Twenty-Eighth Symposium on Naval Hydrodynamics
PAPER INSTRUCTIONS

SUBMITTED FILE <u>MUST</u> BE IN PDF FORMAT WITH EMBEDDED FONTS. Paper may include color.

Site to upload PDF file to is https://onroutside.onr.navy.mil/aspprocessor/mec333_28/. Please contact Jennifer McDonald, Jennifer.McDonald1.ctr@navy.mil; phone: 540-645-0424, if you have any difficulties uploading your paper.

Please email the names and email address, phone and fax number of no more than three individuals to be discussers for your paper to Jennifer McDonald at Jennifer.McDonald1.ctr@navy.mil

PDF FORMAT

<u>*When uploading your file, the file name should consist of the primary author's last name followed by first initial and middle initial.</u>

PDF file should be no larger than 10MB. Graphics should be compressed or resolution reduced as much as possible without distorting image.

Instructions for embedding fonts:

1) Open Adobe Acrobat Distiller
2) Choose "Settings" from the pull-down menu
3) Choose "Job Options"
4) Click on "Fonts" tab
5) Check box titled, "Embed All Fonts" and click "OK"

LENGTH

Desired length of paper– 16 pages; maximum – 20 pages; one page for discussion/reply.

TEXT

1. Page size should be 8 1/2 x 11 inches, 10 pt. Times Roman or equivalent size font, single-space, 1-inch margins, and a two-column newspaper format. Pages should be sized to 8 ½" x 11" (not to A4).

2. Use 10-pt. Times Roman or equivalent for the font.

3. Leave one space between equations and text material.

4. Paragraph indentations should be one-half inch (tab set at 0.5).

5. All papers submitted shall use standard international (SI) units. Other units may be included in parentheses.

TITLE

1-1/2" margin at top of page. The title should be centered, in a Times New Roman 18-point font, bold. Authors' names should be 14-point, non-bold font. If the author(s) are from no more than two institutions, the name of the institution should follow the names of the authors from that institution, see samples 2 and 3. If there are more than two institutions and more than one author, then the institutions are subscripted, see sample 1.

HEADER

The following header should be placed in the top right corner of the first page of the paper and should be right aligned:

28th Symposium on Naval Hydrodynamics
Pasadena, California, 12-17 September 2010

FOOTNOTES

Footnotes are designated by superscript numerals, and are numbered in consecutive order starting with one. The text of the footnote should be 8-pt. Times Roman.

BIBLIOGRAPHIC REFERENCES

List all bibliographic references at the end of the paper. When referring to them in the text, type the author's last name and publication year in parentheses, preceding the period if it falls at the end of a sentence. References should be complete. In listing them, please follow the style recommended by the Engineers Joint Council and illustrated below (do not use separate headings for journals, book, etc.).

Journal Articles

Del Sasso, L.A., Bey, L.G., and Renzel, D., "Low-Scale C-Flight Ballistics Measurements of Guided Missiles," Journal of Aeronautical Sciences, Vol. 15, No. 10, Oct. 1958, pp. 605-608.

Books

Turner, M.J., Martin, H.C., and Leible, R.C., "Further Development and Applications of Stiffness Method," Matrix Methods of Structural Analysis, 1st ed., Vol. 1, Macmillan, New York, 1964, pp. 203-266.

Segre, E., ed., Experimental Nuclear Physics**.,** 1st ed., Vol. 1, Wiley, New York, 1953, pp. 6-10.

Reports

Book, E. and Bratman, H., "Using Compilers to Build Compilers," SP-176, Aug. 1960, Systems Development Corp., Santa Monica, Calif.

Transactions or Proceedings

Soo, S.L. "Boundary Layer Motion of a Gas-Solid Suspension," Proceedings of the Symposium on Interaction Between Fluids and Particles, Institute of Chemical Engineers, vol. 1, 1962, pp. 50-63.

EQUATIONS

Number the equations in sequence from equation (1) to the end of the paper, including appendices, if any. Enclose the equation numbers in parentheses and place them flush with the right-hand margin of the column.

ILLUSTRATIONS

All artwork, graphs, and tables should be inserted in the appropriate position within the file. Figures should be reduced to one-column width; in exceptional cases figures or tables may be extended across the page. Figure numbers, captions, and any explanatory legend should be below the figure. There should be a minimum of two line spaces between figures and text. If a full-width figure is used, the caption should be properly centered. Return to the column layout for the subsequent text. Color figures are permitted.

TABLES

Tables with a moderate amount of information should be positioned within one column. However, tables with a large amount of information may be extended across two columns. Information in tables should be no smaller than 8-pt. Time Roman. Again, there should be a minimum of two line spaces between tables and text. Table numbers and captions should be placed before the table text.

Sample titles and 3 pages of a sample paper follow, which show examples.

Sample Titles:

Sample 1

Failures, Fantasies, and Feats in the Theoretical/Numerical Prediction of Ship Performance

L. Larsson,[1,2] B. Regnström,[2] L. Broberg,[2] D.-Q. Li,[1,3] C.-E. Janson[2]
([1]Chalmers University of Technology, [2]FLOWTECH International AB,
[3]SSPA Maritime Consulting AB, Sweden)

Sample 2

Intelligent Regression of Resistance Data for Hydrodynamics in Ship Design

L. Doctors (University of New South Wales, Australia)

Sample 3

Some Remarks on the Accuracy of Wave Resistance Determination from Wave Measurements Along a Parallel Cut

F. Lalli, F. Di Felice, P. Esposito, A. Moriconi
(Istituto Nazionale per Studi ed Esperienze di Architettura Navale, Italy),
R. Piscopia (Universitá di Roma La Sapienza, Italy)

26th Symposium on Naval Hydrodynamics
Rome, Italy, 17-22 September 2006

Prediction of Vertical-Plane Wave Loading and Ship Responses in High Seas

Zhaohui Wang[1], Jinzhu Xia[2], J. Juncher Jensen[1] and Arne Braathen[3]
([1]Technical University of Denmark, [2]The University of Western Australia,
[3]Det Norske Veritas, Norway)

ABSTRACT

The non-linearities in wave- and slamming-induced rigid-body motions and structural responses of ships such as heave, pitch and vertical bending moments are consistently investigated based on a rational time-domain strip method (Xia, Wang and Jensen, 1998). A hydrodynamic model for predicting sectional green water force is also outlined for the investigation of the effect of green water loads on the global hull girder bending moment. The computational results based on the non-linear time-domain strip theory are compared with those based on the fully non-linear 3-D panel method SWAN-DNV and other published results.
From the rather extensive computations and comparisons, it is found that non-linear effects are significant in head and bow waves in the motion-wave resonant region for both heave and pitch motions, bow accelerations and vertical bending moments for two container ships considered, whereas not significant for a VLCC. The non-linearities in motions and structural loads of conventional monohull ships seem well predicted by the present non-linear strip theory.

INTRODUCTION

Linear strip theories and 3D linear potential theories have been widely accepted and used by naval architects as the main tools for estimating the performance of a ship in waves due to the relatively small computational effort and the generally satisfactory agreement with experiments. The difficulties come in higher and extreme seas and when trying to establish maximum lifetime loads for structural design.

Non-linearities in wave- and slamming-induced structural responses of ships have been observed from full-scale measurements and in model experiments. Strain measurements on ships with fine forms such as warships (Smith, 1966) and container ships (Meek et al, 1972) in moderate and heavy seas have shown that the wave-induced sagging bending moments can be considerably larger than the wave-induced hogging bending moments. The non-linearity in the vertical-plane bending moments has to be taken into account in structural design. To minimise wave-making resistance and enhance seakeeping performance at relatively high speed, fast vessels are usually designed with large length to beam ratio, large bow flare and low block coefficient. These properties put them outside the application range for the rules of the classification societies for hull girder loads calculation. Individual considerations based on direct calculation procedures are therefore required to derive the design loads (Zheng, 1999). Many empirical non-linear strip methods have been proposed predicting the non-linear wave- and slamming-induced structural loads with reasonably good accuracy (see the proceedings of the International Ship and Offshore Structures Congress (ISSC) and the International Towing Tank Conference (ITTC)).

The importance of the non-linearities in heave and pitch motions of ships was not recognised until late 1980's. In the benchmark seakeeping experiments carried out for ITTC on a standard hull form designated the S175 container ship by twenty three organisations, a significant scatter was found in some of the transfer function results for heave and pitch motions in head seas (ITTC, 1987). Later model tests by O'Dea, et al (1992) demonstrated a variation of the heave and pitch transfer functions with wave amplitude, indicating a non-linear motion behaviour. Recently, Kapsenberg and Brouwer (1998) showed that linear prediction of the heave motion may be insufficient if a ship hull is designed to minimise both resistance and wave-induced motions. Model testing at this stage is still essential in hull form optimisation for seekeeping performance.
In order to predict non-linearities consistently in both wave-induced rigid-body motions and structural loads,

a rational time-domain strip method was developed by Xia, Wang and Jensen (1998) for the vertical-plane problems. A higher-order ordinary differential equation was used to approximate the hydrodynamic memory effect due to the free surface wave motion. The hydrodynamic and restoring forces were estimated exactly over the instantaneous wetted surface. The 'momentum slamming' force was automatically obtained in the formulation. The fluid force expression was coupled with the structure represented as a Timoshenko beam to form a hydroelasticity theory. By specifying wave amplitudes, non-linear frequency response functions were presented for the S175 Containership in head seas, including the heave and pitch motions, bow acceleration and sagging/hogging bending moments, see Figure 1. Two different bow geometries of the ship were considered to demonstrate the relationship between the bow flare of ships and the non-linearity of the responses, see Figure 2. The predicted results were compared with available experimental data from the elastic model test made by Watanabe, Ueno and Sawada (1989) and the experimental investigation by O'Dea, Powers and Zselecsky (1992). Very good agreements were obtained between the predictions and the measurements for wave-induced rigid-body motions and bending moments.

A ship sailing in a heavy sea may experience shipping of water on the fore deck. The green water load may result in severe impact loading on the deck, the superstructure and the equipment mounted on the deck. Prediction of green water loads is especially important for fast ships and for FPSOs as shipping of green water may place severe operational restrictions on these kinds of vessels.

Recently, a significant research effort has been initiated to solve the problem. Model tests have been performed on FPSOs in MARIN (Maritime Research Institute Netherlands), and design guidelines are issued addressing the bow shape and the necessary freeboard and breakwater. However, the present numerical methods cannot predict correctly the green water loads due to the very complicated and non-linear water flow around the bow and over the deck. Volume-Of-Fluid (VOF) methods seem to be the most promising, but require significant improvement (Fekken, Veldmann and Buchner, 1999).

The extreme sagging wave bending moments in ships are usually determined by taking into account the non-linearities due to momentum slamming and hydrostatic restoring action. These non-linearities are very important to container ships with a large flare, yielding extreme sagging moments twice as high as those obtained by a linear analysis, see Figure 2. However, the effect of green water on deck is seldom included in the calculations of the sectional loads but if it is, the associated vertical forces are often based just on the static water head by which the relative motion exceeds the freeboard.

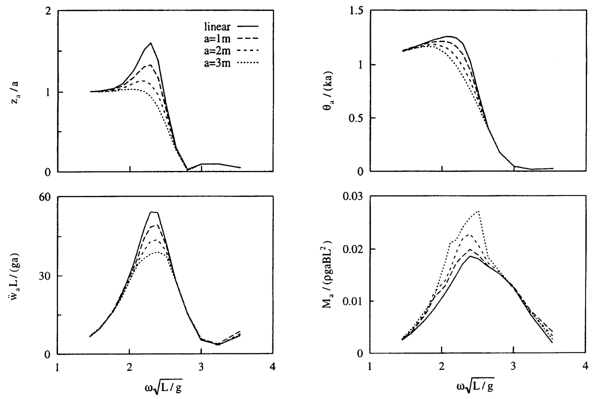

Figure 1: Calculated non-dimensional frequency response functions (FRF) of heave, pitch, bow acceleration (FP) and midship bending moment of the original S175 container ship for different regular wave amplitudes, Fn=0.25 (Xia, Wang and Jensen, 1998).

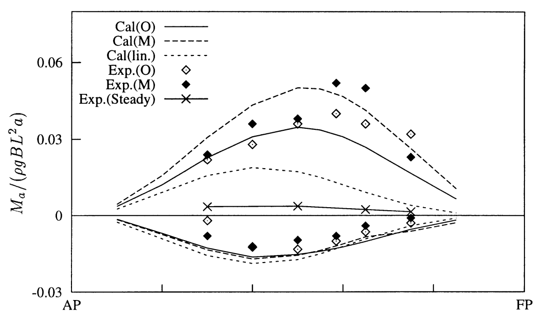

Figure 2: Non-linear sagging (positive) and hogging (negative) bending moments of the original (O) and the modified (M) S175 container ship, moving in regular waves, $\lambda = 1.2\ L$, a = L/60 and Fn=0.25. Comparison is made of the experiment (Watanabe et al., 1989) and the numerical calculation (Xia, Wang and Jensen, 1998).

Buchner (1994, 1995) has shown by measurements that the actual pressure due to water on deck might be several times larger than the static water head. A much more accurate description of this load was obtained by including a term proportional to the change of the momentum of the water on deck. Later, Wang, Jensen and Xia (1998) proposed a modified formula to account for the forward-speed effect of the ship. The concept of effective relative motion was used and a Smith correction factor was introduced to account for the wave pile-up effect during green water.

The present paper outlines several of the recent validations and applications of the non-linear hydroelasticity method for heave and pitch motions, vertical bending moments and other wave-induced responses of ships. A short introduction of the non-linear time-domain strip theory model will be given in Section 2. The modelling of the longitudinal distribution of green water loads will be introduced in Section 3. In Section 4, the non-linearities of wave loads and ship responses in head seas will be discussed for the S175 container ships. Comparison will be made of the present predictions with other numerical and experimental results, particularly, the fully 3-D non-linear simulation by SWAN-DNV (Adegeest, Braathen and Vada, 1998). Section 5 of this paper will be devoted to the prediction and validation of wave loads and ship responses in all headings for a panamax container ship and a VLCC. This will also demonstrate the relationship between the non-linearities and the hull forms.

THE TIME-DOMAIN STRIP THEORY

According to Xia, Wang and Jensen (1998), the non-linear time-domain hydrodynamic force *F*(*x*, *t*) at the longitudinal position *x* on the hull may be expressed by

$$\begin{cases} F(x,t) = \dfrac{DI}{Dt} \\ \sum_{j=0}^{J} \left(B_j I - A_j \dfrac{D\bar{z}}{Dt} \right)^{(j+1)} = 0 \end{cases} \qquad (1)$$

where *I* in represents both the impulsive and memory effects in the hydrodynamic momentum; *D*/*Dt* is the total derivative with respect to time *t*, $\frac{D}{Dt} = \frac{\partial}{\partial t} - U\frac{\partial}{\partial x}$, with *U* being the forward speed of the ship; $()^{(j)} = \frac{\partial^j}{\partial t^j}$; $A_j(x,\bar{z})$ and $B_j(x,\bar{z})$ are the so-called frequency-independent hydrodynamic coefficients derived by a rational approximation from the frequency dependent added-mass and damping coefficients. Furthermore, the relative motion $\bar{z}(x,t) = w(x,t) - \bar{\zeta}(x,t)$, where *w(x,t)* is the vertical motion of the hull and $\bar{\zeta}(x,t)$ is the wave elevation with Smith correction.

If the frequency-independent hydrodynamic coefficients $A_j(x,\bar{z})$ and $B_j(x,\bar{z})$ are taken as functions of only *x*, i.e. the change of wetted body surface is neglected, Equation (1) represents a time-domain counterpart of the linear strip theories, for example, Salvesen, Tuck and Faltinsen (1970). Generally, *J*=3 suffices for most sectional shapes for symmetric ship motion problems.

By integration of the higher order differential equation in Equation (1) and by incorporation of the hydrostatic buoyancy force f_b under the instantaneous wave surface and the green water force f_{gw}, the total non-linear external fluid force *Z*(*x*,*t*) acting on a ship section can be expressed as

$$Z(x,t) = -\bar{m}\frac{D^2\bar{z}}{Dt^2} + U\frac{\partial\bar{m}}{\partial x}\frac{D\bar{z}}{Dt} - \frac{\partial\bar{m}}{\partial\bar{z}}\left(\frac{D\bar{z}}{Dt}\right)^2 - \frac{Dq_J}{Dt} + f_b + f_{gw} \qquad (2)$$

where $\bar{m}(x,\bar{z})$ is the added mass of the ship section when the oscillating frequency tends to infinity; $\frac{Dq_J}{Dt}$ accounts for the 'memorial' hydrodynamic effect with q_J governed by the following set of differential equations

$$\begin{cases} \dfrac{\partial q_j(x,t)}{\partial t} = q_{j-1}(x,t) - B_{j-1}\, q_J(x,t) - (\bar{m}B_{j-1} + A_{j-1})\dfrac{D\bar{z}}{Dt} \\ q_0(x,t) = 0 \end{cases}$$

$$j = 1, 2, ..., J \qquad (3)$$

The third term of *Z*(*x*,*t*) in Equation (2) is the momentum slamming force. It is assumed to be zero when the ship section exits water. The still-water response of the ship due to the difference of the distribution of the weight and the buoyancy forces is ignored in the calculations.

MODELING OF GREEN WATER LOADS

A brief introduction to the formulation of the green water sectional force f_{gw} (in Equation 2) is given below, whereas a detailed derivation can be found in Wang, Jensen and Xia (1998) and Wang (2000).

The vertical load f_{gw} per unit length due to green water on deck in a longitudinal position *x* and at a time *t* is taken to be

$$f_{gw}(x,t) = -g m_{gw}(x,t) - \frac{D}{Dt}\left[m_{gw}(x,t)\frac{Dz_e}{Dt} \right] \qquad (4)$$

directed positively upwards. Here $z_e(x,t)$ is defined as the effective relative motion and m_{gw} denotes the instantaneous mass per unit length of green water.