ROPES; JOINT INDUSTRY PROJECT ON EFFECT OF PASSING SHIPS ON MOORED VESSELS

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ABSTRACT

Ships have significantly increased in size and number over the last decades. Ports and waterways are accommodating these ships and at the same time new terminals are designed in the existing infrastructure. In restricted water moored vessels can be affected by hydrodynamic forces induced by passing ships. The ROPES project was initiated to investigate these effects, to develop a numerical model for predicting these loads and to validate this model. To this end systematic scale model tests as well as extensive full scale measurements have been conducted. The research was conducted as a joint industry project with the support of port authorities, terminal operators, vessel operators, engineering companies, suppliers of mooring equipment and research institutes.

Within the ROPES project systematic model tests with captive models have been conducted to determine the effect of basic parameters such as water depth, canal width, speed and passing distance for various ship types. Dedicated captive model tests were conducted to investigate the effect of complex harbour geometries, current and drift angle of the passing vessel. Finally tests were conducted taking into account the full dynamics of the moored vessel including lines and fenders.
At the same time an extensive full scale monitoring campaign was conducted. On four selected locations in the Port of Rotterdam, the moored vessel motions and mooring line loads were measured in combination with the weather conditions while tracking the passing vessels. On several occasions in the monitoring campaign the effect of dynamic mooring systems was recorded and compared with conventional passive mooring. Within the project the ROPES software was developed to predict the loads excited by passing vessels on moored vessels for arbitrary port and waterway geometries. Special attention was paid to the practicalities and user friendliness of the software and the required computational time on a PC. The ROPES software was successfully correlated with both model tests and full scale results.

In this paper an overview of the ROPES project and its results are presented. More detailed information will be provided in separate papers in the same session. Finally some main conclusions are drawn.

INTRODUCTION

Over the last decades global shipping has been growing substantially. For many ship types the size of the fleet and the dimensions of the vessels are increasing rapidly. Some 20 years ago the largest container vessels were the Panamax size; typically 300 x 32 m with a cargo capacity of around 3500 TEU. Over the last decade the fleet developed with large series of “Post-Panamax”-vessels first with a cargo capacity of typically 6500 TEU followed by 9000 and then the NewPanamax size of 14,000 TEU. This year the new Panamax canal will open its locks but the recent entries of 18,000 TEU are already too big to pass these.

Development of ports and waterways cannot keep the pace set by global shipping and shipbuilding. New ports and extensions of existing harbour infrastructure require large deep water acreage, extended loading and unloading equipment and reliable large volume connections with the hinterland. This all requires planning and development and thus time.

This implicates that existing ports and waterways have to accommodate more and larger ships. At the same time more quay length and berths are required for loading and unloading these vessels. Preferably such berths are planned alongside existing waterways and sometimes blocking a part of

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that waterway for navigation. The swift handling of these vessels as well as the manoeuvrability of the large vessels requires an adequate speed; extreme speed limitations are not desirable.

Vessels navigating in restricted water cause a pressure wave which can be observed as water draw down. In a shallow and narrow waterway this piston effect can be substantial; the water level raises ahead of the vessel and the flow accelerates alongside the hull to fill up behind the vessel. For vessels moored in such a waterway or adjacent harbour, the change in water draw down can result in resonant horizontal vessel motions and large loads in the mooring lines. Container cranes, loading arms for oil and LNG and automated dry bulk excavators can normally only allow limited horizontal vessel motions. Dangerous situations for crew and vessel and large down time may occur when motion limits are exceeded or when mooring lines fail. Many ports and terminals alongside waterways are regularly confronted with such situations which can result in considerable downtime of the terminal and eventually also in dangerous breakaway from e.g. loading/unloading equipment.

A recent development is the use of active mooring systems to restrain the vessel motions alongside a quay or jetty. Experience in ports with vessels of convenience is that the state of the mooring equipment is often not equal to the task. Lines are not well maintained or replaced and winches cannot provide the specified load. By providing adequate forces from the shore side these problems can be avoided and vessels can be safely moored in adverse conditions.

Figure 1: VLCC "TI-Europe" during ROPES measurement campaign

In view of the above, in 2010 the ROPES (Research on Passing Effects of Ships) project was initiated. The objectives of the project were to investigate the physical phenomena systematically, develop a practical computational tool to predict the effects of passing ships and to validate this tool by means of model tests and full scale measurements (Figure 1) and finally to assess its application boundaries.

In this paper an overview of the ROPES JIP is presented. For detailed information reference is made to the following PIANC papers:

A more detailed description of these tasks is given in the following adjacent papers presented at PIANC:

“A fast, user-friendly, 3-d potential flow program for the prediction of passing vessel forces”
Authors: J.A. Pinkster & H.J.M. Pinkster (PMH BV)

“Passing-ship effects in complex geometries and currents”
Authors: A.J. van der Hout, M.P.C. de Jong, S.P. Reijmerink (Deltares)

“Full scale measurements of passing ship effects”
Authors: E. Wictor and H.J.J. van den Boom (MARIN)

“Loads on moored ships due to passing ship events in a straight harbour channel”,
Authors: H. Talstra and A.J. Bliek (Svasek)

PREDICTION OF THE EFFECTS OF PASSING SHIPS ON MOORED VESSELS

The physics involved in passing ship effects are rather complicated and concern many parameters. The 3-D geometry of the port and the bathymetry of the waterway, the displacement of the vessels, the passing distance and speed are the most dominant parameters. The effect of current, the non-linear track of the passing vessel and possibly its drift angle and the detailed geometries of the hull can also affect the loads on the moored vessel. For the dynamic response of the moored vessel obviously it's mooring configuration, the line characteristics and fender stiffness and not –least the pre-tension in the mooring lines are dominant parameters.

For the design of ports, the mooring of vessels and possibly developing strategies and policies for vessel traffic passing vessels at berth, it is essential that the effects of passing vessels on moored ships can be predicted in advance. For this purpose until recently scale model tests were the most common approach. For designing new berths, harbours and ports, evaluation of mooring configurations and for developing strategies and policies for vessels passing moored vessels, the parameters involved are just too many and the physics involved too complicated to rely on simple rules of thumb or empirical models. Model tests provide adequate results but require an extensive program, time and budget.
A numerical tool with an acceptable reliability of results and computational time would be the best tool for design and engineering companies to derive the required data. Fortunately over the last decade significant advances have been made in computational models based on first principles in ship hydrodynamics.

Already in the 1970's systematic model tests were conducted by NSMB (now MARIN) to investigate the effects of dominant parameters such as passing distance, speed and under keel clearance, see REMERY, G.F.M. (1974) After this pioneering work for several new ports and harbour developments specific model test programs were carried out to measure motions and line loads of the moored vessels. In 2009 Pinkster published results of a numerical model based on linear 3-D potential theory neglecting free surface effects by utilizing double-body flow around the passing ship mirrored in the calm water surface. With this approach the forces excited on both the passing and moored ship can be computed by direct integration of the pressures over the wetted surface of the hull. The approach ignores free surface effects as well as fluid rotation and viscous effects. Nevertheless a good agreement was found with the original model tests results published by Remery.

In recent years computational models have been introduced which actually overcome these restrictions of double body potential theory. In 2011 Bunnik and Toxopeus published results of an approach where the disturbance caused by the passing ship on the moored ship and port geometry was computed by a RANS method. The effects caused by the moored ship were derived from linear 3-D diffraction. The modelling complexity of such models and the computational efforts required however, are prohibitive for design and engineering projects. The following question therefore arises: Is a linear double body potential flow model sufficiently accurate and can it be made practical and computational efficient for use in day to day engineering and what are the limitations of this approach? Answering this question was the main objective of the ROPES JIP.

SCOPE OF THE ROPES JIP

The Research on Passing Effects of Ships project, shortly ROPES, comprised the following tasks:

1. Literature & computational model survey
2. Development and delivery of a practical software tool to predict forces on moored vessels,
3. Systematic model tests to quantify the influence of the ship type and size, draft, course, speed and passing distance displacement, port geometry, ship mooring and current.
4. Full scale measurements of motions and line loads of moored ships and the relevant data of passing vessels as well as the environmental conditions such as current and water draw down.
5. Correlation of the model test and full scale measured data with dedicated numerical simulations using the ROPES software.

The conduct of the ROPES JIP required a wide range of expertise and research facilities. To bring this expertise to the table, to share the costs and to arrive at a common understanding on the subject, the project was conducted as a Joint Industry Project in which all stakeholders were represented.

The main tasks in the JIP were carried out in a concerted action of the following partnership:

- MARIN: Full scale measurements, Model tests with moored vessel & JIP Management
- PMH: Software tool development & literature review
- Deltares: Model tests in current & complex harbour layouts
- Svasek: Correlation & evaluation of results

Ropes Software

A versatile and practical software package to compute the loads excited by passing ships on other multiple vessels was developed by Pinkster Marine Hydrodynamics. The kernel of the software has been based on double body 3-D linear potential theory. For each time step the forces on the vessels are obtained by direct pressure integration over the hull. The 3-D geometries of the waterway, port and the vessels are represented by a panel distribution. For the vessels MARIN provided some 10 typical geometries of different ship types and barges. These geometries can be scaled in the ROPES software based on the actual length, beam and draft of the vessels considered, for further details see PINKSTER, J.A., & PINKSTER, H.J.M (2014). To find the actual motions and mooring line loads of the moored vessel the ROPES results have to be used as input to non-linear mooring simulation software such as aNySim.

Model tests

At the start of the project an extensive systematic model tests program was further carried out by Flanders Hydraulics in Borgerhout, Antwerp (Figure 2). With their fully automated towing tank they contributed the results of 386 captive model tests with various ship types using systematic variations of speed, passing distance and under water clearance. A second series of systematic model test results was contributed by the Port of Rotterdam. These tests have been conducted by MARIN or the new Yangtze port in the Maasvlakte II development and comprised valuable data with large container ships. The effects of current and complex harbour geometries were subsequently investigated by Deltares by means of captive model tests see HOUT, A.J. VAN DER., JONG, M.P.C. DE., & REIJMERINK, S.P. (2014). Finally MARIN conducted model tests with the moored vessel in both captive modes as well as in mooring lines and fenders to measure actual motions and mooring line loads excited by passing vessels under various drift angles.

Figure 2: Fully automated systematic model tests at FHR in Borgerhout

Full Scale Measurements

A major effort in the ROPES JIP was the full scale measurement campaign (Figure 1). On four selected locations in the port of Rotterdam the dynamics of moored vessels were monitored in conjunction with the data of the passing vessels. The locations concerned a deep sea container terminal, a berth for dry cargo alongside the river, an inland canal location and finally a dolphin mooring for VLCC's in the Caland Canal. On the moored vessel the vessel motions at wave frequencies and low frequencies were recorded by RTK-GPS and MRU's. The mooring lines were instrumented with wireless load cells. Water drawdown was measured ahead and behind the moored vessel and the current and wave height was measured by ADCP. The relevant data such as vessel size, speed and passing distance of the passing traffic were recorded from AIS data and from traffic control radar. See TALSTRA, H., & BLIEK, A.J. (2014). An example of the recorded water draw down and mooring line loads is presented in Figure 3.

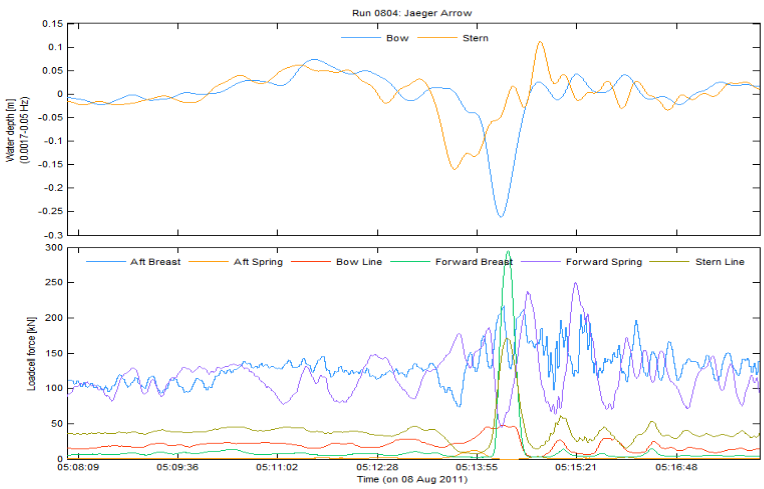

Figure 3: Water draw down and mooring line loads measured at the Nieuwe Maas river location

For two locations measurements were also conducted with an active mooring system; in these cases the ShoreTension were incorporated in the breast lines. Although a direct comparison for the same vessel in the same conditions was not feasible, vessel motions and line peak loads were clearly reduced by ShoreTension.

The actual full scale measurements were conducted by MARIN with extensive support from the Port of Rotterdam and terminal operators. The practical support of the Rotterdam boatsmen (KRVE) and pilots (NLC) were indispensible for this campaign.

Correlation study

To validate the newly developed ROPES software, the software was used to simulate all the model tested situations as well as selected actual full scale situations from the measured data sets. The forces on the moored ships as predicted by the software were directly compared to the forces measured on the captive models. For the model tests with the vessel moored in lines and fenders as well as the full scale data, the forces computed by ropes were used as input for non-linear dynamic mooring simulations. The resulting line loads and vessel motions were then compared with the measured values. All partners contributed to the huge correlation task to simulate the measured model tests situations. Arcadis, Moffatt & Nichol and MARIN were involved in the simulation of the situations encountered in the full scale monitoring campaign. Svasek led the final evaluation of the correlation results, see TALSTRA, H., & BLIEK, A.J. (2014).

RESULTS

The ROPES research program resulted in a valuable and comprehensive set of experimental, computational and full scale data. Furthermore the practical and user-friendly ROPES software was developed and validated. The software was delivered to all participating companies enabling them to compute the forces excited by passing vessels on moored vessels.

This computational tool has been based on the assumptions that the pressures originating from the passing vessels can be described by double body 3-D potential theory thus neglecting free surface effects, fluid rotation and viscous effects. Both the 3-D geometry of the port and waterway configurations as well as the vessels involved is accounted for. For practical reasons it is assumed that the vessel(s) navigate on a straight course without a drift angle. The vessel geometries are derived from standard ship types scaling the main dimensions. This approach which saves substantial input efforts is based on the knowledge that it is mainly the displacement distribution over the length of the vessel and not the accurate 3-D geometry that dominates the effects. The moored vessel is captive; The ROPES software only provides the exiting forces to the moored vessel. To analyse the subsequent motions and mooring line loads, the ROPES force records have to be used as input to a dynamic mooring analysis program.

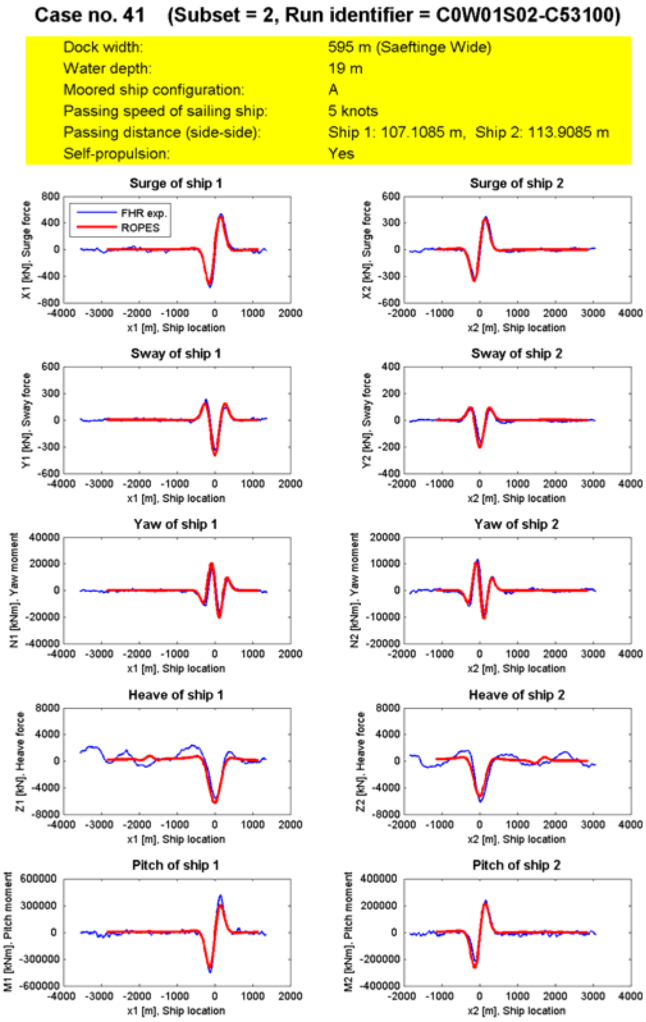

Figure 4: Forces measured on captive moored vessel compared with ROPES computational results.

The core data set for understanding and quantifying the effects of passing vessels on moored vessels in a straight water way with constant depth is undoubtedly the data measured by Flanders Hydraulics with captive models of various ship types for 386 situations. Each of these situations has been simulated with the ROPES software. The forces acting on the moored vessel were then compared with the forces measured on the captive model in the scale tests. An excellent agreement was found for the situation which is most practical interest. A typical example of the correlation result is given in Figure 4. When the passing speed was beyond the normal region (above 7 knots or Fn > 0.3) results from the ROPES software started to deviate from the measured results. For further details see WICTOR, E., & BOOM, H.J.J. VAN DEN (2014).

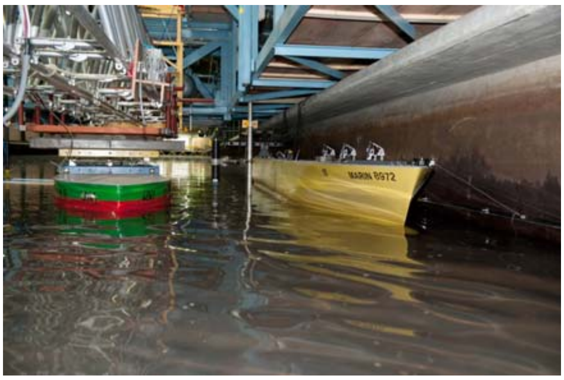

Figure 5: MARIN tests with moored vessel and passing ship under drift angle

The model tests conducted by MARIN with a captive moored vessel and a vessel moored by lines and fenders were conducted to study the effect of drift angle of the passing vessel on the moored vessel. It was found that for drift angles beyond 6 degrees these effects can be significant. It was also found that effects for a negative drift angle (bow away from the moored vessel) were milder than for a positive drift angle (bow toward the moored vessel) (Figure 5). The explanation is in the vortices around the bow of the vessel which are obviously neglected in the potential theory. BUNNIK, T., & TOXOPEUS, S. (2011) has shown that RANS models can predict these situations better. The dynamic behaviour of the moored vessel was simulated with ANYSIM software. By using the measured forces of the captive tests as input it was shown that the vessel motions, line loads and fender deflections can be simulated accurately as illustrated by Figure 6. Using the forces computed by ROPES as input showed a slightly less good but still acceptable agreement.

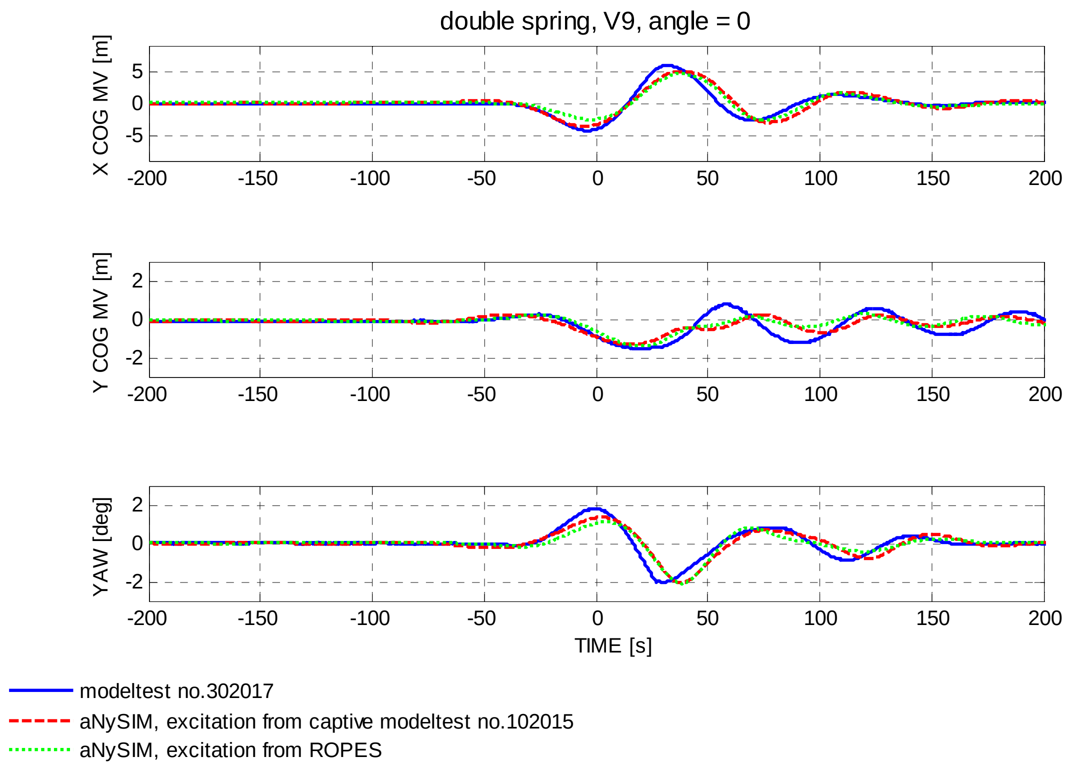

Figure 6: Correlation between aNySIM & Model tests

The model tests conducted by Deltares focussed on the effect of current and complex port geometries.

In this case the navigating vessel was following a fixed course in a straight canal with constant water depth while the moored ship was captive alongside the waterway or in one of the simulated side basins. Figure 7 shows the various tested harbour configurations. All these situations have been computed with the ROPES software and the computed forces on the moored vessel were compared with the measured forces on the captive model. A good agreement was found between measured and numerical results. The effect of current could be simulated in the ROPES software by moving the waterway geometry and the moored vessel with the current speed but in opposite direction. Alternatively and less accurate the navigating vessel can be simulated with a speed equal to the speed through water. For the high speed range (Fn > 0.3) it was concluded that free surface effects cannot be neglected. Also for some complicated shaped narrow side basins the forces predicted by the ROPES software deviated from the measured data. See HOUT, A.J. VAN DER, JONG, M.P.C. DE & REIJMERINK, S.P. (2014).

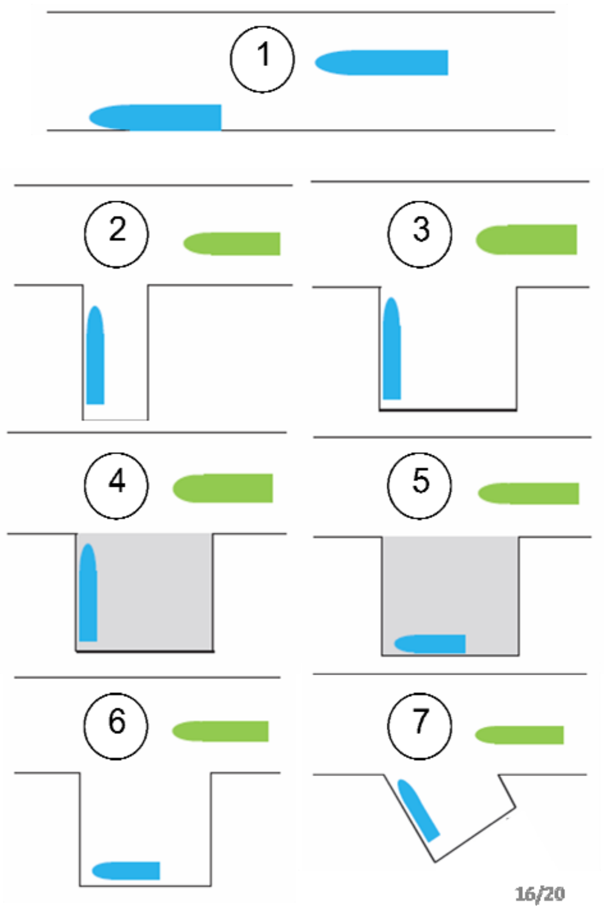

Figure 7: Harbour configurations tested by Deltares

Besides the dedicated monitoring campaign on the four locations in the Port of Rotterdam also an extensive data set acquired on an existing jetty in Port Hedland (Australia) equipped with Cavotec's Moormaster system was contributed by the Port Hedland Authorities and Cavotec. In this case the vessel was considered to be captive and the measured mooring loads were directly compared with the forces computed by ROPES for this situation taking into account the 3-D banks and bathymetry of the waterway and berth. A reasonable agreement was found for the longitudinal forces. The measured transverse forces showed peaks which could be attributed to the dynamic control of Moormaster.

For selected cases from the full scale campaign, simulations with the ROPES software were used as input to dynamic mooring analysis so that computed vessel motions and line loads could be compared with the measure values. As not all of the large number of parameters was known, some systematic variation of the unknown parameters such as the line stiffness was carried out. Using average realistic numbers for these parameters, a good agreement in extreme vessel motions and line loads was found. As illustrated by Figure 8 in several cases a good deterministic comparison between the measured and simulated time records was found as well.

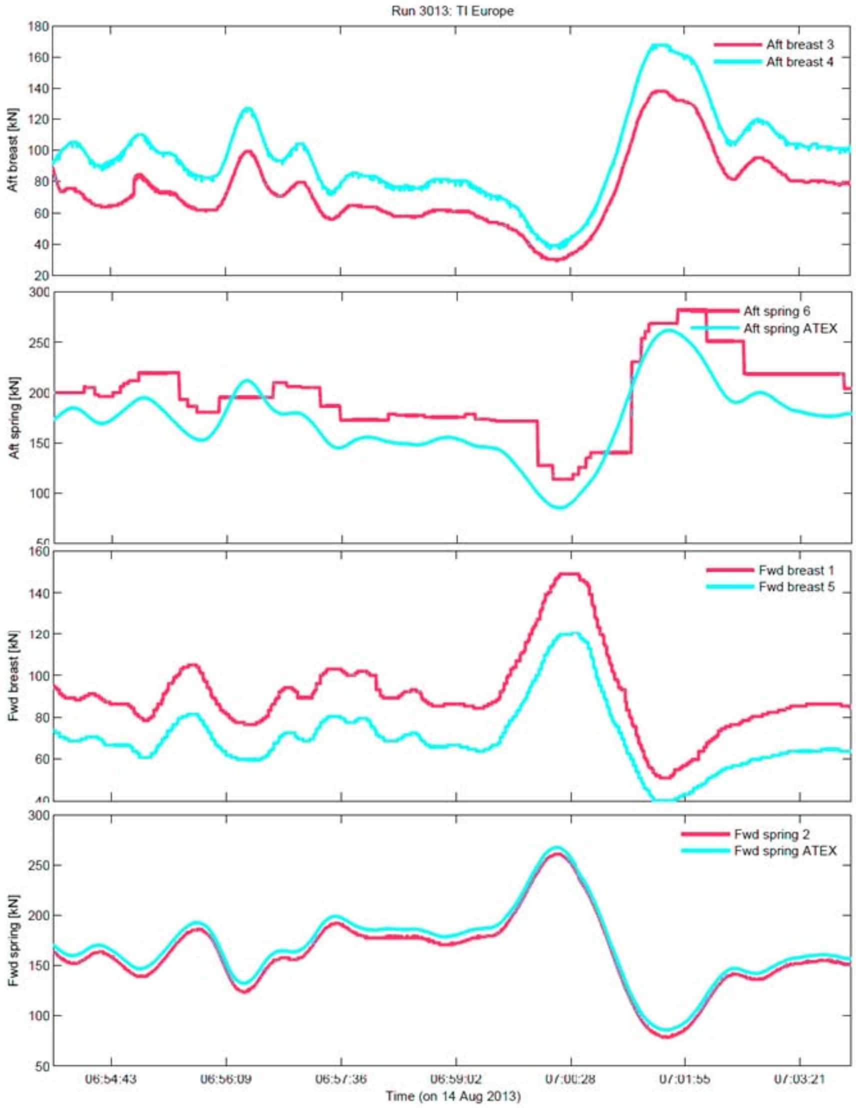

Figure 8: Comparison of simulated and measured line tensions for VLCC measured at Caland Canal.

CONCLUSIONS

From the extensive results of the 3-year ROPES project the following conclusions were drawn:

- In restricted waters, passing ships can excite large forces on moored vessels which may result in resonant horizontal motions and excessive mooring line and fender loads.
- These exciting forces are strongly related to the 3-D geometry of the waterway/port, the displacements and under keel clearance of the vessels, the passing distance and the passing speed.
- The ROPES software developed in the JIP based on 3-D double body potential flow theory has proven to compute these forces accurately for most practical cases.
- The ROPES software has been validated by means of model tests with various vessels, speeds, passing distances, waterway and port geometries. Both in calm water and in current and for vessels passing at drift angles.
- In case of high passing speeds (Froude number above 0.3) a simple correction factor can be applied on the forces.
- The ROPES results start to deviate from the measured data in case the drift angle of the passing vessel is beyond 6 degrees.
- ROPES results have been used as input to various dynamic mooring simulation packages and in this way mooring loads and motions could be correlated with results of full scale

measurements. Given the large number of parameters involved a reasonable correlation was obtained.

- Dynamic controlled mooring systems such as Moormaster and ShoreTension have the capability to restrict the motions of moored vessels, avoiding resonance and thus peak loads in the mooring.

ACKNOWLEDGEMENT

The authors would like to thank all partners, participants and sponsors in the ROPES JIP for their support to conduct this work and present this paper. The logos of the companies participating in the ROPES JIP are presented in the Figure 9 below.

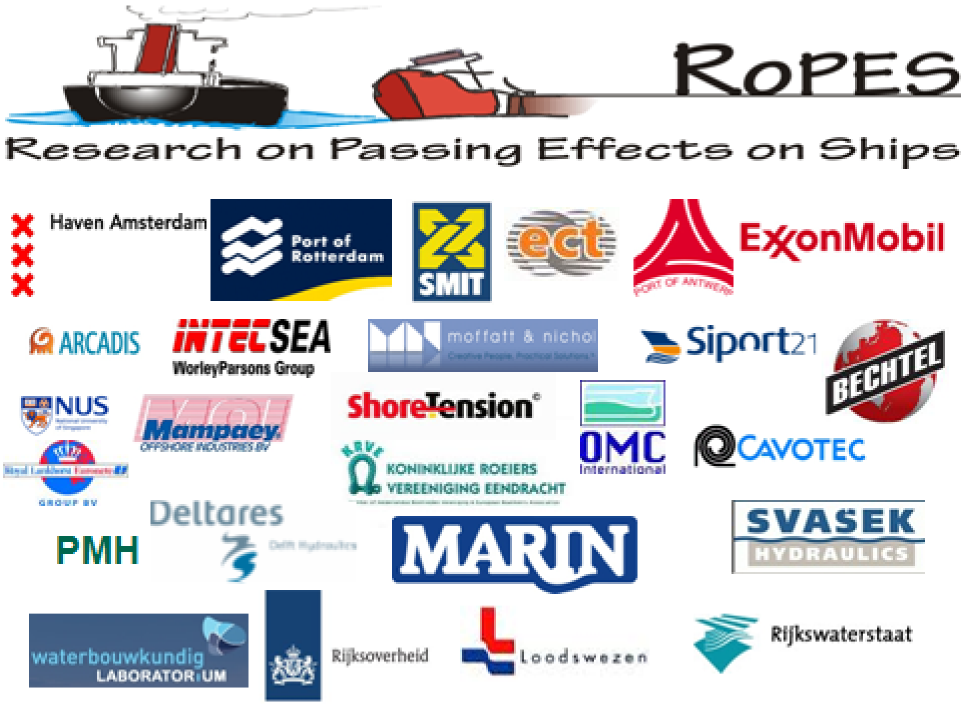

Figure 9: Organisations that participated in the ROPES JIP

REFERENCES

Remery, G.F.M., “Mooring Forces Induced by passing Ships”, OTC 2066, Houston Texas, May 6-8, 1974.

Pinkster, J.A., “Suction, Seiche and Wash Effects of Passing Ships in Ports”, ISOPE Lisbon, Portugal, July 1-6, 2009.

Bunnik, T. and S. Toxopeus, “Viscous Flow Effects of Passing Ships in Ports”, OMAE2011- 49519, Rotterdam, The Netherlands, June 19-24, 2011.

Pinkster, J.A. and H.J.M. Pinkster, “A fast, user-friendly, 3-d potential flow program for the prediction of passing vessel forces ", PIANC, San Francisco, USA, 1-5 June, 2014

Hout, A.J. van der, M.P.C de Jong and S.P. Reijmerink, “Passing-ship effects in complex geometries and currents”, PIANC, San Francisco, USA, 1-5 June 2014.

Talstra, H. and A.J. Bliek, “Loads on moored ships due to passing ship events in a straight harbour channel”, PIANC, San Francisco, USA, 1-5 June 2014.

Wictor, E. and H.J.J. van den Boom, “Full scale measurements of passing ship effects”, PIANC, San Francisco, USA, 1-5 June 2014.