CHAPTER 58

Influence of Long Waves on Ship Motions in a Lagoon Harbour

Volker Barthel¹ and Etienne Mansard²

<u>ABSTRACT</u>

A physical model study of a vessel moored inside a lagoon harbour was undertaken in order to optimize a breakwater layout that best reduces the penetration of long wave energy inside the lagoon. The longer the breakwater at the entrance: the smaller the surge motion inside the lagoon. A combination of a short breakwater at the entrance channel and a pair of groynes in front and in the rear of the vessel also led to an efficient reduction of the surge motion. However, cost estimates and evaluation of vessel manoeuvrability are required to make an optimal choice of the breakwater layout. The use of a deterministic approach in wave generation led to a quicker testing procedure.

INTRODUCTION

In the design process of a harbour, its location, size and infrastructure are usually determined by economic factors such as the magnitude and structure of the expected marine traffic, the hinterland, the amount of throughput cargo and many other parameters. A preliminary lay-out of basins, berths, access channels, jetties, breakwaters and other coastal structures is then optimized with the help of numerical and/or physical models of tidal motions, currents, waves and sediment transport. However, the fine-tuning of the design such as the length and orientation of breakwaters can be carried out only with the help of a ship mooring study. This is generally done in a physical model, although various promising numerical approaches have been presented in literature (see for instance Sand and Jensen, 1990).

¹Federal Admin. of Waterways and Navigation, Directorate North Kiel, Germany.

²Institute for Marine Dynamics, National Research Council of Canada, Ottawa, Canada.

This paper describes a physical model study of a 35,000 tdw bulk carrier moored in a lagoon harbour. The objective of the study was to evaluate the magnitude of vessel response induced by irregular waves. It was therefore, focussed on the propagation of irregular waves through an access channel, past a breakwater, into a lagoon harbour. The modification of the irregular wave train and its group-bound long wave components, during the shoaling process and the effect of various breakwater layouts on their penetration into the lagoon harbour were evaluated by measuring the motions of the moored vessel with highly sensitive instrumentation.

EXPERIMENTAL SET-UP

Figure 1a is a sketch of the lay-out of the lagoon harbour used in this study. It consisted of an offshore section of 25m depth, a 1:100 sloped bathymetry and a channel at the 15m contour cutting into this slope. At the end of the 1250m access channel, a circular lagoon with a radius of 280m accommodated a trestle structure berth and a ship moored to it. Permeable gravel beaches were installed on either side of the entrance channel to absorb incident wave energy. Slopes of the harbour basin were at 1:10. Since a model bulkcarrier of 35,000 tdw was readily available at a scale of 1:70, the same scale was chosen for the entire investigation. The hydrodynamic similarity of the vessel had been established in previous tests, including the definition of CG, GM, roll period and pitch gyradius. The model ship was ballasted for a 100% load condition.

In order to obtain the highest possible accuracy in vessel response, mooring lines and fenders of the model were designed to reproduce nonlinear characteristics of the desired prototype lines and fenders including hysteresis. Forces were measured by high-resolution load cells, while the six-degrees-of-freedom motions of the model were monitored using an optical tracking system. Details of the instrumentation and mooring line simulators can be found in (Barthel, et al., 1989; Laurich, 1989). The model was moored with 12 polypropylene mooring lines arranged in a pattern which had been previously optimized (Kubo and Barthel, 1992, Barthel et al, 1994). Figure 1b shows a photograph of the model set-up.

Water surface elevations were measured in the model basin using capacitance type wave gauges. Their locations are shown in Fig. 1a. The array of gauge 1 - 5 was used to determine reflections coming from the model layout. Simulation of waves in the model basin was carried out using the wave generation package developed at the Hydraulics laboratory of the National Research Council Canada. This package contains several algorithms for simulation of uni and multidirectional waves.



Figure 1 . Layout of the Experimental Set-up : a) Sketch indicating the position of gauges; b) Photograph showing the vessel in place.

PROPAGATION OF LONG WAVES INTO THE LAGOON

The understanding of the physical processes involved in the propagation of waves on a complex bathymetry and layout such as the one used in this study is limited. However, it can be expected that, as the waves propagate the shoaling of wave groups and their associated groupbound long waves will induce the breaking of the first order (short) waves and cause their energy dissipation. The long waves can then be expected to detach themselves from the group and continue to travel at free wave velocity to be either reflected off the beach or to propagate along the beach at an angle (set-up / edge waves). An experimental description of this process was attempted by (Mansard and Barthel, 1984). The present situation is however more complicated. From what could be observed during tests, the following happens:

During the propagation of waves from deep to shallow water, the shoaling process induces breaking of the first order waves and releases the energy of the group bound long waves that continue then to propagate into the lagoon. These long waves, although hardly visible to the observer because of their small amplitudes, can move the vessel to its maximum limit. In this particular set-up, the surge motion and the loads on the mooring lines which restrained the surge motion, were most sensitive to long waves.

The main objective of this study was therefore to optimize a breakwater lay-out that will reduce the penetration of the long wave energy and the resulting ship motions.

SHIP MOORING TESTS

Experimental Procedure

Many laboratories in the world use the stochastic approach in ship mooring tests by subjecting the model to a very long time series of water surface elevation, in order to ensure the inclusion of worst combination of waves that will cause the maximum motions of the vessels, as well as maximum loads on the mooring lines. In this particular study, a deterministic approach was adopted by simulating short time series of predefined surface elevation, in order to save testing time and cost of model investigations. This use of short time series was also expected to minimize any potential build-up of long wave energy in the model set-up.

The time series used in this study were 2.4 minutes long in model scale and it corresponded to 20 minutes in prototype duration. This length was also equivalent to 12 periods of 100s long waves that were found to

excite the ship substantially in an earlier study (see Barthel et al, 1994). In order to select time series that would be appropriate for this deterministic approach, the methodology described below was used.

Synthesis and selection of time series

From a JONSWAP spectrum, time series of water surface elevation were first synthesized by the commonly used random phase spectrum method. This method pairs a given amplitude spectrum with a phase spectrum generated by random numbers. By varying the random numbers, different realizations of wave records, with varying time domain characteristics can easily be simulated.

Since it is believed that narrower spectra result in higher degree of wave grouping, JONSWAP spectra with two different values of γ (i.e. γ =1 and γ =7) were used in this synthesis. (According to Sand (1982), higher degree of grouping results in larger amplitude of group-bound long waves that are responsible for the excitation of the horizontal motions of the vessel). From each target spectrum, ten realizations of time series were synthesized and reproduced in the model. The response of the vessel was then measured for all the twenty realizations of the time series described above. Figure 2 presents the results obtained by this procedure.

The RMS values (i.e. standard deviation) of the long waves measured in the lagoon, in the proximity of the vessel are shown in Figure 2a for the various realizations of time series. These long waves were derived by lowpass filtering the water surface elevation with a frequency cut-off of 0.03 Hz (full scale). Figure 2b illustrates the RMS values of the corresponding surge motions.

The results show that narrower spectra (γ =7) results in higher long wave content and consequently larger surge motions. Amongst the ten realizations of the time series under each γ value, the 8th time series generally leads to the largest response of the vessel. This time series will be denoted in this paper as TRN8. It is also noticeable that the 4th realization (TRN4) generally provides the smallest response. The above findings were also confirmed by analyzing the sway motion and the loads on the mooring lines.

Figure 3 shows the time series of water surface elevations corresponding to TRN4 and TRN8 under the two γ values of JONSWAP. The corresponding SIWEH functions which illustrate their grouping pattern are also illustrated along with the appropriate values of Groupiness Factors (see Funke and Mansard, 1979 for the definitions of SIWEH and Groupiness Factor).

Since the length of each of these time series was only 2.4 minutes in model scale, it was decided to use all the four time series (i.e. TRN4 of γ =1 and γ =7 and TRN8 of γ =1 and γ =7) for the optimization of the breakwater layout, in order to validate the resulting solutions under four different sea states.



Figure 2. RMS values of long waves and surge motion inside the lagoon harbour for the ten realizations of time series.

LAYOUT OF BREAKWATERS

Several breakwater configurations were evaluated in this study during the optimization procedure. They are, as can be seen in Figure 4: a long version of the breakwater (BWL), a medium length structure (BWM) and a short breakwater with (BWD) and without (BWS) a second barrier. In addition several versions of groynes (BWSG1, BWSG2 and BWSGD) upstream and downstream of the moored vessel were also tested in conjunction with the short breakwater BWS.



Figure 3. Time Series and SIWEH of the Selected Time Series



Figure 4. Sketch of the various breakwater options tested

The obvious questions that were expected to be answered by installing these breakwater configurations were the following:

Can a breakwater help reduce the penetration of long wave energy? Is there an optimal layout which ensures an efficient reduction of energy with smaller capital costs?

PEFORMANCE OF BREAKWATER LAYOUTS

Influence of Short Breakwater (BWS)

In terms of engineering practice and as an obvious economical measure for reducing the wave excitation inside the harbour, the short breakwater seemed to be a reasonable solution. This breakwater extended from the high water line at the beach to the edge of the sloped channel. Its performance is illustrated in Figure 5 by comparing it with results obtained without any breakwater (i.e. NBW). In Figure 5a, a comparison of the spectra and the time series measured at the offshore region during the No and Short breakwater tests, are presented to illustrate the similarity in the inputs. Also shown in this Figure is the standard deviation of the long wave energy measured at different locations of the experimental set up (see Figure 1 for the locations).



Figure 5. Comparison of results with and without short breakwater

It is interesting to note in Figure 5a that the long wave energy prevailing in the lagoon is substantially reduced by the presence of the short breakwater while at the entrance of the channel, the presence of short breakwater induces a sharp rise in the energy of the long waves. On examining the time series presented in Figure 5b, it appears that this sharp rise may be due to the reflective nature of the breakwater. In spite of this, the net long wave energy that penetrates the channel is shown to be smaller, as the value at gauge 12 illustrates. This reduction leads subsequently to small amplitudes of long waves inside the lagoon. A similar physical process was found when testing with other sea states.

Figure 6 provides an overall view of the results for the four preselected sea states, by presenting the spectral densities of long waves measured in the proximity of the vessel by the gauge 8 and the resulting surge spectra. The legends presented in this Figure correspond to the following situations:

GAM7_TRN8 correspond to γ =7 and TRN8; NBW and BWS correspond to No and Short Breakwater situations.

As can be seen in Figure 6a, the shape of the long wave spectra encountered near the vessel remains nearly the same under the two situations of breakwater. The sea state with the largest degree of grouping exhibits the most dramatic influence of the breakwater, possibly due to severe breaking induced by the largest wave group.

Tests using Bichromatic waves

In order to confirm the good performance of the short breakwater a test series was also undertaken using bichromatic waves. Bichromatic waves are waves composed of two primary frequency frequency components f_1 and f_2 , and a long wave component with a frequency (f_1 - f_2). In an earlier study of this lagoon harbour, Barthel et al (1994), determined the critical frequency at which the ship responded significantly, by running several combinations of (f_1 - f_2). The particular bichromatic wave which created this critical frequency (i.e. 100s prototype) was also used in this study to assess the performance of the short breakwater. Figure 7 illustrates the results obtained for three different amplitudes of the long waves characterized by the gain factor. The influence of the short breakwater causing an effective reduction in the long wave amplitude and in the surge motion can easily be appreciated.



Figure 6 : Spectra of long waves and surge motions under No and Short breakwater situations.



Figure 7. Test results under bichromatic waves

Performance of Other Breakwater Options

A limited series of tests with longer breakwaters (BWM AND BWL) and with the entrance barrier (BWD) showed that they can reduce the ship motions further. However, their results have to be analysed in conjunction with the cost of the structures and with the ship manoeuvrability studies for vessel approach.

Influence of Groynes.

It was speculated that although the short breakwater is effective in reducing the penetration of the long wave energy inside the lagoon, the groynes close to the structure can effectively cut-off the influence of orbital current associated with the long waves and thereby reduce the motions of the vessel and the loads on the mooring lines. Although the installation of groynes will restrict the manoeuvrability of the vessel, it is believed that tug assistance will be needed in a closed environment such as this lagoon. Hence the trade-off between a longer berthing procedure and a safer mooring system had to be explored. Tests were therefore initiated with one groyne in front of the moored vessel (BWSG1 and BWSG2) and pursued with a combination of one in front and another in the rear (BWSGD). Note that these groynes were evaluated with the short breakwater in place.

As expected, the combination of groynes in front and in the rear generally provided the best protection.

Test Series with Grouped wave trains

In order to validate this optimization process under different severities of sea states, a grouped wave train, synthesized using the SIWEH concept was used. A JONSWAP spectrum with γ =3.3 and a peak period T_p = 12 s was chosen for this simulation. The SIWEH function adopted for this purpose had a Groupiness Factor of 0.9 and a peak period of 120s (see Funke and Mansard 1979 for details on this synthesis process). Six different values of H_{m0} were used in this test series. The results were then used to assess the relationship that may exist between long wave energy and vessel response. Figure 8 presents the RMS values of the surge measured under different breakwater configurations as a function of the long wave energy measured at gauge 10, just before the entrance of the channel. Although the model was subjected to its maximum response, these results clearly illustrate the the good performance of the BWSGD option (short breakwater with two groynes). Note that for this particular test series, other options such as BWL, BWD and BWSGD1 were not unfortunately explored.

CONCLUSIONS

A physical model of a ship moored inside a lagoon harbour under the attack of irregular waves with different grouping properties permitted to make the following observations:

- Sophisticated simulation and wave generation techniques including non-linear properties of mooring lines and fenders are required to achieve the necessary accuracy for ship mooring studies;
- Instead of reproducing long time series of water surface elevation, a deterministic approach of using short realizations of pre-selected time

series was adopted successfully in the optimization of the breakwater layout; This approach helped reduce the testing time;

- While inside the lagoon first-order waves were hardly visible, long waves of low amplitudes induced significant motions of the vessel;
- The arrangement of breakwaters at the entrance channel enhanced the dissipation of the long wave energy and reduced the ship motions; The longer the breakwater: the greater the reduction in surge motion.
- Substantial reduction of the surge motion achieved by the short breakwater option was well illustrated by the test series;
- The construction of groynes interrupting the orbital currents associated with long waves is another option to reduce the surge motion further;
- Although efficient breakwater lay-outs have been established in terms of vessel motions inside the lagoon during this experimental program, manoeuvrability of the vessel in the presence of reflections in front of the main breakwater and in the presence of groynes inside the lagoon was not part of this study and therefore has to be explored.



Figure 8 : RMS values of the surge motions as a function of the long wave RMS measured at gauge 10, under different breakwater options.

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