Effects of the Large-scale Earthquake and Tsunami on an LNG Receiving Terminal

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1. Introduction

On March 11, 2011 the largest earthquake ever recorded in Japanese history (magnitude 9.0) with an epicenter located off the Pacific coast of the Tohoku region shook a wide area of Japan (from the Tohoku region to the Kanto region) with a maximum seismic intensity of 7 on the Japanese scale of 0 to 7. The earthquake was followed by a tsunami far beyond all prior expectations. This Great East Japan Earthquake and the subsequent tsunami caused huge damages centered on the Tohoku region, with the loss of many precious lives and the destruction of buildings and other property. This great earthquake and tsunami was also the first to cause serious damage to a Japanese city gas business LNG receiving terminal.

This paper presents a detailed report of the damages to this LNG receiving terminal (the Sendai City Gas Bureau Minato Works) from the earthquake and massive tsunami of a scale beyond all expectations, describes the emergency recovery and restoration efforts, and notes what can be learned from this experience.

2. Outline of the Great East Japan Earthquake

The earthquake occurred at 2:46 p.m. on March 11, 2011 with an epicenter approximately 130km east-southeast from the Oshika Peninsula of Miyagi Prefecture (offshore the Sanriku coast) at a depth of approximately 24 kilometers. A maximum seismic intensity of 7 on the Japanese scale of 0 to 7 was observed, and violent swaying continued for around 2 minutes. This was a magnitude 9.0 quake, surpassing the 1923 Great Kanto Earthquake (magnitude 7.9) to be the most powerful earthquake ever recorded in Japan and the fourth most powerful ever recorded worldwide. The earthquake triggered huge tsunami waves which traveled up to around 6 kilometers inland, took many lives, and destroyed many buildings and other property. The height of the tsunamis was also unprecedented, reaching a maximum run-up height of about 40 meters in Miyako City, Iwate Prefecture.

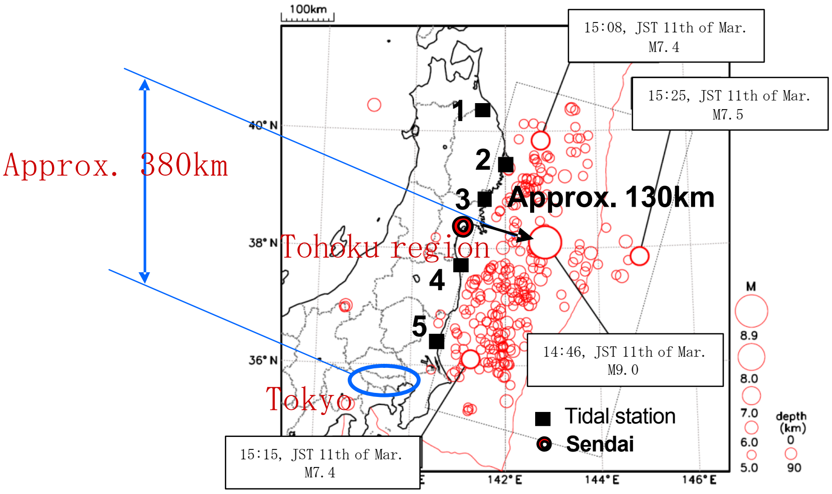


Fig. 1 Outline of the Great East Japan Earthquake

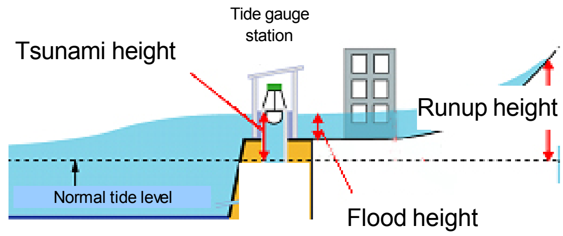


Fig. 2 Definition of Tsunami Height, Etc.

Table1　Observed value at each tidal station

		First wave		maximum wave	
1	Hachinohe	－0.8m	15:22, 11 th	2.7m and over	16:51, 11 th
2	Miyako	＋0.2m	14:48, 11 th	6.3m	15:12, 11 th
3	Kamaishi	－ 0.1m	14:45, 11 th	6.8m	15:12, 11 th
4	Kesennuma	(+) 6.0m	14:54, 11 th	6.0m	15:14, 11 th
5	Souma	＋0.3m	14:55, 11 th	7.3m and over	15:50, 11 th
6	Oarai	＋1.8m	15:15, 11 th	4.2m	16:52, 11 th

< The Japan Metrological Agency HP >

3. Damages to the LNG Receiving Terminal

(1) Outline of the Sendai City Gas Bureau Minato Works

The process flow through the main facilities is presented in Figure 3. The gas supply process comprises this LNG gasification system and a natural gas high-pressure system from inland, with a supply ratio of around 7 to 3.

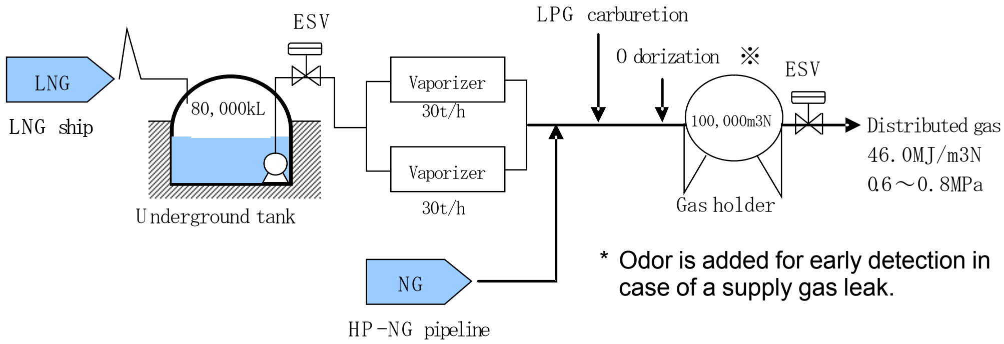


Fig.3 Process flow of Minato LNG terminal

(2) Damages

Although a seismograph inside the works measured a maximum ground acceleration of 615 gal, the production equipment—which was designed based on seismic design

standards—suffered almost no damages from the earthquake. The production equipment did suffer extensive damages from the tsunami flooding, which reached a maximum height of 3-4 m. There was no loss of life, LNG leaks or other secondary damage.
The initial response following the earthquake and tsunami was as follows. Immediately after the earthquake, the commercial electric power supply shut down, the backup power supply turned on, and production was safely suspended. Preparations were then made to resume production by starting up the emergency power supply facilities, but a tsunami struck one hour after the quake. With the tsunami, the resumption of production was immediately abandoned and the LNG storage tank and other emergency shut-off values were closed remotely to prevent secondary damages. The flooding continued for about 1 hour.

Fig. 4 Damage from the Tsunami

The area flooded by the tsunami reached as far as 4 km inland. While the flooding only covered a portion of the Sendai City Gas Bureau supply area, the Minato Works (98,000 m^2) were completely underwater.
With the suspension of production, the gas supply to over 300,000 households was cut off.

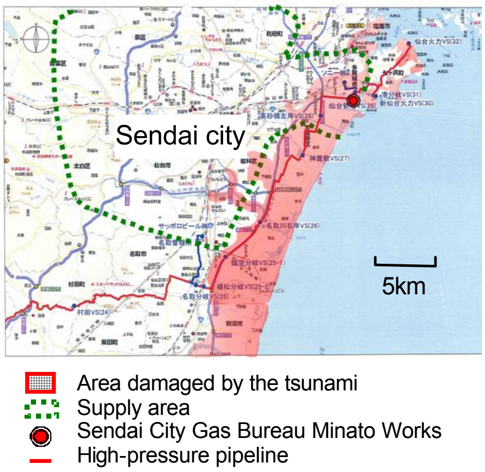


Fig. 5 Area Flooded by the Tsunami

1) Main Facilities Damaged by the Tsunami

(a) Buildings and Equipment

The damages to indoor equipment (power receiving equipment and substation, instrumentation and ventilation equipment, boiler, LNG receipt monitoring equipment, truck shipment monitoring facilities, etc.) and buildings included severe damages to a doorway (Fig. 6) and the loss of functions as a result of flooding via air vents and other building openings (Fig. 7).

Fig. 6 Damaged Door


Fig. 7 Damaged Building

Fig. 8 Scouring of Piping Framework


Fig. 9 Deformed Piping

(b) Structures with Shallow Foundations

The piping framework which has a shallow foundation collapsed from scouring in some areas (Fig. 8) and piping that was not fixed to the framework floated and was deformed (Fig. 9). The truck shipment monitoring building, which has a shallow foundation, was washed away (Fig. 10).


Fig. 10 Washed Away Building

Fig. 11 Road Scouring

(c) Outdoor Facilities, Etc.

The extent of the scouring was severe at locations where the tsunami flow concentrated (Fig. 11). Most of the site gauges were flooded, and could not be used. The flooded valves failed because of salt and fine sand in their actuators.

2) Facilities Not Damaged by the Tsunami

(a) Receiving Facilities

The berth facilities (which have a steel-pipe structure) were sound, including the loading arm. The BOG compressor was at an altitude higher than the tsunami, and avoided flooding. The seawall had no liquefaction damage and maintained its function.

(b) LNG Storage Tanks

The tanks were sound as they were on ground higher than the flooding level. Tanks were partially submerged at other gas utilities, but there were no damages.

(c) LNG Vaporizer

Some of the equipment was flooded, but there were no damages. At another gas company, heat exchanger panels were damaged from being struck by floating debris.

(d) Pile Foundation Piping, Etc.

While there was scouring around the piping framework and pipes, the functions were maintained.

(e) Odorization Equipment

The odorization room, which is designed not to leak offensive odors, uses highly airtight doors and has no open areas, so the structure prevented flooding. This provided useful information for building flood prevention measures.

4. Emergency Recovery of the LNG Receiving Terminal Functions

It was determined that the complete recovery (restoration) of the Minato Works would take a substantial amount of time for the replacement and repair of equipment that was flooded and damaged. So a high-pressure natural gas pipeline (Fig. 12) and temporary LNG regasification equipment were used for the early restoration (emergency restoration) of supply.

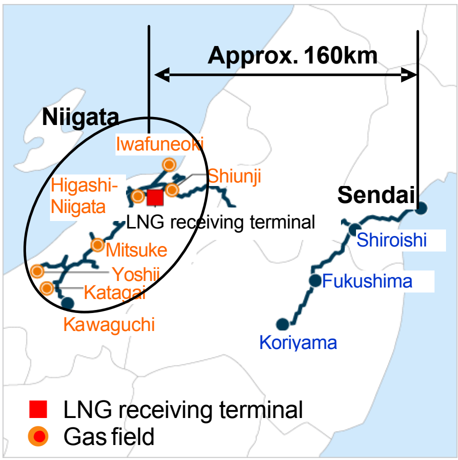


Fig. 12 High-pressure gas pipeline

(1) Emergency Recovery Using a Natural Gas High-pressure Pipeline

Since the natural gas high-pressure pipeline and the facilities required for emergency restoration of supply within the Minato Works (piping, odorization equipment, etc.) were confirmed to be sound, while conducting safety measures within the Minato Works and implementing emergency measures for the minimum necessary monitoring from the control room, which was undamaged, gas supply was resumed using gas from the natural gas high-pressure pipeline. This took place on March 23, 12 days after the Minato Works were damaged. It took 35 days, until April 16, to resume supply to all of the approximately 300,000 users whose gas had been cut interrupted by the earthquake.

1) Safety Measures

a) LNG Tank Boil-Off-Gas (BOG) Measures

To prevent the BOG generated in the LNG storage tank from mixing and being delivered together with regular gas supply, the gas was burned off using ground flare equipment while monitoring the pressure inside the tank at the control center. To confirm sound combustion (continuous combustion), equipment was installed so that the ground flare exhaust temperature could be monitored at the control center.

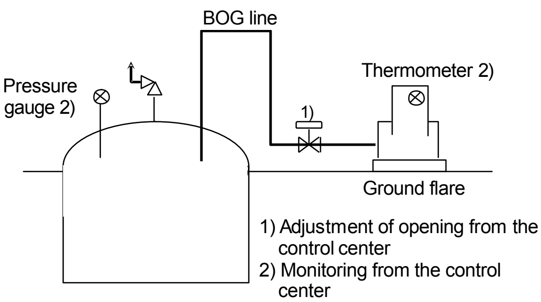


Fig. 13 LNG Storage Tank BOG Apparatus

b) Fire-extinguishing Equipment

Arrangements were made so that water from an industrial use water tank could be used in case of emergency as fire-extinguishing equipment for the emergency recovery.

2) Emergency Recovery

In arranging emergency recovery with gas from the natural gas high-pressure pipeline, the measuring instruments required for monitoring and control from the control center (receipt volumetric flow, delivery gas volumetric flow, pressure gauges, odorant input volume, etc.) were installed or restored (Fig. 14). A temporary electricity source that can operate continuously for long time periods was installed to provide the electric power required for emergency recovery safety measures and for monitoring and control from the control center (DCS control, power source for instruments).

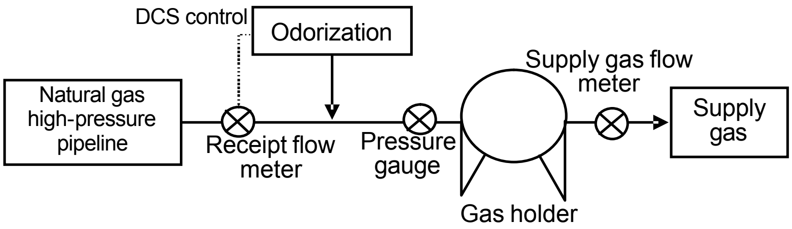


Fig. 14 Control of Natural Gas High-pressure Pipeline

(2) Emergency Recovery Using Temporary LNG Regasification Equipment

The medium-pressure gas pipes within the Sendai City Gas Bureau's supply area were not damaged by the earthquake and tsunami. For that reason, it was possible to maintain supply to users with a public nature (such as hospitals and communications companies) that receive their gas directly from medium-pressure gas pipes using the gas stored in gas holders. Since the amount stored was limited, LNG gas trucks, temporary LNG regasification equipment and odorization equipment were brought in from Tokyo (Fig. 15), set up outside the Minato Works, and gas supply was maintained.

Fig. 15 Temporary LNG regasification equipment

5. Measures for Restoration

(1) Basic Approach to Tsunami Countermeasures

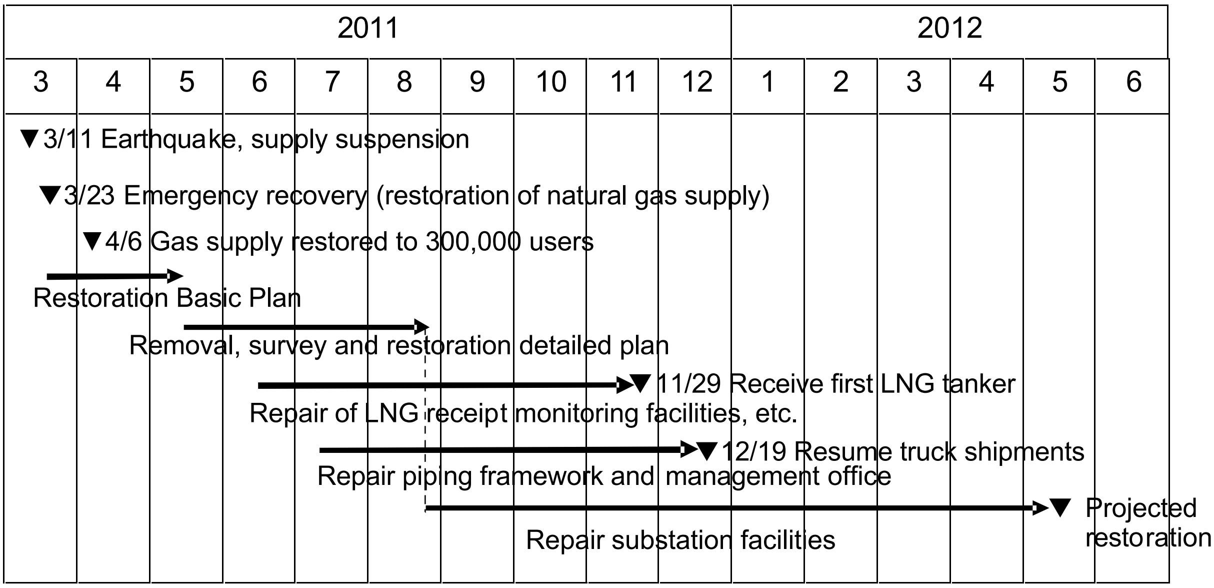
The basic approach to tsunami countermeasures was revised for the restoration based on the tsunami damage, as follows.

1) Assume the actual tsunami height this time for the design
2) Arrange certain safety measures to protect human life
3) Improve tsunami resistance at important facilities that impact early restoration

(2) Restoration Schedule

Among the works for early emergency recovery using the natural gas high-pressure pipeline, after surveys and planning for restoration of the existing production equipment, the repairs to damaged equipment and facilities and tsunami countermeasures construction works began from three months after the disaster. Nine months later, the facility began to receive LNG tankers and resumed partial LNG gas manufacturing using vaporizers and delivery via trucks. It is scheduled to take a total of 14 months from the earthquake for full recovery of LNG gas production. The critical path to recovery involved preparation of the special high-voltage power receiving equipment and other substation equipment (eight months). Because of the widespread effects of the earthquake, the sourcing of parts and materials took longer than usual.

Table 2 Restoration Schedule



(3) Facilities Improvement Measures (Tsunami Countermeasures)

The main facilities improvements being implemented as tsunami countermeasures based on the March 11 disaster are as follows.

(a) Improved Building Flood Prevention

The doors of buildings with important facilities such as the power receiving and substation equipment that became the critical path to recovery were replaced with airtight (watertight) doors like those in the odorization room (Fig. 16), and the building opening was moved to a higher location (Fig. 17). Additionally, the LNG receipt and truck shipment monitoring facilities, which had been on the first floor and suffered damages, were relocated to the second floor.

Fig. 16 Watertight Door

Fig. 17 Relocation of Building Opening

(b) Preventing Piping Framework and other Structures from being Washed Away

The piping framework foundation was changed from a shallow foundation to a pile foundation. A broad foundation base was poured (Fig. 18) and measures implemented to prevent piping from floating (Fig. 19).

Fig. 18 Foundation Base

Fig. 19 Damage from the Tsunami

A reinforced concrete design was adopted for the new truck shipment monitoring building, and other walls were reinforced by increasing the number of pillars at each facilities building(Fig. 20).

(c) Safety Measures to Protect Human Life

The evacuation area when a tsunami warning is given was changed from outside the works to on top of the management office building. A new emergency stairway (Fig. 21) was installed to secure an evacuation route for employees, construction company workers and visitors.

Fig. 20 Reinforcement of Pillars

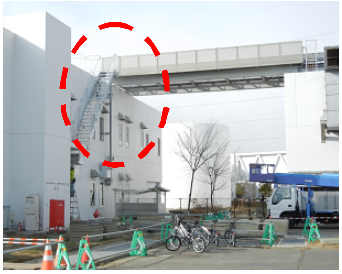


Fig. 21 Additional Emergency Stairway

6. Conclusion

In the Great East Japan Earthquake, the City of Sendai Gas Bureau Minato Works experienced the first tsunami flooding of an LNG receiving terminal, suffering large-scale damages that will take over a year until restoration. Based on this experience, the Gas Bureau is revising its basic approach to tsunami countermeasures, and drafting and implementing a restoration plan from the perspectives of protecting human life and improving tsunami resistance.

Our report should provide a useful reference for future tsunami countermeasures at LNG bases worldwide.