Date May 2009
Author Ir. P. Naaijen
Delft University of Technology
Address Ship Hydromechanics Laboratory
Mekelweg 2, 26282 CD Delft

TUDelft
Delft University of Technology

Computation and validation of passing ship Induced waves in confined water

by

P. Naaijen

Report No. 1618-P 2009

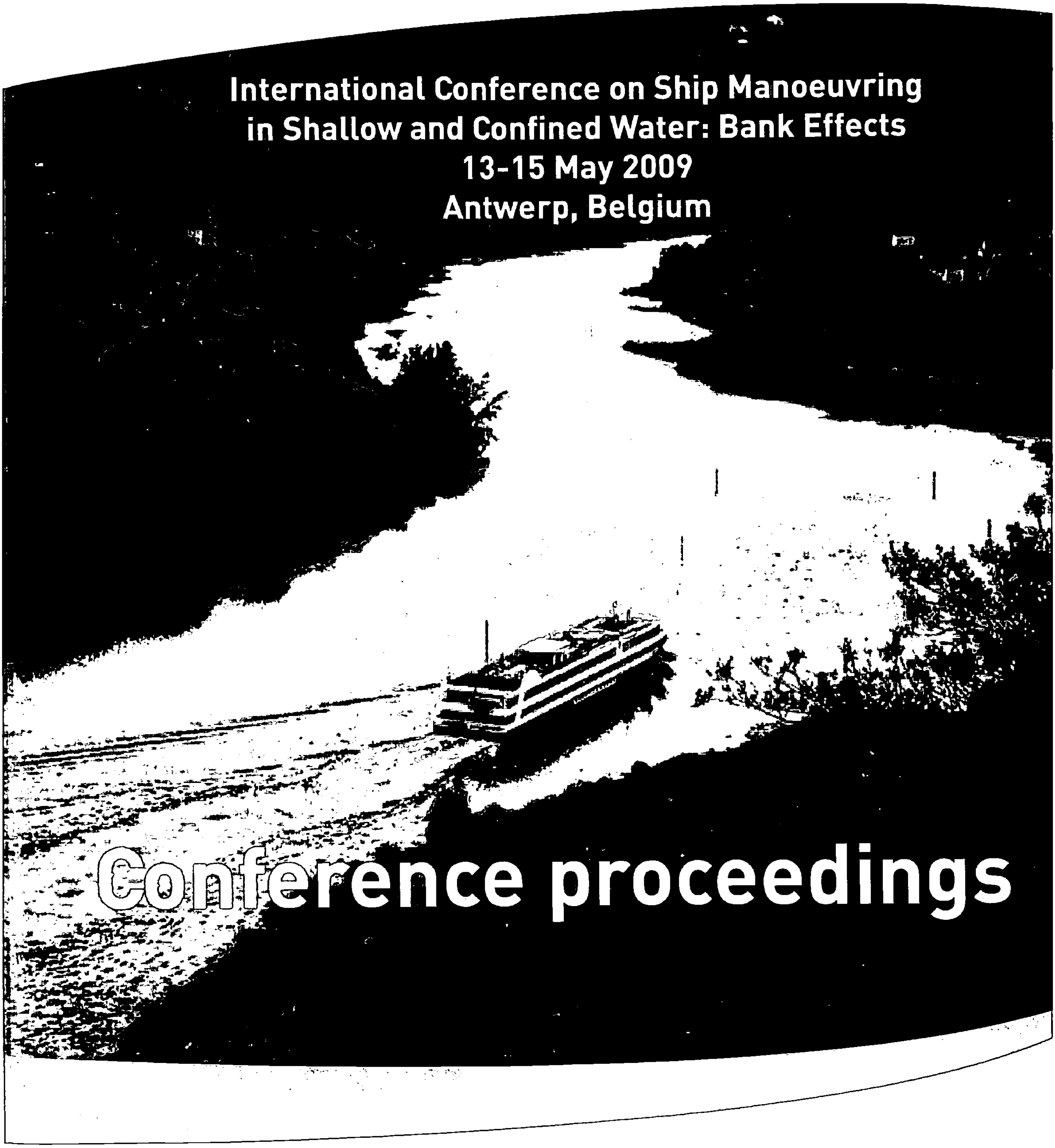
Proceedings of the International Conference on Ship Manoeuvring in Shallow and Confined Water: Bank Effects, 13-15 May 2009, Antwerp, Belgium, ISBN No. 978-1-905040-46-9

UNIVERSITEIT GENT

MARITIME TECHNOLOGY
GHENT UNIVERSITY

RINA
CORPORATE PARTNER

flanders
HYDRAULICS RESEARCH



International Conference on Ship Manoeuvring in Shallow and Confined Water: Bank Effects

13-15 May 2009

Antwerp, Belgium

Conference proceedings

Vlaamse overheid

INTERNATIONAL CONFERENCE ON SHIP MANOEUVRING IN SHALLOW AND CONFINED WATER: BANK EFFECTS

13 – 15 May 2009

Editors

Prof. Katrien ELOOT
Prof. Marc VANTORRE

THE ROYAL INSTITUTION OF NAVAL
ARCHITECTS
10 Upper Belgrave Street
London SW1X 8BQ

Telephone: 020 7235 4622
Fax: 020 7259 5912

Cover photo: © E. Lataire

ISBN No: 978-1-905040-46-9

INTERNATIONAL CONFERENCE ON SHIP MANOEUVRING IN SHALLOW AND CONFINED WATER: BANK EFFECTS

INTERNATIONAL ORGANIZING AND PAPER COMMITTEE (OPC)

MSc. Trevor BLAKELEY	Royal Institution of Naval Architects
Mrs. Karine DE GRAUWE	Flanders Hydraulics Research
Dr. Guillaume DELEFORTRIE	Flanders Hydraulics Research
Prof. Katrien ELOOT	Flanders Hydraulics Research, Ghent University
Mr. Philip ELTRINGHAM	Royal Institution of Naval Architects
Ms. Viki KRUYNIERS	Flanders Hydraulics Research
MSc. Evert LATAIRE	Ghent University
Dr. Frank MOSTAERT	Flanders Hydraulics Research
Prof. Marc VANTORRE	Ghent University
MSc. Jeroen VERWILLIGEN	Flanders Hydraulics Research

PREFACE

Most ships are designed and optimised for operation at full ocean, to cover large distances from port to port, following a straight course at an economic speed. However, almost every ship will inevitable leave her natural habitat from time to time to berth in a harbour, that can only reached by channels with restrictions in both depth and width. Speed has to be slowed down, bends have to be taken, external effects such as wind and current on the ship's track will become increasingly important. The distance between the vessel and the bottom, the banks of the waterway and other shipping traffic is significantly reduced, so that hydrodynamic interaction forces will disturb the ship's controllability.

An increased interest in ship behaviour in shallow and restricted water can be observed on an international scale. As a matter of fact, the importance of the maritime transport for global economy does not allow any weak links that may jeopardise the entire chain; just as all the other links, the connection port-sea has to be covered in a safe and efficient way, at an acceptable price to the local and international society. Especially the last decade, a spectacular increase of the overall dimensions of several ship types can be observed, while for port and waterway authorities it is not straightforward or even impossible to increase the dimensions of access channels and harbour areas at the same rate. As a result, a better knowledge of interaction effects will be essential on several levels: for the pilots and tug masters who are confronted with these effects on a daily base, for waterways authorities who have to judge whether ships with given dimensions can make use of their fairways in a safe and smooth way and decide upon capital investments, for port authorities and terminal operators who need to know the opportunities and limitations of their facilities, for waterway designers who must decide upon the dimensions of existing and future access channels, for simulator developers and users who apply their tools for research, design and training. Not only the maritime industry is challenged in this way; also for all stakeholders in inland shipping there is an increasing need for reliable information about the behaviour of push convoys and inland vessels in order to fulfil optimally their role in contributing to a solution for the mobility problem.

The Knowledge Centre "Manoeuvring in Shallow and Confined Water", established by Flanders Hydraulics Research in partnership with the Maritime Technology Division of Ghent University, intends to increase the understanding of phenomena that dominate the behaviour of ships in restricted navigation areas by creating an additional forum for all parties interested in this field. The International Conference on Ship Manoeuvring in Shallow and Confined Water that is organised in association with the Royal Institution of Naval Architects, aims to offer a new opportunity for communication and discussion, with the non-exclusive focus on: ship-bank interaction effects or, in short, *bank effects*. The organisers express their hope that this Conference will be the first event in a periodic series, to be organised in the future in co-operation with other institutions.

The 16 papers that will be presented during this Conference cover a wide variety of aspects and viewpoints. Although focused on ship-bank interaction, related topics – the most important being squat – will be dealt with as well. The opportunities of theoretical, numerical, experimental and empirical research techniques will be discussed, but several authors will also present their – sometimes many years' – practical experience in the field. In this way, the programme offers all elements to stimulate fruitful and inspiring discussions.

The organisers are extremely pleased with the international character of the Conference: the authors of the papers represent 13 countries from four continents: Australia, Belgium, Bulgaria, China, France, Germany, Japan, Korea, Malaysia, the Netherlands, Norway, the United Kingdom, and the United States of America, This illustrates once more the worldwide interest in ship behaviour in shallow and confined water. The initial list was still longer, but unfortunately due to different factors – among which the present global economic situation – some authors could, much to their and our regret, not make their commitments.
It will be hard to find a venue for a conference on bank effects that is more suitable. Not only for obvious reasons, being located on the right bank of the river Scheldt, but also because this location has a nearly symbolic meaning. In a historical perspective, the accessibility of the port of Antwerp through this river has proved to be the main and even the only condition for the prosperity of the city and the country. Although in history the main concern for the accessibility has not been hydrodynamics, the latter is of increasing importance due to recent evolutions in the shipping world. The awareness of the maritime community for the accessibility of the harbours is illustrated by the presence of Mr. Marc Van Peel, Alderman of the Port of Antwerp and Chairman of the Port Authority, and is also proved by the impressive response on the organisers' request for sponsoring. The sponsors of this event represent harbour authorities, waterway authorities, maritime services, ship owners, port terminal operators, tugboat companies, water dependent industries and engineering companies.

On behalf of Flanders Hydraulics Research, the Maritime Technology Division of Ghent University and the Royal Institution of Naval Architects, the organising committee wishes the delegates a rewarding conference and a pleasant stay in Antwerp, and hopes this Conference on Manoeuvring in Shallow and Confined Water will be the first of a long series.

Antwerp, May 2009

Prof. Marc Vantorre
Organizing committee

IN COOPERATION WITH:

Arcelor Mittal Ghent

Beverrent Diamanttechnieken

Grimaldi Belgium

Port of Antwerp

Port Authority Zeebrugge

Maritieme Dienstverlening en Kust

Promotie Binnenvaart Vlaanderen

PSA HNN

Technum

URS Towage and Salvage

Waterwegen en Zeekanaal NV

TABLE OF CONTENTS

Manoeuvring Behaviour of an LNG Vessel in a Restricted Waterway (p.101)
A. Maimun – Universiti Teknologi Malaysia, Malaysia
A. Priyanto – Universiti Teknologi Malaysia, Malaysia
Rahimudin – Universiti Teknologi Malaysia, Malaysia
Baidowi – Universiti Teknologi Malaysia, Malaysia
Nurcholis – Universiti Teknologi Malaysia, Malaysia

Roll Motion of Containership in Shallow Water (p.107)
E. Milanov – Bulgarian Ship Hydrodynamics Centre (BSHC), Bulgaria
V. Chotukova – Bulgarian Ship Hydrodynamics Centre (BSHC), Bulgaria

Study on the algorithm of collision avoidance for large container vessel in shallow confine waterway (p.107)
N. Son – Maritime and Ocean Engineering Research Institute (MOERI)/KORDI, Korea
Y. Furukawa – Kyushu University, Japan

Numerical Simulation of the Viscous Flow around a Ship Undergoing Unsteady Berthing in Shallow Water (p.121)
H.M. Wang – School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, China
Z.J. Zou – School of Naval Architecture, Ocean and Civil Engineering, State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, China
Xi-Min Tian – Marine Design & Research Institute of China, China

Evaluation of Ship-Bank and Ship-Ship Interaction Forces using 3D Panel Method (p.127)
H. Yasukawa – Hiroshima University, Japan
S. Kawamura – Hiroshima University, Japan
S. Tanaka – Hiroshima University, Japan
M. Sano – Hiroshima University, Japan

Presentation of STS research and invitation for next conference (p.135)
B. Pettersen – Norwegian University of Science and Technology, Norway
Tor Einar Berg – MARINTEK, Norway

Action/Reaction and Interaction a Case Study of a Failed Overtaking Manoeuvre in a Confined Waterway (p.141)
Capt. P Drouin – Transportation Safety Board of Canada, Canada
G Bussieres – Transportation Safety Board of Canada, Canada

Prediction of Manoeuvrability of a Ship with Low Forward Speed in Shallow Water (p.147)
S.W. Kim – Daewoo Shipbuilding & Marine Engineering Company, Ltd., Korea
D.J. Kim – Seoul National University, Korea
K.P. Rhee – Seoul National University, Korea
D.J. Yeo – Maritime and Ocean Engineering Research Institute/KORDI, Korea

COMPUTATION AND VALIDATION OF PASSING SHIP INDUCED WAVES IN CONFINED WATER

P Naaijen, Delft University of Technology, the Netherlands

SUMMARY

In this paper, a study is presented to validate a computational model that was developed to calculate passing ship induced waves in confined water. The model itself is briefly explained and two experiments to validate it are described. The first experiment involves an accelerating barge in a straight channel of constant width. The effect of the acceleration on the generated transient wave is considered. In the second experiment the effect of a vessel passing a constriction in a canal on both the wave height upstream in the canal and the wave height in a harbour alongside the canal are examined. A comparison of the computed and measured wave elevation is presented.

1. INTRODUCTION

Vessels sailing through confined water generate transient waves that result in forces on moored vessels. Resulting vessel motions may cause difficulties during loading or offloading operations and/or cause damage to the mooring system.

Different wave systems can be distinguished whose resulting forces have their own characteristics: the primary pressure system around the ship results in low-frequency forces also known as suction forces. More high frequency forces are generated by the so-called wash waves and finally, unsteady sailing behaviour and changes in the geometry of the waterway that the passing ship is sailing through may cause soliton-like waves that are different from the two previously mentioned wave effects in the sense that they are transient with respect to the vessel that is causing them. It is the latter kind of waves that has been focused on in the present study.

Mooring forces due to the primary pressure system were subject to a full scale validation study in earlier work; see Pinkster et al. [1]

2. THEORY OF COMPUTATIONAL MODEL

The computational method used for the prediction of the wave height or exciting forces on other (floating) structures anywhere in the harbour/fairway, is based on 3D linear potential theory. A numerical panel method is used for the calculation: both ship and waterway, and any moored vessels present, are represented by a 3D panel distribution. The method can be presented by four steps:

1. Determination of the flow around the passing ship. Here, a so-called double body flow around the ship is calculated: the free surface boundary condition implies zero normal velocity at the free surface. Contrary to previously published work (Pinkster et al. [5]) where only depth restrictions were taken into account in this first calculation step, restrictions in both vertical and horizontal direction of the waterway can now be taken into account.
2. Time traces of the disturbance by the passing ship's double body flow at each of the panels of the waterway and any moored ships (ignoring the presence of the passing ship itself) are Fourier- transformed into frequency components.
3. The diffraction effects of the waterway and moored ships are determined: the velocity potential is solved, this time taking into account the linearised free surface boundary condition enabling the generation of diffraction waves.
4. The obtained frequency domain solution of the velocity potential is inverse-transformed into the time domain. Pressures, velocities and wave heights at any desired location can be determined now from the known velocity potential.

Each of these four steps will be explained in detail in the following:

2.1 DOUBLE BODY FLOW

The model is similar to that described by Korsmeyer et al [3] in that it is based on 3-dimensional potential flow. For the double-body flow model, the potentials describing the flow are based on the Rankine source formulation taking into account restricted water depth and a rigid still water level. To this end the Rankine source formulation needs to be modified to take into account the zero normal velocity which is applicable at both the still water level and the bottom of the waterway. This implies that sources are mirrored an infinite number of times about both the free surface and the bottom. We have made use of the formulation given by Grue [2]. The infinite mirror series is replaced by a polynomial representation thus making the computations less demanding in terms of time. The double-body flow model is suitable for computing interaction forces in 6 D.O.F. on multiple vessels, taking into account the harbour or fairway geometry. This is done by applying sources on both the vessel(s) and the waterway and any moored vessels present. Use is made of a three dimensional panel model of both ship and waterway. In Figure 1 a panel model of a ship sailing through a straight canal is depicted. For both the ship's hull surface and the waterway walls the no-leak boundary condition is satisfied:

$$\frac{\partial \phi_{DB}}{\partial n} = v_n \text{ at the hull surface of the vessel} \quad (1)$$

Where:

v_n = component of forward speed of vessel in normal direction

$$\frac{\partial \phi_{DB}}{\partial n} = 0 \text{ at the walls of the fairway} \quad (2)$$

For a more detailed description of the calculation of the double-body flow, reference is made to Pinkster [6].

Passing ships are generally assumed to sail on a straight course at constant speed. However, as zero normal velocity at the water surface level is imposed, there is no so-called memory effect due to the occurrence of free surface waves. This enables a relatively simple way to take into account varying forward speed: during a simulation the double body flow is calculated for the instantaneous forward speed at each discrete time step. A reason for varying the speed of the passing ship i.e. to slowly increase the speed up to the nominal passing speed and slowing down at the end of the run is related to the fact that when accounting for free surface effects (second stage of the computations), we need to avoid the generation of unwanted start-up transient waves which would occur if the computations start with the vessel at the nominal speed.

Recalculating the double-body flow for each discrete time step is necessary when the vessel is passing through a harbour with changing waterway geometry. If for example the ship passes through a constriction in a canal, a transient effect will be noticed on the strengths of the sources on the passing ship.

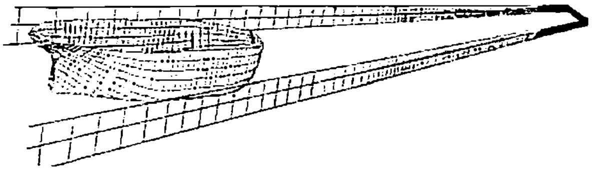


Figure 1: 3D Panel model of a ship in a canal

2.2 DISTURBANCE AT CANAL WALL IN FREQUENCY DOMAIN

The double body calculation of the previous calculation step yields the potential flow due to the instantaneous forward speed of the ship. This double body velocity potential, Φ_{DB}, satisfies the no leak condition at the ship's hull surface and the bottom and side walls of the waterway. In the ship bound reference system this flow can be transient due to either varying speed or changing waterway geometry. At constant speed and constant waterway geometry, the flow is time independent with respect to the ship bound system of axes.

For the next step in the calculation process the sources on the waterway panels (whose strengths were calculated in the previous step) are ignored. The remaining sources (on the passing ship(s)) will create a velocity potential that satisfies the no-leak condition at neither ship nor walls of the waterway anymore. We call this potential $\Phi_{DB,ship}$ and use it to calculate normal velocities at the waterway walls:

$$v_n(t) = \frac{\partial \Phi_{DB,ship}(t)}{\partial n} \quad (3)$$

Where:

$v_n(t)$ = time-dependent normal velocity at a panel of the waterway

$\phi_{DB,ship}(t)$ = time-dependent velocity potential of the double body flow at a panel of the waterway induced by the sources of the passing ship only

Thus obtained time traces of these normal velocities are Fourier transformed into frequency components:

$$v_n(\omega) = F\{v_n(t)\} \quad (4)$$

These frequency components of the normal velocities can be calculated at each of the panels of the waterway and form the input disturbance for the frequency domain diffraction problem in the next calculation step.

2.3 DIFFRACTION PROBLEM TAKING INTO ACCOUNT FREE SURFACE B.C.

Another velocity potential is now created using frequency domain linear diffraction theory. This potential will satisfy the linearized free surface boundary condition, allowing surface waves to be generated:

$$g\frac{\partial \phi}{\partial z} + \omega^2 \phi = 0 \text{ at z=0} \quad (5)$$

Ignoring the presence of the passing ship thus assuming that the diffracted waves are long and are not modified by the presence of the passing vessel, pulsating source strengths at the panels of the harbour / fairway walls (and, if present, at the panels of a moored ship) are now calculated. At these panels, again the no leak boundary condition is to be satisfied. This means that the normal velocities induced by the double-body flow sources on the passing ship are to be counteracted by the normal velocities due to this new potential (induced by the pulsating sources on the panels of the harbour / fairway/ moored ship which we will call Φ_{Diff}:

$$v_n(\omega)+\frac{\partial \phi_{Diff}}{\partial n}(\omega)=0 \tag{6}$$

Equation (6) is satisfied by simultaneously solving the amplitudes and phases of the source strengths at all the waterway panels. This is the actual diffraction calculation and it is carried out for all the frequency components present in the normal velocities on the panels as derived by FFT from the time records. See Pinkster [4] for a more detailed description of the diffraction problem.

2.4 INVERSE TRANSFORMATION

The total velocity potential representing both the double body flow and its reaction by the canal walls is obtained by superposition of the double body potential and the diffraction potential:

$$\Phi=\Phi_{DB}+\Phi_{Diff} \tag{7}$$

Knowing the amplitudes and phase angles of the sources of the diffraction potential Φ_{Diff} following from the previous step, the total potential itself and derived quantities such as wave height and pressure can be obtained at any desired location in the fluid domain.

6 DOF forces and moments on a moored ship are obtained by integrating the pressures (evaluated at all of its panels) over the hull.

Inverse Fourier transformation *(IFFT)* finally yields the desired quantities in the time domain.

3 EXPERIMENTS

In order to investigate the acceleration effect on ship wave making in confined water and to validate the results of calculations with the previously described model, a first set of tests were carried out in one of the basins of the TU Delft Ship Hydromechanics Laboratory. The procedure of these experiments was simple: Starting at one end of the towing tank (length approx. 80 m) the ship model was given a prescribed acceleration until the required speed was obtained and then moved on at that speed towards the end of the tank. During a run, the water level was measured at four locations along the towing tank length, thus obtaining the time varying water level at these points before, while and after the ship model passed by.

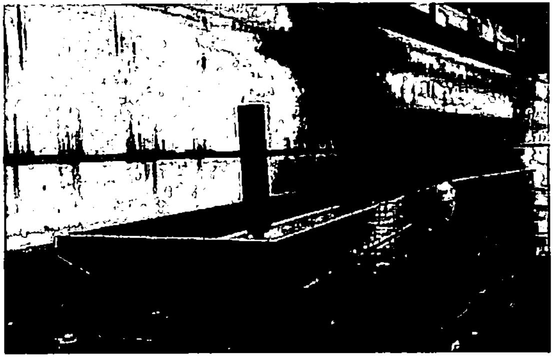
During a second set of experiments, transient wave effects were considered that are not a result of a unsteady vessel speed but rather caused by changing geometry of the channel the ship is passing through: a channel constriction was built in the same model basin and wave elevation was measured alongside the narrow part of the canal while a barge was sailing from the wide part of the canal into the narrow part. Also measurements were performed within a sheltered harbour-like area along side the narrow part of the channel, hereafter referred to as the 'harbour configuration'.

A more detailed description of the experimental set-up of both the accelerating barge and canal constriction tests will be given in paragraphs 3.1 and 3.2 respectively.

3.1 EXPERIMENTS WITH ACCELERATING BARGE

For the experiments a 1:35 scaled ship model with a barge like hull shape was towed along the center line of the basin. The water depth amounted to 5.25 m (full scale).

Error! Reference source not found. shows the model.



The main dimensions of this ship are given in Table 1

	Model scale	Full scale
Length [m]	2.60	91.0
Beam [m]	0.63	22.05
Draft [m]	0.075	2.625
Depth [m]	0.15	5.25
Displacement [kg]	117.8	$5050.7*10^3$

Table 1, model dimensions

The model was rigidly attached to the carriage resulting in zero sinkage and trim during the experiments.

To measure the wave height, twin wire electrical resistance type wave probes were used.

Three wave probes were positioned at roughly ¼, ½ and ¾ of the total towing tank length at ca. 20 cm from the starboard tank side wall. A fourth wave probe was positioned at the end of the towing tank at the center line of the tank.

Exact dimensions of the experimental setup are given in Figure 2 which shows a schematic top view of the towing tank. The dots indicate the wave probe positions.
Tests were carried out for nine different combinations of acceleration (being 0.01, 0.02 and 0.03 m/s^2) and final speed (being 3.0, 4.0 and 5.0 m/s).

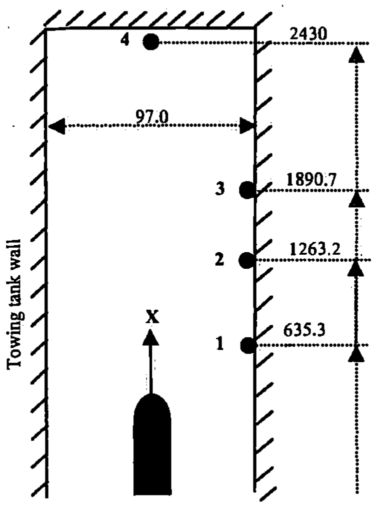


Figure 2, experimental set-up accelerating barge tests

3.2 EXPERIMENTS WITH BARGE PASSING CANAL CONSTRICTION

3.2 a Canal Configuration: Wave Measurements in Canal

These experiments were meant to simulate the same barge type vessel as was used for the previous mentioned tests passing a constriction in a canal. See Figure 3 for a plan view of the experimental lay-out in which again the dots indicate the wave probe locations. The scale of these experiments was 1:70 and the water depth amounted to 5.6 m. From its start position the ship model was given a prescribed low acceleration of 0.01 m/s^2 until a prescribed target speed was reached. From there on the model was moving with constant speed and then decelerating to zero speed at the end position.

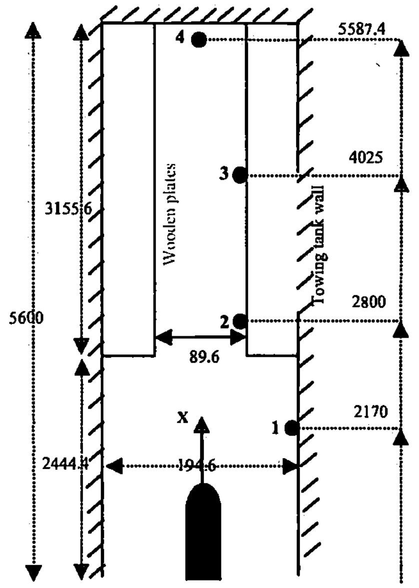


Figure 3, experimental setup canal constriction tests, canal configuration

The narrow part of the canal was modelled by vertical wooden boards. The wave height was measured at four different locations by means of wire-type wave probes.

3.2 b Harbour Configuration: Wave Measurements in Sheltered Area

Additional tests were carried out in the so-called harbour configuration for which an opening was created in the starboard side wall of the narrow part of the canal and the wave probes were positioned in the obtained sheltered area as indicated in Figure 4

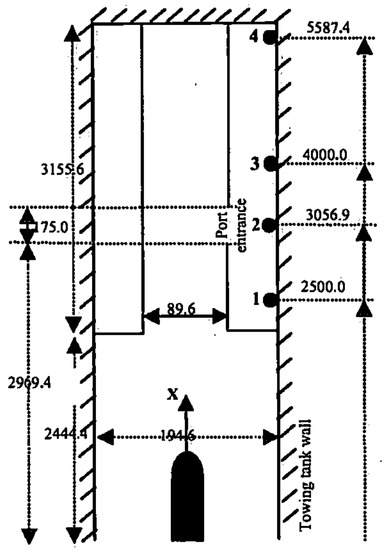


Figure 4, experimental setup canal constriction tests, harbour configuration

4 RESULTS, OBSERVATIONS AND CONCLUSIONS

4.1 ACCELERATING BARGE

See Figure 5 which shows time traces of both measured and calculated wave elevation (at model scale) at all four probe positions. Acceleration and final speed amount to 0.03 m/s^2 and 3 m/s respectively in this figure.

Also the position of the bow of the ship model with respect to the concerning wave probe (in meters behind the wave probe) is plotted by the dashed line at the same time scale using the vertical axis at the right hand side of each figure. As can be seen in the plots, the phenomenon of a wave preceding the ship model is obviously observed. The speed at which this wave travels ahead of the ship is approximately equal to the critical speed belonging to the water depth ($\sqrt{gh}$) in all cases. So at lower speed, the wave travels further ahead of the ship than at higher speeds.

Especially for the two lowest speed cases (2 and 3 m/s) the influence of the ship acceleration on the height of the preceding wave appeared to be obvious: Both the calculation and test results show higher wave amplitude at higher acceleration. At the mentioned cases the calculations show a fairly good agreement with the measurements both in terms of amplitude of the preceding wave and time of occurrence. Except for wave probe no. 4 (which is positioned at the end of the towing tank, quite close to the vertical end wall) the calculations tend to slightly underestimate the amplitude of the preceding wave as well as the depth of the primary suction trough travelling with the ship. It should be noted however that for the accelerating barge case, in the first calculation step as described in paragraph 2 only the depth restriction of the canal was taken into account which makes the approach slightly different from that used for the canal constriction calculations. For the latter calculations, a both vertically and horizontally confined water way was taken into account showing a better agreement for the amplitude of the observed preceding wave and the depth of the trough accompanying the vessel.

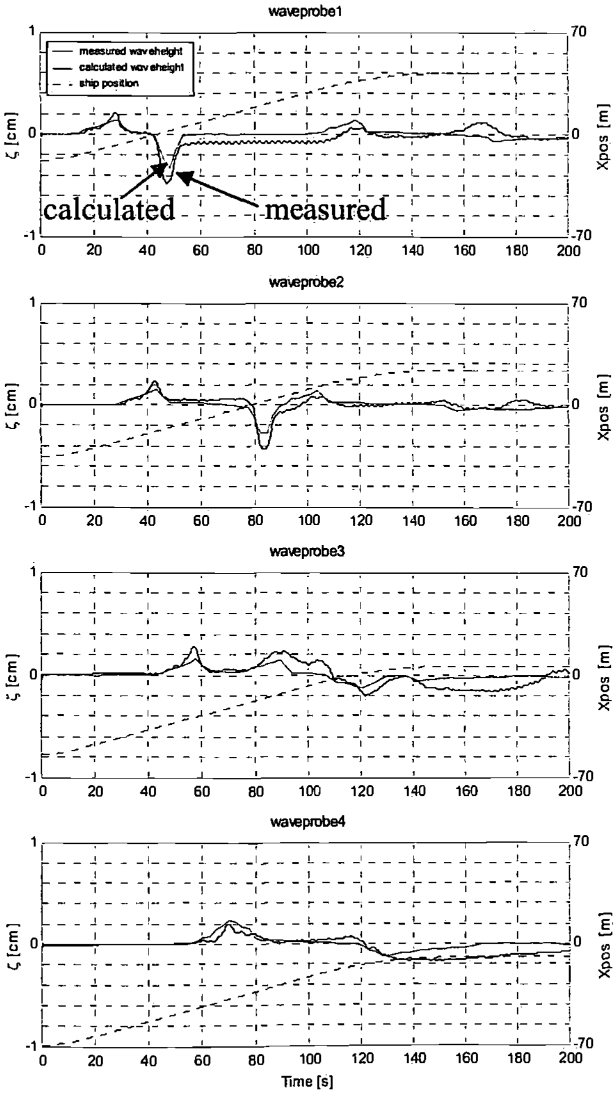


Figure 5, typical result for time traces of wave elevation due to passing barge

At wave probe no. 4 the amplitude of the preceding wave is overestimated in all cases. Probably this is caused by the narrow (but at this very shallow water depth perhaps significant) opening between the end wall of the towing tank (which is formed by the flap of the wave maker) and the tank bottom. This leaking end wall probably results in an incomplete reflection of the wave. For that reason, the higher wave amplitude (caused by reflection against the end wall) that one would expect and which is found by the calculations, is not observed that clearly during the experiments.

For the cases at which the end speed was the highest, the agreement between test results and calculations was less good. At all three cases the preceding wave was underestimated.

As can be seen in Figure 5 and as was observed from the other cases as well, the wave elevation associated with the primary pressure system (the trough that occurs when the vessel passes the concerning wave probe) is as well slightly underestimated. Increasing the number of panels appeared to improve results in this sense. For the unsteady wave phenomena (preceding wave) however, hardly any difference with the original calculations was observed when increasing the number of panels.

4.2 BARGE PASSING CANAL CONSTRICTION

For both the canal and harbour configuration, typical results (at full scale) are shown in Figure 6 and Figure 7 respectively. Dashed lines represent measured wave elevation records and solid lines the computed records. The sloping line in each figure again indicates the position of the model along the track. At the zero crossing of the sloped line the model is at the position of the relevant wave probe. (If a zero crossing does not occur, the model was stopped before reaching the relevant wave probe.)

For both cases the water depth amounted to 5.6 m. The speed of the vessel was 3 m/s for the canal configuration case and 5 m/s for the harbour configuration.

For the canal configuration the occurrence of a solitary wave preceding the vessel is obvious and predicted fairly well: a single wave crest is observed at wave probe locations 2 and 3 well before the barge passes the concerning probes (which is accompanied by the draw-down trough). The somewhat more complicated wave pattern generated by the vessel passing the harbour entrance also shows a fairly good agreement with the prediction.

In some cases the computed wave elevation records show some ripples well before the model reached the relevant probe due to effects that can be attributed to numerical reasons rather than physical ones. This may be seen, for instance, in Figure 7 for wave probes 3 and 4. This is related to the fact that the solution method using the FFT method coupled to a frequency domain solution is equivalent to the case that an infinite number of vessels are entering the canal at time intervals corresponding to the basic duration of the simulation. As a result, any reflections set up by previous passages which have not died out will show up on subsequent passages, an effect that shows more obvious for the harbour case due to the fact the waves keep being reflected back and forth in the harbour. Such effects may be reduced by increasing the basic duration of the simulation for instance by padding the excitation record (first phase of the computation involving double-body flow) with zeros. In the present case, the effects of the reflections are small.

The results shown for the canal configuration indicate that the solitary wave generated at the canal constriction proceeds down the canal and passes the probes in the sequence to be expected based on their locations. (The very mild crest observed in Figure 7 preceding the just mentioned actual solitary wave due the constriction is caused by the initial acceleration of the model.) Results at higher vessel speeds showed a higher solitary wave of which the propagation velocity is slightly underestimated by the calculations. This can probably be explained by the fact that no non-linear effects are taken into account by the numerical model. Calculated soliton heights do agree very well with the measurements also for higher vessel speeds. Experiments carried out at a smaller water depth (4.2 m) showed higher solitary waves of which again the height was very well predicted by the calculations. However the difference in predicted propagation velocity based on linear potential flow and measurements was slightly more pronounced for the smaller water depth. For tests in the harbour configuration, it is shown that the wave enters the harbour to the side of the canal first increasing the elevation at probe 2 which is opposite the entrance and the wave crest then proceeds back up to the probe 1 and in the direction of probes 3 and 4. Probe 1 being closer to probe 2 than probe 3 is, the crest reaches probe 1 first and almost doubles in amplitude due to the fact that probe 1 is at an end wall of the harbour section. This doubling effect is also seen in probe 4.

In the measured wave elevation records, see for instance, probe 2 in Figure 7, the effects of the shorter wash waves of the model can be seen just as the draw-down trough passes probe 2. The results show that the wash wave is, in this case, of almost negligible influence. Similar effects due to variation of water depth and vessel speed were observed as mentioned above for the canal configuration.

5. REFERENCES

[1] Pinkster J.A. and Naaijen P. 'Computation of passing ship effects in harbours', *Proceedings 31st PIANC Congress, Estoril, May 2006*

[2] Grue, J. and Biberg, D. 'Wave Forces on Marine Structures with small speed in water of restricted depth' *Applied Ocean Research 15, pp 121-135, 1993.*

[3] Korsmeyer, F.T., Lee, C.-H. and Newman, J.N. 'Computation of Ship Interaction Forces in Restricted Waters', *Journal of Ship Research, Vol. 37, No. 4, pp 298-306, 1993.*

[4] Pinkster, J.A. 'Hydrodynamic interaction effects in waves' *ISOPE'95*, 1995

[5] Pinkster, J.A. and Naaijen, P. 2003 'Predicting the effect of passing ships' *18th International Workshop on Water Waves and Floating Bodies, Le Croisic, France, 2003*

[6] Pinkster, J.A. 2004 'The influence of a free surface on passing ship effects' *International Shipbuilding Progress, Vol. 5, No. 4, pp 313-338*, 2004

6. AUTHOR'S BIOGRAPHY

Peter Naaijen holds the current position of assistant professor at Delft University of Technology. He is responsible for education on linear theory on ship motions in waves and offshore hydromechanics. Next to passing ship induced wave effects, currently the main research field is short term deterministic prediction of motions of offshore structures by means of remote wave sensing.

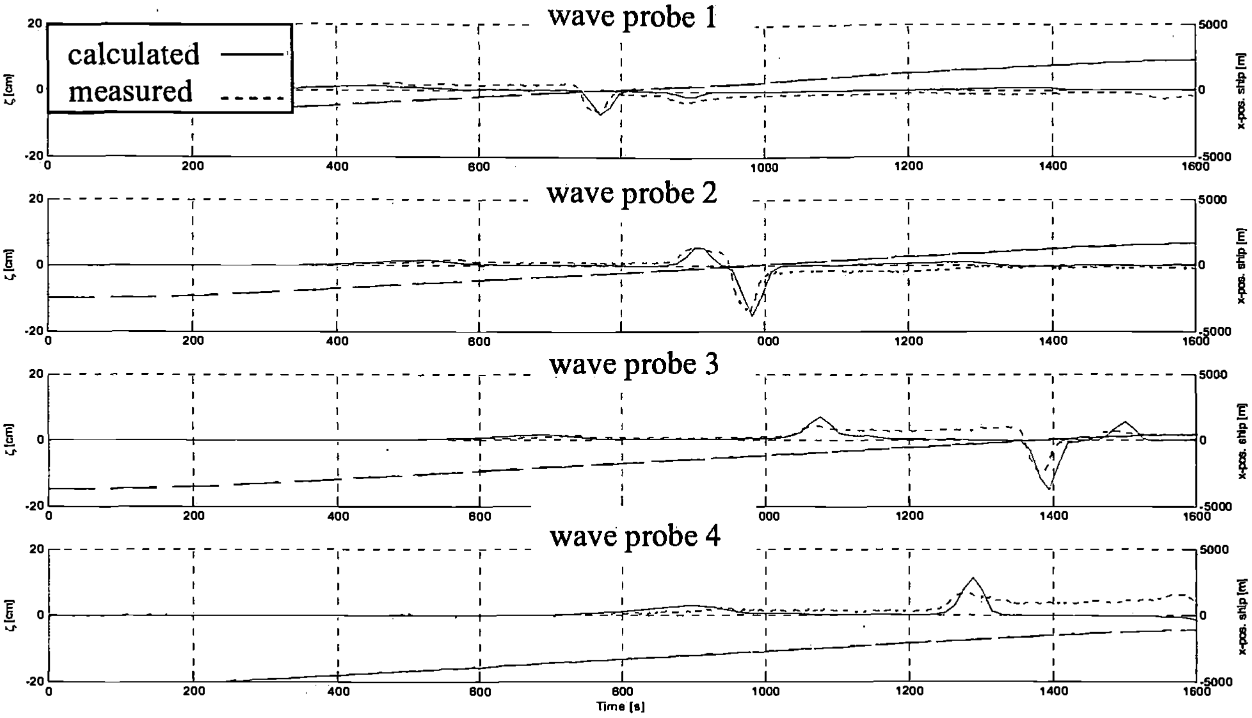


Figure 6, measured and predicted waves in canal configuration, vessel speed 3 m/s , water depth 5.6 m

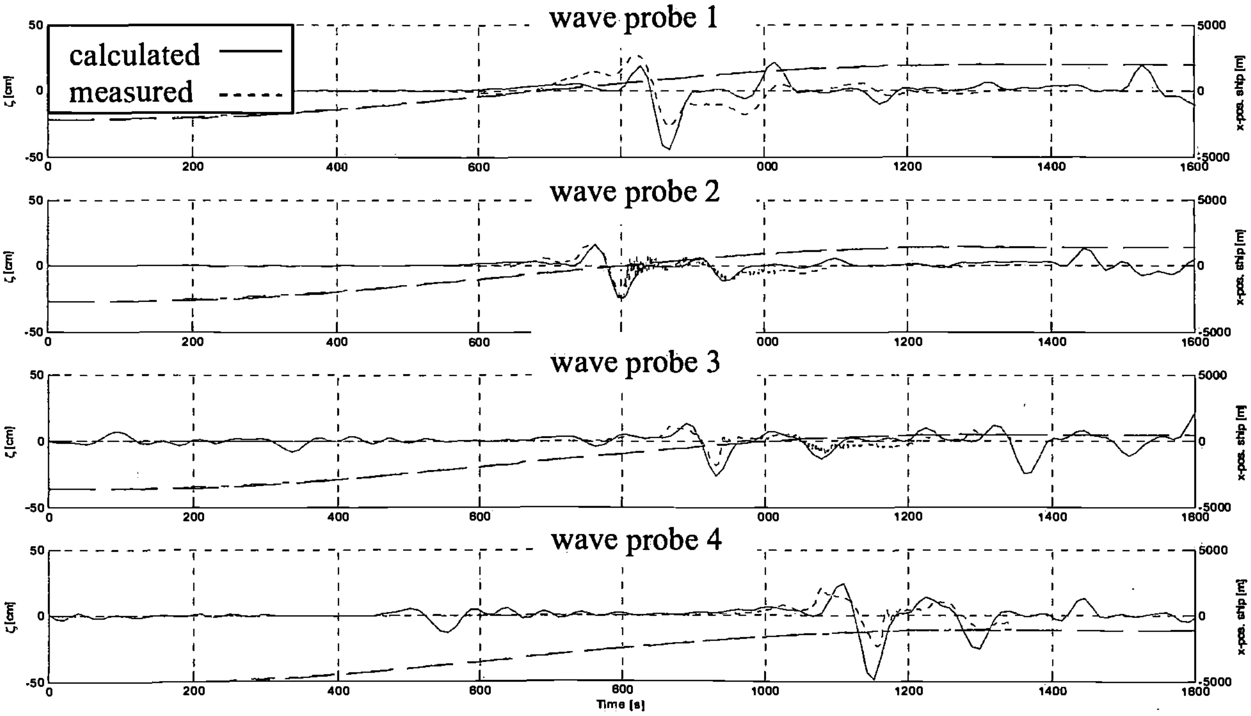


Figure 7, measured and predicted waves in harbour configuration, vessel speed 5 m/s, water depth 5.6 m