ABSTRACT

The paper reports on partial results of the EU funded project SHEAKS dealing with the development of an advanced computer system suitable for the evaluation of wave induced motions and loads acting on fast ships in waves. In the framework of this project, BAZAN shipyard and the Ship Design Laboratory of NTUA have addressed the validation of the 3D seakeeping panel code NEWDRIFT by systematic comparison of numerically obtained data for a fast round-bilge monohull with model experimental results, obtained through an earlier experimental study performed at DTNSRDC on behalf of BAZAN shipyard.

KEY WORDS: Seakeeping, numerical validation, 3D panel code, forward speed, round-bilge monohull

INTRODUCTION

The present work refers to the validation part of the EU funded project SHEAKS (see, Perez de Lucas, 1997-2000), necessary to evaluate the individual performance of different seakeeping codes, available to or under development by the SHEAKS consortium partners. The integration of the validated codes will eventually lead to the formation of the integrated SHEAKS Computer System (CS), enabling the hydrodynamic and structural analysis of ships with forward speed in waves. The reported work should serve to evaluate the performance of a specific part of the SHEAKS CS regarding its possible exploitation in practice. The paper addresses specifically the numerical validation of the seakeeping code NEWDRIFT assigned to BAZAN.

NEWDRIFT is a six degrees of freedom, three dimensional panel program which allows the evaluation of motions and wave induced load, including drift forces, acting on arbitrarily shaped bodies, including shiplike structures, in regular waves and eventually in natural seaways by use of spectral analysis techniques.

The NEWDRIFT code has been initially developed on the basis of a linear, zero-speed 3D pulsating source potential theory (see, Papanikolaou, 1985), and was later extended to account for quasi second-order effects (see, Papanikolaou & Zaraphonitis, 1987) and finally for forward speed effects by consideration of a slender body theory and for the calculation of sectional loads by application of a beam theory (see, Papanikolaou & Schellin, 1992). The code includes the option for consideration of viscous roll damping (see, Ikeda, Himeno & Tanaka, 1978) and is currently reviewed to allow for the consideration of nonlinear, vertical plane motion damping effects (see, Papanikolaou et al, 2000).

The code calculates the 6 DOF motions of the ship (surge, sway, heave, roll, pitch and yaw), the motions and accelerations of specified points located on the hull, as well as the wave induced loads (forces and moments) at specified ship sections. In addition, the code delivers the hydrodynamic pressures along the wetted surface of the freely moving body hull, in response to a regular incident wave train. The prediction of the ship responses in natural seaways is herein accomplished by use of common, linear spectral analysis techniques, assuming the knowledge of the ship’s transfer functions (RAO’s), calculated by the main NEWDRIFT code module.

The present seakeeping validation study refers to the calculation of the transfer functions for the heave, pitch, roll and relative motions and accelerations, both at the stern and bow of a round-bilge fast monohull. In addition, a brief reference to the accuracy of application of linear spectral analysis techniques to the evaluation of ship’s performance in irregular waves is shown.

The ship model selected herein by BAZAN for the validation study is a BAZAN design, typical for small frigates or corvettes. It is a round bilge hull form, the seakeeping performance of which was studied earlier at the
David W. Taylor Naval Ship Research and Development Center (DTNSRDC) (see, Motter & Bishop, 1978) on behalf of BAZAN. The seakeeping model experiments were conducted in both regular and irregular waves at various headings and ship speeds.

**BASIC STRATEGY OF VALIDATION PROCEDURE**

The mathematical modelling of the responses of a given ship to a random sea by a linear response theory is nowadays a well-established concept (see, St Denis and Pierson, 1955). Ship spectral responses are calculated by simple multiplication of the squared ship’s transfer functions with a properly defined wave excitation spectrum, representing the natural seaway conditions, or by use of a discrete wave spectrum made-up of measured spectral ordinates.

For the purpose of the present validation study, it should be sufficient to analyse the accuracy of the obtained transfer functions, RAOs, in a quantitative and qualitative comparison with the experimentally obtained transfer functions and so to assess the validity and practicality of the employed numerical NEWDRIFT code. The comparison regards herein the transfer functions of heave, pitch, roll, the relative vertical motions and vertical accelerations, both at stern and bow fixed reference points. In addition, a comparison between experimental and computational results for the spectral responses to two different sea states is provided, in order to check the accuracy of the employed linear spectral theory when calculating ship responses to random seas. In this latter case, the mathematical representation of the calculatory input wave spectrum used for comparison with the experiments is the same discrete spectrum, as measured at the model experiments.

**DESCRIPTION OF THE SHIP MODEL TESTS AND OF MODEL TEST ANALYSIS PROCEDURE**

The hull form selected for the present validation study is a BAZAN round bilge fast monohull design. The main geometric particulars and the hull form of this ship appear in Table 1 and Figure 1, respectively. A wooden model of this hull was built in Spain and shipped to DTNSRDC for experimental testing. The model, built to a linear ratio of 19.75, was appended with appropriately scaled bilge keels, sonar dome, twin rudders and twin outboard rotating propellers. Note that only the influence of bilge keels was considered in the present numerical validation study.

For testing, the model was ballasted to correspond to the desired hydrostatic characteristics of the ship. It should be noted that initially assumed standard value for the roll radius of gyration, \( k_\phi \) (35% of the ship’s beam), was finally changed. Based on DTNSRDC full-scale data obtained from conducted sea trials aboard similar type of naval ships, this value was recommended to increase to a value close to 45 % of the beam. The finally accomplished roll radius of gyration by reballasting the existing model was 0.38 times the beam, which was the maximum possible radius without structural modification or extensive reballasting of the model.

The model was equipped with an electric motor and drive train for self-propulsion under the carriage, with a towing force applied only during the acceleration phase of each run.

![Table 1. Main particulars of tested round bilge ship](image)

During a test run, the propeller RPM was adjusted manually to keep the model centred axially under the carriage. The model was also fitted with a servo-controlled steering unit to drive the rudders. The rudder could be made to respond to either a manual or an automatic control command. In the auto-mode, steering was accomplished automatically by the servo system, which sensed sway and yaw error relative to the carriage. This mode was used during the test in all cases except for when ship control problems, induced by large waves in oblique headings, could not be remedied by adjustments of the rudder servo electronics. Propulsion power and rudder control signals were carried to the model, and transducer signals carried back to the carriage by means of an umbilical cable.

Wave elevation was measured by a boom attached to the carriage, extending approximately one ship length ahead of the model’s center of gravity, in order to avoid interference from model generated waves. The waves were generated by pneumatic type wavemakers using a sinusoidal function generator as the control signal. Wave, heave, sway and relative bow motions were measured by ultrasonic transponders. Electromechanical gyroscopes measured pitch, roll and yaw. Wire probes were installed at the stern, port and starboard locations, to measure relative stern motions.

With the instrumentation installed, lead weights were added to bring the model to the desired displacement. After trimming the model in water, the vertical center of gravity was measured by an inclining experiment, so that, ballast weights were raised accordingly to the desired transverse metacentric height. Pitch and roll radius of gyration were measured, as the natural periods of the model in air for each axis. A final trim check and inclining experiment prepared the model for the seakeeping experiments.

On typical runs, the model was accelerated by means of a towline. After a steady carriage speed was achieved, the towline was released and the model continued under its own power. Data collection then began, continuing until the carriage was required to stop at the end of the basin, where a second line attached to the stern was used to decelerate the model. During the run, small rudder action were automatically introduced as the model deviated from a
straight path under the carriage, and this in turn caused a small oscillatory roll motion to occur in many runs, which obviously, should theoretically not occur, especially in head waves. The time between the test runs was typically 15 to 20 minutes.

Regular and irregular wave experiments were conducted, with the model running at corresponding speed of 15 and 20 knots and in various wave heading angles (head, bow, beam, quartering and following wave trains, 180, 145, 90, 45 and 0 degrees respectively).

**Experimental procedure for regular waves excitation**

The motions of the model in regular waves excitation were measured for constant wave steepness and period. The commonly used wave height to wavelength ratio at the DTNSRDC experiments was 1/50, with additional steepness values included at certain conditions to check linearity of responses. For a slender hull, as the present one, ship responses are assumed to be linear for wave steepness of 1/50 or less.

Onboard data analysis consisted of harmonic analysis of the entire run length. This was followed up by a reanalysis to determine if the obtained data were corrupted by unsteady speed, poor wave generation or loss of data signals. In such a case, only the acceptable part of a run was used for final analysis.

**Experimental procedure for irregular waves excitation**

The wave spectra used for the irregular waves experiments were an approximation to a wave energy distribution of measured ocean wave spectra selected by BAZAN. The spectral energy distribution is a statistical function and subject to considerable variation from run to run, when reproduced during tests in a model basin. For avoiding possible error sources in the present validation study, the experimentally obtained wave spectrum was used to carry out the comparison between numerical and model experimental response values.

**Description of model test analysis procedure**

Since in the regular wave analysis all data should be nominally periodic in time, the basic procedure was to perform a harmonic analysis on all data channel for extracting the fundamental harmonics and for determining the transfer functions between the wave input and motion response output.

In the DTNSRDC experiments, data were digitised at a rate of 20 samples per second on each channel. The total number of encounter cycles collected on each run was typically between 5 and 10, as determined by model speed, wave period, and available run length. The initial step in the analysis was to determine the actual period of encounter by searching for the zero-crossing on the measured wave record. The average encounter period over the available run length was then used to determine the fundamental frequency, and a harmonic analysis of all the data channel followed using the same foundation. Essentially, a Fourier series analysis was used to fit the data, with the first few harmonics being considered. The quality of this fit was monitored by comparing the energy of the estimated first harmonic to the total energy of the signal. For most experimental runs this percentage indicated that the fitted data were close to a pure sinusoid and that the first harmonic was correctly captured. Finally, the transfer functions of the responses were determined by assuming that the first harmonics of responses represented the linear response. Thus, the ratio of the magnitude of a response first harmonic to the magnitude of the wave first harmonic defined the magnitude of the transfer function.

**DESCRIPTION OF HULL FORM DISCRETIZATION**

For the numerical validation study, the wetted surface of the ship’s hull was discretized by 2x100 surface elements (Figure 1).

![Figure 1. Surface discretization of round bilge ship hull](image)

The herein employed, relatively coarse discretization of 100 panel elements per half ship was considered acceptable for the initial design stage and for a preliminary evaluation of the performance of the NEWDRIFT code. But certainly this panel number limitation might have caused some inaccuracies in the calculated responses, especially at higher frequencies (shorter wave lengths). As a rule of thumb, for satisfactory numerical results the maximum panel length dimension should be not greater than 20% of the shortest studied wave length. Note that in the course of the SHEAKS project validation study much larger panel numbers of up to 800 panels, per ship half, have been considered. Note also, that with the selected coarse discretization of herein 2x100 panel elements, a 3% loss in displacement and a 5% moving back of the LCB result.

The hull form discretization and panelling has been herein accomplished by use of the geometry-panelling module GiD®, a software product of the SHEAKS partner CIMNE, embedded within the SHEAKS CS. Note, that within a separate task of the SHEAKS project, NTUA-SDL has been developing a WINDOWS version of the NEWDRIFT code, namely WINDRIFT, allowing the interactive preparation of the ship data input, including the geometry handling by GiD® or AUTOCAD® and the post-processing of the obtained results by PC environment standard graphic tools.
COMPUTATIONAL AND EXPERIMENTAL RESULTS

Presentation of regular waves results

At first, the measured data and calculations for the responses in regular waves are presented, as transfer functions of heave, pitch, roll, relative motions and accelerations. All symbols follow ITTC standard definitions. The results are plotted against the nondimensional wave frequency, \( \omega \sqrt{L/g} \). Presented quantities are made nondimensional, as follows: heave divided by wave amplitude, pitch and roll divided by wave slope, accelerations divided by wave amplitude and multiplied by length/gravity and relative motions divided by wave amplitude. Standard International Metric Units were used throughout. In the following graphs note that NEWDRIFT means numerical calculation by use of the NTUA-SDL panel code (2x100 panels) and BAZAN means corresponding model experimental values obtained at DTNSRDC (Motter and Bishop, 1978).

Figure 2. Transfer Functions for “Round Bilge 85m vessel” in regular head waves (\( \beta = 180^\circ \)) at 15.0 Knots.

Figure 3. Transfer Functions for “Round Bilge 85m vessel” in regular head waves (\( \beta = 180^\circ \)) at 20.0 Knots.
Figure 4. Transfer Functions for “Round Bilge 85m vessel” in regular bow waves (β=135°) at 20.0 Knots.

Figure 5. Transfer Functions for “Round Bilge 85m vessel” in regular beam waves (β=90°) at 20.0 Knots.
Figure 6. Transfer Functions for “Round Bilge 85m vessel” in regular quartering waves (β=45°) at 20.0 Knots.

Figure 7. Transfer Functions for “Round Bilge 85m vessel” in regular following waves (β=0°) at 20.0 Knots.
Presentation of irregular waves results

The following graphs show the spectral response densities for the round bilge ship at 20 knots in head, bow and beam waves (180, 135 and 90 degrees respectively), considering the irregular seaways excitation measured in each run. That means, the exciting wave spectrum used for the comparative numerical calculations is the same as the actually measured on site wave spectrum. For the above headings, the spectral densities of heave, pitch, roll, relative vertical motions and vertical accelerations, both at ship bow and stern are given. The theoretically impossible roll motion in head waves and the significant pitch in beam waves, which appear in the experimental records, should be considered, when comparing with the theoretical-numerical data. Especially, it should be noted that roll responses, for some headings, are much greater than predicted by calculation. This increased roll motion, along with some yaw motion, was observed during the experiments. The model appeared to be very responsive to small rudder movements and to dispose a strong roll-yaw coupling. Of course, these phenomena cannot be predicted by a regular seakeeping code, it is rather the scope of a manoeuvring simulation code, able to take properly into account the action of the seaway.

Note: The data marked in the graphs as SEA SPECTRUM BAZAN SS5 are the experimental data obtained at the DTNSRDC towing tank.

Figure 8. Spectral Density of “Round Bilge 85 m vessel” Ship Responses in Sea State 5 Head Waves at 20.0 Knots.

Figure 9. Spectral Density of “Round Bilge 85 m vessel” Ship Responses in Sea State 5 Bow Waves at 20.0 Knots.

PITCH SPECTRAL DENSITY 180 DEG HEADING 20 KNOTS
SIGNIFICANT AMPLITUDE OF EXP. PITCH = 2.86 deg
SIGNIFICANT AMPLITUDE OF NEWDRIFT PITCH = 3.00 deg

HEAVE SPECTRAL DENSITY 180 DEG HEADING 20 KNOTS
SIGNIFICANT AMPLITUDE OF EXP. HEAVE = 1.00 m
SIGNIFICANT AMPLITUDE OF NEWDRIFT HEAVE = 0.99 m

ACCEL. AT THE BOW SPECT. DENSITY 180 DEG H. 20 KNOTS
SIGNIF. AMPL. OF EXP. ACCEL. AT THE BOW = 0.45 g
SIGNIF. AMPL. OF NEWDRIFT ACCEL. AT THE BOW = 0.99 g

RELATIVE BOW MOTION SPECT.DENSITY 180 DEG H. 20 KNOTS
SIGNIF. AMPL. OF EXP. RELATIVE MOTION AT F.P. = 3.98 m
SIGNIF. AMPL. OF NEWDRIFT REL. MOTION AT F.P. = 2.75 m

ROLL SPECTRAL DENSITY 135 DEG HEADING 20 KNOTS
SIGNIFICANT AMPLITUDE OF EXP. ROLL = 3.12 deg
SIGNIFICANT AMPLITUDE OF NEWDRIFT ROLL = 1.53 deg

HEAVE SPECTRAL DENSITY 135 DEG HEADING 20 KNOTS
SIGNIFICANT AMPLITUDE OF EXP. HEAVE = 1.17 m
SIGNIFICANT AMPLITUDE OF NEWDRIFT HAVE = 1.29 m

RELATIVE BOW MOTION SPECT.DENSITY 135 DEG H. 20 KNOTS
SIGNIF. AMPL. OF EXP. RELATIVE MOTION AT F.P. = 3.49 m
SIGNIF. AMPL. OF NEWDRIFT REL. MOTION AT F.P. = 3.83 m

Figure 8.

Figure 9.
ANALYSIS AND DISCUSSION OF RESULTS

The main goal of the work, presented in this paper, is the validation of computational results for the ship responses in regular (harmonic) waves using the panel code NEWDRIFT and an assessment of the code’s usage in practical applications. This validation continues a large series of successful comparative studies for a large variety of applications (see, e.g., Papanikolaou & Schellin, 1992).

Regular wave results

Figures 2 and 3 show the ship responses for speeds of 15 and 20 knots in head waves. The measured heave-pitch response amplitude operators are excellently captured by the numerical code results at both speeds.

For the 20 knots case, the vertical accelerations at bow and stern are also satisfactorily predicted, except for the overprediction at the heave-pitch resonance region due to apparent nonlinear effects. The relative bow motion shows a substantial peak of resonance at the same frequency region, as expected. Note also, that the transfer functions approach a value of 1.0 in the high frequency waves range where the ship does not respond to the waves (total reflection). The experimentally obtained relative stern motion amplitude at the port propeller in head waves shows an interesting behavior: Although the experimentally and numerically obtained transfer functions go correctly to zero at low frequencies, at high frequencies the experimental values do not approach the value of 1.0 as the calculated theoretical data suggest. It should be mentioned that exact measurements at high wave frequencies are very difficult, because of the small associated signal values. As could be seen from the data, in high frequencies ship motions at ship stern are not as high as the bow ones, as expected.

Figures 4 respectively 5 show the transfer functions for 20 knots in bow quartering respectively beam waves. In the bow quartering (135 deg. heading) seas case, predictions can be considered in general fully satisfactory, except for the overprediction of the stern vertical acceleration and bow relative motion in the heave-pitch resonance region. In the beam seas case, the heave motion is equal to the wave amplitude at all frequencies. The nearly zero pitch is not shown. The important roll resonance peak appears clearly in both the experimental measurements and the code calculations and there are no significant differences between them. Bow and stern vertical accelerations are properly captured, but to a lesser degree the relative vertical stern motion. The set of figures 6 show the motion responses for 20 knots in stern quartering waves (45 deg heading). Model experiments in both stern quartering and following wave conditions, are difficult to conduct. In response to the low encounter frequencies, the model suffers large amplitudes in yaw and sway, with significant effect on measured roll motions. The rudder action necessary to maintain heading is known to be very significant and so is the effect on the roll response, which is trivially not considered in the herein calculated values. As a conclusion, there is a considerable scatter in the data shown in these figures, especially in the measured roll transfer functions, reflecting the complicated physics of the observed phenomena. Noting the unclear effect of the coupled sway-yaw and rudder motions on the experimentally obtained roll response, it is of importance to
register the calculatory low roll values in stern quartering waves. Anyway, the bow vertical accelerations and bow relative motions are well captured.

Finally, the set of figures 7 shows the responses for 20 knots in following waves. Heave and pitch decrease softly without peaks into the studied frequency range. Accelerations and relative motions are well captured by the numerical predictions.

Irregular wave results
The sets of figures 8, 9 and 10 show the different response spectra, obtained by using the same input, wave excitation spectrum as for the model experiments, with the ship running at 20 knots in head, bow-quartering and beam seas, respectively.

A brief comparison of the results for the heave and pitch spectral responses at the three headings show a quite satisfactory agreement for the heave-pitch motions, whereas the roll spectral responses, obtained in bow-quartering and beam seas appear non satisfactory, despite the relatively good agreement of the relevant roll responses in regular waves. A clear non-linear behaviour of roll in the measured roll responses is shown. In the bow-quartering waves case, namely, the roll spectrum peak is significantly shifted compared to the peak frequency of the fundamental wave spectrum, due to obvious nonlinear effects ("subharmonic resonance phenomena"). For both headings, the theoretically calculated significant amplitudes of roll appear quite small, compared to the measured ones and they possibly could not be used to extrapolate for the real ship's behaviour. However, note that the comparable experimental values have been obtained by use of an auto-piloted model, for which the keeping of the right course and speed, by continuous rudder and propeller action are beyond the range of assumptions of the employed seakeeping code.

On the other hand, the calculated bow acceleration spectra are overestimating measured responses in head waves, though they appear satisfactory for other wave headings. The deviations in head waves are apparently due to the observed overprediction of the peak response in regular head waves at frequencies near heave-pitch motion resonance (nonlinearities).

Calculated relative bow motion spectra are close to the measured ones, except for the overestimated peak values and the peculiar behaviour of the experimentally obtained spectral data for high and low frequencies in head seas. Note that a linear theory, as employed in the numerical code, is not able to account for the breaking bow head waves or slamming effects significantly affecting measured values. A different explanation seems meaningful for the beam waves case. Due to a relatively high pitch response, which proves to be much greater than the theoretically predicted, the calculated relative bow response is much smaller than the measured one. This latter observation comes again to stress the high impact of the rudder action leading to a strong pitch-yaw coupling in the attempt to keep the specified heading.

CONCLUSIONS
The present validation study relieved a good overall agreement between numerically obtained results and corresponding model experimental data. The degree of agreement is particularly satisfactory when careful attention is paid to the "quality" of the comparable experimental data (specific conditions of the model experimental procedures). Especially, in the experimental data reported herein for the autopiloted model in oblique seas, a high degree of dependence of the ship responses on rudder action was found, and this, of course, has to be taken into account when a seakeeping code validation work is performed.

In terms of bias and precision error regarding the measured ship responses, the following conclusions are possible. First of all, it is important to state that the relative error in the set of measured data is approximately 3-5% of the maximum value of the transfer function. On the other hand, referring to the compared transfer functions, the bias between two consecutive experiments is of the same order of magnitude as the precision error mentioned. Regarding the observed deviations in the irregular wave analysis, the additional difficulties occurring, when modelling the irregular sea conditions on the basis of a spectral approximation should be taken into account. Finally, the quite significant impact of the rudder action on the measured ship motions, especially in oblique seas, should be considered.

Under these circumstances, it is the opinion of the authors that a further improvement of the agreement between numerical predictions and experimental measurements is hardly achievable. The results reported herein clearly demonstrate that it is necessary, in terms of the possible agreement between numerically obtained data and towing tank measurements, to take special care with respect to the reliability of experimental measurements, in order to be absolutely sure that the reference basis for the comparison is correct. If this is not ensured, any conclusions about the reliability of employed computer codes will be under question, especially when trying to explain large deviations.

It is also clear that different hull forms, at different speeds, may be more or less sensitive than the present one with respect to test conditions such as frequency of encounter or wave steepness. In the course of the SHEAKS project a validation study for further three types of vessels is planned, namely a fast displacement monohull, a fast displacement catamaran ferry and a fast containership (see, Perez de Lucas, 1997). This study will include, also, the validation of theoretical predictions for the wave induced forces, based on experimental data of segmented model analysis.

For a regular wave analysis, commonly performed for obtaining qualitative and quantitative information for ship design optimisation and fine tuning, the main goal of the envisaged validation has been accomplished, as accurately as possible, based on the underlying assumptions taken in the development of a seakeeping program like NEWDRIFT. In this sense, we have reached the conclusion that this code matches the initial objectives of our project, as it was specified in the originally scheduled validation work.

1 Note that the experimentally determined significant pitch amplitude is 0.57 deg, whereas the computational one merely 0.07 deg)
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REFERENCES


Perez de Lucas, A. (1997-2000), Development of a Computer-Based System for Enhanced Seakeeping and Structural Design – SHEAKS, EU-BRITE EURAM project BE97-4342, 1997-2000. Project Consortium: BAZAN (co-ordinator, Spain), CIMNE (Spain), QUANTECH (Spain), NTUA-SDL (Greece), Alpha Marine (Greece), BEC (France), ENVC (Portugal), IGA (Germany).