G I I G N L

Lessons learned by the LNG community from earthquakes

2012

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INTRODUCTION

Several LNG facilities have been subjected to earthquakes. In this study proposed at the Executive Committee in Versailles, we wanted to make some focus on consequences of earthquakes on LNG facilities and decided to make a short track study, which aims to complement other feedbacks produced by number of companies.

This paper highlights a few important lessons learned by the LNG community from recent earthquakes in the form of key statements that are explained and justified in appendixes. The feedback clearly separates the effects of earthquakes and effects of tsunami.

This paper includes the magnitude 9.0 earthquake that occurred Friday 11 March, off the Pacific coast of the northeastern part of the Japanese main land (Tohoku Region), which was one of the largest earthquakes ever to hit Japan and the forth most powerful ever recorded worldwide in modern times, and caused unexpected large tsunami and led to devastating damages.

The next study proposal will be based on sharing design practices including feed-back after major earthquakes.

KEY STATEMENTS

Key statement #1: Earthquakes, even very large ones, have never led to major accidents on LNG facilities.

Key statement #2: Pile foundation for essential facilities is an effective countermeasure against tsunamis.

Key statement #3: Resistance to tsunamis is greatly improved by avoiding submergence of electric/system equipment (including spare facilities) through water tightness and/or adequate foundation level.

Key statement #1

Earthquakes, even very large ones, have never led to major accidents on LNG facilities.

Lessons learned:

- Even for the larger earthquakes, only minor damage of facilities of LNG terminal was observed.
- LNG facilities are able to withstand against earthquake as long as an adequate seismic design is done.
- Current seismic design standards include adequate safety margins.

Possible improvements for the LNG community / further work to be performed:

- The LNG community could benefit from a shared review of seismic design practices after major earthquakes occur.
- A more detailed investigation should be performed on the behavior of such and such type of equipment.
- It is important to review the local regulations, standards and fitness for service on the seismic design every time a large earthquake resulting in serious damages occurs.

Facts gathered from earthquakes:

- Typical damages on facilities caused by major earthquakes around the world are shown in Table 1.
- See appendix for a more detailed description.

Appendix 1	Damage vs seismic design method/standards.
Appendix 2	Detailed damages on facilities in Minato LNG terminal caused by the Great East Japan Earthquake March 11, 2011

Table 1 -Typical damages on facilities caused by major earthquakes around the world

TYPE	EARTHQUAKE NAME	TERMINAL	DESCRIPTION	TYPICAL DAMAGES ON FACILITIES
Very large earthquakes	Japan 2011	Minato LNG	Magnitude: 9.0 PGA: 615gal(0.615G)	relaxation of tie rod of gas holder
	Japan 1995	Osaka gas	Magnitude: 7.3 PGA: 818gal (0.818G)	sinkage of some small basement due to liquefaction
	Chile 2010	GNL Mejilones	Magnitude: 8.8 PGA: 780gal (0.78G)	No damage
		GNL Quintero	Magnitude: 8.8 PGA: 780gal (0.78G)	Only slight damage to one cargo unloading arm, counterweight plates were required to be adjusted. Regas operations resumed same day after power was restored.
	Samoa 2009		Magnitude: 8.1 PGA:	
	Sumatra 2007		Magnitude: 8.5 PGA: N/A	N/A
	Sumatra 2005		Magnitude: 8.6 PGA: N/A	N/A
	Sumatra 2004		Magnitude: 9.1 PGA: N/A	N/A
	Alaska 1964		Magnitude: 9.2 PGA: N/A	LNG Facilities not operational
Large earthquakes	Chile 2012	GNL Quintero	Magnitude: 6.5	No damage
	US (Virginia) 2011		Magnitude: 5.8 PGA:	
	Spain 2011		Magnitude: 5.1 PGA: N/A	No damage
	Alaska 2011		Magnitude: 6.8 PGA: N/A	No damage
	Italy 2009	GNL Italia La Spezia	Magnitude: 6.3 PGA: N/A	No damage
		GNL Italia Rovigo	Magnitude: 6.3 PGA: N/A	No damage
	China 2008		Magnitude: 7.9 PGA: N/A	N/A

Key statement #2

Pile foundation for essential facilities is an effective countermeasure against tsunamis.

Lessons learned:

- Great damage can be caused when a tsunami hits the facilities' pedestal of foundation and scrapes away ground just below the pedestal.
- The foundation are generally designed from the viewpoint of seismic not tsunami. However it is recognized that pile foundation is an effective countermeasure in terms of tsunami.

Possible improvements for the LNG community / further work to be performed:

- The LNG community could benefit from sharing methods to assess the likelihood of a tsunami on a facility.
- Practical design of relevant foundation for tsunami mitigation should be discussed for facilities where a large tsunami can occur.

Facts gathered from tsunamis:

- Typical damages on facilities caused by major tsunamis around the world are shown in Table 2.
- See appendix 2 for a more detailed description.

Table 2 -Typical damages on facilities caused by major tsunamis around the world

EARTHQUAKE NAME	TERMINAL	DESCRIPTION	TYPICAL DAMAGES ON FACILITIES
Japan 2011	Minato LNG	approximately 4 m and over above usual tide level	Facilities supported by pile foundation were not damaged. On the other hand, facilities such as small size piping unsupported by pile foundation were greatly damaged, but the damage did not cause LNG leakage.
Sumatra 2004	Osaka gas	approximately 1m above usual tide level	No damage of facilities
Chile 2010	Mejilones	approximately 0.5m from usual tide level	No damage of facilities GNLM took the decision to disconnect and send the ship far away from the terminal

Key statement #3

Resistance to tsunamis is greatly improved by avoiding submergence of electric/system equipment (including spare facilities) through water tightness and/or adequate foundation level.

<u>Lessons learned:</u>

- Buildings to store electric/system equipment shall have water-tightness and/or foundation level of electric/system equipment shall be raised above the height of tsunami
- Spare facilities of electric motors etc. should be prepared and stored above the height of tsunami.

<u>Possible improvements for the LNG community / further work to be performed:</u>

- The LNG community could benefit from sharing methods to assess the likelihood of a tsunami on a facility.
- Practical design of relevant foundation for tsunami mitigation should be discussed for facilities where a large tsunami can occur.

<u>Facts gathered from tsunamis:</u>

- Typical damages on facilities caused by major earthquakes around the world are shown in Table 2.
- See appendix 2 for a more detailed description.

CONCLUSION

Despite the fact that very large earthquakes have hit areas where LNG facilities are located, no severe damage on such facilities was found, which verified that the current seismic design standard was adequate (Japan, Chile, Samoa, Sumatra, Alaska, US, Spain, Italy, China)

On the other hand, in locations where large tsunamis are likely to occur, specific countermeasures against tsunami should be considered in the design of LNG facilities not to lead to gas outage.

APPENDIX

APPENDIX 1 -Damage vs seismic design method/standards

TYPE	EARTHQUAKE NAME	TERMINAL	detailed description of damage		Brief description of the methodology			
			what type of equipment ?	what sort of deformation?	Reference of the relevant standards / regulations	requirements (operability, safety, no accident etc.)	elasticity/plasticity to satisfy requirements	safety devices
Very large earthquakes	Japan 2011	Minato LNG	tie rod of gas holder	elasticity (relaxation)	Japan standard =safe shutdown of EN standard	According to the facilities, objectives have been set for the OBE and the SSE (for example integrity, stability or operational fonctionality)	- Elasticity for the OBE as, in principle, there is no damage for the corresponding accelerations - possible incursions in the plasticity area for the SSE, depending on the objective of performance set to the facility	
	Japan 1995	Osaka gas	small basement of E & I equipment	liquefaction	Japan standard =safe shutdown of EN standard	safety	elasticity	
	Chile 2010	GNL Mejilones	No damage		NFPA59A V2006 (US) / Chilean code	According to the facilities, objectives have been set for the OBE and the SSE (for example integrity, stability or operational fonctionality)	- Elasticity for the OBE as, in principle, there is no damage for the corresponding accelerations - possible incursions in the plasticity area for the SSE, depending on the objective of performance set to the facility	a system of seismograph which can provoke an ESD due to the acceleration if above 0,2g two seismic sensors and condor system to shut down the terminal
	Chile 2010	GNL Quintero	cargo unloading arm	counterweight plates required adjustment (SVT)	National Precast Concrete Association (NPCA) for plant and tank construction. Other EU standards were applied as well.	safety and plant reliability	elasticity	seismic isolators beneath storage tanks
	Samoa 2009							
	Sumatra 2007		N/A	N/A	N/A	N/A	N/A	N/A
	Sumatra 2005		N/A	N/A	N/A	N/A	N/A	N/A
	Sumatra 2004		N/A	N/A	N/A	N/A	N/A	N/A
	Alaska 1964		LNG Facilities not operational	LNG Facilities not operational	LNG Facilities not operational	LNG Facilities not operational	LNG Facilities not operational	LNG Facilities not operational
Large earthquakes	Chile 2012	GNL Quintero	No damage	No damage	N/A	N/A	N/A	N/A
	US (Virginia) 2011							
	Spain 2011		No damage	No damage	N/A	N/A	N/A	N/A
	Alaska 2011		No damage	No damage	N/A	N/A	N/A	N/A
	Italy 2009	GNL Italia La Spezia	No damage	No damage	N/A	N/A	N/A	N/A
	Italy 2009	GNL Italia Rovigo	No damage	No damage	N/A	N/A	N/A	N/A
	China 2008		N/A	N/A	N/A	N/A	N/A	N/A

APPENDIX 2 - Detailed damages on facilities in Minato LNG terminal caused by the Great East Japan Earthquake March 11, 2011

Source: Effect of the Large-scale Earthquake and Tsunami on an LNG Receiving terminal, IGU Kuala Lumpur 2012
LNG journal July/August 2012

General information

- The main process flow through the Minato LNG terminal of Sendai is shown in Figure 2.
- Maximum ground acceleration of 615 gal
- Tsunami flooding reached a maximum height of 3-4 metres. The flooding continued for about one hour. The area flooded by the tsunami reached as far as 4km inland from the LNG terminal.
- There was no loss of life, LNG leaks or other secondary damage.

Initial response

- Immediately after the earthquake, the commercial electric power supply shut down, the back-up 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 the tsunami struck one hour after the quake.
- With the tsunami, the resumption of production was immediately abandoned and the LNG storage tank, and emergency shut-off valves were closed remotely to prevent secondary damage.

Damage situation caused by earthquake

- Although a seismograph inside the LNG terminal measured a maximum ground acceleration of 615 gal, the production equipment, which had a construction based on seismic design standards, suffered almost no damage from the earthquake.

Damage situation caused by tsunami

- The terminal's production equipment did, however, suffer extensive damage from the tsunami flooding
- Some facilities were not damaged by the tsunami.
- Detail is as follows:

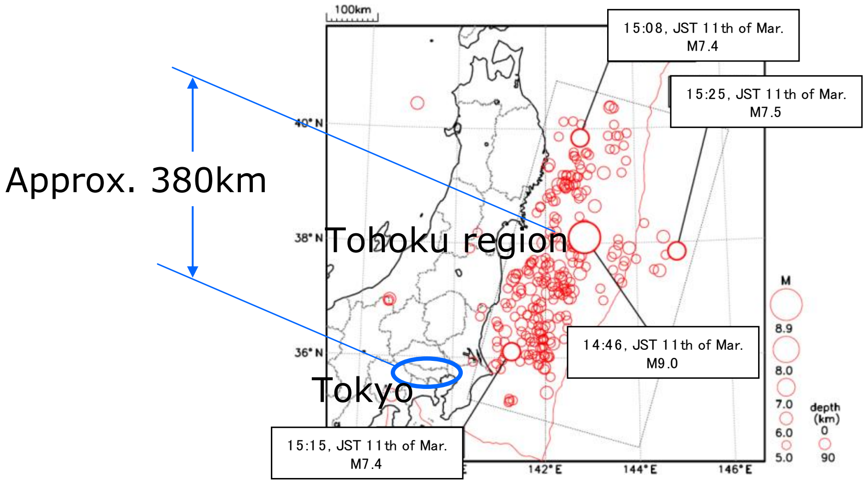

Figure 1 - Earthquake scale (Source: The Japan Metrological Agency)

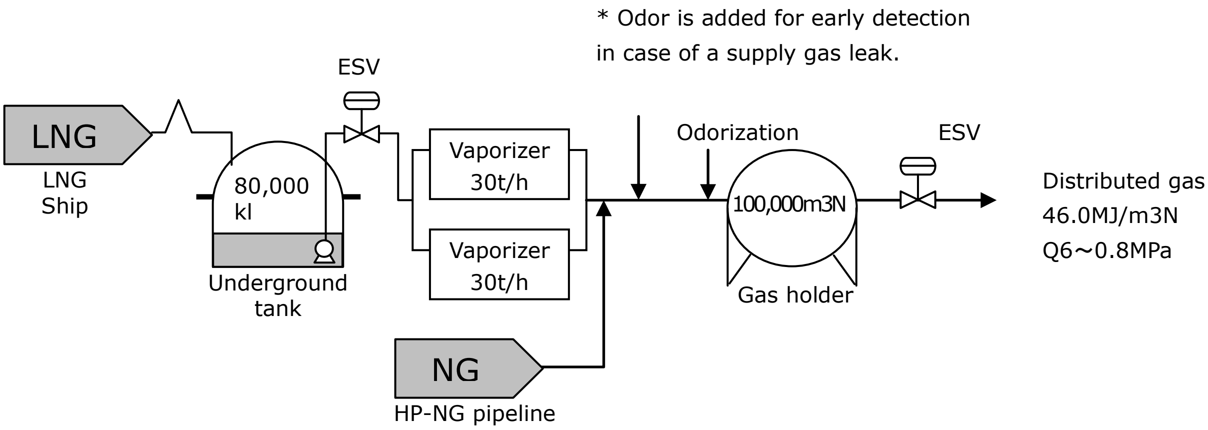

Figure 2 - Process flow at the stricken Minato LNG import terminal

Facilities	Detail damage situation caused by tsunami
Berthing facilities Loading arm	The berthing facilities which have a steel-pipe structure were sound, including the loading arm.
Boil-off gas compressor	The boil-off gas compressor was at an altitude higher than the tsunami and avoided flooding.
Sea wall	The sea wall had no damage and was still functional.
Storage tank	The tanks were sound as they were on ground higher than the flooding level.
LNG vaporizer	Some of the equipment was flooded, but there was no damage.
Piping framework and piping with shallow foundations	The piping framework, with shallow foundations, collapsed from scouring.
Piping framework and piping with Pile foundations,	While there was scouring around the piping framework and pipes, they were still functional.
Odorization equipment	The odorization room, which is designed not to leak offensive odours, uses highly airtight doors and has no open areas, so the structure prevented flooding.
Site gauges	Most of the site gauges were flooded and could not be used.
Building	A building was washed away. Damages and loss of functions of equipment located indoors including power receiving equipment and sub-station instrumentation, LNG monitoring equipment and boilers, as a result of flooding via air vents and other building openings.

Table 1 - Detail damage situation caused by tsunami