1st ShipWave

International Workshop on Ship-induced Hydrodynamic Loads in Shallow Confined Coastal Waterways

Federal Waterways Engineering and Research Institute (BAW):
Ingrid Holzwarth, Gregor Melling
Leichtweiß-Institute for Hydraulic Engineering and Water Resources (LWI), TU Braunschweig:
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Editors

Book of Abstracts of the 1st ShipWave
International Workshop on Ship-induced Hydrodynamic Loads
in Shallow Confined Coastal Waterways
Hamburg, Germany
22 to 24 March 2023

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Preface

(Why) Is there a need for an international workshop on ship-induced loads?

A dramatic increase in the size and draft of seagoing ships has intensified the worldwide discussion on its effects that have been witnessed on embankments and the bottom of shallow and confined waterways. Not only in Germany, where the organizers of this 1st international workshop reside and work, questions related to the ship-waterway interactions have increasingly gained traction. Taking a ship-centered stance, the maneuverability in shallow and confined coastal waterways is of critical importance. This issue is covered mainly by nautical and naval engineers and is, for example, scientifically reflected by the MASHCON conference series (www.mashcon2022.ugent.be). Conversely though, the waterway perspective, on the receiving end of the energy released into the water body by the ship's motion, is of equal relevance, yet arguably less well researched. We note here e.g. the effects on stability of bank protection, integrity of natural bank structures as well as estuarine and bankside ecosystems and waterway morphology. Indicated by the relatively small, but increasing, amount of scientific publications on the workshop's topic of ship-induced loads, we perceive an intensifying demand for coordinated and cross-disciplinary actions to deepen our scientific understanding on the underlying processes. This is where the motivation for the workshop organization has originated from; international exchange and a platform to debate ideas for future research seemed indispensable yet difficult to establish.

In 2020, the Federal Waterways Engineering and Research Institute (BAW) and the Leichtweiß-Institute for Hydraulic Engineering and Water Resources (LWI) entered a research cooperation recognizing the need for methodological advances and a demand for more coordinated research on the topic of ship-induced hydrodynamic loads in coastal waterways and, particularly, on the development of a practical numerical tool for load prediction on bank structures. A comprehensive literature review followed swiftly in that context, laying bare that, in recent years, considerably more studies on our topic of interest had been published than before. Still, we could not identify a networked community for exchange and debate, hence the idea for this workshop, whose book of abstract we proudly preface with this editorial, was born.

We are pleased that so many people from all over the world accepted our invitation to participate in this workshop and are excited about participants and contributions from five continents. We congratulate the authors for their individual contributions reflected in the workshop program and the high-quality presentations that are given during our gathering. In the workshop, we sincerely hope to connect individuals and research groups who are jointly, though still somewhat disconnectedly, working in the field of ship-generated hydrodynamics and their effects in confined waterways. While our focus is on coastal and estuarine waterways, as sailed by seagoing vessels, relevant contributions from inland waterways were welcomed.

The workshop aim is to learn, how different or similar the scientific and practical issues around the globe are, how challenges are handled and which methods are used or developed. Of course, we hope that all participants benefit from ideas and solutions presented and discussed during the workshop. At the same time and due to existing knowledge gaps, the insight that methods need to be further improved and the expectation of upcoming questions related to ship-induced loads, we consider it important to foster an international exchange of knowledge. Finally, we sincerely hope to have planted a seed for subsequent, fruit-bearing workshops on this exciting topic for the years to come. Welcome to ShipWave 2023!

Ingrid Holzwarth[1] and Nils Goseberg[2]
on behalf of the Local Organising Committee

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Supporting Institutions

ShipWave 2023 – Workshop programme

Wednesday 22 March 2023	
	Arrival
Time	**Agenda**
13:00 - 14:30	Registration open & Welcome reception
14:30 - 17:00	Icebreaker boat trip
17:00 - 17:15	Welcome address Ingrid Holzwarth, German Federal Waterways Engineering and Research Institute and Nils Goseberg, Leichtweiß Institute, TU Braunschweig and Coastal Research Centre, Germany
17:15 - 18:00	**Opening address: Ship waves and methods: the BAW perspective on estuarine waterways** Ingrid Holzwarth and Gregor Melling, German Federal Waterways Engineering and Research Institute, Germany
18:00 - 19.30	Hotel check-in / free time / socialising / networking
19:30	Dinner

Thursday 23 March 2023	
08:45 - 09:30	**Keynote address: Evolving narratives of ship wake science and management** Tarmo Soomere and Kevin Parnell, Wave Engineering Laboratory, Department of Cybernetics, School of Science, Tallinn University of Technology, Estonia
Technical presentations – Ship wave effects and design 1 Session chair: Luca Zaggia, National Research Council, Institute of Geosciences and Earth Resources, Padova, Italy	
09:30 - 09:45	Ship Effects – case study of the St. Lawrence River, Canada Michael Davies, Coldwater Consulting Ltd., Canada
09:45 - 10:00	Russell's solitary wave in 21st century Scotland Momchil Terziev, Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow, UK
10:00 - 10:15	A design method for rock groynes subject to ship wave-induced overflowing Arne Seemann, German Federal Waterways Engineering and Research Institute, Germany
10:15 - 10:30	Malamocco-Marghera Navigation Channel (Venice Lagoon): Study of operational and structural solutions to achieve a sustainable navigation Hisham Elsafti, DHI WASY GmbH, Germany
10:30 - 11:00	Coffee break
Interactive session 1 – World café	
11:00 - 12:30	**Topic: Region-specific experiences and issues associated with ship-induced waves.** E.g. scale and nature of issues / geographical commonalities and differences / management and mitigation strategies / design against ship-induced loads / knowledge gaps. Discussion in breakout groups with participants from different geographic backgrounds. Session will be moderated; the discussion outcomes will be documented and provide input for the fish bowl (interactive session 3).
12:30 - 13:30	Lunch break

Technical presentations – Ship waves in lab and field Session chair: Carolin Gesing, Federal Waterways Engineering and Research Institute, Karlsruhe, Germany	
13:30 - 13.45	Pressure and velocity measurements of low-frequency cargo vessel wake in the Savannah River, Georgia, USA Alexandra Muscalus, Georgia Institute of Technology, School of Ocean Science and Engineering, USA
13:45 - 14:00	New methods for in-situ measurement of shallow-draft vessel wake impacts along coastal waterways Rachel Bain, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Vicksburg, MS, USA
14:00 - 14:15	Over 25 years of in situ ship wave measurements at BAW, where does the future lead to? Hanne Jansch, German Federal Waterways Engineering and Research Institute, Germany
14:15 - 14:30	Analysis of ship waves along the Scheldt estuary Dieter Meire, Flanders Hydraulics, Antwerp, Belgium
14:30 - 14:45	The importance of full-scale trials when quantifying and managing vessel wave wake in confined waterways Gregor MacFarlane, Australian Maritime College, University of Tasmania, Australia
14:45 - 15:15	Coffee break
Technical presentations – Ship wave effects and design 2 Session chair: Charlotte van der Vorm, Rijkswaterstaat, Utrecht, Netherlands	
15:15 - 15:30	Estimation of extreme primary ship-induced wave loads by the application of the Non-Parametric Bayesian Networks Sargol Memar, Department of Civil Engineering and Geosciences, TU Delft, Delft, The Netherlands
15:30 - 15:45	Waterway bank erosion risk model by oceangoing ships Raul Redondo, Siport21, Spain
15:45 - 16:00	A geohydraulic analysis of sediment shear strength during drawdown Laura Dechant, German Federal Waterways Engineering and Research Institute, Germany
Interactive session 2 – World café	
16:00 - 17:30	**Topic: Method-specific exchanges**. E.g. methodological state of the art / challenges and shortcomings / interfaces to other methods / future developments and improvements. Discussion in breakout groups according to participant's method expertise (e.g. numerical, experimental, observational, design). Session will be moderated; the discussion outcomes will be documented and provide input for the fish bowl (interactive session 3).
17:30 - 19:00	Free time / socialising / networking
19:00	Dinner

Friday 24 March 2023	
Technical presentations – Numerical modelling 1 Session chair: Christian Windt, Leichtweiß-Institut, TU Braunschweig, Germany	
09:00 - 09:15	A semi-implicit finite volume scheme for a simplified hydrostatic model for fluid-structure interaction Cristian Brutto, Laboratory of Applied Mathematics, University of Trento, Trento, Italy
09:15 - 09:30	Development of a numerical towing tank and comparison with experimental results: study of the flow around a vessel in a restricted waterway Pablo Nieutin-Redon, Institut Pprime, Department of Fluids, Thermal and Combustion, HYDÉE team, University of Poitiers, France
09:30 - 09:45	Systematic validation of an efficient numerical tool to predict long-period primary waves Leon-Carlos Dempwolff, Leichtweiß-Institut, TU Braunschweig, Germany
09:45 – 10:00	Ship-induced wave force effects on moored ship using reduced two-layer nonhydrostatic model Mohammad Saidee Hasan, IHE Delft Institute for Water Education, Netherlands | Delft University of Technology, Netherlands | Bangabandhu Sheikh Mujibur Rahman Maritime University, Bangladesh
10:00 - 10:30	Coffee break
Technical presentations – Numerical modelling 2 Session chair: Arne van der Hout, Deltares / TU Delft, Netherlands	
10:30 - 10:45	Numerical modeling of low-frequency cargo vessel wake in the Savannah River, Georgia, USA Kevin Haas, Georgia Institute of Technology, USA
10:45 - 11:00	Simulation and validation of ship induced waves in shallow and confined water conditions Christian Kochanowski, German Federal Waterways Engineering and Research Institute, Germany
11:00 - 11:15	Intermission
Interactive session 3 – Final group discussion	
11:15 - 12:30	Moderated discussion: i) synthesis of world cafés; ii) concrete steps & developments required in the face of future challenges; iii) barriers to successfully tackling these steps; iv) conclusion / outlook
12:30 - 13:30	Lunch break
13:30 - 16:30	Field trip: Ship wave basin of Federal Waterways Engineering and Research Institute (BAW)
16:30	Departure

Ship waves and methods: the BAW perspective on estuarine waterways

Gregor Melling and Ingrid Holzwarth

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Status quo

Ship sizes have increased dramatically over the last decades leading to increased ship-induced loads in estuarine waterways. Particularly, the action of the long-period primary ship wave has been associated with a number of deleterious effects such as damage to infrastructure, erosion and sediment transport, impairment of habitat and recreational value and in rare cases even risk to life (cf. Dempwolff et al. 2022). Recently, the impacts of ship waves on shallow estuary margins are becoming ever more evident and with it multi-faceted questions in regard to prediction of wave loads, impacts and design of mitigation measures. Investigations have shown that existing empirical formulae are neither sufficiently universal nor accurate enough to be used for prediction of long-period wave loads. Furthermore, the interaction of these waves with structures has given rise to load cases that differ significantly from e.g. wind wave loading and, in some cases, cannot be treated with existing design formulae (cf. e.g. Melling 2020).

Looking into the future

The introduction of legislation such as the EU Water Framework Directive along with the recognition of the ecological value of estuaries has resulted in a need to balance the economic significance of ports and shipping with environmental concerns. This has led to a desire for more natural banks, e.g. by removal of embankment protection, increased use of bioengineered defences as well as restoration/renaturation efforts. With this comes a host of multi-faceted questions for the prediction of ship-induced effects for unprotected embankments, efficiency of bioengineered defences and sediment mobilisation for which appropriate methodologies are required. To this end, BAW is heavily involved in the application and development of a variety of methods.

Methods

The BAW has been involved for many years in the measurement of ship-induced waves and currents resulting in a rich database of measurements around German estuaries. Field measurements are still essential to quantify bankside loads for design purposes. Recently, a set of measurements has been used for the development of design methods for rock sizing against primary wave loads and improvement of predictive load equations. The ship wave basin represents another well-established tool for the investigation of various questions regarding ship-ship interaction and ship-waterway interactions in scaled physical models. This includes investigations of ship hydrodynamics, waterway dimensioning, navigability, manoeuvrability and ship-induced loads.

Figure 1 - Elbe estuary at Wittenbergen: narrow channel with reinforced embankments and beaches secured by groynes.

In recent years, BAW has developed CFD models that are sophisticated enough to model ship-waterway interactions with high accuracy even in real topographies. Presently, efforts are ongoing to extend the range of applicability of CFD models with a focus on nearshore long-period wave transformation and interaction of waves with (bioengineered, conventional) structures and unprotected embankments.

References

Dempwolff, C-L.; Melling, G.; Windt, C. et al., 2022. Loads and effects of ship-generated, drawdown waves in confined waterways - A review of current knowledge and methods. Journal of Coastal and Hydraulic Structures, 2, 13.

Melling, G.; Jansch, H.; Kondziella, B. et al., 2020. Evaluation of optimised groyne designs in response to long-period ship wave loads at Juelssand in the Lower Elbe Estuary. Die Küste, 89.

Evolving narratives of ship wake science and management

Tarmo Soomere[1,2] and Kevin Parnell[1]

[1] Wave Engineering Laboratory, Department of Cybernetics, School of Science, Tallinn University of Technology
[2] Estonian Academy of Sciences

From Kelvin wake to Mach stem
The wake of a vessel sailing on sea surface is commonly depicted as a V-like pattern of linear waves generated by a single point source. Its main geometric properties were known already to Lord Kelvin (Thomson, 1887). A real ship, however, produces an extremely complicated system of disturbances that often contains highly nonlinear components (Sorensen, 1973) and may have properties of a Mach stem (Rabaud and Moisy, 2013). The appearance, development and magnitude of the related phenomena are governed by several nonlinear equations about which Lord Kelvin did not have a faintest idea.

Nonlinear wakes
Changes to the classic Kelvin wake stem from the increase in the vessel speed or a decrease in the water depth, or both. Ships sailing at Froude numbers larger than about 0.2 commonly generate shallow-water solitons ahead of the Kelvin wake (Wu, 1987), often described using the Korteweg-de Vries (KdV) equation. While usually small and almost invisible, they may form a powerful bore (Gourlay, 2001). Their reflections and interactions are a major source of danger near shallow waterways as predicted by another (Kadomtsev-Pethviashvili) nonlinear equation (Peterson et al., 2003).
Increased bottom sediment disturbance can be caused by the increase in leading wave periods with speed (Soomere, 2005). Another nonlinear structure, the 'envelope' or Schrödinger soliton, is often generated at higher subcritical speeds (Brown et al., 1989). These are sets of a few moderately high but extremely steep long-crested waves with exactly the same period (Soomere and Rannat, 2003).

Shallow water effects
Prior to the mid-1990s, most shorelines affected by ship wakes were adapted to the energy conditions and the effects were generally accepted. It was the introduction of large and fast vehicle and passenger carrying ferries ('fast ferries') in the mid-1990s (Parnell and Kofoed-Hansen, 2001), the adverse effects of which caused considerable concern, that saw the beginning of a new phase of measurement and analysis. Regulation of vessel operations using empirically based approaches that emphasised nearshore hydrodynamic loads and highlighted the importance of wave period soon followed (Croad and Parnell, 2002).

Environmental concerns
By the mid-2000s, strongly powered conventional (displacement) vessels were common, the effects of which could dominate coastal sediment transport and coastal morphology in some environments even where there is substantial natural wave activity (Parnell et al., 2008, Soomere et al., 2011). Additionally, the importance of non-linear components of generated wakes was becoming clear (Soomere, 2007; Torsvik et al., 2009). In the mid-2010s, waves of depression were identified as a cause of significant environmental damage in some coastal environments (Parnell et al., 2015; Scarpa et al., 2019).

Reading ship properties from her wake
Measurement techniques and analyses have improved considerably over the years with the use of time-frequency methods or 'spectrograms' (Torsvik et al., 2015; Pethiyagoda et al., 2017) and the remote determination of vessel parameters (identification, position, speed and course) (Rätsep et al., 2020; 2021) being highlights.

References
Brown, E.D., Buchsbaum, S.B., Hall, R.E., Penhune, J.P., Schmitt, K.F., Watson, K.M., Wyatt, D.C. 1989. Observations of a nonlinear solitary wave packet in the Kelvin wake of a ship. J. Fluid Mech. 204, 263–293.
Croad, R., Parnell, K.E. 2002. Proposed controls on shipping activity in the Marlborough Sounds: A review under Section 32 of the Resource Management Act. Report to Marlborough District Council. 51pp.
Forsman, B. 2001. From bow to beach, SSPA Highlights No 3, 4–5.
Gourlay, T.P. 2001. The supercritical bore produced by a high-speed ship in a channel. J. Fluid Mech. 434, 399–409.
Parnell, K. E., Kofoed-Hansen, H. 2001. Wakes from large high-speed ferries in confined coastal waters: Management approaches with examples from New Zealand and Denmark. Coast. Manage. 29 (3), 217–237, doi: 10.1080/08920750152102044.
Parnell, K.E., Soomere, T., Zaggia, L., Rodin, A., Lorenzetti, G., Rapaglia, J., Scarpa, G.M. 2015. Ship-induced solitary Riemann waves of depression in Venice

Lagoon. Phys. Lett. A 379(6), 555–559, doi: 10.1016/j.physleta.2014.12.004.
Parnell, K., Delpeche, N., Didenkulova, I., Dolphin, T., Erm, A., Kask, A., Kelpšaite, L., Kurennoy, D., Quak, E., Räämet, A., Soomere, T., Terentjeva, A., Torsvik, T., Zaitseva-Pärnaste, I. 2008. Far-field vessel wakes in Tallinn Bay. Estonian J. Eng. 14(4), 273−302, doi: 10.3176/eng.2008.4.01.
Peterson, P., Soomere, T., Engelbrecht, J., van Groesen, E. 2003. Soliton interaction as a possible model for extreme waves in shallow water, Nonlin. Process. Geophys. 10, 503–510.
Pethiyagoda, R., McCue, S.W., Moroney, T.J. 2017. Spectrograms of ship wakes: Identifying linear and nonlinear wave signals. J. Fluid Mech. 811, 189–209. doi: 10.1017/jfm.2016.753.
Rabaud, M., Moisy, F. 2013. Ship Wakes: Kelvin or Mach Angle? Phys. Rev. Lett. 110(21), 214503, doi: 10.1103/PhysRevLett.110.214503.
Rätsep, M., Parnell, K.E., Soomere, T., Kruusmaa, M., Ristolainen, A., Tuhtan, J.A. 2020. Using spectrograms from underwater total pressure sensors to detect passing vessels in a coastal environment. J. Atm. Ocean. Technol. 37(8), 1353−1363, doi: 10.1175/JTECH-D-19-0192.1.
Rätsep, M., Parnell, K.E., Soomere, T., Kruusmaa, M., Ristolainen, A., Tuhtan, J.A. 2021. Surface vessel localization from wake measurements using an array of pressure sensors in the littoral zone. Ocean Eng. 233, 109156, doi: 10.1016/j.oceaneng.2021.109156.
Rodin, A., Soomere, T., Parnell, K.E., Zaggia, L. 2015. Numerical simulation of the propagation of ship-induced Riemann waves of depression into Venice Lagoon. Proc. Estonian Acad. Sci. 64(1), 22–35, doi: 10.3176/proc.2015.1.04.
Scarpa, Gian Marco; Zaggia, Luca; Manfé, Giorgia; Lorenzetti, Giuliano; Parnell, Kevin; Soomere, Tarmo. 2019. The effects of ship wakes in the Venice Lagoon and implications for the sustainability of shipping in coastal waters. Sci. Repts. 9, 19014, 1–14. doi: 10.1038/s41598-019-55238-z.
Soomere, T. 2007. Nonlinear components of ship wake waves. Appl. Mech. Rev. 60(1–6), 120–138, doi: 10.1115/1.2730847.
Soomere, T. 2005. Fast ferry traffic as a qualitatively new forcing factor of environmental processes in non-tidal sea areas: a case study in Tallinn Bay, Baltic Sea. Environ. Fluid Mech. 5(4), 293–323.
Soomere, T., Rannat, K. 2003. An experimental study of wind waves and ship wakes in Tallinn Bay. Proc. Estonian Acad. Sci. Eng. 9, 157–184.
Soomere, Tarmo; Parnell, Kevin E.; Didenkulova, Ira 2011. Water transport in wake waves from high-speed vessels. J. Mar. Syst. 88(1), 74–81, doi: 10.1016/j.jmarsys.2011.02.011.
Sorensen, R.M. 1973. Ship-generated waves. Adv. Hydrosci. 9, 49–83.
Thomson, W. (Lord Kelvin) 1887. On ship waves. Trans. Inst. Mech. Eng. 409–433.
Torsvik, T., Soomere, T., Didenkulova, I., Sheremet, A. 2015. Identification of ship wake structures by a time-frequency method. J. Fluid Mech. 765, 229–251, doi: 10.1017/jfm.2014.734
Torsvik, T., Didenkulova, I., Soomere, T., Parnell, K. E. 2009. Variability in spatial patterns of long nonlinear waves from fast ferries in Tallinn Bay. Nonlin. Process. Geophys. 16(2), 351–363.
Wu, T.Y. 1987. Generation of upstream advancing solitons by moving disturbances. J. Fluid Mech. 184, 75–99.

Ship effects – case study of the St. Lawrence River, Canada

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Overview

This is an overview of the effects of ship traffic on bank erosion, with reference to commercial navigation in the St. Lawrence River. Field measurements, geospatial analysis and hydro-numerical modelling have been used to develop of coherent picture of the role of ship-generated flows in bank erosion, and the performance of protection works.

Setting

The St. Lawrence River downstream of Montreal provides maritime shipping with access to the Port of Montreal and to the St. Lawrence Seaway which extends through the Great Lakes. The focus of this paper is on a 70km reach downstream of Montreal. This portion of the St. Lawrence Ship Channel can accommodate post-Panamax vessels with up to an 11m draft. Bank erosion affects much of the shoreline along this reach with recession rates as high as 1 to 2m/yr.

Models

SGH is the Ship-Generated-Hydrodynamics model – a finite-difference model that simulates both the drawdown and short-period wakes generated by moving vessels in confined waterways. The model is constructed to permit the use of complex channel geometry and bathymetry, realistic ship hull shapes and variable sailing lines. Originally developed in 2001, the model was originally developed for application to the St. Lawrence River but has subsequently been applied to waterways throughout North America. The SGH model has twice been independently assessed and found to accurately simulate ship-induced wake and drawdown (Gharbi et al, 2007 and Taylor et al, 2007).

The riverbanks of this waterway are composed predominantly glacial clays and tills. Erosion and resulting shoreline recession has been modelled using a 1-dimensional cross-shore model for wakes, river currents and wind waves. This model has been used to simulate decadal-scale recession rates calibrated against long-term observations of bank recession.

Application

Calibration of the SGH model against measured ship wakes and calibration of the cross-shore erosion

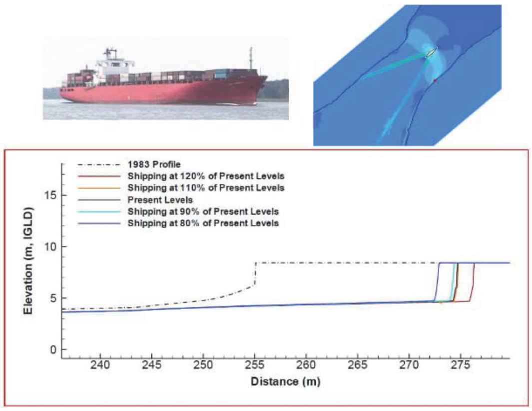

Figure 1 – Erosion response modelling to ship traffic

model against historical recession rates the models were used to evaluate the effects of changing ship traffic and variations in river hydrodynamics. The result of this analysis is a set of predictive tools for riverbank response to varying ship traffic and river conditions. While much of the original work was conducted between 2000 and 2010, the sites have recently been re-evaluated (in 2022) with technical refinements to the computational models and updated erosion data.

Conceptual Model

These studies have resulted in the development of a conceptual model of how ship traffic has changed the geomorphology of the shore and created steep erosional scarps which have contributed to land loss and habitat degradation. The tools developed have provided a technical basis for vessel speed controls to mitigate erosion, and for the design of bank protection.

References

MacDonald N (2003) Numerical modelling of coupled drawdown and wake. In: Proceedings of Canadian Coastal Conference, Kingston, Canada, 16 pp,

Gharbi, S., Valkov, V., Hamdi, S., and Nistor, I (2010) Numerical and field study of ship-induced waves along the St. Lawrence Waterway, Canada. In: Natural Hazards (2010) 54:605–621.

Taylor, D., Hall, K.R., and MacDonald, N. (2007) Investigating ship-induced scour in a confined ship channel. In: Coastal Sediments 2007, ASCE.

Russell's solitary wave in 21st century Scotland

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Introduction

At the end of the 19th century, Scotland's relatively new canals were abuzz with activity. Canal boats were transporting bulk cargo and people, stimulating a flourishing economy. Darrigol [1] recants the well-known fable of the discovery of the solitary wave by John Scott Russel when a horse pulling a boat was frightened into gallop. To everyone's surprise, the boat offered less resistance than at low speeds. Exploiting that discovery, businesses began offering high-speed boat services from Glasgow to Edinburgh along the Forth and Clyde Canal. This paper aims to investigate the occurrence of solitary waves on Scotland's canals.

Motivation

The first author has collected accounts of small, quasi two-dimensional waves in several locations along Scotland's canal network. These waves are typically described by the Scottish boating community as unaccompanied by a vessel, spanning the entire width of the canal, and consisting of a single wave crest with no wave trough; a description which matches the properties of solitary waves.

For example, when running canal boat cruises, the Linlithgow Canal Society, located between Glasgow and Edinburgh, use the presence of such a wave is a reliable indicator that their canal boat returning from a cruise.

Methods

The first author is collecting accounts of solitary waves from canal societies and the public in Scotland's central belt. The currently collected accounts indicate the most common experience in the boating community is that of a single fore-aft movement of lightly moored (or unmoored) craft in the absence of other vessels or otherwise visible disturbances. The first author joined canal society members on cruises along the canal network to observe the hydrodynamics of the canal boats and explore the likelihood of solitary waves being emitted from a canal boat.

The Linlithgow Canal Society's vessel Saint Michael is taken as a case study in the observations reported subsequently. The vessel has a length of 16.8m, a beam of 3m, a draft of 0.5m, and a displacement of 24t with a capacity to carry 40 passengers.

Outcomes

First-hand observations of the wave patterns and boat-induced disturbance indicated that canal boats create a significantly stronger disturbance that would be expected at speeds of between 1 and 2 knots. The disturbance comprised the acceleration of unconsolidated sediment, causing a visibly turbulent boundary layer on the canal bottom. At the aforementioned cruising speed range, a breaking wave emanates from the stern shoulder of the vessel, creating a danger of erosion of the canal bank.

The vessel becomes difficult to steer, accelerate or decelerate, and the rudder is subject to significant vibrations. These observations indicate that the critical speed, a combination of the ratio of vessel and canal cross-sectional area in addition to the speed is likely reached. The St Michael did not have sufficient installed power to overcome the trans-critical barrier. However, the likely proximity to the trans-critical range of the blockage-speed curve indicates the possibility of such vessels emitting solitary waves.

Future and ongoing work

Subsequent investigations will focus on abrupt reductions in canal cross-section along the track of the vessel. It is hypothesised that such reductions could temporarily push the operational condition past the trans-critical boundary, where solitary wave generation is expected. Such a scenario entails a reduction in vessel speed due to the additional blockage while energy builds at the bow. The chief question is whether that energy, in the form of a wave elevation at the bow, is able to escape upstream. That would explain the collected observations. These may also be produced under the same conditions without crossing the trans-critical boundary, by analogy to the *mini-tsunamis* observed in Norwegian fjords. Mini-tsunamis are generated when a high-speed vessel passes over an abrupt reduction in water depth. If that is the mechanism responsible for generating such waves, then the authors suggest the term *micro-tsunamis*.

Acknowledgements

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Reference

[1] O. Darrigol, "The spirited horse, the engineer, and the mathematician: Water waves in nineteenth-century hydrodynamics," *Arch. Hist. Exact Sci.*, vol. 58, no. 1, pp. 21–95, 2003, doi: 10.1007/s00407-003-0070-5.

A design method for rock groynes subject to ship wave-induced overflowing

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Introduction

Since the early 2000s increased damage at rock groynes in German estuaries has been observed. The damage characteristics include an erosion of the rock armour layer on the crest and leeside slope of the groynes, typically accompanied by severe deterioration of the root area. The damage is caused by high-volume overflow over the groyne crest which occurs as a result of the interaction of the drawdown and stern wave components of long-period primary ship waves with the groyne. To date, no design formula exists to predict the resulting loads nor required rock grading on groynes for this load case. This study aims to address said knowledge gap by exploiting similarities between the described groyne overflow phenomenon and certain aspects of weir and rough bed flow, thus, evaluating the applicability of existing hydraulic engineering design formulae to the described problem.

Field data

Data to evaluate the formulae is available from a field experiment in the Lower Elbe Estuary in which the hydraulic loads and corresponding deformation of the rock armour layer of two prototype groynes was recorded over a number of years. The field study and available data is documented in Melling et al. (2021).

Methods

In a review of existing analytical and empirical formulae for comparable hydraulic phenomena such as weir overflow, rough bed flow and overflowing riprap, suitable equations were identified to create a design workflow for rock sizing. The field data was used to evaluate the performance of the individual equations in the design workflow.

Results

The Poleni formula with an adapted weir coefficient is able to calculate the overflowing discharge during a primary wave ship event with high accuracy, indicating that the overflow can be treated similar to quasi-stationary flow over a weir. This maximum overflowing discharge serves well as a predictor for critical erosion when used in conjunction with the riprap stability formula of Thornton et al. (2014). A method to calculate the critical primary wave height for the groynes was developed (Seemann et al, in review). This allows the prediction of the maximum expected overflow discharge for a specific wave and relates it to the required rock size (cf. Figure 3). The relationship also highlights the profound impact of tidal water level on the hydraulic load on the riprap, as with low water level, the groyne is not overflown and with high water level, the flow cannot accelerate on the leeward slope, leading to a smaller impact on the groyne.

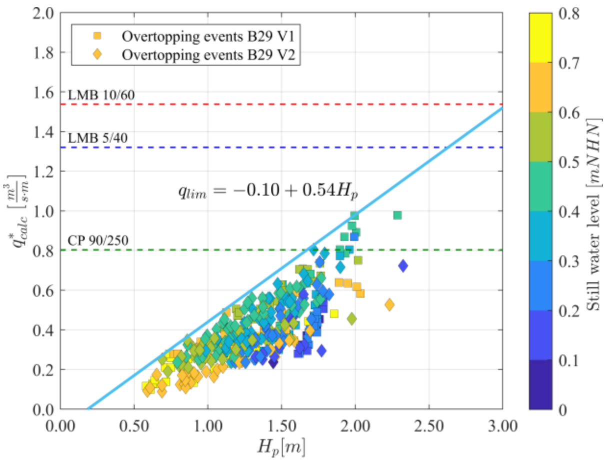

Figure 1 – Critical ship wave heights depending on the water level and associated overflow discharge

References

Melling, G.; Jansch, H.; Kondziella, B.; Uliczka, K.; Gätje, B. (2021) Evaluation of optimised groyne designs in response to long-period ship wave loads at Juelssand in the Lower Elbe Estuary. *Die Küste* 89. pp. 29-56.

Seemann, A.; Melling, G.; Jansch, H.; Kondziella (in review) A design method for rock groynes exposed to overtopping from long-period ship wave loads. Submitted to Journal of Coastal and Hydraulic Structures

Thornton, Christopher I.; Abt, Steven R.; Scholl, Bryan N.; Bender, Theodore R. (2014): Enhanced Stone Sizing for Overtopping Flow. *J. Hydraul. Eng.* 140 (4), S. 6014005

Malamocco-Marghera Navigation Channel (Venice Lagoon): Study of operational and structural solutions to achieve a sustainable navigation

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Introduction and study objective

This advanced and multi-disciplinary study aims at identifying sustainable solutions to enhance navigation capacity along the Malamocco-Marghera Channel (hereafter MMC), in the Venice Lagoon, at the same time mitigating the erosion processes affecting the surrounding tidal flats, achieving and maintaining safe navigation conditions. Following Public Tender procedures, Port of Venice assigned the study to a Consortium led by DHI S.r.l. and formed by DHI A/S, FORCE Technology, HS Marine S.r.l., Cetena S.p.a. and Around Water S.r.l.. The project activities fit into the "Channeling the Green Deal for Venice", a CEF European funded project that tackles the limited nautical accessibility of the port of Venice, fully respecting the environment and the Venice Lagoon. Moreover, seeking synergies between port sustainability and mitigation of human and climate change impacts on endangered habitats is part of the challenge. To achieve this ambitious goal, navigation, hydrodynamic and morphodynamic models mutually interact to identify the best solution.

Methodology

The effect of navigation on the hydrodynamics of the MMC and surrounding areas primarily deals with two types of waves induced by passing vessels: primary (draw down) and secondary waves (Kelvin wake). Primary waves are bound displacement waves induced by the acceleration of the flow under and around the vessel hull. The secondary wave system consists of diverging and transverse waves in a restricted wedge-shaped region around the vessel. In the MMC, primary waves showed greater importance than secondary (Kelvin) waves. Primary waves were simulated using a 3D hydrodynamic model (DHI's MIKE 3 HD FM) covering the MMC and surrounding areas (Fig. 1). The passing vessel is simulated accurately as a moving pressure field boundary condition, where the pressure field is proportional to the draft of the vessel. The numerical model for simulating the draw-down, that has previously been successfully validated against physical model tests, was calibrated against wave data measured by CNR (August 2019 to February 2020) and against new wave data collected by HS Marine in a dedicated campaign. The propagation of the secondary waves into the tidal flats was simulated using DHI's MIKE 21 SW. The implementation of the above modelling made it possible to assess the morphological impact of passing vessels on the nearby tidal flats based on sediment transport rates and sediment budget calculated during a series of events.

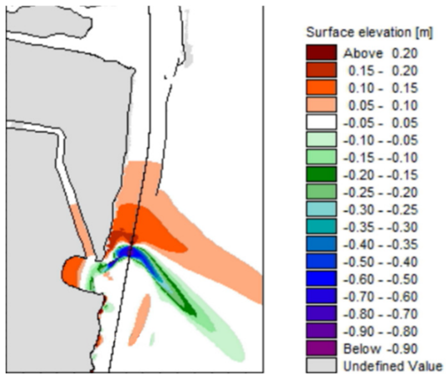

Fig. 1 - Example of displacement wave

The development of the design solutions moves within a series of needs and constraints of different nature: functional, environmental and economic, and involves alternating phases of study and analysis of the results with phases of confrontation with the Port Community. The most critical phenomenology, i.e. the displacement wave, is in fact directly linked to the dimensional relationship between the section of the Channel, the submerged hull of the ship and the speed with respect to the water. Consequently, the 3D hydrodynamic simulations have been replicated, with special focus on the displacement wave and its potential impact on the morphological response of the tidal flats around the Channel. After proper quantification of the local bed shear stresses in the various areas of interest, both large scale and local design solutions aiming at preventing the erosion of the tidal flats and Channel banks have been identified. The result is a complete framework of solutions, both infrastructural and management-led, that balance enviromental and port performance needs.

Pressure and velocity measurements of low-frequency cargo vessel wake in the Savannah River, Georgia, USA

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Introduction

Low-frequency (LF) cargo ship wake can be a major source of energy along shorelines near commercial shipping channels. It has been investigated in the tidal Savannah River, Georgia, USA (see Figure 1) due to high erosion rates at Bird/Long Island, which splits the river into two channels. The Main Channel houses a shipping channel with a maintained depth of 14.3 m and about 5,000 annual vessel transits, including both inbound and outbound vessels. The smaller South Channel is used only by small craft, but LF wake from the shipping channel is the dominant energy source in both channels.
The LF wake consists of a bow wave, a depression spanning the length of the vessel, a return surge produced by the stern wave, and trailing waves that persist for about 30 minutes. The most powerful component is the Bernoulli wave, spanning the depression and surge with a period of 2-4 minutes and wave heights up to 2.1 m at the shipping channel margins. All large cargo vessels pass the field sites at subcritical depth Froude numbers.

Measurements

To support characterization of the wake in the Savannah River and nearby waterways, four sets of hydrodynamic measurements were collected at the margins of the Main Channel: one in 2017, and three in 2022. All data was band-pass filtered to separate the LF wake signals from tidal effects and wind waves, and each wake was linked to vessel properties with AIS data. Raw speeds and positions were processed jointly to get quality tracks and speed estimates.
In October 2017, one month of 1 Hz Aquadopp curent profiler measurements captured velocity and pressure signals of 176 large vessel wake events at the north end of Bird/Long Island, where erosion is most severe. In early February 2022, one month after the shipping channel was deepened by 1.5 m, a pressure sensor was deployed for 5 days near the same site and captured the wake of 48 vessels at 2 Hz.
Two longshore array deployments of several days each were completed near the midpoint of Bird/Long Island in the Main Channel in 2022. In the first, a array spanning 290 m with seven pressure sensors was deployed at approximately 3 m mean water depth and captured 37 LF wakes. The second spanned 240 m with six pressure sensors at 2 m depth and one Aquadopp at 4m depth, and it captured 42 LF wakes.
In 2017, the largest vessel captured was 333 m long, the fastest cargo vessel passed the field site at 8.4 m/s, and the largest wake was 2.1 m. In 2022, the largest vessel captured was 396 m long, the fastest was 8.1 m/s, and the largest observed wake was 0.93 m.
In total, the field campaigns produced 1-2 Hz pressure and/or velocity records for 303 cargo vessel wakes to be used for wake characterization and analysis.

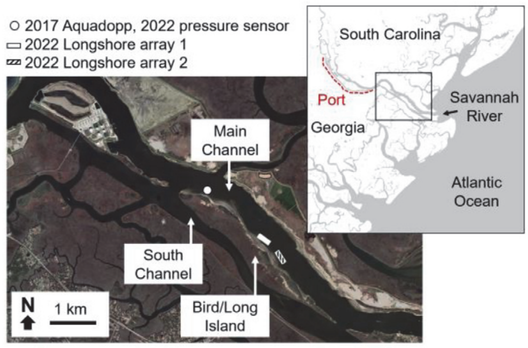

Figure 1 - Map of the measurement sites along the Main Channel of the Savannah River near Bird/Long Island in Georgia, USA.

Analysis

For each data set, wake characteristics such as wave height, velocities, and energy flux are compared to vessel properties, tidal conditions, and combinations thereof to identify variables most relevant to wake magnitude. For the longshore array data, wake features are tracked across all instruments to characterize longshore and cross-shore propagation and evolution of the LF wake components.
Additionally, 14-year trends in vessel traffic and wave heights are assessed using AIS records and a tsunami monitoring pressure gauge in the river. With a recording frequency of 1 min, the gauge does not resolve LF wake well. However, LF wake produces distinct water level fluctuations in its data, and since there are thousands of events each year, the fluctuations can be used to identify long-term trends in wake magnitude.

New methods for in-situ measurement of shallow-draft vessel wake impacts along coastal waterways

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Problem statement

Prior studies have documented wake-induced bank erosion from commercial vessels traversing deep-draft navigation channels (*e.g.*, Houser 2010), but limited data are available to quantify analogous erosive processes from shallow-draft vessels. Along fetch-limited interior coastal waterways, it is hypothesized that wakes generated by shallow-draft vessels are a significant contributor to coastal marsh retreat. We present a new methodology for collecting in-situ measurements of vessel wake forces on marsh scarps and discuss the data's implications for coastal management and restoration.

Methods

To relate wake characteristics to impact forces, wake height and period are measured along a cross-channel transect using bed-mounted pressure sensors, a surface tracking ADCP, and/or a laser rangefinder. Simultaneous measurements of wake impact forces are collected at the bank using an array of submersible S-type strain gauge load cells (Figure 1). Following preliminary testing, a data acquisition system was designed to ensure instrument synchronization and to permit remote data quality assessment and telemetry.

Prior to deployment at the field sites, instrument performance was evaluated using a series of laboratory experiments. Wave flume tests conducted at the U.S. Army Engineer Research and Developent Center quantified the measurement uncertainty associated with empirical relationships between wave energy and impact force. Additional experiments examined the effect of sampling rate on the recorded maximum dynamic load with the goal of defining optimal sampling parameters.

Figure 1 – Photo of two load cell arrays measuring vessel wake forces on a marsh scarp in Louisiana, USA

Study sites

The proposed methodology was implemented for three coastal waterways in the United States:

1. the Houma Navigation Canal, Louisiana
2. the Atlantic Intracoastal Waterway near St. Augustine, Florida
3. the Atlantic Intracoastal Waterway in Barnegat Bay, New Jersey.

The three sites had varying geometries and hydrodynamic conditions, including differences in bed profile, scarp height, tidal range, and distance from the authorized navigation channel. This permits an analysis of how each parameter influences vessel wake forces on the bank.

Results and implications

The collected data indicate an order-of-magnitude relationship between wake energy flux and impact pressure on the marsh scarp. However, the results are dependent on tidal stage, and the parameterization of the energy-versus-impact relationship appears to be location specific. Peak forces on the bank occurred when the tide was below the scarp midpoint because the incident wake was more likely to break on the scarp (Priestas *et al*., in review). This suggests that scarp undercutting by vessel wakes may contribute to bank retreat along interior coastal waterways, and constructed dissipative features may perform optimally when designed to protect low- to mid-tide elevations.

References

Houser, C. (2010). Relative importance of vessel-generated and wind waves to salt marsh erosion in a restricted fetch environment. *J. Coast. Res.*, v. 26(2), pp. 230-240.

Priestas, A., Styles, R., and Bain, R. (in review). Vessel wake impact forces on marsh scarps. Submitted to *J. Coast. Res.*

Over 48 Years of In Situ Ship Wave Measurements at BAW, Where does the Future lead to?

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Introduction
Various research concerning the measurement of waves do exist, for example Bourdier et al 2014. These however mainly refer to measuring sea state and not the single event, such as ship-induced long- and short-period primary and secondary waves. Yet, the importance of this topic is significant. Benefiting this task are the recent developments of instrumentation to record single ship wave heights and ship induced currents. Nowadays they are much more suitable for detecting every detail of long- and short- period ship waves then over 48 years ago, at the time of the first measurement campaigns by BAW. Recent developments in remote sensing technologies such as LiDAR (Light Detection and Ranging) and stereo photogrammetry could even bring the future solution to determine 3D data of a single ship wave surface elevation.

In situ measurements at BAW
For over 48 years, BAW (Hamburg) has been carrying out ship wave measurements along the German navigable maritime waterways, predominantly the German estuaries and Kiel Canal. Experience has been gained from more than 24 measurement campaigns (own and outsourced). A broad variety of instruments to detect ship induced hydrodynamic loading on waterway banks and waterway infrastructure have been utilized during those years. Until now sensors such as pressure sensors (strain gauge and resonant quartz crystal technology) as well as capacitive wave gauges have been used to detect the water surface elevation. Every system though has its own advantages and disadvantages, for example the capacitive wave gauge is a very precise instrument (resolution: 3mm), but is almost always associated with a complex installation, such as setting up on a pole. In order to determine the overall picture of the ship induced hydrodynamic loading BAW has also used, where possible, sensors to determine the ship induced current. This mainly involves acoustic instruments, for example (single point, high temporal resolution, 3D) acoustic doppler velocimeters (ADV) or acoustic doppler current profilers (ADCP), providing a full water column profile. Additionally, electromagnetic current meters (ECM) have occasionally used. The advantage of ECMs is that they still provide data even if the sediment concentration in the water is too high for acoustic methodologies (e.g., fluid mud in the Ems estuary). It should be noted however that the accuracy and temporal measurement resolution of the 2D ECMs is lower than that of the 3D ADVs.
One of the latest campaigns by BAW was carried out as a pilot study for instrument testing in the Elbe estuary by installing and evaluating the following sensor types: strain gauge and quartz pressure sensors, an acoustic surface tracking (AST) ADCP for recording water surface elevation as well as ADCPs (Figure 1) and an ADV for recording water current. Additionally, a turbidity sensor was deployed, to investigate the ship induced sediment transport at the river bank.

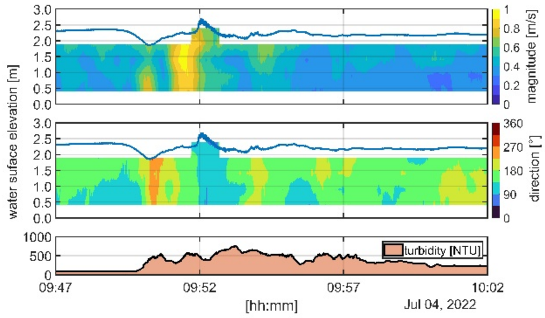

Figure 1 - ADCP profile and turbidity of a ship wave

Where does the future lead to?
The future goal of BAW is to not only establish a time series of ship waves at a single point along the coastal bank, but to derive the overall 3D picture including the wave transformation from ship to shore. One way to reach this goal could be the utilization of remote sensing methods such as LiDAR or stereo photogrammetry. These technics have already been successfully applied for topics such as undular bore (Guimarães 2019) or extreme sea state (Martins 2017).

References
Bourdier, S., Dampney, K., Fernandez, H., Lopez, G., Richon, J.B. (2014). *MARINET.*
Guimarães,P, Leckler, F., Filipot,J.F., Horstmann, J., (2019). Extreme Sea State Measurements by Stereo Video System. *IJOPE*
Martins, K., Bonneton, P., Frappart, F., Detandt, G., Bonneton, N., Blenkinsopp, C.E., (2017) High Frequency Field Measurements of an Undular Bore Using a 2D LiDAR Scanner. *Remote Sensing. 9(5):462*

1st International Workshop on Ship-induced Hydrodynamic Loads in
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Analysis of ship waves along the Scheldt estuary

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Introduction

The Scheldt estuary is an important navigation route, situated in the northern part of Belgium and the southern part of the Netherlands. Sea-going vessels are sailing far upstream (e.g. to the port of Antwerp) and inland navigation is present along the whole course of the estuary. Besides its economical function, the estuary also has an important ecological function. Intertidal areas along the estuary are important habitats for fauna and flora.

The morphological evolution and intrinsic ecological values of these intertidal areas depend on the hydrodynamic stresses exerted on this areas. Both tidal currents and waves, which can be generated by wind and ships, are responsible for this hydrodynamic conditions. Measurements were performed on several mud flats along the estuary to quantify these conditions.

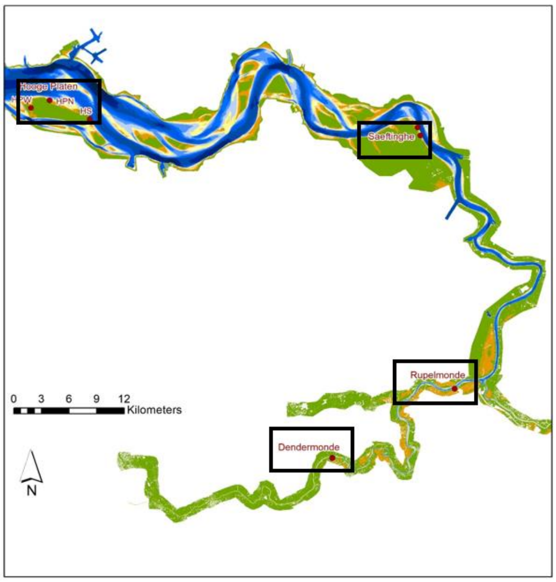

Figure 1 – Overview of measurement location (black boxes) along the Scheldt estuary

Material and methods

Measurement instruments were deployed close to the low water line. High-frequency pressure sensors were installed to characterise the wave signals. The pressure data are transformed to wave data by applying corrections (depth-pressure attenuation and atmospheric pressure correction) and removing other signals (tidal water variations). Additionally, an ADCP (Aquadopp) is used to measure the tidal currents. These measurements were performed over a spring-neap cycle.

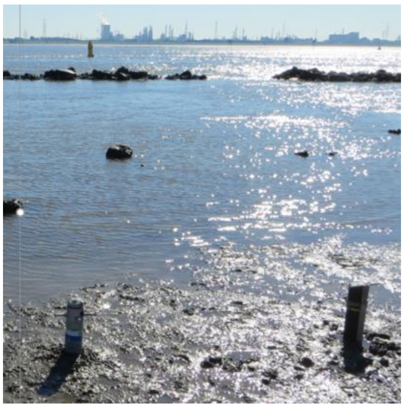

Figure 2 –Aquadopp (left) and high frequency pressure (right) on a mud flat

Besides the project specific measurements, also monitoring data is used to analyse the data. For two locations (Hooge Paten and Saeftinghe) the shipping traffic was evaluated based on AIS-data (Automatic Identification System). This dataset contains dynamic information on the position, course and sailing speed of the ship, together with static information of the ship itself (length, beam, draught). Furthermore the information of tidal gauges and meteorological measurements (wind) are used as well.

Results

The overall wave climate is calculated per tidal cycle. There is a clear decrease of the significant wave height, ranging from 0.30 m at the mouth to 0.05 m in the upstream region. For ship waves, both primary waves and secondary waves are isolated in the analyses, using the information of ship passages (AIS). Primary waves range from 0.10 m to 0.80 m. Secondary ship waves range from approx. 0.40 m at the mouth to 0.10 - 0.20 m in the upstream region.

References

Meire, D.; Kolokythas, G.; Smolders, S.; Plancke, Y.; Verwaest, T.; Mostaert, F. (2019). Agenda voor de Toekomst – Waves in the estuary: analysis of wave measurements at Saeftinghe. Version 2.0. FHR reports, 14_082_1. Flanders Hydraulics Research: Antwerp.

The importance of full-scale trials when quantifying and managing vessel wave wake in confined waterways

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The waves generated by vessels (often referred to as wave wake, wake wash or simply wash) that operate within confined and sheltered waterways can result in a variety of issues for other users of the waterway and surrounding environment [1]. This has resulted in a growing need for tools that accurately predict the characteristics of these waves to assist in the provision of effective waterways management.
The Wave Wake Predictor is an empirical tool developed for this purpose, covering a wide variety of hull forms from large full-form ships, small commercial vessels (such as monohull and catamaran ferries 20 to 40 m in length) and recreational craft that frequently operate in confined or sheltered waterways [2]. This tool has been successfully validated against measured data from numerous full-scale trials on a variety of different vessels. However, full-scale trials conducted in shallow water have highlighted the difficulty in predicting the key characteristics of the often excessively high energy waves that can be created when a vessel approaches the critical depth Froude number – a scenario that can readily occur in many depth-limited harbours and rivers.
This paper presents a comparison of full-scale results against empirical predictions that highlight these difficulties. An example is presented in Figure 1 where the resultant energy of the most dominant waves created by a 33m catamaran passenger ferry operating in relatively shallow water is plotted as a function of vessel speed (depth Froude number).

The only difference between the two data sets presented is the water depth: the full scale trials were performed in approximately 3.5 m deep water while the predictions from the *Wave Wake Predictor* are provided for the slightly deeper depth of 6.0 m (the lower limit of applicability for a vessel of this length).

In general, the agreement between the trials data and empirical predictions in Figure 1 is good for both subcritical speeds (Frh < ~0.75) and most super-critical speeds (typically in excess of Frh ~1.2). However, this seemingly small difference in water depth has contributed to some massive differences within the trans-critical speed range, where the reduced water depth has resulted in the generation of large, long-period waves as the critical speed is approached. For example, between 0.9 < Frh < 1.05 both the wave height and period measured during the trials (not presented here) were under predicted by as much as ~300%. As wave energy is proportional to the square of both wave height and period, these differences are amplified such that wave energy can be ~20 times greater than the predictions within this narrow range of speeds (as observed in Figure 1).

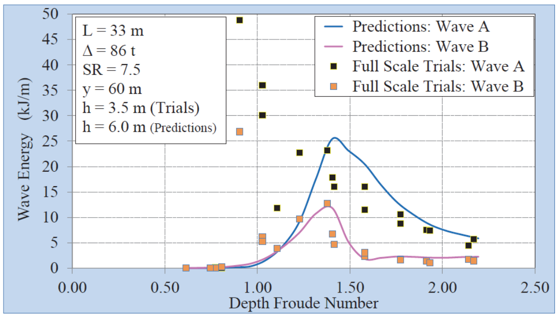

Figure 1 – An example of the full scale trials results (experimental points) and empirical predictions (curves). Wave energy is plotted against depth Froude number. Note the significant increase in wave energy from the full scale trials close to the depth Froude number of unity – a result of the significantly higher wave height and longer period measured.

The paper also outlines how trials data can be used to enhance the predictive capabilities of the empirical prediction tool; and emphasizes the benefits of first making two very basic "back-of-the-envelope" calculations whenever initiating an assessment of vessel operations on busy waterways.

References

[1] Parnell, K.E. and Kofoed-Hansen, H., 'Wakes from large high-speed ferries in confined coastal waters: management approaches with examples from New Zealand and Denmark', *Journal of Coastal Management*, vol. 29, pp 217-237, 2001.

[2] Macfarlane, G.J., 'Marine vessel wave wake: focus on vessel operations within sheltered waterways', *Doctor of Philosophy thesis*, Australian Maritime College, University of Tasmania, Australia, 2012.

Estimation of extreme primary ship-induced wave loads by the application of the Non-Parametric Bayesian Networks

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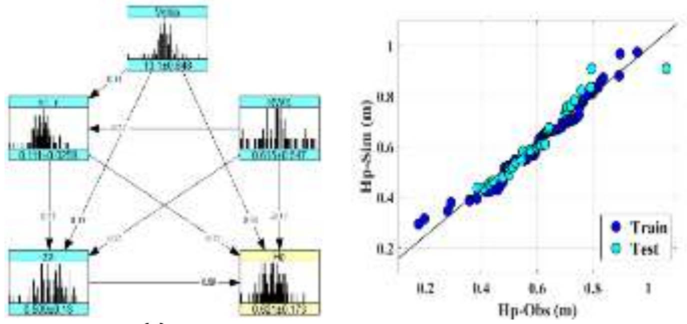
The primary ship-induced waves are detected as the main cause of increasing damage to Elbe river infrastructures over the last two decades. The evolution and upsizing of container ships in shallow and confined waterways resulted in larger ship waves, leading to an intensive damage to rock structures such as groynes in the Elbe estuary (Melling et al. 2021). Hence, a solution for the design of rock groyne structures in tidal estuaries is required. For this purpose, the estimation of the probability of extreme ship-induced primary wave loads is a key element. Several studies have focused on the estimation and characterization of ship waves in rivers and estuaries. Among them, Memar et al. (2021), investigated the stochastic characterization of extreme primary ship-induced wave components and ship speed through water in Elbe Estuary. Kochanowski and Kastens (2022) simulated ship waves in shallow and confined waterways with the CFD method and validated with experimental data. However, current methods neglect the dependence between the magnitude of the primary wave height, ship characteristics, waterway characteristics, and drawdown extent, potentially leading to under or overestimation of the primary wave height. In addition, they are time-consuming and computationally expensive. In this study this issue is addressed by using Non-Parametric Bayesian Network (NPBN) to estimate the extreme primary wave height at the tip of a prototype groyne. The groyne is located on the Lower Elbe Estuary where the groynes experienced major deteriorations due to shipping. In a pilot study by BAW the investigated groyne was renovated and the loading data were gathered from the installed pressure sensor at its tip from 07.2015 to 02.2019. NPBNs are graphical tools for statistical inference in which the joint probability distribution of the variables of interest is determined via bivariate dependence (Hanea and Kurowicka (2006)). In the network, the nodes represent the random variables while the arcs define the relationship between the connected nodes, which is quantified by the conditional rank correlation coefficient (see Figure 1 (a)). The NPBN is developed based on the AIS (Automatic identification system) dataset and the load dataset. More specifically, the nodes of the NPBN are ship speed through water (Vship), partial blockage factor (nT_r), ambient water level (RWS), drawdown (za) and primary wave height (Hp) (Figure 1 (a)). The extreme primary wave height can contribute to a significant damage to river infrastructures. Therefore, the weekly maxima Hp are selected for modeling (94 observations), while the other variables are its concomitants and not necessarily extreme. The toolbox BANSHEE (Paprotny et al. 2020) in MATLAB 2019b was used to carried out the analysis. The data were split into 70% and 30% for the purpose of training and testing the model, respectively. We performed 5 run simulations. In Figure 1 (b), the predicted and observed extreme primary wave heights are compared. The predicted values correspond to the 50th percentile of the distributions of extreme primary wave height conditioned on the remaining variables for every primary ship wave load event. Additionally, the performance of the training and testing models were measured via diagnostic metrics Nash–Sutcliffe model Efficiency Coefficient (NSE) and the Root Mean Square Deviation (RMSE). In table 1, the predicted and observed extreme primary wave heights were compared. Values of NSE close to 1 indicate an excellent model performance. In addition, low RMSE values demonstrate the robustness of the model. The results show the suitability of the model in the estimation of extreme primary wave height. Overall, the model developed in this study can be used to predict the probabilities of extreme wave loads on groynes for future condition and for design and assessment purposes.



(a) (b)

Figure 1- (a) NPBN model created in Uninet Software (b)Comparison between observed and predicted weekly maxima primary wave height for the training and testing model

Table 1- Test metrics for the observed and predicted Hp

Variable	Training model		Testing model	
	NSE	RMSE	NSE	RMSE
Hp	0.96	0.22	0.94	0.21

References

Melling, G., Jansch, H., Kondziella, B., Uliczka, K., & Gätje, B. (2021). Evaluation of optimised groyne designs in response to long-period ship wave loads at Juelssand in the Lower Elbe Estuary. *Die Küste, 89*, (89), 29-56.

Kochanowski, C. A., & Kastens, M. (2022). Simulation and validation of ship induced waves in shallow and confined water. In *Proceedings of the 6th MASHCON International Conference on Ship Manoeuvring in Shallow and Confined Water, with special focus on port manoeuvres; 22-26 May 2022, Glasgow, UK* (pp. 89-101).

Paprotny, D., Morales-Nápoles, O., Worm, D. T., & Ragno, E. (2020). BANSHEE–A matlab toolbox for non-parametric bayesian networks. *SoftwareX*, *12*, 100588.

Memar, S., Morales Napoles, O., Hofland, B., Melling, G., & Melling, G. (2021, September). Characterization of Long-period Ship Wave Loading and Vessel Speed for Risk Assessment for Rock Groyne Designs via Extreme Value Analysis. In 31st European Safety and Reliability Conference (pp. 2525-2532). Research Publishing Services.

Hanea, A. M., Kurowicka, D., & Cooke, R. M. (2006). Hybrid method for quantifying and analyzing Bayesian belief nets. *Quality and Reliability Engineering International*, *22*(6), 709-729.

Waterway bank erosion risk model by oceangoing ships

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The erosion risk of the riverbank due to ships in navigation is very important, not only for the environmental aspects in an area of special sensitivity, but also for the stability of structures which support and protect diverse installations.

Ship navigation has an influence in the dynamics of the erosion and sedimentation processes of the waterway, as collected on PIANC Report 99 ("Considerations to Reduce Environmental Impacts of Vessels", 2008).

It is therefore considered a secondary agent of erosion, after river hydraulics, geology, morphology, and coastal dynamics. The passage of ships produces waves combined with a "suction" phenomenon, which can lead to shore erosion. The main parameters governing this phenomenon are the shape, dimensions and draught of the vessel, the depth and section of the channel. The critical variables are the speed of the vessel and its position with respect to the channel axis.

Current work presents the methodology developed to create a waterway bank erosion risk model by considering the complete fleet of ships transiting through the waterway.

The risk model developed is based on deterministic methods which allow to calculate both suction forces and associated return currents a swell as the secondary waves which are propagated towards the banks. These parameters are used to evaluate the eventual erosion, both at the bank slope and at the emerged area of the bank

Ships transit at different speeds and distances form he waterway axis, as well at different water level conditions (either fluvial, tidal or both) and associated currents

The randomness of the different parameters involved in the calculation is obtained from both nautical risks and water level related access models, also developed by Siport21, thus giving the global analysis a probabilistic character.

A comparison of the ship-induced return current effect on the banks of the waterway are compared with those coming directly from the river current. This comparison allows to determine the relative importance of shipping traffic in bank erosion in comparison with river currents.

Siport21 has long been applying analysis methodologies based on the use of integration techniques and Monte-Carlo-simulations to accurately determine the navigational risks and the relevance of the different variables. The same methodology is now being applied, focused on determining the risk of affecting the waterway banks and setting operating limits based on the admissible probability.

The main advantage of this risk model is that it provides erosion warnings depending on the type/size of vessel, its loading condition and speed. It can be used to support channel design, detecting vulnerable areas and providing a basis for implementing shore stabilisation/protection systems. It can also be used in combination with traffic management systems, thus being able to adapt the planning of operations (ship size, draught, water level, speed) based on objective criteria of acceptable risk, defined according to the characteristics of the waterway.

The work will present practical examples of application, facilitating the understanding of the methodology, the necessary information, and the assessment of its usefulness.

References

Report PIANC 99 ("Considerations to Reduce Environmental Impacts of Vessels", 2008)

A geohydraulic analysis of sediment shear strength during drawdown

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Drawdown and sediment shear strength

The presence of even small amounts of entrapped gas in the sediments, for example as a result of water level fluctuations or biogenic processes, in combination with rapid variations of water levels and/or stress can affect pore pressure propagation dynamics significantly [Montenegro et al. 2022]. The expression "rapid" must be considered in respect to the hydraulic conductivity and water storage properties of the sediment and involves accordingly a wide range of time scales (wave characteristics) and sediment types. Depending on the soil properties vessel induced drawdown may amplify pore pressure gradients, reducing the effective stress and the shear strength. In extreme cases this may lead to complete liquefaction of the upper sediment layer. The loss of shear strength may have a wide range of consequences. The pore water flow forces may loosen grains from the sediment matrix and enhance erodibility. Once the upper layer is liquified, the sediment may no longer resist the current's shear forces and its general behaviour transforms from that of a porous solid to that of a viscous fluid.

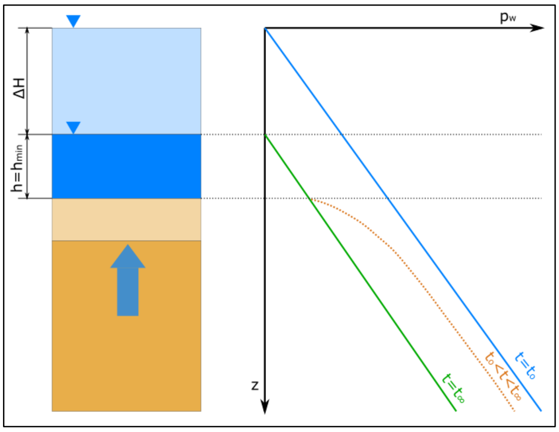

Figure 1: Pressure distribution during drawdown

Effect of rapid drawdown on the soil

In this presentation we will focus on the consequences of ship-induced drawdown for sheet pile wall design based on drawdown measurements. The geohydraulic analysis is established on Biot's Theory of Poroelasticity and considers a continuum consisting of three deformable phases, the solid grains, the porous matrix and the pore fluid which is able to flow within the porous matrix. The pore fluid's compressibility depends on the amount of entrapped gas while the solid grains generally are considered as incompressible. Figure 1 shows a schematically the vertical pressure distribution in the sediment during drawdown. Initially hydrostatic conditions prevail. Due to the falling water level the water pressure at the sediment surface decreases continuously. Depending on the hydraulic conductivity and the entrapped gas volume within the sediment the water pressure decline may not propagate sufficiently fast into the sediment giving rise to pore pressure gradients (excess pore pressure) as shown in Figure 1. These pressure gradients reduce the effective stress and accordingly the shear strength of the sediment. Generally, drawdown induced instabilities are momentarily due to pore pressure dissipation and a new hydrostatic state may establish without further water level fluctuations. However, if the ship-induced loading consists of a series of waves, rather complex pore pressure and deformation patterns in the sediment may occur.

Coupled flow-deformation modelling

For simplistic, one-dimensional conditions analytical solutions for the prediction of variations of pore pressure, effective stress and shear strength were developed and used for model verification. More realistic conditions require numerical analyses. The numerical implementations led to **poroMechanicalFoam** a hydro-mechanically coupled 3D Finite-Volume-Element solver based on the openFOAM software platform which permits a versatile interface to any CFD openFOAM solver.

Conclusions

In this study a characteristic ship-induced drawdown loading on a sheet pile wall was considered while the soil properties were varied within the range typically encountered in engineering practice. Depending on the sediment type and the volume of entrapped gas a loss of shear strength can occur with varying spatio-temporal characteristics, the consequences of which are discussed with respect to sheet pile wall design.

References

Montenegro, H., Maier, D., Odenwald, B., & Nuber, T. (2022). *Hydromechanical analysis of structure-soil-interactions at the flood barrier "Eidersperrwerk" in Germany*. 20th SMGE International Conference.

Tang, T. (2014). *Modeling of soil-water-structure - A Finite Volume Method (FVM) approach to fully coupled soil analysis and interactions between wave, seabed and offshore structure. Ph. D. Thesis.*

1st International Workshop on Ship-induced Hydrodynamic Loads in Shallow Confined Coastal Waterways

22. – 24.03.2023, Hamburg, Germany

A semi-implicit finite volume scheme for a simplified hydrostatic model for fluid-structure interaction

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Abstract

In this talk, a novel semi-implicit finite volume scheme (SIFSI) is presented for the coupled solution of the water flow and the movement of one or more floating structures. The model is well-suited for geophysical flows, as it is based on the hydrostatic pressure assumption and the shallow water equations. The coupling is achieved via a nonlinear volume function in the mass conservation equation that depends on the coordinates of the floating structures. Furthermore, the nonlinear volume function allows for the simultaneous existence of wet, dry and pressurized cells in the computational domain. The resulting mildly nonlinear pressure system is solved using a nested Newton method. The accuracy of the volume computation is improved by using a subgrid, and time accuracy is increased via the application of the theta method. Additionally, mass is always conserved to machine precision. At each time step, the volume function is updated in each cell according to the position of the floating objects, whose dynamics is computed by solving a set of ordinary differential equations for their six degrees of freedom. The simulated moving objects may for example represent ships, and the forces considered here are simply gravity and the hydrostatic pressure on the hull. For a set of test cases, the model has been applied and compared with available exact solutions to verify the correctness and accuracy of the proposed algorithm. The model is able to treat fluid-structure interaction in the context of geophysical free surface flows in an efficient and flexible way, and the employed nested Newton method rapidly converges to a solution. Initial results of the introduction of dispersion effects will be shown. The proposed algorithm may be useful for hydraulic engineering, such as for the simulation of ships moving in inland waterways and coastal regions.

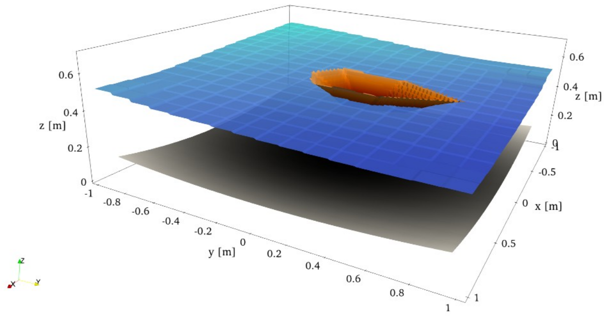

Figure 1 - Typical output from the code application-based on the SIFSI model. In this example, the gradients in the free surface elevation configuration move the water in the lake, and the water carries the ship with it.

Acknowledgment

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References

Brutto C, Dumbser M. A semi-implicit finite volume scheme for a simplified hydrostatic model for fluid-structure interaction. Int J Numer Meth Fluids. 2022;1-36. doi: 10.1002/fld.5143

Development of a numerical towing tank and comparison with experimental results: study of the flow around a vessel in a restricted waterway

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Abstract
Inland navigation has a significant impact on riverbanks. In order to estimate the contribution of navigation to the erosion of these banks, it may be useful to develop a numerical model reproducing a towing basin. This work is a follow-up to the experimental tests in a towing basin previously performed at the Pprime Institute in Poitiers. More precisely, this article studies the different means and models available in the STAR-CCM+ software, with the aim of comparing them. This study uses a Wigley hull with a block coefficient of 0.889, in order to be close to a river vessel. A reference geometry and Froude number are studied, as well as the influence of parameters such as turbulence patterns. The comparison is made on the basis of measurable physical values, such as the deformation of the free surface in the wake of the ship or the resistance of the ship. This paper also compares two ways of simulating the same flow, namely by moving the ship in the stationary fluid, or by keeping the ship stationary in front of the moving fluid. The reason why the first of these methods cannot yet be applied to this type of flow at this time is also explained.

1 Geometry of the channel and the boat
This section deals with geometric parameters, such as channel geometry, ship speed or hull geometry. The present study was conducted on a single reference geometry, with the objective of being able to be compared with existing experimental data.

2 Numerical simulations
This section, divided in three subsections, deals with the choice done between several parameters.

2.1 Influence of the simulation type
This subsection relates a study comparing two ways to simulate the same flow. The first one, called Overset, Replicates the experiment identically, i.e. recreate a virtual traction channel, where the fluid is fixed, and in which the digitally reproduced 3D model of the vessel moves at the same speed as the physical model in the channel. The second, more often used in similar papers, consists in changing the reference frame with respect to the first one, i.e. to fix the ship model and to put in motion the fluid which surrounds it, always at the desired speed. This part explains why the first one cannot be used with the current calculation means.

2.2 Influence of the turbulence model
This section compares two turbulence models: k-ω and k-ε. The comparison is achieved using experimental data, from a thesis conducted in the towing tank of the Pprime Institute in 2015 [1].

2.3 Influence of the automated mesh refinement
This last comparison studies the relevance of using automatic mesh refinement in confined waterway flows and explains what is the best way to use it. Unlike other mesh models, it acts during the simulation, and not only before the calculation starts. The principle of this model is to refine the mesh at the desired locations in space, according to a criterion defined by the user, and this at regular time intervals.

3 Results
This last section discusses the numerical results obtained and compares them to the experimental results. The simulations have given very satisfactory results on different aspects. The Figure 1 shows the free surface aspect for both the numerical calculation and experimental data. The wavelength is well reproduced, as the water height.

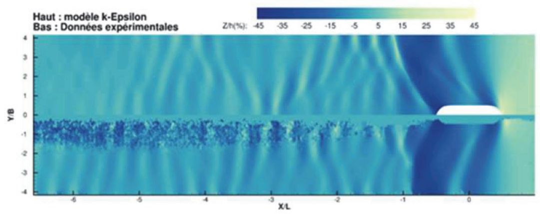

Figure 1 – Comparison between the numerical solution (top) and the experimental data (down)

References
[1] Caplier, C.: Étude expérimentale des effets de hauteur d'eau finie, de confinement latéral et de courant sur les sillages et la résistance à l'avancement des navires., (2015).

Systematic validation of an efficient numerical tool to predict long-period primary waves

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Experimental benchmark data for ship wave models

In recent years, especially the long period primary waves induced by large sea-going ships navigating in confined waterways have been reported to have various damaging effects on the built and living environment of shallow and confined waterways[1].

Depth-averaged numerical models, based on shallow-water equations or Boussinesq equations, have proved successful to predict key design parameters of the long-period wave system compared to field data (e.g [2]). However, a challenge when using field data for the validation of numerical prediction models lies within the uncontrolled parameter space typically prevalent during field data collection and the complexity of the examined cases.

Experimental procedures, in contrast, allow a setup within an exactly controlled environment and additionally provide the possibility to systematically investigate the effect of specific parameters, such as draft or ship velocities. Using such experimental data for validation, therefore, allows shedding light on the level of confidence of the numerical methods and existing model limitations alike.

Validation of REEF3D::SFLOW

The REEF3D hydrodynamic modeling framework comprises the non-hydrostatic shallow water-equation solver REEF3D::SFLOW, which was recently extended to simulate ship-generated waves via a free surface pressure term[3].

After some first verification tests and the validation of the module for the prediction of primary waves in shallow, laterally unconfined water, this presentation now focuses on additional validation of the novel module with more complex experimental data. The additional features in this data set comprise lateral confinement and sloping embankments. Under such conditions, the intensity of the return current and the magnitude of the primary wave system increases, compared to laterally unconfined waterways.

The numerical model shows satisfying agreement with the measured time histories of the return current and the primary wave indicating the model's applicability for very narrow waterways with a high blockage ratio. The controlled parameters in the experimental setting allow an exact quantification of the remaining deviations so that the level of confidence for applications can be determined.

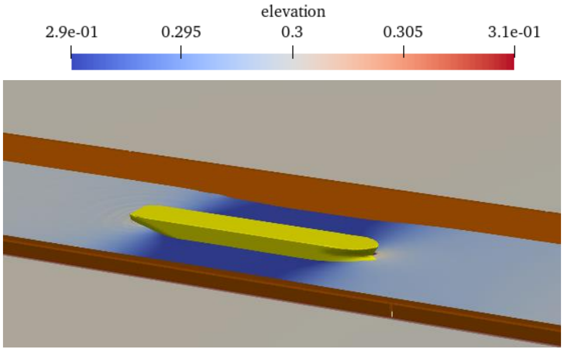

Abbildung 1: Free surface elevation around a ship progressing in a confined channel simulated with REEF3D::SFLOW

REEF3D Modeling framework

An important advantage of the numerical model REEF3D::SFLOW compared to other methods such as RANSE-CFD is, that it efficiently balances the need for accurate simulations with computational efficiency. Further, it is embedded in the REEF3D framework of hydrodynamic solvers. An ongoing integration of the different REEF3D modules is pursued, which will allow the user to specifically exploit the capabilities of the different solvers dependent on the required level of accuracy and the prevalent processes.

References

[1]. Dempwolff, L.-C.; Melling, G.; Windt, C.; Lojek, O.; Martin, T.; Holzwarth, I.; Bihs, H.; Goseberg, N. Loads and Effects of Ship-Generated, Drawdown Waves in Confined Waterways - A Review of Current Knowledge and Methods. *J. Coast. Hydraul. Struct.* **2022**, *2*, 46, doi:10.48438/jchs.2022.0013.
[2.] Almström, B.; Roelvink, D.; Larson, M. Predicting Ship Waves in Sheltered Waterways – An Application of XBeach to the Stockholm Archipelago, Sweden. *Coast. Eng.* **2021**, *170*, 104026, doi:10.1016/j.coastaleng.2021.104026.
[3.] Dempwolff, L.-C.; Windt, C.; Goseberg, N.; Martin, T.; Bihs, H.; Melling, G. Verification of a Free-Surface Pressure Term Extension to Represent Ships in a Non-Hydrostatic Shallow-Water-Equations Solver. *J. Offshore Mech. Arct. Eng.* **2022**, 1–12, doi:10.1115/1.4056121.

Ship-induced wave force effects on moored ship using reduced two-layer nonhydrostatic model

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Due to the increase in ship sizes and traffic, the effect of passing ships on the mooring forces of moored ships has recently become an important aspect in restricted waterways, channels, and ports.

The objective of the presented work is to investigate the effects of different parameters, such as ship velocity, passing distance and current speed, on the mooring forces of moored ships when another vessel passes through the waterway. XBeach nonhydrostatic with one (nonh) or two layers (nonhq3d) has been used to simulate the waves generated by the ship movement (Ma 2012; Almström, Roelvink, and Larson 2021). Also, XBeach-NH model has been extended to calculate the mooring forces of the ships (Zhou, Zou, and Roelvink 2015).

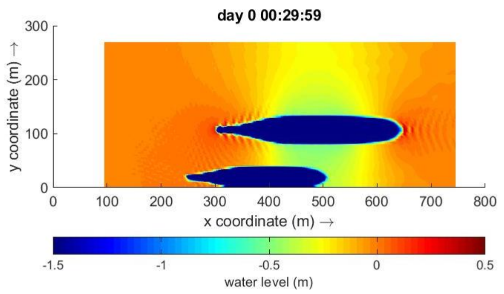

Figure 1 – simulation of passing ship effects in XBeach numerical model (cropped)

In this research, XBeach-NH in (nonhq3d) mode is used to simulate the physical model tests carried out as a part of the JIP Ropes (Joint Industry Project, Research On Passing Effects on Ships) project at the Atlantic basin of Deltares (van der Hout and de Jong 2014).

Even though various layouts were tested in the project, the focus of the current paper is only on the straight channel layout; different combinations of passing distance, ship velocity, and current speed are simulated and the resulting mooring forces and water level variations are compared with measurements in the physical model.

Figure 1 illustrates the Water levels variation representing ship waves in XBeach numerical model for passing ship effects.

This research shows that XBeach slightly overestimates the draw down effects (water level depression) due to the primary waves and also the surge forces compared to measured data. However, sway forces and yaw moments are in good agreement with the measured data. This variation in results is consistent in almost all XBeach runs. Results also indicates that XBeach is capable of reproducing similar effects due to the change of various physical parameters as observed in model tests. Surge forces increase with increase of ship velocities and follow a trend line higher than quadratic while the sway forces follow a close to quadratic trendline.

References

Almström, Björn, Dano Roelvink, and Magnus Larson. 2021. "Predicting Ship Waves in Sheltered Waterways – An Application of XBeach to the Stockholm Archipelago, Sweden." *Coastal Engineering* 170 (July). https://doi.org/10.1016/j.coastaleng.2021.104026.

Hout, A J van der, and M P C de Jong. 2014. "Passing Ship Effects in Complex Geometries and Currents." *PIANC World Congress* 31 (0): 17.

Ma, H. 2012. "Passing Ship Effects in a 2DH Non-Hydrostatic Flow Model." IHE Delft Institute for Water Education. https://ihedelftrepository.contentdm.oclc.org/digital/collection/masters1/id/6844/.

Zhou, Ming Gui, Zao Jian Zou, and Dano Roelvink. 2015. "Prediction of Ship-Ship Interactions in Ports by a Non-Hydrostatic Model." *Journal of Hydrodynamics* 27 (6): 824–34. https://doi.org/10.1016/S1001-6058(15)60545-5.

Numerical modeling of low-frequency cargo vessel wake in the Savannah River, Georgia, USA

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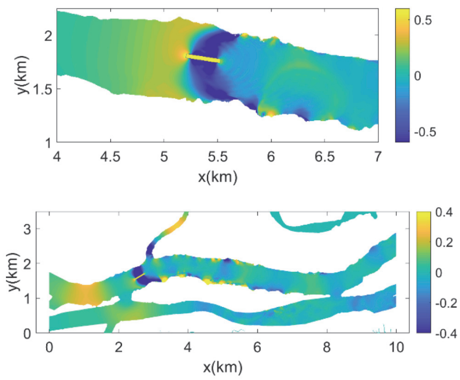
Introduction

Large vessels in narrow channels produce low-frequency wake that consists of a positive front wave at the bow of the vessel, a depression (drawdown) spanning the length of the vessel, and an upwards surge produced by the stern wave. This low-frequency wake is followed by continued low-frequency trailing waves that may persist in the channel more than 30 minutes after a vessel passage. Extensive observations in the Savannah River, Georgia, USA has shown that the low-frequency cargo ship wake and the trailing waves that follow are ubiquitous features and are the most energetic contributions to the hydrodynamic loads at the shoreline. Therefore, numerical modeling is used to better understand the relationship between the vessels and the corresponding low-frequency wake and trailing waves.

Numerical Model Setup

Cargo ship passages are simulated using FUNWAVE-TVD, a 2D Boussinesq model [1]. The model simulates the vessel as a pressure source [2] with the same dimensions and speed as cargo ship observed in the field. To simulate the complex bathymetric features, the grid was generated using survey data for the Savannah River from the US Army Corps, the USGS, and additional surveys. In order to accurately simulate the pas-sage of particular cargo vessels, high resolution AIS data from multiple sources was utilized for developing the ship tracks. However, the model was sensitive to noise that would show up in the interpolated ship track; therefore, the vessel positions were low-pass filtered to estimate vessel track and velocity. In addition, to prevent artificial waves during the model startup, the ship track was modified to bring the vessel in the domain more slowly than measured and was smoothly accelerated to the actual vessel speed over the first kilometer of the grid. The model output is composed of water level snapshots across the domain at fixed time intervals and time series of the water level and velocity at the same locations as the in situ measurements. The field measurements available for comparisons included pressure and velocity data in relatively shallow water along the main channel.



Model Results

Numerous cases are chosen to be simulated from the more than 300 vessel passages that have direct field measurements. In order to more broadly characterize the impact on the wake generation, these cases span a range of tidal conditions, vessel size, and speed. Model validation is done by comparing the in situ measurements to the model output and comparing the generated wake properties. Time series of the model output end up showing a striking resemblance to the observations, allowing the model to be used to help interpret the more complex aspects of the measurements. An example of the model results are shown in Figure 1, illustrating the complexity of the generated wake system. In the top panel, the depression attached to the vessel is clear, along with the shoaling effect where the portion of the depression extending into shallow water increases in amplitude. The bottom panel shows the trailing waves generated after the vessel passes the island. These waves are propagating and bouncing back and forth between the headlands on the island. Further analysis is being done to further characterize the trailing wave field that is generated by the vessel passage.

References

[1] Shi, et al. (2012). A high-order adaptive time-stepping TVD solver for Boussinesq modeling of breaking waves and coastal inundation. Ocean Modelling, 43, 36-51.
[2] Lam, M. A. Y. H., Malej, M., & Shi, F. (2022). Operational modeling of large container-type vessel-generated waves with related erosion and scour effects.

Simulation and validation of ship induced waves in shallow and confined water conditions

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Introduction

The Federal Waterways Engineering and Research Institute (BAW) needs methods for predicting ship-induced wave loads. Both for currently operating ships in present situations and for future ship designs operating in planned situations. In addition to the established hydraulic scale model, the method of computational fluid mechanics (CFD) is to be increasingly used. In order to demonstrate the reliability and quality of the method, a validation of the model results is necessary.

In this presentation we examine and validate two different system environments: moderately sized bulk carrier in extremely shallow and confined conditions with moderate ship speed (Kiel canal) and ultra large container vessels (ULCVs) in shallow water conditions with higher speed (harbour approach channel of Bremerhaven). Since the primary wave field is responsible for numerous damages to the waterway infrastructure, it is given the greatest importance.

Method

The RANSE based CFD solver Star-CCM+ is used to simulate the ship hydrodynamics. The free water surface of the two-phase model is calculated by the Volume of Fluid (VoF) method (see figure 1). A Dynamic Fluid Body Interaction (DFBI) module and a mesh morpher take care of the ship motion. The experimental data used for validation was measured in model tests in the BAW ship wave basin at a scale of 1:40 or 1:60. To avoid scaling effects, the numerical model is run at the same scale as the hydraulic model.

Results

From the calculated data characteristic ship wave parameters (draw down height, primary wave height, maximum return flow velocity) are derived and compared with their experimental counterparts. The wave heights were predicted with a deviation of less than 20 % and a mean deviation of 10 %; the maximum return flow velocity with less than 30 % and a mean deviation of 20 % (1).

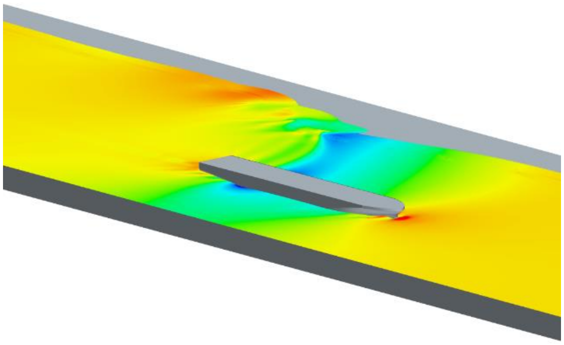

Figure 1 – Free water surface of the model section Bremerhaven

Conclusion

The calculation results of the presented CFD method agree very well with the measurements from the hydraulic model considering that the measurement results are also subject to uncertainties. Therefore, the CFD method can be considered as a valid and reliable method for determining the load from the primary wave system of ships.

Future Work

For the new challenges of the biological and technical bank protection at long harbour approach channels in Germany we will use the CFD tool in the future. The method itself is to be further developed to a full-scale model with real 3D-bathymetries implemented. This allows the observation of the ship's wave field under more realistic conditions.

References

(1) Kochanowski, C.; Kastens, M. (2022): Simulation and validation of ship induced waves in shallow and confined water. In: Candries, M.; Lataire, E.; Yuan, Z.; Eloot, K.; Delafortrie, G.(Hg.): Proceedings of the 6th MASHCON, 22 - 26 May 2022, Glasgow, UK. S. 89-101.

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