Design, Siting and Marine Operation of an Offshore LNG Receiving Terminal

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Abstract

The world demand for Liquefied Natural Gas (LNG) has been increasing steadily and is expected to continue to grow well into the first half of the new century. Supply of LNG to most regions of the world requires transportation by sea in highly sophisticated LNG Carriers. These ships require dedicated marine terminals especially designed to receive this cargo. Suitable land sites to build these LNG Receiving Terminals must be close to the markets, easily accessible to ships and environmentally acceptable. In some parts of the world, these sites are difficult to find or are not available economically.

Concern for this problem has led to extensive search for possible solutions. One of the solutions is to create a LNG Receiving Terminal offshore, on a man-made island. This man-made island can be a Gravity Based Structure (GBS) constructed of concrete. The GBS would house the storage tanks, re-gasification units and the marine terminal. The liquid cargo would be processed into a gas and sent ashore via a pipeline to a power plant or distribution grid.

In a GASTECH98 paper, we described the design of equipment and facilities of an offshore GBS receiving terminal. This paper addresses the design and siting of such a terminal as well as the related marine operations. Design considerations to satisfy SIGTTO guidelines are described. In addition, environmental data and ship handling requirements for offshore operations are discussed. Results of ship handling simulation on a PC-based simulator as well as on a full-scale, real-time simulator will be presented.
1. **Introduction**

Worldwide demand for liquefied natural gas (LNG) is projected to double in the next decade [1]. It is expected that new demand will come from continuing expansion of traditional markets like Japan, Korea, and Taiwan as well as from emerging markets such as India and China. This increase in demand must be supported by an increase in the number of receiving terminals. By its very nature, a receiving terminal must be located near its end user, be it a power plant or city gas. As concerns for the environment and population safety grow, it becomes more and more difficult to locate a terminal on land near its end user. Moreover, in these areas, the cost of land is often so high that it could render the project uneconomic. Some alternative means must be sought to locate receiving terminals.

One alternative is to locate the terminal offshore[2-7]. Figure 1 illustrates this concept. A LNG receiving terminal serves three basic functions: unloading, storage, and processing (vaporization). An offshore LNG terminal performs all three functions offshore. Only gas is sent to shore via a subsea pipeline. An offshore terminal offers at least four major advantages over a traditional onshore terminal:

- Avoid escalating land cost
- Avoid time and cost of construction of a harbor
- Away from population
- Less environmental and visual impact

Offshore terminals can be built on a natural island as in the case of Revithoussa terminal, or on a man-made island. In locations where land is scarce and valuable, a man-made island provides the real estate to support the operations of the standard LNG receiving and processing equipment. There are many ways to build a man-made island including, for example, land fill. The man-made island in ExxonMobil’s proposal is made of a concrete gravity base structure (GBS). The GBS technology has been in use for over half a century and today is used routinely to support drilling, storage, processing, and shipping of oil and gas. People live and work safely on these man made islands, 24 hours a day. There are thousands of GBS’s worldwide, each tailor-made to the local environment and many operating safely in harsh sea and weather conditions. In a previous paper [3], we reported a feasibility study of an offshore GBS terminal with the environmental conditions of the West Coast of Northern Taiwan. The study concluded that a GBS terminal is a low cost, low risk and safe solution to reliable gas supply to this region. This paper is a sequel to the previous one and expands the description of the siting, design and marine operation of the proposed GBS terminal.

2. **Description of A Typical GBS Terminal**

A 3D view of the GBS terminal is shown in Figure 2. Briefly, it is approximately 60 m wide and 630 m long. There are 3 storage modules and one process module, installed adjacent to each other, and a freestanding flare. The regasification plant is capable of processing 2 million tons per annum of LNG. Due to its modular structure, future expansion can be easily accomplished by adding storage modules.

All equipment used in the GBS terminal, such as unloading arms, cryogenic pipes, storage tanks, and vaporizers, is identical to those presently used in onshore and offshore LNG terminals around the world. For our Northern Taiwan example, the main deck level is 25 m above the seabed. At a 20-m water depth and a 3-m tide and surge, this provides a minimum freeboard of 2 m. On the ocean side of the GBS, a 10-m high wall provides adequate protection against waves, and storm seas. The berth is located on the opposite side of the sea wall at the center of the GBS island on the storage module. Conventional Chicksan LNG unloading arms are fitted on a concrete platform located at the berth. The unloading of the LNG carriers is performed in the same
manner as for a typical onshore LNG terminal. The berth is designed for LNGCs of 135,000 m$^3$. For more details of the facilities of the GBS terminal, please refer to our previous paper [3].

3. **Terminal Siting and Berth Design**

The offshore GBS terminal design follows the principles of SIGTTO guidelines [8-10] for siting LNG terminals and designing berths. Some of the guidelines are automatically satisfied with the GBS Terminal. For example, one SIGTTO guideline is to locate the berth close to the storage tanks to reduce cryogenic pipeline lengths because a shorter pipeline reduces the failure risk and minimizes the rise of temperature while LNG is transferred between the ship and the tanks. For the GBS terminal, the berth is right next to the storage tanks. Other SIGTTO guidelines require careful consideration in the design and siting of the GBS terminal. Summarized below are design features of the GBS terminal.

- **Wind and Wave**

Consideration was given to the availability of sheltered water and prevailing wind direction on the West Coast of Northern Taiwan. A 10-year hindcast study was carried out for the general area near the GBS site. The results were calibrated against local wind and wave data, measured offshore in about the same water depth. Table 1 shows the long-term operational wind and wave statistics from the hindcast study. Storm data was removed from the statistics since a LNGC will not be berthed during storms or typhoons.

During the summer, the sea state is generally calm and the terminal accessibility is expected to be good. During the winter, prevailing wind and waves can exceed the normal berthing criteria due to strong monsoons from the northeast. Berthing during the winter is still achievable because there are breaks between the monsoons. An average monsoon lasts 7-8 days and weather breaks usually last 1-2 days, sufficient for LNGC berthing. During November and December especially, however, ship berthing will likely be subject to weather delays.

A Monte Carlo shipping simulation was carried out to determine the optimum number of ships and LNG storage capacity required to ensure uninterrupted supply of sendout gas. This simulator has been used successfully to model crude transport to and from the North Sea. To account for the local weather conditions, continuous hindcast wind and wave data were used in the shipping simulation. Statistics averaged over a period of 10 years indicate that the GBS terminal needs to provide an extra LNG storage of 20 days of consumption above normal demand for a total of 30 days of supply to accommodate weather induced ship delays. For a 2 MMTA terminal, this means three 135,000 m$^3$ LNGC and a 360,000 m$^3$ LNG storage capacity will be needed.

- **Breakwater Effect**

To increase accessibility, the GBS is designed to perform like a long, stand-alone breakwater to shelter the LNGC from the prevailing wind, waves, and swells. The Taiwan GBS is 630 m long, more than twice the length of a typical LNGC. It creates a sheltered berth on the shoreward side where LNG carriers can safely dock and unload their cargo. It also provides some protection during the ship approach. If needed, breakwater extensions can be added to either or both sides of the GBS to provide extra protection.

Refraction calculations show that waves generated from deeper water arrive more or less perpendicular to the GBS at the water depth of 20 m. By orienting the GBS properly, maximum protection from the prevailing seas and swells behind the GBS can be achieved. The beneficial effects of the GBS in attenuating waves have been studied using 2-D and 3-D diffraction computer programs. Frequency dependent wave kinematics and wave crest elevation data for waves typical of this area were developed. Waves with various approach angles ranging from 15 to 90° to the longitudinal direction of the terminal were studied [2,3]. In the lee or shoreward side of the GBS, there is a large calm area where significant wave heights are reduced by 50% or more from that
of the incident waves. This effect was confirmed in a wave tank experiment. As illustrated in Figure 3, the calm area can be observed on the lee side of the GBS where a LNGC would be located.

- **Water Depth**

A LNG terminal would be ideally located in a site where there is sufficient depth of water in the vicinity for ship approach and handling, at all states of tide. On the other hand, locating the GBS too deep would require a higher structure, thus increasing the cost of the GBS. Therefore the optimum water depth of the GBS site is based on a balance of these two factors. A loaded 135,000 M$^3$ LNGC would have a draft of 11.5 m. The lowest recorded tide in the area is —2.62 m below chart datum. To provide a safety margin for under keel clearance, a 15 m water depth was set as the minimum for ship handling. The bathymetry of the seabed shows a very gentle slope of 1/125 to 1/200 at the selected site. To give about 600-900 m (2-3 ship lengths) of open space between the GBS and the 15 m depth contour line for ship approach and maneuvering, the GBS would need to be located in 20 m water depth.

- **Tidal Current**

Current in this area is tidal driven. Based on preliminary data the currents are expected to run parallel, or nearly so to shore. Primary current direction is ENE or WSW, reversing with the change of tides, but may develop a higher strength in certain directions due to seasonal variations. Current speed ranges from 20 to 60 cm/sec with a maximum speed of about 100 cm/sec (2 knots). There are four changes of direction per day, thus creating four periods of slack water. With a daytime berthing limit of 1 knot current, there are at least two slack water periods per day to berth the LNG ship. The orientation of the GBS is also more or less parallel to the current. This allows the ship to approach the GBS from either direction, using the current to optimize ship handling. The GBS structure is expected to cause some eddy currents at the corners of the GBS, but the effect would not be sufficient to adversely affect safe ship handling.

- **Ship Movement and Local Traffic**

In order to provide maximum safety for LNGCs, consideration was given to the movement of the ship to and from the berth, especially with regard to other ship traffic and the use of any access channels. Passing traffic can cause surging of a berthed ship, which will cause excessive strain on moorings.

The selected GBS terminal is located in 20 m water depth. International cargo ship routes such as those from Kee Lung Harbor are located further offshore in 60 m water depth. The Sha Lung SBM oil terminal, is located about 5 km away and in 40 m water depth. Neither is expected to interfere with the LNGC’s approach and berthing. The vessel traffic closest to the area consists primarily of small fishing boats, but the fishing activities here are low. A patrolled safety zone of 500 m would be established to exclude other vessels from the vicinity of the GBS. Therefore surge at the GBS berth is not expected to be a concern.

One of the advantages of a GBS terminal is that the LNGC can approach from either end of the GBS. This is discussed further in the Ship Handling Section below.

- **Mooring and Fendering**

Another consideration is the ability to locate mooring positions that will be effective for a vessel berthed at the GBS. The mooring design took into consideration the prevailing environmental conditions of wind, waves and currents found offshore west coast of Taiwan. Since the LNGC can berth either port or starboard side, most mooring operations can take advantage of positioning the current on the bow of the LNGC. The hydrodynamic behavior of a LNGC was studied to determine the maximum dynamic surge motion at berth for a significant wave height of 3 m and a period of 10 seconds.
The mooring fenders would be positioned to allow a ship to land on them while berthing when slightly off the fore and aft final position. Also, the design allows either of the primary fenders to take the full berthing load of the vessel should the approach not be exactly parallel to the fender line. This mooring system uses a Yokohama fender system which can handle the impact of a LNGC moving at a berthing velocity of 15 cm/sec (0.3 knots).

4. **Ship Handling**

The concepts and procedures for safely maneuvering and docking a LNGC to a GBS are based on general marine practices and the results of ship handling simulation studies. The ship handling studies were first conducted on a PC-based simulator (PORTSIM) and were confirmed on a real-time simulator at National Taiwan Ocean University. A photo of the simulator is shown in Figure 4.

- **Limiting Weather Conditions**

The approach and berthing of LNG carriers to the GBS is performed using the same wind and wave limits established for traditional onshore terminals. A study of the berthing criteria of various terminals around the world was conducted. The berthing criteria of Taiwan’s Yung-An terminal are among the most conservative, while European terminals tend to be less conservative than Asian terminals. The limiting conditions selected for this offshore GBS terminal represent the most conservative criteria used in conventional onshore terminals. Table 2 gives the recommended initial limits for GBS berth operations. The primary factor that determines the limiting weather conditions is the sea state and wind in which tugs can safely and effectively work along side a LNGC during berthing. Four tugs, 45 to 50 ton bollard pull each, will be available to moor and unmoor the LNGC.

It is expected that the criteria can be relaxed to the upper range of the traditional criteria, such as 1.5 m wave and 12 m/s wind, after a few years of safe operational experience. This would allow more cargo delivery at the terminal and increase the sendout gas volume without the need to add another storage module.

In this region, typhoons can occur from June to September. It is important to marine operations at this facility to include typhoon tracking along with general weather forecasting. When storms are tracking toward this area and are predicted to arrive within 24 hours it may be necessary for the LNGC to leave the berth and proceed to safe waters. This should occur before the limiting weather conditions in Table 2 are reached at the GBS.

- **Arrival to Berth**

The configuration, placement, and orientation of the GBS were designed for vessels to approach from either end, against the direction of the prevailing current and weather, without restrictions to the stage of the tide or a confined channel. In northern Taiwan, a LNGC will typically approach the GBS terminal from either the southwest or the northeast direction. The maneuvering plan is illustrated in Figure 5.

As the LNGC reduces speed at a distance of 10-15 km from the GBS terminal, two docking tugs rendezvous to escort the LNGC and establish a moving safety zone. The moving safety zone will prohibit other vessels from approaching within 1.5 km ahead and 1 km astern of the LNGC. At reduced speed, the LNGC passes safely offshore from any obstructions before turning toward the facility. Arrivals and mooring will be during daylight and scheduled to coincide with slack currents at either high or low water tides. Three to four tugs will be used to moor and unmoor the LNGC, depending on the environmental conditions at the time.
In normal conditions, the pilot will board 5 to 7 km from the GBS. From this point the vessel is maneuvered and secured to the berth on the GBS in the same manner of a conventional harbor. As discussed earlier, the GBS provides a shelter of calm sea-state. When weather conditions prohibit the pilot from safely boarding as described above, the Master of the LNGC will maneuver the vessel to the sheltered area behind the GBS where the pilot can board safely. Once the pilot is on board, the LNGC could either berth directly or leave the sheltered area and make another approach under the direction of the pilot.

Should the LNGC be required to await berthing for any reason, it can anchor at a safe distance from the GBS, outside the shipping lanes. The safety zone would be temporarily extended to include the LNGC at anchor.

- **At the Berth / Cargo Transfer**

At the GBS terminal, the same industry procedures and equipment will be used for the transfer of LNG cargo as in a traditional harbor. Tracking weather forecasts and changing conditions will be as important for operations at the GBS terminal as in a conventional harbor.

The cargo loading arms are articulated and move freely in all directions, allowing for ship movement at the dock. They are expected to stay within the operating envelope, with ample margins of safety, up to and slightly beyond the limiting weather conditions described in Table 2. Those are: stop transfer when winds exceed 13 m/sec with sea state above 1.2 m; and disconnect the cargo arms when winds exceed 15 m/sec with sea state above 2.0 m. The cargo loading arms are further protected with warning alarms, as well as emergency shut down and emergency disconnect systems to prevent damage to the arms or ship.

When heavy weather is possible while the LNGC is discharging cargo, the discharge sequence will be planned to maintain adequate vessel stability in the event the vessel has to leave the berth prior to the completion of discharge.

While the LNGC is berthed, two tugs, with fire fighting and rescue capability, will remain in the vicinity on stand-by. Their purpose will be to assist in removing the LNGC from the berth in an emergency.

At all times a stand-by vessel will remain in close proximity to the GBS terminal. It serves a dual role: to assist the evacuation of GBS personnel in an emergency; and to monitor the 500 m safety zone, prohibiting unauthorized vessels from entering. This is similar to the protection provided to manned offshore production platforms.

A Mooring Master will remain on board at all times while the LNGC is moored to the GBS. While on board he will be responsible to remove the vessel from the berth on short notice or in an emergency. Additionally, he will liaise between the GBS and vessel to ensure the safe transfer of cargo, maintain good communications, and ensure procedures specific to the GBS are followed.

- **Departure from Berth**

At the completion of cargo transfer, the pilot and tugs will assist in undocking the LNGC. The LNGC can leave the opposite end of the GBS from which it approached. Unlike departure inside a closed harbor, turning of the ship is not required but is an option if preferred.

The pilot will leave the ship after it has safely cleared the GBS at a distance of 2-3 km, weather permitting. The tugs will escort the LNGC, maintaining the moving safety zone as described on arrival, until it increases speed and returns to open sea.

- **Validation by Ship Handling Simulators**
The approach and berthing of the LNGC was validated with ship handling simulators. A PC-based ship-handling simulator, called PORTSIM, was used to provide an initial technical evaluation of ship maneuvering in various weather and current conditions. This identified conditions for further evaluation on a real-time, full-scale ship-handling simulator at National Taiwan Ocean University. Local Taiwanese and international Mooring Masters participated in the tests. A total of 52 runs were made. Figures 6 and 7 show typical ship trajectories. Conclusions are:

1. Ship approach against the wind and the current is recommended.
2. Ship handling capabilities are enhanced when maneuvering a ship bow into a current. In some cases, ship approach against the wind but following the current is viable.
3. Ship approach following the wind and current should be avoided.

The ship handling tests confirmed that a minimum of 600-900 m wide channel between the GBS and the grounding line was sufficient for ship maneuvering.

- Advantages of Ship handling at the GBS Berth

GBS terminal, such as the one considered here for Northern Taiwan, offers special ship handling advantages, as validated by the simulations. To name a few:

1. Approaches are not confined to narrow channels and do not require sharp turns, avoiding difficult maneuvers.
2. Allows larger turning circles and room to maneuver LNG Carriers near the dock.
3. Ample depth of water is available at all stages of the tide in all directions. Mooring and unmooring is not restricted by tides.
4. LNG cargo transfer operations are done at greater distances from other port activities, no harbor traffic nearby.
5. Provides flexibility to approach the GBS from either end.

The flexibility of approaching the berth from either end of the GBS is an important safety feature of the GBS terminal. It provides easy ship handling because it allows the ship to approach the berth against the prevailing weather and current direction. It also enhances the ship's ability to react should an approach fail due to sudden changes of weather or for any reason during approach and berthing. The LNGC can quickly, safely, and easily abort the operation by sailing out the other end. This option is not available in the case of a closed harbor.

5. Conclusion

Based on a thorough consideration of environmental data, following the guidelines of SIGGTO for LNG terminal design and validation by ship handling tests, we conclude that the offshore GBS terminal can be a safe and reliable method of receiving LNG in Northern Taiwan.

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References


2. Shu, W. R., Offshore LNG Receiving Terminal for Northern Taiwan, Hydrocarbon Asia, September, 1998


Table 1 Summary of Wind and Wave Statistics in Northern Taiwan
Numbers in Percent

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Table 2  Recommended Initial Limits of GBS Terminal Operations

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Figure 1  Schematic of an offshore GBS LNG Receiving Terminal
Figure 2  Bird’s eye view of Northern Taiwan GBS terminal
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Figure 6  Typical ship trajectory of a ship handling test — Plan F [Run 10]
**Figure 7**  Typical ship trajectory of a ship handling test — Plan H

![Figure 7: Typical ship trajectory of a ship handling test — Plan H](image)

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[Run11]