Liquid Natural Gas (LNG) is becoming an increasingly important energy source. Floating LNG production on LNG FPSOs is considered to be a realistic option for gas field developments nowadays and several innovative gas-receiving terminal concepts are presently being investigated. Report gives an update.

MARIN focuses on new

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Floating LNG production and offloading is new and challenging. The required amount of process equipment is massive and it has not been applied on a moving structure before, therefore special attention has to be paid to the motion levels at the structure. Motion reduction during the design of the hull and effective control of the heading during operation are two aspects under consideration. The amount of process equipment on board results in large barge sizes (400 m plus), which makes the effective and safe mooring of the structure in survival conditions a subject that needs careful consideration.

In 1996, MARIN was already involved in a feasibility study of side-by-side transshipment of LNG from an LNG FPSO for a group of Japanese companies including JNOC, JGC and Kawasaki Heavy Industries.

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But from there it becomes even more challenging. Due to the cryogenic nature of LNG (-163 degrees Celcius), the fluid transfer from the LNG FPSO to the offloading vessel cannot be carried out with floating hoses. For LNG carriers on jetties, special LNG loading arms are in use but they have not been applied on floating structures before and their motion envelope is limited. This makes the subject of offshore offloading one of the most challenging in offshore LNG utilisation.

For offloading from an LNG FPSO, there are two basic concepts under investigation: side-by-side mooring and tandem (stern-to-bow) mooring. In the side-by-side situation the use of existing LNG loading arms is possible, although they should be evaluated for use on a moving structure. In tandem mooring, new fluid transfer systems for the LNG over a much larger distance (more than 80 m) are under development.

Relative motions and mooring loads are the main aspects that need consideration in the evaluation of these concepts. Besides the moored situation itself, for both mooring options the approach, connection and disconnection, procedures close to the large LNG FPSO are aspects that need careful consideration with respect to safety and operability.

After the offloading of the LNG to LNG carriers, the challenges are not over yet. Also in the field of receiving terminals there are a lot of new developments. Where LNG jetties close to the shore were the only feasible option in the past, nowadays all types of different options are under investigation. Floating Storage and Regasification Units (FSRUs) and Gravity Based Structures (GBS) are two of them. For FSRUs the same ship-to-ship mooring options as for the LNG FPSO are under investigation. GBS-type structures provide process

For the development of the Bayu Undan Field, BHP Petroleum investigated the use of a GBS with LNG carrier moored alongside, in 1997. MARIN performed model tests, simulations and downtime analyses.

offshore LNG concepts

equipment space and storage in areas where these are not available or possible onshore, but can also play a major role as a shielding barrier for the moored LNG carrier along its side.

Solving hydrodynamical challenges

Since the early days of these offshore LNG developments, MARIN has worked on solving the hydrodynamic challenges. Some of them are outlined here.

- Sloshing of LNG in partially-filled tanks is an important subject for offshore LNG operations. It is presently under joint study by MARIN and DNV, using the ComFLOW program (developed by the University of Groningen in co-operation with MARIN)[1].

- The LNG FPSO motions and mooring loads need to be determined accurately in realistic environmental conditions of wind, current and waves. These realistic conditions often involve combined wind seas and swell under different directions. The new Offshore Basin has the capability to generate these type of conditions, allowing an accurate evaluation of the motions and mooring loads and the effect of motion reduction measures, such as heading control.

- During side-by-side mooring, there is a strong hydrodynamic interaction between the LNG FPSO and the shuttle carrier. Based on a joint pilot study between MARIN and Shell, it was discovered that this interaction is much more complex than accounted for in existing time domain simulation tools[2]. Based on these results the MARIN LIFSIM program has been updated, now allowing a good evaluation of side-by-side mooring loads and relative motions in an early stage of the concept development. Hydrodynamic interaction research, the interaction

In 1998 a Joint Industry Project was initiated by BP for the development of a safe and reliable offloading system for LNG from a Floating Production Liquefaction Storage and Offloading unit (FPLSO) to a dedicated LNG carrier at sea. This JIP focused on the FMC Boom to Tanker (BTT) concept, with the FPLSO and the shuttle carrier in tandem arrangement. MARIN performed the simulations, model tests and contributed to the overall evaluation of the concept.

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In the process of confirming the feasibility of side-by-side offloading operations of the Shell Floating LNG System at the Sunrise field, in 1999 Shell commissioned MARIN to perform numerical simulations and model tests.

between the structures related to wind loads, current loads and viscous damping forces, is also still going on.

- For vessels in tandem mooring the situation is even more complex because the LNG FPSO and shuttle can move more independently. Special measures are necessary to guarantee sufficient clearance between the shuttle bow and FPSO stern, as well as to reduce the possibility of unstable fishtailing of the shuttle carrier or large relative motions and angles between the two. The LIFSIM program is able to simulate typical behaviour but model tests are still needed to study the details of the systems under investigation, such as single hawser moorings, bridle type mooring and yoke type systems. In addition, the complex connection and disconnection procedures of the LNG transfer systems are studied in the basin.

- For LNG receiving terminals, mooring of LNG carriers in shallow water to open jetties or along a GBS are important options. However, shallow water hydrodynamics are still a complex field. Using MARIN's multiple-body diffraction program DIFFRAC and its time domain simulation program, TERMSIM, these options were studied. Special attention was paid to the possibilities of shielding the moored LNG carrier behind the GBS in critical environmental conditions.

- Because of the optimised heading of the GBS beam to the dominant sea direction, typically the survival conditions will be beam to the GBS as well. This means that the wave run up and possible green water on the deck of the GBS is a problem that needs serious evaluation[3].

Research into these hydrodynamic aspects is continuing because this knowledge is crucial to make offshore LNG 'work'. MARIN

1) 'The Numerical Simulation of LNG Sloshing with an Improved Volume Of Fluid Method', Erwin Loots, Wouter Pastoor (DNV), Trym Tveitnes (DNV) and Bas Buchner, OMAE-conference, 2003.

2) 'Numerical Multiple-Body Simulations of Side-by-Side Mooring to an FPSO', Bas Buchner, Adri van Dijk and Jaap de Wilde, ISOPE-conference, 2000.

3) 'Hydrodynamic aspects of Gravity Based Structures in shallow water', Bas Buchner, Erwin Loots, George Forristal and Erik van Iperen, OTC-conference, 2003.

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In September 2000, MARIN completed model tests for the AZURE project which was performed to study the fully floating LNG chain. This LNG chain is based on a permanently-moored FPSO, an offshore LNG transfer system and an FSRU. This European-funded project was headed by Bouygues Offshore. Chantiers de l'Atlantique designed the steel hull for the FPSO, while the hull for the FSRU was designed by Fincantier and Bureau Veritas was involved in the classification.