Kakyoin bridge between Sendai and Furukawa Stations on the Tohoku Shinkansen line

   (3) No. 2 Odawara viaduct between Sendai and Furukawa Stations on the Tohoku Shinkansen line

   (4) Iwakiri viaduct between Sendai and Furukawa Stations on the Tohoku Shinkansen line

   (5) Nanakitagawa bridge on the Sendai City Subway line

   The following road bridges:

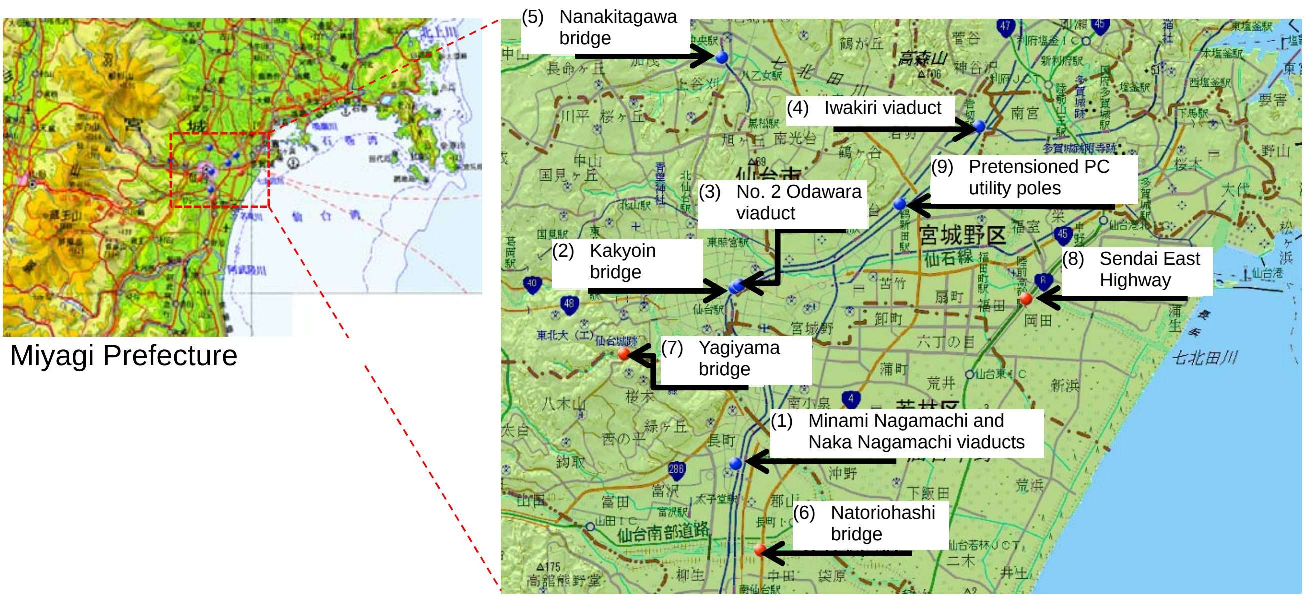
   (6) Natoriohashi bridge on national road No. 4

   (7) Yagiyama bridge on a Sendai city-administered road

   (8) Part of Sendai East Highway (Sendai Toubu Douro) near Sendai Kohoku IC

   The following additional items:

   (9) Pretensioned PC catenary support poles



Map of structures surveyed (Blue and red marks indicate railway and road structures, respectively.)
(Source: Cyber Japan, URL http://cyberjapan.jp/)

3. Overview of survey carried out in and around Sendai City, Miyagi Prefecture

The scope of the survey, the structures surveyed, and the overall findings are outlined below.

3.1 Railway viaducts and bridges

(a) Railway viaducts and bridges of East Japan Railway Company

This survey of structures in areas not affected by the tsunami confirmed that seismic reinforcement work undertaken by East Japan Railway Company to prevent the collapse of concrete structures had been effective. East Japan Railway Company has developed various seismic reinforcement methods and put them into practical use; the seismic reinforcement work carried out on the surveyed structures aimed at mainly improving ductility, not strength. A separate survey conducted by the company also confirmed that the foundations or footing beams of the structures were not damaged. The survey up to this time (March 28, 2011) confirms that seismically reinforced bridge piers and columns had not been damaged.

Of the bridge piers and columns that had not yet undergone seismic reinforcement, those with relatively low earthquake-resistant performance suffered damage. The mechanism of the damage was the same as seen after the 2004 Mid Niigata Prefecture Earthquake and the repair of the damaged structures was quickly completed.

One structure on the Tohoku Shinkansen line, which had suffered no damage to their main structure, but had damage to steel girder bearings and the track, including the rails. These structures have also been repaired quickly by jacking up the steel girders and moving them horizontally to restore the bearings to their original positions.

(b) Bridge on the Sendai City Subway line

Although there was no structural collapse, one of the bridge abutments surveyed this time was found to be damaged. This damage was probably caused by alternating cyclic loading on the breast wall at the rear of the bridge abutment. Regarding the rigid frame bridge on the side opposite to this damaged abutment, concrete had broken away from the corner of the support for the cantilever girder on the bridge pier.

3.2 Road bridges

The surveyed road structures (bridges), which are all administered by the Ministry of Land, Infrastructure, Transport and Tourism, had undergone seismic reinforcement. There was no major damage to these structures that caused usage restrictions. Restoration work was carried out on damaged viaduct bearings on the Sendai East Highway two weeks after the earthquake. A level difference of about 10 cm in the road surface was noticeable at the rear of one bridge abutment. Repair work had already been carried out and the road was in service at the time of this survey.

3.3 Other structures (pretensioned PC catenary poles)

Many catenary support poles (more than 400) along the Tohoku Shinkansen line suffered damage, including breakage. The large number of damaged poles and difficulties encountered in repairing the electrical system were the biggest obstacles to the resumption of operations on the Tohoku Shinkansen line.

4. Outline of survey results

The results of the survey are presented from next page.

Date of survey:	**March 28, 2011 (Monday), 9:50 a.m.**
Structures surveyed:	**Minami Nagamachi viaducts R8 to R13 and Naka Nagamachi viaduct between Shiraishi Zao and Sendai Stations on the Tohoku Shinkansen line**
Administrator of structures:	**East Japan Railway Company**
Type of structures:	**Rigid frame viaduct of RC beam and slab type**
Date of completion:	**March 1979**
Damaged members:	**Columns**

Outline of survey results:

The Tohoku Shinkansen line and the local Tohoku line run adjacent to each other at the survey location. Damage to the RC rigid frame viaducts on the Tohoku Shinkansen line was similar to the damage seen after the 2004 Mid Niigata Prefecture Earthquake. A total of four columns at each end of the three-span rigid frame viaducts surveyed this time are shorter than the other four columns. This is because these four end columns have girder supports for the cantilever girders of the neighboring viaducts. These short columns consequently have a relatively small strength ratio (shear capacity / flexural capacity) and tend to fail. The most heavily damaged columns in the surveyed location were the columns at each end of the rigid frames. (Fig. 1)

Fig. 1 Details of damage to the Naka Nagamachi viaduct
(Source: East Japan Railway Company)

Basically, seismic reinforcement of shear failure type columns of viaducts on the Tohoku Shinkansen line had been completed. The columns damaged by this earthquake were of flexural failure type with a small strength ratio. Nearby columns that had been seismically reinforced with a steel casing were undamaged.

The method of repair for these damaged columns was exactly the same as that adopted after the Mid Niigata Prefecture Earthquake. Emergency repair work was being carried out by injecting resin into the cracks and constructing forms into which no-shrinkage mortar was poured. (Fig. 2)

The viaducts of the local Tohoku line running in parallel with the Tohoku Shinkansen line (Fig. 3) were designed in conformity with new seismic design standards based on lessons learned from the Great Hanshin Earthquake. The columns include spiral bars at the column hinge to provide them with a very high deformation capacity. No extensive damage was found to the columns of these viaducts, although flexural cracks were observed on the columns.

Fig. 2 Emergency repair work

Fig. 3 Local Tohoku line (left) and Tohoku Shinkansen line (right)

Date of survey: March 28, 2011 (Monday), 10:55 a.m.
Structure surveyed: Kakyoin bridge between Sendai and Furukawa Stations on the Tohoku Shinkansen line
Type of structure: Composite box girder
Date of completion: November 1980
Damaged members: Bearings

Outline of survey results:

This bridge is a composite box girder bridge with a length of 74,500 mm. The earthquake motion caused breakage of the pin at the fixed parts of the bearings and there was a sideways movement of about half the width of the bearings. Repair work involving jacking up the girder had been completed by the time of this survey. The work was carried out without the need to close the national road running under the bridge, since there were concrete walls on both sides of bridge abutment and there was no possibility of the girders falling down.

Fig. 1 General view of the bridge
(Source: East Japan Railway Company)

Fig. 2 Details of damage to bearing
(Source: East Japan Railway Company)

Fig. 3 Bearing after repair

Date of survey:	**March 28, 2011 (Monday), 11:15 a.m.**
Structure surveyed:	**No. 2 Odawara viaduct R1 between Sendai and Furukawa Stations on the Tohoku Shinkansen line**
Type of structure:	**RC four-span double-layer rigid frame viaduct (with two spans in the transverse direction)**
Date of completion:	**December 1978**
Damaged members:	**Middle-layer transverse beams**

Outline of survey results:

The survey location is near Sendai Station in the center of Sendai City. The columns of the viaduct had not yet undergone seismic reinforcement when the earthquake struck and the damage was found in the beams. The damaged middle-layer beams measure 1.1 m high by 6.5 m long by 1.2 m wide; they have no haunches. At a hearing prior to the survey, it was reported that diagonal cracking had occurred in two or more middle-layer beams in the transverse direction. Repair work had already been carried out so the cracks could not be visually checked during this survey. Since repair work had been completed, damage to R2 and subsequent blocks (adjacent to the one surveyed) could not be checked; however, a similar degree of damage was assumed to have taken place from observations of the repair work. Damage to concrete caused by the stoppers was observed on the girder supports at the ends of the rigid frame structures. Within the scope of the visual inspections, there was no noticeable damage to other members (such as middle-layer longitudinal beams, columns, column-beam joints, or slabs.)

The damaged middle-layer beams were being repaired by removal of the damaged portion and injection of epoxy resin into the voids. Steel shear stoppers were being installed at the girder supports to restrict displacement of the girders in the transverse direction. All repair work, from initial planning to final removal of scaffolding, was scheduled for completion by the end of March.

Although shear cracking was observed in the middle-layer beams of this viaduct, the viaduct did not collapse. Similar damage has been observed after previous earthquakes. Deformation of the track was investigated in this survey.

Fig. 1 Details of damage to block R1
(Source: East Japan Railway Company)

Fig. 2 Beams after repair and steel shear stopper being installed

Date of survey: March 28, 2011 (Monday), 12:05 p.m.
Structure surveyed: Iwakiri viaduct between Sendai and Furukawa Stations on the Tohoku Shinkansen line
Type of structure: Three-span continuous PC hollow girder
Date of completion: May 1978
Damaged member: Bridge pier

Outline of survey results:

This viaduct carries the track over the local JR Tohoku line and consists of four piers. The damaged pier, at the end closest to the Furukawa station, had not yet been seismically reinforced when the earthquake struck. It was reported that, following flexural yielding of the bridge pier starting from the rebar cutoff point, concrete fell away as a result of failed cover concrete and shear cracking. (Fig. 1) Repair work by the RC envelope method had been completed by the time of this survey. (Fig. 2)

Two intermediate bridge piers, which carry a high superstructure dead load, had already undergone seismic reinforcement by the RC envelope method when the earthquake struck. The on-site visual inspection identified no damage to these piers. No deformation of the track was identified.

Fig. 1 Details of damage to bridge pier 4P of Iwakiri viaduct (Source: East Japan Railway Company)

Fig. 2 Repaired bridge pier of Iwakiri viaduct

Date of survey:	**March 27, 2011 (Sunday), 6:00 p.m. and March 28, 2011 (Monday), 7:05 a.m.**
Structures surveyed:	**Nanakitagawa bridge and rigid frame approach viaducts**
Type of structure:	**Simple steel box girder and RC rigid frame viaduct with two consecutive spans**
Date of completion:	**1991**
Damaged members:	**Base of breast wall and girder support**

The Nanakitagawa bridge is on the Sendai City Subway Nanboku line. Details of the observed damage are summarized below.

1. Damage to breast wall at boundary with bridge abutment

   The breast wall at the rear (on the cantilever girder side) of the bridge abutment failed in flexure at the boundary with the lower part of the abutment, with buckling of the steel rebars and crushing of concrete. (Figs. 1.1 and 1.2) A possible cause of this damage was that cyclic loading applied on the breast wall, which supports the cantilever girder, and that the girder (considered in terms of design to have a free end) transmitted horizontal loading onto the wall. Looking at the damaged area, a concrete placing joint coincides with the boundary between the breast wall and the lower part of the bridge abutment. The bridge girder support on the opposite side of the abutment to the cantilever girder seems to have collided with the cantilever girder, causing chipping of the concrete.

Fig. 1.1 General view of damaged breast wall

Fig. 1.2 Details of damage to the breast wall

Fig. 1.3 Damaged cantilever girder

2. Bridge pier support for cantilever girder

At the rigid frame bridge piers at the opposite end of the girder to the pier described above, concrete broke away from the corner of one bridge pier support for the cantilever girder. (Fig. 2) The cause of this damage was that the cantilever girder bearing was not completely free in the horizontal direction and horizontal seismic loading was transmitted to the bearing. This caused the concrete to crack.

3. Ground deformation

Cracking due to deformation of the ground was found in at least two bridge piers and column bases. (Fig. 3)

4. Shear cracking

Minor shear cracking was observed in a column of the rigid frame viaduct.

Fig. 2 Damaged girder support

Fig. 3.1 Deformed ground (Nanakitagawa bridge, Izumi Chuogawa abutment)

Fig. 3.2 Cracking at the column base of rigid frame viaduct

Fig. 4 Shear cracking in column of rigid frame viaduct

Date of survey:	**March 27, 2011 (Sunday), 2:00 p.m.**
Structure surveyed:	**Natoriohashi bridge on national road No. 4**
Type of structure:	**17-span 5-main girder simple steel welded composite I girder**
Date of completion:	**March 1963**
Administrator of structure:	**Ministry of Land, Infrastructure, Transport and Tourism**
Damaged members:	**Portions about 35 cm above the top of the seismic reinforcement RC envelope around RC bridge piers**

Outline of survey results:

The piers of this bridge had already undergone seismic reinforcement by the RC envelope method. The seismic reinforcement had been applied to the section of the bridge piers below the rebar cut-off plane. (Fig. 1)

Cracks measuring from about 0.3 mm up to 5 mm in width had developed in the horizontal direction at locations about 30 cm above the top end of the RC envelopes that had been added to seismically reinforce the RC bridge pier. (Fig. 2) At bridge pier P16 on the Sendai end of the bridge, part of the cover concrete broke away and rebars in the axial direction buckled. (Figs. 3 and 4) This buckling of rebars in the axial direction occurred where there was single spacing of tie hoops. A possible cause of this damage was that the top end of the seismic reinforcement RC envelope (at the point where the cross-sectional area begins to change to form the rebar cut-off plane) weakened and flexural cracking developed as a result of the inertia force of the superstructure.

Cracks in the ground due to the response of the bridge piers to earthquake motion were observed around bridge pier P16, where the seismic reinforcement RC envelope was completely under the surface. (Fig. 5)

Flexural cracks due to earthquake motion were observed on at least two bridge piers, but the damage was not severe enough to restrict service and the road was in use at the time of the survey. No shear cracking was found on bridge piers and there was no noticeable damage to the superstructure or bearings.

Fig. 1

Fig. 2

Fig. 3

Fig. 4 (Closeup of the damaged portion in Fig. 3)

Fig. 5

Date of survey:	**March 27, 2011 (Sunday), 4:15 p.m.**
Structure surveyed:	**Yagiyama bridge**
Type of structure:	**Three-span center-hinge PC box girder bridge**
Date of completion:	**October 1964**
Administrator of structure:	**Sendai City**
Damaged members:	**Steel bridge railings and road surface subsidence (due to ground subsidence at rear of bridge abutment)**

Outline of survey results:

Within the limitations of visual inspection from a distance, no major damage to bridge piers or girders was apparent. (Fig. 1) Deformation of the steel bridge railings was found around the center of the span. (Figs. 2 and 3) This railing deformation was probably caused by the three-hinge arch structure before the earthquake. Deformed railings were also observed in other bridge sections. (Fig. 4) There was no sign of significant deformation at the joint in the center of the span. (Figs. 2 and 5)

There was a drop in the level of the road surface due to ground subsidence at the rear of the bridge abutment on the Yagiyama side. (Figs. 6 and 7) This had already been repaired with asphalt and the road was open at the time of the survey. (Fig. 8)

Fig. 1

Fig. 2

Fig. 3

Fig. 4


Fig. 5


Fig. 6


Fig. 7


Fig. 8

Date of survey: **March 28, 2011 (Monday), 4:25 p.m.**
Structure surveyed: **Part of Sendai East Highway near Sendai Kohoku IC (around P69)**
Type of structure: **RC single-column viaduct, steel single-column viaduct**
Administrator of structure: **East Nippon Expressway Co., Ltd.**
Date of completion: **Not yet confirmed (though this section of road opened to traffic in 2001)**
Damaged members: **None**

Outline of survey results:

The Sendai East Highway is a north-south expressway crossing the eastern part of the Sendai Plain. Prefectural road No. 10 runs under the elevated expressway. It was reported that the area near the Sendai Kohoku IC had been damaged by the tsunami, but at the survey point about 1.5 km south of the IC, no earthquake damage was observed to RC or steel bridge piers. Within the limitations of visual inspection, no damage was found to the superstructure. (Figs. 1 and 2) The on-site visual inspection identified that a device designed to restrict the movement of a girder in the transverse direction was displaced. (Figs. 3 and 4)

Work to repair bearings was being carried out on P56 and lanes had been closed (with only one lane instead of two open each way), although details of the work were not available. (Fig. 5)

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Date of survey: **March 28, 2011 (Monday), 1:10 p.m.**
Structures surveyed: **Catenary support poles along the Tohoku Shinkansen line**
Type of structure: **Pretensioned PC catenary support pole (steam cured)**
Damaged members: **Catenary support poles**

Outline of survey results:

About 470 catenary poles are reported to have suffered failure, tilting, or cracking along the Tohoku Shinkansen line (as of March 18). (Fig. 1) Catenary poles had been damaged (failure, tilting, and cracking) in previous earthquakes, but the damage caused by this one was greater and more extensive than ever before. The repair of catenary poles and wires will take a long time, although restoration of civil engineering structures related to the Tohoku Shinkansen line is expected to be completed relatively soon.

Fig. 1 Damaged catenary support poles on the Tohoku Shinkansen line