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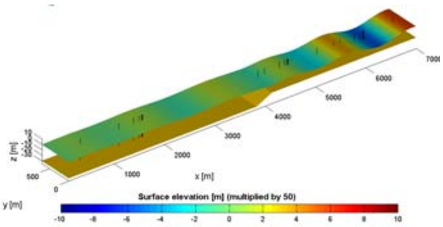
HawaII JIP

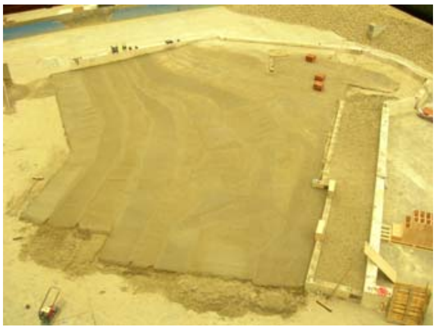
Aim:
To develop a consistent design methodology for offshore terminals in a nearshore wave climate

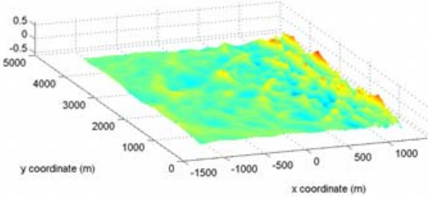
Version 2.0

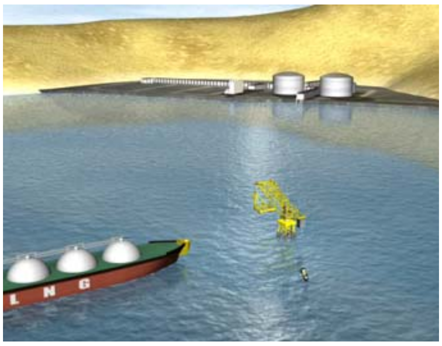
A JIP initiative of:

Maritime Research Institute Netherlands (MARIN)
Deltares (formerly Delft Hydraulics)
Bureau Veritas (BV)











Background

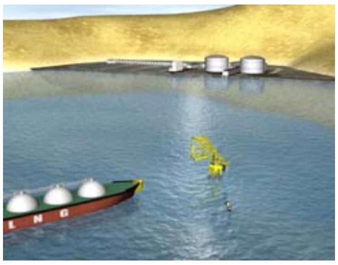
This document describes the project plan of the HAWAII-JIP. HAWAII is the follow-up of the HAWAI JIP in which the objective was “to improve the reliability of offshore (LNG) terminals in shallow water by using the combined expertise of offshore hydrodynamics and coastal engineering”. The HAWAI JIP was initiated in 2005 after a series of basin experiments in shallow water for which the results could not be explained satisfactorily. The parties involved realized that the complexity of the shallow-water wave conditions in the basin would similarly apply to the real world. This indicated a lack of knowledge on terminal design in shallow water, related scale-model tests and numerical simulation techniques. Therefore a JIP was proposed and together with 24 participating companies this project set out to investigate:

- spurious wave effects in model test basins
- free and bound low-frequency (LF) wave energy (in the basin as well as in the field)
- wave mechanics in shallow water
- drift forces in shallow water
- drift forces in directional seas
- application of diffraction theory in shallow water

In the first HAWAI JIP these and other issues were addressed, which greatly improved the insight in the behavior, in a scale model as well as in the field, of (low frequency) shallow-water waves and their interaction with offshore terminals. By the end of the JIP, in spring 2008, the participants of the JIP were fully informed of the findings by a series of reports and data DVDs.

Introduction

In the FPSO JIP week of November 2008 an informative meeting was organized by Deltares (formerly Delft Hydraulics) and MARIN to discuss the possibilities for a follow-up of the HAWAI JIP. The motivation for this meeting was that after a successful first project there remained a number of unresolved research questions, primarily related to the design process of offshore terminals in shallow water.



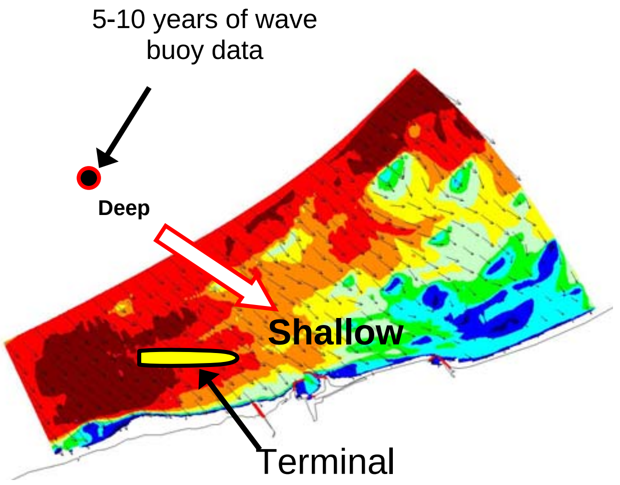
The central question in the informative meeting was how the knowledge that was developed in the HAWAI JIP could be translated in a design methodology for an offshore terminal in a nearshore environment. The following questions are believed to be important:

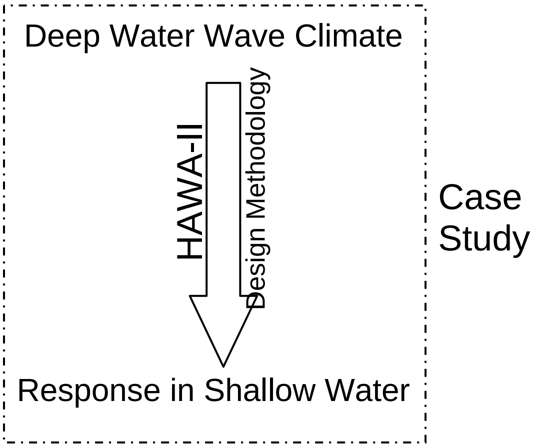
- How do we implement knowledge from the HAWAI JIP in the design (engineering) process?
- Is it possible to find ‘preferred locations’ for a terminal in an early stage of the project in order to focus design efforts and resources?
- How do we get an effective screening of the limiting design cases?
- In which nearshore environments are LF waves (free and/or bound) important?
- In which situations is it required to include the bathymetry of a (planned) site in a model test?
- How are probability levels of mooring loads affected by the LF waves?
- How do we obtain phase-correlated time-domain results for the LNG carrier motions in an actual shallow water environment? Is this important for the design loads (statistics)?

These are the questions and attention points that have been used as a starting point for this project proposal. These attention points, together with additional input provided in recent discussions with several participants of the HAWAI JIP, have led to the following objective for the HAWAII JIP:

‘To develop a consistent design methodology for offshore terminals in a nearshore wave climate’

The focus of the HAWAII JIP will be on the development of practical methods for the design of terminals in shallow and intermediate water depths (15-40 m). A realistic (but fictitious) design case will be chosen to demonstrate and validate the methodology . A bathymetry and a deep-water wave climate will be the starting point for the design cycle.





The purpose of the design case is to build a generic example where state-of-the-art methods are demonstrated in each stage of the design. The design case will show how relatively simple methods can be used in preliminary design stages up to detailed modelling in final design stages. This should lead to a decision marker for further, more complex, analyses.

Typical parameters that influence the decision for a more sophisticated analysis are:

- system natural period
- system damping
- water depth
- wave paremeters (Tp,Hs, LF content, directional spreading, frequency spreading)
- currents
- effect of local bathymetry to added mass and damping
- nearby coastline

The combination of these parameters for a specific design should lead to the assessment whether a more detailed approach is required. This demands for the development of a systematic approach for the design of a shallow water terminal. As part of the HAWAI JIP we have investigated and evaluated the (numerical) methods that are already available and the relatively new methods that could be further developed.

General approach

The general approach of the HAWAII JIP is described here first. As mentioned before, the project will focus on developping a design methodogy for shallow water terminals. At present it is believed that the following steps are required to design a shallow water terminal design:

1. Define deep water sea states
2. Translate deep water sea states to shallow water, including LF free waves
3. Select design seastates based on response model in frequency domain
4. Time domain simulations of ship response based on 2D QTF and local wave field
5. Time domain simulations of ship response based on wave group forced model combined with linear diffraction theory
6. Model Tests on a varying bathymetry

In the project the knowledge and methods to apply these steps will be developped and applied for a realistic case. The lessons learned will be documented such that a guideline will become available how to design a shallow water terminal in a nearshore environment.

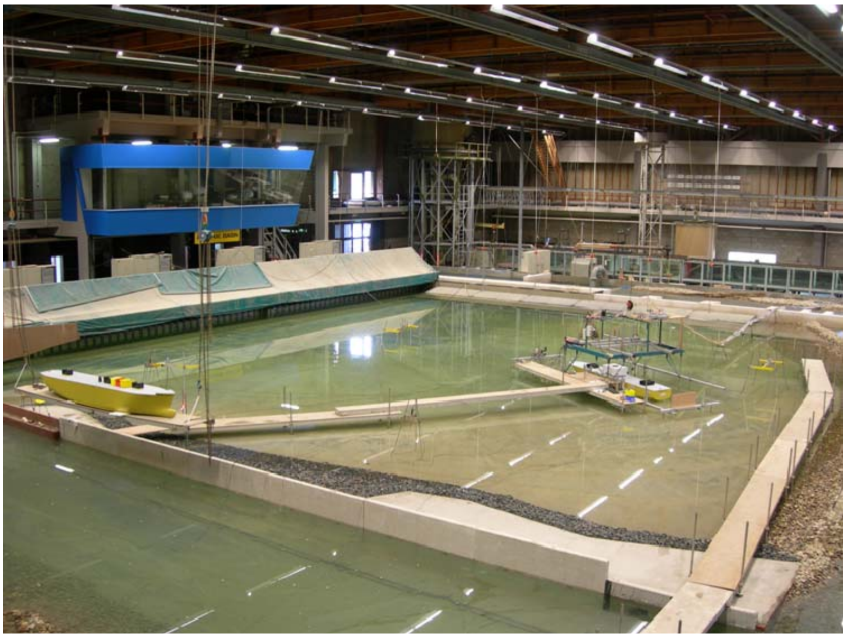
The philosophy behind this methodology is that in the first response assessment of the design the analysis does not need to be very detailed but rather computationally efficient to be able to investigate general trends or compare different options for the design. This requires simplified (linearised) techniques to compute the vessel response (in frequency domain). In the HAWAI JIP it was found that the LF free wave can dominate the overall response of an LNG carrier in shallow water. Therefore, in this stage an estimate of the low frequency free wave energy is required to predict the trends in the response for a large number of cases. The computed response will be based on the first order wave spectrum (on shallow water), the bound wave (which is included in the QTF) and the LF free wave.

Because the LF free wave energy will not be estimated accurately in height and direction a sensitivity study of the response to relative LF free wave directions with respect to the setdown and carrier waves is needed. The aim is to derive the relevant design cases from this analysis. This analysis will also show if the free wave is dominating the response or not.

The next step would be to use the 2D QTF methodology including the estimated LF free wave to obtain the (non-linear) response of the vessel in time domain. The 2D QTF describes the wave drift forces in directional seas. This 2D QTF was computed in the HAWAI JIP and can be used to generate time traces of the wave drift forces. Using this method the response can be computed in time domain (but of course still with high uncertainty of the LF free energy and direction).

The response parameters (added mass and damping) can be affected by local variations in the bathymetry. Two methods to investigate this effect using linear diffraction theory are proposed.

As the design becomes more fixed, more complex wave models could become required, particularly when a complex bathymetry or coastline is present at the foreseen site. In order to determine the extent to which it is presently possible to cover such situations in the design methodology, an evaluation will be made of the coupling of a low-frequency wave model suitable for a complex bathymetry to a diffraction model to obtain an approximation of the response in the design sea state at such locations. That coupling will be developed in this JIP and described in the deliverables.



The final step before building the actual terminal would be model tests on a varying bathymetry. In this step the response can be measured on a local bathymetry for a known incoming wave. The present project will focus on model test methodologies and points of attention will be documented. Note: to be able to start the project even when the initial budget is limited, a large part of the model test scope is optional in this proposal.

The table below shows an overview of existing methods and of methods that will be developed in the HAWA-II JIP:

Increasing physical detail →

	Method		Present Status	First LF wave energy assessment (parallel bathy)	Selection of seastates based on Frequency domain response (linearised)	Non linear Time Domain Response	Detailed LF wave energy assessment (complex bathy)	Time domain response including local bathy	
Wave Models	**Wave parameters (Hs, Tp,Wdir,S)**		🟩	🟩	🟩	🟩	🟩	🟩	
	Spectral model (e.g. Swan) 2D		🟩	🟩	🟩	🟩	🟩	🟩	
	Spectral wave model LF waves (Parallel depth contours)			🟧	🟧	🟧			
	Time domain wave model LF waves (parallel depth lines or a more complex bathymetry)						🟧	🟧	
	As 3 and 4, now with coupled phase								🟥
Response Models	**Engineering Judgment**	**Flat Bottom**	🟩	🟩	🟩	🟩	🟩	🟩	
	Linear Response (frequency domain)		🟩	🟩	🟩			🟧	
	Frequency Domain Response (QTF)				🟧				
	Time Domain Response (QTF)		🟩						
	Frequency Domain Response (Dir QTF)								
	Time Domain Response (Dir QTF)					🟧			
	Amass+Damp including bathymetry	**Bathymetry**				🟧		🟧	
	QTF including bathymetry					🟧		🟧	
	Dir. QTF including bathymetry					🟥		🟥	
Model Tests	**Model Test on local bathymetry**		🟩	🟩	🟩	🟧	🟧	🟧	

In this table the different available (or foreseen) methods to assess shallow water waves and the response of a moored LNG carrier are presented. Some of these methods are well established in offshore engineering, others are more state of the art and are generally used by specialists only. The colors in the table indicate the level of the method, these are described below.

The green methods are relatively well known and often used in engineering companies.

The orange methods are relatively new to the subject and will be addressed in this JIP.

The red fields indicate the areas where we believe future research should focus on. These are not intended to be investigated in this JIP.

Based on this overview of the methods a task list is defined between Marin, Deltares, Bureau Veritas and Pinkster Marine Hydromechanics. These tasks were then distributed over comprehensive work packages which are described in the back of this document.

The table below shows the same scheme as presented before, now describing the work packages that will address these items. The detailed content of these work packages is described on the next pages.

		Method		Present Status	First LF wave energy assessment (parallel bathy)	Selection of seastates based on Frequency domain response (linearised)	Non linear Time Domain Response (flat bottom)	Detailed LF wave energy assessment (complex bathy)	Time domain response including local bathy	
Wave Models	1	Wave parameters (Hs, Tp,Wdir,S)		🟩	🟩	🟩	🟩	🟩	🟩	
	2	Spectral model (e.g. Swan) 2D		🟩	🟩	🟩	🟩	🟩	🟩	
	3	**Spectral wave model LF waves (Parallel depth contours)**			**WP 1**	**WP 1**	**WP 1**			
	4	**Time domain wave model LF waves (parallel depth lines or a more complex bathymetry)**				↓	↓	**WP 1**	**WP 1**	
	5	As 3 and 4, now with coupled phase				↓	↓		↓	🟥
						↓	↓		↓	
Response Models	6	Engineering Judgement	**Flat Bottom**	🟩	🟩	🟩 ↓	🟩 ↓	🟩	🟩 ↓	
	7	Linear Response (frequency domain)		🟩	🟩	🟩	↓		**WP2.2**	
	8	Frequency Domain Response (1D QTF)				**WP2.1**	↓			
	9	Time Domain Response (1D QTF)		🟩			↓			
	10	Frequency Domain Response (2D QTF)					↓			
	11	Time Domain Response (2D QTF)					**WP2.2**			
	12	Amass+Damp including bathymetry	**Bathymetry**				**WP2.3**		**WP2.3**	
	13	QTF including bathymetry					**WP2.3**		**WP2.3**	
	14	Dir. QTF including bathymetry					🟥		🟥	
Model Tests	15	Model Test on local bathymetry		🟩	🟩	🟩	**WP4.1**	**optional**	**optional**	

Based on the numbered items in the above table the following tasks are foreseen within the project. These tasks are divided into four main work packages. Each of the tasks in the work packages is described in more detail in the back of this project plan.

WP1 Wave Models (lead: Deltares)

Frequency domain calculation of LF wave energy content

- Generate wave data for input to response model with spectral domain LF wave model (setdown+free waves)(3)
- Report wave model properties (3)

Simulations with time domain LF wave model

- Generate wave data for input to (coupled) response model with time domain LF wave model (4)
- Report wave model properties (4)

Coupling of time domain LF wave model to diffraction method

- Set up output interface with panel model (4)
- Report with description of coupling (4/7)

WP2 Response Models (lead: Marin)

Linearized Frequency domain response method

-Compute the 1st and 2nd order wave forces in frequency domain (FD) (8)

WP2 Response Models (continued)

-Linearize the spring matrix at mean offset (8)
-Solve equation of motion in FD including mean offset (8)
-Impose motion onto non-linear mooring system (8)

Non linear Response in time domain

-Generate 1st and 2nd order time domain wave forces (11)
-Simulate response in Time Domain (11)
-Response modeling with diffraction code using Surfbeat model output(7)

Response on a local varying bathymetry

-Compute added bass and damping in frequency domain on a flat bottom (12)
-Compute added mass and damping on simple bathymetry, i.e. a constant, plain slope (slope steepness ranging from 1:20→1:200) (12)
-Compare results of the two methods (12)
-Compute QTF on simple bathymetry (13)
-Sensitivity check using existing methods (local water depth effect)

WP3 Modeltests (lead: Deltares)

Flat bottom tests

purpose: validation of Dir. QTF
-directional seas
-wave measurements (low frequency wave energy content)
-response measurement
-soft mooring

Parallel bathymetry (optional)

purpose: validation of response on plain slope bathymetry
-longcrested seas
-directional seas
-wave measurements (low frequency wave energy content)
-response measurement
-soft mooring

Captive tests (optional)

purpose: validation of response on plain slope bathymetry
-Force motions tests for added mass and damping on bathymetry
-Wave frequency force measurements

Tests on a complex bathymetry (optional)

purpose: validation of response on complex bathymetry
-longcrested seas
-wave measurements (low frequency wave energy content)
-response measurement
-soft mooring

WP4 Methodology Development and Case Study (lead: MARIN)

Define deep water sea states (Deltares)

-Collect wave parameters (Hs,Tp, Wdir, S)
-Determine offshore wave climate (classes of environmental conditions)
-Format data as input for SWAN

Translate deep water sea states to shallow water, including LF free waves (Deltares/Shell)

-Define translation matrix from deep to shallow water
-Convert deep water climate to nearshore climate (SWAN calculation)
-Run WF→LF wave model to estimate low frequency wave energy content
-Specify wave climate (WF, Setdown, LF free)

Select design seastates based on response model in frequency domain (Marin)

-Compute wave forces in FD for various LF free wave directions
-Compute responses in FD
-Select critical cases based on response

Time domain vessel response based on 2D QTF with and w.o. local bathy effects (Marin/BV/Pinkster)

Time domain simulations of ship response based on time domain LF wave model combined with linear diffraction theory (Deltares/Pinkster)

Deliverables:

- Report with description of stepwise general design methodology
- Description of used methodologies for each design step
- Documented design case example for a shallow water terminal on a complex bathymetry
- Description of linearized LF response model
- Report on the methodology of a diffraction computation and results with and without bathymetry
- Reports with descriptions of methods and computational results
- Animations of wave computations
- Coupling code (Matlab) between LF wave model and diffraction model
- Best practice guidelines for model tests including bathymetry (optional)

Schedule:

The HAWA-II project will run for 2 years. The kick-off meeting will be held in the FPSO-JIP week in San Fransisco, Thursday November 12th, 2009.

Budget & Participation Fees

MARIN	EURO 150,000.=
DELTARES	EURO 195,000.=
DELTARES (budget price initial model tests WP3.1)	EURO 100,000.=
SHELL (frequency domain wave modeling)	EURO 50,000.=
Pinkster Marine Hydromechanics (PMH)	EURO 30,000.=
Bureau Veritas	EURO 30,000.=
MARIN (management)	EURO 45,000.=
Total	EURO 600,000.=

Because we believe it is very important to start up this project even if the available budget is limited we have decided to make the tests in WP3.2 and WP3.3 optional in the initial project plan. If there are sufficient participants we foresee also tests on a varying bathymetry at the DELTARES test facilities in Delft.

Participation fees

The participation fees for the HAWA-II JIP are as follows:

Oil companies	EURO 50,000.=
Other companies	EURO 30,000.=

As noted above the aim for the initial budget is 600 kEuro. This means that around 15 participants are required join before the kick off the project.

Participants that are new to the HAWAI-JIP will have to contribute to the first HAWAI JIP before joining the second JIP. The deliverables of the first HAWAII JIP will be made available. Please contact o.waals@marin.nl for details.

Information:

If you are interested to join the HAWA-II JIP or if you have any questions regarding this project plan, please contact:

Olaf Waals
o.waals@marin.nl
+31 317 493 277

Other JIPs

To give a complete overview of the activities that are related to the mooring of large LNG carriers we have summarized the related JIPs below:

- ROPES JIP [new] : Mooring loads due to passing vessels
- Offshore and Operability 1 JIP: Tandem Offloading
- Offshore and Operability 2 JIP: Side by Side Offloading
- SafeTug JIP : Operability of Tugs in limiting sea states

As noted above the new HAWAII jip will specifically address the design of near shore terminals in open water. The project will focus on how to deal with low frequency wave excitation in the design process.

WP1 Wave Models (lead: Deltares)

The main objective of the Work Package 1 is to develop methodologies to compute the (LF) wave energy in a shallow water environment. In the HAWAI JIP a range of different types of models from coastal engineering were evaluated for application in the design process of a nearshore shallow-water terminal. The model class of ‘Shallow-water models forced on wave-group scale’ was found to have most potential for practical applications. In this WP the focus will therefore be on the validation and evaluation of applicability of that model class for this specific purpose. This will be done by considering two models from that class.

There are two sub work packages foreseen:

WP1.1 Frequency domain wave model for LF wave conditions
WP1.2 Time domain model for LF wave conditions

The results of these wave models will be used in WP2 to compute the response of the vessel in these waves.

WP1.1 Frequency domain wave model for LF wave conditions

Frequency domain wave models exist that can compute very efficiently the LF wave conditions in shallow water (free and bound waves). Since the computations require relatively little time, this method can be used to translate complete offshore primary wave climates to nearshore climates of LF waves. These methods are suitable for situations with parallel depth lines.

Shell is working on the development and validation of such a model. They will join the JIP as a partner and two students will carry out simulations with their LF wave model.

WP1.2 Time domain model for LF wave conditions.

The operational software Delft3D-FLOW/Surfbeat, a time domain model, will be applied to cover plain sloping bathymetries and non-uniform, more complex bathymetries. Other operational time domain LF models, including a public domain version[1], are available. They are based on a similar principle and have similar characteristics.

Numerical simulations will be made with Delft3D-FLOW/Surfbeat for a range of (site) situations, from fairly basic to complex (Model situation 4 from the table). The foreseen situations and related activities are described below.

1. A number of simulations will be made for a 1D shallow-water case for which detailed measurements are available, made by MARIN in the HAWAI JIP. This case will be expanded to a 2D case, with parallel depth lines, to study the influence of waves approaching the slope at an angle, and the effect of directional spreading. This will provide insight into the:
    a. versatility of the wave model

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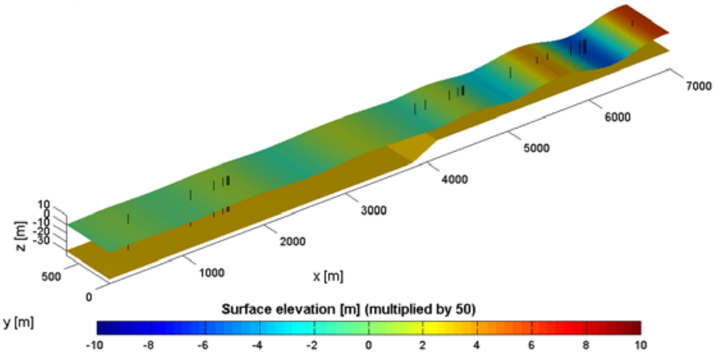
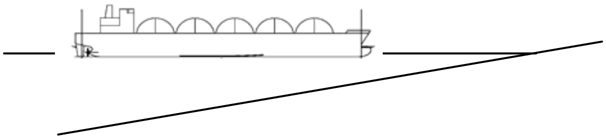
[1] A relevant development in this context is the numerical shallow-water wave model called ‘Xbeach’, which is a public-domain model that is developed with funding and support by the US Army Corps of Engineers by a consortium of UNESCO-IHE, Deltares (Delft Hydraulics), Delft University of Technology and the University of Miami (www.Xbeach.org).

   b. robustness of the (open) boundary conditions (influence angles of outgoing waves)
   c. accuracy of the approximation of directional spreading (see below)



2. The second stage consists of numerical simulations to validate the method for calculating the wave conditions that will serve as input for the calculation of the corresponding vessel responses. In this case 2D situations will be considered, starting with a reference geometry with a vessel on a plain sloping bottom (parallel depth lines). First wave conditions in Delft3D-FLOW/Surfbeat will be unidirectional, followed by situations including the effect of directional spreading. For this situation the wave conditions will be calculated and the response of the vessel under those conditions will be determined (see WP 2). The results based on this way of representing the influence of directional spreading can be compared to other approaches (see also WP 2).



3. After the first tests included in Step 2, numerical simulations of wave conditions will be made of a complex (natural) bathymetry . A specific situation will be selected in consultation with the participants:
   a. non parallel depth lines? a headland? a channel?
   b. similar simulations schedule as above?
   c. which level of directional spreading?

   This situation with a complex local bathymetry (either natural or man-made) will be made increasingly complex by adding e.g. the influence of directional spreading or a coastline (reflections).

The calculated wave conditions from Step 2 and 3 can be used to calculate the vessel response (WP 2). However, this requires the development of a numerical tool which will form the coupling between the wave model and the vessel response model. In the past such a coupling has been made for the Boussinesq-type wave model TRITON (Deltares) to the response model DELMULTI of Prof. J. Pinkster (see Wenneker *et al.*, 2006). A similar interface will be developed within HawaII JIP for coupling wave conditions calculated with Delft3D-FLOW/Surfbeat to a vessel response model. The coupling code/method will be made as generic as possible (within technical possibilities) so it can be coupled to another wave model and/or response model. The method will be described in detail in a report, enabling participants to set up other connections based on that description.

The applicability of an LF wave model might be limited by the fact that the phases of the primary waves are not resolved in the numerical model. As a research element (step R1), the influence of the phase coupling between wave frequency (WF) and LF waves in shallow water, and the possibilities to overcome this drawback, will be studied (the extent of this evaluation depends on the budget available to the HAWAII JIP). The following key questions are foreseen to be covered:

a. Is a separated approach for WF and LF waves accurate/adequate enough (SWAN and a LF wave model)? And if so, in which conditions (depth ranges)?
b. Can information from primary waves be derived/approximated from wave group information from Delft3D-FLOW/Surfbeat?
c. Is it possible to identify/label a minimum depth for which LF waves dominate vessel motion response?

The total number and details aspects of wave conditions to be covered will be determined in the kick off meeting in consultation with the participants and depends on the final budget available. Conditions can be defined for different values for wave parameters: main directions, unidirectional waves, directional spreading etc, or for different bathymetries (from uniform, to plain slope or complex non-uniform bathymetries).

WP2 Response Models (lead: Marin)

The main objective of the Work Package 2 is to develop methodologies to compute the response of an LNG-Carrier in shallow water. There are three sub work packages foreseen:

WP2.1 Linearized Frequency domain response method
WP2.2 Non linear Response in time domain
WP2.3 Response on a local varying bathymetry

WP2.1 Linearized Frequency domain response method

The advantage of a frequency domain response model is that a large number of response spectra can be generated, without too much computational effort. It is noted here that in frequency domain the response of the system is linearised.

We intend to carry out the following steps:

1) Linearize the spring matrix around the mean position
2) Compute 1st and 2nd order wave forces for a wave spectrum
3) Compute the motion response in frequency domain
4) Impose the found motions on the mooring system to find the forces

Using this method the response can be quickly (but relatively roughly) assessed for a large number of cases. The wave spectra from the SWAN model will be used to generate the first and second order wave forces. The wave force associated with the LF free wave energy will be computed using a linear force transfer function from a normal diffraction database. Since the magnitude and direction of this LF free wave is an estimate (with considerable uncertainty) a variation of the relative direction with the SWAN wave system will be carried out.

Based on the outcome of the response from this model a choice can be made which conditions are the most critical for the shallow water terminal. These critical cases will be used in the more complex analysis methods. By running the cases with and without free wave energy it is possible to investigate how important the free wave energy is for a particular configuration.

WP2.2 Non linear Response in time domain

This part of the JIP will focus on time domain response computations. A total of four different methods will be used for time domain simulations. The first three are based on more traditional QTF approach, where the effect of including directionality and the local bathymetry will be investigated.

In the fourth method the wave forces are computed by a coupling between the time domain LF wave model (as described in WP1.2) and the linear diffraction program Delmulti. This approach is similar as was used to couple the Boussinesq-type model TRITON (Deltares) to Delmulti in the first HAWAI JIP. After computing the wave forces the responses will be simulated using the same time domain model as in the QTF approach for the first 3 methods.

The various methods for time domain simulations are described in more detail below.

Method1: Compute the Wave Forces using a 1D QTF on a flat bottom

This method is the traditional method used in engineering. A QTF for longcrested seas is used to compute the low frequency wave forces for each independent wave direction and simulate the motions and mooring forces of the vessel. The forces associated with the carrier waves (normal wave spectrum) and the LF free waves are computed using linear force transfer functions that are obtained from a regular diffraction database.

Method2: Compute the Wave Forces using a 2D QTF method on a flat bottom

This method is one step more complex than the first method, because the interaction between different incoming wave directions is included.

On a flat seabed the response in time domain can be computed by generating time traces of the wave drift forces from the multi directional (2D) QTF. In the HAWAI JIP the directional (2D) QTF were computed. Based on these results the spectra of the wave drift forces can be computed. The next step is to compute the response of the vessel in time domain. In the first HAWAI JIP these 2D QTF were computed by BV for the LNG carrier. In the present project it is proposed to use these QTF to do simulations in time domain. The method how to generate time traces of wave drift forces will be described and number of example runs will be carried out in the case study. The carrier waves (normal wave spectrum) and LF free waves will be dealt with in the same way as in method1.

Method3: Compute the Wave Forces using a 1D QTF on a varying bathymetry

In this method the QTF is computed without directional interaction for the incoming waves, but the effect of the shoaling of the waves on a varying bathymetry is taken into account, just as the effect on the added mass and damping. To carry out this case the results of WP2.3 will be used to generate the wave drift forces in time domain. The proposed time domain simulations will be carried out for both methods that are presented in WP2.3.

Note: at this point it is believed to be too complicated to generate a 2DQTF on a varying bathymetry, because the effect of setdown (which can be a dominant term) to the drift forces is difficult to approximate using existing techniques. This is because the incoming waves will refract onto the bathymetry, resulting in a setdown that is difficult to define to approximate the wave drift forces.

Method 4: Compute wave forces using wave results from time domain LF model

As first step in predicting the wave forces due to bound waves, the Froude-Krylov force due to the LF waves from the time domain LF wave model can be determined, i.e. integrating the undisturbed pressures on the hull (Bowers, 1975) to asses the effects of the second order potential.

As a more complete step, the wave forces on the vessel can be derived using the program Delmulti (PMH). Delmulti is a frequency-domain, multi-body radiation diffraction code based on the source formulation and the zero-order panel method.

The time domain LF model generates time-domain kinematics and pressures due to the low-frequency bound waves in an irregular wave field. It is stressed that the wave model only describes LF waves. Additional wave frequency contributions are not considered in that wave model (in a design approach they should be considered separately). In order to compute the wave loads on a vessel in the wave field described by the time domain LF wave model, first of all the time records of the undisturbed bound wave velocity components (u,v) and the undisturbed pressure, p are generated by the time domain LF

model for all collocation points (mean position of the centroids of the panels describing the vessel). Note that w=0 in the 2DH (depth-averaged) shallow-water flow model.
Subsequently this file is transferred to Delmulti and, by means of FFT, all time records are transformed to frequency components. In this process, the number of frequencies is limited by subdividing the total time record in to a number of overlapping intervals.
The frequency components of the velocities u and v are input to the diffraction computation replacing the classic long-crested regular wave input based on linear wave theory.
The diffraction problem is solved in the normal manner and finally, all frequency domain results are transformed back to the time-domain to yield time records of wave forces in 6 DOF. These forces constitute the forces due to the bound wave field generated by the time domain LF wave model. The procedure described here is general in the sense that no a-priori assumptions have to be made on the nature of the incoming bound wave field, e.g. the incoming field can have arbitrary spreading properties. Furthermore, the difference in wave celerity of the bound waves (setdown) and the free LF waves is included in the output of the time domain LF wave model.

WP2.3 Response on a local varying bathymetry

The problem with linear potential theory in frequency domain is that the non-uniform bathymetry can not be modeled in a straightforward manner, since the outer edges of the modeled bathymetry will give unwanted reflections in the computational domain, leading to non-physical oscillations in the added mass and damping and wave forces.
In this part of the project the response of a vessel floating above a varying bathymetry will be investigated. There are two main topics that will be studied:

1- Added Mass and damping on a local varying bathymetry
2- Wave Drift Forces (1D QTF) on a local varying bathymetry

For the 1st topic the added mass and damping will be computed using two different methods using linear potential theory as a basis. The first method is developed by BV and uses semi transparent panel in the outer domain to avoid reflections from the edge. The second method is developed by Pinkster and uses a multi domain approach. These two methods will also be used to compute the standard QTF (without multi directional interaction) on the bathymetry. The results between methods will be compared in frequency domain for the Added Mass, Damping and QTF.

To show the effect of the varying bottom in the final response the compute hydrodynamic databases will be used to simulate the response in time domain in WP2.2. The time domain motions and mooring forces will be compared between results for a flat bottom (standard diffraction database) and the results including the varying bathymetry for both methods.

A more detailed description of the methods that will be used is given on the next page.

Method1: Response on Local bathymetry using semi transparent panels (BV)

The way to take into account the effect of varying bathymetry on the behavior of a floating body operating in shallow water is an important issue. With the purpose of developing an efficient and accurate method, Bureau Veritas has devoted large effort in the development of new approach within the framework of our in-house seakeeping software HydroStar.

The bathymetry is modeled by a second fixed body. The problem of the bathymetry truncation has been treated by the introduction of semi-transparent panels that allow a smooth disappearance of bottom in a limited area beneath the ship.

The radiation problem is correctly solved; the spurious reflections around the edge of the bathymetry are successfully removed by the smooth truncation. It has been noticed that motion of the ship was affected by the modification of the incident field, but also by a modification of the hydrodynamics coefficient of the ship (Added mass and damping)

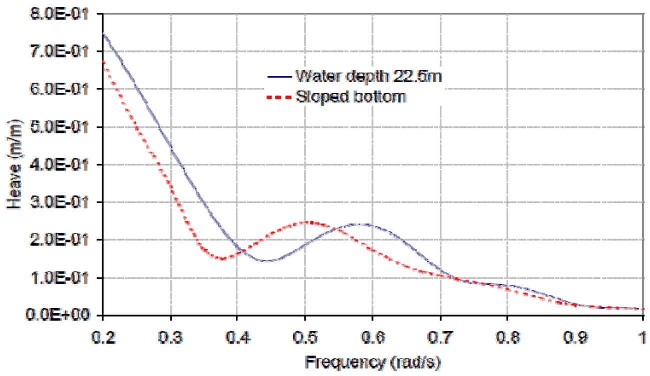
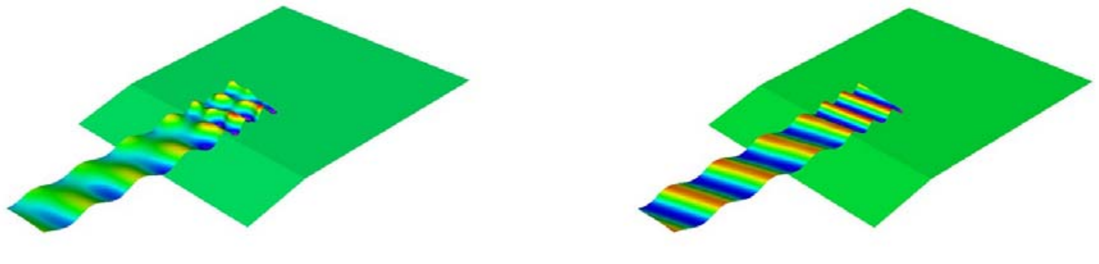


Figure 1 : Heave RAOs with and without the uneven bottom (15° heading)



(a) Without treatment

(b) With smooth truncation

Figure 2 : Wave kinematics above a slope

Although the new method developed by Bureau Veritas represent a significant step towards a solution that enable the consideration of variable bathymetry by diffraction/radiation codes, additional work still needs to be done on the consideration of the incident wave potential. Until now, the incident wave potential is obtained for a constant depth (the deepest depth at a certain distance from the body). A more accurate approach for the estimation of the incident wave potential makes the object of the work proposed by BV for the following phase of HAWAI JIP.

BV proposed work for HAWA-II (TBD)

1. Improvement of incident wave field

The calculation done so far used an incident wave field computed at constant depth. The perturbation potential is computed so that the boundary condition is satisfied on the uneven bottom. An enhancement of the developed method would be on the calculation of the incident wave kinematics by coupling a shallow water wave model with a diffraction/radiation code. There exist several wave models that may be used:

- Ray theory (refraction only, first order only), simplified model but represent significant enhancement compared to constant depth wave field. Easy to implement in classical diffraction/radiation codes.

- Mild-slope equation to solve the wave kinematics as the incoming waves.

- Boussinesq or Green-Nagdhi (much more difficult practically but possibility of non linear kinematics).

2. Second-order computation

Work could be done to extend the method to obtain the second order solution including wave drift and low-frequency QTF. A more sophisticated incident wave field might have to be computed.

Method2: Response on Local bathymetry using multi domain approach (PMH)

When applying 3-d diffraction codes, locally varying bathymetry is modeled as a second body. Two of the problems associated with locally varying bathymetry are :

1. When considering a simple bathymetry we tend to chose a prismatic shape extending from y=- inf to y= inf. Truncating the bathymetry model , as we must, leads to reflections from the truncated ends. These are associated with
    a. the incoming wave field
    b. the diffracted and radiated waves from the vessel
2. The dimensions in the x-direction are limited. If the bathymetry is a simple slope coming from a deeper to a shallower water depth this also leads to reflections of both incoming waves (assumed to propagate from deep to shallow water) and diffracted and radiated waves.

Assuming an incoming wave field at right-angles to the slope (simplest case) , problem 1.a. can be circumvented by using a 2-d solution for the wave kinematics on the slope. The mild slope assumption could be useful here.

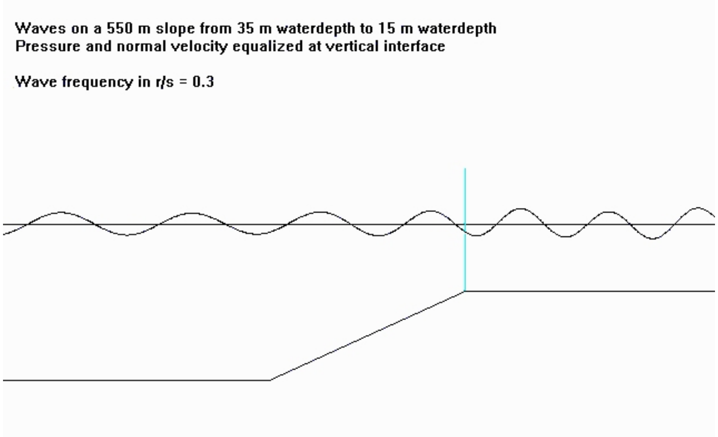
Problem 1.b. has to be reduced by proper shaping of the ends of the slope as demonstrated recently by Newman or by applying damping regions

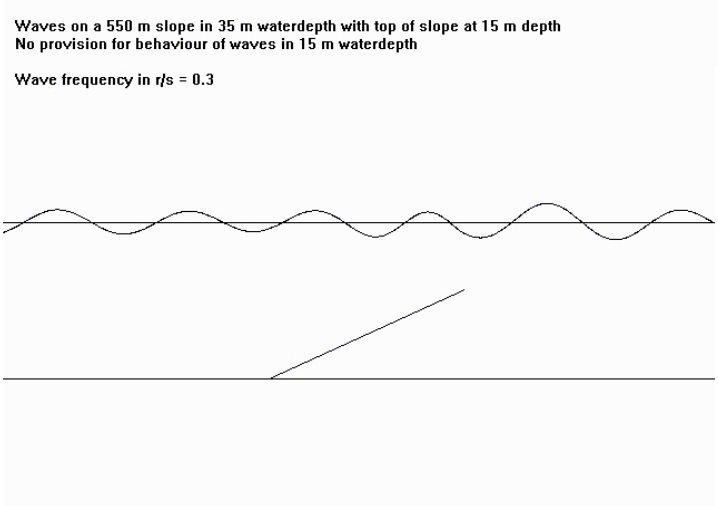
Problem 2 can be reduced by applying a two domain solution i.e. in the direction of wave propagation (x direction) , the first domain extends from – infinity to the top of the slope . The water depth for this part is the deeper water value. The slope is described by panels up to the smaller water depth. At the top of the slope , a vertical, fully transparent boundary is created which consists of two sets of identical panels which are in a back-to-back set-up with one set facing the deeper part and the slope and the second set facing the shallow water part. For this interface additional equations are formulated which express equality of normal velocity and pressure. This assured transfer of momentum between the two domains. At this time, a vessel can be positioned in either domain.

The solution obtained in this way is , strictly speaking, restricted to the first order solution and the mean second order drift forces. Low frequency forces can be computed in the same way as carried out for a horizontal sea floor i.e. by transforming a first order wave force , but at this time there is no indication regarding the accuracy of this part.

In the figure shown below, an example is given of a regular wave on the slope which is modeled as a truncated slope which ends abruptly after which the water depth is again the same.

In the second figure the same slope is shown connected to a second domain with a smaller water depth. Note the differences in wave lengths to the right of the top of the slope.





Note: These figures were made based on RAO’s from frequency domain computations

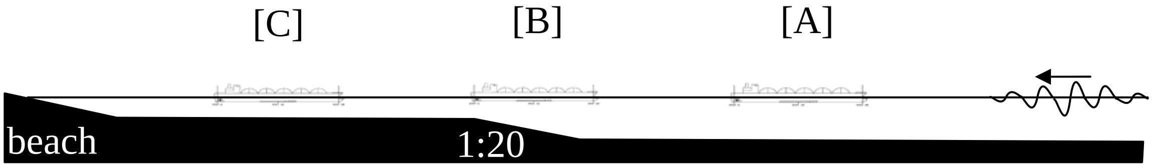
WP3 Model tests (lead: Deltares)

The main objective of the Work Package 3 is to obtain model test data to validate the developed design methodologies. Attention will also be paid to guidance for model testing on varying bathymetries. There are three sub work packages foreseen:

WP3.1 Flat bottom tests
WP3.2 Tests on a parallel bathymetry (optional)
WP3.3 Tests on a complex bathymetry (optional)

Because we believe it is very important to start up this project even if the available budget is limited we have decided to make the tests in WP3.2 and WP3.3 optional in the initial project plan. If there are sufficient participants we foresee also tests on a non-uniform bathymetry.

As a first data set for validation of the wave models, the model tests from the HAWAI JIP can be used. This is a 2D situation with a 1:20 sloped bottom as shown below:



Prior to setting up additional physical model tests in the HAWAII JIP, an evaluation will be made of the best practice for shallow water scale-modeling for situations in which a bathymetry is included. In such situations the LF waves will behave differently because reflection behavior, either physical (off beaches) or spurious, will be different compared to other situations (either deep water, or shallow water with uniform depth, or parallel depth lines). Furthermore, the requirement to model a section of the surrounding area results in relatively small model scales in order to fit the area inside a model basin. This makes these measurements different significantly from deepwater scale model tests. Main questions to be addressed are therefore:

a. how to avoid spurious (LF) waves?
b. how to achieve the correct representation of LF waves in basin?
c. what is the required scale to cover surrounding area vs. scale suitable for vessel? Related to:
    i. scale-effects in environment (waves etc)
    ii. scale-effects vessel response (viscous damping…)
    iii. representation of surrounding area (how do waves reach the project location, required accuracy, required level of detail etc.).

For non-uniform bathymetries the wave shoaling and shallow water effects are complex to analyze. For the model tests in this work package it is proposed to build a complex bathymetry in a step by step approach. Each step can then serve as a reference, as validation data, for specific approaches listed in the table.

The first step is a model test in directional seas on a flat bottom. Because this is an important reference case we have included it in the base scope of the project.

WP 3.1 Flat bottom tests

purpose: validation of Directional QTF
-directional seas
-wave measurements (low frequency wave energy content)
-response measurement
-soft mooring

The scale model will include a vessel and motions of the vessel will be measured. A reference test, without vessel, will be made to measure the undisturbed wave conditions at the site.

At present it is foreseen to cover four different directions and four levels of directional spreading. Details of the measurement schedule will be determined in consultation with the participants and can be expanded in case the available budget exceeds the originally foreseen budget.

WP 3.2 Tests on a parallel bathymetry (optional)

purpose: validation of response on plain slope bathymetry
-longcrested seas
-directional seas
-wave measurements (low frequency wave energy content)
-response measurement
-soft mooring

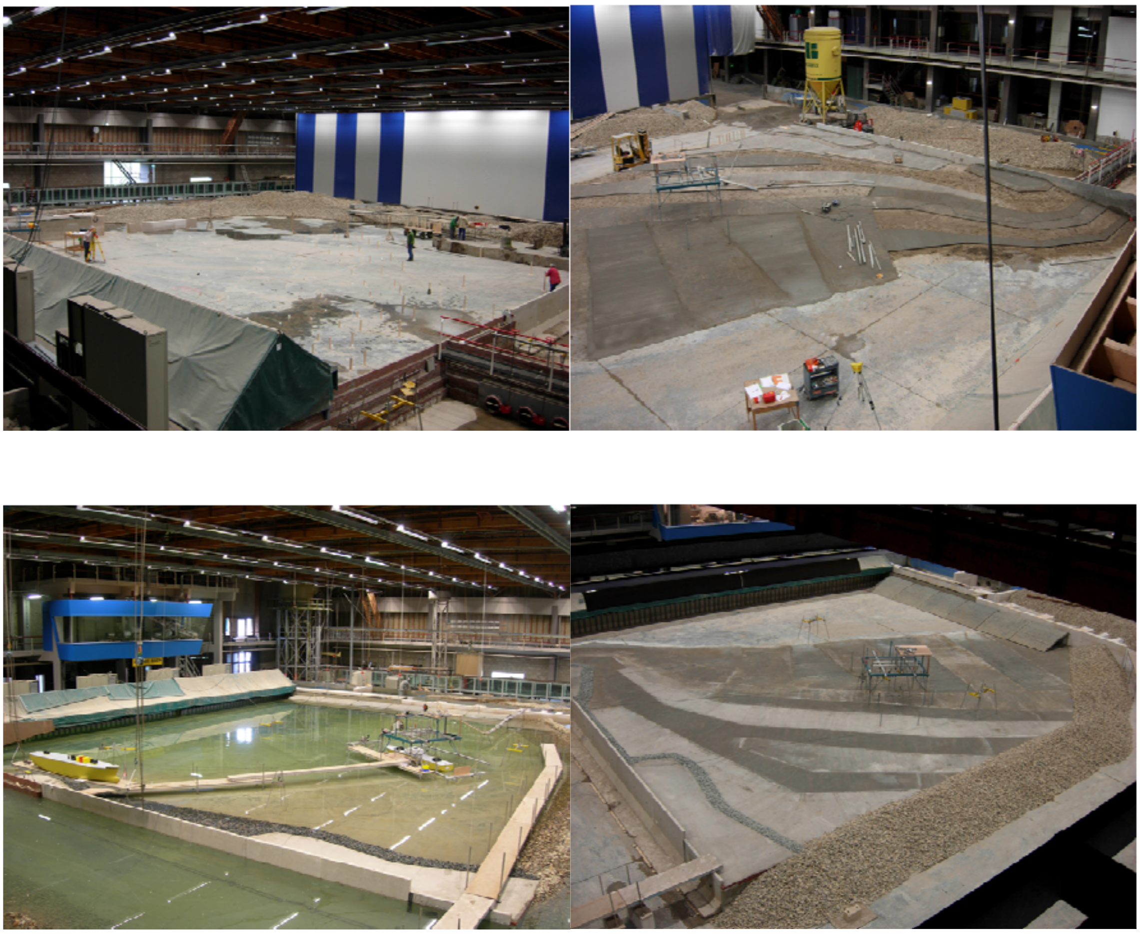
purpose: validation of response on plain slope bathymetry
-Force motions tests for added mass and damping on bathymetry
-Wave frequency force measurements

WP3.3 Tests on a complex bathymetry (optional)

purpose: validation of response on complex bathymetry
-longcrested seas
-wave measurements (low frequency wave energy content)
-response measurement
-soft mooring

The (optional) complex bathymetry to be considered will be selected in consultation with the participants. Possible options to include in the situation to be considered are: a nearby headland, irregularly shaped coast line, naturally non-uniform complex bathymetry, or a man-made complex bathymetry (an optional item, representing e.g. a situation such as an approach channel, other nearby structures).
Which steps can be taken, i.e. which level of complexity can be considered in the scale-model tests, will depend on the number of participants. At the kick-off meeting, or in the course of the project in case of additional participants, the details of this part of the scope will be discussed.

An example of a scale model including a bathymetry is shown below. Starting upper left panel and continuing clockwise: empty basin/setting out required heights, construction of bathymetry, bathymetry finished, measurements.



WP4 Design Methodology & Case Study (Lead: Marin)

The main objective of the Work Package 4 is to apply all the developed methodologies to compute the response of an LNG-Carrier in shallow water. The results will be documented and validated against each other. The final outcome of this work package will be the design methodology and guidelines for shallow water terminal design.

There are five sub workpackages foreseen:

WP4.1	Define deep water sea states
WP4.2	Translate deep water sea states to shallow water, including estimate for LF free waves
WP4.3	Select design seastates based on response model in frequency domain
WP4.4	Time domain simulations of ship response based on 2D QTF and local wave field
WP4.5	Time domain simulations of ship response based on time domain LF wave model combined with linear diffraction theory

All the developed methods in the HAWA-II JIP are applied in the case study that forms Work Package 4 (WP4). A realistic (possibly non-uniform) shallow-water bathymetry will be defined for this case study, in consultation with the participants.

The case study will be used to develop a methodology for the design of offshore terminals in shallow water. The case study will be documented such that the designer has a concise description of which tools/methodologies to apply in a specific design situation of a shallow-water terminal. The objective is to determine at the end of each design stage whether the next stage is required for a specific project or not, e.g. depending on the complexity of the location and governing environmental conditions.

WP4.1 Define deep water sea states (Deltares)

-Collect wave parameters (Hs,Tp, Wdir, S)
-Determine offshore wave climate (classes of environmental conditions)
-Format data as input for SWAN

For the purpose of this case study the first step will be based on deep water hindcast model results. These wave spectra will be selected as input for WP4.2.

WP4.2 Translate deep water sea states to shallow water, including LF free waves

-Define translation matrix from deep to shallow water
-Convert deep water climate to nearshore climate (SWAN computations)
-Run WF→LF wave model (This will be done with a model as used in Shell)
-Specify wave climate (WF, Setdown, LF free)

For WP4.2 the SWAN model will be used to propagate the wave energy from deep to shallow water. The changes in wave spectrum will be documented. Besides translating the deep water wave spectrum to its shallow water equivalent, a simplified method will be used to estimate the influence of LF free wave energy on the vessel motions. The approach for this simplified method is developed in WP2.

WP4.3 Select design seastates based on response model in frequency domain

-Compute wave forces in FD for various LF free wave directions
-Compute responses in FD
-Select critical cases based on response

For WP4.3 a frequency domain response model will be used to analyse the main trends in the response. The advantage of the frequency domain model is that many cases can be run due to the limited computational effort. However, because in the frequency domain the properties of the system are linearised this method can only be used to predict general trends in the response.

WP4.4 Time domain simulations of ship response based on 2D QTF and local wave field

WP4.4 will include the time domain simulations including directional interaction between waves coming from different directions. MARIN will develop a time domain module in Work Package 3 to carry out these simulations. In these simulations the non linear system properties can be modelled and the statistics of mooring forces can be assessed. The wave forces associated with the bound wave energy (setdown) will be modelled based on second order wave theory as described in driftforce theory. The free LF wave energy will be assumed using the simplified method from WP1.2.

WP4.5 Time domain simulations of ship response based on wave group forced model combined with linear diffraction theory

The state-of-the-art approach to model response in shallow water is to use a wave group forced shallow water flow model. For this, the time domain LF wave model Delft3D-FLOW/Surfbeat (Deltares) will be used. The resulting pressures and velocities can be coupled by PMH to a linear diffraction code which then computes the wave forces. As a final step MARIN will use the time traces of the wave forces to compute the response in the same time domain model as used in WP1.4 above.

In the Delft-3D-FLOW/Surfbeat model the bound and free LF wave energy is resolved, but the phase relation with the incoming carrier waves is lost. Therefore, a random phase between the carrier waves and the LF waves will be assumed. The effect of this assumption will be investigated by checking multiple relative phases between the wave systems.

As a final step the effect of a complex bathymetry can be assessed by means of physical scale-model tests. The purpose of these model tests is to verify all the developed methodologies against measurements and to document experience in model testing LNG carrier terminals on complexe bathymetries. This is described in Work Package 3. To limit the total required budget to start the project this is presently seen as an optional scope of work. In the initial validation of the above methodology the model tests on a sloped bathymetry from the first HAWAI JIP will be used. If budget allows, the tests on a complex bathymetry (WP4.2 and WP4.3) will be executed in the second stage of the project.

Definitions/Clarification list

1D Wave spectrum	Irregular wave spectrum defined for one wave direction
2D Wave spectrum	Directional wave spectrum that describes wave energy for each incoming wave direction
0D QTF	Quadratic Transfer Function of the classical type that describes the 2nd order mean drift forces. This method can be used to estimate the wave drift forces in deep water (Newman approximation)
1D QTF	Quadratic Transfer Function of the classical type that describes the 2nd order mean and low frequency drift forces for each incoming wave direction, **without** taking into account wave drift forces related to the interaction between different wave directions. (full matrix)
2D QTF	Quadratic Transfer Function as the 1DQTF but **with** taking into account wave drift forces related to the interaction between different wave directions.
Surfbeat	Time domain shallow water wave model.
Diffraction code	Software that uses linear frequency domain potential theory to solve the diffraction of waves on a vessel or bathymetry and computes the related wave forces
Bound Wave/ Setdown	Second order low frequency wave that is bound to the wave groups. Note: the amplitude of the bound wave is generally larger in shallower water.
LF Free wave	A low frequency free wave that obeys the dispersion relation (and is not bound to a wave group) . These waves initiate when a bound wave reflects back from a beach or in the process where deeper water waves enter shallow water.
Varying bathymetry	An uneven sea bottom that may influence the wave celerity and traveling direction. In this process the directional wave spectrum may changes its shape and bound and free waves may be initiated.
Local varying Bathymetry	An uneven sea bottom in the vicinity of a vessel that may affect the response (added mass and damping) and low frequency wave forces on the vessel
Response	The motions and forces related to a moored vessel in waves.

References:

Wenneker, I, M. Borsboom, J. Pinkster, and O. Weiler (2006), A Boussinesq-type wave model coupled to a diffraction model to simulate wave-induced ship motion, *31th PIANC Congress*, Estoril, Portugal, May 14-18, 2006.

Waals, O.J., (2009) The Effect of Wave Directionality on Low Frequency motions and Mooring Forces, *OMAE2009-79412* , HAWAI, June 2009

Pinkster, J.A.,"Wave Drift Forces in Directional Seas in Shallow Water", *OMAE2009-80110*, HAWAI, June 2009

Waals O.J., "On the Application of Advanced Wave Analysis in Shallow Water Model Testing (Wave Splitting)", *OMAE2009-79413*, HAWAI, June 2009

Bowers, E.C. : "Long-period oscillation of moored ships subject to short wave seas ", *Paper presented to R.I.N.A.,* August 1975.

HAWA-II response form/letter of intent

(deadline 1 October 2009)

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Company/organization : ………………………..
Contact person : ………………………..
E-mail address : ………………………..
Signature : ………………………..

Please tick:

○ We intend to become a HAWA-II JIP participant. However, we have the following comments to proposed scope of work:

○ We do not have interest in this JIP, please remove us from the contact list