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THE MOTIONS OF SHIPS IN SHALLOW WATER

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SUMMARY

Wave induced vertical motions of ships docking in shallow water were investigated in order to aid prediction of docking downtime for various breakwater configurations. A deep water strip theory program was modified for shallow water effects, and the output compared with the results of full scale measurements taken on three vessels. The numerical predictions showed good agreement with published data. The comparison with full scale measurements indicated reasonable agreement, but wave field variability introduced significant errors. There was evidence of non-linear response with respect to wave height in the measurements on the smallest vessel.

BACKGROUND

The Centre for Marine Science and Technology (CMST) was commissioned to investigate motions of vessels docking at the Marine Support Facility in Jervoise Bay, Western Australia, with a view to predicting the docking downtime due to vertical vessel motions for various proposed breakwater configurations. A component of this task involved the measurement and prediction of pitch and heave motions in shallow water. The starting point for theoretical predictions was an in house deep water motion prediction program written by Sutherland (1987) based on the work of Ursell (1949), Bishop et al (1978) and Von Kerczek and Tuck (1969). It combines a multi-term conformal mapping with linear strip theory.

THEORETICAL PREDICTIONS

The strategy adopted was to develop a shallow water motions computer program for cylindrical shapes, compare the results with published theoretical and experimental data, then use the program output to generate shallow water corrections to deep water added mass and damping values generated by the existing program of Sutherland (1987).

A program to calculate the 2D added mass and damping of a circular cylinder, floating on water of a finite depth, was implemented on a personal computer. The program was based on the potential flow approach of Yu and Ursell (1961).

The calculations conducted by the authors at intermediate water depths generally supported the calculated results of Kim (1969) rather than Yu and Ursell (1961). The added mass and damping calculation required the evaluation of a Cauchy integral which had two singularities. Two independent integration methods were tried by the authors to obtain results for the integral. Both methods produced very similar results and agreed with those of Kim (1969) for Kh greater than 0.5, where:

K = deep water wave number
h = water depth.

The authors' results disagreed with those of Kim (1969) in the region Kh less than 0.5. The reason for the disagreement was not found, but in the final version of the program the authors' integral results were used rather than Kim's. This was because the authors' Cauchy integral results yielded added mass and damping predictions closer to those observed in published data (Andersen & Wuzhou 1985, Vugts 1968).

The development of a conformal mapping procedure for vessel sections in finite depth was not considered practicable within the time available, so the existing deep water motions program was modified to account for limited water depth by multiplying the deep water sectional added mass and damping by the ratio of shallow water to deep water added mass and damping for a cylinder.

FULL-SCALE TRIALS

The shallow water motions predictions software was verified by undertaking a programme of full scale measurements on vessels at the Marine Support Facility. An instrumentation system to measure primarily vertical vessel motions was constructed, calibrated and tested. The measurement system was based on two accelerometers, which were fixed on the vessel centreline and aligned vertically. The signals were passed through a 3Hz low pass filter then digitised at 10Hz on a personal computer. The raw time series was then processed into pitch and heave amplitude spectra.

The ocean wave field was measured with commercial directional and non-directional bottom mounted pressure sensors, and several surface suspended pressure sensor recorders developed by CMST staff. (see fig 1). The CMST wave recorder has been subject to many calibration deployments and the opportunity was taken during these trials to investigate its performance further. It was deployed at the same time as the commercial sea bed sensors in an adjacent location. The resulting spectra were of similar shape with a consistent overestimation of the spectral ordinates, (figure 2), as experienced in earlier calibration tests. A further investigation was conducted by deploying the same CMST instrumentation in sea bed mounted configuration, at the same location as a surface suspended recorder. The resulting spectra, again shown in fig 2, indicate very good agreement in the frequency range of overlap. On several occasions the wave recorders could not be deployed at the vessel berthing site, so the nearest alternative site was used. On those occasions the wave spectrum for the corresponding time period was processed and corrected for changes in water depth. Heave and pitch response amplitude operators (RAOs) were created by combining the motion and wave spectra, the result being normalised to unity RAO at zero frequency.

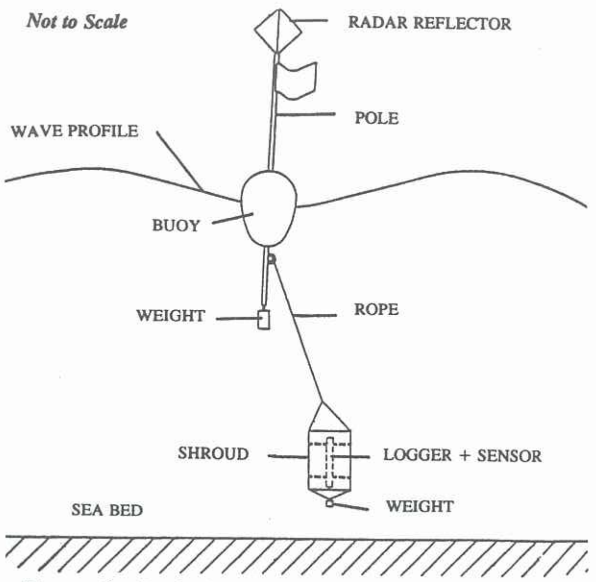

Figure 1 Typical CMST wave recorder deployment

The first set of motion measurements were taken on board HMAS *Swan*, a destroyer-escort vessel, during launching of the vessel and whilst under tow from the Marine Support Facility. Very low wave heights were experienced during the trials (significant wave height = 0.27 m) but despite this the onboard system performed well. The data analysis methods used showed that difficulties with low acceleration levels and high electrical noise could be overcome.

Motion measurements were carried out next on the HMAS *Moresby*, a hydrographic vessel, whilst the vessel was moored in the wet-berth at the Marine Support Facility. Measurements were taken in all six degrees of freedom, although the trials program was mainly directed to the measurement of heave and pitch. Eight valid heave, and six valid pitch RAOs were obtained from the trials, providing a good data base for comparison with theoretical results. The trials highlighted that the wave environment around the Marine Support Facility site was variable, both in time and space. From the response of the vessel it was apparent that waves reaching the vessel were often different to those recorded by the pressure sensor only 150 m away. The measured wave spectra also varied from hour to hour. Another significant characteristic of the wave fields encountered was their bidirectionality. High frequency waves generated by the local sea breeze were centred around a 135 encounter angle whilst the lower frequency swell waves were head seas.

The final set of trials was carried out on TRV *Tailor*, a torpedo recovery vessel, whilst the vessel was moored over the shiplift platform. The water depth was varied by raising and lowering the platform. The trials program consisted of two runs at each of four water depths, providing a comprehensive data set. A comparison of the four depths at which motion measurements were made, showed the influence of water depth on the vessel's response was less than 5.0%. The amplitude of the heave and pitch response at high frequencies appeared to be dependent on wave height, rather than water depth. The low frequency response tended to a value less than unity, probably due to wave attenuation between the wave measurement position and the vessel's position. The degree of permeability of the lift platform, and its effect on the vessel's response, was unknown.

COMPARISON OF NUMERICAL AND MEASURED VESSEL RESPONSE

The full conformal mapping procedure was carried on the hull form of HMAS *Moresby*. The procedure failed to map two of the 22 sections, for which Lewis mappings were eventually used. Motion predictions were then carried out for the infinite water depth case and for a water depth of 10.5 m.

General agreement was found between the predicted and measured heave RAOs, (see fig 3) although the measured heave RAOs were generally higher than the predicted RAOs above frequencies of 0.12 Hz. This difference may be related to the influence of the heading angle on the vessel's predicted response. There was general agreement between the predicted and measured pitch RAOs (fig 4) at frequencies above 0.17 Hz, whilst below this frequency there was a large disparity. Again the reason for the disagreement in the predicted results was due to possible shortcomings in the theory, whilst the low measured RAO was probably due to wave attenuation. The influence of water depth on the predicted heave and pitch RAOs was negligible, for the depth at which the measurements were carried out.

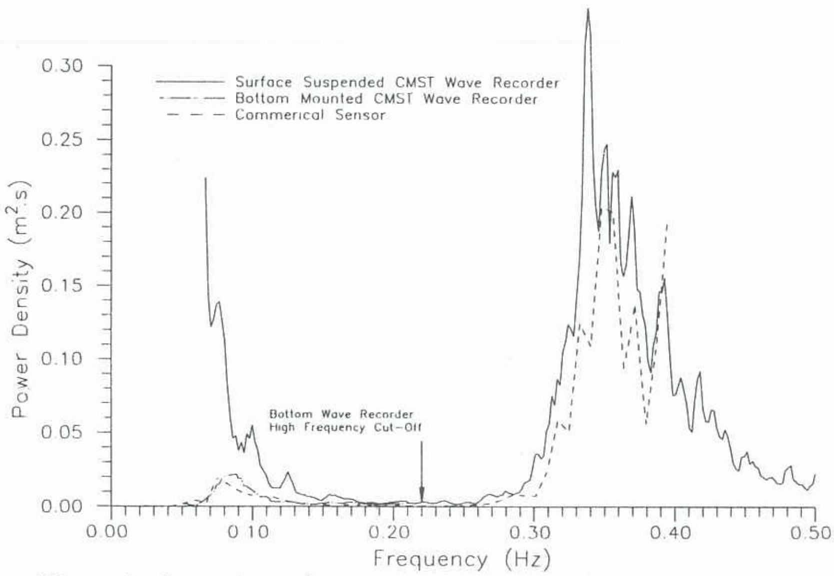

Figure 2 Comparison of wave spectra as measured by the Seadata 635-12 and surface and bottom mounted wave recorders

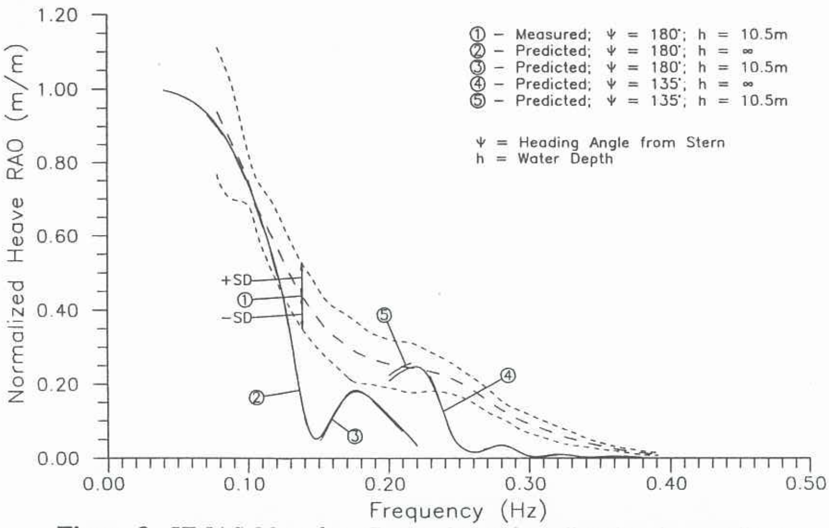

Figure 3 HMAS *Moresby*. Comparison of predicted and normalised measured heave response, for a water depth of 10.5m ($\frac{\text{water depth}}{\text{draught}}$ = 3.0)

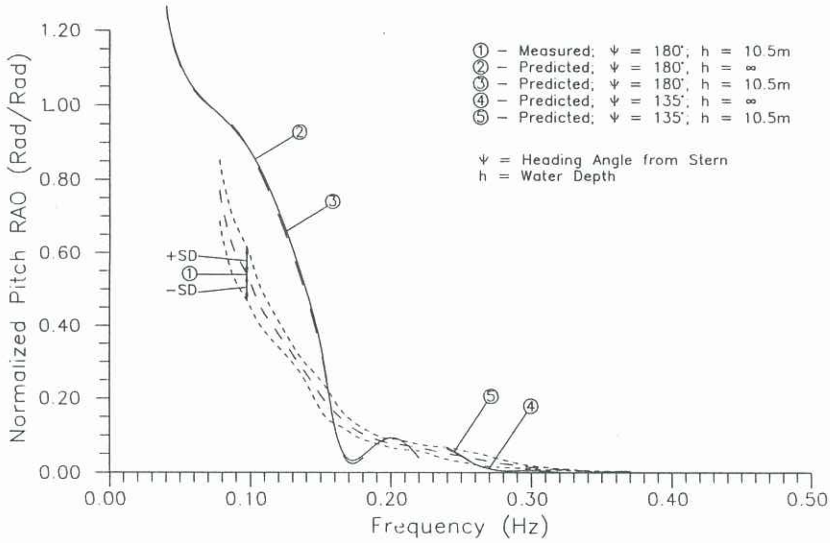

Figure 4 HMAS *Moresby*. Comparison of predicted and normalised measured pitch response, for a water depth of 10.5m ($\frac{\text{water depth}}{\text{draught}}$ = 3.0)

Again the full conformal mapping procedure was applied to the hull form of TRV *Tailor* and all but two sections mapped successfully. These two were mapped using Lewis sections. Motion predictions were then carried out for the vessel for infinitely deep water and at the four depths corresponding to the average depths at which the full-scale trials were conducted. These predictions showed that the effect on the RAOs of reducing the midship water depth to draught ratio to 2.80 was less than 5.0%. (see figs 5 & 6). The numerical predictions also showed the strong influence of heading angle on the vessel's response. There was general agreement between the measured and predicted RAOs, although measured responses were insufficiently accurate to indicate any change in the vessel's response with water depth.

CONCLUSIONS

A numerical prediction method for shallow water vertical motions based on a modified existing deep water strip theory program was developed. The limited water depth added mass and damping values calculated for a cylinder compared favourably with those obtained from published data. The correction to the two-dimensional added mass and damping could be improved by applying conformal mapping to the solution.

Full-scale trials results showed good general agreement with the numerical predictions, but as the experimental errors were relatively high, and the water depth to draught ratio generally above two, any change in the vessel's response with water depth could not be detected.

The heave and pitch RAOs from vessel trials did not tend to unity at low frequencies. This may be due to wave attenuation around the Marine Support Facility structure.

The response of the smallest vessel investigated appeared to be non-linear with respect to wave height in the high frequency wind waves. This behaviour should be investigated further and incorporated into the numerical predictions.

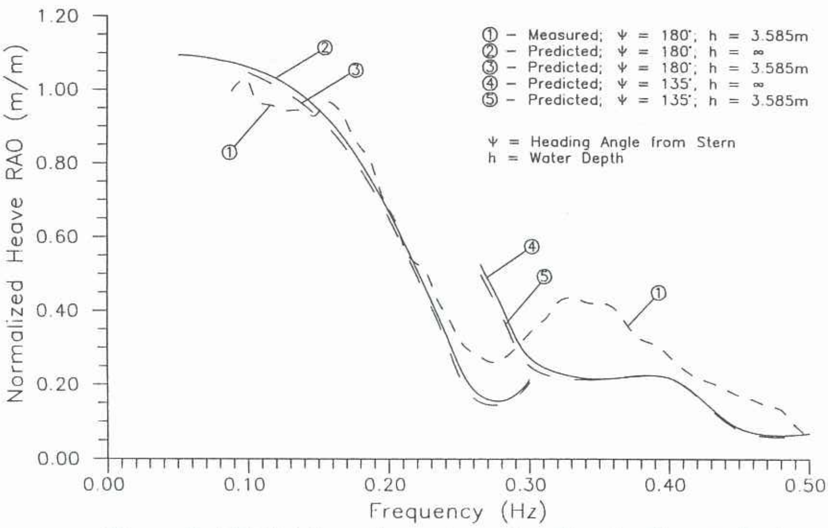

Figure 5 TRV *Tailor*. Comparison of predicted and normalised measured heave response, for a water depth of 3.585m ($\frac{\text{water depth}}{\text{draught}}$ = 2.8)

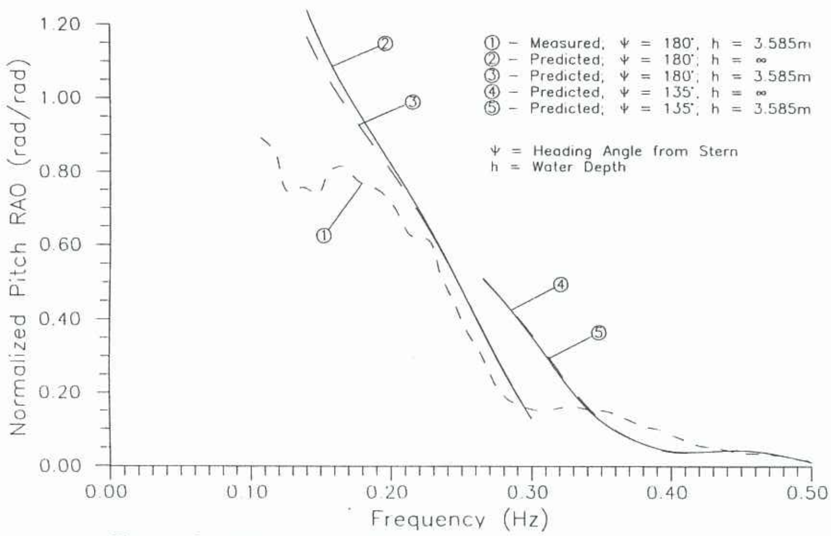

Figure 6 TRV *Tailor*. Comparison of predicted and normalised measured pitch response, for a water depth of 3.585m ($\frac{\text{water depth}}{\text{draught}}$ = 2.8)

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