Damage caused to concrete structures along the Tohoku Shinkansen line by the Great East Japan Earthquake and methods used to restore the damage

1. Introduction

The Great East Japan Earthquake that struck on March 11th 2011 resulted in widespread earth movements lasting for a long time. A great deal of damage was caused to railway structures under the jurisdiction of East Japan Railway Company (JR East), including many along the Tohoku Shinkansen line. Figure 1 shows the locations of major damage to the Tohoku Shinkansen line and the number of damage locations.

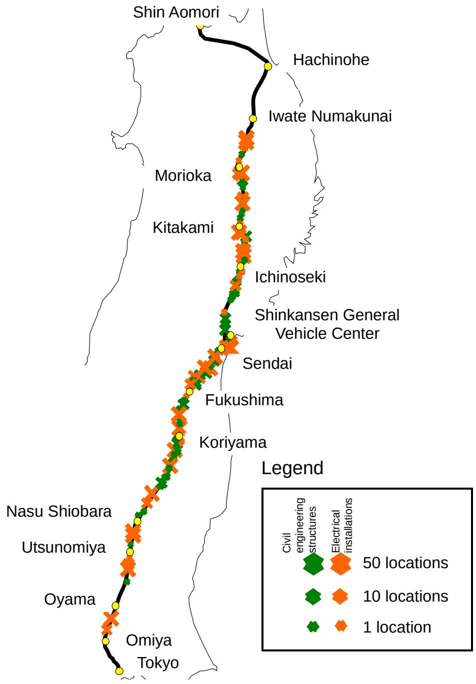

Fig. 1 Concrete structures along the Tohoku Shinkansen line damaged by the March 11th Earthquake

The main shock on March 11th caused damage to aboveground installations at about 1,200 locations over a length of about 500 km between Omiya and Iwate Numakunai Stations. Civil engineering installations suffering major damage were mainly viaduct columns and similar structures with about 100 locations, displaced bridge girders at 2 locations, and damaged support points for bridge girders at 30 locations. Although emergency restoration work had mostly been completed on these structures by the time a major aftershock occurred on April 7, with only at about 90 locations left un-restored, a further 550 or so structures were damaged by the aftershock. In this case, the civil engineering structures with major damage were viaduct columns and similar structures with about 20 locations, displaced bridge girders at 7 locations, and damaged support points for bridge girders at 10 locations. Although the extent of damage caused by the aftershock was smaller than that by the main shock, some sections of the line, such as that between Sendai and Ichinoseki Stations, suffered more severe damage.

This report outlines the extent of damage caused by the Great East Japan Earthquake to concrete structures along the Tohoku Shinkansen line and the methods used to restore the earthquake damage.

2. Earthquake damage to concrete structures along the Tohoku Shinkansen line and work to restore the damage

2.1 Damage and restoration of reinforced concrete rigid-frame viaducts

In response to the 1995 Great Hanshin Earthquake and the 2003 Sanriku Minami Earthquake, JR East was working on a program of seismic reinforcement for viaducts and bridges. All concrete columns with low seismic resistance to shear failure on viaducts along its Shinkansen and conventional railway lines in large urban areas had already been reinforced. As a result of this reinforcement work, the Great East Japan Earthquake did not result in severe damage, such as viaduct collapse. However, fracture patterns characteristic of flexural failure were found in columns with low seismic capacity.

Photo 1 shows a case where the top of a column suffered flexural damage and, as a result, the track dropped slightly. The viaduct in question is a single-layer three-span RC rigid-frame viaduct and the damaged column is located at one end of a block of columns. This block of the damaged viaduct has simple RC girders at both ends, and the damaged column was about 0.4 m shorter than the columns in the middle of the block. There were about nine columns along the Tohoku Shinkansen line that suffered damage like this, causing the track to drop. Of these, columns where concrete had been pushed out from inside were among those damaged by the main March 11th shock. This is probably because of the long duration of the earthquake motions.

The structural performance of the columns whose cross-sectional area had been reduced by the earthquake damage was restored to that prior to the earthquake as follows. First, the girder was temporarily supported with a steel structure, the rebars were cut in the longitudinal direction, and the supports were then jacked up to the correct level. The rebars were then made good using welded joints. Resin was injected into cracks and larger gaps were filled with mortar (See Photo 2). This restoration work took about seven days for each column. Permanent restoration work, involving seismic reinforcement of all the columns in each damaged block with a steel casing to increase seismic capacity, will take place in future.

Photo 1 Damaged columns of rigid-frame viaduct

Photo 2 Restored columns

2.2 Earthquake damage to reinforced concrete bridge piers and work to restore the damage

Of the reinforced concrete single-column bridge piers damaged by the earthquake, none overturned as a result of shear failure there were no cases in which bridge beams fell. Most of the damage to RC bridge piers was spalling of cover concrete and diagonal cracking at anchor points, part way up the longitudinal rebars. A typical damage case and the method of repair are described below.

Photo 3 shows a bridge pier damaged by the March 11th main shock. The pier is a cylindrical reinforced concrete single-column bridge pier 4.5 m in diameter and 18.0 m high. The pier supports two PC box girders with spans of 50 m and 35 m. Damage consisted of spalling of the cover concrete and cracking at an anchor point part way up the longitudinal rebars. Photo 4 shows the restored column. The reduced cross-sectional area of the damaged column was restored by injecting resin into cracks, rearranging the transverse rebars, and placing non-shrinking mortar. The work of restoring the damaged pier took about 8 days.

Photo 3 Damaged column

Photo 4 Restored column

2.3 Damage to seismically reinforced structures

As already mentioned, a program of seismic reinforcement of rigid-frame viaducts and single-column bridge piers with low seismic capacity was ongoing. Reinforcement of structures with extremely low seismic capacity had already been completed. Generally, the seismic reinforcement method used for RC rigid-frame viaducts was to place a steel casing around the column. In cases where the below-girder space was in use for some purpose, newly developed methods were adopted. Photos 5 to 8 show the columns of viaducts seismically reinforced by these various methods. Although there was minor damage to these seismically reinforced viaducts in the earthquake, such as peeling of paint from joints between sections of steel reinforcement casing, no serious damage occurred. The earthquake thus unintentionally ascertained the efficacy of these seismic reinforcement methods.

Photo 5 Seismic reinforcement using steel casing sections (interlocking joints)

Photo 6 RB seismic reinforcement

Photo 7 RP seismic reinforcement

Photo 8 Single-face seismic reinforcement

3. Conclusions

This report provides a brief summary of the damage caused by the Great East Japan Earthquake to concrete structures along the Tohoku Shinkansen line and how restoration was carried out. Fortunately, the collapse of bridge beams was avoided and those bridge piers that suffered damage could be restored quickly as a result of the program of seismic reinforcement implemented after the 2004 Mid Niigata Prefecture Earthquake. The author wishes to offer his greatest respect to those who pursued rapid completion of the seismic reinforcement effort and to those whose efforts achieved such quick restoration of those structures that were damaged in the earthquake.