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COMPARATIVE ANALYSIS OF SEAKEEPING METHODS: NUMERICAL, SOFTWARE SIMULATION AND EXPERIMENTAL STUDY

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ABSTRACT

The current study case presents a comprehensive comparison of seakeeping analysis methods, utilizing the seakeeping numerical analysis based on Lewis's form description of a hull, Ansys Aqwa, and experimental data obtained from the towing tank of the Faculty of Naval Architecture in Galati. The primary objective of this study is to assess the accuracy and reliability of two numerical approaches in predicting the seakeeping performance of a vessel under varying conditions. The experiment was carried out under two scenarios, one with the model at zero speed and another with the model towed at 1.28 m/s and 180^o heading angle. The diverse set of conditions aimed to simulate real-world scenarios and capture the dynamic nature of ship motions in waves. The employing of Lewis forms numerical analysis, Ansys Aqwa simulation, and experimental data, the results were compared and evaluated in terms of their accuracy and agreement.

Keywords: linear seakeeping, 3D-BEM analysis, experiment.

1. INTRODUCTION

Seakeeping performance is a vital factor in the design and operation of vessels, influencing their safety, efficiency, and comfort in varying sea conditions [1]. With advancements in computational methods and experimental techniques, the evaluation of a ship's behavior in waves has become more sophisticated, allowing for detailed predictions and assessments [2].

The current study bridges the gap between theory and practice by comparing various seakeeping analysis methods, focusing on numerical simulations based on Lewis's form description of a hull and Ansys Aqwa software, against empirical data from towing tank experiments. The vessel in question, a ship of significant commercial and naval relevance, serves as the study's subject due to its representative characteristics and the availability of detailed full-scale and model-scale data. The towing tank experiments were conducted at the Faculty of Naval Architecture in Galati, a facility renowned for its precision and advanced capabilities [3].

2. SHIP MODEL DESCRIPTION

The vessel's dimensions and hydrostatic properties play a crucial role in its seakeeping abilities. The length overall (L_{OA}) of the full-scale ship is 46.4 meters, with a corresponding waterline length (L_{wl}) of 44.151 meters, and a length between perpendiculars (L_{pp}) of 43.2 meters. The model used for the towing tank experiments was scaled down to a 1:16 ratio, maintaining geometric similarity and ensuring accurate representation of the full-scale ship's performance characteristics [5]. The model's corresponding dimensions were meticulously crafted, with a length overall of 2.9 meters and a waterline length of 2.759 meters [6].

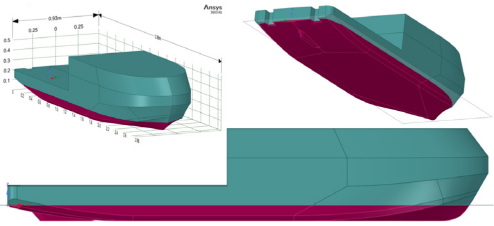

Fig.1 Survey model CAD geometry [8].

The breadth (B) and draught (T) of the ship are 13.0 meters and 1.5 meters, respectively, with the model reflecting these at 0.813 meters for breadth and 0.094 meters for draught. The longitudinal and vertical centers of gravity (LCG and VCG), along with the transverse metacenter height (GM_T), are critical for the ship's stability and were accurately replicated in the model.

Table 1. Model main particulars [3].

Characteristics	Symbol U.M.	Full scale	Model scale 1:16
Length (overall)	L_{OA} [m]	46.4	2.9
Waterline length	L_{WL} [m]	44.151	2.759
Length between perpendiculars	L_{BP} [m]	43.2	2.7
Main deck height, side	H_{side} [m]	3.25	0.203
Breadth	B [m]	13.0	0.813
Draught	T [m]	1.5	0.094
Longitudinal centre of gravity	LCG [m]	20.074	1.255
Vertical centre of gravity	VCG [m]	1.992	0.125
Transverse metacentre height	GM_T [m]	8.950	0.559
Displacement (volumetric)	∇ [m³]	680.97	0.166
Block coefficient	c_B	0.791	0.791
Amidship section coefficient	c_M	0.991	0.991
Waterline area coefficient	c_W	0.941	0.941
Number of elements	N_{EL}	-	3041
Average element length	d_x [mm]	-	48
Maximum GZ curve angle	φ_{max} [deg]	26	26
Water density	ρ [kg/m³]	1010.0	998.9
Ship and model speed	v[kn]:v[m/s]	10	1.28
Froude number	F_n	0.246	0.246

Displacement and various coefficients such as the block coefficient (c_b), amidship section coefficient (c_m), and waterline area coefficient (c_w) are essential for determining the ship's hull efficiency and seakeeping performance. These coefficients, along with the ship's displacement of 680.97 cubic meters, were preserved in the model to reflect the full-scale ship's physical properties.

3. ANALYSIS AND EXPERIMENT

The analysis conducted in this study case encompassed both static and dynamic scenarios [7]. The static scenario involved the model at zero speed, while the dynamic scenario included the model towed at a speed of 1.28 meters per second with a 180° heading angle. This dynamic condition aimed to replicate a full-scale ship speed of 10 knots, with both scenarios observing a Froude number of 0.246 to ensure similitude [6].

Fig.2 Towing tank model, Survey vessel [8].

The numerical analysis employed Lewis forms to describe the hull's geometry and its linear interaction with the water. In contrast, Ansys Aqwa provided a boundary element fluid dynamics (BEM) approach to simulate the vessel's response to wave-induced forces and moments [2]. The experimental data from the towing tank offered a tangible benchmark to evaluate the numerical methods' predictive capabilities.

The comparison focused on the accuracy and reliability of these numerical approaches in forecasting the ship's motions and the forces acting upon it in waves. By examining the results under various conditions, the study sought to understand the dynamics of ship motions and the effectiveness of simulation tools in a rather controlled environment, contributing to the advancement of the studies and numerical approaches in naval architecture and marine engineering practices [8].

Ansys Aqwa uses potential flow theory to model the hydrodynamic behavior of the ship or offshore structure. It assumes that the fluid is inviscid (fluid with zero viscosity), incompressible and irrotational, which simplifies the governing equations to the Laplace equation for velocity potential. Aqwa solves this equation using a boundary element method (BEM), which discretizes the wetted surface of the hull into a mesh of panels (Fig. 3). The software calculates wave loads using linear wave theory, which includes regular (sinusoidal) waves and irregular (stochastic) sea states based on wave spectra. For seakeeping analysis, Aqwa can consider the encounter frequency of the vessel with waves, which is a function of the vessel's speed and heading relative to the wave direction.

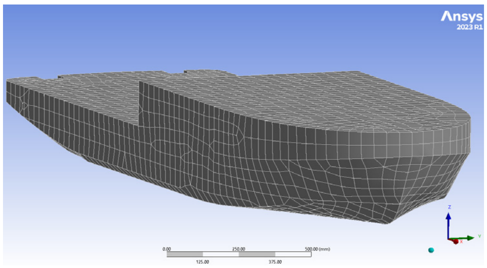

Fig.3 Ansys Aqwa diffracting model.

While the potential flow theory does not account for viscous effects, Aqwa can include viscous damping and other nonlinear effects through empirical data and correction factors. This includes the estimation of damping due to hull friction, wave breaking, and other phenomena that affect the accuracy of the simulation.

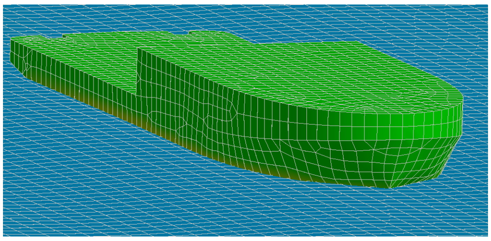

Fig.4 Diffracting model and free surface, Aqwa.

4. Results and Discussion

4.1 Overview

The figures below presented, illustrate the results from a seakeeping analysis comparing experimental data with numerical simulations using two different methods: a numerical dynamic seakeeping analysis employing Lewis's hull form description with the internal DYN program and Ansys Aqwa. The graphs display the Response Amplitude Operators (RAOs) for heave, pitch, and roll motions of a scale model vessel (1:16) under various conditions including stationary (v=0 m/s) and in motion (v=1.28 m/s) at different headings (μ=0°, 90°, 180°)[9]. The RAOs are plotted against wave frequency in Hertz (Hz).

4.2 Heave Motion Analysis

The heave RAO graphs depict the vertical motion response of the vessel to wave excitation. For the stationary condition (Figs.5,6,7), both numerical methods show a decreasing trend as frequency increases, which is consistent with the expected physical behavior where heave response typically decreases with increasing wave frequency.

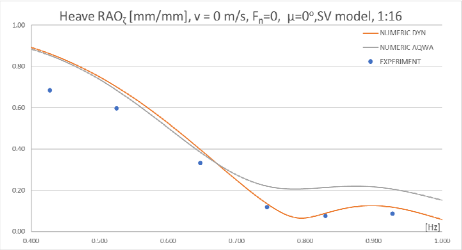

Fig.5 Heave motion result plot, v=0 m/s, μ=0°.

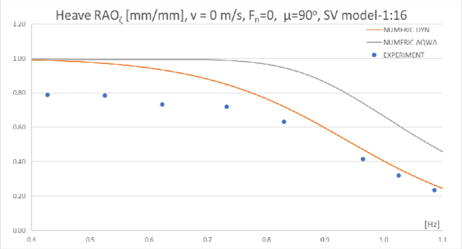

Fig.6 Heave motion result plot, v=0 m/s, μ=90°.

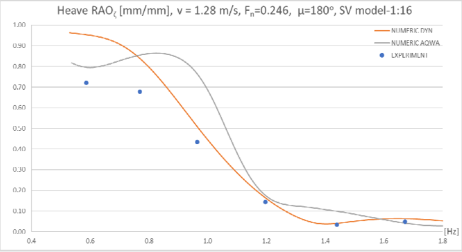

Fig.7 Heave motion result plot, v=1.28 m/s, μ=180°.

The experimental data points suggest a higher response in the lower frequency range compared to the numerical results, indicating potential differences in damping or stiffness in the actual model, not fully captured by the numerical simulations.

In the case of the model under tow (v=1.28 m/s), the heave response is higher, especially in the lower frequency range, which might be attributed to the increased energy input from the towing condition. It is evident that the experimental data points tend to follow the trend of the numerical dynamic analysis more closely than the Ansys Aqwa results, highlighting possible discrepancies in the simulation's modeling of the combined motion of the heave and the forward speed.

4.3 Pitch Motion Analysis

The pitch RAO graphs show the angular motion around the transverse y-axis. The experimental data, while sparse, indicate a peak response at mid-frequency ranges, which is typical due to resonance effects where the wave excitation frequency approaches the natural pitching frequency of the vessel.

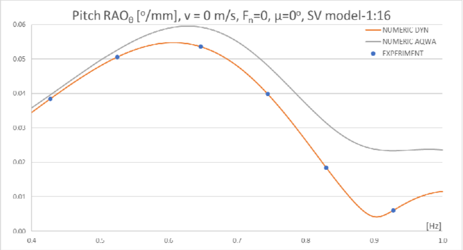

Fig.8 Pitch motion result plot, v=0 m/s, μ=0°.

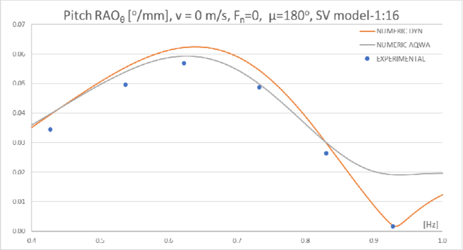

Fig.9 Pitch motion result plot, v=0 m/s, μ=180°.

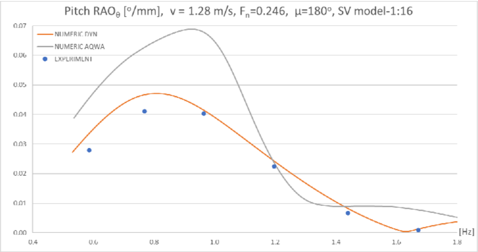

Fig.10 Pitch motion result plot, v=1.28 m/s, μ=180°.

The numerical dynamic analysis with the internal DYN program captures this trend with reasonable accuracy, although it appears to slightly underestimate the peak value compared to the experimental results, which can be justified by the lack of intermediate experimental points.

Ansys Aqwa's results show a less pronounced fall of the motion relative to wave frequency and a smoother curve, suggesting that it might be less sensitive to the resonance effects or that its damping model affects the results.

Figures 8-10, suggests that the Ansys Aqwa curve, indicated by the grey line, has a broader peak for pitch RAOs, which does not align as closely with the experimental data points. The peak occurs at a slightly higher frequency compared to the Numerical DYN, that shows a less pronounced response at the resonant frequency. After the peak, the Ansys Aqwa simulation predicts a steeper decline, suggesting it calculates a more significant reduction in pitch response as the frequency increases.

The Numerical DYN results curve from Figures 8-10, indicated by the orange line, shows a sharper peak that is closer to the experimental data points, suggesting a better correlation with the observed behavior during the experiments. The peak response is smaller than that of Ansys Aqwa, which implies that this simulation anticipates a smoother pitch response at the resonant frequency. The decline after the peak is more gradual, suggesting a less pronounced reduction in pitch motion with increasing wave frequency.

The experimental data points suggest the vessel's pitch response is less than what the Numerical DYN predicts at the resonant frequency. However, the data follows the general trend of the Numerical DYN more closely than Ansys Aqwa, particularly in the descending part of the curve after the resonant peak. This indicates that while the Numerical DYN method may slightly overestimate the pitch response, it seems to capture the overall trend more accurately than Ansys Aqwa.

4.4 Roll Motion Analysis

Roll motion analysis is only provided for the stationary condition with a 90° heading. The roll RAO graph is particularly significant because roll motion is often associated with the comfort and operational limits of the vessel.

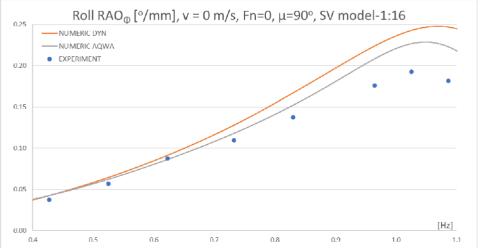

Fig.11 Roll motion result plot, v=0 m/s, μ=0°.

Numerical DYN result curve shows a progressive increase in roll motion RAO with frequency. It starts off lower at the beginning of the frequency range and increases more steeply after around 0.7 Hz, indicating a higher sensitivity to roll as the wave frequency increases.

The Ansys Aqwa results present a more conservative increase in roll motion RAO compared to the Numerical DYN. The initial response is similar to the Numerical DYN curve, but it diverges as the frequency increases, indicating less roll motion at higher frequencies. This could suggest that Ansys Aqwa is calculating higher damping or a different roll stiffness in the vessel's response.

The experimental data points display an increase in roll RAO with frequency, but the trend suggests a less aggressive increase compared to the Numerical DYN predictions. The data points are closer to the Ansys Aqwa results at higher frequencies, suggesting that the actual roll damping may be higher than what is estimated by the Numerical DYN simulation. At the lower end of the frequency spectrum, the experimental data points suggest a higher RAO than predicted by both numerical methods, which could indicate a discrepancy in the modeling of roll at lower frequencies or the presence of additional roll-inducing effects not captured in the simulations.

5. Conclusions

Heave Response Evaluation

The comparative analysis of the heave response under stationary and towing conditions revealed several key insights. Numerically, both the internal DYN program and Ansys Aqwa predicted a reduction in heave RAO with increasing frequency, which corroborates well with theoretical expectations of vessel behavior in waves. However, a discrepancy was observed in the lower frequency range, where experimental results exhibited a heightened heave response. This deviation suggests that there may be additional damping or stiffness mechanisms present in the physical model that the numerical simulations fail to encapsulate fully.

When assessing the model under tow, the heave response augmentation at lower frequencies may be attributed to the additional energy input from the towing action. Here, the experimental trend mirrored the numerical dynamic analysis more closely than the Ansys Aqwa results, potentially highlighting shortcomings in Ansys Aqwa's simulation approach in accounting for the combined effects of heave and forward motion.

Pitch Response Dynamics

The pitch motion analysis across the frequency spectrum displayed a characteristic peak at mid-range frequencies, indicative of resonance phenomena where the excitation frequency aligns with the vessel's natural pitching frequency. The internal DYN program's numerical dynamic analysis captured this peak with reasonable accuracy but displayed a slight underestimation when juxtaposed with the experimental results. This could be attributed to a paucity of intermediate experimental data points or to nuances in the physical experiment not reflected in the numerical modeling.

In contrast, Ansys Aqwa's simulation results presented a less defined peak and a smoother response decline post-resonance, implying a potential underrepresentation of the resonant effects or a difference in the damping model used. Notably, the Numerical DYN analysis provided a closer approximation to the experimental data, particularly in the trend observed post-peak, suggesting that it may offer a more precise prediction of pitch behavior during resonance despite its propensity to marginally overestimate the peak response.

Roll Motion Characterization

Roll motion analysis, conducted at a stationary condition with a 90° heading, held particular significance due to its implications for vessel comfort and operational limitations. The Numerical DYN model demonstrated a heightened sensitivity to increasing wave frequency, manifesting as a progressive and steep increase in roll RAO. This behavior contrasts with the more subdued escalation depicted by Ansys Aqwa, implying a divergence in the modeling of roll motion sensitivity, potentially due to differences in the estimated damping or roll stiffness.

Experimental data revealed an incremental rise in roll RAO with frequency, aligning more closely with Ansys Aqwa's predictions at higher frequencies. This alignment suggests that actual damping effects may be more pronounced than those estimated by the Numerical DYN model. Furthermore, the experimental data indicated a higher initial roll RAO than predicted by either numerical method, pointing to potential model limitations or the existence of additional physical effects inducing roll that are not captured by the numerical simulations.

Synthesis of Findings

The findings from this investigation underscore the complexity of accurately modeling seakeeping behavior. Despite the advanced capabilities of numerical simulation tools, clear variances between predicted and observed responses necessitate ongoing refinement of these models.

Particular attention is required for the accurate simulation of damping phenomena and the modeling of resonant frequencies to enhance the precision of seakeeping predictions. This study advocates for the integration of experimental validation within the modeling workflow to inform and improve the calibration of numerical tools, ensuring their robustness in the design and analysis of maritime vessels.

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