THE LNG TERMINAL OF ZEEBRUGGE: FUTURE DEVELOPMENTS

by

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ABSTRACT

In 1976, Zeebrugge – Belgium’s main coastal harbor – has been selected to accommodate the national LNG Terminal. Construction works started in 1979. For safety reasons, the LNG Terminal was constructed into the outer harbor, on a site of some 30 hectares. The terminal is operational since 1987. From 2004 to 2008 a first extension of the terminal took place. At this moment (2009), studies for a second jetty and additional storage and send-out facilities are ongoing.

This paper treats briefly the history of the LNG terminal of Zeebrugge. Further the LNG market request, being the reason for the planned second extension, is considered. Finally the planning, design, construction, safety issues...of the future developments.

1 THE LNG PROCESS

LNG stands for Liquified Natural Gas and concerns natural gas which has been made liquid by cooling it down to its boiling point (-162°C at atmospheric pressure). The main component of LNG is methane, together with some heavier hydrocarbons, and some nitrogen.

After capturing the natural gas from the gas field, it is transported to the consumer either under gas form (mostly through pipelines) either as LNG (Fig. 1). The natural gas is transformed to LNG in liquefaction plants, situated at or nearby the LNG export terminal. The LNG is transported afterwards by LNG ships to import terminals, where the LNG is stored and turned into natural gas again by a regasification process. At that point the natural gas is ready to be distributed by pipelines to the consumers.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{LNG_distribution_chain.png}
\caption{The LNG distribution chain}
\end{figure}

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The choice between transportation of natural gas through pipelines or under form of LNG, is a trade-off between several parameters:

- **Investment cost:** For smaller distances, the investment cost for a pipeline system is less than for LNG; for longer distances (from about 3000 km), this shifts in the advantage of LNG.
- **Energy consumption:** Energy consumption is higher for the LNG process - about 10% of the gas is consumed in the liquefaction, transportation and regasification process.
- **Flexibility:** Generally, for every export capacity unit two or three import capacity units exist. This makes the LNG market a real ‘world’ market, because a ship loaded at an export terminal, can sail to any import terminal having capacity available. In the actual world market, it can be seen that LNG is exported to the region where gas prices are the highest (Asia – US – Europe). This flexibility does not exist, or only on smaller scale, for the pipeline systems.

The processing of the LNG at the Zeebrugge import terminal can be described as follows (Fig. 2):

- Once the LNG carrier is connected to the jetty, unloading arms and a vapor return arm are connected to the cargo tanks and the ship pumps the LNG to the on land storage tanks.
- The LNG is stored in LNG tanks, which are kept at light overpressure (typically 50-200 mbarg), where the LNG is at its boiling point. The storage tank is insulated as good as possible. The boil off gas in the tank, is transferred to the boil off gas system, and by the use of compressors, injected in the recondenser, where this boil-off gas is re-liquefied in the liquid LNG flow. The liquid LNG flow is generated by in-tank LNG pumps.
- High pressure LNG pumps pump the LNG to a pressure of 90 à 100 barg.
- Regasification of the LNG - two systems are used:

![Processing of the LNG at the Zeebrugge import terminal](image-url)
Submerged Combustion Vaporizers (SCV): the LNG flows through a tube bundle in a water bath, which is cold at a temperature of 15°C, by burning natural gas. The LNG undergoes transition from liquid to gas through a one phase flow (if working above 72 barg).

Combined Heat & Power Unit (CHP): in agreement with Electrabel, a CHP was built on the LNG terminal, delivering 40 MW of electricity, and 72 MW or heat, which is in a quench tower transferred to water, which on its turn is fed to the water baths of the SCV’s.

- Pressure & flow are measured and regulated.
- In case the boil-off gas cannot be recondensed in the recondensor, the gas can be compressed up to grid pressure through reciprocating compressors, called ‘pipeline compressors’.

2 HISTORY FROM 1970’S UP TO 2009

2.1 Short presentation of Fluxys, Fluxys LNG & Zeebrugge area

Fig. 3 shows an overview of the high pressure transport and transit lines, compressor stations, underground storage, LNG Peak Shaving Plant and LNG Terminal at Zeebrugge.

In the actual investment program, the east-west as well as north-south transport capacity are being evaluated to be increased, by placing additional pipelines and increasing the compression stations capacity (new station of Zelzate operational since 2009, increase of capacity at Weelde, Berneau and Winksele between 2010-2013). Also, the capacity of the underground storage at Loenhout is under expansion.

Fig. 3: Overview of the transport-transit grid and main facilities of Fluxys

The drawing below (Fig. 4) shows the importance of the Zeebrugge area:

- LNG Terminal Zeebrugge
- Peak Shaving Plant
- Zeepipe coming from Norway (ZPT)
- Interconnector coming from Bacton – UK (flow possible in 2 directions)
Fig. 4: Overview of gas facilities in Zeebrugge area

The drawing in Par 3.1.2 on its turn shows the main pipelines from the Zeebrugge area through Belgium to France, the Netherlands and Germany.

Because of the importance of the Zeebrugge area, it also here that Huberator was created, a platform where traders can meet, and trade gas amongst each other. The gas prices at the Hub are an important reference for the gas prices in Europe.

2.2 History from 1970 – 2004

When in the 1970’s the gas consumption in Belgium increased significantly, the authorities and Distrigas (at that time, the combined gas supply and transport company) looked for a storage facility at the Belgian coast. In 1974, the decision was taken to construct the Peak Shaving Plant (Fig. 5), which liquefied natural gas coming by pipeline from the Netherlands. The LNG was stored in LNG and liquid nitrogen tanks, and in wintertime at peak consumption, regasified. The ‘first drop of liquid’ was realized in 1978.

At this point, we can already mention that in 1987, the liquefaction unit was de-commissioned, and from then on supply of LNG was performed by LNG trucks coming from the LNG Terminal.

Fig. 5: Fluxys peak shaving plant at Dudzele

In 1975, in full energy crisis, a supply contract for 20 years with the Algerian Sonatrach was concluded, with provision for first supply in 1980.
The initial purpose was to convert the Peak Shaving Plant to a full LNG Terminal, but no final authorization was possible to allow big LNG ships through the lock Vandamme.

Since importation of LNG necessitated the development of a suitable infrastructure, the Belgian government decided in 1977 to build the LNG Terminal at Zeebrugge, where important harbour extension works were in progress.

In trying to meet the date of the first delivery, some thought was given to a temporary solution consisting of a floating terminal, since the site on which the terminal was to be built, was still to be reclaimed from the North Sea. The floating terminal concept involved one or two modified LNG carrier structures for storage and an additional modified structure to contain the regasification plant. This project was soon abandoned, and the first delivery had been delayed to October 1982.

Again, meeting that second date was not possible with a conventionally designed receiving terminal since at that time the site was planned to be ready in early 1980. Considerable effort was then given to develop a solution in which the storage tanks would be built in a dry-dock elsewhere, then floated, towed to the site and partially sunk next to the reclaimed land on which the regasification plant was to be built. In December 1978, this idea was also abandoned for reasons of safety and reliability, and it was decided to go for a conventional design and to wait for the completion of the terminal site on the Eastern breakwater at the outer harbor of Zeebrugge.

As the LNG Terminal sub-infrastructure, i.e: site and protecting breakwater, were constructed before the protecting outer harbor breakwaters were finished, the LNG site and breakwater were conceived to withstand the open sea during a period of five years. Due to the poor bearing capacity of the sea bottom at that location, soil replacement and improvement had to be performed in several zones. Fig. 6 shows a picture of the construction works of the outer harbor of Zeebrugge (Van Damme, L. & Steyaert, L. & Gyselynck, G. & D'Hondt, E. (1982)).

In this first project, following main installations were built:

- 1 jetty, for receiving LNG carriers (at that time, typically up to 140,000 m³ of LNG),
- 3 full containment semi-buried LNG tanks with workable volume of 80,000 m³ of LNG each
- send-out facilities for guaranteed send-out rate of 900,000 m³(n)/h.

The first unloading took place in June 1987. An overview of the LNG Terminal anno 2000 is given in Fig. 7.
2.3 Zeebrugge LNG 1st Extension project 2004-2008

Because in 2007 the 20-year supply contract of LNG between Algeria and Belgium expired, and because of the growth of the LNG market in general, it was decided, after an extensive market consultation, to double the capacity of the LNG Terminal, by constructing:

- One additional storage tank of 140,000 m³ working volume (Fig. 8)
- Send-out facilities for an additional 900,000 m³(n)/h, which brings the total up to 1,700,000 m³(n)/h of guaranteed send-out capacity
- Related installations: a fourth firewater pump, the required piping and pipe racks, utility buildings, a second pipeline compressor, active protection systems

2.4 Some statistics anno 2009

Anno 2009, following statistics can be mentioned:

- Reception of 1,100 LNG carriers (of which 23 Q-flex)
- Unloading of 62 million tonnes LNG = 80 bcm of natural gas
- Storage capacity: 380,000 m³ LNG
- Guaranteed send-out capacity: 1,700,000 m³/h
- LNG carriers from 80,000 to 217,000 m³ LNG
- About 60 different ships received
3 DESIGN AND SAFETY MEASURES

Since the LNG Terminal at Zeebrugge was the first of the kind in Western Europe, and legislation was different from today, the entire process of decision making was supervised by the so-called 'Interministerial Working Group safety measures LNG Terminal Zeebrugge'.

Several studies, which will be further discussed in Par. 6.2 ‘Safety studies and permitting’, were performed by external consultants, such as Applied Technology Corporation (for heat and dispersion calculations), Cremer & Warner (safety studies – nautical and land based) and Battelle (TNT explosion).

The results of those studies, and decisions made by the Interministerial Working Group, were summarized in the operating permit. Those prescriptions are still valid today for other projects, unless deviations are approved by this Interministerial Working Group.

Some of the main safety measures are described and discussed below:

- Internal safety distances: imposed distances are well beyond those imposed by the LNG standards such as NFPA59A (Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)) and EN1473 (Installation and equipment for liquefied natural gas. Design of onshore installations), and this is an important passive safety measure;
- All LNG piping runs over impoundings, which, in case of leak, contain the leak, and limit the evaporation rate or radiation of the pool drastically;
- Extensive High Expansion Foam and Dry Chemical Powder extinguishing means;
- Scenario of catastrophic tank failure is considered, and in case of fire, the other tanks remain intact through deluge systems. This leads the LNG Terminal to a firewatergrid 36" all around the terminal, with 4 firewaterpumps, each doing about 3000 m³/h. Buildings are also protected with deluge systems, and in certain areas, water curtains separate process zones.
- Construction of the tanks: as on most of the LNG import terminals today, the tanks are of the full containment type, which means the liquid is contained in a primary container, and a secondary container contains not only the liquid in case the first container would fail, but contains also the gaseous gas (Fig. 9).

![Fig. 9: Principle of full containment tank according to EN 1473 (EN 1473 version 2007)](image)

The main differences between the tanks at LNG Terminal Zeebrugge, and most tanks built according to the design standards, are:

- The tanks in Zeebrugge are constructed for full hydro test, i.e. the tanks are tested with water level up to the maximum LNG level. Because the density of water is more than the double of
LNG, the inner tanks and foundations need to be designed to resist the forces from the full hydro test;
- The top of the tanks may not exceed 22 m above ground level;
- On top of the full containment, an annular space between the concrete outer tank and the diaphragm wall is created. This annular space is sufficient in volume, to contain the entire volume of LNG in case the 9% Nickel tank and the concrete outer tank would fail, and can be completely filled with High Expansion Foam in order to limit the evaporation rate or radiation;
- The tanks in Zeebrugge are designed for TNT explosion of 500 tons of TNT in the harbor;
- The tanks in Zeebrugge are designed to resist the impact of a small aircraft type Cessna.

The sketch below of the 4th tank shows the main principle (Fig. 10):
- At first, diaphragm walls are constructed down to the Bartoon clay layer, about 45 m below grade;
- After pouring a ring beam, the sand is emptied from the pit. During this task, a water depressurization below the Bartoon clay layer is applied, in order to avoid cracks or burst in this layer;
- After soil improvement, the foundation of the concrete outer tank is started;
- After construction of the outer tank walls, and Carbon Steel vapor barrier, the prefabricated Carbon steel roof is lifted;
- Next, the concrete roof can be poured, and the 9% self supporting Ni-steel tank can be constructed;
- Remark: the foundation can be posed on vertical beams, or directly on the soil. For the initial 3 tanks, the first principle was applied, for the 4th tank, the second principle was applied. In this last case, also a slab heating system to prevent soil freezing is installed.

![Fig. 10: Drawing (section) of 4th LNG tank](image)

4 LNG MARKET – WORLDWIDE, EUROPE, WESTERN EUROPE ANNO 2009

On a global world level, the importance of natural gas and LNG is still growing, with an expected growth of 17% from 2007-2030. However, for 2009 the primary gas demand will decrease by 3% due to economic contraction. (World Energy Outlook 2009 Fact Sheet, International Energy Agency, available on www.iea.org)
On a world level, the share of LNG on the total natural gas (pipeline and LNG combined), is about 27% of the total (excluding Former Soviet Union and United Arab Emirates) (source : GIIGNL, Report LNG Industry 2008 available on www.giignl.org)

In total, 26 LNG export terminals exist (and 60 ‘projects’) over 15 countries, against 60 LNG import terminals over 18 countries (and 181 ‘projects) (California Energy Commission, 2009. Website : http://www.energy.ca.gov/lng/international.html).

The major quantity of natural gas transported to Western Europe by pipeline is supplied by Norway & the Netherlands, with a growing importance of Russian gas. Major pipeline projects from Russia to Europe are being developed. Market analysis shows a strong decline in intra-EU production of natural gas (Norway excluded) from 203 bcm (billion Nm³) in 2008 to 90 bcm in 2020. These gaps will be filled mainly with natural gas from Russia through pipelines and by LNG. European gas supply dependence towards LNG sources is therefore set to double to almost 20% by 2020 (source : European gas demand prospects : How to meet long term needs, by Armelle Lecarpentier, Gas Analyst, CEDIGAZ)

Most relevant for the commercial position of Zeebrugge, are the LNG Terminals in the UK, France and the Netherlands. In France, several projects are at stake at the Atlantic coast, more in particular Antifer near Le Havre, Le Verdon near Bordeaux and the nearest, Dunkerque LNG. In the Netherlands, the Gate terminal at Rotterdam is under construction, other projects in Rotterdam (Europoort) and in Eemshaven are under study.

We refer also to the LNG map (Fig. 11) of GLE (Gas LNG Europe), an organization which currently gathers and represents the interest of 16 LNG terminal operators in Europe. LNG Terminals marked in blue in Fig. 11 are existing and operational, terminals in red are under construction, and terminals in yellow are under study or operational beyond 2011.

![LNG map](www.gie.eu.com)

A potential customer wanting to import LNG into western Europe, makes a trade-off between the cost he has to pay for the service, the kind of service offered or available, the timing this service is available, and the flexibility and opportunities offered by the transmission grid downstream of the LNG Terminal.
5 MARKET REQUEST FOR LNG TERMINAL ZEEBRUGGE

5.1 LNG-RV

LNG-Regasification Vessels (LNG-RV) are now in operation since some years. Brand new LNG-RV’s were built by Exmar and Excelerate Energy, and by 2010, they will have a fleet of 8 LNG-RV’s. Different options with these vessels exist:

- Either the LNG-RV remains at the jetty or at a buoy with Submerged Turret Loading Buoy System (STLT), and another LNG ship unloads its LNG in the LNG-RV through ship-to-ship transfer
- Either the LNG-RV sails as a classic LNG ship, and then regasifies its LNG directly into a high pressure gas grid

In addition to these new build vessels, also existing LNG ships have been converted and equipped with on-board regasification facilities in order to stay on one dedicated place at a jetty, to receive LNG from another LNG ship and to regasify the LNG into a high pressure transport grid.

Exmar and Excelerate Energy performed their first LNG-RV operations at Gulf Gateway Deepwater Port (Gulf of Mexico) in 2005, and since then, at Teesside (UK), Bahia Blanca (Argentina), North East Gateway (USA) and Mina Al Ahmadi Gas Port (Kuwait), and is also looking for access to Belgium.

Analyses have been done to have access at Antwerp via the Scheldt, or off shore before the coast of Zeebrugge, but finally, an agreement was made with Fluxys LNG, whereas Fluxys LNG will develop a jetty fit to receive LNG-RV’s, with direct connection to the high pressure transmission grid.

Fig. 12: The world’s first regasification vessel Excelsior, leaving the shipyard in January 2005

The LNG-RV vessels of the Exmar-Excelerate fleet, can transport 138,000-151,000m³ of LNG, and need about 6 days to regasify its content of LNG into the grid at maximum capacity.

A Memorandum of Understanding has been signed between Fluxys LNG and Exmar setting out their agreement, where Fluxys LNG will perform the detailed study for a jetty fit to moor regasification ships, and Exmar is prepared to book long-term capacity.

Other main players on the market are Golar (converted vessels) and GDF Suez/Leif Hoegh with its Neptune vessels.

5.2 ‘Small’ LNG ships

A first potential market for small LNG ships, is the one of ‘stranded’ customers: locations where development of a transport grid is too expensive. For these customers, multiple small LNG storage...
facilities exist, which are supplied by small LNG ships. These small LNG ships supply LNG either at local liquefaction plants, or could supply LNG in Zeebrugge.

Another market which could develop in time, is the one of LNG Bunkering, as legislation for emissions from ships will become more and more severe, initially on SO\textsubscript{x} and NO\textsubscript{x}, and later also CO\textsubscript{2}. Natural gas as a fuel can address all these issues, without having to install emission treatment equipments such as SCR (Selective Catalytic Reduction) and EGR (Exhaust Gas Recirculation), and reduce SO\textsubscript{x} to zero, NO\textsubscript{x} with 80-90% and reduce CO\textsubscript{2} with 20-25%. With MARPOL VI coming into effect, more and more shippers (especially for ECA zones North Sea and East Sea) get interested in LNG as fuel, and thus other shippers get interested to develop LNG bunkering services. MARPOL VI Tier III will require from 2016 80% lower NOx-emissions than today (Source : Werner, K.)

5.3 LNG Storage & Regasification capacity
Fluxys LNG has had an Open Season in 2008, in order to know the market interest in additional storage and regasification capacity.

It is known as a fact, that Belgium has too few storage capacity for natural gas, having only the underground storage of Loenhout, and the Peak Shaving Plant at Dudzele. Storage capacity is important for operational reasons, so that at high peak off-take, especially in winter time, the grid can be fed with sufficient molecules of gas. On the other hand, storage does create also commercial opportunities for the traders.

As a conclusion of the open season, Fluxys LNG can conclude that there is a big request for storage capacity in Belgium. The remarks to be made are that this request is in competition with LNG storage capacity in Dunkerque, Rotterdam and other LNG Terminals, and that a commercial Shipper can only express a firm interest, in case the horizon for realization of the project is not more than 6 à 7 years ahead.

The required regasification capacity is linked to the kind of services offered in one ‘slot’ (combination of jetty-capacity, storage capacity and send-out capacity in well defined operational rules), or can be subscribed by the transmission operator, who can you use this capacity in order to perform grid balancing of the transmission grid.

5.4 Q-flex
Since 2008, after the required dredging works were performed by the Port Authority and all permits were in place, Q-flex ships with a capacity of 217,000 m\textsuperscript{3} of LNG can enter the harbor of Zeebrugge. Since then, about 20 Q-flex vessels moored at the LNG Terminal Zeebrugge, and it is likely that the quantity of Q-flex vessels will only grow in the future.

5.5 Q-max
Since 2008, the first Q-max LNG vessels, with a capacity of up to 265,000 m\textsuperscript{3} of LNG and a length of 355 m, are operational.

Fluxys LNG is performing the required studies and preparing the required permits, in order to be able to receive Q-max vessels at its jetty in Zeebrugge.

5.6 Loading LNG
Since 2008, Fluxys LNG offers LNG loading services for LNG vessels, which has been used several times since then.

6 PLANNED PROJECTS IN ZEEBRUGGE

6.1 Description – overview

6.1.1 Open Rack Vaporiser
In frame of rational energy use, reduction of gas consumption and emissions, an ‘Open Rack Vaporiser’ (ORV, Fig. 13) will be installed, which will use the heat of the seawater to regasify LNG instead of burning gas in the Submerged Combustion Vaporiser (SCV). The principle is that LNG flows through narrow pipes
in a bundle, over which the ‘hot’ seawater flows. The seawater cools down, and the LNG heats up to a temperature slightly above 0°C.

**Fig. 13: Principle drawing of Open Rack Vaporiser**

It is to be noted that most of the southern LNG Terminals (or the more northern ones next to power installations which have hot cooling water as residual product) run on SCV’s.

Because the temperature of the seawater at Zeebrugge drops sometimes often below the minimum temperature of 6°C in order to guarantee the contractual send-out rate, SCV’s were installed for the initial and the extension project.

To solve this problem, this ORV will receive also a backup heating system for the seawater, so that its capacity can be used throughout the year, and the guaranteed send-out rate of the LNG Terminal will go up to 1,900,000 m³(n)/h.

The main issues to be solved, were:

- Seawater outlet and temperature dispersion: because being surrounded by natural protected areas, the only place to be allowed to reject the cold seawater, was in the LNG dock. The risk of re-aspiring the cold seawater was analyzed based upon a 3D water dispersion model by the MUMM

- Anti-fouling: extensive studies were carried out by Ghent University and Laborelec, to determine the minimum but required level of chlorination. This level has been determined at 0.5 ppm at active chlore during the active seasons of mussels and oysters. On top of this, once a year, a thermo-shock will be applied.

The ORV will be operational end 2011.

### 6.1.2 Project 2nd Jetty

With the sold capacity of 110 slots per year on the existing jetty there is no extra capacity available. In order to be able to respond to the need of having more jetty capacity for the LNG-RV vessels, for loading of LNG vessels, and for unloading of LNG vessels, a second jetty is needed.

Three different layouts were analyzed, based upon ship simulations on the 3D simulator of Flanders Hydraulics (see below), evaluation of impact of meteo conditions (wind, waves,...) and protection against collision.

A very important parameter in this evaluation was also the existence of the Tern Island at the north side of the existing terminal, with 3 species of the Tern which are protected species.

The conclusion of the Interministerial Working Group, was that the Option B as shown below (Fig. 14, Fig 15 is the best solution. Even though the maneuvering is more difficult than in other options, it is proven to
be perfectly safe even in the most severe wind conditions. Once the ship is moored, it is perfectly protected against other ships in the harbor as well as against wave conditions.

![Fig. 14: Plan of the 2nd jetty and extension of the LNG island](image)

The next challenge was to define the routing for all interconnecting piping between the transmission grid, the LNG Terminal and second jetty. After analysis of several options, it was decided to place the High pressure gas pipe 20" between the LNG-RV unloading arm and the transmission grid, in the breakwater. The cryogenic piping, will be placed upon sleepers on top of the dam. In order to avoid difficult and expensive expansion loops, Invar will be used, which is austenitic steel with 36% Nickel and a thermal expansion 10 times lower than that of stainless steel.

![Fig. 15: Impression of the 2nd jetty project](image)

The new jetty mainly consists of an unloading platform, breasting and mooring dolphins, trestle and catwalks. A cross-section over the jetty platform and the access bridge is shown on Figure 16, a front view of the unloading platform with breasting dolphins is given on Figure 17.

![Figure 16 Cross section over jetty platform and trestle](image)
As shown on Figure 16, the jetty is located in front of the existing LNG dike, and therefore needs to be located at sufficient distance away from the dike structure, as to guarantee sufficient water depth at the mooring face and obviously also to avoid stability problems at the dike structure. The available depth at the dolphins has been fixed at -14.00m TAW, which has proven to be adequate for the Q-flex vessels arriving in the LNG dock. Some preliminary dredging will be required prior to jetty construction in order to realize this dock bottom level.

The unloading platform consists of a reinforced concrete deck of 65m length and 33m width composed of prefabricated beams and a cast in place RC slab. The structure is supported by driven open end steel tubular piles of 1200mm diameter and a wall thickness of 18mm, filled with concrete. The platform is connected to the breakwater by means of a pile supported concrete bridge with a length of 50m. All piles are driven to a depth of -22.00m TAW in the dense tertiary sand layers. The structure has been designed for all loads acting on the platform (loading arms, etc…), and also for seismic events characterized by a PGA= 0.29g. Therefore the entire structure has been modeled and analyzed with a FE software capable of performing a dynamic structural analysis. Figure 18 shows an example of the model.

The layout of the dolphins has been fixed in conformity to the results of the mooring studies. The dolphins are composed of monopoles (steel tubular piles with a 2500mm diameter and a variable wall thickness) equipped with a steel platform at the top to fix the quick release hooks. Monopiles are driven to levels -41.00 to -37.00m TAW for the breasting dolphins and to -29.00m for the mooring dolphins. Five breasting dolphins are equipped with fenders and triple quick release hooks and have been designed to absorb the vessel’s energy during berthing, as well as to keep the ship in its position when being unloaded. Six
mooring dolphins are situated approximately 50m closer to the breakwater, and are equipped with double or triple quick release hooks to fix the hawsers. This will allow to fix a Q-flex carrier with a total of 16 or 18 mooring lines.

The upper structure takes into account the need to unload Q-Flex vessels at an unloading rate up to 14,000 m³ LNG/hour with 3 liquid LNG arms and 1 cryogenic vapor return arm, to load small LNG ships (1 combined liquid / vapor return arm) and to unload the LNG-RV vessels (one HP Gas arm).

6.1.3 Extension of LNG Island with storage tanks and regasification facilities

In order to create an island stable enough to support LNG facilities including semi-burried LNG tanks, stable land has to be created at the north side of the existing LNG Terminal, again with the constraint of the Tern Island being present (Fig 19). The construction and the role of the Tern Island were discussed at the PIANC congress in Sydney 2002 (source: L. Van Damme, B. Verboomen and E. Stienen (2002))

In a first step a detailed soil analysis will be performed, in order to determine the exact soil layers at the location of the planned extension of the terminal. Due to strong local erosion during and shortly after the realization of the present land for the LNG terminal, erosion holes of more than 20m arised. These erosion holes have been filled up with soft sediment once the breakwaters of the outer harbor were constructed. The heterogeneity of the soil at the location of the planned extension, together with the presence of the Tern Island nearby, will complicate the construction works of the extension of the LNG Island.

Once a final decision is made by all involved parties (Fluxys LNG, Port Authority of Zeebrugge, Flemish Authority), which requires also an agreement on the Tern Island, LNG tanks and regasification facilities could become operational within +/- 8 years.

The steps which have been decided, are:

- Development of a scale model of the harbor of Zeebrugge at Flanders Hydraulics
- Detailed soil analysis from a hoisting platform, in collaboration with Geotechniek

Seen the commercial and operational interest to create additional storage capacity on a relatively short term, Fluxys LNG is analyzing the possibility to build a 5th storage tank on the remaining free space of the actual LNG island.
6.2 Safety studies & permitting

6.2.1 Nautical study by Flanders Hydraulics / Ghent University
(Source: Eloot, Vantorre, Mostaert (2009))

Flanders Hydraulics, located in Antwerp, owns a powerful ship simulator, as well as models for all types of LNG carriers and the harbor of Zeebrugge.

When evaluating the different options for a 2nd LNG jetty at Zeebrugge, following steps were taken:

- Performing fast time runs with standard maneuvers, for validating the behavior of a Q-max carrier in deep and shallow water;
- Performing fast time runs or force equilibrium in order to determine the kinematical properties of the ship, the tug boat assistance and/or the required space for maneuvering firstly between the access channel and the jetty and secondly between the jetties;
- Performing real time simulations, with LNG pilots for a selected number of ‘worst case’ conditions.

The general conclusion is that for the proposed layout, both jetties are accessible. Some proposals are made regarding the use of tug boats. A typical result of simulations of Q-max and Q-flex maneuvers is given in Fig. 20. At the same time, an analysis is made of emergency scenario’s, where one LNG carrier - under extreme wind conditions, and coming lose from its jetty or tug boats - hits the other LNG carrier. Forces and displacements are calculated, showing no possibility to create a leak in the cargo tanks.

Fig. 20: Typical result of simulations of Q-max and Q-flex maneuvers

6.2.2 Nautical safety study by MARIN

6.2.2.1 Introduction
(Source: BEALE JP, 2006)

First of all, one can not stress enough the safety track record of LNG shipping. Since more than 40 years, LNG is transported per ship, without any accident leading to the failure of the cargo tanks. One of the major reasons is the concept of an LNG ship, where there is significant space between the outer hull of the ship, and the cargo tanks, as well as the strength of the whole.
For a so-called 'Moss' LNG ship with spherical storage tanks, the distances between cargo tanks and outer hull are even greater (Fig. 22).

The most famous incident is the one that happened with the El Paso Paul Kayser in 1979, which hit at nominal speed the rocky bottom at Gibraltar, with severe damage to the outer hull but keeping the cargo tanks intact.

6.2.2.2 Nautical safety study
(Source: Van der Tak (2009))

The nautical safety study performed by MARIN (Maritime Research Institute Netherlands), is the update of the Cremer & Warner study of the late 1970’s, for the nautical aspects.

The main reasons to perform this study are:
- The development of the harbor (actual and future) different from predictions in 1980;
- The development of size and number of ships;
The first step of the safety study encloses in a conservative manner determining the frequency of accidents. This analysis is done according to the SAMSON (Safety assessment Model for Shipping on the North Sea) model developed by MARIN, initially developed for the Dutch authorities, but recently also used for projects in Belgium, off-shore projects, France, Canada and Spain. The basis of the model is a database, based upon Lloyds Register Fairplay and updated with a Dutch database with accidents on sea, in the harbors and on the rivers from 1980 on.

The SAMSON steps can shortly be described as follows:

- All ship movements of all ships are modeled;
- For each ship along the route, the probability to meet an LNG carrier is determined;
- The probability that a meeting of ships becomes a collision, depends on the type and size of the ship and LNG carrier (typically 1 in 10,000 – 100,000 meetings);
- Distinction is made between head-on, overtaking and crossing collisions.

The measures from the nautical procedures are taken into account in the safety study, except the presence of the tug boats and the cable length distance (thus results are conservative).

The ship movements were traced based upon AIS data (Fig. 24), and the traffic view 2030 was determined in close cooperation with the Port Authority.

The result of the probability analysis is the probability of collision for one LNG route.

The next step of the study, is the so-called MARCOL-step (Maritime Collision). MARIN developed a collision damage model, which requires minimal input, is time efficient, and sufficiently accurate. This analytical model is much more accurate than empirical formulas, somewhat less accurate than Finite Element Models, but much faster than Finite Element Models. The MARCOL model allows running tens of thousands of collision scenario’s, with different impact speeds, angles, depths and types of ships.

The information needed from the collided vessel are the characterizing segments with structural elements (stringers and decks).
The MARCOL model was full scale tested in 1998 by Bart Boon Research Consultancy in collaboration with the TNO (Fig. 25).

![Fig. 25: Full scale testing of the MARCOL model](image)

The result of the MARCOL model, in combination with the results of the SAMSON model, give for each LNG trajectory, and for each part of the trajectory, the probability of the existence of a whole in the LNG carrier, with its surface, and distinction between hole above and below water level.

### 6.2.3 Consequence analysis and safety studies for land installations

For the land installations, the Flemish legislation requires an external safety report, and the rules and failure probabilities to be followed. Each failure scenario is studied regarding probability and consequence, and the final outcome of the study are the risk contours around the installations.

The final criteria to be respected are the $10^{-5}$ IRC (Individual Risk Contour per year) not to exceed the borders of the plant, $10^{-6}$ IRC not to reach habitations and $10^{-7}$ IRC not to reach sensitive areas. Also societal risk is evaluated against acceptance criteria.

It has been decided to follow the same methodology to the results of the nautical safety study. This will be done early 2010.

### 7 CONCLUSION / SUMMARY

In 1976, Zeebrugge – Belgium’s main coastal harbour – has been selected to accommodate the national LNG Terminal into the outer harbour. Construction works started in 1979. During this first project, 1 jetty for receiving LNG carriers (up to 140,000m³ of LNG) was built, 3 full containment semi-buried LNG tanks with a workable volume of 80,000m³ each and send-out facilities for a guaranteed send-out rate of 900,000m³(n)/h. In 1987 the terminal was operational.

As a 20-year supply contract of LNG between Algeria and Belgium expired in 2007, and because of the growth of the LNG market in general, between 2004 and 2008 a first extension of the LNG terminal took place. The capacity of the terminal was doubled by building one additional storage tank of 140,000m³ working volume, send out facilities for an additional 900,000m³(n)/h send-out rate and some related installations (a fourth firewater pump, the required piping and pipe racks, utility buildings, a second pipeline compressor, active protection systems).

Since the LNG Terminal at Zeebrugge was the first of the kind in Western Europe, the entire process of decision making was supervised by the so-called ‘Interministerial Working Group safety measures LNG Terminal Zeebrugge’.

On a global world level, the importance of natural gas and LNG is still growing. At this moment (2009), the fleet of LNG regasification vessels on the one hand and small LNG-ships on the other hand is growing. A market request showed that additional storage capacity and regasification capacity at
Zeebrugge is asked for. It should be mentioned that the request for extension in Zeebrugge is in direct competition with LNG storage capacity in Dunkerkque, Rotterdam and other LNG Terminals.

Anno 2009, studies for a second extension of the LNG terminal of Zeebrugge are ongoing. The studies enclose the installation of an Open Rack Vaporizer (operational end of 2011), the construction of a second jetty for LNG regasification vessels (to be finished in 2012), the extension of the LNG Island with storage tanks and regasification facilities and possibly a 5th storage tank on the shorter term in order to fulfill the LNG market needs.

Extensive safety studies are ongoing for this second extension. Nautical studies using a ship simulator are performed by Flanders Hydraulics and Ghent University. Nautical safety studies using the SAMSON model and the MARCOL model are performed by MARIN. Also consequence analyses and safety studies are performed for the land installations.

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