ABSTRACT

The paper presents experimental results from model tests with a containership advancing in abnormal wave conditions and comparisons with numerical simulations. A nonlinear time domain method based on strip theory is used for the calculation of vertical ship responses induced by abnormal waves. This code combines the linear diffraction and radiation forces with dominant nonlinear forces associated with vertical response arising from Froude-Krylov forces, hydrostatic forces and shipping of green water. The time domain simulations are compared directly with experimental records from tests with a model of a container ship in deterministic waves for a range of Froude numbers. Extreme sea conditions were replicated by the reproduction of realistic abnormal waves like the New Year Wave and abnormal wave from North Alwyn. Head sea condition is considered and the comparisons include the wave elevation, the vertical motions of the ship and the vertical bending moment at midship.

1 INTRODUCTION

Several methods varying from linear strip theory (Salvesen et al. [1]) to completely nonlinear method (Beck et al. [2], Subramani et al. [3]) have been developed to predict the ship response in moderate to extreme sea conditions. Practical application of most of the fully nonlinear methods is limited due to numerical complexity and the time consumed for running the numerical code while dealing complex hydrodynamic problem. In order to overcome such complexity, methods have been developed that use the partial nonlinear approach which makes use of the simplification of linear theory for the radiation and diffraction effects, while trying to incorporate the most important nonlinear contributions.

Several partial nonlinear methods have been developed where some nonlinearity is accounted for (Watanabe and Sawada [4], Xia and Wang [5]) and comparisons of their performance are available (Watanabe and Guedes Soares [6]).
The results presented here use the partial nonlinear numerical method developed by Fonseca and Guedes Soares [7], [8] to predict the ship response in extreme conditions. The method makes use of two dimensional strip theory to calculate the diffraction and radiation coefficients combined with nonlinear Froude-Krylov forces and hydrostatic forces calculated over the instantaneous wetted surface under the undisturbed wave profile.

To validate these codes, it is necessary to have sufficient experimental data for comparison. Unfortunately, there is insufficient experimental data available for the validation of these codes in extreme sea condition which include nonlinear phenomenon like green water shipping and increased dynamic swell up. O’Dea and Walder [9], Lloyd et al. [10], Buchner [11], Fonseca and Guedes Soares [12] [13] investigated on the problem of green water shipping by conducting experiment on ship advancing in waves. These studies revealed the effect of bow flare on shipping of green water and behavior of water on deck.

The interest to study abnormal waves and their effect on the ship responses has increased in the last several years. An abnormal, freak or rogue wave is generally understood as one that it outside the normal expectations for a given probability level, based on state of the art wave theories. Initially their characteristics were defined with reference to linear theory and later to second order theory, while more recently it has become increasingly clearer that even higher order theories are required to describe them. These assumptions are normally reflected in ratios like the abnormality index, which is the ratio of the wave height to the sea state significant wave height (Hs), or the crest ratio, which is the ratio of the wave crest to Hs. Reviews and additional information on those aspects can be found in Clauss et al. [14], Guedes Soares et al. [15] and Kharif, and Pelinovsky [16].

The response of ships and offshore platforms to time series containing one such wave have been studied, among others by Guedes Soares et al. [17][18], in some cases obtaining much higher responses than the design value and in other cases lower values. Therefore further studies are required to better understand the effect of this type of waves.

This paper presents the experimental study conducted in deterministic abnormal waves located at different positions along the length of a container ship moving with different Froude number. The experimental data is compared with the numerical results and a discussion is provided to explain the discrepancies observed.

**Experimental Setup**

The model tests are conducted in the seakeeping basin of the Ocean Engineering Division, Technical University Berlin (TUB), at model scale 1:70. The basin is 110 m long, with a measuring range of 90 m, the width is 8 m and the water depth is 1 m. On one side an electrically driven piston type wave generator is installed. The wave generator is fully computer controlled and a software is implemented to generate regular waves, transient wave packages, deterministic irregular sea states with defined characteristics as well as tailored critical wave sequences. On the opposite side a wave damping slope is installed to suppress interfering wave reflections.

To transfer the real-sea registrations into the wave tank, an optimization approach for the experimental generation of tailored wave sequences with predefined characteristics is applied (Clauss and Schmittner [19]). This method enables the generation of scenarios with a single high wave superimposed to irregular seas. During the experimental optimization, special emphasis is laid on the exact reproduction of the wave height, crest height, wave period as well as the vertical and horizontal asymmetry of the target wave. With this technique real-sea registrations including single abnormal waves are reproduced in the seakeeping basin, like the well known New Year Wave (Cherneva and Guedes Soares [20]; Clauss and Klein [21]), to evaluate the effect of these abnormal waves on floating structures.

This paper is concerned with the analysis of the response and structural loads acting on a containership subjected to abnormal waves. Table 1 presents the main dimensions of the containership.

<table>
<thead>
<tr>
<th>Length between perpendiculars [m], Lpp</th>
<th>117.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth [m], Bwl</td>
<td>20.2</td>
</tr>
<tr>
<td>Draught [m], T</td>
<td>8.1</td>
</tr>
<tr>
<td>Displacement [t], ∆</td>
<td>12499</td>
</tr>
<tr>
<td>Block coefficient [-], C_b</td>
<td>0.65</td>
</tr>
<tr>
<td>Longitudinal centre of gravity [m], Xcg</td>
<td>58.8</td>
</tr>
<tr>
<td>Vertical centre of gravity [m], Zcg</td>
<td>8.12</td>
</tr>
<tr>
<td>Transversal metacentric height [m], GMt</td>
<td>1.1</td>
</tr>
<tr>
<td>Scale of the model</td>
<td>1:70</td>
</tr>
</tbody>
</table>

Figure 1 shows the wooden containership model. For the investigation of the vertical wave bending moment, the model is subdivided into two segments at Lpp/2, being connected with three force transducers. Two transducers are installed close to the deck level and one underneath the bottom of the model. The force transducers register the longitudinal forces during the experiments. Based on the measured forces and the given geometric arrangement of the three force transducers the resulting vertical wave bending moment and the longitudinal forces are obtained. On this basis, the superimposed vertical wave bending moment resulting from the vertical and horizontal forces on the hull is determined.

During the tests the model is towed with an elastic suspension system consisting of a triangular towing arrangement that pulls the model without inducing a moment. The longitudinal motions are controlled with a spring in the front and a counter weight behind the model. That way, surge motions are restricted but heave and pitch motions remain unrestrained. The ship motions are recorded by an optical tracking system consisting of a seven by ten meter frame that
carries four infrared cameras which can be shifted parallel to the moving ship model. The system enables high precision, contact-free motion tracking over large distances by following the trajectories of infrared light emitting diodes mounted on the ship model.

Figure 1: Wooden model of the containership – at scale 1:70 - subdivided into two segments at the mainframe to measure the vertical wave bending moment.

The surface elevation has been measured at two positions with surface piercing resistance-type wave gauges installed on the towing carriage. The wave gauges have been installed in such a way that the surface elevation is determined at the forward perpendicular as well as at the midship section at the equilibrium position of the towing arrangement for the stationary ship – knowing that the ship slightly oscillates in x-direction due to the restricted but not eliminated surge motion. For the tests at stationary conditions the undisturbed surface elevation has been measured without the ship whereas it has been directly measured during the test runs for the cruising vessel since the radiated ship’s wave field does not affect the cruising wave gauges. Claus et al. [22] present further details of the experimental setup.

Table 2 gives a brief description of the list of experiments. The New Year Wave, which was measured at the Draupner platform in North Sea in 1995, was recreated in the tank. Abnormal waves at North Alwyn were measured in 1995 and 1997 with the abnormality index of $H_{max}/H_s = 1.92$.

Table 2: Predefined waves tested

<table>
<thead>
<tr>
<th>No</th>
<th>Type of wave</th>
<th>Target</th>
<th>Fn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>New Year Wave</td>
<td>Midship</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>New Year Wave</td>
<td>F.P</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>Abnormal Wave North Alwyn</td>
<td>Midship</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>Abnormal Wave North Alwyn</td>
<td>Midship</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>New Year Wave</td>
<td>F.P</td>
<td>0.06</td>
</tr>
<tr>
<td>6</td>
<td>New Year Wave</td>
<td>F.P</td>
<td>0.12</td>
</tr>
<tr>
<td>7</td>
<td>New Year Wave</td>
<td>F.P</td>
<td>0.18</td>
</tr>
<tr>
<td>8</td>
<td>New Year Wave</td>
<td>Midship</td>
<td>0.06</td>
</tr>
<tr>
<td>9</td>
<td>New Year Wave</td>
<td>Midship</td>
<td>0.12</td>
</tr>
<tr>
<td>10</td>
<td>Abnormal Wave North Alwyn</td>
<td>F.P</td>
<td>0.06</td>
</tr>
<tr>
<td>11</td>
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<td>Midship</td>
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<tr>
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<td>0.12</td>
</tr>
<tr>
<td>13</td>
<td>Abnormal Wave North Alwyn</td>
<td>Midship</td>
<td>0.18</td>
</tr>
</tbody>
</table>

In table 2, “Target” means the position on the ship model where the abnormal wave crest is generated, which is either the midship or the forward perpendicular. Only head waves and Several Froude numbers were considered.

2 FORMULATION OF THE NUMERICAL METHOD

The formulation of the numerical model is explained in detail in Fonseca and Guedes Soares (1998a, b). It will be briefly described here for an overview of the numerical code. A coordinate system fixed with respect to the mean position of the ship is defined, $X=(x, y, z)$ with $z$ in the vertical upward direction and pointing to the bow and $y$ perpendicular to the later and in the port direction. The origin is in the plane of the undisturbed free surface.

Flow is assumed to be inviscid and irrotational along with the strip theory assumption of small amplitude incident waves and small unsteady motion of the hull. Hull is slender and forward speed is assumed to be small. It is also assumed that longitudinal unsteady forces are negligible.

Equations of motion are obtained by equating hydrodynamic external forces to the mass and gravity forces and the equation is solved using time-domain method. Equating the hydrodynamic external forces to the mass and gravity forces one obtains the equations of motion. These equations, which combine linear and nonlinear terms, are solved in the time domain by a numerical procedure. For heave and pitch the equations are:

\[
\begin{align*}
\left[M + A_{33}^H\right] \ddot{\xi}_3(t) &= \int \left[K_{33}^H(t - \tau) \ddot{\xi}_3(\tau)\right] d\tau + C_{33}^H \dot{\xi}_3(t) + A_{33}^{\ddot{F}_3} \ddot{F}_3(t) + A_{33}^{F_3} F_3(t) + A_{33}^{K_3} K_3(t) - \int \left[K_{33}^\tau(t - \tau) \ddot{\xi}_3(\tau)\right] d\tau + C_{33\tau} \dot{\xi}_3(t) + A_{33\tau}^{\ddot{F}_3} \ddot{F}_3(t) + A_{33\tau}^{F_3} F_3(t) + A_{33\tau}^{K_3} K_3(t) - \int \left[K_{33\tau}^\tau(t - \tau) \ddot{\xi}_3(\tau)\right] d\tau + C_{33\tau}^\tau \dot{\xi}_3(t) + A_{33\tau}^{\ddot{F}_3} \ddot{F}_3(t) + A_{33\tau}^{F_3} F_3(t) + A_{33\tau}^{K_3} K_3(t) - \int \left[K_{33\tau\tau}^\tau(t - \tau) \ddot{\xi}_3(\tau)\right] d\tau + C_{33\tau\tau} \dot{\xi}_3(t) + A_{33\tau\tau}^{\ddot{F}_3} \ddot{F}_3(t) + A_{33\tau\tau}^{F_3} F_3(t) + A_{33\tau\tau}^{K_3} K_3(t) - \int \left[K_{33\tau\tau\tau}^\tau(t - \tau) \ddot{\xi}_3(\tau)\right] d\tau + C_{33\tau\tau\tau} \dot{\xi}_3(t) + A_{33\tau\tau\tau}^{\ddot{F}_3} \ddot{F}_3(t) + A_{33\tau\tau\tau}^{F_3} F_3(t) + A_{33\tau\tau\tau}^{K_3} K_3(t) - \int \left[K_{33\tau\tau\tau\tau}^\tau(t - \tau) \ddot{\xi}_3(\tau)\right] d\tau + C_{33\tau\tau\tau\tau} \dot{\xi}_3(t) + A_{33\tau\tau\tau\tau}^{\ddot{F}_3} \ddot{F}_3(t) + A_{33\tau\tau\tau\tau}^{F_3} F_3(t) + A_{33\tau\tau\tau\tau}^{K_3} K_3(t) - \int \left[K_{33\tau\tau\tau\tau\tau}^\tau(t - \tau) \ddot{\xi}_3(\tau)\right] d\tau + C_{33\tau\tau\tau\tau\tau} \dot{\xi}_3(t) + A_{33\tau\tau\tau\tau\tau}^{\ddot{F}_3} \ddot{F}_3(t) + A_{33\tau\tau\tau\tau\tau}^{F_3} F_3(t) + A_{33\tau\tau\tau\tau\tau}^{K_3} K_3(t)
\end{align*}
\]

(1)

where $\ddot{x}_3$ and $\ddot{\xi}_3$ represent respectively the heave and pitch motions and the dots over the symbols represent differentiation with respect to time. $M$ is the ship mass, $g$ is acceleration of gravity and $I_{55}$ represent the ship inertia about the y-axis.

The wave induced global structural dynamic loads at a cross section are given by the difference between the inertia forces and the sum of the hydrodynamic forces acting on the
part of the hull forward of that section. The vertical shear force and vertical bending moment are given respectively by:

\[ V_i(t) = I_i(t) - R_i(t) - D_i(t) - K_i(t) - H_i(t) - G_i(t) \]  

\[ M_i(t) = I_i(t) - R_i(t) - D_i(t) - K_i(t) - H_i(t) - G_i(t) \]  

where \( I_i \) represents the vertical inertia force (or moment) associated with the ship mass forward of the cross section under study. As assumed for the calculation of the ship motions, the radiation (\( R_i \)) and diffraction (\( D_i \)) hydrodynamic contributions for the loads are linear, and the Froude-Krylov (\( K_i \)) and hydrostatic (\( H_i \)) contributions are non-linear since they are calculated over the “exact” hull wetted surface at each time step. \( G_i \) represents the contribution for the structural loads of the green water on deck forces.

The formulation to calculate all hydrodynamic contributions for the loads is consistent with the formulation applied to solve the unsteady motion problem. The convention for the loads is such that the sagging shear force and hogging bending moment are positive.

The time domain formulation derived by Cummins [23] is used to represent the radiation forces in terms of unknown velocity potentials. The basic assumption is the linearity of the radiation forces. The radiation force in the \( k \)-direction due to an oscillatory motion in the \( j \)-mode is:

\[ F_{kj}^r(t) = -\frac{\partial}{\partial t} \left[ A_{kj}^m(t) - C_{kj}^m \xi_j(t) \right] - \int_0^\infty \left[ K_{kj}(t-\tau) \xi_j(\tau) \right] d\tau \]

where \( A_{kj}^m \), \( C_{kj}^m \) and \( K_{kj}(t) \) represent respectively infinite frequency added masses, radiation restoring coefficients and memory functions.

The restoring coefficients in (3) represent a correction to the hydrodynamic steady forces acting on the ship due to the steady flow. The convolution integrals represent the effects of the whole past history of the motion accounting for the memory effects due to the radiated waves. The memory functions and the radiation restoring coefficients are obtained by relating the radiation forces in the time domain and in the frequency domain by means of Fourier analysis:

\[ K_{kj}^m(t) = \frac{2}{\pi} \int_0^\infty \left( B_{kj}(\omega) \cos \omega t \right) d\omega \]

\[ C_{kj}^m(t) = \omega^2 \left[ A_{kj}(\omega) - A_{kj}^s(\omega) \right] - \int_0^\infty K_{kj}^m(\tau) \sin(\omega \tau) d\tau \]

where \( A_{kj}(\omega) \) and \( B_{kj}(\omega) \) are the frequency dependent added mass and damping coefficients calculated with a strip theory method (Salvesen et al. 1970).

The vertical forces associated with the green water on deck, which occurs when the relative motion is larger than the free board, are calculated using the momentum method (Buchner, 1995). The vertical force per unit length is:

\[ f_{gw}^{v}(x,t) = \left( \frac{\partial m_{gw}}{\partial t} \right) w + \left( g \cos \tilde{\eta} + \frac{\partial \tilde{\eta}}{\partial t} \right) m_{gw} \]

which includes one term that accounts for the variation of mass of water on the deck, the hydrostatic component and one term associated with the acceleration of the deck. \( m_{gw} \) represents the mass of water on the deck per unit length and \( w \) is the vertical velocity of the deck. The mass of water on the deck is proportional to the height of water on the deck, which is given by the difference between the relative motion and the free board of the ship. Finally the heave green water force and pitch green water moment are:

\[ F_j^{gw}(t) = -\int f_{gw}^{v}(x,t) dx \]

\[ F_j^{gw}(t) = \int x f_{gw}^{v}(x,t) dx \]

3 DIRECT COMPARISON OF EXPERIMENTAL DATA AND SIMULATIONS

This section presents the results of the comparison between experimental and numerical time series data. Numerical results are obtained from linear and nonlinear approach. In the linear approach all forces are linear and the green water effects are not included. Wave traces are simulated in the numerical code using Fourier transform of the experimental waves. Here the waves were measured at a point in space so that it coincides with the midship forward perpendicular of the ship that are reproduced exactly in the numerical code and the corresponding vertical responses were compared with the measured ones. All responses are presented for the full scale.

Figures 2 to 7 give the comparison between numerical and experimental results with the input waves measured at midship and forward perpendicular and the responses measured at midship. These calculations were done for both New Year Wave and the abnormal wave from North Alwyn and it was seen that the numerical codes are able to produce the exact experimental input waves in all cases. These runs were done separately for Froude numbers 0, 0.06, 0.12 and 0.18. Vertical response motions (heave and pitch) calculated using numerical method matches well with the experimental response motion even at extreme crest for both linear and nonlinear cases.

Figures 2 and 3 show the comparison of numerical and experimental responses for the New Year Wave acting on midship and forward perpendicular, respectively, of the ship for a Froude number 0. It is seen that maximum crest and trough occurs between 850 and 870 sec. Experiment and numerical input waves exactly follow each other and a slight deviation in heave and pitch response was visible only between 850s and
870s where the maximum input wave peaks occurs as shown in Figure 2. This trend was repeated for all other conditions and hence the plotting of the wave and response motions for rest of the cases was avoided.

Within the above mentioned time period where the abnormal wave occurs, it is observed that the experimental peaks of response motion is slightly higher than linear and nonlinear codes and there is a large discrepancy between the calculated vertical bending moment and experiment. Regarding the vertical bending moment, sagging peaks are larger than hogging peaks for both experiment and numerical results.

In the case of NYW peak forced at midship section (figure 2), the maximum hogging occurs when the abnormal wave crest is at midship and the maximum sagging peak occurs before that when the wave crest is approximately at forward perpendicular. The second sagging peak occurs after the largest crest passes through midship and the ship bow dives into the next wave crest. One observes a cut off of the second experimental sagging peak value due to some phenomenon. This phenomenon was observed in most of the experimental records, and it makes the second sagging peak always smaller than the first one.

![Figure 2](image-url)

**Figure 2** Experimental records and time domain simulations of the undisturbed New Year Wave elevation at Midship, heave, pitch and vertical bending moment at midship (Top graph with linear simulations and bottom graph with nonlinear simulations). Ship with Froude number of 0.

In the case of NYW peak forced at the forward perpendicular of the ship (figure 3), maximum sagging occurs when the largest wave peak is at forward perpendicular and maximum hogging occurs before the forward perpendicular encounters the following trough. The second largest sagging peak occurs when the bow encounter the following trough and this was verified from the corresponding positive pitch motion value which shows the bow down condition occurring.

![Figure 3](image-url)

**Figure 3** Experimental records and time domain simulations of the vertical bending moment at midship when the New Year Wave is at forward perpendicular (left graphs with linear and right graphs with nonlinear simulations). Ship with Froude number 0.
approximately at 870 sec. The occurrence of sagging peaks even when the bow encounters the wave trough is related to large relative motion of the ship. The additional buoyancy due to immersing of the bow section inside the water might have caused the second sagging peak. But this sagging peak value was cut off partially due to the presence of green water on the deck which imposes a downward force on the bow section of the deck giving rise to counter acting hogging moment, hence a reduction in the sagging value.

Figure 4 Experimental records and time domain simulations of the vertical bending moment at midship when the North Alwayn Wave is at midship or forward perpendicular (left graphs with linear simulations and right graphs with nonlinear simulations). Ship with Froude number 0.

Figure 5 Experimental records and time domain simulations of the vertical bending moment at midship when the New Year Wave and North Alwayn Wave is at forward perpendicular/midship (left graphs with linear simulations and right graphs with nonlinear simulations). Ship is advancing with Froude number of 0.06.
Regarding the numerical predictions, the linear method highly underestimates the sagging peaks while over predicts the hogging peaks. The nonlinear method is able to predict the largest sagging peak but highly over predicts the second largest sagging peak due to the immersing of the bow in the water. The model is not able to capture correctly the physical phenomenon happening at the second largest peak.

Similar tests were conducted to study the effect of the abnormal wave from North Alwyn on the ship responses and similar behavior as mentioned before was noticed and given in Figure 4. Here the nonlinear model captures the first largest sagging and hogging peaks, especially when the wave crest is at forward perpendicular and over estimate the second sagging peak arising due to bow immersion. The linear model over predicts the hogging peaks and under predicts the first sagging peak, while almost exactly predicts the second sagging peak, however this could be considered as mere coincidental due to the fact that linear model sagging peaks in most of the other investigated cases were less than the experimental ones. The nonlinear model is able to capture the hogging peaks when the wave crest is forced at forward perpendicular but slightly over predicts when the wave crest is at midship.

Figure 6 Experimental records and time domain simulations of the vertical bending moment at midship when the New Year Wave and North Alwayn Wave is forced at midship (left graphs with linear simulations and right graphs with nonlinear simulations). $F_n = 0.12$

Figure 7 Experimental records and time domain simulations of the vertical bending moment at midship when the New Year Wave and North Alwayn Wave is forced at forward perpendicular/midship (left graphs with linear simulations and right graphs with nonlinear simulations). Ship is advancing with Froude number of 0.18.

The aforementioned calculations were repeated for Froude numbers 0.06, 0.12 and 0.18 and are plotted in Figure 5 to 7. Similar trend as discussed in the previous paragraph was observed for linear and nonlinear models. We observe a general tendency for the linear model to over estimate the maximum hogging peaks and underestimate the two large sagging peaks, especially the first one. The nonlinear model was able to capture the hogging peaks and largest sagging peak.
when the wave crest is at forward perpendicular while largely over estimate the second largest sagging peak. It slightly overestimates the hogging peak when the wave crest is at midship section.

Figure 8 and 9 shows the comparison of numerical and experimental largest hogging peak and two adjacent largest sagging peaks occurring just before and after the hogging peak. As discussed before, linear hogging peaks were very high compared to experimental ones. Nonlinear hogging peaks were close to the experimental data when the wave crest is at forward perpendicular while the deviation is larger but less than linear model when the wave crest is at midship.

Nonlinear prediction of the sagging peaks corresponding to largest experimental sagging peak is very close, but it highly overestimates the second largest sagging peak which happens after the abnormal wave crest passes through midship and the ship’s bow goes down and immersed into the following wave. Basically the experimental data shows a reduction of the sagging moment from the first to the second peak, while the nonlinear model predicts the opposite. This reduction of experimental sagging peak can be, partially, attributed to green water effect on the deck and the numerical model is not able to calculate the exact green water height above the deck.

Figure 8 1st Sagging Peak (occurring just before the largest hogging peak) and largest hogging peak value comparison between experimental records and time domain simulations (linear and nonlinear) for different input waves, Froude number and locations along the ship. First letter, N or S, on the horizontal axis denotes respectively the New Year Wave and the North Alwyn Wave, followed by Froude number and location of input wave along the ship which is either at Midship (MS) or Forward Perpendicular (FP).

Figure 9 2nd Sagging peak value (occurring just after the largest hogging peak) comparison between experimental records and time domain simulations (linear and nonlinear) for different input waves, Froude number and locations along the ship. First letter, N or S, on the horizontal axis denotes respectively the New Year Wave and the North Alwyn Wave, followed by Froude number and location of input wave along the ship which is either at Midship (MS) or Forward Perpendicular (FP).
4 CONCLUSIONS

The paper presents direct comparisons between experimental time records and linear and nonlinear time domain simulations for a 117m container ship in extreme sea conditions. Predefined wave traces, corresponding to the New Year Wave and a freak wave measured at North Alwyn, were reproduced in the tank.

The calculated response motions compare well with the experiments. The vertical bending moment at midship calculated using linear method underestimates the sagging peak while overestimate the hogging peaks. Hogging peaks calculated using non linear method matches well with the experiments. There are two large sagging peaks, the first occurs when the ship’s bow encounters the abnormal wave crest and the second after this crest passes through midship and the ship bow dives into the following wave. The numerical method systematically over estimates the second large sagging peak.

The experimental second large sagging peak seems to be cutoff by some phenomenon that is not correctly represented by the numerical method. One possibility is that the green water forces on the forward deck are underestimated by the numerical model. In fact the green water events occur approximately in phase with the sagging peak and they produce a hogging effect.

5 ACKNOWLEDGEMENTS

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6 REFERENCES