STREP PROJECT
TST5-CT-2006-031489

HANDLING WAVES
DECISION SUPPORT SYSTEM FOR SHIP OPERATION IN ROUGH WEATHER

PRIORITY 6.2
Integrating and Strengthening the European Research Area – Sustainable Surface Transport

PUBLISHABLE FINAL ACTIVITY REPORT

CONTENTS

1. Project execution

Project objectives

The objective of the project is to develop an on-board decision support system for tactical decisions of ship handling in waves, considering in particular rough sea conditions. Besides monitoring in real time the accelerations on the ship, the system will incorporate numerical models to:

- Estimate actual relative motions at the bow and wave induced structural loads,
- Estimate probabilities of occurrence of rogue waves and their effects on the ship motions and structural loads,
- Estimate probabilities of occurrence of large amplitude roll motions and capsizing,
- Predict the near term changes in motions and loads that would arise from any change in course and speed by the shipmaster.

The project will also carry out in service pilot applications in three ships.

The activity of the project has been organized into 6 technical work packages which objectives are described in the following:

Work package 1:

The objectives of this task include:

- Improve the understanding of the mechanisms of generation of the rogue waves, of their geometries and of the probability of occurrence in wave records
- Improve the methodology to generate experimentally in a seakeeping tank deterministic rogue waves and extreme wave groups.
- Generate in a seakeeping tank a set of tailor-made wave groups that include rogue waves for posterior experimental analysis of rogue wave kinematics and the effects of rogue waves on ship structures.
- Improve the existing probabilistic models to account for the probability occurrence of rogue waves in a synoptic scale

Work package 2:

The objective of this task is to investigate experimentally conditions that lead to the loss of ship stability and capsizing of ships and also to unexpected large roll motions. Although the subject of large amplitude motions and in particular the intact and dynamic stability at large angles has been much studied in the past, there are still several aspects that remain unclear and in fact represent a threat to the ship safety and operability. These aspects, which will be investigated in this task, include: the motions induced by rogue waves, the loss of stability at large wave crests, parametric rolling and broaching due to loss of directional stability.

To accomplish these objectives an experimental program will be carried out with models of three different ships in deterministic wave sequences that include rogue waves, extreme wave groups and other adverse wave conditions. Besides improving the understanding of these complex phenomena that compromise the ship safety and operability, the new experimental data will support the calibration and validation of numerical models that estimate these ship responses.

The present work package deals with experimental tests with self propelled models for measurements of motions and capsizing conditions, while work package 3 deals with experiments with captive

segmented models for measurement of structural loads.

Work package 3:
The behaviour of ships when they encounter rogue waves and the related effects on the ship structures are still basically unknown, although it is generally accepted that the consequences may be dramatic. The objective of this task is to carry out a program of experimental tests with three models of ships in deterministic wave sequences that include rogue waves and extreme wave groups. The effects to be analysed include local (slamming and green water on deck) and global structural wave induced loads. The results from these tests will, firstly, enhance the understanding of the behaviour of the ship when subjected to extreme waves. Secondly the results will permit the calibration and validation of existing numerical methods to predict the structural loads induced by rogue waves.

Work package 4
This task deals with the development and application of methods for numerical calculation of ship responses. The decision support system to be installed onboard of ships will be based on various numerical procedures and results regarding the ship behaviour in waves. This way the objective here is to validate and generalise the existing methods, and develop the new needed ones. More specifically:

- the existing nonlinear time domain seakeeping code will be generalised to include the effects of slamming and green water on deck induced by rogue waves,
- a data base with the motions and structural loads induced by all possible wave conditions will be produced for one ship, which will be used to
- develop a neural network model that relates the ship accelerations with the structural loads. This way the wave induced structural loads are assessed via the measured accelerations instead of using less reliable and more complex strain gauges,
- finally a method will be developed which allows the estimation of the sea spectra from the measured motion records. This way one avoids the use of much more expensive and complex systems based on X band radars.

Work package 5
The onboard decision support system is developed in this task. The objective of the system is to improve the ship performance at sea by informing the shipmaster on the level of various ship responses to the waves, comparing the actual ship responses with safety and comfort criteria, and advising on the best route.

Work package 6
Demonstrate the applicability of the system through pilot applications on different ship types, namely a Bulk Carrier, a Ferry and a Container ship. After the development of the onboard decision support system, in this WP the system will be installed on three ships for testing under operational conditions during a period of approximately 3 months.

Contractors involved

Participant name	Participant short name	Country
RINA Services SpA, Project Coordinator	RINA	Italy
Instituto Superior Técnico, Technical Coordinator	IST	Portugal
Rodriquez Cantieri Navali	RCN	Italy
Technical University of Varna	TUV	Bulgaria
Technical University of Berlin	TUB	Germany
Hamburgische Schiffbau-Versuchsanstalt GmbH	HSVA	Germany
Portline	Portline	Portugal
Navigation Maritime Bulgare	NaviBulgar	Bulgaria
Grimaldi Group Naples	GRIM	Italy
St. Petersburg State University	SPSU	Russia

Work performed and end results

Wp 1 – Analysis and modelling of rogue waves

The main criteria for rogue waves identification have been elaborated and used for rogue wave selection. Generalized sample of rogue waves, measured in different regions of the world ocean has been considered.
Statistics of several waves in groups was estimated, storm wave records in different locations were used.
The software for stochastic simulation of wave-records with incorporated freak waves was developed. This software allows simulation of the stochastic spatio-temporal wave field on the base of scenarios spectrum, where the freak waves (as the values from another sample of meteocean events then the ordinary waves) are arise with the certain probability. The shapes of freak waves are obtained directly from the data base of measurements. Thus, the software allows generation of input data for software on ship dynamics simulation and safety prediction.

A detailed analysis of the measured data from the North Sea has been carried out.

Various extreme wave sequences were generated in a small wave tank. The available data were analysed and different parameters which characterise the sea state were calculated.

Additional analysis was made on waves generated in a deep-water wave basin, which were characterized with modulational instabilities induced by third-order nonlinear interactions among freely propagating waves. Comparisons were provided of the statistics of wave envelopes and phases, wave heights, and crest and trough amplitudes observed to various theoretical approximations based on Gram-Charlier expansions. This allows statements about the probability of occurrence of abnormal waves according to that distribution.

Generation of irregular seas for the evaluation of the model scale and generation of deterministic wave sequences including rogue waves ("New Year Wave"; "Yura Wave") has been done.

The measurement of an irregular sea state with the embedded New Year Wave at different positions in the towing tank has been done, as well as the generation of two further deterministic wave sequences including rogue waves ("Single Freak Wave at North Alwyn", „Critical Wave Sequence").

The approach to probability estimation of rogue waves in short-term and long-term scales has been estimated.

The software suite for analysis of freak wave occurrence in climatic scale was developed. The components of the suite are:
- software for climatic wave spectral analysis and computation of spectral jumps and the transitions;
- software for spatio-temporal storm dynamics analysis;
- software for multivariate metocean probability distributions modelling.

This software suite allows processing the hindcased wind and wave data for the estimation of the multivariate cases of meteocean parameters, where the freak waves might be arise.
The software was tested on the selected subset of HIPOCAS hindcasting data.

The analysis of wave data to determine statistics of the larger waves has been done.

The possibility to use the directional wave spectra for characterization of the wave-making conditions (where the rogue waves arising are possible) is the result of better knowledge of the wave generation and propagation process, which has been implemented in various wave modelling packages.

WP 2 - Ship capsizing in rough seas

In Wp2 ship models for capsizing test have been prepared. In particular the following activities have been done.

Ship Model 1 (Container Vessel) and Ship Model 2 (RoRo Cargo Ship):

Preparation of detailed drawings and electrical data for the manufacturing of the ship models with appendages and superstructures.

Manufacturing of the segmented model hull (tow parts), appendages and superstructures and assembling of a watertight ship model with all superstructures.

Planning and construction of the frame and assembling of the frame and fitting of strength gauges have been done.

Installation of the 6-component force balance at midship section and instrumentation of the model for capsizing tests.

Selection of test load case; installation of equipment; model tests preparation; test setup; performance of forced roll motion tests (one tank day); analysis of test results.

Capsizing tests with 2 ship models:

- Generation of regular and irregular sea states during the capsizing tests
- Analysis of the test results
- Transformation of the measured wave elevation to the midship section of the ship models

Additional Tests with the Container Vessel:

The following investigations were performed during the test series:

- Roll decay tests in calm water at different ship speeds and initial heeling angles.
- Continuative model tests in regular bow waves and irregular bow seas in order to get further measured data for the numerical investigation of the parametric rolling phenomenon.
- Tests with the free drifting container vessel in regular beam waves and irregular beam seas (Dead ship condition).
- Measurement of the wave elevations of four irregular long crested seas at four different locations in the towing tank.

A numerical code has been developed and calculations of parametric roll for the containership have been executed.

It was decided to compare the empirical roll damping established from the forced rolling model tests with an applicable analytical method. Hence, it was found that the roll-damping method of components due to friction, lift, eddy-making, bilge-keels, and wave generation, presented by Ikeda, can be used to accurately calculate the total roll-damping coefficient for bulky hull forms.

A non-linear numerical model has been utilized to simulate parametric resonance of a containership and a RORO in both regular and irregular waves. In addition, special attention has been given to the usefulness of model experiments conducted under conditions as realistic as possible to validate the theoretical approach proposed.

A numerical model of ship motion in waves has been validated by direct contrast and comparison with the experimental results.
In this study a non-linear numerical model is utilized to simulate roll responses in regular and irregular beam waves.

Wp3 – Waves induced loads in rough seas

The wave tank of the Technical University of Berlin has been upgraded with equipment for properly measuring the motions of the models.

The models (Container Vessel, Ro/Ro-Ship, Bulk Carrier) are manufactured and equipped with strain gauges. Synchronisation of the wireless motion measurement systems with the established electronic measurement system of the TUB has been done.

Preparation and instrumentation of the three ship models have been done.

Semi-captive model tests with the three ship models have been carried out:

RoRo Vessel:

- Head and following seas at stationary conditions

Container vessel:

- Head seas at different forward speeds

Bulk Carrier:

- Head and following seas at different forward speeds

Additional model tests with the three ship models have been carried out:

RoRo Vessel:

- Tests in regular head waves with different wave steepness

Container vessel:

- Tests with a freeboard extension at the bow to evaluate possible influences of the freeboard height and green water loads on the vertical bending moment

Bulk Carrier:

- Tests in regular head waves with different wave steepness

The experimental data was analysed and systematically compared with the numerical results from the nonlinear seakeeping code.

The tests have been made in several irregular sea-states with large significant wave heights and represented by the JONSWAP wave spectrum. Deterministic wave sequences were also tested and these correspond to abnormal waves, or rogue waves, measured in real sea-states.

The calculations have been carried out with a time domain nonlinear strip theory.

Calculations have been performed for the containership and the bulk carrier, however more comprehensively for the containership. The responses to the irregular sea-states are compared in terms of probability distributions, while the deterministic rogue waves were compared directly in terms of time histories of the measurements and of the simulated results.

The work in this subtask involved a detailed analysis of the experimental data obtained within WP3 with models of a containership, a bulk carrier and a RoRo ship in severe seastates, and the comparison with the results from the time domain nonlinear numerical codes. Mostly, head seas have been considered, and the wave conditions included deterministic wave traces including abnormal waves and also random irregular sea states. Heave and pitch motion have been analyzed, as well as the vertical bending moment at midship. The random seastates experimental data is compared with numerical results in terms of statistical values (mean values, variance, kurtosis and skewness) and probability distributions of maxima. The deterministic wave trace time records are compared directly with numerical predictions. Overall, the heave and pitch motions are well predicted, as well as the hogging bending moments, while sagging vertical bending moment peaks tend to be over predicted.

Wp4 - Numerical assessment of ship response to extreme waves

The existing method to calculate green water on deck and the related effects on the global structural loads was improved and a procedure to calculate slamming loads and the related transient hull response was tested. A comprehensive analysis has been carried out by amplifying the relative motion at the bow in the numerical calculations, with a method based on previously obtained experimental data, to assess the effects on the vertical bending moment. Direct comparisons have been carried out for many abnormal wave conditions tested in the tank, and it was concluded that the prediction of the largest sagging peak improves significantly.

A database with histories of motions and wave induced loads in the time domain has been developed based on ship motions simulations and structural loads calculated with the program developed in the previous task.

A time-domain technique based on Artificial Neural Networks (ANN's) for estimating wave-induced ship hull bending moment and shear force from ship motion measurements has been developed and implemented, by training the network with the time series included in the database of previous task.

The procedure for spectral estimation based on the rotating reference frame Kalman filter has been implemented in LabVIEW® RT and C, to run under Phar Lap ETS real-time operating system in a dual core PC.

The ocean wave spectral properties are estimated by the software in the real-time OS and sent via Ethernet to the user interface computer which can be running a non deterministic system such as Windows® OS.
Numerical tests have been performed using the data acquisition routines of WP5. These tests have been successful and indicated that some additional spectral smoothing may be necessary.

Wp5 – On board decision support system

System requirements and architecture have been outlined.

Because long connections will be necessary, the team has opted to use the National Instruments compact RIO (cRIO) controller system with two Ethernet ports and expansion chassis as the data acquisition and pre-processor system. The cRIO is installed in a safe room along with the data processing PC, the Ethernet switch and all the necessary power supply equipment. With respect to sensors installation, sensor group 1 represents all sensors close to the cRIO and sensor group 2 are those closest to the expansion chassis. Both are linked by EtherCAT deterministic network at distances up to 100 m/segment. The data processing and storage PC is a conventional dual core with Phar Lap real-time OS and is responsible for the deterministic Kalman filter calculations. The Ethernet switch is industrial grade 100 MB and enables connection between system components and to the ship's LAN, thus making information available wherever it may be needed throughout the LAN's presence.

An overview of the onboard Decision Support System (DSS) that facilitates navigational aids to the vessels in ocean navigation was provided.

The following activities have been done:

Investigation of the new concepts for monitoring systems developed by the leading suppliers in Civil Engineering and Shipping;

Design of Long Base Strain Gauge (LBSG) sensor for monitoring hull girder stress;

Design and fabrication the trial model of Short Base Strain Gauge (SBSG).

Design of test bench for laboratory testing and calibration of LBSG and SBSG

The manufacturing and the laboratory testing of the prototype of the data acquisition system and the analog or digital output variants of the sensors has been completed. All sensors are considered with analog (voltage or current) or digital output for testing the performance, cable distance, errors etc. Different sensor amplifier variants (voltage or current) are tested for solving the problems with long cable (distances) between the sensors and the system.

Documentation, such as Vessel's plans; Vessel's stability book has been collected.

The vessels which had been nominated for mounting of the handling waves equipment were visited and it was investigated the best places for cables and sensors mounting.

Information about the already available instruments on board has been collected.

The general arrangement of M/V Grande America has been studied.
Drawings have been made for the installation of sensors on board. Analysis and modification of existing drawings for the installation of sensors have been carried out.

Analysis of the possible indicators of the state of the vessel: strains and accelerations have been done and information about rough sea conditions has been collected.
Analyses of the possible devices to store elaborated data and of the interfaces to receive data have been done.
Analysis of the possible sensors and of the way to transmit their signals has been done.

Analysis of the load conditions and used software has been done.

The main data transfer bus is established through Ethernet connections. Both deterministic (EtherCat®) and non-deterministic protocols (TCP) are used.

The user interface application performs background frequency domain and probability domain calculations which use conventional Fourier analysis.

Line diagrams are used to represent data collected from installed sensors. These are used for monitoring ship motions, accelerations and loads and to verify if sensors are operating correctly.

The required software for data acquisition has been developed. The main objective of the data-acquisition system is to facilitate sensors and systems to communicate each-other to achieve the system objectives. The data-acquisition system mainly consists: Laptop and Desktop computers, GPS unit, CompactRIO and EntherCAT units, Unmanaged Ethernet Switch, and two power supplies.

The following activities have been done:

Laboratory testing of evaluation module of TDC technology (Time-to-Digital Converter);

Undergoing development of Data transmission system composed from uniform hardware devices (wireless sensing units);

The Structural Loads Estimator integrating software and hardware was developed.
The main activity was the preparation of specific loading software for test ships.
According to the plan, the cargo loading conditions and associated still water structural loads was obtained by the software ALCOS. However, for avoiding the installation of two loading instruments, with the need of entering twice the information required (this was a major problem for the Ro-Ro vessel), the software already available on the ships was employed. ALCOS has been actually used on board the Bulk Carrier.

Taking as reference the RINA additional class notation MON-HULL (Hull stress and motion monitoring) requirements and other hull monitoring systems already existing on the market, a numerical methodology which could be able potentially to replace the sensors required by MON-HULL additional class notation, giving information on hull girder normal stresses at a proper number of transverse sections has been defined.
For better analysing the behaviour of the structure with severe sea states, taking into account also instabilities due to compression, a procedure based on the hull girder ultimate strength analysis, provided by RINA rules at design stage, was proposed. A further check involving shear stresses induced by vertical shear forces due to global loads was proposed for the task. A simplified formulation has been adopted.
Also a fatigue analysis employing a methodology based on the accumulation of damage (Palmgren-Miner approach) is foreseen.

The procedures for the assessment on board of structural conditions were transposed in computer codes written in Fortran. Particularly, checks on the bending moments provided by the system have been implemented considering two approaches: a linear and a simplified nonlinear procedure. Moreover, a routine for the evaluation of the number of stress cycles (for the estimation of fatigue) was implemented, employing a Rainflow counting algorithm.

Setting files for the three test cases of the project, which include the description of the sectional properties or the characteristics of the longitudinal elements of the section, depending on the approach employed, have been prepared.

A more simplified procedure, to be employed onboard instead of the direct evaluation approach, has been elaborated and the related code has been prepared. It relies in any case on the procedure considered previously (hull girder ultimate strength approach), but allows simplifying the calculation that the system has to perform in real time onboard. This new procedure considers limits curve which identifies a subset of combinations of vertical and horizontal bending moments resulting to be safe for the integrity of the structure.
Warning and alarms are raised if the coupled values of vertical and horizontal bending moments estimated by the system cross the borders of the “safe space”, defined by the limit curves.

The limit curves have been calculated for three vessels which the system prototype has been installed on. Simulations, considering both the direct approach and the limit curves approach, have been performed employing the results of towing tank tests. Also the module for estimating fatigue has been tested with the same data.

Wp6 – Pilot applications on board

The sensing equipment and hardware components of the system, before integrated and tested in a laboratorial environment, has been installed on board of the three ships as scheduled on the installation plan. The main cRio terminal strip unit has been improved.

The algorithm employed for correlating strains measured by the LBSG with related bending moments has been defined. Also the procedure adopted for the calibration/zeroing of the sensors has been developed.

The entire signal from the different sensor and equipment have been collected and brought up to the bridge via connection and junction box designed on purpose. Also protection and boxes for the various sensor and equipment have been assembled and built with success for all the sensor and equipment acquired.

2. Dissemination and use

Results achieved during the Handling Waves Project have been published in the project website (http://www.mar.ist.utl.pt/handlingwaves/overview.aspx) as well as in some papers and reports.

In the following the list of publications is detailed.

Clauss, G., Klein, M., Dudek, M.:
Influence of the Bow Shape on Loads in High and Steep Waves (PDF, 3.02MB)
29th OMAE - International Conference on Offshore Mechanics and Arctic Engineering, June 6-11, 2010, Shanghai, China

Clauss, G., Klein, M., Sprenger, F., Testa, D.:
Evaluation of Critical Conditions in Offshore Vessel Operation by Response Based Optimization Procedures (PDF, 2.59MB)
29th OMAE - International Conference on Offshore Mechanics and Arctic Engineering, June 6-11, 2010, Shanghai, China

Clauss, G., Klein, M.:
The New Year Wave: Spatial Evolution of an Extreme Sea State (PDF, 968kB)
Journal of Offshore Mechanics and Arctic Engineering, Vol. 131, November 2009

Clauss, G., Klein, M., Kauffeldt, A.:
Limiting Loads and Motions of Ships in Extreme Sea States (PDF, 3.13MB)
13th IMAM - International Congress of the International Maritime Association of the Mediterranean, October 12-15, 2009, Turkey, Istanbul

Clauss, G., Stempinski, F., Dudek, M., Klein, M.:
On the Influence of the Water Depth on Wave-Structure-Interactions (PDF, 794kB)
13th IMAM - International Congress of the International Maritime Association of the Mediterranean, October 12-15, 2009, Turkey, Istanbul

Clauss, G., Stempinski, F., Dudek, M., Klein, M.:
Water depth influence on wave-structure-interaction
Ocean Engineering, Vol. 36, Iss. 17-18, December 2009, Elsevier Ltd.
ISSN 0029-8018, doi: 10.1016/j.oceaneng.2009.08.020

Clauss, G., Kauffeldt, A., Klein, M.:
Systematic Investigation of Loads and Motions of a Bulk Carrier in Extreme Seas (PDF, 785kB)
28th OMAE - International Conference on Offshore Mechanics and Arctic Engineering, May 31-June 5, 2009, Honolulu, Hawaii, USA

Clauss, G., Klein, M., Testa, D.:
Spatial Evolution of an Extreme Sea State with an Embedded Rogue Wave (PDF, 1.08MB)
27th OMAE - International Conference on Offshore Mechanics and Arctic Engineering, June 15-20, 2008, Estoril, Portugal

Clauss, G., Kauffeldt, A., Jacobsen, K.:
Longitudinal Forces and Bending Moments of a FPSO (PDF, 703kB)
26th OMAE - International Conference on Offshore Mechanics and Arctic Engineering, June 10-15, 2007, San Diego, California, USA

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Cherneva, Z.; Guedes Soares, C., and Petrova, P. G. Distribuition of Wave Height Maxima in Storm Sea States. Journal of Offshore Mechanics and Arctic Engineering. 2011; 133(041601-1):041601-1 - 041601-5.

Pascoal, R. and Guedes Soares, C. Kalman Filtering of Vessel Motions for Ocean Wave Directional Spectrum Estimation. Ocean Engineering. 2009; 36(6-7):477-488.

Arena, F. and Guedes Soares, C. On Sequence of High Waves in Nonlinear Groups . Journal of Offshore Mechanics and Arctic Engineering. Accepted

Petrova, P. G.; Arena, F., and Guedes Soares, C. Space-time evolution of random wave groups with high waves based on the quasi-determinism theory. Ocean Engineering. Accepted

Conference Proceedings

Arena, F. and Guedes Soares, C.. On Sequence of High Waves in Nonlinear Groups. Proceedings of the 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2008); Estoril, Portugal. New York, USA: ASME; 2008; OMAE2008-57889.

Cherneva, Z.; Guedes Soares, C., and Petrova, P. G. Distribuition of Wave Height Maxima in Storm Sea States. Proceedings of the 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2008); Estoril, Portugal. New York, USA: ASME ; 2008; OMAE2008-58038.

Ribeiro e Silva, S. and Guedes Soares, C. Non-Linear Time Domain Simulation of Dynamic Instabilities in Longitudinal Waves. Proceedings of the 27th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2008); Estoril, Portugal. New York, USA: ASME; 2008; OMAE2008-57973.

Ribeiro e Silva, S. and Guedes Soares, C. Parametric Rolling of a Container Vessel in Longitudinal Waves. Proceedings of the 10th International Conference on Stability of Ships and Ocean Vehicles (STAB 2009); St. Petersburg, **Russia**. 2009: 597-608.

Moreira, L. and Guedes Soares, C. Estimation of Wave-Induced Hull Bending Moment and Shear Force from Ship Motion Simulations using Artificial Neural Networks. C. Guedes Soares, (Eds.). 1st International Conference on Maritime Technology and Engineering (MARTECH 2011). 2011.

Perera, L. P. ; Rodrigues, J. M.; Pascoal, R., and Guedes Soares, C. Development of an onboard decision support system for ship navigation under rough weather conditions. Proceeding of the International Maritime Association of Mediterranean (IMAM 2011); Genoa, Italy. 2011.

Rajendran, S. ; Fonseca, N., and Guedes Soares, C. Experiment and Time Domain Method Comparison for the Responses of a Container Ship induced by the Three Sisters abnormal waves (Direct comparison of measured and calculated time records of the motions and loads on a Container induced by the Three Sisters wave sequence). C. Guedes Soares, (Eds.). 1st International Conference on Maritime Technology and Engineering (MARTECH 2011). 2011.

Rajendran,S; Fonseca, N.; Guedes Soares, C.; Clauss, G. F., and Klein, M. Time Domain Comparison with Experiments for Ship Motions and Structural Loads of a Containership in Abnormal Waves. Proceedings of the 30th International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2011); Rotterdam, The Netherlands. New York, USA: ASME; 2011.

Vasquez, G. A.; Fonseca, N., and Guedes Soares, C. Analysis of vertical motions and bending moments on a Bulk Carrier by model tests and numerical predictions. Congresso Pan-Americano de Engenharia naval, Transporte Marítimo e Engenharia (XXII COPINAVAL); Buenos Aires, Argentina.