Safety of LNG-Shipping around Ports and Terminals

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Introduction
The design of port lay-outs and terminals suitable for LNG-carriers has to meet exceptionally high safety standards. The highly sensitive subject is always treated by the responsible parties with the utmost concern for the design of inherently safe terminals. This is reached through the careful choice of the terminal location within the port and the definition of strict nautical procedures around the entrance, transit, mooring and loading/unloading of the vessel.

In this article, an outline is given of the maritime issues to be addressed if LNG offloading is envisaged. The issues are grouped around four main themes:

- Port infrastructure design;
- Nautical ship operations;
- Overall Port Shipping Safety;
- Training.

The above themes are interrelated. In greenfield sites many issues are free to determine hence laying great emphasis on the design of the total offloading operation, taking into account all possible interactions between the lay-out of the port, the envisaged operation, the future other port users and the required training levels of all personnel involved.

In existing ports often the port infrastructure (lay-out), supporting services (tugs, VTS, aids to navigation) and the other port users are boundary conditions in the process of defining the ship operations and in the assessment of the overall risk. However, the safety primate of LNG operations often allows changes and adaptations to the existing (supporting) infrastructure, traffic flows and operational procedures in the port.

MARIN is covering a good deal of the above-mentioned nautical safety aspects because of her high quality modelling for manoeuvring, safety and mooring purposes. One of our latest projects in LNG-terminal development in Ferrol (Spain) is amongst others a good example of an integrated, safety driven terminal development project, some details of this project are included at the end of this paper. This paper focuses on the inshore LNG offloading terminals and jetties and does not cover the exposed offshore offloading concepts.

Themes in introducing LNG offloading in ports

Port infrastructure design and nautical ship operations
The objective of the port design and definition of the ship operations is first to safeguard the calm, safe and economically feasible offloading of LNG. It first of all requires the safe approach into the port, the safe berthing at the jetty and the calm mooring at the same jetty during as much of the time as possible. Second, the infrastructure and operational procedures in place should enable the safe arrival and departure from the jetty or abort of any entrance manoeuvre during an on-board or on-shore emergency.

Green field port development sites or dedicated harbour basins require a port layout evaluation in relation to wave calmness (safe mooring) and required stopping- and manoeuvring space. Obviously all against the background of port development cost optimization and an acceptable downtime.

Natural or existing ports do not focus on port layout design in the first place (apart from minor adjustments) but evaluate admission policies in relation to downtime of the port against direct risks associated with critical entrance manoeuvres and the moored ship motions (wave penetration). The issues addressed during these evaluations result in:

- A validated port (dimensions of approach, entrance and basin) and jetty lay-out;
- A safe port entrance and berthing envelope (weather window);
- A safe and calm mooring position;
- An optimized tug assistance (escorting) configuration;
- An aids to navigation plan to facilitate the port entrance and departure manoeuvres;
A ship and port operations manual covering all relevant procedures and nautical info;
Additional measures to cope with the evaluated emergency (risk control options).

The above types of evaluations require the use of (fast-time) simulation tools regarding the moored ship motions and the ship
manoeuvring capabilities (or real time simulator). MSCN closely cooperates to this end with Delft Hydraulics to assure high quality
environmental input on currents and wave penetration.

In the field of terminal design, results of the simulation studies are used to determine the dimensions of fenders, the definition of the
mooring line configuration and the required tug assistance, e.g. the number of tugs, tug type and bollard pull. MSCN/MARIN currently
propagates a Joint Industry Project on the design of tugs and appropriate assist strategies to enable tug assistance in exposed conditions
SAFE-TUG). This could eventually lead to terminals in relatively harsh environments minimizing breakwater construction to a length,
which just protects the LNG terminal itself. A first part of the SAFE-TUG project, has been executed by MARIN as a part of our own
research. This first part focused on tug behaviour in waves and is described in a separate article.

Overall Port Shipping Safety
The above issues are focusing on the direct day-to-day safety of operation of individual vessels, however public enquiries or port
authorities additionally need to know the total safety level of the LNG shipping operation in the context of the existing infrastructural
and surrounding shipping movements. It addresses the risks related to collisions, groundings, contacts, fire and explosion on board
eventually leading to the release of gas, and the consequences thereof.

In both design situations, the general risk assessment within the Formal Safety Assessment (FSA) framework requires the use of nautical
risk models to identify areas were traffic risk control options are to be applied. The MARIN SAMSON risk model is one of the very few
models that can quantify these risks and assess the consequences.

Once moored along the terminal the ‘industrial’ and remaining nautical risks (passing vessels, squalls) need to be evaluated.
MSCN/MARIN works in close cooperation with several partners to assess consequential risks to the environment due to leaking LNG
following loading or collision emergencies.

Training
The above studies can lead to recommendations (risk control options) on the training of involved nautical personnel like pilots, tug
masters, traffic controllers and emergency response actors.

In particular following the recommended use of tugs for escorting purposes (a likely requirement in many cases) and the preparedness
for emergencies requires specific, port related manoeuvring training programs for both pilots and tug masters together. MARIN
facilitates the combined full-mission simulation of tugs and LNG carrier. See [1].

Nautical and safety study executed for the port of Ferrol (Spain)
This is an example of a typical port safety study executed for the Port of Ferrol. Regasificadora del Noroeste, S.A. (REGANOSA) is
planning to build a new facility for storage and handling of Liquid Natural Gas (LNG) at Punta Promontorio, at the south side of Ferrol
River, opposite of the city of Ferrol. The site is situated in the North West of Spain close to La Coruna.

Objective
The objective of this study can be divided in the following elements:
• Determination of the required, minimum channel dimensions;
• Study the risks involved in the handling of large LNG carriers, during channel passage and when moored at the terminal;
• Determine the nautical procedures for handling large LNG carriers, during both normal operations and emergency situations.
The content of the study can be divided in the following main items:
- Collection and assessment of data;
- Determination of the required minimum channel dimensions;
- Risk studies;
- Moored ship study;
- Real-time simulations;
- Nautical procedures.

**Collection and assessment of data**
The quality of this type of studies is largely depending on the quality of the available data. In this study many data have been used that were prepared for the development of the new outer port at Ferrol. The University of Santiago executed a dedicated study to determine the flow pattern in the inner channel. This is very important as the flow velocities can reach high values at this location.

Traffic data were received to compute traffic intensity for the present and future situation.

**Determination of the required minimum channel dimensions**
In this study item, the available channel dimensions were checked against criteria published by PIANC and ROM3.1-99 [2, 3]. The PIANC rules for channel dimensioning have been programmed by MSCN. This program (freely available) has been used to make a first judgment of the required channel width. On basis of this first appreciation, it was realized that at three locations in the inner channel the available width was just sufficient.

A first analysis was made of the controllability of the vessel in strong wind conditions using static computations, and it was concluded that tug assistance was required to maintain sufficient control of the vessel in extreme wind conditions and during emergencies.

These first findings were checked with a series of fast-time simulations. These simulations were executed with the fast-time simulation model SHIPMA. The program uses a predefined ideal track combined with a sailing strategy and a sophisticated autopilot to perform the manoeuvres. These simulations confirmed the results of the ROM/PIANC study regarding the channel width. It also showed that the proposed tug assistance scenario is effective, especially for keeping the ship speed low in the inner channel.

An example of a simulation is shown in figure 1.

**Quantitative Risk Assessment studies**
The risk study executed for Ferrol is divided in three elements:
1. Traffic forecast and traffic intensity;
2. Grounding and collision risks;
3. Risk analyses of LNG transportation and unloading.

The traffic forecast and intensity study provides input for the grounding and collision risk study but it also gives insight in the effect of increased traffic intensity on waiting times and the availability of tugs.
The traffic flows to the various locations inside the port are shown in the next figure.

Figure 2 Traffic flows inside the port of Ferrol

Computations were made for the present situation and a number of future scenarios, regarding the development of the LNG terminal and the new outer port. As large ships entering the Ria are restricted to entry on High Water only it was concluded that some traffic scenarios might result in congestion of the port.

The grounding and collision risk study is executed with the SAMSON model. SAMSON stands for Safety Assessment Models for Shipping and Offshore in the North Sea. This model has been developed, extended, validated and improved during the last 20 years in studies performed for the Dutch Ministry of Transport and within many European projects. Although initially developed for the North Sea the model is built up modular and can be used for any location on the world [4]. This model includes the probability on human error and mechanical failures and from that it computes the probability on grounding. The probability data included in the model are based on worldwide statistics, and updated regularly.

Starting point for the computation is a schematisation of the route and the grounding lines. This schematisation is shown in the next figure.

Figure 3 Schematisation of the SAMSON model
The result of the computation is the grounding probability per year for each section of the grounding line. Two classes of grounding are distinguished, the first is “ramming” resulting from a navigational error and the second is “drifting” resulting from a mechanical failure. A typical result is shown in the next figure.

![Figure 4 Grounding probability per year per km for the north side of the entrance channel](image)

The total risk analyses of the LNG transportation and unloading is based upon the aggregated probabilities of accidents and their related consequences in terms of gas spills. The final gas spill amounts and their respective probabilities are first reduced on the basis of effective measures and afterwards used for the calculation of the consequences following the release of a gas cloud (see Figure 5).

![Figure 5 LNG Gas cloud](image)

The cloud itself can be used for the assessment of explosion risk and hence the individual and societal risks involved. This procedure is repeated to study the effect of certain measures on the overall safety of channel passage. Such a result is shown in the next figure.
This figure shows the effect of the ship speed on the probability of fatalities. The middle line (blue line) is the result for the basic speed scenario, the lowest line (orange line) for one knot slower and the highest line (green line) the result for one knot faster. This graph shows that reducing the ship speed with one knot results in an increase of the safety level with a factor 10!

Consequently, the approach in the real-time simulations should be to develop procedures that make it possible to pass the inner channel at low ship speed. By reducing the ship speed the risks involved in the operation becomes much lower than the normally accepted standard.

**Real-time simulations**
A simulator database of the port of Ferrol area was prepared for MARIN’s nautical simulators. In total three simulation sessions were executed with pilots from Ferrol executing entry and departure manoeuvres. During the last session, an experienced tug captain participated in the simulations sailing an ASD tug from a second simulator bridge. The two simulator bridges are shown in the next two pictures:
A picture of the simulator database is shown below:

![Figure 9 Example of the simulator database (LNG carrier in the inner channel)](image)

Simulations were executed under extreme environmental conditions, e.g. spring tide and strong winds.

From the results of the simulations the probability was computed that the channel boundaries are exceeded, during normal passages and during failures. It was found that the 1 per-cent exceedance probability line stays within the 10 meter depth contour line. It should be noted that this is not the grounding line. An example of such a result is shown in the next figure.

![Figure 10 Exceedance probability lines for 10 (blue) and 1 per-cent, detail San Martin to Vispón](image)

The simulations showed that it is possible to transit the channel at a relatively low ship speed. This means that the channel transit is much safer than normal safety criteria applied for this type of operations.
It was also concluded that it is essential to have two escort tugs assisting at the stern of the vessel during channel transit. The role of these tugs is to keep the ship speed low and to assist in case of an emergency. Two tugs are essential to control the vessel during specific failures and to remain under control when one tug fails or when a towing line brakes.

**Procedures**

On basis of the manoeuvring studies and the moored ship studies, a detailed overview of nautical procedures, entrance rules and limiting environmental conditions was prepared. This was all summarized in a ‘nautical summary’ that is used to develop the port procedures.

**References**


[3] ROM 3.1-99, Proyecto de la configuracion maritima de los puertos; canales de acceso y areas de flotacion, Puertos del Estado, 2000