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CONTRACT HPRI-CT-1999-00093

"FUNDAMENTAL HYDRAULIC RESEARCH FOR COASTAL AREAS BY USING LARGE-SCALE FACILITIES OF THE HYDRO-LAB-CLUSTER NORTH GERMANY" – FRANZIUS-INSTITUT FOR HYDRAULIC, WATERWAYS AND COASTAL ENGINEERING

- REPORT -

by

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A B S T R A C T

Physical modelling in the area of hydraulic research is an essential condition i.a. to verify theoretical approaches as well as to reference a connection to numerical modelling. As a consequence, within contract HPRI-CT-1999-00093 with EC the Franzius-Institut for Hydraulic, Waterways and Coastal Engineering offered *Fundamental Hydraulic Research for Coastal Areas by Using Large-Scale Facilities of the **HYDRO-LAB-CLUSTER NORTH GERMANY*** under the Enhancing Access to Research Infrastructures Action of the 5th Framework Programme of the European Commission.

With the **HYDRO-LAB-CLUSTER NORTH GERMANY** (cf. http://www.fi.uni-hannover.de) FRANZIUS-INSTITUT provided access to its physical modelling installations *2-D WAVE CHANNEL SCHNEIDERBERG*, *3-D WAVE BASIN MARIENWERDER* and *RESTRICTED-WATER SHIP TOWING TANK MARIENWERDER* as well as to its numerical modelling installation *COMPUTATIONAL FACILITIES* with its state-of-the-art measuring devices, data acquisition and processing systems, hard- and software platforms, network installations and commercial simulation codes. This offers the rather rare opportunity in Europe to combine physical and numerical modelling in the field of hydraulic (e.g. water inlet structures), waterways (e.g. ship operation on rivers and canals) and coastal engineering (e.g. wave loads on offshore structures) at the same time.

Under the contract with EC FRANZIUS-INSTITUT provided 140 weeks of access to the individual installations of the **HYDRO-LAB-CLUSTER NORTH GERMANY**, whereby 39 users in 15 projects gained access.

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1 Introduction

Physical modelling in hydraulic research is still essential to verify theoretical approaches as well as to provide a data base for numerical modelling. As a consequence, with contract HPRI-CT-1999-00093 with EC the Franzius-Institut for Hydraulic, Waterways and Coastal Engineering offered access to three physical modelling installations and a numerical modelling installation named as **HYDRO-LAB-CLUSTER NORTH GERMANY** over a period of 39 months commencing on March, 1st 2000, in detail:

- *2-D WAVE CHANNEL SCHNEIDERBERG*

  A 110.0 m long and 2.2 m wide channel for water depths up to 2.0 m, equipped with a wave-generator for regular and irregular waves. Wave periods are between 1.5 ÷ 10.0 s and wave heights up to 0.5 m (Figure 1-1);

- *3-D WAVE BASIN MARIENWERDER*:

  A 45.0 m long and 24.0 m wide basin for water depths up to 0.7 m, equipped with five wave-generators for regular and irregular waves. Wave periods are between 1.5 ÷ 10 s and wave heights up to 0.4 m (Figure 1-2);

- *RESTRICTED-WATER SHIP TOWING TANK MARIENWERDER*:

  A 52.0 m long and 3.8 m wide channel for water depths up to 0.4 m, equipped with a towing-unit for accelerating ship models up to a speed of 2.5 m/s (Figure 1-3) and

- *COMPUTATIONAL FACILITIES*

  A hard- and software platform with latest developments in hydrodynamic as well as sedimentation and erosion modelling including waves and coastal processes in combination with geographic information systems (Figure 1-4).

The physical modelling installations are equipped with *Acoustic Doppler Velocimeter*, *Laser Doppler Anemometer* and *Particle Image Velocimeter* as well as standard equipment like wave meters, pressure sensors and force gauges, which are connected to computerized positioning and acquisition systems.

Further, the numerical modelling installation is connected to the *Regionales Rechenzentrum Hannover* disposing extensive computational capacities in terms of calculation power, memory resources and disk space.

Figure 1-1: *2-D WAVE CHANNEL SCHNEIDERBERG*

Figure 1-2: *3-D WAVE BASIN MARIENWERDER*

Figure 1-3: *RESTRICTED-WATER SHIP TOWING TANK MARIENWERDER*

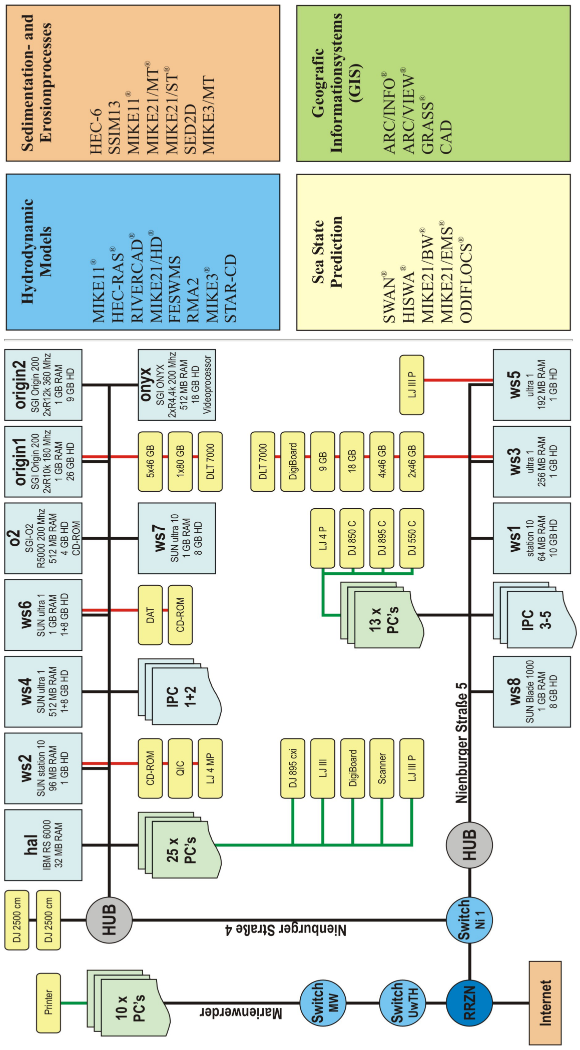

Figure 1-4: *Computational Facilities*

2 Implementation

2.1 Contract Conditions

Contract conditions with EC required regular Calls for Proposals. Therefore, six calls were published during the contract period.

Potential proposals had to indicate the field of interest, give a detailed description of the previous work and the work to be done at Franzius-Institut, required experimental and/or computational equipment and personnel to be delegated. Further, the duration of any proposed project should not exceed 12 weeks.

2.2 User Group Selection Procedure

Following each call proposals received were checked for eligibility according to the contract conditions with EC. Eligible proposals were submitted to an international User Group Selection Panel, which had been approved by EC, in detail:

- Prof. Dr. C. Zimmermann (Chairman)

  Franzius-Institut for Hydraulic, Waterways and Coastal Engineering, University of Hannover, Germany;

- Prof. Dr. V. C. Patel

  Iowa Institute of Hydraulic Research, University of Iowa, United States of America;

- Prof. Dr. H. F. Burcharth

  Department of Civil Engineering, University of Aalborg, Denmark;

- Prof. Dr. J. M. Silva

  Departamento de Engenharia Civil, Instituto Superior Tecnico, Portugal and

- Prof. Dr. H. de Vriend

  Civiele Technologie & Management, University of Twente, the Netherlands.

Following the recommendations of the User Group Selection Panel and the approval of EC successful user groups were informed and letters of intent with all contract conditions were issued (Figure 2-1).

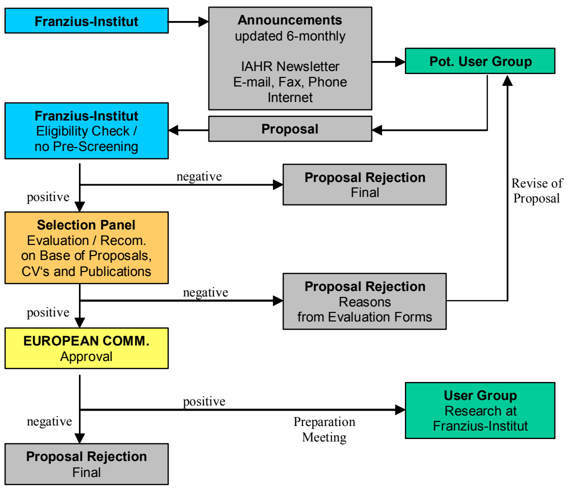

Figure 2-1: User Group Selection Procedure

Expenses and costs for accepted proposals were born from EC, e.g. travel, accommodation or daily allowances depending on the professional status of the user groups.

3 Accomplished Projects

3.1 General

Under the contract with EC 22 proposals from all over Europe were received, whereas 15 projects were selected for access to Franzius-Institut (Figure 3-1).

From the 15 projects only a reduced number will be described in more detail.

Figure 3-1: Countries of User Groups Selected for Access to FRANZIUS-INSTITUT

3.2 Physical Modelling

3.2.1 Mixing Processes and Short Period Waves

User Group

Prof. Dr. R. A. Falconer, Dr. B. Lin, Mr. D. Sandford (Technician) & Mr. J.-M. Studer (Student) - Cardiff University

Intention

The possibility of a contaminant being accidentally or intentionally spilled into coastal waters is increasingly becoming a concern to environmental managers as well as to the public. In order to be able to estimate the extent of the contamination and then take appropriate measures to minimize the environmental impact, an enhanced understanding of the mixing processes is required. Although mixing processes have attracted the interest of many scientists and engineers over the past 30 years, our understudying of and ability to model these processes is still very limited. Dispersion has been used to represent the capability of turbulent fluids to mix and it has been successfully used in many practical problems in the past, but the value of the dispersion coefficient used in coastal water quality models can vary significantly. In this context, the scope for gross errors is significant, e.g. the reported dispersion rate may as big as 35.0 m^2/s or as small as 0.1 m^2/s for the same estuary (Smith & Scott, 1997).

In the past research has been focused on studying the dispersion of contaminants in rivers and estuaries where steady currents, long period tidal waves and bed-generated turbulence are regarded as the governing factors. The effect of wind has generally been taken into account only in terms of its effect through a free surface stress. Research on the effects of short period wind waves on the dispersion processes has been very limited. From an experimental study of a jet injecting into a wave field it has been found that some volume of the jet fluid may be separated from the main plume and this phenomenon can still not be explained using turbulent mixing theory (Swan & Kwan, 1999). Waves may have the same impact on solute mixing and transport. Wind waves have periods of typically between 6.0 ÷ 10.0 s in near-shore coastal waters, and the currents generated by these waves can change direction every 3.0 ÷ 5.0 s. This constant change in the flow direction enhances the mixing processes and must be included in water quality models.

Thus, the main objective of this project was to investigate the effects of short period waves on the mixing processes in coastal waters.

Realization

A series of experiments were performed in the *2-D WAVE CHANNEL SCHNEIDERBERG* to study the solute transport processes under short period waves including both regular and irregular waves using tracer *Rhodamine*. For regular waves, experiments have been undertaken for two wave heights and three wave periods, for irregular waves for two wave heights. The area of interest was focused on coasts with a relatively smooth bed and for wide estuaries, where tidal related bathymetric effects are small. Tracer release was from point sources and line sources (Figure 3-2).

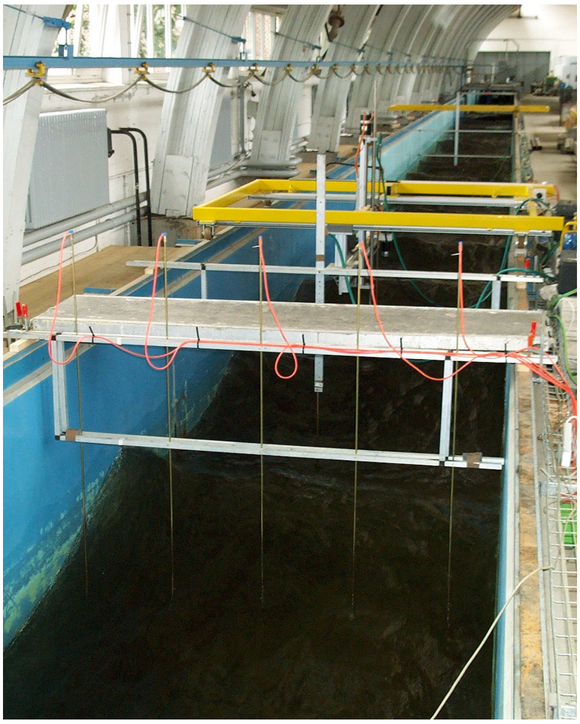

Figure 3-2: Tracer Release from Five Point Sources

Large amounts of data have been collected, including wave heights and periods, velocity distributions using an *Acoustic Doppler Velocimeter* and tracer concentrations.

Results

Initial analysis showed that the distribution of tracer concentration varies significantly for different wave parameters. In particular, the movement of tracers is much faster under irregular waves than under regular waves. More detailed analysis on relationships between wave parameters and mixing characteristics is currently being undertaken at Cardiff University.

The results should give a correlation between wave characteristics and dispersion coefficient including the effect of wind on the dispersion coefficients to be introduced in a coastal zone water quality model.

References

Smith, R. & Scott, C. F.: “Mixing in Tidal Environment." Journal of Hydraulic Engineering, ASCE, Vol. 123, pp 332-340, 1997

Swan, C. & Kwan, S. H.: “Laboratory Measurements of a Jet Discharged into Waves.” Published in Environmental Hydraulics, Eds: Lee, J. H. W., Jayawardena, A. W. & Wang, Z. Y., pp 155-160, 1999

Contact

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3.2.2 Scaling Effects of Modelling Beach Processes

User Group

Dr. K. She, Mr. D. Pope (Engineer), Mr. B. Gaylor (Technician), Mr. P. Edwards (Technician) & Mr. R. Djebli (Student) - University of Brighton

Intention

The depth of our understanding of the dynamic processes of the sediment movements under waves determines the accuracy of predicting the effectiveness of coastal defense works and their effects on the surrounding environment. It affects our ability to develop accurate numerical models for the prediction of coastal sediment movements.

To achieve a good understanding of the beach processes, both field and laboratory studies are necessary. A primary purpose of field studies is to establish a first hand data base for the ultimate calibration of both numerical and physical models. The use of laboratory models serves two important purposes. The first being to provide a prediction of the effectiveness of a coastal defense work and/or effects of such works on the environment, and the second being to provide details of the sediment processes which cannot be obtained under harsh field conditions. Ideally, laboratory models should be as near the prototype scale as possible, but this is not always possible, especially when 3-D models are involved. In the UK, 2-D coastal facilities allow models of 1:50 up to 1:20 scale.

Current UK practice employs three scaling criteria for the selection of model beach material (Coates, 1994). These criteria are related to the percolation slope, the threshold of motion and the onshore/offshore transport, respectively. The effectiveness of these scaling criteria has been a subject of discussion in recent years (e.g. Loveless et al., 1996).

It is necessary to settle these uncertainties before laboratory model results can be confidently interpreted in terms of prototype conditions. This has led to a two year collaborative project between the Universities of Brighton, Bristol and Southampton. Improved scaling equations have been derived as a result of this joint project and the scaling effects of beach models have been partially addressed (She et al., 2000). The scaling effects were investigated by modelling a prototype beach of known material and wave conditions and comparing the profile changes between the field measurements and the model prediction. The investigation showed that the improved scaling equations were a large step forward towards better scaling of beach models. The project could, however draw no firm conclusion in relation to the scaling effects. This is because the model beach was 2-D with a constant water depth while the prototype beach was 3-D and subject to 3-D wave condition with tidal effects.

Thus, the main objective of this project was to provide a solution to this problem by carrying out experiments at near prototype conditions, providing a benchmark data base for comparison with parallel experiments in a small wave flume in Brighton.

Realization

A series of experiments have been undertaken in the *2-D Wave Channel Schneiderberg*. Both a mixed sand/shingle beach and a mixed sand/shingle beach terminated with a seawall were tested under a range of monochromatic and random wave conditions (Figure 3-3). Both types are commonly found along the UK coastline. As sediment beach material typical for the South of UK was used.

Profile changes were taken by means of a *Disto Laser Meter*. An array of pressure sensors was installed in the beach, providing a complete record of pore pressure during each experiment so that a relation between sediment movement and hydrodynamic forces might be formed.

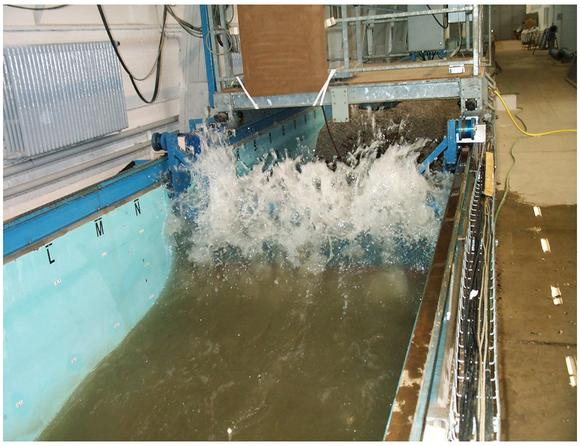

Figure 3-3: Mixed Sand/Shingle Beach in Front of Seawall under Random Waves

Results

A detailed analysis of the experiments is part of a more extensive research work at the University of Brighton. Initial analysis showed that due to the seawall, the profile changes take a different form, while the overall direction of sediment motion remains the same as without the seawall.

References

Coates, T. T.: "Effectiveness of Control Structures on Shingle Beaches: Physical Model Studies." Report SR387, HR Wallingford, 1994

Loveless, J. H.: "The Effects of Groundwater Flows on Scour at Coastal Structures." 25th International Coastal Engineering Conference, Orlando, 1996

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3.2.3 Cross-Shore Distribution of Long-Shore Currents in Irregularly Shaped Beaches

User Group

Prof. Dr. R. A. Falconer, Dr. B. Lin, Mr. A. Davis (Technician), Mr. A. Sweeny (Technician) & Mr. C. Antoniadis (Student) - Cardiff University

Intention

Mathematical models are playing an ever-increasing role in societal decisions involving coastal management. More accurate prediction of waves, currents and their interaction has become more and more important due to the requirements of design and construction of coastal structures and beach nourishment schemes.

During the past 30 years rapid progress has been made in understanding the mechanics of coastal waves and sediment transport. Different levels of numerical models have been developed to simulate wave transformation and predict wave driven currents and sediment fluxes. Many numerical models have been developed based on the mild slope equation to compute the transformation of surface gravity waves in coastal regions (e.g. Dalrymple et al., 1984). For a more detailed understanding of the unsteady and non-linear wave transformation, direct solutions of the Boussinesq equations have been developed. Integrated numerical models that link wave, long-shore current and sediment transport can be found in e.g. Neilson (1992).

In order to follow the natural coastlines more accurately numerical models based on curvilinear grid methods have also been used in the study of waves and wave driven currents. Several numerical models were developed based on the parabolic approximation of the mild slope equation for linear wave propagation (Kirby et al., 1994).

A recent review of the use of engineering models in simulating coastal processes found that many existing models are inadequate for the tasks for which they are used (Thieler & Pilkey, 2000). That is, why many existing models were oversimplifications of complex systems that were poorly understood and as a result of this these models could not accurately reproduce the physical processes. One of the main reasons for this problem was contributed to that some important assumptions were made without being rigorously tested against reliable experimental and field data.

Compared with the numerical model development there are relatively less laboratory and field investigations of wave-current interaction during the recent years. Field observation is very difficult due to the enormous investment and practical problems to obtain synchronous data for a large area, especially in hazardous weather conditions. Most of the limited existing field measurements were collected in beaches with simple shapes (Bayram et al., 2001).

Although some laboratory experimental studies are available in the literature, most of them involve standard bathymetries such as straight line beaches with a constant slope or submerged circular shoals. In general, there is a lack of adequate laboratory investigation that can provide detailed measurements of wave, currents and sediment parameters on realistic bathymetric conditions. These measurements are particularly important to improve our understanding of the complex mechanism of wave-current interaction and to validate more advanced numerical models.

It is known that the distribution of wave driven long-shore currents is affected by the cross-shore exchange of long-shore momentum. This process is caused by the vertical non-uniformity of the horizontal wave driven currents and is referred to as dispersion. Although considerable effort has been made to improve the understanding of this process, so far none of the proposed solutions has been entirely satisfactory. Most of the existing wave-current numerical models neglect this dispersion effect entirely. Kobayashi et al. (1997) developed a method to solve this problem by introducing a momentum flux correction term, in which a cubic vertical distribution of long-shore currents is assumed. When compared with the experimental data measured at a straight line beach, the refined model showed an improved prediction in both wave heights and long-shore currents than that without the momentum correction term. However, it is still not clear what is the real vertical distribution of the long-shore current in more complex shaped beaches, and what the effect of this distribution will have on the exchange of long-shore momentum.

Thus, the main objective of this project was to carry out a laboratory experiment to study the wave transformation and wave driven currents in more realistic beach shapes, whereby emphasis was given to investigate the mechanism of long-shore momentum exchange and its effect on the cross-shore distribution of long-shore currents.

Realization

A series of experiments have been undertaken in the *3-D Wave Basin Marienwerder* with a sand beach. The bed level of the structure included a section of straight line beach and a section of curved beach. A series of regular waves and irregular waves were performed with a fixed incoming wave angle (Figure 3-4).

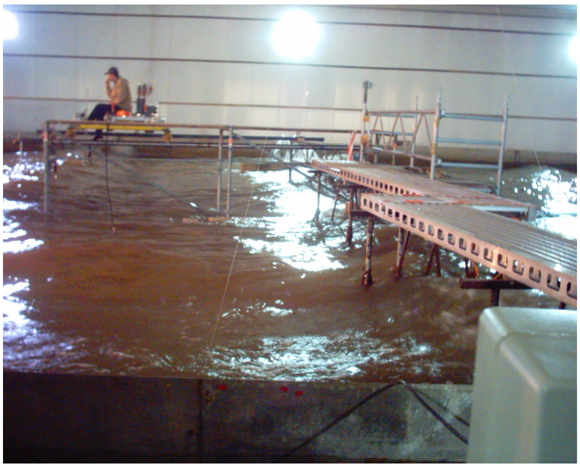
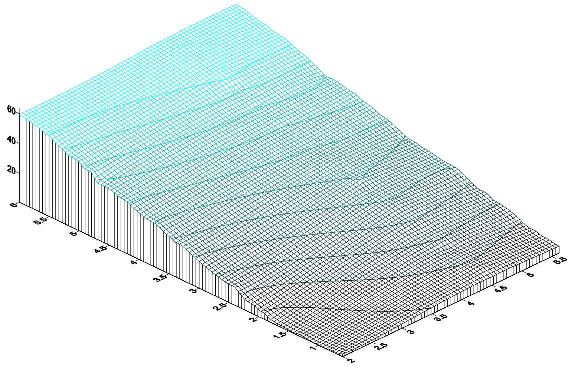


Figure 3-4: Sand Beach Deformation under Oblique Irregular Waves

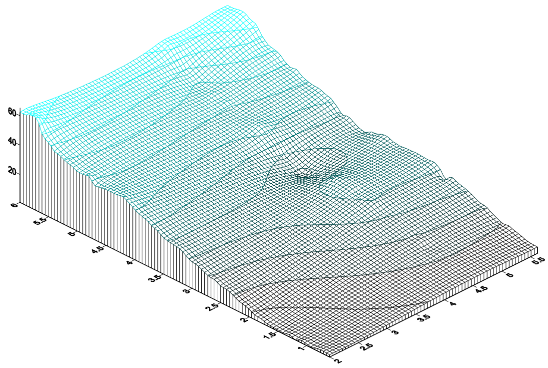
Collected data included wave heights and periods at selected locations, wave driven long-shore currents and flow velocities at various cross-shore sections using *Acoustic Doppler Velocimeter*. Bed level changes due to long-shore currents were also taken.

Results

Currently research continues at Cardiff University to modify an existing 2-D wave-current interaction numerical model to improve on the accuracy of long-shore current predictions. The data collected from this project will be used to test and verify this model (Figure 3-5).



(a)



(b)

Figure 3-5: Bed Level Changes due to Long-Shore Currents ((a) – Start of Experiment, (b) – End of Experiment)

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3.2.4 Innovative Type of Concrete Caisson Floating Breakwater

User Group

Prof. Dr. K. Daskalov & Mr. B. Savov (Technician) - Sofia University of Civil Engineering and Architecture

Intention

Floating breakwaters are applicable in areas where the wave environment consists of short-period waves of moderate height and where water depths are deep relative to wave lengths. In some cases, floating breakwaters could be applied in areas where the foundation is not suitable for conventional type breakwaters of vertical and rubble-mound type. Floating breakwaters offer a number of advantages over conventional type breakwaters as harbour protection structures (e.g. Broderick & Nelson, 1986). The most important being are cost effectiveness, reduced environmental impact and flexibility.

Improving the performance of floating breakwaters such that they can withstand more severe loading conditions while further providing adequate protection to vessels could open up multiple of possible uses, such as coastal protection, aquaculture developments, temporary berthing and so on.

The problem of wave/structure interaction related to floating breakwaters has been studied by many authors. Studies have been carried out to determine wave reflection/transmission, out-of-phase damping, destruction of orbital motion and viscous damping (e.g. Carver, 1979). A new concept in designing floating breakwaters is to combine the floating breakwater with wave damping chamber and air-bubble barrier, a concept known since 1968 (Bulson, 1968). But up to now, a lack of knowledge exists concerning these unconventional floating breakwaters in view of the combined interaction of waves with a floating solid body and with a current generated by a front air-bubble screen.

Thus, the main objective of this project was to carry out a detailed experimental study at large-scale of an unconventional floating breakwater to determine mooring-line forces and wave transmission and therefore to provide basic hydraulic design data for such a structure.

Realization

A series of experiments were done in the *3-D Wave Basin Marienwerder* with a floating concrete caisson breakwater consisting of five floating caissons with attached wave damping chamber and an air-bubble barrier (Figure 3-6).

Figure 3-6: Floating Breakwater Model in *3-D Wave Basin Marienwerder* under Non-Periodic Wave Attack

Wave measurements and mooring line force measurements for periodic and non-periodic waves were analyzed. In addition, the effect of an air-bubble screen was compared with the results for a classical type of a vertical wall floating structure and the structure of an unconventional floating breakwater.

Results

The analysis indicated that the investigated structure, consisting of floating caissons with a wave damping chamber and an air-bubble barrier showed significant wave damping and had positive effects on the mooring forces. It could serve as protection of small harbours and coastal protection concept for moderately exposed locations.

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3.3 Numerical Modelling

3.3.1 Modelling of Pump-Sump Water Intakes

User Group

Prof. Dr. J. M. Silva, Mr. A. P. Duarte (Student) & Mr. H. A. Theias (Student) - Instituto Superior Tecnico

Intention

Problems associated with vortices in water-pump intakes are common and often influence operation and increase maintenance costs. They are described in several papers and reports (e.g. Melville et al., 1994). These problems are associated with air-entraining free-surface vortices, subsurface vortices attached to the walls of the intake bay, strong swirl in the flow entering the pump, uneven velocity distribution at entry to the pump, flow unsteadiness in the intake pipe and flow separation in the suction bell. One or more of the flow characteristics listed above are often responsible for problems such as unbalanced impeller loading and cavitation, preventing pumps to deliver their design discharges.

Study of vortices and suppression of the same have generated much interest in the hydraulic research community for the past several decades. Until recently, the only comprehensive way to identify these flow features and study possible means to eliminate them, was the use of laboratory experiments (e.g. Nakato et al., 1999). Lately, the rapid progress in computational power has allowed the numerical simulation of complex 3-D flows, such as these, through solution of the Reynolds-Averaged Navier-Stokes equations applying Computational Fluid Dynamics models with no simplifying approximations other than those inherent in the turbulence closure that is adopted. These CFD models will soon supplement laboratory model studies, which often are site-specific, expensive, and time consuming. In case of pump intakes Li (2001) made the first successful attempt to advance a CFD model to a real-world water-pump intake with any practical geometry by applying a non-commercial CFD model.

Thus, the main objective of this project was to use an efficient and reliable commercial CFD model to simulate the 3-D flow field in a pump intake and to study the possible formation of free-surface and wall-attached vortices, in order to ensure trouble-free pump-approach flows.

Realization

A series of simulations on the *COMPUTATIONAL FACILITIES* were done for a pump intake under construction in Portugal (Figure 3-7). The simulations applying CFD solver *StarCD* considered most of the geometric features of the real intake, including the divider walls, corner fillets, floor and backwall splitters.

Different cases with the designed intake-geometry layout consisting of about 200.000 cells were selected for the simulations chosen to their potential risk to produce vortices. In this connection as a first approximation the free surface was neglected during the simulations.

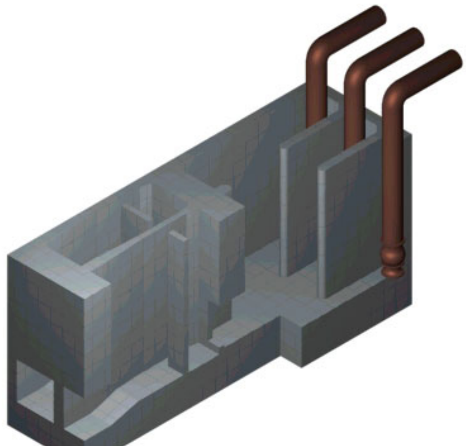

Figure 3-7: Sketch of Pump Intake Geometry

Results

The analysis of simulations demonstrated the ability of CFD solver *StarCD* to predict pump-intake flows while revealing the relevant flow features, such as the non-uniform flow distribution at each pump-sump, the upward approach flow to the suction bell, and the free surface and subsurface vortices in principle (Figure 3-8). Nevertheless, further simulations are currently being undertaken at Instituto Superior Tecnico to validate the results.

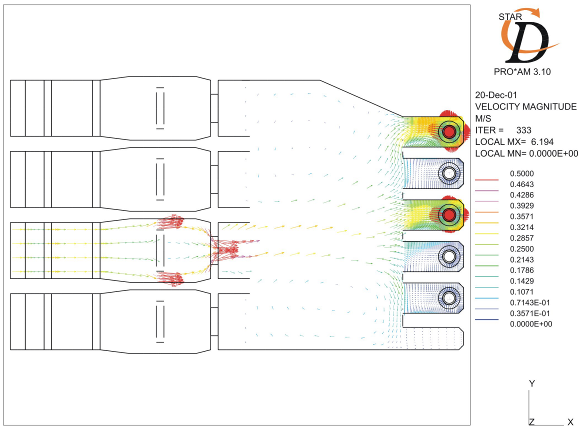

Figure 3-8: Flow Distribution in Pump Intake while Operating Two Out of Five Pumps

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3.3.2 Flow around Ship Propellers - Flows with Partial Cavitation and Blade Tip Flows

User Group

Mr. Z. Z. Zlatev (Engineer), Mr. V. D. Dimitrov (Engineer), Ms. S. D. Kirilova (Engineer) & Mr. P. Markov (Engineer) - Bulgarian Ship Hydrodynamics Centre

Intention

The flow around a ship propeller under operational conditions is very complex, especially when cavitation occurs. Cavitation on ship propeller blades and hydrofoils is known as one of the major sources of vibration, noise and pulsating non-stationary loading on the propeller shaft and ship stern construction. It may be characterized by any combination of the three basic forms sheet cavitation, traveling bubble cavitation and cloud cavitation (Tulin, 1980). Considering only the case of partial sheet cavities, it is usually assumed that the pressure inside and on the sheet cavity is constant and equal to the saturated vapor pressure for water. In reality, the cavity is not a smooth, constant pressure surface. Even in a uniform flow field, the cavity is inherently unsteady due to the occasional break-off of the cavity trailing edge and the entrainment of traveling bubbles in the cavity wake.

Associated with the propeller action are hub and tip vortices which may have vapor-filled cores. The cavitating tip vortex often exceeds in volume the sheet cavity and has a marked effect on the local flow at the tip. Tip vortex cavitation is typically the earliest form of cavitation to appear on ship propellers, sometimes at embarrassingly low speed of rotation.

It is important to point out that these problems and especially the tip vortex formation problem are one of the most difficult in the hydrodynamics of propellers and wings. They are far from being solved at a satisfactory stage, to say nothing about any design procedures useful for the engineering practice. Moreover, experimental investigations of practical propeller or hydrofoil cases are scarce (e.g. Chesnakas & Jessup, 2000) and often confined to idealized geometries.

The present state-of-the-art shows that the methods for numerical analysis of such complex flows can be divided roughly into two general groups. On the one hand, there are the ideal-flow methods, based on the assumption of ideal flow around the relevant objects, whose main goal is to provide insight to the overall cinematic and some averaged or time-varying values like forces and moments. These numerical models are unable to predict reliably such phenomena as the cavitation inception, start of the cavity regions, and the internal structure of the real flow. Nevertheless, such methods were and still are used successfully by number of researchers (e.g. Kinnas et al., 2000).

On the other hand, viscous-flow methods exist, based mainly on the Navier-Stokes equations and numerical analysis/simulation at different levels of complexity, ranging from direct numerical simulation, through large eddy simulation, to the classical flow concept of boundary layer (e.g. Yao et al., 2001). The aim and scope of these numerical models is prediction of cavitation inception, detailed analysis of the flow characteristics, including turbulence modelling and the non-stationary behaviour of the flow. They are much more promising in revealing the fundamental characteristics of the phenomena, but they require serious scientific efforts and huge computer resources.

Thus, the main objective of this project was the simulation of flow around ship propellers with special emphasis on partial cavitation on the blades, the tip vortex formation and its relation to cavitation based on a viscous-flow method.

Realization

A series of simulations were done on the COMPUTATIONAL FACILITIES applying viscous-flow solver *StarCD*. 2-D time-domain viscous flow of partially cavitating hydrofoils of the types commonly used in ship-propeller design was simulated on a hybrid mesh consisting of 28.000 cells (Figure 3-9).

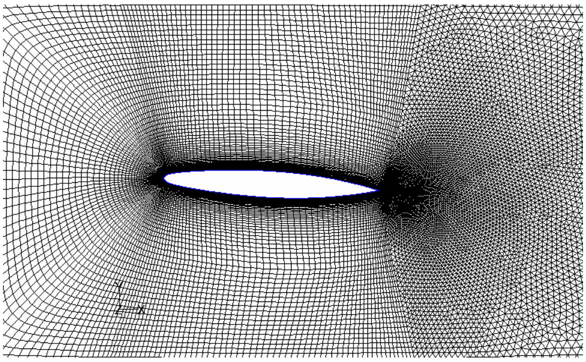

Figure 3-9: Hybrid Mesh around Hydrofoil with 28.000 Cells

Comparisons were made with an experimental test case, which is described by Brewer & Kinnas (1995), where a partially cavitating hydrofoil experiment was conducted at a *Variable Pressure Water Tunnel*, whereby measurements were conducted for fully-wetted flow conditions and for cavitating conditions.

During the simulations the ability of the *Bubble-Two-Phase* (BTF) cavitation model implemented in the numerical model for sheet/bubble cavitation inception prediction has been studied as well as the applicability of the various turbulence models to the cavitational problem.

Results

The BTF cavitation model showed good results in predicting the generation and growth of short-length stable or quasi-periodic sheet and bubble cavitation, even for the difficult case of attached cavities on hydrofoils (Figure 3-10).

The agreement with experimental data was good, in particular for some integral parameters, such as the cavity length, lift and drag coefficients and so on, for which the results were very close to the experimental values. Nevertheless, the extremely complex nature of cavitation requires improved methods, both in physical and mathematical modelling, especially when it comes to phase conversion and hydrodynamic instability.

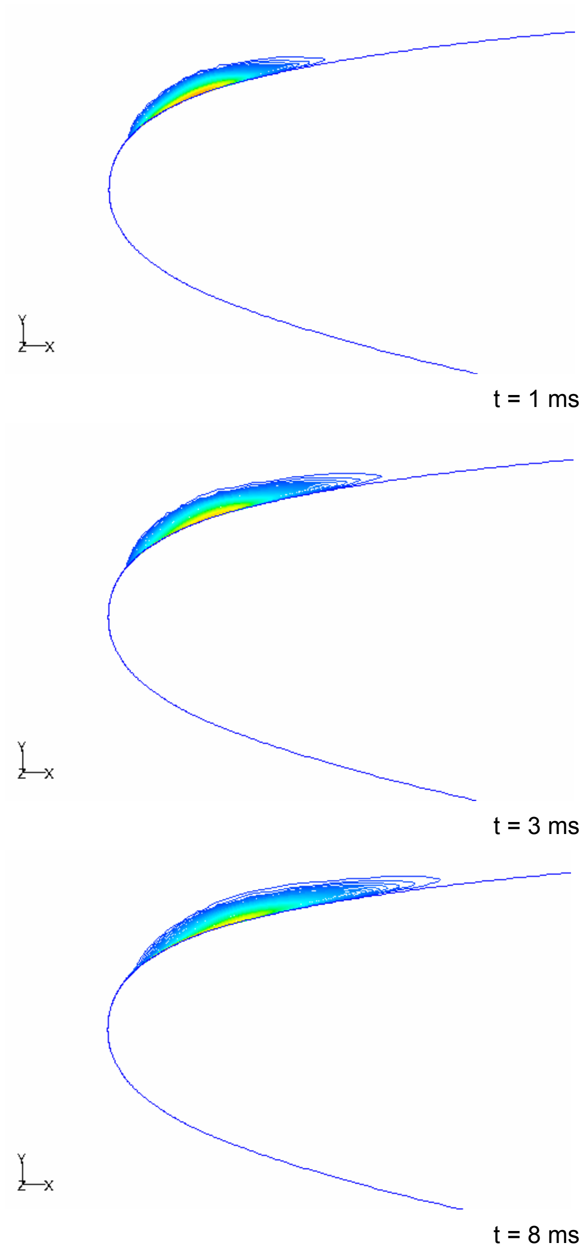

Figure 3-10: Cavitation at Hydrofoil for Reynolds-Number of 2.6×10^6

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3.4 Composite Modelling

3.4.1 Coastal Erosion of Sand Beach Area Protected by Artificial Reef

User Group

Dr. V. S. Pentchev, Dr. D. C. Dragantcheva & Mr. Z. B. Botev (Technician) - Bulgarian Ship Hydrodynamics Centre

Intention

The application of beach nourishment is widely used for the protection of coastal areas against wave- and current induced erosion (e.g. Verhagen, 1998). Cross-shore protection facilities like groins or jetties are usually used to protect the created beaches. Periodical beach nourishment is also applied in order to compensate the escaped volumes. However, the cross-shore facilities break the natural long-shore sediment transport and often cause serious implications to the neighbouring areas. Finally, the hot-spot erosion zone is not efficiently protected, but only shifted in a new place.

The application of submerged breakwaters like sills and reefs is also known as a method to protect coastal beaches (e.g. Amanti et al., 1983). Balance of sediment transport and reducing of nourishment amounts could be reached by this method.

The problem has been studied at the Bulgarian Ship Hydrodynamics Centre for several years in relation with the growth of the number of active landslide areas along the Bulgarian Black Sea Coast. One possibility would be that artificial reefs could be applied to protect the created beaches. Studies on various types of innovative concrete blocks forming an artificial reef have been performed, which could be designed in such a way as to provide natural shell nourishment of the beach but also to provide efficient dissipation of wave energy, this way to prevent erosion. Nevertheless, further investigations are needed in order to optimize the construction of artificial reefs, as well as to study the relationships between wave/current parameters, reef properties, mean sand grain size and beach profile.

Thus, the main objective of this project was to define the effect of depth of submergence, crest width and initial wave conditions on the wave transmission characteristics and on the sediment transport in the neighbouring areas in case of an artificial reef.

Realization

A series of experiments in the *2-D Wave Channel Schneiderberg* followed by a series of simulations on the *Comutational Facilities* have been undertaken.

In the experiments a submerged wide-crest rubble-mound type of artificial reef has been tested for a wide range of periodic and spectral wave conditions corresponding to available field data for the Bulgarian Black Sea Coast. The experiments comprised different wave spectra as well as different wave periods and wave heights for three different heights of the reef (Figure 3-11).

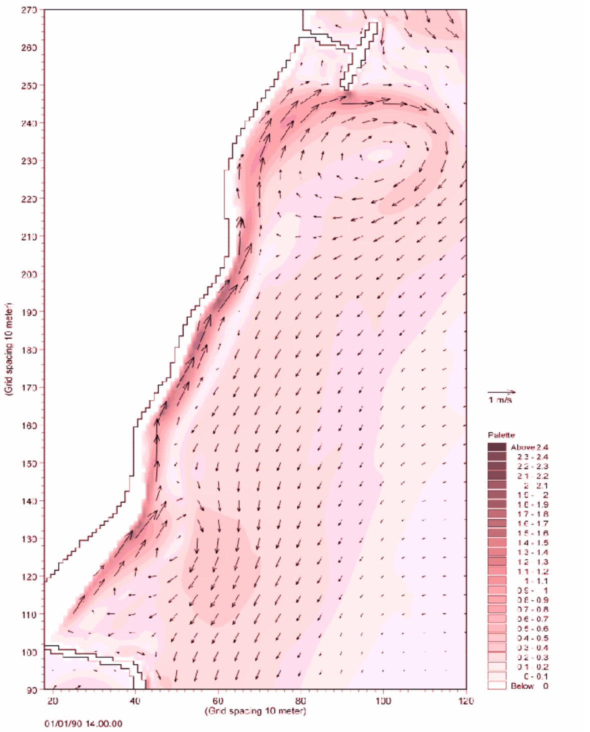
Figure 3-11: Artificial Reef under Spectral Waves

Experimental emphasis was on the measurement of the transmitted wave height and respectively the wave energy dissipation factor. Further, wave induced bottom velocities have been measured using *Acoustic Doppler Velocimeter* behind and in front of the reef, especially near-bottom orbital velocity and its relation to maximum shear velocity for transmitted waves.

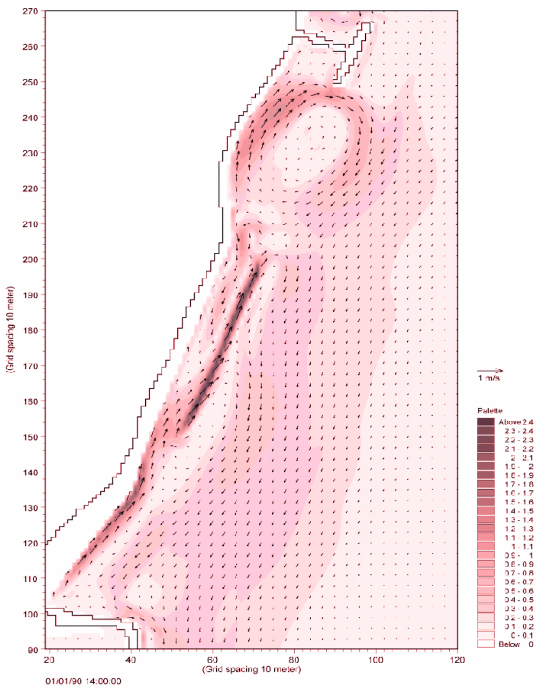
The obtained data were used for 2-D and 3-D simulations of the sediment transport using input data for bathymetry and hydrology/climate from the Bulgarian Black Sea Coast. A numerical model on wind wave propagation based on the Shallow Waves Nearshore model *SWAN* (Ris, 1997) has been established to determine wave transformation parameters and radiation stresses for varying wind speed/directions and water levels. Waves and radiation stress data have been used for further simulations of the coastal hydrodynamics and sedimentation processes using the *MIKE21* numerical modelling system.

Results

Simulations demonstrated a successful application of various numerical models, such as *SWAN* and *MIKE21* numerical models, for simulation on wind waves, currents, and sediment transport in coastal areas protected by artificial reefs under the specific Bulgarian Black Sea Coast conditions (Figure 3-12).



(a)



(b)

Figure 3-12: Off-shore Currents in Black Sea Coast Study Area for Scenario without Artificial Reef (a) / with Artificial Reef (b)

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3.4.2 Flow around Ships in Shallow Waters at Trans- and Supercritical Speeds

User Group

Dr. S. N. Kyulevcheliev, Mr. S. F. Georgiev (Engineer) & Mr. Z. Z. Zlatev (Engineer) - Bulgarian Ship Hydrodynamics Centre

Intention

The flow around a ship hull when moving in shallow water differs much from that in deep water due to the effect of the channel bottom. In this case, the so-called critical speed is a characteristic threshold in the development of the hydrodynamic phenomena accompanying the ship motion in shallow waters. This speed is characterized with an abrupt change of wave-pattern generated by the moving hull, a maximum of wave resistance to the ship and a maximum squat.

In current ship design practice the critical speed is normally considered as a barrier to further increase of the operational speed of a ship. However, there is a stable trend of increasing the speed of inland navigation, which demands designing ships near or with supercritical speeds. This motion regime is connected with a number of side effects, such as an impact of ship-generated waves on river banks and structures as well as other ships and bottom wash and risk of ship grounding. Being very complicated, unsteady and non-linear in their essence, these phenomena are not yet satisfactorily solved by theoretical and numerical methods. Also no satisfying experimental data on the subject exist.

As for the theoretical and numerical modelling of the flow around hulls in confined waters, mainly the wave producing problem has been of primary interest, solved by either boundary element methods (Bertram & Jensen, 1994) or by numerical solution of the Boussinesq equations (e.g. Jiang, 1998).

Thus, the main objective of this project was to carry out a set of benchmark experiments providing a description of the flow around a ship moving in shallow waters at transcritical and supercritical speeds and to test the capability of state-of-the-art numerical models to simulate this subject.

Realization

A series of experiments in the RESTRICTED-WATER SHIP TOWING TANK MARIENWERDER supplemented with a series of simulations on the COMPUTATIONAL FACILITIES have been performed.

In the experiments a model barge was tested in a vertical-walled channel towed along the channel fixed allowing sinkage and trim. Two water depths were investigated resulting in different depth/draft ratios. Wave heights between ship hull and channel walls, bottom pressure and velocities by means of an *Acoustic Doppler Velocimeter* along the ship and under the hull were measured (Figure 3-13).

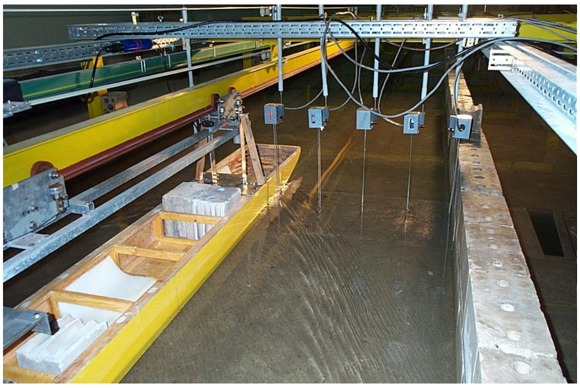

Figure 3-13: Ship Model at Supercritical Speed in RESTRICTED-WATER SHIP TOWING TANK MARIENWERDER

Parallel to the experiments simulations have been undertaken applying viscous-flow CFD solver *StarCD* for modelling the complicated viscous flow and wave-making phenomena accompanying the motion of ships in confined waters. The experimental data obtained were used for validation. Efforts were focused on the numerical modelling of free surface flows, because this is the most typical feature of the hydrodynamics of a moving ship. The classical approach of reversing the flow was applied with a coordinate system fixed to the body and simulating a sudden start of the body.

Results

The results obtained in the experiments provided valuable data for practical design purposes, improving also scaling procedures, i.e. the extrapolation of model results to full scale, evaluation of the impact on bank structures and channel bottom and the validation of theoretical models and CFD models.

Results of the numerical simulations showed that it was impossible to enforce the so-called radiation boundary condition, i.e. the generated waves were progressing upstream and were reflected from the downstream boundary of the computational domain. Systematic variations of grid spacing and length of the computational domain were not successful. However, the partial problem of 3D free surface viscous-flow behind a transom ship stern in shallow waters has been successfully solved (Figure 3-14).

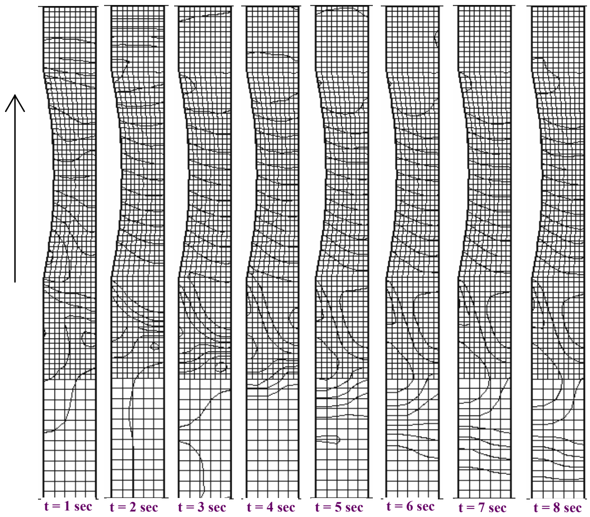

Figure 3-14: Wave Pattern Evolution of Parabolic Wall-Sided Ship at Transcritical Speed in Shallow Water

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3.5 Additional Projects

- **Farfield Effects Study for River Ship Propellers Operating in Restricted Waters** (S. C. ICEPRONAV S. A., Galati, Romania; Numerical Modelling on the COMPUTATIONAL FACILITIES)

  by Onofrei, G.

- **Numerical Modelling of 3D-Incompressible Flows with Complex Free Surfaces** (S. C. ICEPRONAV S. A., Galati, Romania; Numerical Modelling on the *COMPUTATIONAL FACILITIES*)

  by Cobzaru, A.

- **Dynamic Squat over Undulating Bottoms in Shallow Waters** (Polytechnical University of Madrid, Madrid, Spain; Physical Modelling in the *RESTRICTED-WATER SHIP TOWING TANK MARIENWERDER*)

  by Zamora, R., Rojas, L. P., Herreros, M.-A., Santi, G. G., Crespo, C. A., Vargas, I. T., de Juana Gamo, J., Lopez Tagle, A., Oms, E. O., Pinto-Heredero, A., Puyol, C., Salas, F. H. & Valle, J.

- **Hydrodynamic Ship-to-Ship Interaction in Confined Waters** (Varna Technical University, Varna, Bulgaria; Composite Modelling in the *RESTRICTED-WATER SHIP TOWING TANK MARIENWERDER* and on the *COMPUTATIONAL FACILITIES*)

  by Ivanov, I. V.

4 Acknowledgements

Grants for access of 39 users in 15 projects with 140 weeks of access to the **HYDRO-LAB-CLUSTER NORTH GERMANY** of the Franzius-Institut for Hydraulic, Waterways and Coastal Engineering under contract HPRI-CT-1999-00093 with EC are gratefully acknowledged (Table 4-1).

	HYDRO-LAB-CLUSTER NORTH GERMANY			
	2-D WAVE CHANNEL SCHNEIDERBERG	*3-D WAVE BASIN MARIENWERDER*	*RESTRICTED-WATER SHIP TOWING TANK MARIENWERDER*	*COMPUTATIONAL FACILITIES*
Total Quantity of Access Provided [weeks]	21	20	30	69
Total Number of Projects Supported	3	2	3	7

Table 4-1: Access Gained to the **HYDRO-LAB-CLUSTER NORTH GERMANY** of FRANZIUS-INSTITUT under Contract HPRI-CT-1999-00093 with EC

Gratitude is also expressed to all users showing their full cooperation and to the members of the User Group Selection Panel.

5 List of Publications

Cobzaru, A.: “3-D Incompressible Flows with Complex Free Surface.” Proceedings of the 2^{nd} User Group Meeting on Fundamental Hydraulic Research for Coastal Areas by Using Large-Scale Facilities of the Hydro-Lab-Cluster North Germany, 26. – 28. November 2002, Hannover, Germany, 2002

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Dragantcheva, D. C.: “Incipient Sediment Motion behind an Artificial Coastal Reef.“ Proceedings of the 3^{rd} International Conference on Port Development and Coastal Environment, 03. – 06. June 2003, Varna, Bulgaria, 2003

Dragantcheva, D. C. & Pentchev, V. S.: “Study on Wave Velocities behind a Coastal Protection Reef.“ Proceedings of the International Jubilee UACEG Scientific Conference, Sofia, Bulgaria, 2002

Duarte, A. C.: “Modelling of Pump-Sump Water Intakes.” Proceedings of the 2^{nd} User Group Meeting on Fundamental Hydraulic Research for Coastal Areas by Using Large-Scale Facilities of the Hydro-Lab-Cluster North Germany, 26. – 28. November 2002, Hannover, Germany, 2002

Georgiev, S. F. & Kyulevcheliev, S. N.: “Flow Field Around Fast Moving Ships in a Canal.“ Proceedings of the 3^{rd} International Conference on Port Development and Coastal Environment, 03. – 06. June 2003, Varna, Bulgaria, 2003

Kyulevcheliev, S. N. & Georgiev, S. F.: “Experimental Observations of Ship Wave Making at Trans- and Supercritical Speeds.“ Proceedings of the 22^{nd} International Conference on Hydrodynamics and Aerodynamics in Marine Engineering (HADMAR‘ 2001), 01. – 04. October 2001, Varna, Bulgaria, 2001

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Silva, J. M., Theias, H. & Duarte, A. C.: „Modelação Numérica da Tomada de Água para o Terminal de GNL, em Sines." VII Congresso de Mecânica Aplicada e Computacional, Évora, Portugal, 2003

Zlatev, Z. Z.: "Efficient Coupling of Viscous-Inviscid Programming Codes in CFD." Proceedings of the 2nd User Group Meeting on Fundamental Hydraulic Research for Coastal Areas by Using Large-Scale Facilities of the Hydro-Lab-Cluster North Germany, 26. – 28. November 2002, Hannover, Germany, 2002