CHAPTER TWO HUNDRED SEVENTEEN

The Effect of Wave Direction on Ship Motions in a Harbour Entrance Channel - Model Study Approach

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ABSTRACT

Basic knowledge of a ship's vertical motions in waves of different angles of approach is an essential requirement in the formulation of allowance criteria on which to base harbour accessibility under extreme wave conditions.

A comprehensive series of scale model tests are being undertaken to establish minimum underkeel clearance for given channel depths and sea states using two models representing typical 150 000 and 270 000 dwt bulk carriers.

1. INTRODUCTION

The increasing demand for harbour utilization by deeper-draught ships has necessitated a more critical look at harbour accessibility in terms of accepted safety criteria. Based on experience gained at Richards Bay, South Africa's major coal export port (Campbell and Zwamborn, 1977 and 1984; see also Figure 1), it was realized that sufficient knowledge of the effect of wave direction on the motions of bulk carriers in limited depths of water is a primary requirement.

Figure 1. Aerial view of Richards Bay harbour entrance

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Details of field measurements of ship motions in the approaches to South Africa's major export ports were given by Zwamborn and Van Wyk (1981) and Van Wyk (1982). The measurements have confirmed the excessive vertical motions of large coal carriers induced by quartering to near-beam swells in the approach channel to Richards Bay harbour. These swells, up to 3 m in height and with periods ranging between 12 and 17 s, have resulted in maximum draught increases of up to twice the significant wave height (Figure 2).

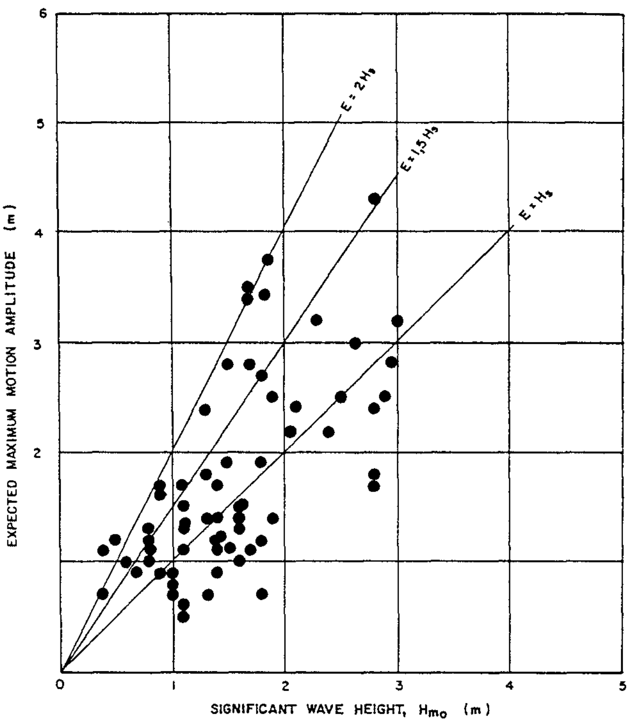

Figure 2. Maximum vertical ship motions at Richards Bay harbour

To assist in the **optimum operation** of Richards Bay harbour and to determine **minimum dredging requirements** in the entrance channel for ships up to 250 000 dwt, an extensive programme of research was undertaken, including both physical and mathematical modelling techniques and further prototype measurements.

A start was made with this programme of research during the second half of 1982 with the acquisition of a computer program, based on the 3-D source technique, to calculate ship motions, preparations for the development of suitable scale model ships and laboratory equipment, and the construction of a test basin equipped with irregular wave generators.

The establishment of these facilities, including the wave generators, took almost two years, so that the basic testing only started just before the conference. The present paper, therefore, includes a brief description of the main objectives of the model studies, the required facilities and equipment and their calibration, the approach adopted for the model studies and some initial results.

2. STUDY OBJECTIVES

The main objective of this study is to determine **vertical ship motions** as function of wave direction. This implies determination of a ship's behaviour, firstly, as a result of her own inherent properties, and, secondly, as a result of the prevailing environmental conditions.

The ship's inherent properties are the principal dimensions, hull shape (as well as appendages), the loading condition, the speed of advance and the manoeuvrability characteristics. The environment comprises the channel dimensions (including the depth of water), the wave conditions, and possibly currents and wind.

The main objective is being met by conducting a series of basic tests, using scale model ships, assisted by the use of the mathematical model.

3. TEST FACILITIES AND EQUIPMENT

Two 1-in-100 scale model ships, representing 150 000 and 270 000 dwt bulk carriers, were built for the basic model tests. The hulls were accurately scaled-down from line drawings of existing prototype vessels and were made of glass fibre (Figure 3).

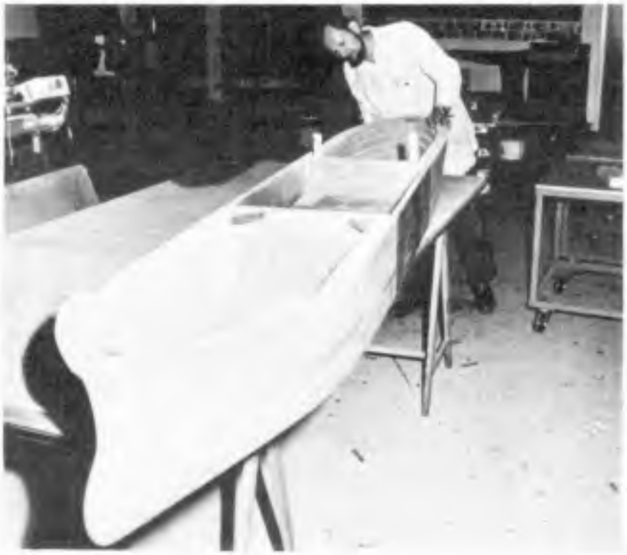

Figure 3. Mould for construction of glass fibre model hull

Figure 4. Distribution of lead weights for proper loading

The required model loading was obtained by proper distribution of lead weights during inclining experiments in air and in water (Figure 4). Provision was made for both a 'short' and long' period natural roll at full load.

The models are self-propelled and self-steered with true-to-scale speed and rudder response (Figure 5).

Figure 5. Model propulsion unit

The basic tests are conducted in a 23 × 28 m^2 flat-bottomed basin, with a maximum depth of 0,35 m, equipped with a bank of SEASIM programmable irregular wavemakers (Figure 6).

Figure 6. Model test basin with Seasim irregular wavemakers

During testing, the model is run along a straight course, at different angles to the waves, covering a distance of about 20 m (2 km prototype). Measurement of the resistance between four electrodes attached to the model's hull/keel (Figure 7) and galvanised steel plates fixed to the basin floor allows continuous recording of the underkeel clearance (UKC) at the ships quarters and shoulders.

Figure 7. Electrodes attached to model's keel for UKC measurement

Simultaneously with the UKC measurements, the following are recorded: the waves encountered (using a wave probe on the ship's bow) and the rudder deflections and propeller rpm's.

At present, both model control and data transmission are done via a light-weight ship/shore cable but this will soon be replaced by a remote-controlled radio telemetry system, which will also include an autopilot system with feedback to shore.

The ship's horizontal excursions are monitored by two remote-controlled overhead cameras which can be triggered as fast as every 0,2 s (Figure 8). This, together with the feedback from the ship, gives information on the course-keeping ability of the model during tests.

Figure 8. Overhead camera to record model's horizontal excursions

Data handling and analysis are catered for by a shore-based data acquisition system, featuring 16 channel A-to-D conversion and an H.P. mini-computer with on-site graphics terminal (Figure 9).

The ship's vertical response will also be calculated using the mathematical model with the ship's hull simulated by a representative number of panels and with the loading conditions in accordance with those of the scale models. This model makes possible a frequency domain solution of the coupled equations of motion. The resulting response amplitude operators (RAO) can also be combined with a wave spectrum to obtain short-term statistical averages of the vessel's motions.

Figure 9. Data acquisition system in the control room

4. APPROACH OF MODEL STUDIES

The studies are conducted in two successive stages, namely Stage I, calibration (Figure 10) and Stage II, the actual model tests (Figure 11).

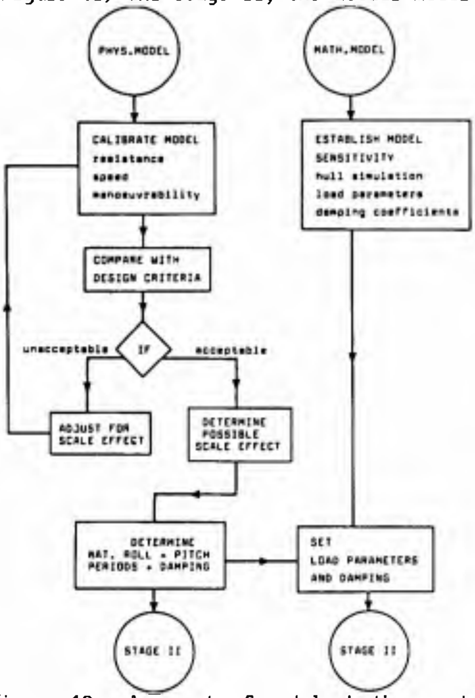

Figure 10. Approach of model studies - stage I

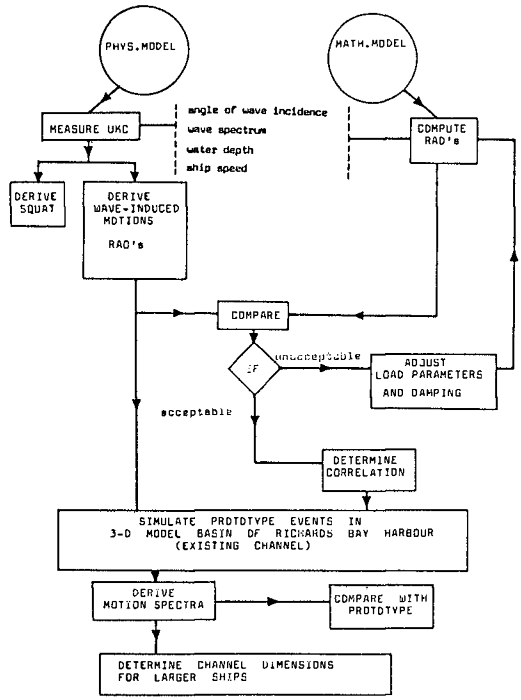

Figure 11. Approach of model studies - stage II

Stage I comprises the basic setting-up procedures and the calibration of the two model ships with respect to resistance in water, speed of advance and manoeuvrability. The natural periods of oscillation in roll and pitch as well as the damping coefficients as functions of water depth were also established for various load conditions.

Stage I also includes a series of sensitivity runs with the mathematical model. The experimentally derived natural periods and viscous damping coefficients will be used as input for the mathematical model runs of Stage II.

Stage II involves a series of model tests concentrated on the two ship sizes selected. The RAO's for the wave-induced vertical motions will be determined for the two ship sizes as function of angle of wave incidence, wave height and period, water depth and ship speed. The physical model test results will then be compared to predicted RAO's obtained from the mathematical model.

5. RESULTS OF MODEL CALIBRATION TESTS

At the time of the conference, most of the Stage I tests were completed with respect to the smaller model ship and the Stage II tests had just started.

The results of the towing resistance and model speed tests for the 150 000 dwt model ship are shown in Figure 12.

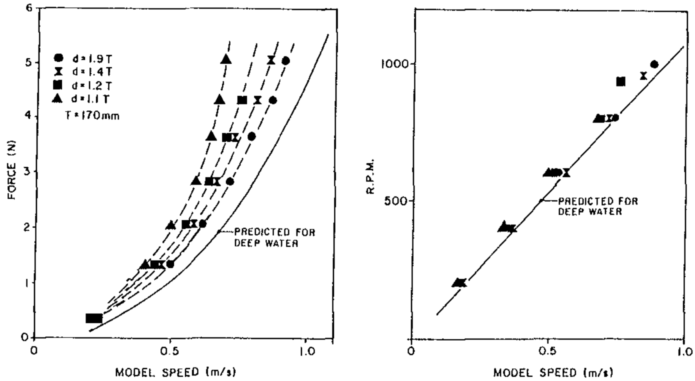

Figure 12. Model towing resistance and speed

The model's towing resistance for a depth-over-draught ratio of d/T = 1,9 was found to agree reasonably closely to the predicted value for deep water. The model speeds for d/T = 1,9 are about 10 per cent less than the calculated deep water values. Since d/T $\geq$ 2 is usually accepted to represent deep water conditions it means that the model's resistance is, perhaps, only slightly too high.

A significant reduction in speed, for the same propulsion force, is evident in shallower water. This reduction is also shown clearly by the relationship between propeller rpm and model speed (Figure 12).

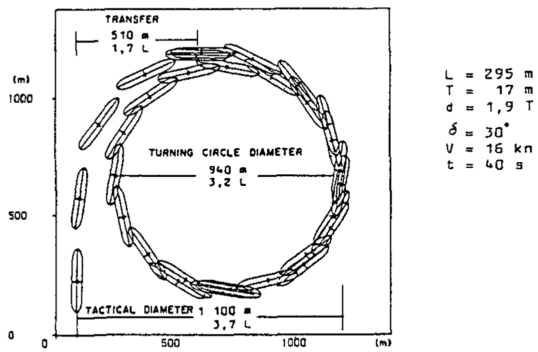

Figure 13. Results of turning circle test

A typical result of a turning circle test is shown in Figure 13. The diameter of the turning circle, the position of the point of maximum advance (transfer) and the tactical diameter are all in agreement with prototype data, obtained under similar conditions.

The effect of d/T on the model roll period and the damping coefficient is shown in Figure 14. The tests were done under full load conditions but with two different load distributions, resulting in 'deep' water roll periods of 1,26 and 1,66 s respectively.

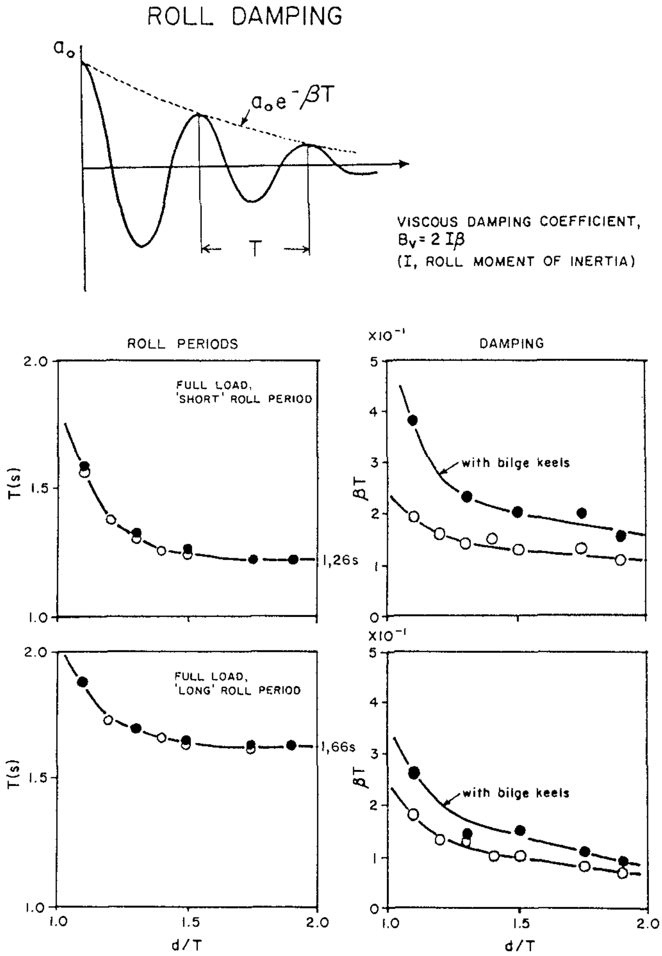

Figure 14. Roll periods and damping for various depth-over-draught ratios

The results show significantly longer roll periods for smaller under-keel clearance, particularly for the 'short' roll period case. A similar trend is visible for the damping coefficients which are much greater in shallower water.

As could be expected, the roll periods are not affected by the presence of bilge keels but the damping coefficients increase considerably (by 30 to 100 per cent) with the presence of bilge keels on the model ship.

6. PRELIMINARY RESULTS OF ACTUAL MODEL TESTS

All the scale-model tests are conducted in unidirectional waves of various spectral shape. Angles of wave incidence will be varied in steps of 15° in the regions where the ship's response is very sensitive to wave direction and in steps of 30° for the remainder of the directions (Figure 15).

Figure 15. Model test run with 90° wave approach

Most of the tests are done with waves which have a spectral shape based on actual recorded wave spectra. Figure 16 shows 128 normalised spectra, recorded at Richards Bay. These cover conditions with H_{m_0} = 1 to = 5 m and T_p = 11 to 17 s, which are the most relevant conditions with regard to ship motions. The spectra are seen to be remarkably similar with quite a narrow variation, and the mean spectral shape was considered representative for conditions at Richards Bay. This spectrum was therefore used for most of the tests although tests with different spectral shapes are also done to check on sensitivity.

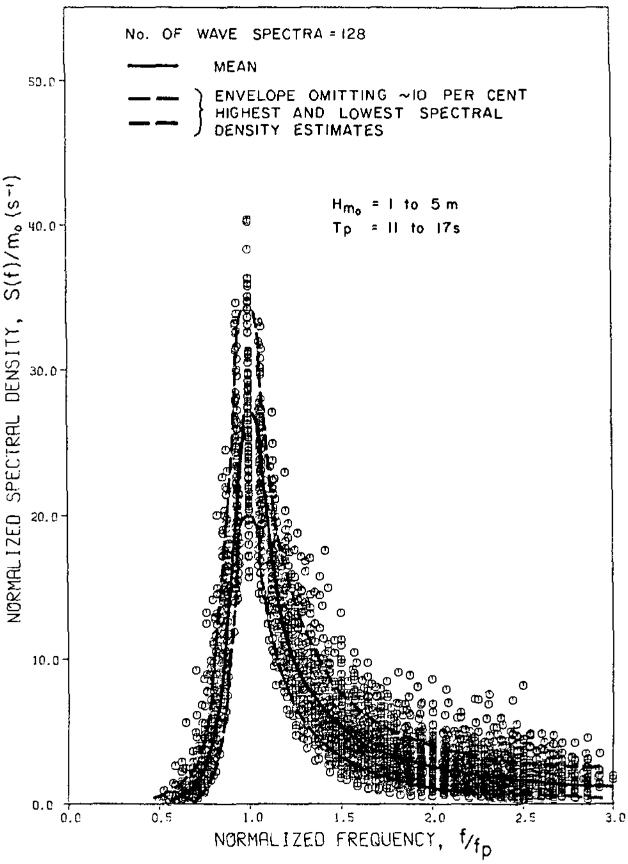

Figure 16. Normalized Richards Bay wave spectra

Sample amplitude response functions for the starboard and port shoulders of the 150 000 dwt model ship for beam waves are shown in Figure 17. These results are based on a model run of 20 m length. The amplitude response (RAO) was determined by dividing the response spectra by the wave input spectrum. Maximum response is seen to occur at about 13 s which is the ship's natural roll period for a depth-over-draught ratio of 1,3. A peak response (mainly roll because of beam waves) of 5 m/m was found for both shoulders.

Some preliminary results of the mathematical model are shown in Figure 18. This figure clearly shows the influence of wave direction on the ship's roll response.

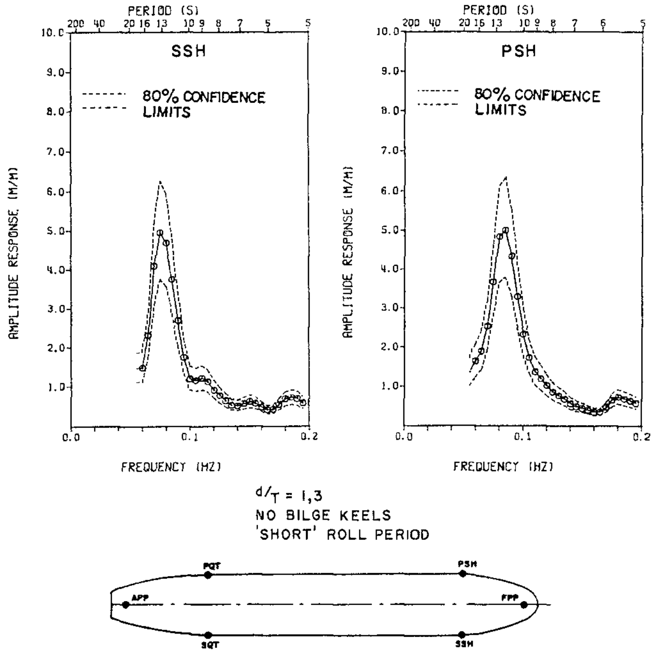

Figure 17. Sample amplitude response functions, 90° wave approach

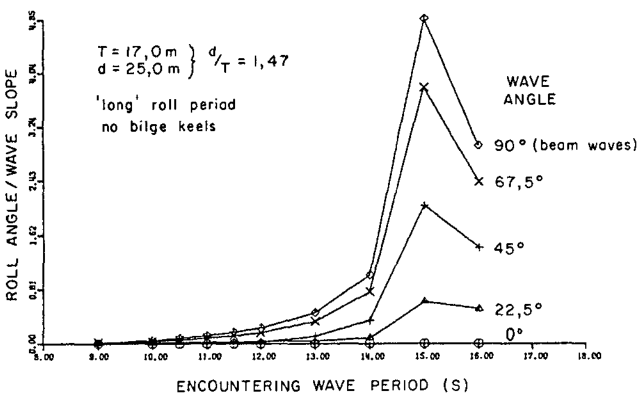

Figure 18. Mathematical model roll response for different wave directions

7. CONCLUDING REMARKS

The results of these studies will be applied to formulate allowance criteria on which to base optimum harbour usage under all wave conditions. This will serve to update and improve the present operational manual being used at Richards Bay harbour (Campbell and Zwamborn, 1984 and Zwamborn and Cox, 1982).

On completion of the basic tests, a series of tests are planned in a 1-in-100 scale model of the Richards Bay harbour entrance channel. These tests will involve simulation of prototype events/conditions to compare the 150 000 dwt model behaviour to field measurements as well as tests using the 270 000 dwt model to determine channel dimensions (dredging requirements) for possible future extensions.

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