Overview of Damage to the Infrastructure Facilities of JR East by the Grate East Japan Earthquake and Their Restoration

1. Introduction

The Grate East Japan Earthquake of M9.0 occurred on March 11, 2011 in the areas between the Kanto and Tohoku regions (400km long from north to south) generated strong shaking more than intensity 6 with difficult enough to standing (Fig. 1-1). And the Earthquake caused flood damage ranging from approximately 561km² mainly in the coastal areas with the Tohoku region by the invasion of the giant Tsunami. Also an aftershock occurred on April 7 raised many damages to new places and ones already restored, and forced to review the recovery process.

Restoration works of facilities had many problems such as work organization, work adjustment between track works and electric works, etc. and securing of materials. Through solving these problems by the effort of the group together with other companies, we were able to resume operations in April 2011 except railway lines damaged by the Tsunami.

In this paper we report the damage situation and recovery overview of each infrastructure facility dividing into civil engineering structure/architectural building, tracks and contact line facilities.

2. Damage to Civil Engineering Structures/Architectural Buildings and Their Restoration

(1) Overview of damage

1) Major damaged areas

Table 2-1 is a list of major damage to the Tohoku Shinkansen (the Shinkansen) and Fig. 2-1 shows the distribution. Table 2-2 shows the major damage to conventional lines.

2) Characteristics of damage

1) Tohoku Shinkansen

Damage to civil engineering structures occurs mainly at the piers of viaducts and bridges, and at the points of support for girders (Photo 2-1).

However, there were no collapsed bridges or other such destruction as the ones seen in the Great Hanshin-Awaji Earthquake of 1995.

Table 2-1 Major damage of ground facilities in the Shinkansen

<table>
<thead>
<tr>
<th>Major damage</th>
<th>Round number of damaged facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damaged pillars of viaducts, etc</td>
<td>100</td>
</tr>
<tr>
<td>Slipped bridge girders</td>
<td>2</td>
</tr>
<tr>
<td>Damaged supporting parts of bridge girders</td>
<td>30</td>
</tr>
<tr>
<td>Damaged tracks in tunnels</td>
<td>2</td>
</tr>
<tr>
<td>Damaged, inclined or detached sound barriers</td>
<td>10</td>
</tr>
<tr>
<td>Broken or dropped ceiling materials</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>140</td>
</tr>
</tbody>
</table>

Public documents from the Japan Meteorological Agency

Fig. 1-1 Intensity distribution of the great East Japan earthquake

Fig. 2-1 Distribution of the major damages on the Shinkansen
The ceiling of platforms and concourses of some architectural buildings fell down and the pillars of some platform sheds were damaged.

2 Conventional lines

Compared to the Shinkansen, there were many changes to the platforms and civil engineering facilities (embankments, cuttings, etc.) of the conventional lines (Photo 2-2).

In terms of the architectural structures, there were damage to the pillars and beams of station buildings, tilting of the buildings caused by liquefaction, and falling of finishing members such as ceiling and others.

(2) Damage to civil engineering structures and restoration

1) Viaducts/bridges

Damage to the piers of viaducts / bridges

Photos 2-3 and 2-4 are examples of typical damage to the piers of viaducts / bridges. Damage of viaducts occurred most often to the reinforced concrete piers at the edge of each block of viaducts. It included exposure of reinforcing bars in the axial direction and falling of interior concrete. There were also cracks and fallen concrete at the termination point of the main reinforcement in the axial direction, as shown in Photo 2-4. These piers of viaducts / bridges were restored in the following order: injection of resin into the cracks, rearrangement of reinforcing bars, and restoration of cross-sections using non-shrinking mortar. Their functions were restored to the same or higher levels than before the disaster.

Steel winding was used to reinforce the piers of damaged viaducts and the piers in the same blocks as the damaged viaducts against earthquakes.

2) Damage to the support point of girders and displacement of girders

Girders became displaced when the member to prevent it from moving laterally was damaged. It is believed that the reinforced concrete girder at the girder-viaduct in the Sendai–Furukawa section of the Shinkansen to have shifted in a right angle to the railway line and damaged the RC side block (made of reinforced concrete) (Photo 2-5).

For provisional restoration, a hydraulic jack was used to return the girder to its original position and anti-move steel member was added to the center of the girder. The full-scale restoration work involved...
removing the damaged RC side block, rearranging the reinforcing bars and pouring new concrete, and building anti-move steel member made of reinforcement concrete installed like enfolding it at the center of the girder.

Due to the horizontal earthquake motion, a steel box girder in Kashimajingu station of the Kashima line rolled over (about a 60° angle between the structure’s centerline and supporting edge), displacing the girder (Photo 2-6). For restoration, a hydraulic jack was used to return the girder to its original position and a member to control movement (H-shaped steel) was installed to harness the lateral force that exerts perpendicularly on the axis of the viaduct. By the way, over a year ago before the Great Hanshin Earthquake took place, bridge-fall protection work (the girder seat widening work) was done on this viaduct to prevent collapse. Therefore, the viaduct did not collapse.

Damage to intermediate beam of rigid frame viaducts

Photo 2-7 shows the damaged condition of an intermediate beam in the Koriyama–Fukushima section of the Shinkansen. The intermediate beam perpendicular to the railway line had cracks. For restoration, we opted not to increase the bearing force of the intermediate beam but instead inject epoxy-acrylic resin into the cracks and repair the cross-section with non-shrinking mortar.

Civil engineering facilities

Collapse of embankment

Collapse of embankment is a typical damage of civil engineering facilities. The damaged site in the Izumizaki–Yabuki section of the Tohoku mainline was a 5-m high embankment, which was built for the expansion of a double-track. About 100m along the track, approximately 3,400 m³ of the embankment collapsed (Photo 2-8).

Restoration entailed removal of the collapsed or cracked embankment. After having confirmed that there were no more major cracks, we used geotextile to cover the whole embankment up to 1.5-m high to reinforce it and used crusher-run stones (C-40) as reinforcing net to restore the embankment. In addition, since the groundwater levels of cutting and supporting soil were quite high, we took the caution to install water drainage pipes to drain water from the cutting as quickly as possible.

Collapse of cutting

Although there were few incidents of cutting collapse, some of them were of considerable sizes (Photo 2-9). In the Toyohara–Shirasaka section of the Tohoku mainline, a 23-m high cutting on the left side of the railway track collapsed over an area of 100m along the track. The volume of soil amounted to approximately 10,000m³. It was the largest damaged site in this disaster.

For restoration, we removed the earth and sand on the track, installed earth-retaining fence behind the stony earth-retaining wall, and made the gradient of the slope behind the earth-retaining fence a stable gradient. At the same time, we installed a landslide detection system to help us stop trains as soon as possible when an aftershock triggers landslide.

Platforms

The stone retaining walls and capping stones of embankment platforms suffered considerable damage. At Hitachitaga station of the Joban line, approximately 10m of the stone retaining wall collapsed and the capping stones scattered onto the tracks (Photo 2-10).

In order to carry out restoration as quickly as possible, we used pre-fabricated L-shaped retaining walls. Many other stations also suffered similar damage.

Damage of architectural buildings and their restoration

Damage to architectural buildings was similar to that of the civil engineering structures. A wide area suffered damage, centering at the focal regions in Iwate prefecture, Miyagi prefecture, and Fukushima prefecture. Among approximately 100 stations damaged by the Earthquake and its aftershock, about 30 stations had structural damage. However, besides the loss from the Tsunami, there were no casualties.
from building collapse.

1) Ceiling

The ceiling of the Shinkansen platform at Sendai station fell onto the whole platform. The platform ceilings in both directions were damaged (Photo 2-11). There was also damage caused by the breakage or fall of bulletin signposts from above the platforms onto the roofs of kiosks underneath them. For temporary relief, all the ceiling members above the platforms were removed.

The slanted or curved vaulted ceiling of Tokai station and two other stations on the Joban line fell down over wide areas. Due to seismic force, the base members of a slanted or curved ceiling generated complicated vibration, causing damage to the base members and boards (Photo 2-12). At Tokai station, brace was used to strengthen the base members of the ceiling and aluminum spandrel was used to restore the ceiling.

2) ALC panel

Fallen walls made of autoclaved lightweight aerated concrete (ALC) were seen at Sendai and other stations (Photo 2-13). Upon investigating how the fallen or damaged ALC panels were installed, we found that the panels were installed using a vertical wall insertion construction method in which a reinforcing bar was inserted between two panels and mortar was poured onto it to stabilize the panels. Since such construction method does not absorb deformation well, it was removed from the 2007 Standard Specifications for Public Architectural Construction Works and the 2005 JASS21. Sendai station was restored with aluminum spandrel using reinforcing bars as the base.

3) Platform shed

The Earthquake caused considerable structural damage to platform sheds (Photo 2-14). Various damage to the sheds of elevated stations, such as Koriyama station on the Shinkansen, were seen, including damage to the protect mortar at the bottom of columns, fractures of anchor bolts, fractures of the beams and braces of platform sheds, and tilting of platform sheds. Since the protect mortar of the column base was believed to have been damaged by shear force during the Earthquake, plates were used to strengthen the four sides of the base plates to prevent side shifting. The fractured beams and braces of platform sheds were repaired by reinforcing them with plates or replacing member materials.

The beams and column materials of rail-made sheds at Kogota and other stations had fractures. For Kogota station, filler PL sandwiched by channel iron was cut to the same web curvature as the rail of the fractured roof column (Photo 2-15) and high-strength bolts were used to stabilize it.

4) Buildings made of prestressed concrete (PC)
Structural damage, such as shear fracture, occurred at some of the building structures designed under the old quakeproof standards. The electric train garage No. 1 at the Katsuta Rolling Stock center, built in 1961, is a shell-roof building made of prestressed concrete. Major damage includes damage to the four PC columns supporting the roof (Photo 2-16).

Of the damaged PC columns, three were repaired by injecting resin and strengthening them with steel plates and one was restored by injecting resin only.

5) Leaning of building caused by liquefaction

Structural damage caused by liquefaction occurred in areas along Tokyo bay and Tone river. At the Keiyo Rolling Stock center, the crew dormitory became tilted at about 9 degrees (Photo 2-17). Piles to provide reaction force were planted around the building. Using the reaction force of the piles as support, we used hydraulic jack to lift up the whole building and restored it.

3. Damage to Tracks and Their Restoration

(Author: Mr. KOZU)

This chapter describes schematically the damage incurred on tracks and relevant equipment, and their restoration.

(1) Damage to conventional lines and their restoration

1) Major damage

Other lines than those damaged by the Tsunami

Owing to the Earthquake and its aftershock, there occurred track deformations on about 2,820 places and crushed stones carried away from ballast at about 220 places in the 36 railway lines (Photo 3-1 and 3-2). The track deformations were mainly caused by the Earthquake vibrations, and the breakdowns and irregularities of civil engineering structures.

Lines damaged by the Tsunami

The seven railway lines along the seacoast (the lines of Hachinohe, Yamada, Ofunato, Kesennuma, Ishinomaki, Senseki, and Joban) were damaged heavily by the Tsunami. Various types and vast amount of equipment in the lines were damaged by being swept away or buried under debris or rubble. It had been almost impossible even to know the scope of damage in those lines for some days (Photo 3-3).

2) Recovery works

In other lines than those damaged heavily by the Tsunami, recovery works started eventually after the inspection of each section of lines was finished. Priority of the works was basically placed on the lines and sections serving within urban areas and between cities, and at the same time on the Banetsu-Saisen line, which could be used for fuel oil transportation by linking Niigata and Koriyama Oil Stock terminals. This was widely accepted by people in Japan. The recovery works for tracks were conducted by about 100,000 man-power, for such works of supplementing ballast on roadbeds with dump cars, and tamping ballast and lining tracks with multiple tie tampers, etc. The Hachinohe line, among the lines damaged by the Tsunami especially, required quite a long time for its recovery and could resume its full operation on March 17, 2012, which was about one year after the disaster.

The major features of the recovery works for the conventional lines are summarized in the following.

Recovery work organization

The damage scale was so huge that the usual work forces of maintenance companies assigned to each area were not enough for the recovery works. Special supporting work forces were arranged by using those of the companies outside the areas to perform the recovery works.

Securing fuel oil

One of the hard tasks for surveying the situation and restoring the damaged lines was to secure fuel oil (light oil and gasoline). Just after
the occurrence of the Earthquake, it turned to be quite difficult to get fuel oil within each relevant city area. However, light oil was relatively easier to secure because we had stored it for diesel cars and other companies gave it to support us. And the financial department tried its best to secure it as early as possible, which contributed greatly to the early startup of recovery works. On the other hand, gasoline was quite difficult to secure because the supply was continuously quite little.

3 Provision of materials
As track related materials should be firstly provided for the recovery works, we set up urgently the special providing channels in order to secure them at the time of their requests and to manage the total works effectively. Due to the damage of the Sendai harbor, where the rails had been unloaded for the use in the Tohoku district, it interfered with the procurement of rails used in the non-affected areas. Then, with full cooperation of the train operating department, the revised transportation route to the Akita harbor and Tokyo were arranged to transport rails.

4 After restart of train operation
For some months after the restart of train operation, it had been controlled under limited speeds to keep safety. During the period, measurements of car shaking were undertaken to decide whether trains could run at the normal specified speeds, and re-inspections and adjustments of welded rails were also undertaken to prevent accidents caused by their expansion in summer time. We did our efforts to recover early from speed constraints on the Tohoku mainline in particular, which should take an important role of wider area transportation between the Kanto and Tohoku or Hokkaido districts and which had forced to stop long-distance trains because of restricted operations. After re-inspecting the welded rails and joint gaps, about 3,000 spans were found necessary to be adjusted due to the Earthquakes. In order to complete adjusting works by the summer time when rail temperature was too high, we decided the priority of restoration works, and tried hard to gather welding operators from wider areas, to secure welding materials and tools, to expand track possession period applicably, etc.

5 Other feature
Except the damage to tracks, there happened the situation that the track inspection train (East-i-E), which was inspecting the Joban line at the time of the Earthquake occurred, was unable to move for about a month. We had to reschedule the inspection works.

(2) Damage and restoration works of the Tohoku Shinkansen

1) Major damaged situation
In the Tohoku Shinkansen (the Shinkansen), besides track deformations by irregular movements of civil engineering structures (viaducts, tunnels, etc.), projected concrete by sliding girder, breakdowns of rail fastening systems, inclination of electric poles, etc. were occurred (Photo 3-4 and 3-5). At the Shinkansen General Car Maintenance center (Car center) in Sendai, there happened also damage of tracks and structures. The Earthquakes, there were about 20 major deformations or damage on tracks, but there were about 2,000 minor deformations. In order to resume normal high speed operation, all of those had to be recovered by adjusting them in the precision of mm, which caused the tremendous amount of works.

2) Recovery works
The actual inspection and recovery works started at the sections where passengers were fully rescued. To make a recovery work system and to secure fuel oil were also the difficult works just as described for conventional lines. We describe hereinafter peculiar matters encountered in recovery works of the Shinkansen.

1 Coordinating competing works and changing the work control system
The damage by the Earthquakes was mostly centered in breakdowns of electric poles, deformations of civil engineering structures, and those of tracks in tunnels. For their recovery works, each engineering party used many maintenance cars. It was required to coordinate closely the working schedule among relevant engineering parties to prevent their competing. At first, to perform the works in those sections where train operation was entirely stopped, it was the rule for workers to get permission of Shinkansen Operation center each time when they enter or leave the section. However, after some time, the new rule was decided in order to eliminate the accumulated handling of train operational procedures to the center. It is that in such sections where no train operation is permitted, each regional branch office can have the authority to manage their sections, to make the procedures be done efficiently. This was based on the lesson learnt at the Chuetsu Earthquake happened in Niigata prefecture.

2 Measurements on tracks
In order to make Shinkansen trains run in the specified speed, it is very important to get accurately the track irregularity in the mm precision and to repair them exactly based on the maintenance schedule. It should be desirable to measure it by using the track inspection train (East-i), but East-i was unable to use due to the breakdowns of electric poles on the line and various other damage in the Car center. We used 10 simplified track measurement devices (Track Masters), some of railway point checking devices, laser activated measuring devices, etc., all of which were borrowed from other branch offices or manufacturer (Photo 3-7). These were only applicable for measurements of limited areas. We then borrowed the track measurement car (EM30) from Keikyu Corporation, and some hauling type Track Masters from Nippon Railroad Co., Ltd., which helped greatly to measure tracks in wider areas (Photo 3-8).

The EM30 of Keikyu Corporation, in particular, runs on the same standard track gauge as Shinkansen trains, and the computer system used for the management of rail equipment is in harmony with that of our company. It was the great feature of the car that the data acquisition and necessary calculation for long waves needed for high speed train operation could be done easily (Fig.3-1). The interoperability of
the computer system helped greatly to early recovery of damaged equipment in case of emergency. This means that the system interoperability should be well taken into consideration in the future.

### Track maintenance

In the sections of slab tracks, rail fastening systems were changed to align rails because of the limit of vertical and horizontal movement. The ones applied especially for tunnels were limited to move upward or downward to 10mm and right or left side to ±6mm. As this was a big bottle neck of recovery, we decided to change the ones into those with wider adjustability used at the recovery of the Mid Niigata Prefecture Earthquake in 2004 (Photo 3-9). There were some cases where vertical irregularities were so large that any rail fastening systems could not be adjustable. In those cases, slab filling material layers and concrete roadbeds were repaired.

On the other hand, in the Car center and ballast sections of main lines, track maintenance by MTT were performed (Photo 3-10). As there were many sections where electric poles were broken down,
MTT could only run after the damaged poles were restored.

Provision of materials

A large amount of materials needed for recovery works, such as adjustable tie plates, iron plates, polymer compounds used for filling layer of slabs, crushed stones, fastenings, track pads, etc. We set up the special provision channels just as described for conventional lines, and got good cooperation with manufacturer, etc., which could secure a certain amount of materials. However, it was quite difficult to provide with necessary materials during the recovery periods, sometimes owing to the stop of production lines at manufacturer, which was inevitable by the scheduled stops of electric power supply, and some other times owing to the difficult arrangements of shipping companies. We also experienced hardship to manage provision of materials for emergency. It is our new task to find a good solution for providing with frequently usable materials not only in normal time, but also in emergency time.

Inspection and maintenance for resuming of train operation and normal specified operation

After the completion of all the recovery works and checking of electric power supplied normally, more than 10 of stranded trains between stations were moved, and the rails just where trains were stranded were inspected and aligned. As the trains were moved away only a few days before the reopening of the operation, the time needed for the works was quite limited.

Though the full reoperation started on April 29 after several regional reoperations, trains had to run on temporal diagrams with limited speed for some months. To make trains run at normal specified speeds, further minute inspection of catenaries, tracks, etc. was in some sections. When the relevant works were finished in the sections, trains resumed to run at normal speeds there. It took almost half a year when the trains could run on the specified diagram used before the Earthquake.

4. Damage to Contact Line Facilities and Their Restoration (Author: Mr. KANEKO)

In this chapter, we report real problems having met in restoration works of the damaged contact line facilities, efforts to resolve them, and restoration methods examined and performed aiming at an early restoration of damaged facilities.

(1) Damage to electric power facilities

The damaged state of main electric power facilities of the conventional lines and the Shinkansen is shown in Table 4-1 and Table 4-2.

The Earthquakes inflicted serious multiple damage, particularly on the contact line facilities among the electric power installations, such as breakage of poles, inclination of poles and breaking of overhead wire. Photo 4-1, 4-2 and 4-3 shows the damaged states of the Shinkansen in particular suffered immense harm.

(2) Preparatory works for restoring the damaged contact line facilities in the Shinkansen

The site survey in damaged section began on the next day of the outbreak of the Earthquake. The situation in all damaged sections has been beyond imagination. As for the restoration of the Shinkansen whose most part of structure consists of viaducts, especially, it was...
forecast that the restoration works would involve much difficulty, because they had to be conducted under the restricted working space and method on account of elevated structure. There had been a lot of various issues having to solve such as an examination of restoration work method, the mobilization of maintenance vehicles and crane vehicles, and the procurement of poles and metal fittings of contact lines.

1) Site survey of the state of damage

A walking patrol survey on viaducts of the Shinkansen in cooperation with members of an electric technical center taking charge of the facility maintenance began on the next day of the Earthquake. The site survey of this time was performed simultaneously by more than one investigation group because the Earthquake had done widespread damage. However, the investigation needed much time because the number of members able to go to work was not limitless, because it was very difficult to secure automobiles and fuel for moving along the investigation areas, and because a succession of aftershocks and an influence of accident in the Fukushima first nuclear power plant had forced to interrupt the investigation. And the reports from each survey group to the countermeasures headquarters were unequal in its pattern. As to the situation of slanted and broken poles, in particular, it was reported under criteria based on a sense of each survey member. Therefore, the reports were amended to get hold of a quantitative damaged situation by using a check list organized the items for confirming them. Afterwards, it became possible to accelerate the efforts for the restoration works such as the site survey, the examination of its method mentioned in the next section, and the mobilization of heavy machinery and the acquisition of necessary materials, with the support of Tokyo Electric System Development and Construction office taking charge of the electric and systematic construction work mainly in Tokyo district. Moreover, through a construction work contract with some partner companies in parallel, they participated in the site survey and study about a method how to bring the damaged poles back into temporarily good condition. Thus almost whole site survey was closed on March 21, 2011.

A grand process of restoration works was drawn up based on the data of damaged situation from the site survey, and at the same time construction work areas were set up and a construction sphere was assigned to each partner company.

2) Arrangement of restoration materials

The preparation of restoration materials was advanced concurrently with the investigation of damage situation. As for the arrangement of restoration materials, it was decided that our company procures the main materials such as steel pipe poles and electric wire in a package deal, and the partner companies taking charge of each construction work area procure directly every other materials, following the below factors:

- A large quantity of materials is needed because of a number of damaged facilities.
- The materials of contact line facilities are little for general purpose, so that it will not be able to have sufficient quantities in stock.
- It is difficult to put an order of materials under control in each construction work area.

Though the spots of damage such as the broken and slanted poles and the breaking of wire has been reported, it was not easy to make a list described in detail the type and quantity of a material necessary for restoration based on only the reported data, because the investigation was conducted narrowing its scope down to main facilities. Meanwhile, it was necessary to make the delivery period of materials shorter and arrange necessary materials in advance, in order to start the restoration works promptly and advance the construction works smoothly. Consequently, it set about to make a list of the minimum materials for restoration by picking up the number and kind of materials equipped with each pole from the standard structure figure of contact lines of the Shinkansen, based on the number of broken and slanted poles. The immediate materials for restoration works were secured by ordering to the manufacturers having their stocks, and arranging to send them to the spots in a hurried manner. From then on, the order was placed with the manufacturers concerned when the need arose.

As to the poles being main material, it was decided to use the steel pipe poles without surface plating processing (with solid state without surface treatment) because it takes about one month to manufacture the steel pipe poles with its processing. It was standardized to be of 12-meter as basis in the length of the poles in order to keep the processing to minimum. The means to fit a joining steel pipe on the top of the poles were adopted to meet the location where needs the more length than 12-meter, such as a neighborhood of substation structure (Photo 4-4).

3) Arrangement of heavy machinery

The arrangement to mobilize the heavy machines indispensable for restoration works was done prior to the start of them. Since the damaged sections caused by the Earthquake runs extensively from the Oyama to Morioka districts, it was necessary to secure machines as many as possible in order to complete the restoration works in a short time.

Procurement of on-rail vehicles

The maintenance works of contact lines in the Shinkansen are usually done using the maintenance vehicle (on rail vehicles) with a fail-safe device for the prevention of collision. Only our company takes possession of them. When executing a construction, our company leases on rail maintenance vehicles to a builder. The maintenance vehicles of our company are basically put in the following places:

- One multifunctional maintenance vehicle (M-M-W) in the technical center of each regional office
- One maintenance vehicle (M-W) in each maintenance center

On the occasion of the restoration works of this time, a total of 22 vehicles were secured by gathering together from Sendai, Omiya and Takasaki.

Procurement of a road railer (overhead contact line maintenance vehicle)

Since the overhead contact line maintenance vehicle with a past record of restoration works in the Chuetsu Earthquake and with facilities to carry in/out railway track easily has been properly validated, it was arranged to mobilize the maintenance vehicles from a rental company in addition to ones of our company.

And it was very difficult that the maintenance vehicles which move in / out main track from maintenance depot went to a job site of restoration, because numerous broken and slanted poles had brought about obstacles to the structure clearance, and the 7 Shinkansen trains had remained in between stations. Therefore, we decided to carry
the road raier in railway track through slope and newly installed five temporary slopes. This made it possible to give mobility of the maintenance vehicles full play and to improve working efficiency.

3 Procurement of a crane road raier and an usual type crane vehicle

In the restoration works, it was absolutely necessary to use a crane vehicle because numerous poles had been broken by the Earthquake. As same as the contact line maintenance vehicles, we could secure a total of nine crane vehicles by borrowing the same type as one of our company from other companies. Besides, necessary cars such as trucks for carrying an ordinary crane, trucks conveying materials including the poles were deployed at each maintenance depot.

4 Examination of the working method and the basic composition of working machines

In order to perform the restoration work efficiently in collaboration with the partner companies, it was studied what formation of working machines should be made up. At first, it was studied to adopt the method which conducts the reconstruction of contact line poles by using the crane placed on the ground below viaducts. As it was found that this method had the following difficult points, afterwards:
- In urban district, especially, it is difficult to utilize side way along viaducts;
- It is difficult to perform the works at the site of high viaducts.

We decided to adopt basically the method to use a crane placed on viaducts. The removing work of the broken poles is shown in Photo 4-5.

(3) Restoration method of the broken and slanted poles

The examination of restoration method also was advanced in parallel to the site survey and the procurement of materials and heavy machinery. As the site survey went on, the following situations had been found:
- The damage on the poles was heavy;
- The damage on the poles was of multiple states such as broken, slanted, with crack and with partial exfoliation of concrete.

Then, judging from the situation that it was very difficult to reuse the poles whose most part of concrete were peeling off and whose internal reinforcing bar were bare and transformed, it was planned to reconstruct them. On the other hand, as to the slanted poles, it was studied to adopt the restoration method such as rebuilding them vertically again after having extracted them according to the damage degree.

1) Reconstruction method of the broken poles

This method is broadly divided into three species according to the type of its footing.

1a Method for the sand filled footing

This footing is filled with sand in a clearance gap between pole and footing. This method was performed by the following work procedure:
- When reconstructing, the broken concrete poles dismounted overhead contact lines and supporting metal fittings were extracted by using the crane;
- A new steel pipe pole was built in the footing after removing the sand remaining in the interior portion of footing.

As well, the extracting work of the broken poles was performed using a jack fitted on a pole after having removed about a half amount of the sand filled in the interior portion of footing.

2) Method for the mortar footing

This is the footing substituted mortar for the above mentioned sand, which was adopted in the beginning of the construction of the Shinkansen. This method was performed according to the following work procedure, because it is not possible to extract the filled materials as sand filling footing:
- The broken concrete pole is cut at the portion near its footing;
- A hole is drilled to the footing bottom by use of core pull-off drill;
- The remaining mortar and the remnant portion of poles are removed from the interior portion of footing. (Fig. 4-1)

3) Method for the anchor bolt footing

In this case, the work is performed according to the following procedure:
- The broken pole is cut at the portion near its footing;
- The concrete covering anchor bolts is chipped off;
- The seat plate of a broken pole remaining at the footing portion is removed;
- After removing the seat plate the new steel pipe pole with a new seat plate is built reusing existing anchor bolts. (Photo 4-6)

2) Restoration method of the slanted poles

At first, it was planned to perform the restoration of the slanted poles with great inclination angle (whose offset distance of upper end from the vertical axis before slanting was equal to or longer than its diameter) according to the following method:
- The slanted pole is extracted using the crane;
- The extracted pole is rebuilt again vertically using the crane.

However, the number of places possible to perform the restoration work of slanted poles concurrently was restricted, because this method needed the similar extent of effort and expense to the reconstruction of them and needed to assemble many heavy machines including the crane for hoisting them. Moreover, the poles whose inside portion of footing severely damaged were found in some places (Photo. 4-7).

As a result, the places that need the change from this method to the reconstruction method with a new steel pipe pole, increased. This caused concerns leading to a shortage of steel pipe poles.

Consequently, a method adding strength to existing poles was studied in connection with the damaged interior portion of footing. This is the method which adds strength to the pole filling the hollow portion of pole inside with zero shrinkage mortar after having raised the slanted pole. The method to raise the slanted pole were changed
from the method adopted at first which rebuilds the existing poles to the method which raises the slanted poles using "Simeler" (tool for tightening wire tension), adopted at the restoration works of the Chuetsu Earthquake so as to reduce process of work (Fig. 4-2).

Furthermore, the above method has been changed to a new method using jack, because the place unable to raise the slanted pole by the method shown in Fig. 4-2 came out from place to place (Fig. 4-3).

By repairing the inclination of poles with the jack, it became possible to do the restoration works in a short amount of time without heavy machines, and to enhance efficiency of work remarkably. Moreover, the matter that the works at multiple places at the same time became possible led to a serious work period reduction. As the poles with low-angled inclination whose upper end offset distance from the vertical axis is less than a diameter of poles, is of about 200 mm of the deviation at the height of 5m of overhead contact line it is possible to bring the said deviation back into condition with an adjustment of overhead contact line deviation. Therefore, it was concluded to sort the restoration method into “the repair only to grout mortar into the interior portion of pole (grouting thickness : about 1,400mm)” and “no necessary to repair” according to the damaged state of footing. A transition of restoration method of the poles is shown in Table 4-3.

The following tasks were comprised of the restoration works:
- The reconstruction of damaged poles;
- The mend of slanted poles;
- The restoration of broken AT protective wires;
- The replacement of insulators and metal fittings of overhead contact lines.

After the completion of restoration operation, the restart of commercial service in the whole line of the Shinkansen was accomplished on April 29, 2011 after a series of steps such as full check of facilities, power applied test, speed advancement test and trial run.

Table 4-3 Transition of the damaged pole restoration method

<table>
<thead>
<tr>
<th>Damaged state</th>
<th>Original method</th>
<th>Final method</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broken</td>
<td>Rebuilding with a steel pipe pole</td>
<td>Rebuilding with a steel pipe pole</td>
<td>broken/fallen</td>
</tr>
<tr>
<td>Slanted (≥1D)</td>
<td>Hoisting slanted pole and rebuilding it again</td>
<td>Jack up slanted pole+ mortar grouting</td>
<td></td>
</tr>
<tr>
<td>Slanted (&lt;1D)</td>
<td>Without repair</td>
<td>Mortar grouting</td>
<td>With footing damage</td>
</tr>
<tr>
<td>Delaminated/cracked</td>
<td>Repair with resin mortar</td>
<td>Repair with resin mortar</td>
<td></td>
</tr>
</tbody>
</table>

Note: 1D shows a length of diameter of pole.

5. Conclusion

The Earthquake gave a great deal of damage to our infrastructure and has given many trials and challenges for each department. Father more hereafter, through analyzing the damage and examining measures, we will effort to improve the earthquake resistance of facilities and to ensure safe and reliable transportation.