MARINTEK and the Safe and Efficient LNG Sea Transport

The size, capacity and numbers of LNG-carriers will increase significantly in the years to come. A number of new terminals, offshore fixed and floating terminals will be constructed, raising several technological and operational challenges in ship design and equipment, ship handling and training as well as in terminal design and operation.

MARINTEK has the knowledge, experience and resources needed to assist the maritime industry in its efforts to develop cost-effective and safe designs.

We are covering a wide range of important aspects of LNG transport at sea:
- Sloshing and impact loads in membrane tanks.
- Hull design for minimizing the dynamic wave loads to avoid structural damages and to optimise speed/power at sea.
- Development of simulation models for training and engineering, models of ships, tugs, mooring lines, fenders etc for all relevant operating modes and conditions.
- Evaluation and testing of terminals in actual environments such as shallow waters, three-dimensional waves and wind.
- Evaluation and testing of flexible hoses for fatigue and extreme loads.
- Developing and optimising the distribution chain.

Our key customers are the leading international oil companies, classification societies, shipyards and ship operators.

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Sloshing and Impact Loads in Membrane Tanks

LNG carriers with membrane type storage tanks are now projected with a significant increase in total loading capacity and tank size. Terminal on- and offloading calls for no restriction of LNG tank filling ratio. Accurate estimation of induced loads from internal violent resonant free surface motion, or sloshing, on the tank structure is needed.

Sloshing and sloshing induced impact loads are highly nonlinear processes. This means that tank loading from regular oscillatory tank motions in computational fluid dynamics (CFD) calculations or model tests cannot be used to accurately represent loads from real irregular tank motions. The sloshing flow usually includes formation of jets and sprays, wave overturning and breaking. State-of-the-art CFD methods cannot be used to reliably predict impact pressures. At best a few oscillation cycles can be reasonably modeled. The reason for this is the importance of physical phenomena highly localized in space and time, for which a CFD solution would require an unrealistically dense discretization in time and space to resolve.

MARINTEK has performed a large number of model tests for different ships and membrane tank geometries. The main objective of these tests has been to identify statistical properties of the peak pressures both with regards to magnitude, location and duration. The model tank is forced to move with irregular motions. The tank motions are found from a realization of ship motions in realistic sea-states.

An essential basis for setting up a test schedule is the identification of critical combinations of tank filling ratio and tank excitation parameters. Numerical tools are used to limit the number of model test cases. Even with the extensive experience gained through all the tests, a large number of pressure sensors are necessary to cover loading hot-spots. An extremely high sampling rate is needed, and the amount of data acquired during a typical run of five hours full-scale time is vast. In order to optimize the test schedule, it is vital to process the data within a reasonable time frame. In-house highly specialized analysis tools have been developed, which render possible a full statistical pressure peak analysis within less than one hour after finishing a test run.

The sloshing flow will influence the ship motions. MARINTEK performs coupled ship motion and sloshing calculations to investigate this effect.

MARINTEK is a partner of the Center of Ships and Offshore Structures, CeSOS, where sloshing is a priority research topic. The multi-modal method currently applied for sloshing analyses at MARINTEK is under further development by CeSOS. This method is documented by several publications in the Journal of Fluid Mechanics. Current research spans experiments utilizing high-speed camera to investigate details of sloshing induced impact flow (figures 2a and b), experiments to validate the three-dimensional multi-modal method (figure 3) and various numerical approaches to model sloshing with heavy induced impacts.
Flexible Hoses for Offshore Loading

Offshore loading of LNG from a floating process unit to a tanker requires a transfer system capable of adapting to large relative movements. Several concepts are being developed, based essentially on two different principles:
- Steel piping incorporating a number of swivels to provide flexibility.
- Flexible hoses.

For both concepts operational reliability and safety are key issues.

MARINTEK operates two test rigs for full-scale dynamic testing of flexible hoses. The larger rig can accommodate specimens up to 15 metres long and 20 inches in diameter. The loading is a combination of tension and bending, simulating the loading of a hose in operation. Internal cooling is provided by liquid nitrogen (-196 °C). In a typical test the fatigue loading of the design life is simulated with an accelerated block loading programme of 1 – 2 million cycles.

The figure shows a test of a seven metre-long section of 10-inch ID hose with end couplings and bend stiffener. The hose consists essentially of a double-wall bellows structure, with the annulus evacuated to provide thermal insulation. Dynamic bending was applied at the far end, static tension at the near end. The test was fully instrumented in order to provide a full record of the load history and response parameters.


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Dynamic test of LNG off-loading hose.

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CeSOS research projects:

Figure 3. Swirling in a square-base tank

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Several technical matters are considered in the design of a terminal, such as:

- Anchoring of ships waiting for access to the terminal
- Number of assisting tugs and power requirement for berthing
- Required mooring system (hawsers, fenders)
- Procedures for berthing and departure
- Availability of the terminal as limited by environmental conditions for the different stages (arrival/berthing, standby alongside berth, offloading, departure)

To determine the loads in mooring lines and fender systems presents several challenges:

- Wave and wind conditions, including effects of sloping seabed, diffraction and reflection from beach and structures.
- Interaction between ship and berth structure
- Nonlinear characteristics of fender and hawser system

A combination of numerical analyses and model tests is required to obtain a realistic ship response and confident estimates of the design forces in hawsers and fenders. Model testing of gravity-base LNG terminals have been carried out in the Ocean Laboratory at MARINTEK. The tests have given important understanding of the physics involved and the importance of modelling of the actual draft, wave and wind conditions.

Through subsequent numerical analysis the dynamic conditions can be studied further, in several steps:

- Hydro- and aerodynamic analysis for estimating the forces on the ship.
- Static analysis to establish mean loads, stiffness, etc.
- Refraction analysis to establish wave conditions outside the berth.
- Calibration of the numerical model, using model test results.
- Dynamic response analysis, time domain or frequency domain, to find motions and forces

The numerical analysis based on a calibrated model is a valuable supplement to the model tests, in which a wide range of environmental conditions (e.g. variation of sea state and wind and wave directions) can be studied. In general the non-linear elastic properties of selected fibre ropes and documented properties (compression-force characteristics and internal damping) of alternative types of fenders can be modelled more accurately in a numerical analysis than in model tests. Series of analyses are therefore also well suited for various parameter studies, such as:

- Variation of hawser configuration and pre-tension
- Variation of fender characteristics, including internal damping and friction
- Systematically introduced failure modes (such as line breakage)

Typical calculation results have been:

- Extreme tension in all the hawsers, varying with weather direction
- Extreme compressive force in all fenders
- Ship motion at the offloading point
- Recommended number and location of mooring lines and fenders, including safety margin for line breakage
- Environmental limits for offloading

In a real-time simulator effects of human actions can be studied, such as hawser connection at arrival or quick release in an abandonment situation.

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Simulator-Based Training

For many years MARINTEK has co-operated with Statoil, Navion and the Ship Manoeuvring Simulator Centre in Trondheim in the development of a simulator-based training programme for deck officers on offshore-loading tankers. Today our focus is on simulator-based training needs for the new generation of LNG carriers operating at all kinds of terminals including offshore loading.

Simulators will be used for training of all deck officers on new LNG carriers as well as for developing and verifying tug boat assistance and operational procedures. Simulator training is a minor insurance cost for safer and more efficient operation of LNG carriers when approaching/leaving a terminal, whether it is land-based, fixed or floating.

In co-operation with other members of the Trondheim Group, consisting of several SINTEF units, the Ship Manoeuvring Simulator Centre and Safetec, nautical safety studies have been performed for the Snøhvit LNG terminal in Northern Norway. Simulation models for the new ships contracted for transport of LNG from the terminal to customers in the USA and Spain will be developed and installed at SMSC for familiarization training of ship crews prior to their first real-life experience of these new ships. Current and wave models for the Melkøya/Snøhvit terminal have been developed using existing and planned topographies for different designs of the terminal. These numerical models have been tested and verified using measurements from the site (for the existing topography) and from small-scale physical models (for modified topographies).

MARINTEK, SMSC and the Norwegian Training Centre – Manila have recently completed a study for Bergesen aimed at improving their company training programme for lightering operations involving LNG carriers. Simulator training has been expanded to include pre- and post-course activities. Company-specific learning notes have also been developed for pre-course and on-course activities. The post-course activities focus on improving the communication between course participants and simulator instructors and the development of a Frequently Asked Questions database for advanced ship handling. For 2004 the study has been expanded to include more shipping companies in Norway and Singapore as part of the Memorandum of Understanding between the Research Council of Norway and the Maritime and Port Authority of Singapore, relating to co-operation in maritime R&D and Education & Training.

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Developing and Optimising the LNG Distribution Chain

MARINTEK has developed a competitive concept for small-scale, short-sea based LNG distribution. This will make natural gas available in regions with lower levels of demand than are commercially viable with pipelines or larger ships. Figure 1 illustrates how the concept could be developed on the western coast of Norway.

The deep-sea LNG market
An LNG production and distribution system is a huge investment and has traditionally been developed on the basis of long-term contracts. This picture is now changing and we are seeing that there are growing opportunities for spot trades in the deep-sea LNG market. This situation offers new possibilities for trading of LNG.

The short-sea LNG market
Small-scale distribution of LNG is a new approach. The source for LNG could be a small-scale LNG production facility, either a base-load LNG plant or an LNG receiving terminal. Compared to the deep-sea LNG market, a short-sea, small-scale LNG distribution system would use smaller ships, in the range from 1 500 m³ to around 10 000 m³ LNG. The receiving facilities and local storage tanks are based on a modular design in order to support standardised solutions with good scalability. As such the concept is based on a multi-modal distribution chain for LNG that would comprise the following elements;
- Small LNG ships
- Modular shore-based storage facilities receiving LNG from the ships.
- Final distribution to end-users by rail or road tankers, and containers or low-pressure pipelines.

The small LNG ships are an important link in the distribution chain. The number of vessels, their capacity and routes should be defined so as to obtain a high frequency of calls at the storage tank facilities. With a short time period between replenishment of LNG to the tank facilities the capacity of, and thereby investment in, regional storage facilities can be kept at a minimum. Figure 2 and Figure 3 show a small LNG ship offloading at an industrial site, and the LNG receiving and storage facilities at site.

In-house (MARINTEK) concept studies

KYSTGASS – Coastal Gas Distribution
A conceptual development of financially viable small-scale LNG distribution systems. The small-scale LNG distribution system comprises smaller, short-sea LNG ships, local terminals and solutions for multi-modal end distribution. The challenge of the conceptual development was to establish a financially viable solution, so that LNG could become cost-competitive with alternatives such as fuel oils. This could make natural gas available in regions with lower levels of demand than are commercially viable with pipelines or larger ships.

LNG as bunker fuel
Given local availability of LNG, our concept for the use of LNG as a bunker fuel shows that it can be cost-competitive with marine bunkers. Furthermore, the environmental benefits would be considerable, e.g. with respect to NOₓ and CO₂ emissions. This concept for gas-fuelled ships is based on gas engine developments at MARINTEK and our general cryogenic knowhow.

Industrial development projects

INNOGASS
Innovative use of LNG for local industrial and domestic applications, based on a short-sea LNG distribution system. The project included the development of technology to support an economically viable small-scale LNG distribution chain. The project is based on the concepts developed in MARINTEK’s KYSTGASS project.

LNG Norge
A commercial feasibility study for the Norwegian oil company Statoil. LNG Norge, a subsidiary of Statoil, was established to conduct the development of a new business segment for natural gas distribution in Scandinavia, based on the small-scale LNG distribution chain conceptually developed by MARINTEK.

CRUISE
Small-scale LNG distribution in EU short-sea regions. MARINTEK was asked by the EU Commission to establish a project for LNG distribution to “energy islands”, i.e. islands that lack connections to the...
electricity grid or gas pipelines. The basis for the request from the EU Commission was the MARINTEK KYSTGASS project. The consortium has been established with Statoil as lead.

Publicly financed studies

ENova SF
Feasibility studies for economical distribution of natural gas in Norway, dimensioned for the Norwegian energy market, i.e. the fossil fuels part of the energy market. The studies included bulk transport of natural gas (LNG, CNG) and pipeline distribution. ENOVA is a Norwegian government-owned energy agency with a mandate to achieve more environmentally sound energy production and efficient energy use.

NVE – The Norwegian Water Resources and Energy Directorate
A basic analysis for a public-sector study for application of LNG as a mode of distribution of natural gas to industrial and domestic users in Norway.

In summary, a small-scale, short-sea based distribution system for LNG, such as the KYSTGASS concept, would make natural gas commercially viable in regions with small-scale needs. The concept as developed is commercially robust, as the main investments are the ships and the modularised storage facilities. The number of ships and the capacity of each storage facility can be adapted as time goes on, to meet the demand for natural gas. Committed investment costs could thus be kept to a minimum while scaling options are retained.

Figure 4 illustrates cost positions for the short-sea LNG distribution chain for alternative routes and volumes along the coast of Norway. On the basis of more detailed knowledge of the alternatives, the conclusions are that the small-scale LNG distribution chain can be commercially viable, even for regions with low levels of demand.

Bergesen’s Pre-Operational Training of Deck Officers on New LNG Carriers

Bergesen regularly uses the Ship Manoeuvring Simulator Centre (SMSC) in Trondheim, Norway, for officers’ conferences. In 2002 the company requested SMSC to develop a brand-new training programme that would focus on taking their new LNG carrier “Berge Boston” in and out of the Port of Boston, prior to its first port visit.

The November 2002 officers’ conference tested the new training programme, using 32 senior officers as test candidates. The officers were divided into eight groups, each of which had to complete four different simulator exercises. This allowed every officer hands-on experience from all positions of a bridge team: captain, second officer, navigator and pilot. The objective of the exercise was to bring the new 138 000 m³ LNG carrier “Berge Boston” safely into Boston port and to berth at the LNG terminal. A specific simulator model was built for the “Berge Boston” as well as complete visual and underwater topography models for the port. The port is technically challenging as it is shallow and narrow, with strong currents.

As an introduction to the simulator exercises, the bridge team had to prepare a plan for the passage. To make the training exercises even more challenging, Bergesen’s marine superintendents, together with safety authorities such as the US Coast Guard Group Boston and the Marine Safety Office Boston, had defined a number of security errors and technical malfunctions that could be introduced during the passage or berthing. Such errors included suspicious-looking crew members, vessel off course, steering gear problems etc., all which required the captain to act decisively. With only 5 – 8 feet clearance under the keel, strong currents and a message that there was a breach of security on board, the captain had to deal with the situation right away. Situational awareness was an important part of the exercise, as well as good planning when unusual situations had been identified and planned for during preparation of the passage plan.

When exercises were being designed, it became clear that in addition to being familiar with the port visual view and underwater topography, the officers also needed to know how the security measures for the Port of Boston operated. Representatives of the US Coast Guard, Boston pilots and Boston Towing and Transportation were invited to the conference to brief the officers about port procedures and security plans, as well as to offer guidance and participate in some of the exercises as representatives of their own organizations.

Through this conference and applications of ship specific training scenarios for a given port, Bergesen demonstrated the ability and willingness of the company to invest in skills development for its ship officers prior to starting operation of a new vessel on charter for a specific customer. The Boston scenario has since been used at all Bergesen Officer conferences at SMSC and on all of the company’s ship-handling courses for LNG vessels.

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“Trondheim Group” - Your partner for Nautical Studies of LNG Terminals

Trondheim is a marine and maritime knowledge hub and provider of advanced research and development as well as consultancy services to the oil and gas industry. To help customers in future projects a number of Trondheim-based research institutes, service and training providers have started a collaborative organization known as the “Trondheim Group”. This group combines the core knowledge of its partners to solve multidisciplinary projects.

The five members of the group are capable of dealing with the following topics:

MARINTEK
- Ship design
- Forces, motions and handling of ships and floating structures
- Multi-ship operations
- Mooring and fender forces
- Pipelines and slender structures
- Logistics

SINTEF Fisheries and Aquaculture/Coastal and Ocean Engineering
- Climate and environmental data
- Harbour design
- Coastal structures

SINTEF Applied Chemistry/Marine Environmental Technology
- Petroleum product spill response analysis
- Pollution and drift models
- Environmental effects of spill treatments

CorrOcean/Safetec
- Safety analyses
- Vulnerability analyses

Ship Manoeuvring Simulator Centre (SMSC)
- Nautical studies of reliability and operability of harbour designs
- Training of ships’ crews, pilots and tug masters
- Operational procedure development and evaluation
- Emergency situations and crisis management.

For the Melkøya case the group has been taking part in testing of terminal design in close co-operation with Statoil, Norwegian Costal Directorate, local port authorities and actual shipping and tug companies. Later on the group made a risk assessment study of nautical (port entry and berthing/unberthing) and general cargo operations.

Some of the products delivered by the group are shown on the block diagram. SMSC has already modeled a number of existing LNG terminals (Port Fortin/Trinidad and Lake Charles/US) and planned new terminals. Some of them have been tested in MARINTEK’s Ocean Basin.

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