NAUTICAL AND RISK STUDIES FOR THE DELIMARA LNG TERMINAL IN MARSAXLOKK PORT, MALTA

Item 5: Nautical risk assessment study

Final report

Report No. : 27689-5-MSCN-rev.2
Date : December 18, 2015

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Item 5: Nautical risk assessment study

Final report

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Document History

Revision	Status	Date	Reported by	Reviewed by
0	Draft	22 December 2014	M.C. ter Brake and W. Lafeber	Y. Koldenhof and J. Dekker
1	2nd draft	22 June 2015	M.C. ter Brake and W. Lafeber	Y. Koldenhof and J. Dekker
2	final	17 December 2015	M.C. ter Brake and W. Lafeber	Y. Koldenhof and J. Dekker

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1 INTRODUCTION

1.1 Project background

Enemalta is developing a new gas-fired power station near the existing Delimara Power Station on the north-eastern shore of Marsaxlokk Bay. The gas for the power plant will be imported through a new to build LNG terminal in Marsaxlokk Bay. Figure 1-1 shows the approximate position of the new terminal.

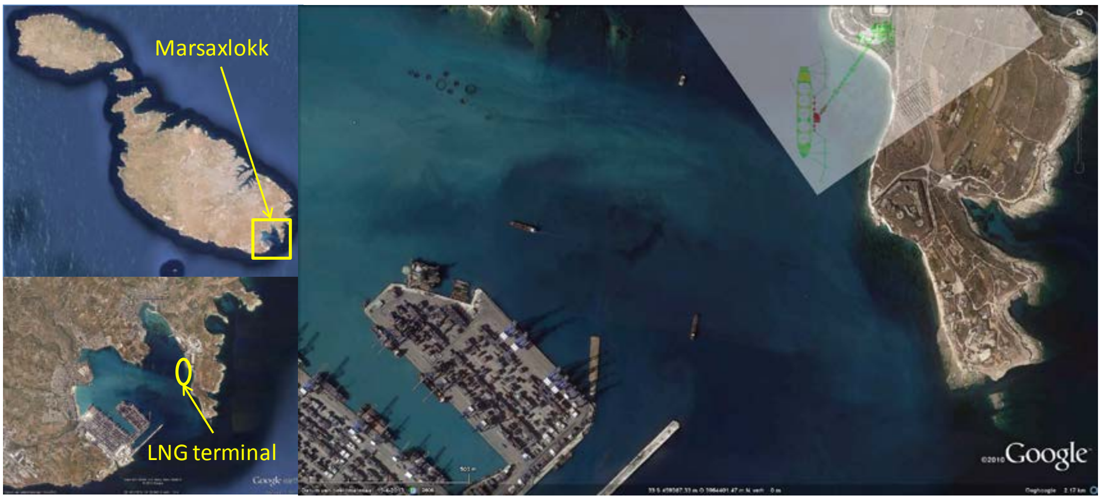

Figure 1-1 Marsaxlokk Port and approximate position of LNG terminal (source: Google Earth)

Enemalta has awarded the contract for design, construction and operation of the new power plant and LNG terminal to Electrogas Malta. The LNG terminal proposed by Electrogas consists of a jetty from the shore south of the power plant to a berth that is positioned where the bay is deeper, so that no or only limited dredging is required. On the jetty a converted LNG carrier will be permanently moored as Floating Storage Unit (FSU), delivering LNG through a cryogenic line over the jetty to the regasification unit onshore. The FSU berth has a conventional layout consisting of a platform, breasting dolphins and mooring dolphins (Figure 1-2). LNG will be imported by LNG carriers (further shortened to LNGCs) that will moor alongside the FSU.

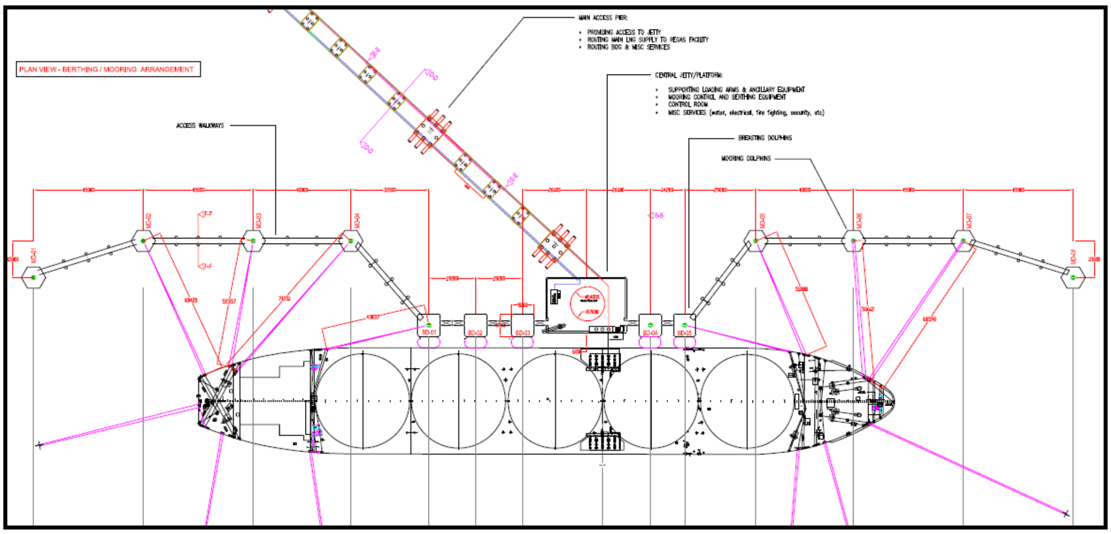

Figure 1-2 Proposed jetty configuration

To verify the design and evaluate safety aspects related to the permanent presence of the FSU in the port and to the regular call of LNGCs to the new LNG terminal, Enemalta has commissioned MARIN to carry out nautical and safety studies for the new LNG terminal. The study addresses a number of items raised by Transport Malta, the authority responsible for the port, who required:

1. Validation of proposed jetty/berth layout
2. Nautical and safety study
    a. Determine the required minimum navigation channel/fairway
    b. Determine the risk involved in the handling of an FSU and LNG carriers when navigating to the terminal
    c. Determine the nautical procedures for the handling of the FSU and LNGC during routine procedures and emergency situations
3. Site specific risk (safety) assessment including
    a. Cargo release
    b. Collision
    c. Fire and explosion
    d. Grounding

The contract for the study (Ref: DPS-GEN-1190) was signed on 25 August 2014 and is based on MARIN's proposal of 24 March 2014.

1.2 Objective, approach and scope of work

Objective

The objectives of the present nautical and risk study for the Delimara LNG terminal are:

- To evaluate the dimensions of the manoeuvring area and port approach
- To determine the operational envelope for ship manoeuvres (input for nautical procedures);
- To evaluate the proposed jetty layout and to determine the limiting operational conditions for safe offloading and for staying safely at the berth (input for nautical procedures);
- To determine the risk involved in the LNG operations in the port regarding grounding of LNGCs and collisions involving FSU or LNGC,
- To determine the consequences (cargo release, fire and explosion) of incidents involving the FSU or an LNGC.

Approach

The above mentioned items are evaluated in this dedicated nautical and safety study for the Delimara LNG terminal. The study consists of the following items:

1. Wave climate study to determine the normal and extreme wave climate outside Marsaxlokk port (frequency of occurrence of directions and wave heights)
2. Wave penetration calculations to determine the wave conditions at the terminal
3. Numerical moored ship response simulations to validate the jetty/berth layout and determine operational limits for the moored FSU;
4. Real-time manoeuvring simulations to verify dimensions of the fairway and determine operational limits for sailing with LNG carriers;
5. Nautical risk study to determine the risks of grounding and collisions involving the FSU or LNG carrier
6. Quantitative Risk Assessment to determine the consequences of collisions in terms of cargo release and risk of fire and explosion

The wave studies (items 1 and 2), which serve as input for the nautical studies (items 3 and 4) were carried out by ARCADIS. Items 3 and 5 were carried out by MARIN. Item 4 was carried out by MARIN in cooperation with MMP (Malta Maritime Pilots) and MMRTC (Malta Maritime Research and Training Centre). SGS Tecnos SA carried out the QRA in item 6.

1.3 Reports

The total study is presented in a series of reports, each one treating one of the above mentioned study items. Table 1-1 gives an overview of the reports presenting the results of the study.

Table 1-1 Overview of reports

Volume	Title	Main author
27689-1-MSCN	Item 1: Wave climate study	ARCADIS
27689-2-MSCN	Item 2: Wave penetration study	ARCADIS
27689-3-MSCN	Item 3: Moored ship response study	MARIN
27689-4-MSCN	Item 4: Real-time manoeuvring simulations	MARIN
27689-5-MSCN	**Item 5: Nautical risk study**	**MARIN**
27689-6-MSCN	Item 6: Nautical Quantitative Risk Assessment	SGS Tecnos

To support the design of the modifications to the FSU and the storm mooring for the FSU, some additional analysis was carried out for ElectroGas Malta on the data from the wave climate and wave penetration studies. This has been reported directly to EGM.

1.4 This report

This report (marked in bold in Table 1-1) describes the approach and the results of the nautical risk assessment study. The focus of this study is on assessing the probabilities of damage to the permanently moored FSU (collisions) or to the LNGC (collisions and groundings) during the visit to the new FSU in the port of Marsaxlokk.

The following individual probabilities have been quantified:

- The probability of a collision between the LNGC and another ship when arriving at or departing from the port;
- The probability of a collision with the moored LNGC or the FSU by another ship;
- The probability of a grounding or contact with the coast of the LNGC when arriving at or departing from the port;
- The probability of a hole in the tank of the FSU or LNG-carrier after a specific collision.

These probabilities are used in the Quantitative Risk Assessment (study item 6). The results of the QRA are presented in [4].

This is the final report in which the several tables have been updated based on a total of 12 calls of LNGCs to the terminal.

Notations

The following notations are used in this report:

. decimal point. Thus 1.5 means one and half.

, digit grouping symbol. Thus 12,000,000 means 12 million.

E for the scientific notation with the exponent of 10. Thus 1.2E-3 means 1.2×10^{-3} = 0.0012

The reciprocal values of the probabilities in the overview tables are not rounded off.

2 SETUP OF THE NAUTICAL SAFETY STUDIES

2.1 Setup of the safety assessment

The nautical safety assessment study for the new LNG terminal consists of three steps:
1. General traffic situation and assessment of available data;
2. Computation of the probability of collision, grounding or contact;
3. Computation of the probability of a damaged containment system;

To assess the nautical risk of a permanently moored FSU in the port of Marsaxlokk and visiting LNG-carriers, a good description of the traffic is necessary. A traffic database is generated, which defines the tracks, the number of vessels and their characteristics (type, dimension) for the port of Marsaxlokk. Data regarding the traffic in the port were provided by the Ports Directorate of Transport Malta in the Excel file ‘Ports in Malta’. This file contains a list of visiting vessels calling at all the ports in Malta for the period January 2013 to December 2013 and their destination within the ports. The data from Marsaxlokk and the other ports were split into separate sheets; the data for Marsaxlokk where further used for setting up the traffic database.

The traffic database, describing the traffic in terms of schematised sailing routes and numbers and types of vessels for each route, is the input for the SAMSON model (see Section 2.3), together with a description of the geometry of the port based describing grounding lines and other objects based on the electronic nautical chart. With the SAMSON model the collision and stranding frequencies are determined for the types of accidents that are identified.

Given the calculated collisions and the ship types and ship sizes involved, different scenarios are defined to calculate the possibility of a damaged tank of the FSU or the LNGC. These scenarios analysed with the MARCOL model (see Section 2.4) and consist of the following variables:
- Ship type
- Ship size
- Bow shape
- Angle of attack (collision)
- Speed at time of collision
- Contact point at FSU or LNGC

The probability of damage to the LNG-carrier or FSU containment system is a results of the coupled probabilities from both models.

2.2 Type of accidents considered

In the present safety assessment quantification is required of what can happen with the permanently moored FSU in the port of Marsaxlokk, and what can happen during the transport of LNG to the FSU.

The risks including LNG operations in the port, can be divided into four phases:
- The LNG-carrier sailing towards the FSU
- The LNG-carrier manoeuvring near the FSU
- The LNG-carrier moored at the FSU
- The permanently moored FSU

For each part of the “operation” different hazards can be identified:

1. The sailing route from the pilot station to the manoeuvring area.
   In this part of the trajectory, the risk for the LNG-carrier consists of two main parts:
   a. Grounding of the LNG-carrier;
   b. Collision with other vessels that are arriving at or departing from the port or other vessel sailing in the area.

   The probabilities will be determined per visit of the LNGC: one entry and one departure. To determine the total risk the probabilities for one trip can be multiplied by the number of calls per year.

2. The manoeuvring area near the FSU
   Before the LNG-carrier can moor at the FSU, the vessel has to turn. During this manoeuvre the vessel has a very low speed. Therefore, the carrier will be at the same location for a period of time. There is a small possibility that, when other ships are allowed to pass in the vicinity, the LNG-carrier may be hit due to a navigational error or mechanical failure.

3. The LNG-carrier moored at the FSU.
   When the LNG-carrier is moored alongside the FSU, it is possible that another vessel will collide with the moored carrier. In this case no other ships are allowed to pass the moored carrier to visit MX Dolphin or MX Power. Only the ships visiting the terminal or the oil tanking facilities are allowed in the port.
   In the calculation of the probabilities it is assumed that the carrier will be present for the whole year. So the results for this part of the trajectory will be given as the total number of contacts per year when the LNG-carrier is moored permanently. These numbers have to be multiplied with the fraction of the year the LNG-carrier will be present at the FSU to find the actual number of contacts per year.

4. The permanently moored FSU
   Since the FSU is permanently moored other ships are allowed to pass and there is a possibility that a passing vessel hits the FSU.

2.3 SAMSON

2.3.1 General description

The frequencies of different events are assessed with the casualty models of the SAMSON-model. SAMSON stands for Safety Assessment Model for Shipping and Offshore on the North Sea. The model can be and has been used for different other locations outside the North Sea. The SAMSON-model is a toolbox with modules developed during many years for the Dutch Ministry of Transport, Public Works and Water Management, Directorate Transport Safety. The model is developed for the assessment of probabilities and consequences for all types of nautical accidents and is used to assess (predict) the impact of different types of measures that influence the safety level. A verification of predicted values to observed incidents is described in [1]. A general description of the SAMSON model can be found in [2]. In the executive summary of POLSSS-Policy for Sea Shipping Safety [3], it is described how SAMSON is used to assess the costs and impacts of a large number of policy instruments (see also paper [4]). SAMSON has been used in several other studies for LNG terminals, including e.g. Rotterdam, Zeebrugge and Montevideo.

Figure 2-1 shows the system diagram of the SAMSON model. The large block “Maritime Traffic System” on the upper right corner contains four main input-data sets. These sets describe the maritime traffic, the ship movements, the ship characteristics (length, GT, etc) and the layout of the sea area. The accident models for collision, grounding, fire/explosions, contacts etc. use the data in the “Marine Traffic System” to determine the accident frequencies. The “Impacts” block contains the modules for assessing the consequences of the accidents. Additional consequence models can be added if required for specific applications. For Marsaxlokk existing modules were used.

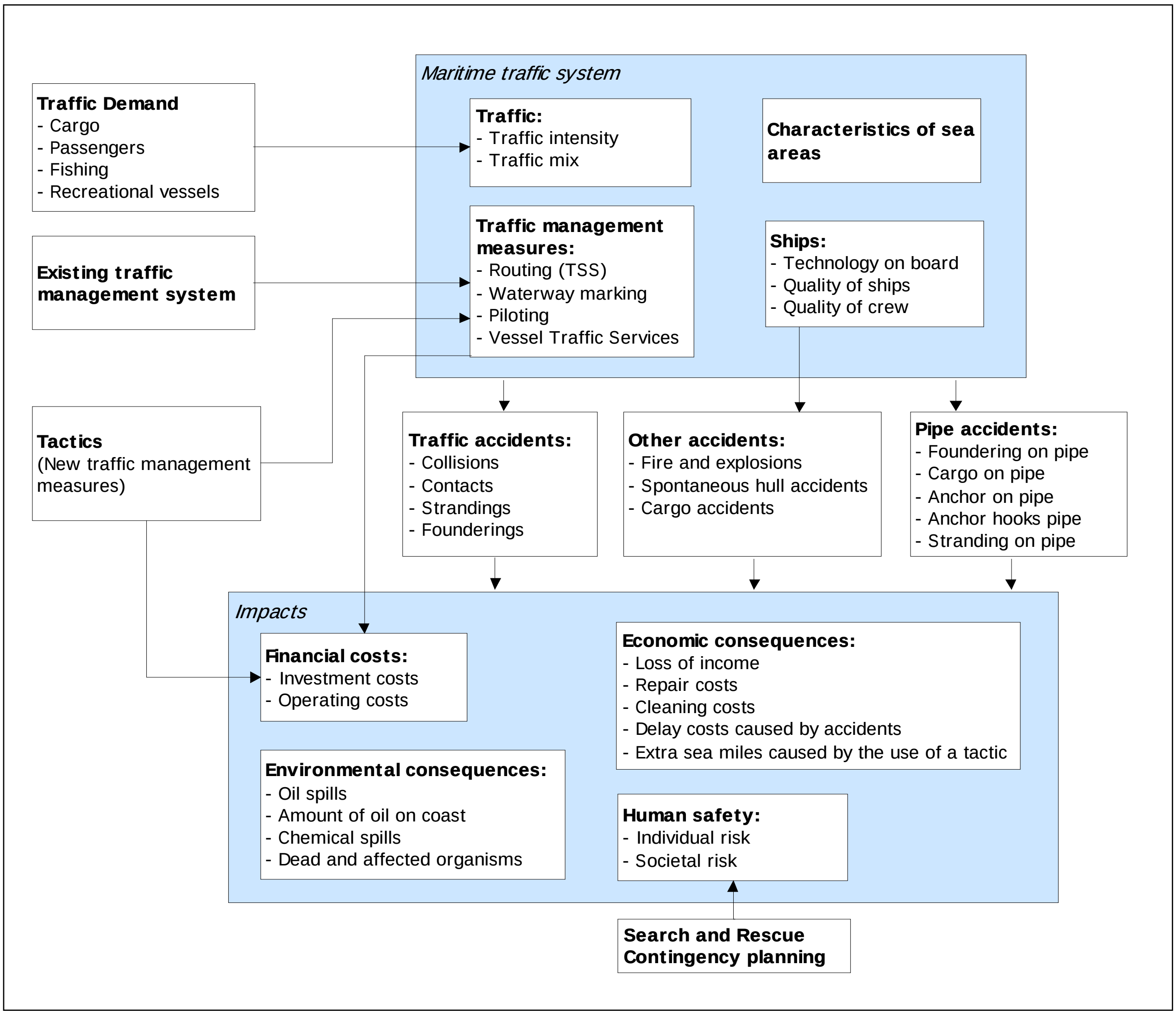

Figure 2-1 SAMSON: System diagram

The parameters of the accident models of SAMSON (probabilities of a certain type of accident given an elementary traffic situation) are independent on the geographical area or the specific port. The parameters are determined from the world wide casualty database from 1990-2007 collected by IHS Fairplay, the world wide shipping register and the traffic flows in the North Sea. The models of SAMSON are generic and can be applied everywhere.

Where possible, verification checks were performed between model predictions and actual incidents recorded historically. In all studies the predictions were in line with the historical records. This gives sufficient confidence for applying the model in areas where a good validity check is not possible by lack of historical data or very scarce data.

The SAMSON model has been applied in several other QRA-studies for LNG transport to ports including Ferrol (Spain), Rotterdam (The Netherlands), Eemshaven (The Netherlands), Goldboro (Canada), Verdon (France), Zeebrugge (Belgium). The program has also been used in safety assessment studies for offshore platforms, offshore wind farms and for the new traffic separation scheme in the approach to Rotterdam. Further the model was used to assess the required capacity for SAR, salvage and oil spill response operating on the Dutch Continental Shelf.

2.3.2 Modules used

Based on the layout and the traffic intensity, the following “undesired” events have been identified in 2.2 for the movement of LNGCs to and from the FSU:

- Collision between the LNGC and other passing vessels;
- Collision between a passing ship and the manoeuvring LNGC;
- Collision of another ship with a moored LNGC or with the permanently moored FSU
- Grounding of the LNG-carrier.

Casualty data analyses have demonstrated that the two main causes of an undesired contact from a ship with an object (e.g. the coastline, a buoy, moored vessel) are:

- A navigational error (ramming);
- A technical failure (for example a rudder or engine failure).

Two separate modules have been developed within SAMSON to determine the probabilities for each of these causes. These two modules are:

- the '*navigational error mode*'
  A ship is on a collision course with an object (a depth line, coastline, pier or other object such as a manoeuvring LNGC) and a navigational error occurs. This error remains undetected until the point of no return and the ship collides with the object. The collision may be at high or low speed depending on the time lapse between the point of no return and the implementation of a corrective action after the detection of the error. This is called a '**ramming**' type collision.
- the '*engine failure mode*'
  A ship in the vicinity of an object experiences a failure in the propulsion engine or in the steering equipment. Since the ship slowly becomes uncontrollable as she loses speed, the combined effect of wind, waves and current may carry it towards the object. If dropping an anchor does not help or is not practical and the repair time exceeds the available time, the ship may collide with the object. This generally happens at a low speed. This is called a '**drifting**' type collision.

In a restricted fairway, the ship has no time for reaching the steady state by wind and current in case of an engine failure and will ground or collide with an object with roughly the same speed as for ramming.

2.4 MARCOL: computing the probability of a damaged containment system

To assess the expected damage to the tanks of a ship in case it is hit by another vessel, MARIN has developed an analytical collision model MARCOL. This analytical model, in contrast to the conventional method (finite elements), is capable of determining the penetration of the cargo tanks in a time span of just seconds. In order to achieve this reduction in calculating time, the model is based on analytical models with application of super elements. These analytical models describe the primary damage mechanics for typical structural components like shell plating and transverse webs. With this model it is possible to calculate the penetration depth into the hull of an LNGC or FS(R)U, taking into account the large variation in size and bow shape of the colliding ship, its speed, collision angle and collision position.
By applying the results of this model for damage to the LNGC or FS(R)U, covering the entire range of encountering ship types and sizes as relevant for a port, the probabilities of collision can be translated into probabilities of a hole in the LNG tanks.

Millions of scenarios have been carried out within other projects to determine the probability of a penetration of the cargo tank. The following parameters can be varied:

- 36 different ship types with 8 ship sizes. Two loading conditions for some ship types and one average draught for the others;
- 7 different bow-bulb descriptions for each of the ship-size combinations;
- the collision angle;
- the contact point on the LNGC, from half aft, to centre, to half front;
- the contact point on the hull plate between the web frames;
- 3 conditions for the LNGC; sailing, manoeuvring in the vicinity of the terminal and when at the jetty;
- different speeds for the LNGC and the other ship.

Figure 2-2 shows an example collision of MARCOL in which the ship has penetrated the cargo tank of an LNGC with the bow and bulb.

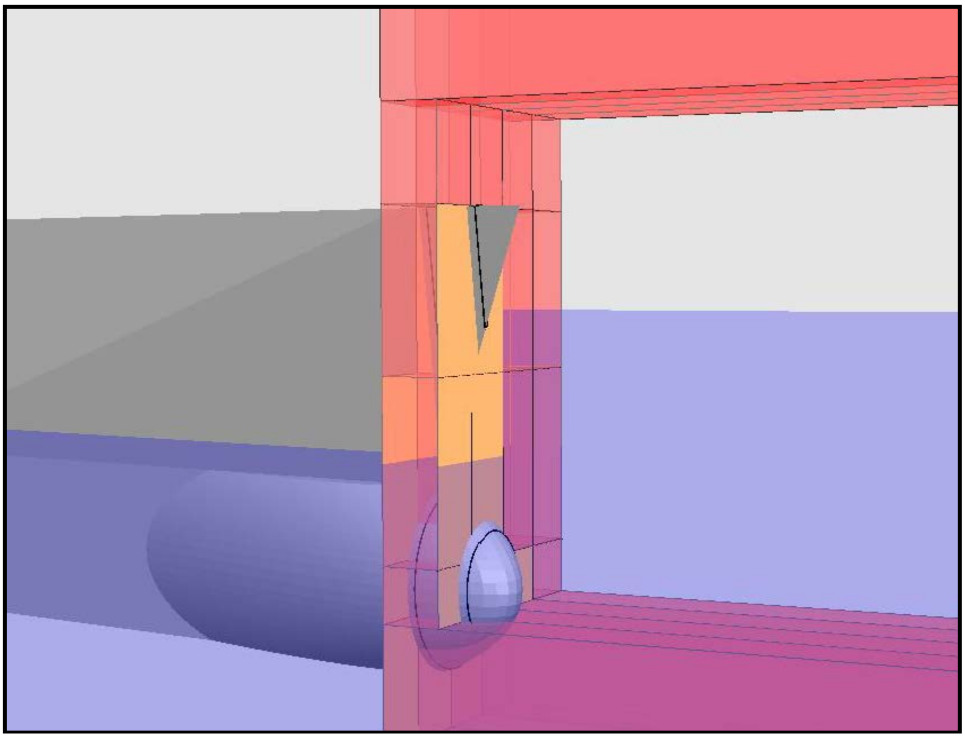

Figure 2-2: Result of MARCOL where a colliding ship penetrates the cargo tank (here membrane type cargo containment system).

A hole can only occur when the ship collides in the cargo part of the LNGC, which stretches over approximately 65% of the side of the ship. Both the FSU and the LNGC in this MARCOL study are of type Moss Rosenberg. These are modelled in MARCOL as a cross section of the cargo part. Since the LNGC for which the analysis is carried out, has very similar principal dimensions compared to the FSU, the same structural model in MARCOL was used.

2.5 Relation with Formal Safety Assessment

In the present study the nautical safety of the handling of LNG in the port is considered in relation with all other traffic in the port. In this study it is assumed that considered operations can be carried out safely in a normal situation. In the safety study the risks and consequences of human and technical failures are evaluated.

In a Formal Safety Assessment as described by International Maritime Organisation (IMO), all possible hazards in the port are identified and evaluated in a systematic way (see e.g. [7]). A Formal Safety Assessment (FSA) is a framework to get an overall view of what can happen and how to reduce risks by new rules. FSA consists of five steps:

1. identification of hazards (a list of all relevant accident scenarios with potential causes and outcomes);
2. assessment of risks (evaluation of risk factors);
3. risk control options (devising regulatory measures to control and reduce the identified risks);
4. cost benefit assessment (determining cost effectiveness of each risk control option); and
5. recommendations for decision-making (information about the hazards, their associated risks and the cost effectiveness of alternative risk control options is provided).

The safety study carried out for Marsaxlokk is not a formal FSA. The present study concentrates on the risks involving the LNGC that are related to sailing to and from the terminal and the risks of nautical incidents involving the FSU and the LNGC when moored at the FSU caused by other vessels sailing in the vicinity are considered. Other possible hazards that may be addressed in a formal FSA, such as incidents in the unloading process of LNG, is outside the scope of work, and therefore not treated in this study. The risks discussed in this report are quantified and the effects of risk mitigating measures are evaluated using the SAMSON model. SAMSON can be used in the framework of an FSA to quantify the risks.

3 MODEL INPUT

3.1 General

The different items given in the Maritime Traffic System block in Figure 2-1 outline the input that is required for the different models. This system block contains the traffic intensity, characteristics of the sea area (layout) and traffic management measures as pilotage, VTS and use of tugs. The different input values and assumptions are described in this section.

3.2 LNG-carrier / FSU

The permanently moored FSU will be located near the power station in the port of Marsaxlokk (Malta). An overview of the approach area and the location of the FSU is given in Figure 3-1. The route of the LNGCs heading for the FSU starts at the pilot station and ends at the FSU.

The proposed LNGC to be used as FSU is the Moss spherical carrier Wakaba Maru. This ship has a length overall of 283 m, a beam of 44.8 m and a draught of about 11 m.

LNGCs of various capacities may visiting the FSU. The LNGC for which the analysis is carried out has a length overall of 290 m, a beam of 46 m and a draught of 11-12 m when fully laden. Note that though incident frequencies are smaller for a smaller vessel (e.g. a 90,000 m3 LNGC), experience in other projects has shown that this difference is only small (~2%).

3.3 Traffic in 2013 and route structure

A good description of the traffic in the port of Marsaxlokk is necessary to determine the possibility of collision, or contact due to ramming or drifting; an LNG-carrier or another vessel collides with the FSU, or with a moored LNG-carrier, or the LNG-carrier collides with another vessel. A traffic database defining the tracks, the number of vessels and their characteristics (type, dimensions) for the port of Marsaxlokk is generated (a memo about the traffic database was sent on October the 28th, 2014.)

Figure 3-1 gives an overview of the port of Marsaxlokk on a Google Earth picture from the port. The figure shows the location of the FSU, the destinations within the port and the proposed route structure. The pilot station is located just outside the area presented in this figure.

Figure 3-1 Overview of the port of Marsaxlokk and its route structure (white lines, where the bold white lines are the sailing route of the LNG-carrier) and the location of the LNG-carrier and the permanently moored FSU (white boxes).

Data regarding the traffic in the port were provided by the Ports Directorate of Transport Malta in the Excel file 'Ports in Malta'. This file contains a list of visiting vessels calling at all the ports in Malta for the period January 2013 to December 2013 and their destinations within the ports. The data from Marsaxlokk and the other ports were split into separate sheets; the data for Marsaxlokk where further used for setting up the traffic database.

Table 3-1 summarizes the calls to the various destinations in Marsaxlokk Port in 2013. The table shows the number of calls of specific vessel types (rows) to each specific destination within the port.

The traffic data include several smaller vessels without a known IMO number. Details of the vessels are therefore not available (dimensions, tonnage). These smaller vessels (marked grey in Table 3-1) are assumed not to cause any risk for either the FSU or the LNGC as their mass is too small to cause significant damage. These are therefore not included in the traffic database.

Table 3-1 Overview of different type of vessels visiting the port of Marsaxlokk in 2013 and the amount of vessels visiting specific destinations within the port.

Type of vessel	FREEPORT TERMINAL	FREEPORT TERMMINAL WEST QUAY	31st MARCH INSTALLATIONS	DELIMARA FISH FARM	MARSAXLOKK	MED SERV	MX DOLPHINS	MX POWER STATION	OIL TANKING	ON ANCHORS	SA MAISON	SAN LUCIAN TERMINAL	SMALL CRAFTS QUAY	Total
BARGE						1								1
BREAKBULK VESSEL	43	1				15								59
BULK CARRIER	1					1								2
BUNKERING BARGE	8		1				4	1	19			14		47
CAR CARRIER	16													16
CONTAINER VESSEL	1919	1												1920
DREDGER	22	4			1	2								29
ERROR	2					1								3
FISH CARRIER				1										1
FISHING TRAWLER	1				9	53		1					13	77
HEAVY LIFT VESSEL										1				1
LPG CARRIER									9					9
NAVAL VESSEL											1			1
OIL RIG	1	1												2
PILOT BOAT	126								1			1	281	409
RESEARCH VESSEL	1				1	2								4
RoRo VESSEL	21					1								22
SUPPLY VESSEL	3	3				48							1	55
SURVEY VESSEL						2								2
TANKER DOUBLE HULL	1		10				27	12	343			25		418
TANKER SINGLE HULL								3	1					4
TUG	5	2				18							1	26
VEHICLE CARRIER	1													1
WORK BOAT	1				4	46							3	54
Total	**2172**	**12**	**11**	**1**	**15**	**190**	**31**	**17**	**373**	**1**	**1**	**40**	**299**	**3163**

The destination SA MAISON to which one naval vessel is going is not within Marsaxlokk Port and is also not further considered. One heavy lift vessel, Hua Hai Long (IMO 9560144), is also excluded from the analysis, since the destination of this vessel is 'On Anchors'.

In the risk study we consider the future situation with the LNG terminal ready and operational. For the additional traffic due to the LNG terminal the following assumptions are made:

- The expected number of cargos per year is assumed to be 6 (mentioned during meetings in October 2014). However, as the capacity of the LNGCs used to deliver the cargo may be larger than the available capacity of the FSU, the LNGCs may be required to leave the port after discharging part of their cargo and re-enter a few days later to discharge the remaining part of the cargo. Depending on the capacity of the LNGCs, the number of calls is hence expected to be between 6 and 12 per year. In the present study 12 calls per year has been assumed. This is considered to be a conservative estimate.

- The time that the LNGC is manoeuvring near the FSU is set to 9 hours per year for 12 calls (0.5 hour on arrival and 0.25 h on departure)
- The time that the LNGC and moored alongside the FSU is set to 288 hours for 12 calls (24 hours per call)
- The impact of a collision with either the LNGC or the FSU depends on the speed of the vessel which hit the LNGC or the FSU. Two typical speeds are considered, a 'low' speed of 4kn and a 'high' speed of 7kn. The speed of 4 kn is representative for the situation in the port where a typical speed when leaving port is about 3.5 kn according to the pilots, while the 7 kn is typical for the speed at "Dead Slow" in the approach to the port.

The traffic database of the port of Marsaxlokk, based on the arrivals of 2013, is given in Figure 3-2. This figure gives the schematized route structure, based on an electronic nautical chart of the port, including the number of ship voyages per main route (as presented in Table 3-3). The destinations and the 'crossings' are depicted with an orange circle, the names are clarified in Table 3-2..

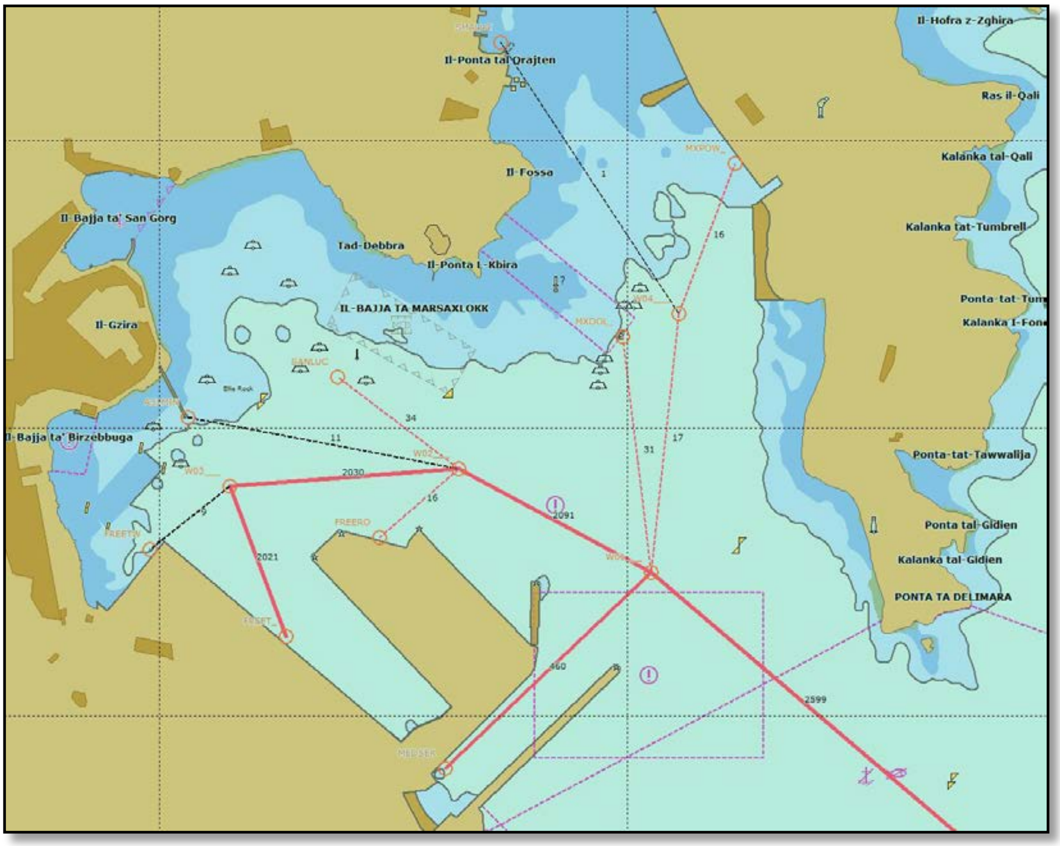

Figure 3-2 Overview of route structure based on an electronic nautical chart of the port, including the number of ships sailing along the presented routes.

Table 3-2 Names of destination as defined in the above figure.

Destination	name
FREEPORT TERMINAL	FREET
FREEPORT TERM. WEST QUAY	FREETW
31st MARCH INSTALLATIONS	A31MIN
MED SERV	MEDSER
MX DOLPHINS	MXDOL
MX POWER STATION	MXPOW
SAN LUCIAN TERMINAL	SANLUC
SMALL CRAFTS QUAY	SMALLC

According to the layout of the port and the locations of the destinations some of the destinations are grouped since this is not of any influence on the risk of any collision with the FSU or with the LNG carriers. The ‘Med Serv’ terminal and the ‘Oil Tanking’ are combined as well as the ‘Delimara Fish Farm’ and ‘San Lucian Terminal’. As shown in Figure 3-2, there is only one route to ‘San Lucian Terminal’ and ‘Delimara Fish Farm’ and one to ‘Med Serv’ and and ‘Oil Tanking’ location. Furthermore the traffic in Marsaxlokk can be divided in three main routes, where

- 2091 ships bound for the Freeport, San Lucian and 31st March terminals
- 460 ships bound for Medserv and Oil Tanking
- 48 ships bound for MX Dolphins/ MX Power and the FSU.

Table 3-3 shows the number of ships voyages on each of these three routes that has been used in the calculations. In total 2599 ships sail to the port of Marsaxlokk, this number excludes small boats as fishing vessels, pilot boats and most of the tugboats.

Table 3-3 Number of ship voyages per main route (over the year 2013)

Type of vessel	Main routes			
	Med Serv & Oil Tanking	Freeport Terminals	MX Power MX Dolphin	Grand Total
BREAKBULK VESSEL	15	44	-	**59**
BULK CARRIER	1	1	-	**2**
BUNKERING BARGE	19	17	5	**41**
CAR CARRIER	-	16	-	**16**
CONTAINER VESSEL	-	1920	-	**1920**
DREDGER	2	27	-	**29**
LPG CARRIER	9	-	-	**9**
OIL RIG	-	2	-	**2**
RESEARCH VESSEL	2	-	-	**2**
RoRo VESSEL	-	22	-	**22**
SUPPLY VESSEL	48	6	1	**55**
SURVEY VESSEL	2	-	-	**2**
TANKER DOUBLE HULL	343	35	39	**417**
TANKER SINGLE HULL	1	-	3	**4**
TUG	18	-	-	**18**
VEHICLE CARRIER	-	1	-	**1**
Grand Total	**460**	**2091**	**48**	**2599**

Most of the ships entering the port of Marsaxlokk, visited one of the Freeport terminals, at the west side of the port. In 2013 there were about 2091 vessels visiting the Freeport terminal. A smaller amount of vessels have destination Med Serv or Oil Tanking, about 460 in the year 2013. Only about 48 vessels visited MX Power or MX Dolphin in 2013.

3.4 Assumptions regarding the traffic situations

Tracks from live AIS websites such as MarineTraffic.com show that occasionally vessels go from one terminal in the port to another (see Figure 4). As this internal traffic is not recorded in the provided data, it cannot be included in the traffic database and will hence not be considered in the risk computations. It is expected that this will generally be smaller vessels (the example in Figure 3-3 is a 93x15 m oil product tanker). As the vessels are small and the speed when sailing within the port will be low (<5 kn in the example), it is unlikely that an incident of these vessels with the FSU or LNGC will lead to damage of the LNG containment system as the energy of the impact is relatively low.

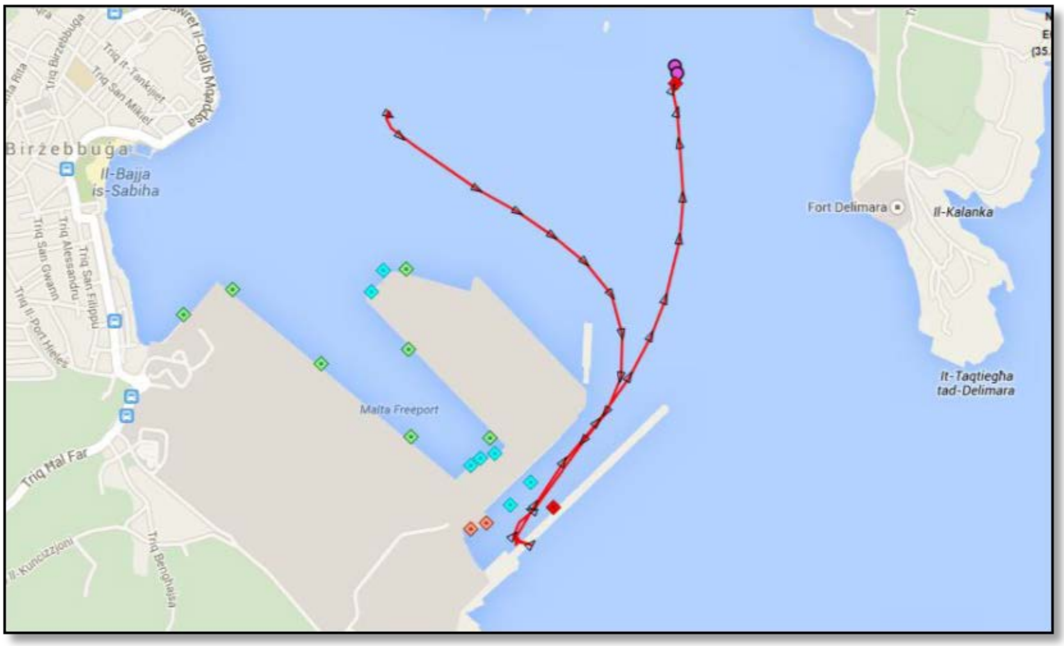

Figure 3-3 Example of internal traffic. Screenshot of www.marinetraffic.com, (28-10-2014).

Note that in the future both the number and the dimensions of ships calling at the port may increase. No data on future traffic scenarios were provided. The present analysis does not consider an increase in visits to the port in the future.

3.5 Risk mitigating factors

To reduce the risk (probability and consequence of accidents), different mitigating measures can be considered. Within this study two main type of measures are distinguished: standard (existing) measures and additional measures. The factor that is applied to quantify the effect of each measure is based on historical data and meetings in which experts gave their best estimates. The factors derived in this way and mentioned in 3.5.1 and 3.5.2, are generally accepted and used in all studies by MARIN.

3.5.1 Existing or typical measures

Already some standard mitigating measures/regulations are in place regarding the LNG-carrier and the other traffic. The existing regulations (referred to as **standard risk control measures** (or **standard risk mitigating measures**) have been included in the calculations. These measures are:

- **Pilot**
On average a pilot reduces the probability of an accident as a result of a navigation error with 62% compared to the same ship sailing the same route without a pilot (based on an analysis of casualty data in the Port of Rotterdam, POLSSS project [4], European projects EMBARC and MarNIS [5]). So the “use” of a pilot on board will reduce both the probability of a grounding due to navigational error as well as the probability of a collision between two ships.
The reduction with 62% is based on a study carried out before pilots frequently used so-called PPU (Portable Pilot Units). By using a PPU a pilot has an even better understanding of the actual local situation regarding for example position in the channel, the water depth, weather condition and other traffic in the area. This means that when using a PPU, the reduction of a pilot on a navigational error could even be more, but real numbers on this extra effect are not available, so that the effect cannot be quantified. The results presented in this study on the effect of the pilot will be a worst case approach: when using a PPU the collision and grounding frequencies will be lower.

- **Escort tugs**
The presence of an escort/accompanying tug for a part of the trajectory can have a risk reducing effect on the number of expected groundings as a result of an engine failure (30%) compared to the same manoeuvre without an escort tug present (based on an analysis of casualty data in the Port of Rotterdam).

- **Tugs**
When the right number and type tugboats are connected this has a reducing effect on both ramming groundings (95%) as well as drifting groundings (99%) probabilities compared to the same manoeuvre without the use of tugboats. The effect of connected tugs on the probability of incidents has been estimated by experts (masters, pilots, traffic management personnel and others).

Assumption regarding the use of tugs and pilot
- A pilot will be on board of vessels of 500 GT or larger, and the correct number and type of tugs will be attached to vessels of 3000 GT or larger.
- A pilot will be on board of the LNG-carrier. Also the LNG-carrier will be accompanied by the correct number of tugs.

3.5.2 Additional risk control measures
Next to the standard risk control measures, as described above, extra measures to reduce the accident probability can be introduced. The effects of potentially relevant measures (referred to as **additional risk control measures**) are quantified here:

- **A VTS Centre** (**Marsaxlokk Port Control**) has a risk reducing effect on the probability of a collision (30%) compared to an area without a VTS (based on an analysis of casualty data in the Port of Rotterdam). Therefore the collision frequencies are also determined including the effect of VTS.

- Applying **restrictions to other traffic in certain areas**. When the LNGC is sailing, restrictions can be applied with respect to other traffic to ensure that other ships remain at such a distance from the LNGC that a collision cannot occur. Which restrictions should be applied needs to be determined by the Port Authority.
The effect of such restrictive measures has been implemented in the model by multiplying the probability of a collision between the LNGC and other passing

vessels with a factor (<1). The probability is not reduced to zero because it is assumed that a percentage of the other traffic will ignore the restrictions. The number of infringements applied in earlier studies is 10% in case of no VTS and 1% in case of a VTS, thus when the traffic is monitored continuously. This possible additional measure is further referred to as "*restricted area*"

- When other traffic comes near the area where the LNG-carrier is moored a speed limit can be imposed in a specified area around the FSU when LNGC is moored. This measure does not reduce the probability of a collision, but reduced the consequences: both the probability of a hole in the tank when a collision occurs will be smaller, as well as the size of the hole.

4 COLLISION PROBABILITIES

The collision frequencies are determined for the four aspects of the operation with the LNG-carrier and for the FSU (see also 2.2):

1. The sailing route from the pilot boarding station to the FSU
2. The manoeuvring vessel in the vicinity of the FSU
3. The LNG-carrier moored at the FSU
4. The permanently moored FSU

It is assumed that a pilot will be on board of vessels of 500 GT or larger, and the correct number and type of tugs will be attached to vessels of 3000 GT or larger. In the SAMSON model, vessels of 500 GT fall in the category smaller than 1000 GT. Therefore, in this assessment it is assumed that all vessel have a pilot on board. Note the amount of ships considered in this analysis smaller than 500 GT is very small.

Two scenarios regarding the other traffic are presented.

Scenario 1: other traffic in the port is allowed to visit MX Dolphins and MX Power.
Scenario 2: other traffic in the port is not allowed to visit MX Dolphins and MX Power.

4.1 The sailing route

The nautical risk on this part of the trajectory consists of two main parts. The probability of a collision between the sailing LNG-carrier and other passing vessels (section 4.1.1), and the grounding probability of the LNG-carrier (in section 0). The probability of penetration of the cargo tank by grounding is discussed in section 4.1.3.

4.1.1 Collisions

The expected number of collisions is determined for one call of the LNG-carrier (arrival and departure). The results are given for the total area, so for the whole trajectory.

Within the SAMSON-model three types of collisions are determined depending on the angle between the two colliding ships: Head-on, Overtaking and Crossing collisions.

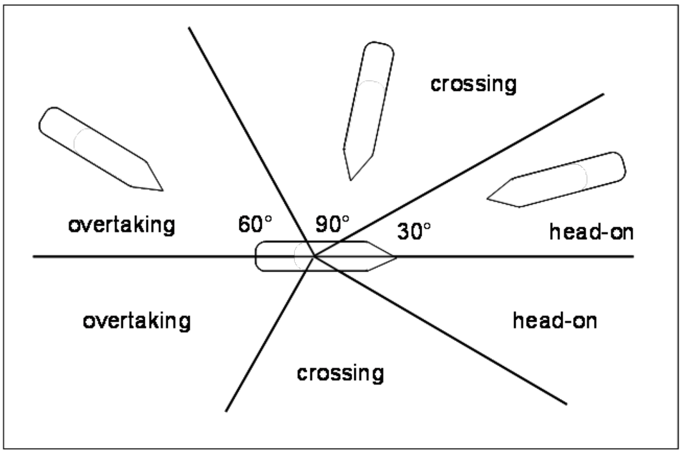

Figure 4-1 Definition of the three different types of collisions.

The total expected number of collisions per call for different scenarios are given in Table 4-1. For the basic scenario the expected number of collision per call is 3.05E-6, this means once every 327708 calls. The existing risk reducing measure is a pilot onboard of the LNG-carrier, when this is taken into account the total expected number of collisions per call will be 1.16E-6 (once every 862389 calls).

In Table 4-2 the total expected number of collisions, involving the LNG-carrier, per year are given, based on 12 calls of the LNG-carrier per year. The total expected number of collisions per year, including a pilot on board the LNGC is 1.39E-5, this means once every 71866 years. When, next to a pilot, also a so-called restricted area is introduced around the sailing LNG-carrier, the total expected number of collisions will be 1.39E-6, once every 718657 years.

Table 4-1 Probability of a collision between an LNG-carrier and other passing vessels per call of the LNG-carrier.

Mitigating factors	Probability of a collision per call of the LNG-carrier				
	Head-on	Overtaking	Crossing	Total	Once in … calls
Basic (no pilot on LNGC)	2.78E-06	2.72E-07	0.00E+00	3.05E-06	327708
Pilot on LNGC	1.06E-06	1.03E-07	0.00E+00	1.16E-06	862389
Pilot and VTS	7.39E-07	7.23E-08	0.00E+00	8.12E-07	1231984
Pilot and restricted area	1.06E-07	1.03E-08	0.00E+00	1.16E-07	8623886
Pilot, VTS and restricted area	7.39E-09	7.23E-10	0.00E+00	8.12E-09	123198378

*Table 4-2 Probability of a collision between an LNG-carrier and other passing vessels per year of the LNG-carrier, based on **12** calls per year.*

Mitigating factors	Probability of a collision per year of the LNG-carrier, based on **12** calls per year				
	Head-on	Overtaking	Crossing	Total	Once in … years
Basic (no pilot on LNGC)	3.34E-05	3.26E-06	0.00E+00	3.66E-05	27309
Pilot on LNGC	1.27E-05	1.24E-06	0.00E+00	1.39E-05	71866
Pilot and VTS	8.87E-06	8.68E-07	0.00E+00	9.47E-06	102665
Pilot and restricted area	1.27E-06	1.24E-07	0.00E+00	1.39E-06	718657
Pilot, VTS and restricted area	8.87E-08	8.68E-09	0.00E+00	9.47E-08	10266531

The majority of the collisions, 91%, will be a head-on collision and 9% will be overtaking. The probability that one of these two types of collision will result in large damage to the LNG-carrier, such that one of the cargo tanks is penetrated, is relatively small. The most damage to the cargo tanks is expected as result of a crossing collision. In this case there are no real crossing collision expected in the approach. This is due to the traffic database layout. As mentioned earlier, the internal traffic is not considered in this analysis. The internal traffic might lead to some crossing, however, the speed will be low in these situations.

Figure 4-2 shows the division between the different ship types. For 60% of the expected collisions with an LNG-carrier, a container vessels will be involved. This is in line with the overall division of ship types present in the port area.

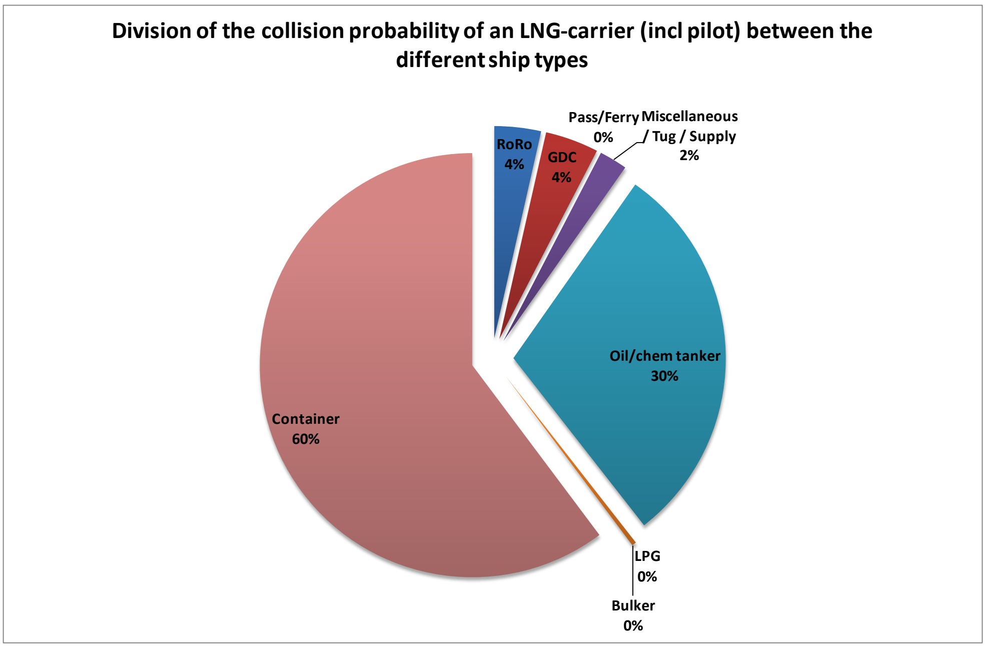

Figure 4-2 Division of the collision probabilities of an LNG-carrier between different ship types.

The actual damage to the LNG-carrier as a result of a collision depends on the speed of both ships and the shape and size of the ship colliding with the LNGC. The distribution of the probability of a collision per call over the various ship size classes (based on GT) is given in Figure 4-3. The figure shows that the expected collisions peak around vessels of 10000-30000 GT. Note that most fishing ships are not included in the analysis, since the damages done by these vessels will be relatively small.

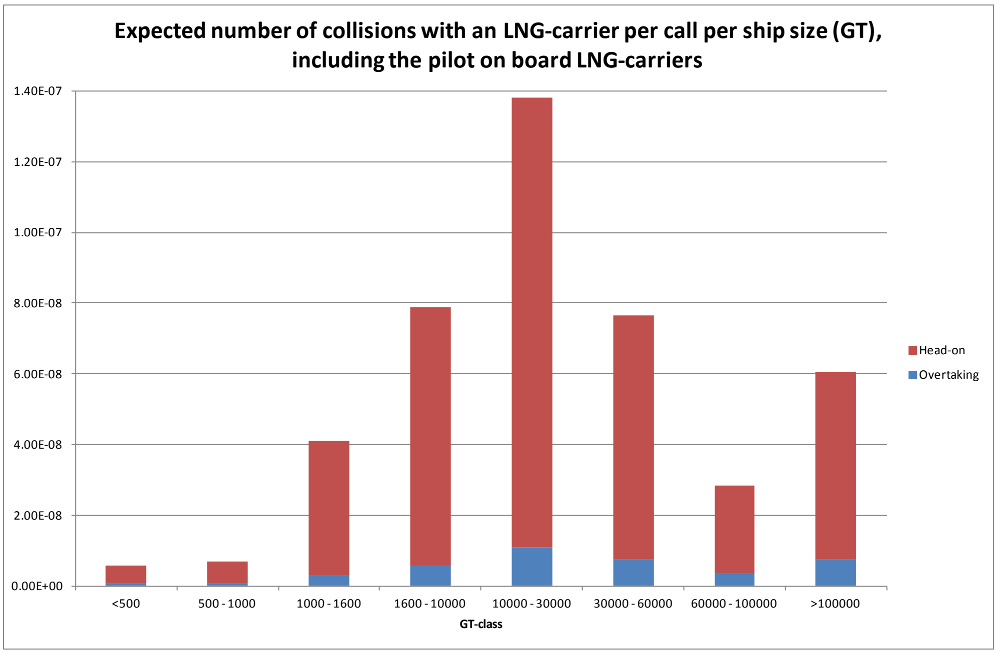

Figure 4-3 Probability per call of a collision between the LNGC and a ship from the given ship size including standard measures (pilot on vessel > 500 GT).

4.1.2 Grounding

The number of groundings is determined for the stranding lines as indicated by the orange lines in Figure 4-4 and for the quay walls indicated as quay FP and quay oil. The stranding line segments are numbered clockwise. For the grounding calculations it is assumed that the LNG-carrier had a pilot and associated tugs.

Table 4-3 gives the probability for the stranding lines (per meter per call, and per line segment per call) and the probability for the two quay walls.

The quay wall 'Oil' has the highest grounding probability, 3.78E-07, this is mainly due to the fact that this wall can be hit from both sides. For the stranding lines, the first three segments have the highest grounding probability per meter. In general the probability of grounding due to navigational error is higher than grounding due to engine failure. The total grounding probability per call is 9.05E-07.

The total grounding probability per year for the stranding lines and the two quay walls is 1.09E-05 (12*9.05E-07), that is once every 92081 years assuming **12** calls per year.

Table 4-3 Probabilities of grounding per call per segment

		Probability per segment per call (incl. pilot and tugs)			Total grounding probability per m per call (incl. pilot and tugs)		
Line	Length [m]	Navigational error	Engine failure	Total	Navigational error	Engine failure	Total
1	755	7.95E-08	4.17E-09	8.37E-08	1.05E-10	5.52E-12	1.11E-10
2	357	5.25E-08	2.75E-09	5.52E-08	1.47E-10	7.70E-12	1.55E-10
3	582	8.48E-08	4.44E-09	8.92E-08	1.46E-10	7.63E-12	1.53E-10
4	131	1.37E-08	7.17E-10	1.44E-08	1.04E-10	5.47E-12	1.10E-10
5	909	4.75E-10	2.49E-11	5.00E-10	5.23E-13	2.74E-14	5.50E-13
6	709	1.72E-08	9.01E-10	1.81E-08	2.43E-11	1.27E-12	2.55E-11
7	287	2.21E-08	1.16E-09	2.33E-08	7.71E-11	4.04E-12	8.12E-11
8	541	3.32E-08	1.74E-09	3.49E-08	6.14E-11	3.22E-12	6.46E-11
9	594	2.89E-08	1.52E-09	3.05E-08	4.87E-11	2.55E-12	5.13E-11
Oil	-	3.32E-07	4.58E-08	3.78E-07			
FP	-	1.56E-07	2.14E-08	1.77E-07			
Total		8.20E-07	8.46E-08	9.05E-07			

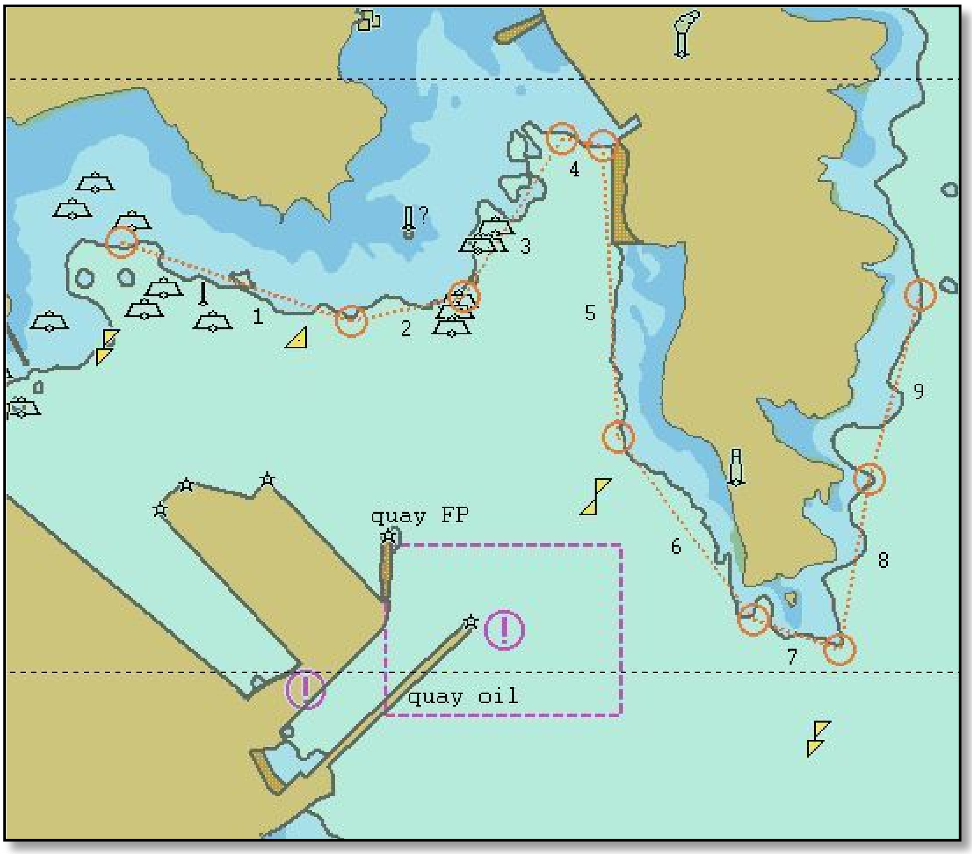

Figure 4-4 Grounding/stranding lines to calculate the grounding possibilities for the LNG-carrier (in orange), following the 10 meter depth contour line.

4.1.3 Probability of penetration of the cargo tank by grounding

Generally it is assumed that a grounding on a sandy bottom will never lead to a hole in the cargo tank of an LNGC, but a grounding on a rocky bottom or a contact with a steep rocky coast can lead to a hole in the cargo tank.

The LNGCs will enter the port of Marsaxlokk and sail to the terminal at relatively low speed (up to 7kn). The LNGCs will be escorted by tugs during almost the entire manoeuvre. The pilot will try to prevent grounding, which will result in a further reduction of the speed. A grounding in the area of Marsaxlokk will therefore occur with limited speed of the LNGC. As the sea bed in the port consists of sediments, it is expected that the cargo tanks will not be penetrated in case of a grounding.

A further confirmation to this statement can be found by considering the world wide casualty databank with respect to grounding of LNGCs. Several (serious) groundings have occurred, namely:

1. The grounding of the El Paso Paul Kayser LNGC with a service speed of 17 knots on the rocky bottom in the Strait of Gibraltar (in 1979) is an illustration of the strength of the LNGC. The bottom of the ship was heavily damaged but the cargo tanks were not penetrated.
2. The grounding of the LNG Taurus in 1980, at the entrance of the Taboata Harbor in Japan, where considerable bottom damage was incurred without damage of the cargo tanks.
3. The grounding of the Tenega Lima in 2004, on the rocks east of Mopko in South Korea. The ship’s shell plating was torn open and fractured, but the cargo tanks were never penetrated.

4. 3 January 2014 the Liberia registered liquefied gas carrier, Navigator Scorpio, ran aground on Haisborough Sand in the North Sea. The vessel was undamaged by the grounding and there were no injuries or pollution; 2.5 hours later, it refloated on the rising tide (source: UK MAIB issues Accident Report).

Of course, this does not prove that it will never happen. However, with respect to the limited speeds and the connected tugs it can be assumed the probability of a penetration of the cargo tank as a result of a grounding is negligible. Nevertheless, it is recommended to scrutinise the seabed in the channel and manoeuvring area on dangerous pinnacles that have to be removed if possible. Also the fact that the port has only recently been dredged supports the assumption that the probability of a loss of containment due to a grounding in the study area is negligible.

4.2 Manoeuvring vessel

Before the LNG-carrier can moor at the FSU, the vessel has to turn and manoeuvre at very low speed. Therefore, the carrier will stay at roughly the same location for a certain period. At this part of the trajectory, the main nautical risk is given by a collision between a passing vessel and the manoeuvring LNG-carrier. Figure 4-5 shows a simulation run of the future situation, which is described in the report on the manoeuvring simulations [3]. This gives an idea of how LNG-carriers will arrive and moor alongside the FSU. LNGC's enter the port along a track with a direction of about 318°N, stop and turn to port opposite of the Freeport Terminal 2 North berth and manoeuvre astern to the terminal. The sailed track and the position of turning will vary from manoeuvre to manoeuvre, also depending on the wind and wave conditions.

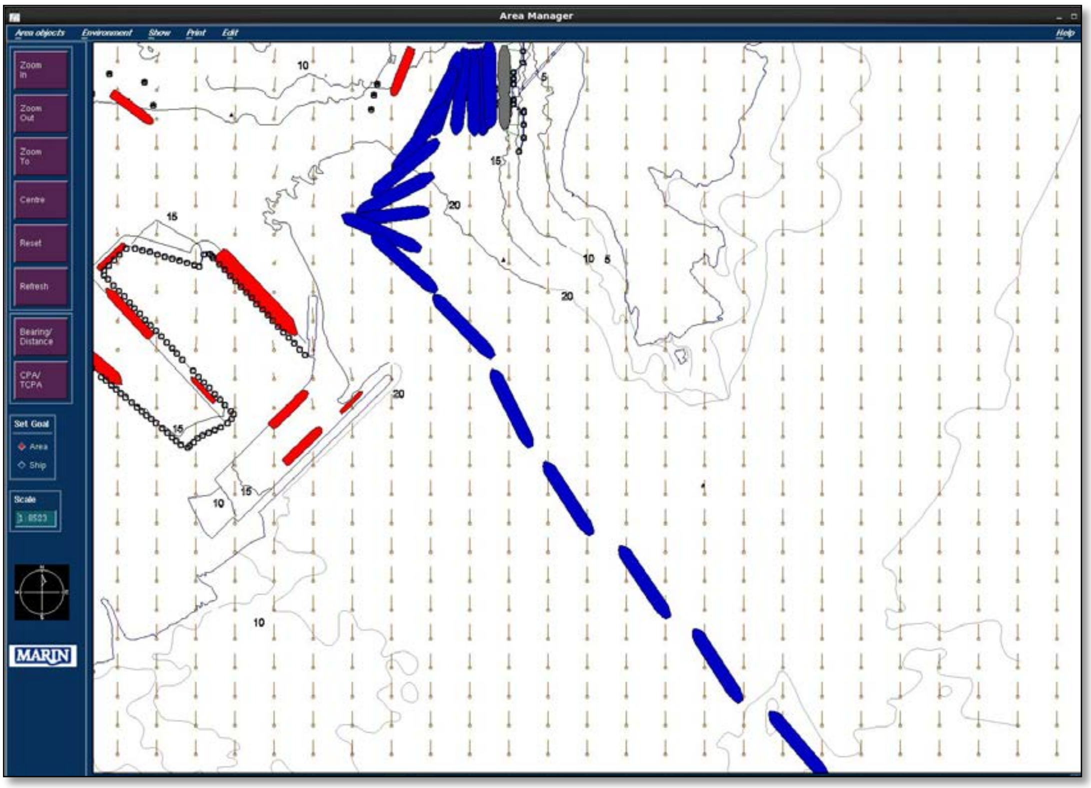

Figure 4-5 Track of a simulation run of an arriving LNG-carrier.

Table 4-4 presents two tables with the calculated accident probabilities of the FSU and the LNG-carrier moored at the FSU or manoeuvring by the FSU. The collision probabilities for the LNG-carrier while manoeuvring are given in the last rows ('LNG manoeuvre') of these tables. Since vessels are not allowed to visit MX power or MX Dolphin when a LNG-carrier is present, only the results of Scenario 2 are of interest (bottom table).

The collision frequencies are generally higher for ramming than for drifting. The collision frequency when 24/7 present, is 2.71E-03 for ramming, 1.54E-03 for drifting. Assuming **12** calls of LNG-carriers to the port, and manoeuvring takes 0.75 hours per call (0.5 h when arriving and 0.25 h for a departure, estimated from real-time manoeuvring simulations [3]), this results in a total collision frequency per year of 4.36E-06. This means once every 229176 year the LNG-carrier is hit by another vessel during manoeuvring. Comparing these results from Scenario 2 with Scenario 1, it shows that the risk reducing measure of not allowing vessels to visit MX Dolphin and MX Power, leads to a collision reduction of 3.1%, see Table 4-5.

4.3 LNG-carrier moored at the FSU

For Scenario 2, the probabilities that a moored LNG-carrier is hit are presented in Table 4-4 in row 2 ('LNGC moored at the FSU'). Assuming that an LNG-carrier is moored at the FSU for 288 hours per year (**12** calls and 24 hours present per call), the total collision frequency per year it 1.33E-04. Once every 7497 years a vessel will hit an LNG-carrier. This number is 2.4% lower due to the measure that ships are not allowed to visit MX Dolphin or MX Power, see Table 4-5.

4.4 Permanently moored FSU

The probabilities that the permanently moored FSU is hit are presented in row 1 ('FSU') in Table 4-4. The FSU alone at the jetty occurs 8478 hours per year, this is all year minus the time that the LNGC is moored (365*24-288). For the FSU only Scenario 1 is of interest. The collision frequency per year for the FSU is 3.79E-03, which means once every 264 years.

Table 4-4 Collision frequencies of the FSU and the LNG-carrier moored at the FSU or manoeuvring by the FSU (pilot on board all vessels > 500 GT).

	Collision frequency when 24/7 present			h/year	**Collision frequency per year**			**Once every …**
	Ram	**Drift**	**Total**	present	**Ram**	**Drift**	**Total**	**year**
Scenario 1:	other ships are allowed to visit MX Dolphin and MX Power when LNGC is moored							
FSU at jetty	2.44E-03	1.48E-03	3.92E-03	8478	2.36E-03	1.43E-03	3.79E-03	**259**
LNGC moored at the FSU	2.62E-03	1.55E-03	4.17E-03	288	8.61E-05	5.09E-05	1.37E-04	**7299**
LNGC manoeuvre	2.78E-03	1.62E-03	4.40E-03	9	2.85E-06	1.66E-06	4.52E-06	**221364**
Scenario 2:	other ships are prohibited to visit MX Dolphin and MX Power when LNGC is moored							
FSU at jetty	2.40E-03	1.43E-03	3.83E-03	8478	2.32E-03	1.38E-03	3.70E-03	**270**
LNGC moored at FSU	2.57E-03	1.49E-03	4.06E-03	288	8.44E-05	4.90E-05	1.33E-04	**7497**
LNGC manoeuvre	2.71E-03	1.54E-03	4.24E-03	9	2.78E-06	1.58E-06	4.36E-06	**229176**

Table 4-5 Increase of collision frequency comparing scenario 1 and 2.

	Increase of collision frequency, comparing scenario 1 and 2		
	Ram	**Drift**	**Total**
FSU	-1.6%	-3.1%	-1.9%
LNG	-2.1%	-4.0%	-2.4%
LNG man	-2.6%	-5.1%	-3.1%

5 PROBABILITY OF A HOLE IN THE CARGO TANK

5.1 General approach

A calamity after a collision with an LNGC may occur when the cargo tank of the LNGC is penetrated. This will only happen when the LNGC is hit in the side where the cargo tanks are located. The probability that the damage is that large that the cargo tank is penetrated, depends on many parameters, such as the construction of the LNGC, the speed of the LNGC, the mass and speed of the striking vessel, the collision angle and the location of the impact point on the LNGC. The MARCOL model described in Section 2.4 is used to determine the damage, based on a certain collision scenario.

MARCOL provides the probability that a typical collision with the expected speed, for all variations as mentioned above, will result in a hole of the cargo tank. SAMSON delivers the probability of a collision with an LNGC for each ship type and size. Combining the results of the two models allows determining the probability of a hole in the cargo tank.

5.2 Schematisation of the FSU and LNGC

Two vessels are considered in the MARCOL analysis: the FSU and an LNG-carrier. The FSU is the Wakaba Maru, a Moss-type LNGC which will be converted for use as FSU, but this does not affect the general structure of the vessel. A likely vessel to be delivering LNG to the new power plant is the Gemmata, also a Moss-type LNGC. It is assumed that the structure of the Gemmata will be similar to the Wakaba Maru, for which a drawing of a typical cross-section was provided.

A conservative approach is taken when modelling a Moss type tanker with spherical tanks. It is assumed that the spherical tanks provide no structural resistance and a collision does not take place “in between” two spherical tanks. Therefore, the found penetration of the inner shell is considered as a hole in the cargo containment of identical size. The general arrangement plan, see Figure 5-1 and the midship section drawing of the Wakaba Maru, see Figure 5-2, were used to build the structural model of the FSU and the LNGC in MARCOL. More details regarding the Wakaba Maru, such as the principal dimensions, can be found in Section 3.2.

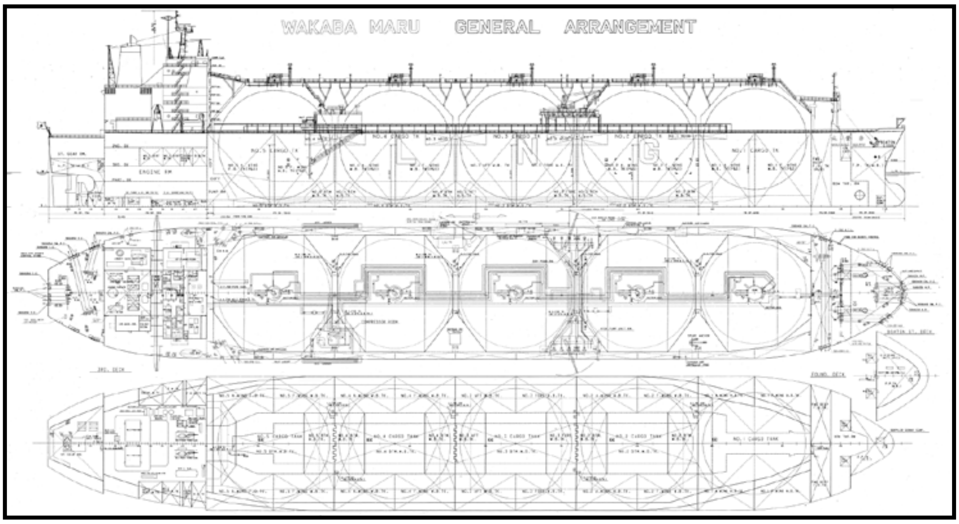

Figure 5-1 General arrangement Wakaba Maru

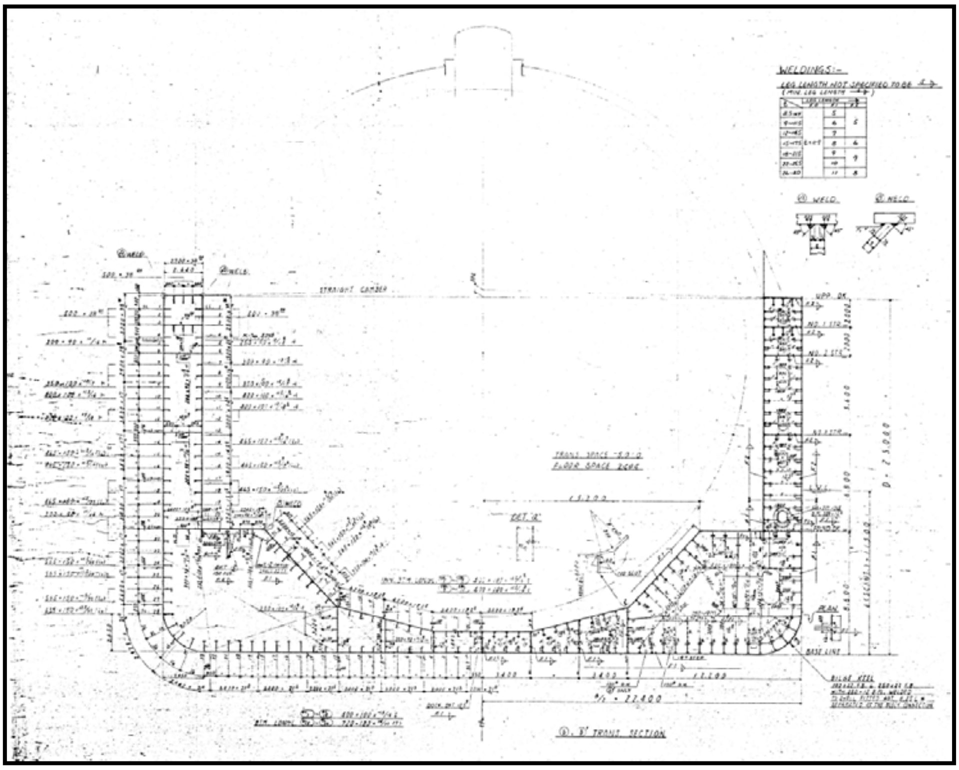

Figure 5-2 Midship section Wakaba Maru

The first step of building the structural model in MARCOL, is to translate these drawings to an overview, in which the outer shell, inner shell, stringers and double bottom are indicated. Stiffeners on the plates are identified and converted to equivalent plate thickness. The result is shown in Figure 5-3.

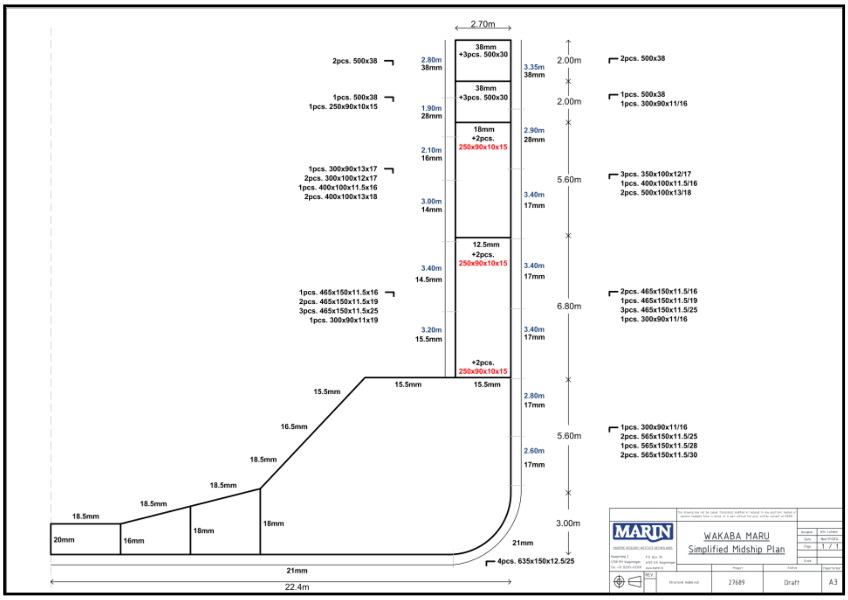

Figure 5-3 Simplified midship section Wakabu Maru

Next, the structural model is build in MARCOL, making use of orthogonally placed elements only. This implies that the shape of curved plates and plates with an angle are simplified. An example starting point of a collision in MARCOL, with one section of the

FSU and a small bulk carrier with a length of 60m, is shown in Figure 5-4. In case the striking vessel penetrates the outer shell, and as a result more sections are involved in the collision, these sections are automatically added to the simulation. Note that the striking vessel in MARCOL is not considered rigid, and will potentially dissipate energy during the collision when its bow deforms.

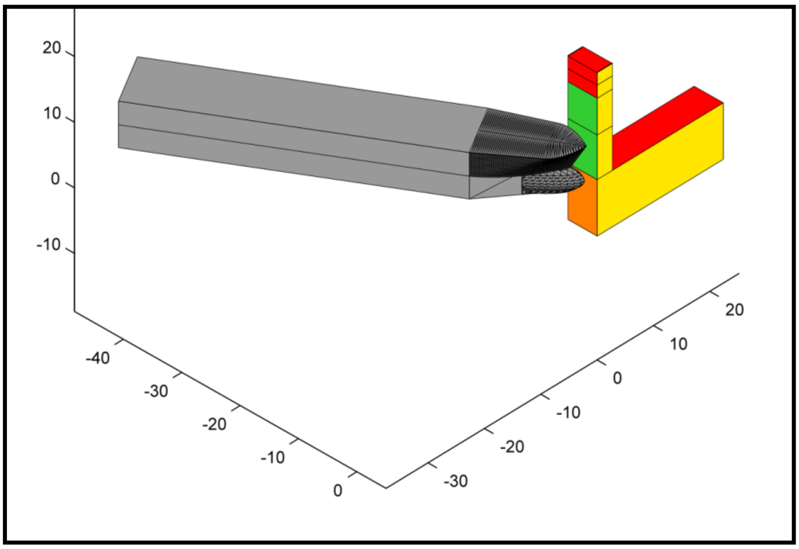

Figure 5-4 Collision between the FSU and a small bulk carrier of 60 meters. The colours of the plates in the structural model, indicate the (equivalent) plate thickness, varying from 25 mm (green), to 57 mm (red).

5.3 MARCOL calculations

MARCOL calculations were carried out for a number of scenarios that are representative for the situations occurring in relation to the new terminal. Table 5-1 shows 5 different scenarios, for which different collisions can lead to a hole in a tank of the 'collided vessel'. Scenario 2 is also considered representative when the LNGC is manoeuvring at low speed from the turning area to berth at the FSU. For the scenarios presented in the table, the consequences are calculated for different collision angles (representing Head-on, Overtaking, Crossing collisions) and different impact points on the FSU or LNG-carrier. Two vessel speeds are considered: 4 kn being a typical speed inside the harbour and 7 kn for the speed in the section between pilot station and port entrance. It is assumed that at moment of the collision the speed of the sailing vessel is 70% of the original speed, due to measures taken to avoid a collision.

Table 5-1 Scenarios for MARCOL

Scenario	Collided vessel	Moored/ Sailing	Speed traffic
1	FSU	Permanently moored	low (4kn)
2	LNGC	Moored at FSU	low (4kn)
3	LNGC	Sailing (7kn)	high (7kn)
4	LNGC	Sailing (4kn)	low (4kn)
5	FSU	Permanently moored	high (7kn)

The above mentioned scenarios are project specific scenarios. Within the MARCOL model a large number of calculations are performed per scenario. These consist of the following typical variations:

- Ship types & sizes colliding with LNGC: 51
- Bow shapes colliding vessel: 7
- Positions of collision point on LNGC (bow to stern): 5
- Positions of collision point with respect to the frames: 4
- Angles of collision (15, 30, 60, 90, 120, 150, 165): 7

For the 5 scenarios given in Table 5-1 all above mentioned variations were calculated using MARCOL, resulting in 49980 calculations per scenario. This large number of MARCOL calculations was carried out on Marin's high throughput grid. The resulting output is a database with penetration sizes of the outer shell and the inner shell (the containment) for each collision scenario.

5.4 Damage to the FSU at the jetty

The event that the FSU at the jetty is hit by other traffic is based on the situation that the FSU is at the jetty 24 hours, 365.25 days per year, minus the time that the LNGC is alongside. The number of LNGC calls is 12 per year and the duration of each offloading is 24 hours.

The probability that a collision leads to a hole in the tank of the FSU has been calculated for two different speeds of the vessels visiting the port. In Scenario 1, the traffic speed is low (4kn), and in scenario 5, the speed is high (7kn). In both cases, no collision leads to a hole in the cargo tank. For scenario 1 (low speed) the probability of a hole in the outer shell given a collision is 0.0984, for scenario 5 (high speed) this is 0.115. Taking the ramming and drifting frequencies from Table 4-4, this leads to the probabilities of a hole in the outer shell as presented in Table 5-2.

This means that once every 2426 years, a collision due to ramming or drifting against the FSU leads to a hole in the outer shell. The size of this hole varies from tiny to about 100m2. A collision with a container ship causes the largest hole in the outer shell of the FSU (100m2), but this only happens in about 0.6% of the collisions.

Table 5-2 Probability of a hole in the cargo tank of the FSU (12 LNGC calls per year)

Type of collision	Collision frequency when 24/7 present	Situation occurrence	Collision frequency	Sailing speed	Probability for each collision of a hole in the		Probability per year of a hole in the	
	[1/year]	[h/year]	[1/year]	[kn]	outer shell	LNG tank	outer shell	LNG tank
Ramming	2.44E-03	8478	2.36E-03	7	0.115	0	2.71E-04	0.00E+00
Drifting	1.48E-03	8478	1.43E-03	4	0.0984	0	1.41E-04	0.00E+00
Total	3.92E-03		3.79E-03				4.12E-04	0.00E+00

5.5 Damage to the LNGC moored at the FSU

As for the FSU, given the current traffic situation a collision with an LNG-carrier moored at the FSU will not lead to a hole in the cargo tank. When the speed of the other traffic is assumed to be 4kn, the probability of a hole in the outer shell given a collision is 0.0984. In Table 5-3 the probabilities of a hole in the outer shell of the LNG-carrier are given, where the ramming and drifting frequencies are taken from Table 4-4 scenario 2 (i.e. other ships are prohibited to visit MX Dolphin and MX Power when LNGC is moored).

Table 5-3 Probability of a hole in the cargo tank of the moored LNG-carrier (12 calls per year)

Type of collision	Collision frequency when 24/7 present	Situation occurrence	Collision frequency	Sailing speed	Probability for each collision of a hole in the		Probability per year of a hole in the	
	[1/year]	[h/year]	[1/year]	[kn]	outer shell	LNG tank	outer shell	LNG tank
Ramming	2.57E-03	288	8.44E-05	7	0.115	0	9.71E-06	0.00E+00
Drifting	1.49E-03	288	4.90E-05	4	0.0984	0	4.82E-06	0.00E+00
Total	4.06E-03		1.33E-04				1.45E-05	0.00E+00

5.6 Damage to the LNGC manoeuvring near the FSU

Also for the manoeuvring LNG-carrier no hole in the cargo tank is expected. In case of a manoeuvring LNG-carrier, other ships are prohibited to visit MX Dolphin and MX Power (scenario 2). The duration of the manoeuvring on arrival per call is assumed to be 0.5 hours, and for the departure 0.25 hours. In Table 5-4 the probabilities are given for 12 LNGC calls per year, where the total probability of a hole in the outer shell leads to a frequency of once every 2102827 years.

Table 5-4 Probability of a hole in the cargo tank of the manoeuvring LNG-carrier (12 calls per year)

Type of collision	Collision frequency when 24/7 present	Situation occurrence	Collision frequency	Sailing speed	Probability for each collision of a hole in the		Probability per year of a hole in the	
	[1/year]	[h/year]	[1/year]	[kn]	outer shell	LNG tank	outer shell	LNG tank
Ramming	2.71E-03	9	2.78E-06	7	0.115	0	3.20E-07	0.00E+00
Drifting	1.54E-03	9	1.58E-06	4	0.0984	0	1.56E-07	0.00E+00
Total	4.25E-03		4.36E-06				4.76E-07	0.00E+00

5.7 Damage to the LNG-carrier sailing

The track of the LNGCs calling at the port can be schematised to two sections (Figure 5-5):

- The approach from the pilot station into the port (3900 m), and
- The manoeuvre from the turning area to the terminal (700 m).

The calculated probabilities of a collision between a sailing LNGC and other traffic (Section 4.1.1) are per call to the port and apply therefore for the entire track from the pilot station to the terminal and back (total probability for arrival and departure). Considering that operations to/from MX Power Station and MX Dolphins will not be allowed when an LNGC is at the terminal, the calculated probabilities are entirely attributed to the section from the pilot station into the port.

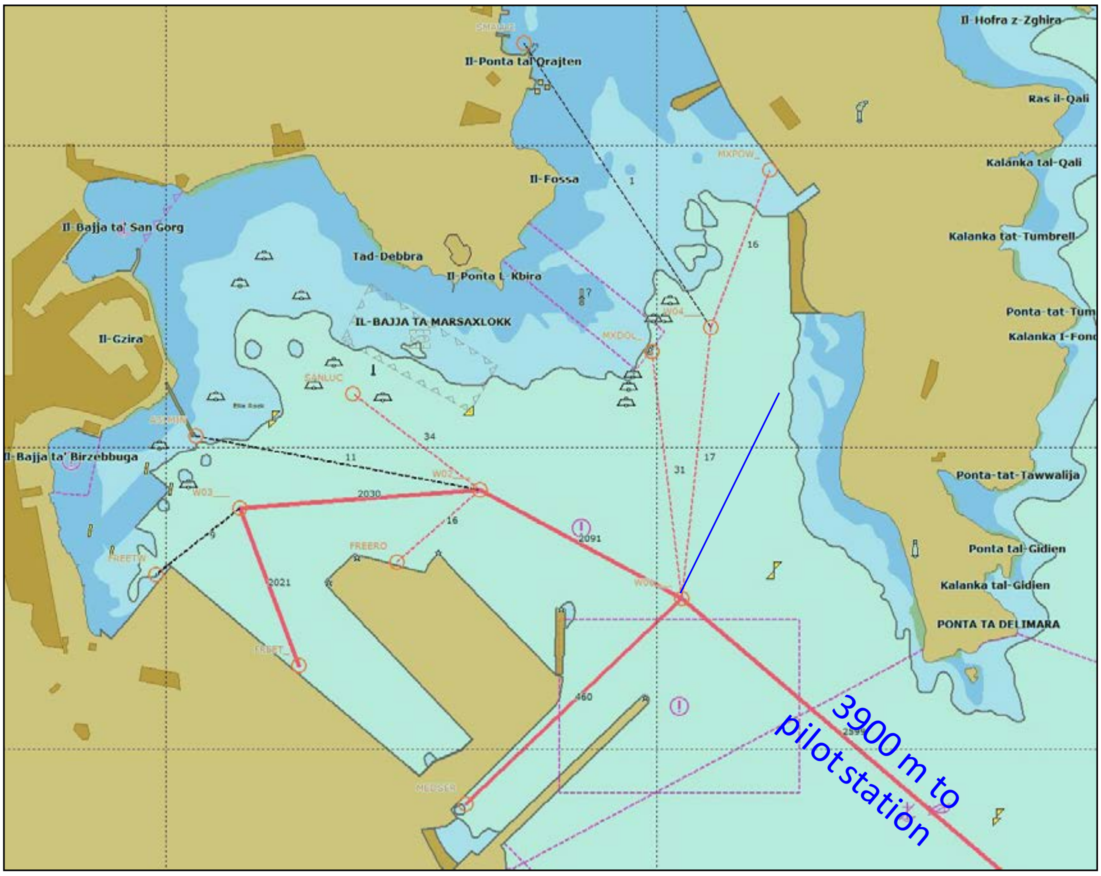

Figure 5-5 Distance sailed by LNGC from the pilot station

The collision probabilities in Chapter 4 are probabilities of a collision for all other traffic calling to the port. Usually the probabilities for damage to the inner and outer shell are therefore also presented as a total for all other traffic. The results of the calculations for the present study show that only 2 of the many considered collision scenarios lead to damage to the inner shell. The probability of damage to the inner shell was therefore evaluated in more detail by analysing these two cases separately, taking into account the probability of a collision with this specific vessel.

Table 5-5 contains the probability of a hole in the outer shell due to a collision between the sailing LNG-carrier and all other passing traffic. The types of collisions considered in 4.1.1 (Head-on, Crossing and Overtaking) are combined with MARCOL results for specific corresponding directions. The third and fourth column give the collision probability per call and per year (taken from Table 4-1), while the fifth column gives the collision frequency per meter of the sailed track (of 3900 m long). This is combined with the probability of a hole in the outer shell per collision (7th column) for the assumed sailing speed (6th column) to the probability to damage of the outer shell per year per meter of the track.

The MARCOL calculations provide also the estimated size of the hole in the outer and inner shell. In some cases the hole in the outer shell is about 80m2 (e.g. when a container ship collides with the LNGC while crossing), but this does not lead to a hole in the inner shell (LNG tank).

Table 5-5 Probability of a hole in the outer shell of a sailing LNGC, for 2 mitigating scenarios, given for each collision as well as per year per meter

Scenario	Type of collision	Collision probability	Collision frequency	Collision frequency along track	Speed other traffic	Probability of a hole in the outer shell	
						per collision	per year
		[per call]	[1/year]	[1/(year.m)]	[kn]		[1/(year.m)]
Pilot, restricted area	Overtaking	1.03E-08	1.24E-07	3.18E-11	7	0.070	2.23E-12
	Crossing	0.00E+00	0.00E+00	0.00E+00	7	0.226	0.00E+00
	Head-on	1.06E-07	1.27E-06	3.25E-10	7	0.064	2.07E-11
	Total	1.16E-07	1.39E-06	3.57E-10			2.29E-11
Pilot, VTS and restricted area	Overtaking	7.23E-10	8.68E-09	2.22E-12	7	0.070	1.56E-13
	Crossing	0.00E+00	0.00E+00	0.00E+00	7	0.226	0.00E+00
	Head-on	7.39E-09	8.87E-08	2.28E-11	7	0.064	1.45E-12
	Total	8.12E-09	9.74E-08	2.50E-11			1.61E-12

Only two of the evaluated collision scenarios result in damage to the inner shell. In both collision scenarios a container ship of 255x32.2m collides with the LNG-carrier while approaching head-on and hitting between two frames. Table 5-6 contains the probability of a collision between a sailing LNG-carrier and a container ship resulting in a hole in the LNG tank. The two scenarios are analysed separately, to take the relative frequency of these vessels into account. The hole in the outer shell is about 60 m2, and the hole in the inner shell is either 0.42 or 0.72 m2. Both holes are above the water line. The holes of 0.42m^2 and 0.72m^2 are assumed to have the same probability of 2.333E-13 (pilot & restriction) or 1.63E-14 (pilot, VTS & restriction) per year per meter. These numbers are calculated by dividing the probabilities in the last column of Table 5-6 by two. It may be noted here again, that this concerns damage to the inner shell. Considering the small holes in the inner shell, it is unlikely that the cargo tanks would be damaged in these two cases.

Table 5-6 Probability of a hole in the LNG tank of a sailing LNGC, for 2 mitigating scenarios, given for each collision as well as per year per meter.

Scenario	Type of collision	Collision probability	Collision frequency	Collision frequency along track	Speed container vessel	Probability of a hole in the inner shell	
						per collision	per year
		[per call]	[1/year]	[1/(year.m)]	[kn]		[1/(year.m)]
Pilot, restricted area	Overtaking	1.50E-09	1.80E-08	4.61E-12	7	0	0.00E+00
	Crossing	0.00E+00	0.00E+00	0.00E+00	7	0	0.00E+00
	Head-on	1.21E-08	1.46E-07	3.73E-11	7	0.0125	4.67E-13
	Total	1.36E-08	1.64E-07	4.19E-11			4.67E-13
Pilot, VTS and restricted area	Overtaking	1.05E-10	1.26E-09	3.23E-13	7	0	0.00E+00
	Crossing	0.00E+00	0.00E+00	0.00E+00	7	0	0.00E+00
	Head-on	8.49E-10	1.02E-08	2.61E-12	7	0.0125	3.27E-14
	Total	9.54E-10	1.15E-08	2.94E-12			3.27E-14

6 SUMMARY AND CONCLUSIONS

6.1 Objective

The focus of this study is on assessing the probabilities of nautical incidents (collisions and groundings) for the LNGC during a visit to the proposed new facility in Marsaxlokk port. Also the probabilities of a nautical incident for the FSU in the port are assessed. The following individual probabilities have been quantified:

- The probability of a collision between the LNGC and another ship when arriving at or departing from the port;
- The probability of a grounding or contact with the coast of the LNGC when arriving to or departing from the port;
- The probability that a moored LNG-carrier is hit by another vessel sailing in or out of the port;
- The probability that the FSU in the port is hit by another vessel sailing in or out of the port.

6.2 Collision with LNGC when sailing

The total expected number of collisions per year, based on **12** calls per year, including a pilot on board the LNGC is 1.39E-05, this means once every 71866 years. When next to a pilot, also a so-called restricted area is introduced around the sailing LNG-carrier, the total expected number of collisions will be 1.39E-06, once every 718657 years.
The majority of the collisions, 91%, will be a head-on collision and only 9% will be overtaking. The probability that one of these two types of collision will result in large damage to the LNG-carrier, such that one of the cargo tanks is penetrated, is relatively small. The most damage to the cargo tanks is expected as result of a crossing collision. In this case there are no real crossing collisions expected with the other traffic inside the port of Marsaxlokk.

6.3 Grounding of LNGC when sailing

The total grounding probability (including pilot on board all the way and tugs connecting) is 9.05E-7 per call. Based on **12** calls per year this would be probability of 1.09E-05 per year, corresponding to once every 92081 years. The probability of loss of containment due to grounding is assumed to be negligible.

6.4 Collision with moored FSU and manoeuvring or moored LNGC

The moored FSU and the LNGC moored alongside the FSU are very similar situations, which have similar basic collision probabilities. When the LNGC is moored at the jetty (or manoeuvring near it), other ships are not allowed to pass the carrier to visit MX Power or MX Dolphins. This reduces the basic probability that other ships could strike the moored LNGC compared to the moored FSU. The actual probability that a moored LNGC is hit by another vessel is significantly lower because this situation occurs a much smaller part of time.

From all considered situations, the probability that the FSU is hit by other traffic is the largest. This is due to the fact that this is a permanent situation.

6.5 Probability of a hole in the cargo tank

A large number of collision calculations have been carried out for 5 basic scenarios for the moored FSU, the moored LNGC and the sailing LNGC. Several collision scenarios may result in a hole in the outer shell of the LNGC, but only 2 of the calculated collision cases lead to a hole in the inner shell. A beam-on collision has the highest risk on a hole in the outer shell.

In spite of the larger collision probability compared to other considered scenarios, the probability of a hole in the cargo tank of the moored FSU or the moored LNGC can be considered as negligible, taking into account the traffic database as defined in this study and the assumptions of the speed of the other traffic. This is mainly due to the fact that the speed of other traffic in the port is relatively low.

For a sailing LNGC there are only two calculated cases resulting in a hole in inner shell (the containment system), both head-on collisions of the sailing LNGC encountering a container vessel. Only in those two cases the combination of the energy of the two vessels and the position of the impact on the LNGC is sufficient to cause damage to the inner shell. The calculated holes of $0.42m^2$ and $0.72m^2$ are assumed to have the same probability of 2.333E-13 (pilot & restriction) or 1.633E-14 (pilot, VTS & restriction) per year per meter.

6.6 Conclusions

From the risk study we draw the following conclusions:

- The probability of tank penetration after a collision with the sailing LNGC is low (assuming a maximum speed of 7kn). It can, however, be reduced by imposing a speed limit in the area, or a restriction of vessels sailing in the port while the LNGC is arriving or departing.
- The probability that the cargo tank of the LNGC is damaged due to grounding is negligible.
- The probability that the cargo tank of the FSU is penetrated is extremely low.
- The probability that the cargo tank of the LNGC is penetrated when being moored at or manoeuvring near the terminal is low compared to other projects

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