SAFEOFFLOAD

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Table of Contents

INTRODUCTION

This report describes the technical work performed within the three and half years of the project in the various workpackages.

The topics that this project addresses are the environmental conditions that influence the whole FLNG system; the interaction between the environment and the production and shuttle vessels; and the responses of the vessels. The goal is to optimise the system to maximise operability and safety.

The objectives of this project are to:

- provide tools that will allow the maximisation of the weather windows during which FLNG barges can be offloaded and FLNG can be operated. An optimised hull design and an active heading control strategy may reduce motion levels.
- maximise the safety and efficiency of the offloading operation, minimise the possibility of collision or breakage of cryogenic lines
- have the capability to predict the behaviour of vessels during offloading
- have the capability to make the best, rational, real-time, risk-based decisions whether to proceed with approach and offloading
- understand the physical processes that govern the vessel motions during offloading
- have the capability to analyse the offloading process for design: specify environmental criteria, perform dynamic analysis, optimise hull shape, moorings and systems
- provide motion ranges for design of high-pressure, cryogenic pipes and flexible connectors for offloading
- provide a prototype of a decision support system that monitors continuously the environment and combines this information with weather forecasts and simulations of vessel motions

The work was organised in seven technical workpackages that concern the research and technology development activities that form the body of the project.

Workpackage 1 deals with the design concepts that are considered in the project. Initial configurations were derived from existing studies by some of the partners as well as from their knowledge of other solutions. Improved designs were developed based on the results of hydrodynamic analysis and model tests in WP3 to WP6.

Workpackage 2 concentrates on environmental winds, waves and currents, including spectral and probabilistic models. It pays particular attention to directional effects that may excite ship roll. Long-term data are analysed in terms of the persistence of severe conditions that prevent operations and weather windows in which operations may be performed. Representative data sets are provided to subsequent workpackages for response analysis. Also, investigated in this workpackage are temporal and spatial models that can be used in combination with conventional forecasting to predict environmental conditions in the near term. Probabilistic models of relevant wave parameters are developed.

Workpackage 3 concentrates on hydrodynamic tools and models relevant to responses to waves. A sophisticated, second order, wave diffraction theory was extended to treat large, closely spaced, multiple, large bodies that can move independently. A fully non-linear boundary element method is developed and tested against the diffraction theory. A code was developed for the low speed manoeuvring of the tankers. The hydrodynamic models were tested against physical model tests in WP4.

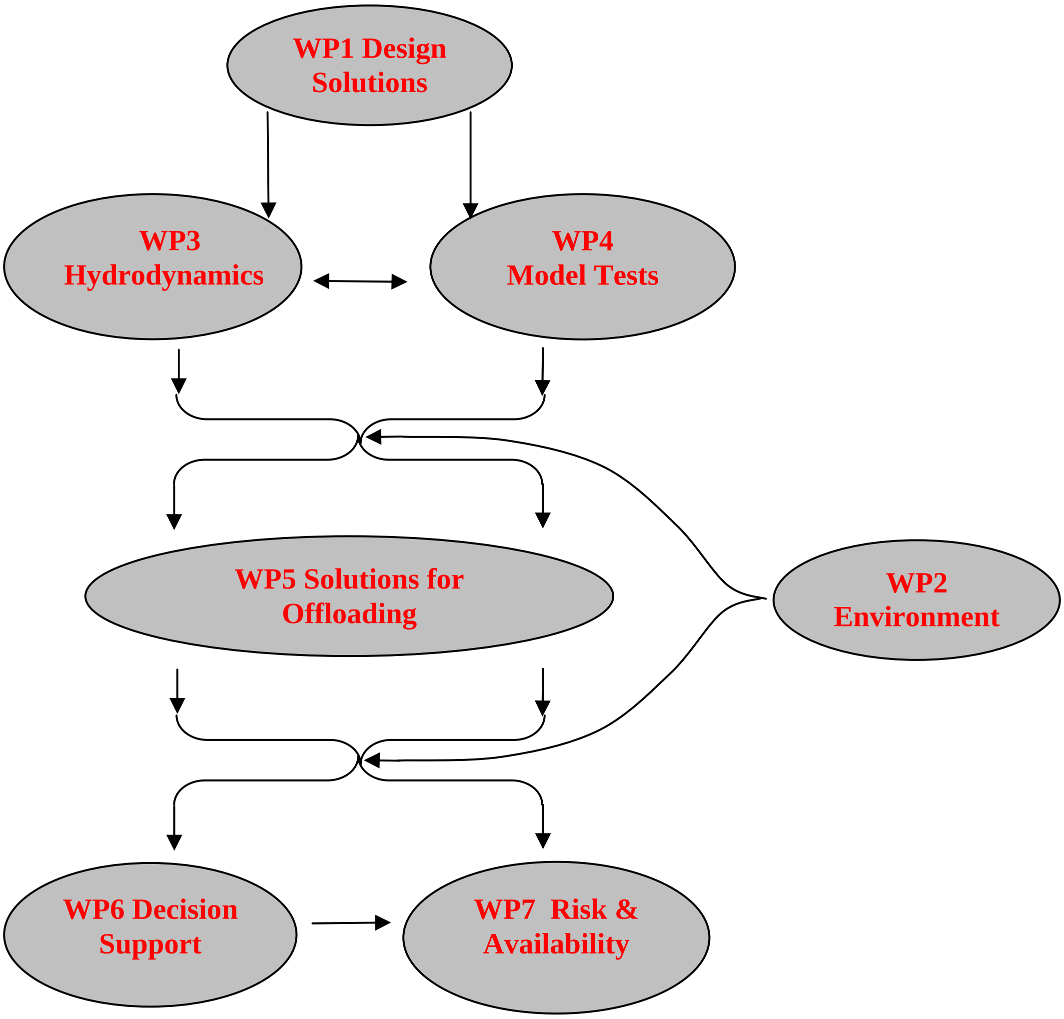
Workpackage 4 deals with model tests. It includes the tests in the wind tunnel, which determine the wind loads in the platform and LNG tankers as well as the shielding effect when the two vessels are in proximity. Model tests were made with the models under the action of waves to validate the numerical tools and to examine the behaviour of the modified hulls.

Workpackage 5 studies the approach manoeuvre of the tanker for offloading and its station keeping under the effect of the environmental disturbances. The role of dynamic positioning in tandem situations was investigated.

Workpackage 6 covers the development of a procedure to aid real time decisions concerning approach, mooring and offloading. It developed a manoeuvring simulation tool that is able to simulate the approach and departure conditions from offloading vessels.

Workpackage 7 concerns long-term analysis. It provides a risk assessment, develops design criteria and assesses the operability of the system in terms of production and offloading. It relies on input from all the other workpackages.

The relation between the workpackages is as indicated in the figure.



DESCRIPTION OF THE WORK

Workpackage 1 - Design Solutions for Floating LNG Platforms

The objectives of the work package 1 have been to deepen the understanding of the offshore gas solutions comprising LNG, to arrive at a more consistent FLNG design approach, combining efforts of the experienced representatives of the Offshore Industry, and to contribute to more comprehensive decision-making processes, by providing background on the different technological solutions.

The key issues in this work package are the large relative size of the process vessel (required to support the production and storage system) and the limitations on production and offloading due to environmentally generated responses, particularly relative motions.

A comprehensive review and analysis was conducted on the latest global LNG market, the state of art LNG transportation and offloading methods, and the challenges faced in these areas.

The main findings and conclusions are summarised as follows:

- The global gas consumption has been growing faster than the total energy consumption. The imbalance between the region of consumption and region of production increases the demand on LNG transportation and delivery. This is particularly the case for the European Union as it has the largest deficit between the consumption and production
- LNG terminals are being pushed further offshore to the more exposed seas due to environment, security and safety concerns. This has brought new challenges in many areas. Associated with more exposed environments, new LNG terminal concepts as well as a variety of offloading systems are under development. Large vessels/barges are being considered, in order to accommodate all necessary equipments/storage for offshore LNG production activity. This is one of the main challenges due to the offshore business inexperience on the prediction of large structures exposed in severe conditions.
- Main concepts of LNG vessels or structures
    - FRU - floating re-gasification unit
    - GBS - gravity based structure
    - FRSU - floating re-gasification storage unit
    - FLNG/LNG FPSO - floating LNG production storage and offloading
    - FONG - floating oil and natural gas
- Main concepts of LNG offloading systems:
    - Conventional loading arms for side by side connection
    - Soft Yoke Mooring and Offloading for tandem connection (SBM)
    - Fixed Tower with Floating Dock for side by side connection (SBM)
    - Single Point Moored Dock (Bluewater)
    - Big Sweep (Bluewater)
    - FMC Boom for tandem connection
- All concepts already developed for Offshore LNG industry, must be accepted or validated in terms of reliability, availability, safety and economical viability.

The following three offloading options have been selected:

- **Option 1 - Ship to ship in 80m water depth, both side by side and tandem connections**.

  The selected ship was an existing Golar LNG trading tanker with a standard 130,000 cubic meter capacity.

- **Option 2 - Ship to FLNG unit in 250m water depth, side by side connection.**

  The ship was the same as in Option 1, i.e. the Golar LNG tanker. A rectangular hull was selected for the FLNG unit as the base hull form. A number of other hull forms were studied too in the selection of an optimal hull form with minimum relative vertical motion.

- **Option 3 - Ship to GBS in 30m water depth, side by side**

  The ship was the same as in Option 1, i.e. the Golar LNG tanker.

In order to identify the FLNG hull form with the minimum motion, the following six different hull forms, including the base case, were analysed. Note that these hull forms have the same draft of 21.25m, and same displacement of 610,000 tonnes in order to eliminate the effects of factors other than the hull form.

- Long rectangular (base case. Length x Breadth x Depth: 400x70x36 m)
- Square (L x B x D: 167.33x167.33x36 m)
- Triangular (Equal side length: 254.29m; Depth: 36m)
- Circular (diameter: 188.82m; Depth: 36m)
- Diamond (L x B x D: 311.44x179.81x36m)
- U-shape (Loa: 340m; B(at stern):155.2m; B(at bow):126m; D:36m;
  Inter pool L:300m, B:66m)

Diffraction/radiation analysis was performed using AQWA to calculate the wave force and motion RAOs for each individual FLNG hull proposed above. Based on the comparison, the following three hull forms were selected for further study: Base case long rectangular hull (base box), U-shape hull, two hulls with the lowest vertical motions, and triangular hull.

Workpackage 2 - Environmental Models in Normally Mild Areas

Models of directional and long waves

Applicability of the Torsethaugen spectrum for locations outside the Norwegian Continental Shelf and uncertainties related to use of the spectrum have been studied. Hindcast data for three locations are considered: West Shetland, NW Australia and off coast of Nigeria. The wave data used in the study have been received from Shell and represent hindcast data generated by Oceanweather Inc. The original hindcast data have been post-processed by Shell by the program APL Waves, developed by the Applied Physics Department of John Hopkins University. Because the wave data were generated by a recognized wave model the results seem to indicate strongly that the Torsethaughen spectrum should be used with care for locations outside the Norwegian waters.

A study was made to assess the adequacy of using a Jonswap model to represent swell spectra and to compare its performance with the one of a Gauss model that some authors have used. The fit of the two models have been made to the swell component of double peaked spectra and to the spectra of single sea states of vey large period that correspond to swell conditions.

The data used was from Maui, west coast of New Zealand and from Bonga. The results showed that the Gauss distribution missed high frequency components of the spectra and in some cases also some low frequency components, showing that the Jonswap model is a better choice.

Sea states are normally assumed stationary for three hours, but this has not been extensively examined for sea states in which swell is dominant. For example, it might be expected that such sea states are stationary for longer periods than three hours. Knowledge of this would be beneficial for planning of offloading operations.

Accordingly, an examination of the stationarity was undertaken, using the Waverider data from the Duck location. These data, recorded in 18m water depth show a more or less continuous swell component. Wavelet analysis allowed the signal to be decomposed into frequency components for which the time history of the variance could evaluate. The run test was used to test for stationarity of the swell component.

The run test for the swell component results in a classification of stationarity, while the sea state in general would be classified as non-stationary, the non-stationarity apparently being entirely associated with the wind-sea. For the purposes of offloading the wave field can be considered to be stationary.

It was concluded that non-stationary records are generally associated with changing wind-sea conditions and usually local wave growth, and swell is stationary for durations up to 160 minutes at the Duck location.

The time evolution of an initial surface elevation has been studied by use of the higher order spectral method (HOSM). The advantage of HOSM in comparison to others methods is that it allows simulating a large number of random realizations of the surface elevation, within a reasonable computational time, without limitations in terms of the spectral bandwidth. Numerical simulations have been performed based on the truncated potential Euler equations and assuming the Jonswap spectrum for long-crested and short-crested waves. It has been shown that wave directional spreading suppresses modulational instability and effetcs statistics of surface wave characteristics. Further, it has been demonstrated that the wave spectral shape changes as the wave field evolves in time. A part of the wave energy is transferred towards low wave numbers, yielding the downshift of the spectral peak; the effect which is not accounted in the current design practice. What implications the modulational instability may have for design and operational criteria of LNG terminals still need further investigations. However, the analysis indicates that the effect maybe significant for locations where long-crested wind sea and/or swell, or crossing seas are present.

Infragravity (IG) waves are long waves with periods of 30 to 300 seconds. A study was performed of IG waves as these can induce significant motions in ships moored in shallow water, such as LNG carriers, and large associated mooring loads. They are therefore important for offloading operations.

The main objective in this study was to develop models to enable IG wave design criteria to be established. Accordingly, a model for prediction of IG waves from the short wave spectrum was evaluated and validated for two measurement locations, and detailed analysis of the measurements were undertaken to examine the characteristics of the phenomenon.

Models for current

A number of unpublished studies within the oil and gas industry suggest that wind and storm driven currents are sufficiently correlated over time and space that measurements at one location might, in some circumstances, be used to predict values at another location. It is not known whether the method may be applicable to other types of current such as large scale ocean circulation. The objective of the present study is to investigate the applicability for west of Africa.

The hindcast data received from Shell and used in the analysis provide the total surface current speed and the residual current when the tide is removed. The 3-parameter Weibull distribution has been fitted to the total current.

Joint Models of Wind, Wave and Current

Availability studies involve the analysis of long-term data sets. A number of potential locations were considered for the case studies. The locations considered were the Northwest Shelf of Australia, the Southern North Sea, and the Gulf of Guinea. The Northwest Shelf of Australia site is a location where there is a good mix of wind-sea and swell sea states – some dominated by wind-sea, some by swell, and some bimodal. The Southern North Sea is a location where sea states are typically dominated by wind-sea conditions. The Gulf of Guinea is a site dominated by persistent low-frequency swell with occasional small wind-seas.

A joint environmental description has been established for the three locations applying the Conditional Modelling Approach (CMA). The CMA utilises the complete probabilistic information obtained from simultaneous observations of the environmental variables. Hindcast data received from Shell from three locations: NW Australia, off coast of Nigeria and the Southern North Sea have been used in the study. The developed joint environmental description included wind, waves (wind sea and swell) and current. Uncertainties related to the joint fit have been documented. A procedure allowing adopting the joint model for operational conditions has been proposed. Joint long-term environmental models are required for a consistent treatment of the loading in a level III reliability analysis and for assessment of the relative importance of the various environmental variables at failure.

Availability statistics were developed for side-by-side offloading of a FLNG to a LNGC, at the three case study locations – The Northwest Shelf of Australia (deep water), offshore Nigeria (intermediate water depth), and the Southern North Sea (shallow water).

Analyses have been performed using different types of criteria. The base case could be chosen as that for which the operations are based solely on the in-field mariner decisions, without any engineering input. We refer to these as the “Mariner’s” criteria. However, extensive engineering studies have been performed within the industry in order to be understand the effect of the environment on the various stages in the offloading operation. In particular, the study reported here has considered the implication of applying more refined criteria associated with the operability of the tugs during approach, and the application of a limiting mooring line tension when the FLNG and LNGC are in the side-by-side configuration. These criteria are referred to as “Engineering” criteria, and the effects of applying the different criteria is examined and the results presented.

Surprisingly, the application of “Engineering Criteria” for offloading, including “Tug criteria”, for the application of Tug boats using long lines for the Approach, and “Line Tension criteria” for the alongside mooring operability, gives increased probabilities of waiting on weather by comparison with “Mariner’s criteria” based on simply meteorological and oceanographic considerations, the type that might be used in the field in the absence of engineering input.

WP 2 has provided input to the remaining project workpackages.

Workpackage 3 - Hydrodynamics of Multi-Bodies

This package is concerned with development and application of numerical models relating to offloading.

Extend diffraction codes

Part of this task related to extending and improving the University of Oxford computer program DIFFRACT. A series of papers and reports since then [2-14] have outlined the increasing capabilities of the program, and how it has been used in a range of applications for first and second order hydrodynamics.

A second numerical model, based upon a multiple-flux boundary element method (MF-BEM) developed at Imperial College London, has also been employed within the. This is a fully nonlinear model in which calculations are undertaken in physical space and the solution time-marched using the nonlinear free-surface boundary conditions.

Further work in this task has involved the time-domain WAMSIM code being extended by DHI to handle multiple bodies. Computations of a FLNG and a tanker moored side by side were made and comparisons are made with results obtained by University of Oxford and Noble Denton for the case of a FLNG barge and a tanker moored side-by-side. WAMSIM relies on WAMIT to calculate the hydrodynamic quantities in the frequency domain.

Both linear and second order analysis have been undertaken for three cases:

a) two rectangular boxes in close proximity

b) a simplified tanker model held fixed alongside a GBS

c) the case study tanker alongside the case study FLNG.

Particular attention has been directed at modelling the violent free surface motions in the gap between the vessels, and in understanding the physical effects and their significance, including the influence of spacing between the vessels and their motions.

Extend manoeuvering code

The main part of work corresponding to this task was related to extension of a multi-model manoeuvring code developed earlier at IST. That object-oriented code did not permit simulation of so-called low-speed manoeuvres i.e. manoeuvres performed with the help of active control means without limitations on values of the drift angle and path curvatures. Such manoeuvres are characteristic for berthing-unberthing operations performed with the help of side thrusters and/or tug boats. The following elements of the model were developed:

1. 4-quadrant model for the propeller thrust.
2. Model for the propeller-generated sway force and yaw moment.
3. 4-quadrant model for the rudder forces including the slipstream influence.
4. Consistent model for side thrusters.
5. Simple model for tug actions.
6. Model for aerodynamic forces.
7. Account for a uniform current.

Workpackage 4 - Model Tests

The purpose of this workpackage was to undertake the experimental work necessary for the validation of the numerical calculations undertaken in workpackages 3 and 5, to provide new laboratory data facilitating improvements in semi-empirical models, and to provide model scale studies highlighting the benefits of particular offloading configurations. Overall, the work package was divided into three parts:

(a) Aerodynamic tests of two vessels

The aim of the tests was to provide non-dimensional drag coefficients of the wind forces acting on ship hulls. The first set of tests was performed on a LNG carrier hull “Galea”, in the 0 to 360 deg range in the wind tunnel at IST. The ship is not symmetrical, hence the decision of carrying out the tests over the whole 360 deg. The model was built of wood and preserved the main geometrical characteristics of the above water hull shape

Secondly a LNG barge known as “DSME 350K FSRU” was also tested. Since this time the hull has symmetry about the ship’s centre plane, the range of necessary tests reduced to 0º to 180º. After the tests with isolated hulls, combinations of relative positions and different distances were also considered. Finally, to assess the measurement uncertainty three runs were made for each test by different people.

(a) Model tests under waves

The present study sought to contrast the wave effects associated with three very different loading configurations:

(i) LNG tanker moored alongside a gravity based structure (GBS)

(ii) LNG tanker moored side-by-side to an FLNG barge

(iii)LNG tanker moored side-by-side to a second LNG tanker

In each of these cases the LNG tanker was represented by a 1:100 scaled model of the tanker Galea; both the scaling and the choice of tanker being consistent with those adopted in Task 4.3. Furthermore, the dimensions of the GBS and the FLNG barge are also consistent with those adopted elsewhere in the project, allowing inter-comparisons between other experimental observations and related numerical calculations. The test cases ((i), (ii) and (iii) above) were undertaken in a wide range of wave conditions including regular waves of varying frequency, focused waves and random waves. In all three cases beam-seas and head-seas were considered and, in a smaller sub-set of cases, inter-lying angles were also addressed.

(b) Model tests with two bodies subject to current, wind and waves

Model tests have been carried out at DHI on different mooring concepts in deep water and shallow water conditions.

The model test programme comprised the following concepts:

- Tanker moored side-by-side to a Floating LNG plant (FLNG) in d= 300m,
- Tanker to tanker side-by-side configuration in d= 80m, and
- Tanker to a gravity based structure (GBS) configuration in d= 30m.

The FLNG and the permanent moored tanker were kept on location by a bow turret attached to chain legs. The objective of the model tests was to provide data for validation of theoretical and numerical models developed within the SAFEOFFLOAD project. For this purpose the model tests were planned to measure, under operational wave conditions, ship motions, tension in mooring lines, forces exerted on fenders and, in the case of tanker-to-tanker and tanker to FLNG also the forces on the external turret and in the anchor chains.

Workpackage 5 - Solutions for Offloading

The objective of the WP 5 was to study the interactions between two vessels during the process of LNG offloading to and from a shuttle carrier. The FLNG production vessel to be considered was selected on the basis of work carried out in WP1.

The study includes numerical modelling of the relative motions between the two vessels at each stage of the offloading process. The effect of FLNG mooring systems on the approach, connection and disconnection of the LNG tanker was assessed. The mooring of the shuttle tanker to the production vessel or offloading system was also studied. The study includes the control strategies for dynamic positioning of the shuttle tanker.

Design of Mooring Systems

Mooring systems are widely used as the means for position-keeping of the vessels during offshore operations. In the Safeoffload project, four offloading options were studied, i.e. ship to ship side by side, ship to ship tandem, ship to FLNG barge side by side, and ship to GBS. For each option, a mooring system was designed for constraining the motion of the vessels. The mooring system design includes the mooring configurations, mooring line properties of the turret mooring system, vessel to vessel or vessel to GBS mooring systems and the fender size and properties.

A panel model for the side-by-side configuration of two identical LNG carriers has been established. The model has been used in WP 7 for carrying out the risk and availability assessment. The calculations for the side-by-side configuration of two of identical LNG carriers have been carried out. Linear diffraction analyses of two identical LNG carriers in a side-by-side configuration have been performed using the DNV program WADAM. The results show good agreement with corresponding analyses performed by Noble Denton using the program AQWA. A time domain simulation model in SIMO has been developed using the linear diffraction analyses results as input, Th**e** results from using this model ha**ve** been extensively compared to results from model tests performed at DHI. The developed model compare**s** well with model tests and has been found to be well suited for long-term response calculations for the tanker to tanker side by side concept.

The features of the mooring systems for each offloading options are summarised below:

(1) Ship to ship (i.e. tanker to tanker) side by side

- *External turret mooring:* The external turret was selected to constrain the motion of the vessel in 80m water depth. Sixteen 4in studlink chains were grouped in four bundles with 90 degree separation between adjacent bundles. Within each bundle, each leg is 5 degrees apart. The horizontal spread of each mooring line is 440m with a pretension of 42 te.
- *Vessel to vessel mooring:* Vessel to vessel mooring lines were comprised of a steel wire of 42mm in diameter and a 20m long nylon tail of 80mm diameter. A conventional configuration was adopted, i.e. three breast lines at the stern and another three at the bow, and two spring lines, all being twin lines. The length of the steel wire in each line was adjusted to achieve a pretension of about 10 te in each single line.
- *Fenders:* Four Yokohama pneumatic fenders were deployed between the two vessels moored side by side, two of them were deployed near the stern and the other two near the bow, both locations were on the straight section of the hull. The diameter of the fender is 4.5m and the length is 9.0m.

Minimization of Relative Motions in side-by –side option

The main objectives of this task were to identify the FLNG hull form which has the lowest vertical motion relative to the tanker moored side by side, and to identify the limiting sea states and limiting factors for the offloading operations on the basis of the relative vertical motion and mooring capacity.

- The base case longitudinal rectangular hull form has the lowest vertical motion in general and therefore is the optimal hull form among the six hull forms studied.

- The key limiting factor is the capacity of the vessel to vessel or vessel to GBS mooring, which reaches its limit in a sea state corresponding to Beaufort number of about 5, or Hs=2m for all the three side by side options. For tandem option, the limiting sea state is higher, corresponding to Beaufort number 7, or Hs=4.1m.
- For the relative vertical motion, the limiting sea state is reached at Beaufort number 7 for the tanker to GBS option, and at Beaufort number 8 (Hs=5.5m) or greater for the vessel to vessel options.

A study was made of the wave elevations in the gap between the tanker and FLNG at 4m spacing (corresponding to the separation due to the fenders). The main objective of the work was to use the higher order method to analyse the higher order hydrodynamic phenomenon observed in the gap between the two vessels in close proximity.

Without bilge keels, ship shaped vessels can suffer from severe and unpredictable roll. An empirical model has been developed based on basic vessel parameters for estimating viscous roll damping due to bilge keels. Considering the simple nature of the model, it works very well and is sufficient for early design and development of environmental criteria.

Station-Keeping and Dynamic Positioning for tandem solutions

The design of the control system was addressed including a method to estimate the wave spectra by using vessel motions. The spectral estimation procedure relies on an existing method that has been updated and applied accounting for specific hydrodynamic characteristics of the LNG vessel considered as the representative shuttle tanker in this project. The controller, on the other hand, is not known to have been previously applied to marine systems. A Lyapunov based nonlinear controller which also uses a Hilbert-Huang transform based filtering scheme. Presently most controllers used for station-keeping depend on the linear separation principle, using LQG control systems if not simply tuned PID controllers. This solution is suboptimal because the tanker is nonlinear in the kinematics and dynamics.

Workpackage 6 - Decision Support Methods for Offloading Operations

The simulator of the LNG tanker dynamics in the Virtual Environment (VE) considered two main types of motions according to their nature: the manoeuvrability and wave induced motions. Manoeuvrability considers only the motions of Surge, sway and yaw, while the wave induced motions are computed for the six degrees of freedom. The resulting ship motion is the sum of these two components.

For the case of the wave induced motions, sinusoidal functions are applied for motions in each degree of freedom. The response of the ship is the sum of the responses for each wave component with different amplitudes, frequencies and directions of propagation, which define the current sea state. Each individual response of the ship is computed according to linear theory for small wave amplitudes, based on the ship transfer functions and response amplitude operators (RAOs). These operators are calculated in frequency domain for a set of encounter frequencies and ship headings. During the simulations, ship responses for intermediate values are computed by linear interpolations in real-time.

Manoeuvrability motions are based on a mathematical model, which is able to perform the calculations in real-time. For this model, the hydrodynamic properties of the LNG vessel are computed previously and made available to the model.

The sea state is defined in the frequency domain by a directional wave spectrum of JONSWAP type. In order to compute the sea state in time domain with the required performance for an interactive VE, an appropriate discretization of the spectrum must be applied. Thus, an interactive tool was also developed for this purpose.

The VE allows the navigation through a flying camera from which the observer may watch the relative positions of the vessels and the progression of the operations as an external observer.

Workpackage 7 - Risk and Availability Assessment of Production and Offloading Operations

The overall objective of this workpackage has been to develop a risk based approach for the design of the FLNG system (FPSO, shuttle tanker, tug, offloading mooring) and statistics for the estimation of the safety and economics of its operation (production and offloading). The case studies demonstrating environmental design criteria required included assessing of approach and berthing alongside the floating structure, station keeping, offloading, production and survival. The statistics of operability included the availability of sufficient weather windows for safe offloading and continuity of production.

The work was divided into the following tasks:

- Approach
- Station Keeping
- Offloading Operations
- Design Guideline

The following concepts and configurations have been studied by the Safe Offload project:

- Tanker to tanker, side by side
- Tanker to FLNG barge, side by side
- Tanker to GBS
- Tanker to tanker, in tandem.

There are design criteria for LNG terminals which are related to the permanently located terminal being exposed to unrestricted weather conditions at that location, such as criteria for the turret mooring for an FLNG barge; and there are design criteria for structural parts exposed to weather restricted conditions, such as criteria for the connecting mooring lines and fenders. The design criteria ensure that the terminal complies with specified acceptance criteria that in the general case relate to safety, economy, pollution and company reputation.

The operational criteria include limiting weather conditions under which LNG transfer operations can be carried out such that compliance with acceptance criteria are obtained. The limiting weather criteria ensure that the probability that the design criteria be exceeded is lower than the specified target probability.

A consistent risk-based approach for the offloading operations from LNG terminals has been proposed. It is impracticable to define generally applicable weather limitations because such limitations will be system specific and will be related to economic risk. Therefore in SAFE OFFLOAD, the developments of limiting weather conditions have been exemplified for specific cases. The met-ocean data and models provided by WP 2 have been used in the study. The limit states considered were: mooring line failure (station keeping) and excessive relative motion (offloading).

The SAFEOFFLOAD Guidelines have been developed by DNV with the contribution from the Partners. The purpose of the document is to summarize findings and lessons learned from the project that are useful for the designer of safe offloading from floating LNG platforms. Recommendations for design criteria are given that are in compliance with specified risk and acceptance criteria. The document may serve as useful input to a possible future Recommended Practice for design of safe offloading systems.