# DAMAGE CAUSED BY THE EAST JAPAN EARTHQUAKE AND RECOVERY FROM THIS DISASTER AT THE KASHIMA WORKS, CHUO DENKI KOGYO CO., LTD

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## ABSTRACT

*The magnitude 9 East Japan Earthquake that occurred on March 11, 2011, off the coast of Miyagi prefecture seriously affected our Kashima site, where it measured magnitude 6. The Kashima coastal industrial area was also hit by the associated tsunami.*

*This paper describes how the amount of damage caused by the earthquake at our Kashima works was minimized by making employee safety and the restoration of the facilities top priority. None of our employees or their families were injured in this disaster and the earthquake warning and communication system introduced in 2010 was utilized to the full.*

*Four of our electric furnaces were submerged as a result of the disaster but were closed down in good order immediately after the earthquake by means of "Genba-ryoku" (highly disciplined workmanship) and were able to restart operation again in only two weeks.*

*However, this earthquake also revealed weak points in our operations and we are now concentrating on the necessary improvements.*

## 1. INTRODUCTION

The East Japan Earthquake occurred on March 11, 2011. At the Kashima works, Chuo Denki Kogyo Co., Ltd. ensured the safety of all employees and shut down operations properly. After the disaster, we then gradually re-established normal operations as the electricity supply was progressively restored.

On March 18, 2011, seven days after the disaster, we were able to restart operations. Details of how this was achieved are described below.

## 2. OUTLINE OF THE EARTHQUAKES

Table 2.1 and figure 2.1 outline the nature of the earthquake-related disaster. The main shock of magnitude 9.0 was followed 30 minutes later by a magnitude 7.7 aftershock off the coast of Ibaraki prefecture.

The main shock was felt at Kashima City, where our Kashima works is situated, as a magnitude 6 event, according to the JMA (Japan Meteorological Agency) seismic intensity scale. Such a large earthquake is only expected to occur once every 1,000 years.

Figure 2.2 shows the number of aftershocks experienced in the 90 days following the initial disaster and shows just how numerous the earthquakes and aftershocks were and how extensive the damages was.

**Table 2.1:** Earthquake outline

| | **Main shock** | **(Typical)Aftershock** |
|---|---|---|
| **Time of occurrence** | **14:46** | **15:15** |
| **Earthquake center** | **Miyagi prefecture (offshore)** | **Ibaraki prefecture (offshore)** |
| Magnitude | 9.0 | 7.7 |
| JMA seismic intensity scale (peak ground acceleration,(PGA)) | 6-lower (658 g) | 5-lower |
| Duration of earthquake | 150 sec | - |

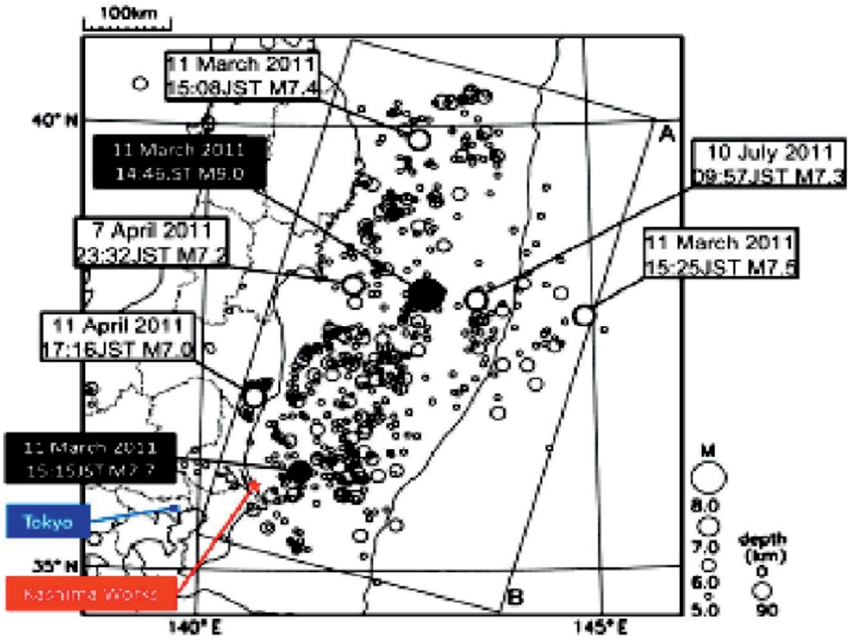


**Figure 2.1:** The 2011 earthquake off the Pacific coast of Tohoku: location of the main shock and aftershocks (12:00 JST, March 11–12:00 JST, March 8, 2012) [1]

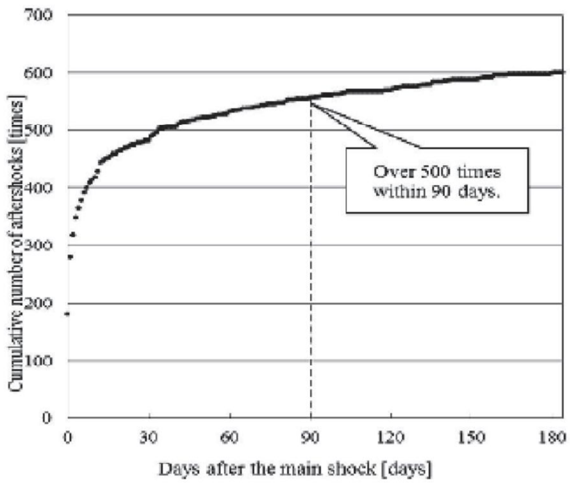


**Figure 2.2:** Aftershock occurrence [1]

## 3. OUTLINE OF DAMAGE AND RECOVERY

### 3.1. Damage in Kashima City and neighboring areas

Figure 3.1.1 ~ 3.1.3 shows the damage caused by the earthquake and the results of the tsunami that affected the bay area of Kashima port.

Figure 3.1.1 shows the uplift and caving-in caused by the liquefaction of the ground beneath the road. Figure 3.1.2 shows how roof tiles were dislodged from houses and how concrete block walls crumbled. Figure 3.1.3 shows the damage caused by the tsunami at Kashima port (near our facility). Many shipping containers located near the port were swept away by the tsunami.

**Figure 3.1.1:** Uplift and caving-in caused by liquefaction

**Figure 3.1.2:** Damage to roofs and walls

**Figure 3.1.3:** Tsunami damage near Kashima Port

## 3.2. Details of damage at the Kashima works

### 3.2.1. Safety of employees

An earthquake alarm and early warning system was installed at our works in 2010 (operated via NSSMC and the JMA). In addition, a safety confirmation system using mobile phones and PCs was also installed in August 2010.

This alarm and warning system sounded an alert 45 seconds before the main shock occurred. As a result, we were able to shut down our furnaces safely. This alarm and warning system was also very useful in facilitating the evacuation of employees.

The safety confirmation system was very useful for communication with employees' families, other work sites, and head office. Table 3.2.1 lists the activities carried out by the safety confirmation system.

**Table 3.2.1:** Use of the safety confirmation system

| | Date and Time | | No. of persons targeted | No. of persons who responded | Proportion |
|---|---|---|---|---|---|
| | Sent | Response | | | |
| **1** | 3/11 14:57 | 3/11 21:00 | 250 | 152 | 61% |
| | | 3/14 14:50 | | 220 | 88% |
| **2** | 3/14 14:54 | 3/14 18:00 | 180 | 164 | 91% |

### 3.2.2. Damage to facilities at the Kashima works

Table 3.2.2.2 shows the condition of the furnaces and other equipment after the earthquake.

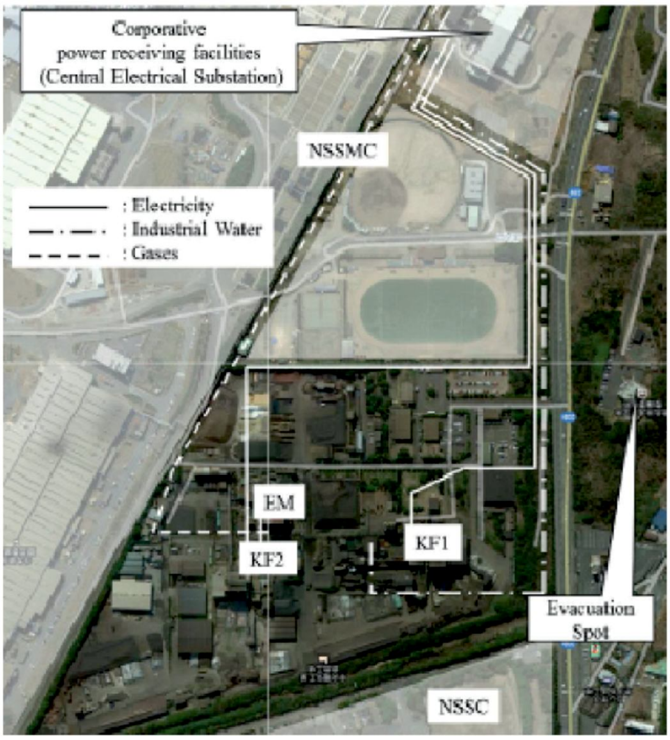


**Figure 3.2.2.1:** Utility routes

**Table 3.2.2.2:** The condition of facilities after the earthquake

<table>
<tr><th>Facility</th><th>Item</th><th colspan="2">Condition</th></tr>
<tr><td rowspan="8">Utilities (Figure 3.2.2.2)</td><td>Electrical power</td><td colspan="2">Just after the quake<br>One of two lines used to access electricity was shut down by KF-2’s power transformer*. Another furnace (KF-1) could still access electricity*.<br>Next day (3/12)<br>We found dielectric oil leaking from the receiving cable and had to shut down the electricity supply**. Therefore, the entire Kashima works lost power.</td></tr>
<tr><td>Industrial water</td><td colspan="2">A broken pipeline underground caused the water supply to fail.</td></tr>
<tr><td>Drinking water</td><td colspan="2">The water supply failed because of a broken pump in Kashima City.</td></tr>
<tr><td rowspan="3">Gas</td><td>$N_2$</td><td>Pipeline stoppage on the supply side.</td></tr>
<tr><td>$O_2$</td><td>Pipeline stoppage (as with $N_2$). One pipeline had broken after restarting supply.</td></tr>
<tr><td>LPG</td><td>Automatically shut down by the quake.</td></tr>
<tr><td>Electrical furnace gas</td><td colspan="2">Gas normally supplied from the furnaces to Sumitomo Metals Industries., Ltd. (SMI) was discharged into the atmosphere instead.</td></tr>
<tr><td>Etc.</td><td colspan="2">A shortage of gasoline made it difficult to get into the office, etc.</td></tr>
<tr><td rowspan="3">Furna ces</td><td>Kashima Furnace No. 1 (KF-1)</td><td colspan="2">Just after the quake<br>KF-1 could access electricity, so we could operate it properly, as follows.<br>1) Discharging gas from KF-1 into the atmosphere.<br>2) Implementing electricity cut-off procedures.<br>3) Cooling the furnaces.<br>Next day (3/12)<br>We found dielectric oil leaking from the receiving cable and had to cut off the power.</td></tr>
<tr><td>Kashima Furnace No. 2 (KF-2)</td><td colspan="2">Just after the quake<br>The transformer of KF-2 registered the quake and tripped, so we had to act as follows:<br>1) Discharging gas from KF-2 into the atmosphere using an emergency electricity generator.<br>2) Receiving electrical power from KF-1 in order to maintain the electricity supply and operate the cooling pump.<br>Next day (3/12)<br>As noted above, we used a single line to access electricity but had to cut off power due to damage.</td></tr>
<tr><td>Furnace for industrial municipal waste (EM)</td><td colspan="2">Two EM furnaces received electric power via KF-2’s line. As noted above, the transformer of KF-2 tripped along with the EM transformer. As a result, we could not discharge gas into the atmosphere.</td></tr>
</table>

* Used an OF cable for access to electricity.

** The leak of dielectric oil from the receiving cable occurred at the central electrical substation.

Immediately after the quake, we were only able to use one of two lines to access electricity from the central electrical substation. The line to Kashima Furnace 1 (KF-1) that was needed to maintain cooling was still live, so we could follow normal procedures to close down the electricity supply to KF-1.

However, there was a problem getting water to the furnaces for cooling because the industrial water supply had been cut off.

We had stored a supply of clean water for emergencies, but there was not enough for the use of toilets or washing after recovery work, and gas from the furnaces had to be discharged into the atmosphere.

### 3.3. The disaster recovery system

An emergency drill is held once a year at the Kashima works (figure 3.3.1) and each department has a disaster prevention scheme adapted to its daily work schedule, as shown by the organization chart illustrated in figure 3.3.3.

A disaster prevention scheme had, therefore, been organized as a matter of course and meetings were held twice a day (morning and evening), as shown in table 3.3.2. Recovery workers were provided by the various equipment constructors associated with the Kashima works. Dynamo-electric generators and air compressors were also leased in order to provide cooling and lighting, as necessary from the morning of March 12.

**Figure 3.3.1 Comprehensive disaster-preparedness drill (2010)**

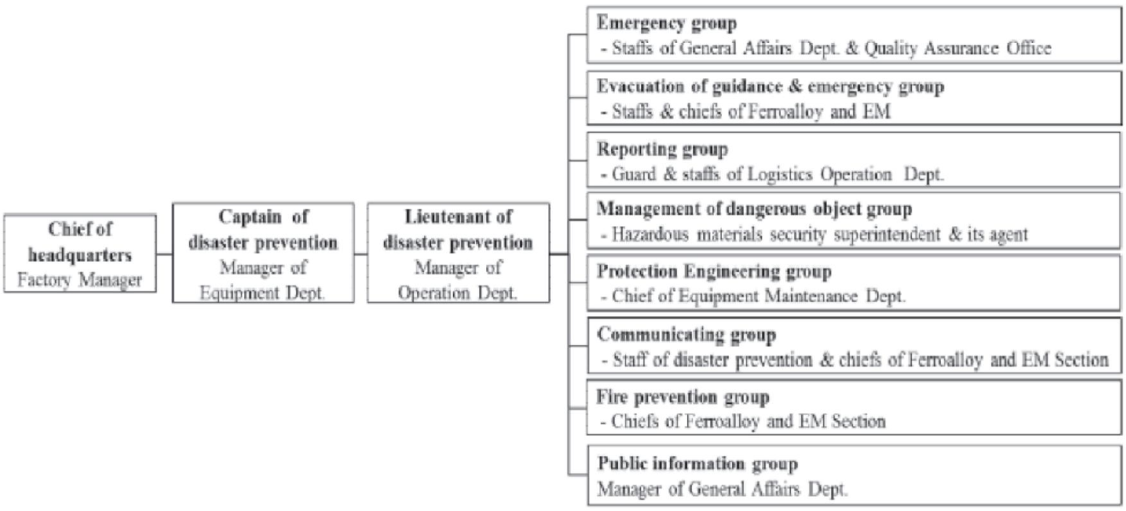


**Figure 3.3.3:** Disaster prevention scheme

**Table 3.3.2:** Confirmation items addressed at meetings

| | **Confirmation items** |
|---|---|
| **Morning** | (1) Restoration work for the day<br>(2) Safety precautions and disaster prevention<br>(3) Other notes |
| **Evening** | (1) Restoration progress for the day<br>(2) Schedule for the following day |

## 4. DISASTER RECOVERY

### 4.1. Electricity

Figure 4.1.1 shows the power system diagram for the Kashima works. We have two electrical lines which carry 33 kV to KF-1, KF-2 and EM. If one of these two lines is out of order, it can receive electricity via another high voltage line used for pumping cooling water and other purposes. The power transformer for KF-2 tripped because the induction disk relays (manufactured in 1973) malfunctioned as a result of the quake.

Figure 4.1.2 shows extensive damage to the electrical transmission facility at the central electrical substation.

The electrical transmission facilities of KF-1 are located on the 2nd floor of a two-story building. During the quake, a load of nearly 500 ~1500 kg (stress) was exerted on the terminal area and the material structure of this equipment via the connected conductors.

This caused the connecting wires to disconnect, breaking the switch and allowing the dielectric oil in the insulator of the OF cable to leak out.

Figure 4.1.3 shows how restoration work was carried out. The broken insulator was found to have been caused by the lack of a seating face and the cracking of the joint connecting the metal flange and the insulator. The cracking area was filled using an epoxide paste with a high electrical insulation rating and temporary packing was used to repair the sealing area.

In addition, since large aftershocks were still occurring frequently, each rack of equipment was coupled together and firmly secured in place to prevent any recurrence of the previous problems (figure 4.1.4).

These problems were all repaired within two weeks. At the end of April, we exchanged the temporary insulator for the correct type of insulator and analyzed the oil in the transformers to confirm that all was normal.

### 4.2. Utilities

Before restoration of the industrial water line was completed, we used water transported in from outside using cement mixer vehicles (figure 4.2.1) and cooled the bottom of the furnace using air compressors (figure 4.2.2).

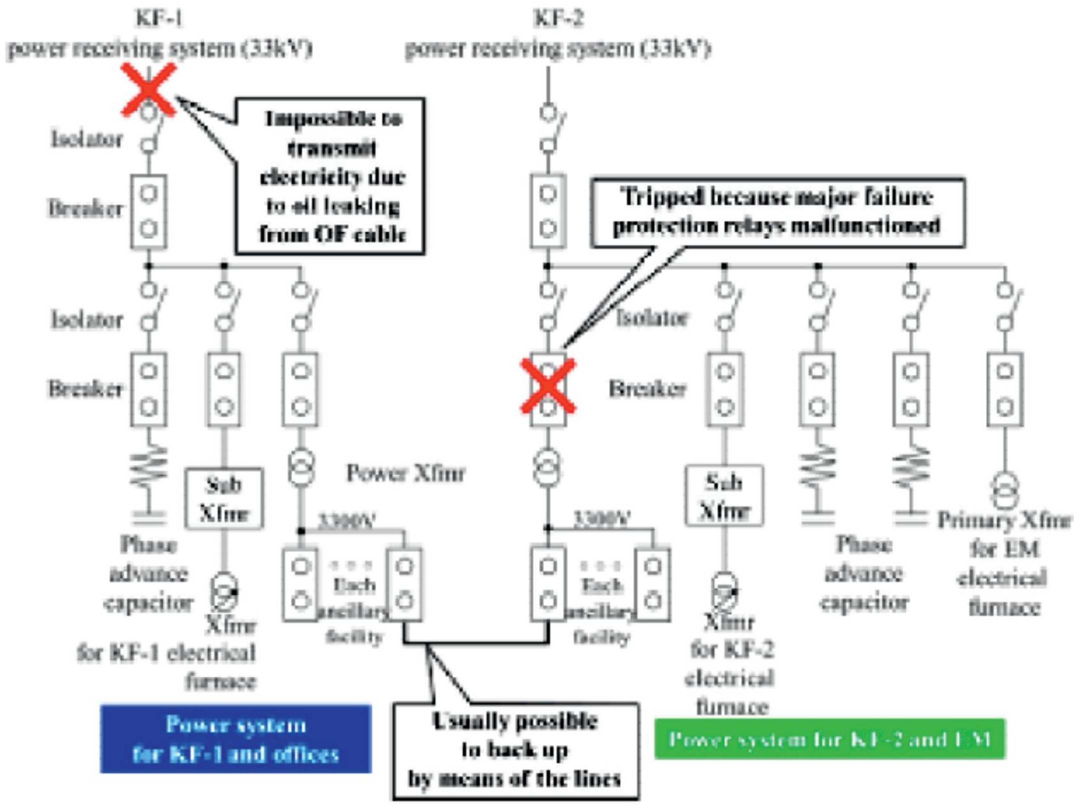


**Figure 4.1.1:** Power system diagram

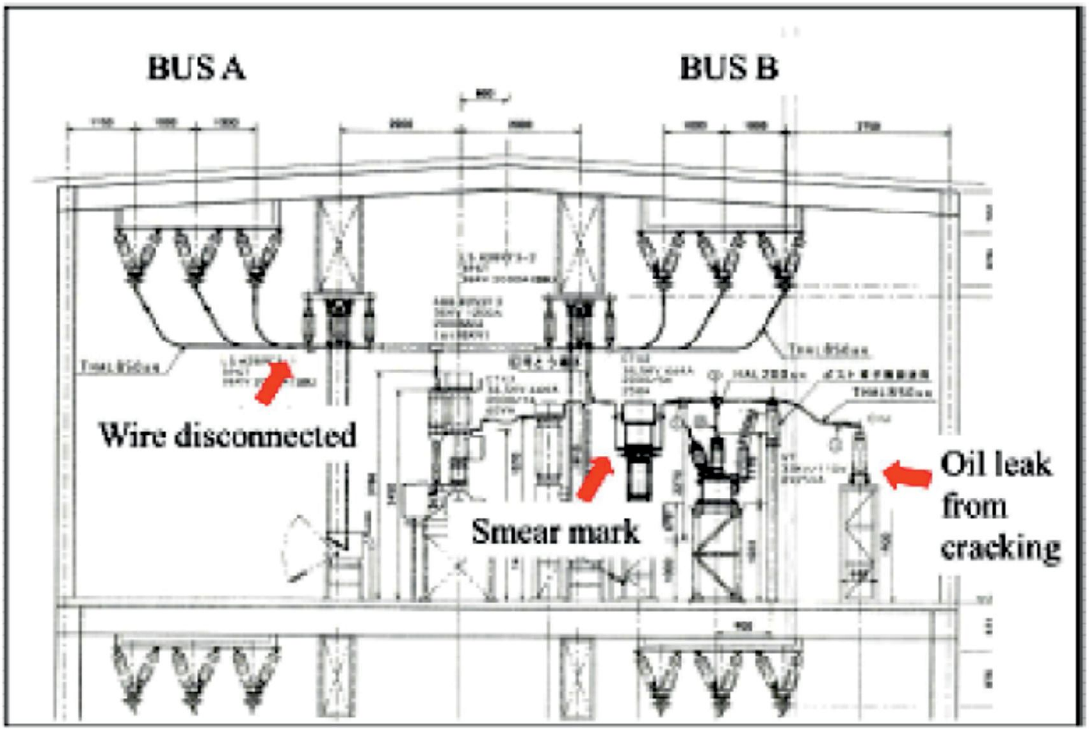


**Figure 4.1.2:** Damages of the electrical transmission facility at central electrical substation

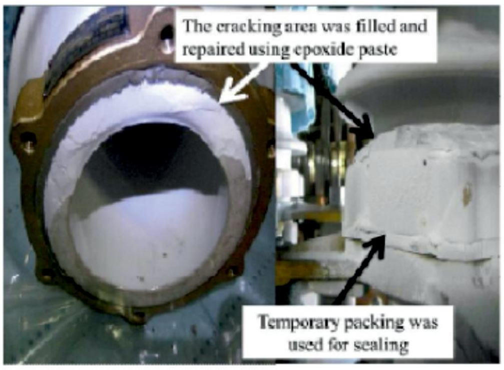


**Figure 4.1.3:** OF cable insulator

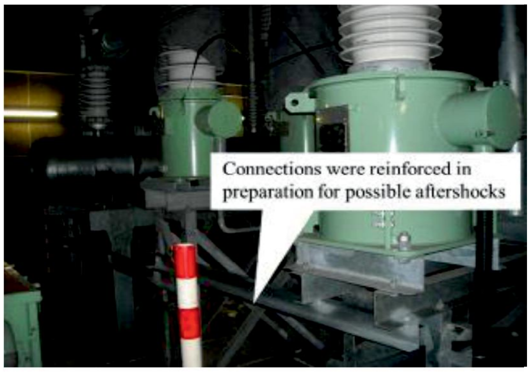


**Figure 4.1.4:** Current transformer base

**Figure 4.2.1:** Cement mixer vehicles

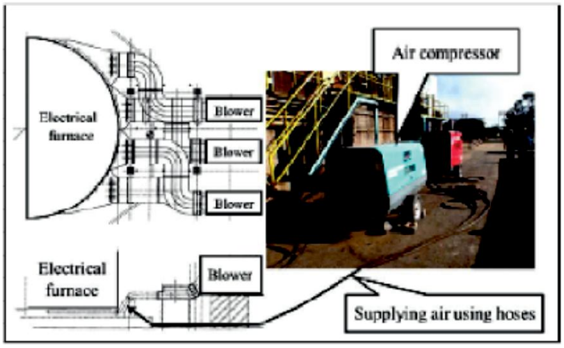


**Figure 4.2.2:** Air compressors

## 4.3. Equipment

Figure 4.3.1 ~ 4.3.3 shows the damage to various items of equipment. We decided to repair these in order of priority, as necessary, to restart operation of the furnaces.

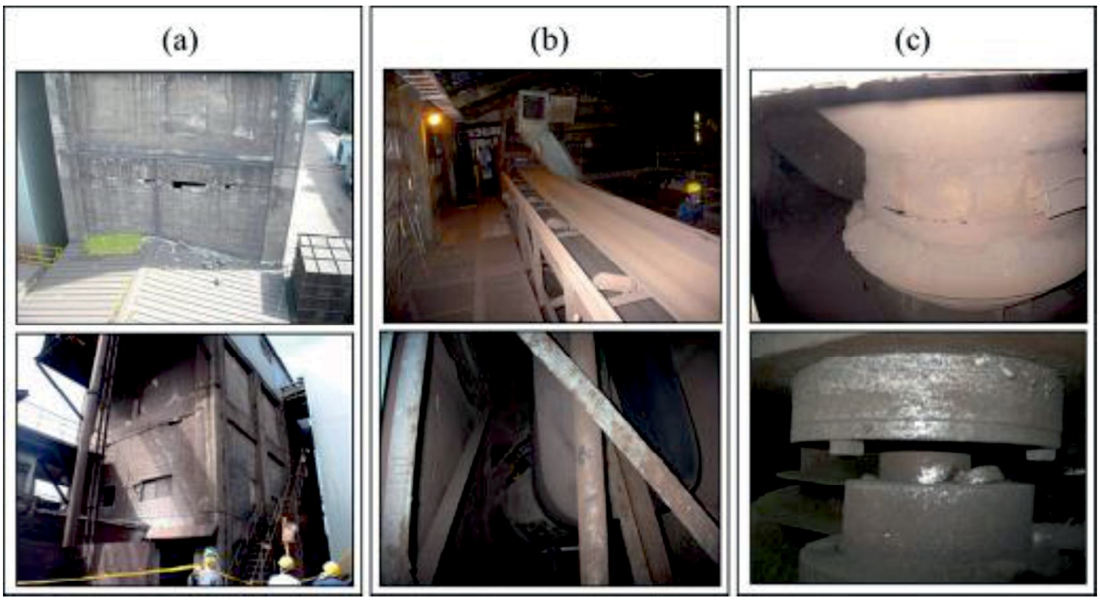


**Figure 4.3.1:** The damage of (a) outer wall of material storage tank, (b) raw materials conveyor, (c) bin above the material furnace

In figure 4.3.3, the left-hand pictures show the damaged bolts supporting the bracing in the furnace building. The middle pictures show the deformation of the dust-catching hood, while the right-hand pictures show the analytical laboratory after the quake.

In figure 4.3.1, the upper left-hand picture shows the partially collapsed wall of the material storage area, while the middle picture shows the derailment of a truck on a raw materials conveyor belt. The right-hand pictures in figure 4.3.1 show cracking in the cushion of the bin above the furnace and damage to the load detection device.

In figure 4.3.2, the left-hand pictures show the partially collapsed outer wall of the office and the broken braces inside. The middle pictures show the damage caused to the insulation around the electrodes and deformation of the supporting pipe used to measure the temperature at the center of the electrode. The right-hand pictures show uneven subsidence around the base of the gas facilities.

In figure 4.3.3, the left-hand pictures show the damaged bolts supporting the bracing in the furnace building. The middle pictures show the deformation of the dust-catching hood, while the right-hand pictures show the analytical laboratory after the quake.

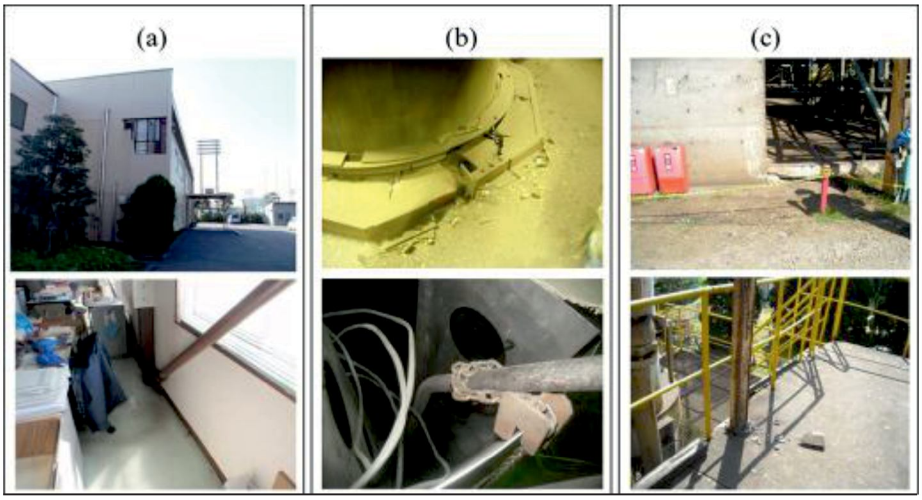


**Figure 4.3.2:** The damage of (a) office building, (b) Eelectrode facility, (c) gas facility

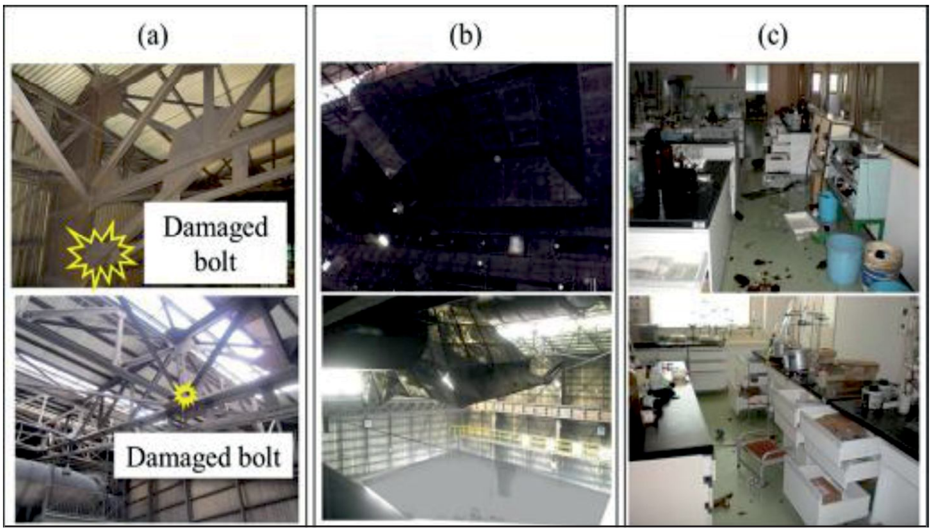


**Figure 4.3.3:** The damage of (a) KF-1 roof truss,
(b) dust-catching hood, (c) analytical laboratory

### 4.4. Time schedule for restoration

Table 4.4 shows the time schedule for restoration, from March 11 (when the disaster occurred) to March 25 (when all the furnaces restarted normal operation).

We started restoration work the day after the disaster. On March 18, seven days after the initial disaster, we were able to restart EM operation. On March 22, 11 days after the disaster, KF-2 was able to restart operation and, finally, on March 25, two weeks after the disaster, KF-1 was able to restart operation.

### 4.5. The process used to change the wall temperature in KF-1

Figure 4.5 shows the process used to change the wall temperature in KF-1. KF-1 was initially able to receive electricity normally just after the disaster. However, on the day after the earthquake, we found dielectric oil leaking from the receiving cable and had to cut the electricity supply. As a result, we were unable to cool the furnace body normally using blowers.

As shown in figure 4.2, however, we were still able to cool the main body of the furnace and lower its temperature, according to plan.

**Table 4.4:** Time schedule for restoration work

| Item \ Date | | March | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | |
| **Earthquake occurrence/evacuation** | | ◎ | | | | | | | | | | | | | | | |
| **Temporary installation of power generators and furnace cooling facilities** | | | | | | | | | | | | | | | | | |
| **Temporary installation of nitrogen, oxygen gas, etc.** | | | | | | | | | | | | | | | | | |
| **Restoration of industrial water facilities** | | | | | | | | | | | | | | | | | |
| **Restoration of KF-2 power supply facilities** | | | | | | | | | | | | | | | | | |
| **Restoration of KF-1 power supply facilities** | | | | | | | | | | | | | | | | | |
| **Repair of other facilities** | | | | | | | | | | | | | | | | | |
| **Restart operation of each furnaces** | **EM** | | | | 175 hrs | | | | | | | | | | | | |
| | **KF-2** | | | | 265 hrs | | | | | | | | | | | | |
| | **KF-1** | | | | 338 hrs | | | | | | | | | | | | |

## 5. LESSONS LEARNT FROM THE DISASTER AND PLANS FOR THE FUTURE

To ensure that we are a truly disaster-resistant factory, we need to be able to successfully accomplish the following:

1. Collect and transmit information more effectively. We're considering introduction of mobile PCs and satellite phones because the collection and transmission of information was delayed especially just after the quake.

2. Ensure that utilities, such as the electricity supply, etc., always function properly. It was difficult to find dynamo-electric generators to lease immediately after the quake. The installation of emergency power generators is scheduled to be completed by September 2013.

## 6. CONCLUSION

During this disaster, we experienced only property damage and no lives were lost. We were able to make efficient use of the simultaneous announcement system and the emergency contact system.

With help from these systems, and by making full use of "Genba-ryoku" (highly disciplined workmanship), we were able to restart operation of our four furnaces earlier than any other plants in the Kashima industrial area.

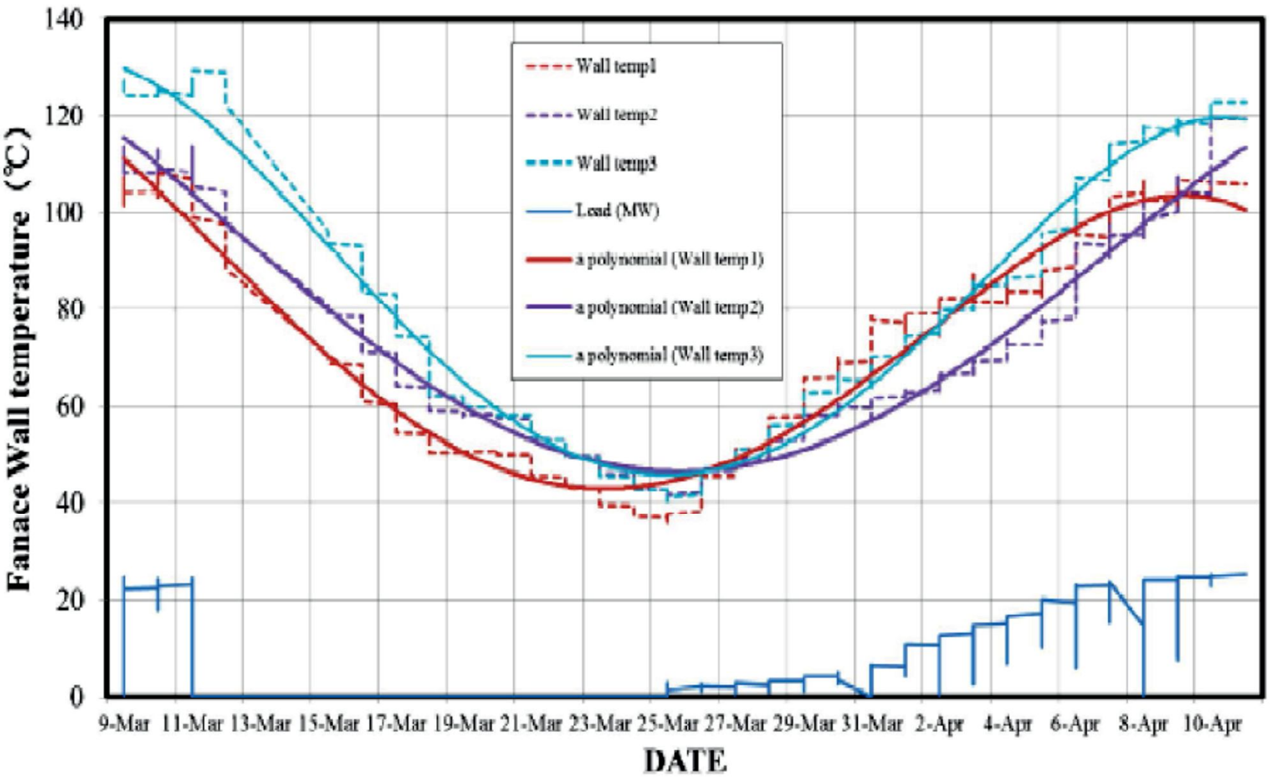


**Figure 4.5:** The relation of wall temperature and load

However, we found that some aspects of our operations still needed improvement. We will deal with these problems and implement the necessary improvements in order to become a truly disaster-resistant factory.

## 7. REFERENCES

[1] Japan Meteorological Agency Homepage, www.jma.go.jp
[2] Kashima City Official Homepage, www.city.kashima.ibaraki.jp