CHEMICAL ENGINEERING TRANSACTIONS
VOL. 31, 2013
Guest Editors: Eddy De Rademaeker, Bruno Fabiano, Simberto Senni Buratti

ISBN 978-88-95608-22-8; **ISSN** 1974-9791

A publication of
AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

DOI: 10.3303/CET1331086

Lessons Learned by the Strong Local Earthquake at the Petrochemical Plant

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On 11 and 12 April, 2011, unexpected strong local earthquakes stroke petrochemical plants in Fukushima Prefecture. That local earthquake is caused by the old active fault near the plant activated by the Great East Japan Earthquake. The plants were attacked by the Great East Japan Earthquake, and all facilities of the plant had been stopped since 11 March, 2011. In spite of having received twice earthquakes (especially the bigger second local earthquake), damages of main facilities of the plant were little. The investigation team constituted by specialists of material safety, plant engineering and engineers of that petrochemical company, searched the damage of the facilities and emergency response, and recovery efforts. We summarized the lessons learned from the large earthquake of the chemical plant, related with the emergency correspondence and its organization, support for surrounding, recovery and reconstruction program, etc.

1. Introduction

On March 11, 2011, the Great East Japan Earthquake and subsequent tsunami caused extensive damage to eastern Japan. The tsunami damage in particular, including images of victims, was reported around the world, along with footage of the damage to the nuclear power stations in Fukushima Prefecture. On the other hand, it is not widely known that chemical plants in Fukushima Prefecture were extensively damaged by a subsequent powerful local earthquake having peak ground acceleration measuring 509 Gal. A chemical plant suffering earthquake-related damage has no historical precedent anywhere in the world. Examination and reporting on the state of damage is highly important for consideration of future earthquake countermeasures for chemical plants.
The Japan Society for Safety Engineering started focusing attention on chemical plants immediately after the Great East Japan Earthquake. In this paper, we report on a survey conducted with the cooperation of KUREHA Corporation, a company that suffered damage from the local earthquake.

2. State of Damage to the Chemical Plants

2.1 The Great East Japan Earthquake

- Time of occurrence: 14:46, March 11, 2011 (Friday)
- Earthquake parameters: Off the Sanriku coast; magnitude 9.0 (as reported by the Japan Meteorological Agency (JMA))
- Seismic intensity: 6+

Please cite this article as: Wada Y., Wakakura M., Hayashi Y., Takagi N., Oba H., Kumasaki M., Miyake A. and Arai M., 2013, Lessons learned by the strong local earthquake at the petrochemical plant, Chemical Engineering Transactions, 31, 511-516 DOI: 10.3303/CET1331086

- Seismic motion: 310 Gal (KUREHA Corporation measurement)
- State of damage: No tsunami damage (5 to 6 m above sea level, 2 km from the coastline)
  Increase of approximately 50 cm in the water level of channels within the plants
- Human injuries: One person suffered facial lacerations from glass fragments due to the explosion of a hydrogen gas holder pipe. One person fell down the stairs due to an oil leak.
- Property damage: Discussed below
- Damage to utilities:
  - Electricity: Power outage immediately after the earthquake, restoration at 15:21
    Damage to a private power generator, outage until the end of April
  - Industrial water supply: No stoppage, used as clean water after purification
  - Tap water supply: Stoppage until March 14
  - Instrument air supply: Stoppage, restoration at 17:00
  - Steam: Boiler damage, restoration at the end of April
    Restoration at 24:00 on March 11 using a package boiler
  - Nitrogen: No stoppage
  - Mobile phones: Communication difficulties for approximately 1 week
  - Fixed-line phones: No service outage
  - Wireless: Service available

2.2 Earthquakes of April 2011

- Time of occurrence: 17:16, April 11, 2011 (Monday)
- Earthquake parameters: Hamadori, Fukushima Prefecture; magnitude of 7.1 (as reported by JMA)
- Seismic intensity: 7
- Seismic motion: 410 Gal (KUREHA Corporation measurement)
- Time of occurrence: 14:07, April 12, 2011 (Tuesday)
- Earthquake parameters: Hamadori, Fukushima Prefecture; magnitude of 6.3 (as reported by JMA)
- Seismic intensity: 7
- Seismic motion: 509 Gal (KUREHA Corporation measurement)
- State of damage: No tsunami damage
- Human injuries: One person suffered a fractured little finger while attempting to avoid a falling shelf
- Property damage: Discussed below
- Damage to utilities:
  - Electricity: Power outage after the earthquake, restoration at 15:00 on April 12
  - Industrial water supply: Supply disrupted due to stoppage of a Fukushima Prefecture water intake pump
    Small amount of water reserved within the plants
  - Tap water supply: Stoppage until April 13
  - Instrument air supply: No abnormality
  - Steam: Restoration on April 12 using a package boiler
  - Nitrogen: No stoppage
  - Mobile phones: Difficulty in establishing connections
  - Fixed-line phones: No service outage
  - Wireless: Service outage due to damage to a wireless base station

The earthquakes of April 11-12 were located nearly directly beneath the chemical plants. It is thought that a fault located to the west of the plants became active due to the effects of the March 11 earthquake.

3. Status of Response During the Earthquakes

3.1 The Great East Japan Earthquake

14:46: All equipment except the boilers shut down due to the earthquake. This is because there was a rule to shut down the chemical plants in the event of seismic motion of 150 Gal or higher. Equipment set up for automatic shutdown also shut down without incident. The boilers shut down due to pipe damage.

14:49: The company set up a response headquarters. Daily meetings were held until May, and the headquarters remained until July 21.

14:58: The company set up a field command headquarters near the site of the hydrogen explosion. During a period of 20 to 30 minutes, the company completed measures to shut down facilities, a site inspection, and employee safety assurance measures. At that time, since mobile phone service was unavailable, the company used wireless communication.

3.2 Earthquakes of April 2011

Since the chemical plants had already stopped operating due to the Great East Japan Earthquake, no emergency measures were taken.

4. Response at the Time of Earthquake

4.1 Facilities

- Shutting down the plants and conducting inspections are standard practice for the company in the event of seismic motion of 150 Gal or more.
- The company had conducted a ground survey on the premises and made prioritized improvements for earthquake countermeasures based on risk assumptions.
- An automatic shutdown function using a seismic sensor had been installed on a heating furnace
- A distributed control system (DCS) was used for the display and notification of seismic measurements.
- The company had conducted impact analysis concerning the loss of utilities on key facilities.
- The company had compiled ground survey results and utilized them in earthquake countermeasures.

4.2 Crisis management system

- The company set up both response and field command headquarters.
- The necessary items for a business continuity plan (BCP) had already been decided.
- States of emergency at chemicals plants were defined as utility stoppage, abnormal events, and earthquakes.
- The company had granted a foreman prioritization of plant shutdown over automatic shutdown.
- The company bylaws had pre-established emergency vehicle and employee evacuation routes.
- The company had, at its own discretion, made decisions about the shutdown of emergency cutoff valves and the entire business site according to the risks associated with the circumstances.
- In the absence of management and authority during an emergency, the order of delegated authority in 60 management-level employees had been decided.
- Disaster scenarios had been reflected in emergency response planning.
- The spread of damage in the event of fire or explosion accident had been taken into account.

4.3 Trainings

- The company had examined individual emergency responses for each plant and conducted training.
- The company had conducted education and trainings on the basis of scenarios of likely eventualities.
- The company had conducted surprise trainings for scenarios that were only disclosed immediately before the trainings (not random scenarios).
- The company had conducted media response education and trainings.

5. Lessons Learned

5.1 Successes

- Since there was a rule that managers and employees of key sections had to report to work in the event of an earthquake with seismic intensity of 5- or higher, the necessary employees assembled on-site after the earthquake.
- Since it was difficult to obtain food, the provision of meals at the employee cafeteria was effective for carrying out repair work. It is likely that the food environment was better at work than at home. Meals were also provided to employees of affiliated companies.
- The local area has a strong sense of community, and the employees actively cooperated.
- Prompt restoration of the power supply contributed to rapid plant restoration.
- Continuity of nitrogen supply contributed to safety assurance. It was good that the company had set up a nitrogen manufacturing facility on an adjacent site in cooperation with a gas manufacturer and maintained a liquid nitrogen supply.
- Since a refrigerated vehicle was supplied by a manufacturer, refrigeration of catalytic chemicals requiring cold storage was possible. The company implemented the securing of refrigerator trucks in its future earthquake countermeasures.

5.2 Failures

- Assumption of emergency scenarios and risk identification were insufficient.

- The emergency communication network involving telephones and mobile phone mail did not function adequately because of the damage to telephone lines.
- The company had been systematically conducting seismic reinforcement construction. Although this was effective for facilities for which construction had been completed, there was damage to facilities that had not yet been reinforced.
- As liquefaction prevention measures, differences became clear in the state of damage between friction piles and end-bearing piles and between pile foundations and spread foundations.

5.3 Matters for Consideration

- Securing of utilities, particularly nitrogen gas and water supply, is important.
- It is necessary to expedite seismic reinforcement and countermeasures for aging facilities.
- It is necessary to increase the frequency of inspections of safety valve effectiveness.
- It is necessary to consider measures to maintain refrigeration for catalytic chemicals requiring cold storage (organic peroxide).
- It is necessary to review the emergency communication network for contacting employees.
- It is necessary to consider alternate means of communication (such as satellite telephony) in cases where mobile phones and wireless communication fail.
- Imagine emergency scenarios and re-examine risks.
- Since boiler pipe damage was apparent, consider earthquake countermeasures for boiler pipes.

6. Others

- In the numerous aftershocks following the Great East Japan Earthquake, no major damage or leaking of dangerous substances occurred.
- Although the company possessed chlorine gas, measures implemented at the time of a chlorine gas leak accident 40 years ago were effective.
- It was fortunate that the Great East Japan Earthquake occurred during a shift change when twice the usual number of employees were on-site.
- The company president issued a companywide announcement that he would delegate complete authority for restoration of the chemicals plants to the field offices. As a result of this announcement, the chain of command was clearly defined and restoration work progressed.
- Although the April earthquake entailed more powerful vibrations, since the plants had been shut down due to the Great East Japan Earthquake, there was little damage.
- The earthquake resistance of the chemicals plants was high, and judging from the example of other chemicals plants, much of the damage is presumably attributable to the tsunami.
- The strong cooperation with business partners was effective in restoration activities.
- The opening of the hospital attached to the chemical plants and the provision of bathing facilities at the chemical plants, as well as numerous other social contributions and employee volunteer activities enhanced the company's corporate image.

7. State of Damage to Facilities

Whereas the Great East Japan Earthquake struck while the chemical plants were in operation, the April earthquakes struck when the plants were shut down for repair work. The table below indicates the number of earthquake restoration work tasks following the Great East Japan Earthquake and April earthquakes.

Table 1: Number of Earthquake Restoration Work Tasks

	Plant A	Plant B
The Great East Japan Earthquake	77	68
Earthquakes of April 2011	138	97

The table shows that the amount of damage caused by the April earthquakes with powerful vibrations was higher.

7.1 State of damage from the March earthquake

Figure 1 Damage to column base braces and detachment of pipes and automatic valves

Figure 2 Damage to pipes in the upper section of a container and a hydrogen pipe holder due to pipe damage

Figure 3 Damage to exterior walls and glass windows from a hydrogen explosion and the steel pipe brace welds of a 2,000 t tank

Figure 4 Road caving due to liquefaction and road subsidence below pipe racks due to liquefaction (no damage on the pile foundation pipe racks themselves)

7.2 State of damage from the April earthquakes

Figure 5 Uneven settlement of the base of a 2,000 kL heavy oil tank and pipe stress due to uneven settlement

8. Conclusion

The company had been systematically conducting seismic reinforcement construction since before the Great East Japan Earthquake, and this can be considered a primary reason for the absence of major damage. In addition, soundness was demonstrated in nearly all of the facilities that meet current quake-resistance standards in laws applying to chemicals plants in Japan, such as the Building Standards Act, the High Pressure Gas Safety Act, and the Fire Service Law.

However, in view of the tendencies found in the damage situation from these earthquakes concerning plant piping, tank foundation, and liquefaction and uneven settling of the ground in particular, earthquake countermeasures should be reinforced. Factors such as the importance of the facilities and the dangerousness of the substances handled should be taken into consideration. Additionally, vibration countermeasures such as methods for pipe repair and support should be reviewed taking earthquake-resistant design, configuration, and strength into account.

Acknowledgement

We appreciate the cooperation by KUREHA Corporation and Iwaki Factory. We also appreciate the support by the Japan Society for Safety Engineering.