INTEGRATION OF MARINE SIMULATION IN HARBOUR DESIGN

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Abstract

The strong increase in the capabilities and efficiency of modern marine simulators are briefly outlined as the background for demonstrating the advantages of a much closer coordination of hydraulic and maritime oriented design work in relation to harbour planning and alteration. The interaction of the two disciplines and the implications on the final configuration of two different harbours are described.

Introduction

In the design of a harbour the two dominating engineering disciplines are hydraulic engineering and naval architecture. Just the fact that two different disciplines are involved brings about the inevitable risk of lack of coordination, which in turn may be the explanation for several far from well functioning harbours in the past.

Traditionally, the hydraulic engineer conducts environmental investigations, basic lay-out studies, sediment transport assessments, down time analyses, etc. Some of the key activities herein are numerical wave and current computations, wave disturbance model testing and stability tests of breakwaters.

In the design of a new harbour the naval architects have typically been consulted (separately) on assessment of space requirements, dredging limits, approach, berthing and departuring strategy for a given class of ships, which are planned to call on the harbour. The most important tools in manoeuvring studies have traditionally been Planar Motion Mechanism (PMM) tests or free sailing model tests in combination with theoretical considerations. However, these tools cannot fully account for the great complexity and the large number of parameters inherent in the design of an optimal harbour from a maritime point of view. The development of computer based marine simulators has clearly filled a gap in this sense by increasing the number of combined

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variables that can realistically be taken into account in the design process. One of the important additional capabilities of a simulator is the provision of the man-machine interaction. Furthermore, the unique flexibility of a marine simulator as regards description of environmental conditions, harbour lay-out, ship characteristics, etc. is the key to a closer coordination of hydraulic and naval architectural tasks in the design process.

As the background for a call for further integration of marine simulator services in the design of harbours the subsequent sections briefly outline the traditional hydraulic and maritime areas of work and examples of the benefits of integration.

Typical Hydraulic Investigations

The design of a harbour requires the definition of a long list of design parameters which relate to amongst other hydrographic conditions and various criteria for the different installations and structures. The hydraulic investigations for a harbour typically comprise:

i) Definition of wind, water level, tide, wave parameters and statistics. These can be established by various methods ranging from analysis of existing data, performance of measurement programmes to different types of computations and modelling. The definition of design water levels, e.g. in hurricanes, may require mathematical modelling with the most advanced models available for computation of the highly complex influence of winds and barometric pressure on the flow (currents) and water level. The definition of offshore waves and the transformation of waves to the nearshore zone of the harbour also requires numerical modelling using the most advanced models for definition of the wave climate and related nearshore design waves.

ii) The layout and general arrangement of a harbour is often determined by a combination of numerical and physical models using as input the above defined wave and water level statistics. It is further of importance for the interpretation of any model investigation, numerical or physical, that pertinent criteria are available for the harbour. Such criteria are related to wave disturbance, ship movements and mooring forces.

iii) Equally important to the layout is the verification of the long term stability of the protecting structures. Such investigations are still today mainly carried out in physical models.

iv) For almost any harbour on sandy beaches aspects of scour and sedimentation as well as the effect in general on the coastal morphology requires often detailed investigations. Such investigations are mostly performed by means of numerical models.

Typical Maritime Investigations

As mentioned earlier naval architects have traditionally been consulted on ship manoeuvring performance and the implications on operational strategies as well as on physical boundaries such as turning basins, entrance channel, etc. Because of the considerable difficulties inherent in assessing manoeuvring performance under specific environmental conditions, physical restrains, human (navigator, pilot) interaction, etc. a large part of the considerations in the past have been based on simplified rules of thumb. These are typically associated with the standard manoeuvres, e.g. turning circle, zig-zag, stopping, etc.

For illustrative purposes consider the determination of the diamater of a planned turning basin. Often it may be chosen to be equal to the tactical diameter of the ship(s). If tugs are available the diameter may alternatively be determined as 1.2 - 1.5 times the length of the ship(s) as a general rule of thumb. Similarly, the use of duc d'albe's or manoeuvring by means of the ship's anchor may be based on generalized rules.

In contrast to these simple rules it is worth recalling that manoeuvring performance is composed of the interaction between:

hull
propeller(s)
thruster(s)
rudder(s)

which, as described above, should be considered under environmental conditions such as:

wind field, lee effects and gusts
current conditions, incl. shear current
wave action
water depth variations (bathymetry)
bank proximity

It is rather obvious that general considerations as opposed to a true representation of the complexity indicated above may have implications on the servicability and in turn the economics of the harbour.

It is therefore comprehensible that a reliable description of all the elements and their interaction together with an important feature such as real time man-in-the-loop operations are what make today's marine simulators attractive.

Marine Simulators

As an example of a marine simulator the one at DMI is described. DMI is a full member of the International Marine Simulator Forum (IMSF).

The mathematical models represented in the marine simulator cover all vessel characteristics and environmental elements so that design and training tasks related to ship manoeuvring, navigation, dredging, harbour lay-out, offshore operations, etc. can be undertaken.

The simulator was originally developed for two basic purposes, viz. training of navigators and evaluation of manoeuvring performance. However, as clear needs were identified for a more sophisticated simulator it was developed to encompass shallow water effects, limited channel boundaries (bank effects), ship-ship interactions, complex wind and current patterns, etc. DMI is presently developing its fifth generation simulator which amongst other includes first and second order wave effects in six degrees of freedom.

The present software consists of more than 30.000 Fortran statements organized in a general purpose computer. The latter communicates with three graphic computers and in turn three projectors for illustration of the view from the actual ship's bridge on a 6,6 m x 1,5 m screen. The computer is also connected to the ship's instruments such as machinery telegraph, rudder, thruster command, etc. One PC screen shows the actual speed, draught, underkeel clearance, wind, wave and current information as well as machinery characteristics and fender or tug forces. Another PC shows a "radar" picture in the form of a plane "birds-eye-view". Fig. 1 illustrates the DMI simulator.

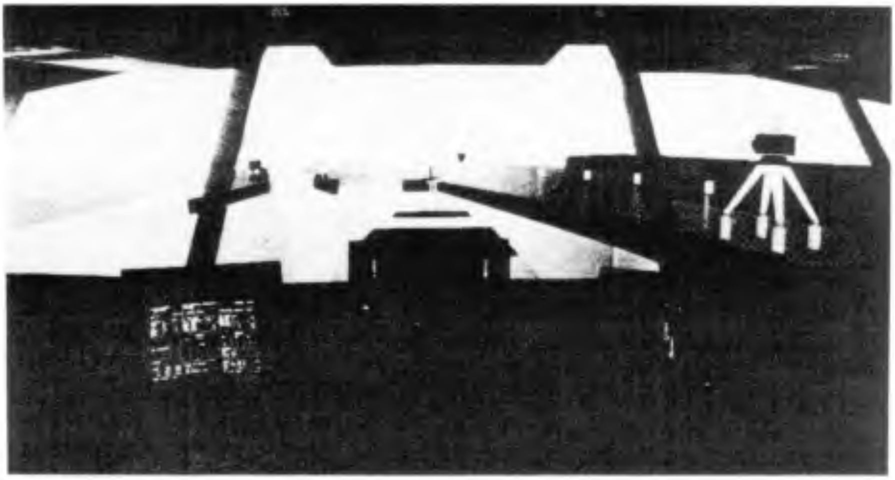


Fig. 1 Illustration of the DMI simulator with instrument screen, steering stand, radar picture and visual screen in the background.

As regards the subjects discussed in section 2 and 3 in relation to the design of harbours the strong points of the simulator is:

- accurate hydrodynamic modelling of vessels
- space and time varying currents
- space and time varying winds including gusts

- wave spectrum modelling
- representation of actual bathymetry
- three-dimenisonal graphics of harbour
- real time man-in-the-loop operations.

in combination with high flexibility such that any of the items above can be easily changed in the search for optimal solutions.

To this end it should be mentioned that also fast-time simulations are available. These do not include a man-in-the-loop, but instead a deterministic rule bound autopilot. The advantage is, however, that a fast screening of various alternative solutions can be performed. A few of the most promising solutions can then be tested in real-time.

Examples of Integrated Designs

The first example of a harbour which has been subject to combined hydraulic design studies and maritime simulations is shown in Fig. 2. The harbour, which is located in the Far East, was planned at a rather open stretch of coast with considerable influence from wind, waves and current.

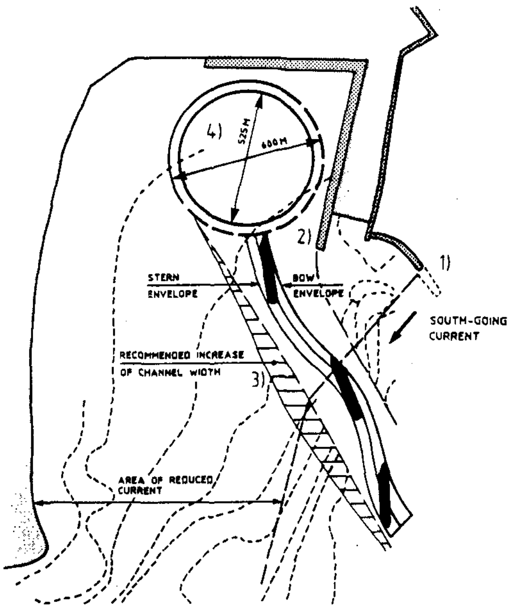


Fig. 2 Far East harbour.

The hydraulic investigations involved field measurements of waves and physical modelling of wave disturbance and currents. The wave disturbance study comprised a number of layouts and lengths of the main breakwater. It was found that the waves breaking over the shoal immediately to the west of the entrance channel caused considerable seiching in the channel and cross-currents in a certain area. These currents were expected to significantly affect the manoeuvring in the entrance channel.

The subsequent maritime investigations in the DMI simulator were based on the following plans:

- approach from north inside outer reef
- approach channel of width X m
- breakwater of length Y m
- turning basin of diameter Z m

After a series of simulations with amongst other a 130,000 DWT bulk carrier in loaded and in ballast conditions the maritime considerations led to the following solutions:

a) The approach from north was too difficult in strong south-going current, because of the rather sharp starboard turn into the entrance channel. A better and cheaper solution was to dredge a channel through the outer reef. A much more appropriate alignment of the vessel when still in deep water had the advantage that the width of the approach channel could be reduced.

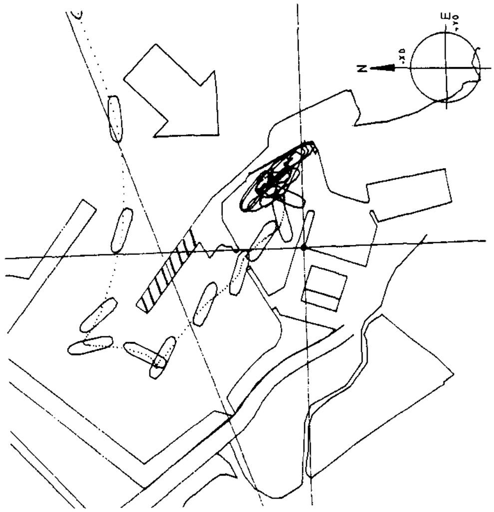
b) Due to the shear current produced by the breakwater 1) in Fig. 2 the vessel had a tendency to turn starboard with the risk of colliding with the end of the quay 2). It was therefore recommended to lengthen the breakwater in order to separate the shear current zone and the deceleration area. Furthermore, the entrance channel 3) should be widened a bit to allow the vessel to keep away from the north bank and the quay.

c) A detailed study of simulated tug boat and winch assisted manoeuvres led to a reduction of the turning basin 4) by about 75 m. The associated savings in dredging were not least important.

From the investigations and the results obtained, this example shows that simulations have a clear influence on the traditional hydraulic design objects and vice versa. The advantage of a coordinated work in the design phase is obvious. Site reports indicate that the harbour operates very well even in rather strong wind and current.

The second example focus on the design of a breakwater in a small ferry and fishing harbour, cf. Fig. 3, in the Faroe Islands.

a)



b)

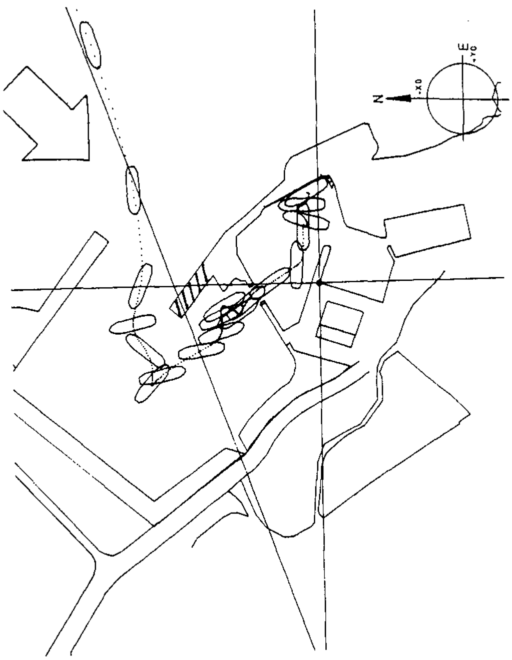


Fig. 3 Harbour in the Faroe Island with
a) rather long 70 m outer breakwater and,
b) a short 40 m breakwater.

The harbour is located in a fiord open in both ends to the Atlantic Ocean. The wave climate is very rough with yearly waves of about, H_S = 4.0 m, and extreme waves exceeding H_S = 6.0 m. The conditions are further aggravated by the wave periods associated with these waves. For H_S = 4.0 m the peak period is in the order of 13-16 s, while in the extreme events the peak period approaches 20 s. The harbour has until recently been characterized by very unacceptable wave disturbances due to resonance oscillations. The size of the basin corresponds to natural periods of 12-14 s waves, which are very frequent in the North Atlantic and in the fiords of the Faroe Islands. Therefore the harbour authorities decided to change the layout of the harbour. Very detailed studies have been performed in physical models including alternative solutions with a new outer harbour in front of the existing harbour. This solution, however, requires the construction of breakwater in water depths up to between 25 m and 35 m and it was consequently given up due to excessive construction costs.

An alternative solution was developed. This solution appearing in Fig. 3 involved construction of a new outer harbour with absorbing rubble-slopes on all boundaries by blasting into the rocky shore. This solution had the advantage that all the stones blasted in the new outer harbour basin could be used for construction of a new reclamation with a berm breakwater as seaward protection. In this way both the quarry-run and the gradation of larger stones were used in an optimum manner.

Physical model tests at DHI showed that the length of the breakwater had the most significant influence on the wave disturbance in the harbour. Lengths from 0 to 100 m were studied.

Having investigated the length of the breakwater from a wave disturbance point of view the aim of DMI's manoeuvring simulations was to test the operational conditions.

First the new 38 m ferry calling on this harbour was mathematically modelled. It was planned to be fitted with two astern propellers, two astern rudders and a bow thruster. Three alternative harbour lay-outs were modelled with all associated land contours, marks, buoys, leading lines, bathymetry, currents (time varying), wind (incl. lee effects) and fenders. A total of 89 simulations were carried out. About one third of these concentrated on the length of the breakwater at the entrance.

Compared to the hydraulic investigations it appeared clearly that the length of the breakwater should be rather short, i.e. not exceeding 60-70 m. Especially in north-easterly winds the manoeuvres were rather complicated. A port or starboard turn was necessary in the outer basin as a part of the preparatory alignment before entering the narrow inner harbour, cf. Fig. 3a). Although an increasing length of the breakwater provided better lee for wind and waves the necessary manoeuvres became increasingly difficult. Compared to a shorter breakwater e.g. Fig. 3b) the one shown in Fig. 3a) causes the ship to initiate the starboard turn earlier and it forces the ship towards the north-west boundary of the basin with the risk of grounding. The latter implies that there is a longer distance for the ship to pass with low speed in order to reach the inner harbour.

As in the preceding example the optimal solution was again a balance between the hydraulic design aspects and the maritime requirements, described above, thus leading to a final length of the breakwater of about 70 m.

Conclusions

A modern marine simulator provides several very important features which form the basis for further integration in the design process of harbours - some of these are:

- quantification of complex ship-environment and man-machine interactions in real time.

- large flexibility and hence an ideal forum for discussion among harbour authorities, consultants and navigators/pilots, of alternative solutions.

- low cost investigations as future harbour alterations, training of crews, call of larger ships, etc. can easily be studied once the graphics of the basic harbour, bathymetry, etc. are established.

The examples discussed in the preceding section clearly illustrate the advantages of carrying out combined hydraulic and maritime investigations as a careful balance of requirements have to be achieved. This is shown schematically in Fig. 4 in which a hydraulic and a maritime organization are illustrated by DHI and DMI, respectively.

Marine simulators represent still a rather new technology, which, however, undoubtedly will be generally accepted as an important tool for developing safe, cost effective and well functioning harbours and waterways. The (fast-time) screening facility of simulator and the interaction with the hydraulic aspects clearly call for simulations at the design stage and not only for verification or testing of decided solutions. Fig. 4 indicates the principle in such an interaction, which is claimed here to result in a harbour where all parties - authorites, consultants, navigators, and pilots - their requirements and views have been taken seriously into account.

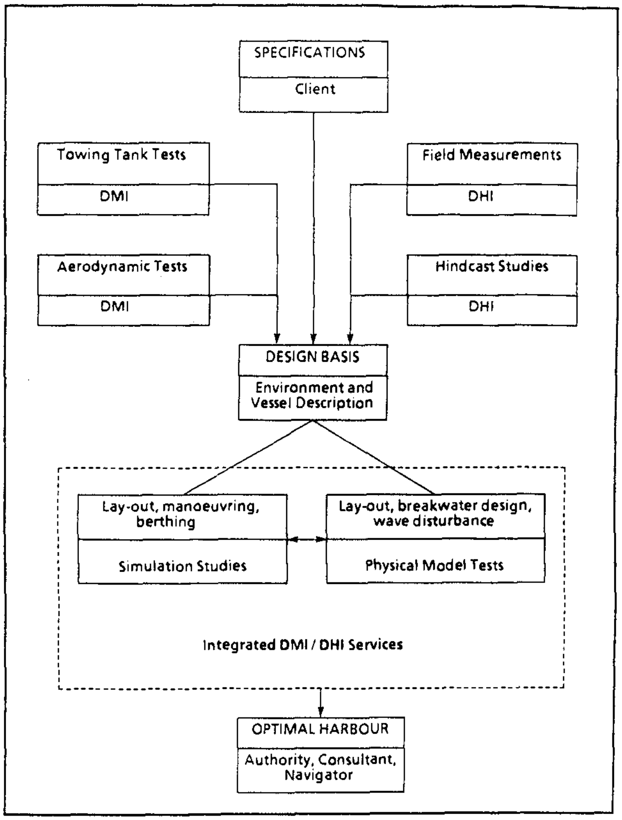


Fig. 4 Illustration of the integration of hydraulic and maritime services in optimal harbour design.

APPENDIX:

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