Hull deflection in still water and in waves of a pipe layer barge

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Abstract. The evaluation of ship’s hull deflection in still water and in waves is an important step which has to be performed starting with early design stages. The different scenarios are depending on the loading cases to be considered as most dangerous ones which could appear during ship’s life time. The paper is focused on the evaluation of forces and moments in calm water and in waves, the last ones being a result of the motions and accelerations of a pipe layer barge in waves for a range of wave frequencies and heading angles. The static case is important due to the implications in the building process and docking. Consequently, the bending moments and shear forces in hogging and sagging conditions are evaluated. The dynamic case could have major implications during operational time when large dynamic forces and moments could lead to dramatic effects. The analysis has been performed and consists in the evaluation of Response Amplitude Operators (RAO) of motions and the induced forces and moments which are calculated based on a computer code using the potential theory. Then, hull deflections are evaluated using FEMAP-NX-NASTRAN.

1. Introduction

During early design stages of offshore structures there are several priorities to be considered due to the high impact on both structural integrity and operational costs. The major influences are practically dependent on the loading cases which could become relevant during ship’s life time.

From the static point of view, the most important effects are directly linked to the building process itself, after launching, when weights distribution versus buoyancy could lead to significant shear forces and bending moments. A particular aspect has to be considered when, due to transportation limitations like channels breadth, limited water depth, air draft, etc., different solutions have to be envisaged. A typical example is the double body solution, the two bodies going to be assembled on destination site. Then, very accurate alignment between the bodies is required and the floating conditions carefully controlled. The static case is also important due to the implications when docking is required and significant local forces and moments could yield, producing important permanent deformations of ship’s hull.

The dynamic analysis is mainly linked to the level of the sea states, defining the operational and survival conditions, depending on the type of operation, particularities of the location, etc. In these cases, a detail analysis is required in order to evaluate the hull induced forces and moments, in sagging and hogging conditions, due to irregular waves. The main steps to be followed are:

- Evaluation of the RAO (Response Amplitude Operators) of the motions for a range of wave frequencies. Spectral analysis is needed in order to calculate statistic values [3]. Mention should be
made that, for different types of floating structures and operations they have to perform, the motions have imposed limitations [10].

- Evaluation of the acceleration response spectra and the statistic values respectively, like average, root mean square (rms), significant (1/3), maximum, etc. The calculated values are compared with the existing recommendations [10] and then, to define the maximum operational limits for a range of heading angles, $\mu = 0^\circ \div 180^\circ$, where $\mu$ represents the angle between the floating body and the wave [6].

- Evaluation of the RAO of shear forces and bending moments along ship girder for a range wave frequencies and heading angles in the range $\mu = 0^\circ \div 180^\circ$. The next step consists in the evaluation of the spectral response for a range of sea states, calculating the statistic values corresponding to the sea spectrum which better simulates the specific conditions on location. Then, the wave design principle can be used in order to define the upper limit of the sea state the floating structure can resist from the structural point of view, using the maximum accepted values by the classification societies [4].

Based on the above mentioned calculations the hull deflections in static conditions and in dynamic ones, i.e. on waves, have been evaluated. The applications were carried out for a pipe layer barge operating on specific locations. Three different loading cases have been considered in order to be able to evaluate the influences on motions and induced forces and moments. [5].

2. Hull deflections in still water

As previously mentioned, three different loading cases have been considered, representing the light ship condition Loading Case 1 (LC1) and two distinct operating conditions Loading Case 2 (LC2) and Loading Case 3 (LC3) respectively. The characteristics of the three loading cases are presented below together with the graphic representation of the load distribution and the static induced shear forces and moments in sagging and hogging conditions. The results are synthetically presented in table 1. The calculations have been carried out using NAPA software.

The main dimensions of the barge are:

- Length overall, $L_{OA} = 96.00$ [m];
- Length between perpendiculars, $L_{PP} = 92.40$ [m];
- Breath, $B = 33.00$ [m];
- Depth, $D = 4.00$ [m].

The main characteristics of each loading cases are given below.

- **Loading Case 1:**
  - Displacement = 3317 [t];
  - Draught = 1.07 [m];
  - Vertical position of the centre of gravity, including free surface corrections, $K_G$ (fluid) = 4.10 [m];
  - Metacentric height including free surface corrections, $GM$ (fluid) = 81.73 [m];
  - Roll radius of gyration, $K_{XX}$ = 8.935 [m];
  - Pitch radius of gyration, $K_{YY}$ = 27.645 [m];
  - Yaw radius of gyration, $K_{ZZ}$ = 27.431 [m].

![Figure 1. Schematic representation of weight distribution – Loading Case 1 (LC1)](image1)

![Figure 2. Shear forces and bending moments, LC1](image2)
Loading Case 2:

Displacement = 5976 [t];
Draught = 1.92 [m];
Vertical position of the centre of gravity, including free surface corrections, KG (fluid) = 3.62 [m];
Metacentric height including free surface corrections, GM (fluid) = 44.84 [m];
Roll radius of gyration, K_{XX} = 8.493 [m];
Pitch radius of gyration, K_{YY} = 25.477 [m];
Yaw radius of gyration, K_{ZZ} = 25.397 [m].

Loading Case 3:

Displacement = 6716 [t];
Draught = 2.16 [m];
Vertical position of the centre of gravity, including free surface corrections, KG (fluid) = 4.00 [m];
Metacentric height including free surface corrections, GM (fluid) = 39.77 [m];
Roll radius of gyration, K_{XX} = 7.994 [m];
Pitch radius of gyration, K_{YY} = 23.739 [m];
Yaw radius of gyration, K_{ZZ} = 23.688 [m].
Table 1. Maximum shear forces, sagging and hogging moments and their locations

| Still water forces and moments | Maximum shear forces | Maximum sagging moment | Maximum hogging moment |
|-------------------------------|----------------------|------------------------|------------------------|
| Value                         | -213.4 t             | 0.0 t                  | 4461.3 tm              |
| LC1                           | 184.3 t              |                        |                        |
| Distance x, from the aft perpendicular (AP) | 62.7 m              | 13.2 m                 | 44.9 m                 |
| Value                         | -491.0 t             | -3752.4 tm             | 2182.9 tm              |
| LC2                           | 302.1 t              |                        |                        |
| Distance x, from the aft perpendicular (AP) | 26.4 m              | 50.4 m                 | 14.1 m                 |
| Value                         | -575.7 t             | -5015.6 tm             | 2862.3 tm              |
| LC3                           | 353.7 t              |                        |                        |
| Distance x, from the aft perpendicular (AP) | 27.6 m              | 4.8 m                  | 14.4 m                 |

The hull deflections results corresponding to Loading Case 2 in static conditions are presented in figure 7 and the representation of the results, using FEMAP-NX-NASTRAN, in terms of vertical hull deformations, is presented in figure 8.

![Figure 7. Hull deflection values corresponding to LC2 case](image1)

![Figure 8. Representation of vertical hull deflection](image2)
3. Motion evaluations
The evaluations of the Response Amplitude Operators (RAO) of the motions have been performed by using a computer code based on the theory developed by Salvesen, Tuck and Faltinsen [8]. The computer code is using the "close fit source distribution technique" developed by Frank. Based on the calculation of the velocity potential (solving the classical boundary problem with initial conditions) the pressure distribution on the hull is obtained using Bernoulli’s equation. Integrating the pressure on the wetted surface of the body the hydrodynamic diffraction forces and moments, induced by regular waves, are obtained. Then, by solving the hydrodynamic boundary problem with initial conditions, the evaluation of the amplitudes and phases for all six degrees of freedom [1], i.e. surge, sway, heave, roll, pitch and yaw motions become possible [2]. The coordinate system is shown in figure 9. A detailed analysis for a larger number of heading angles is presented in [3], [4]. In the present paper only the motions corresponding to the heading angle $\mu = 0^\circ$ and for the heading angle $\mu = 45^\circ$ are presented. Mention should be made that due to the symmetry of the body the $0^\circ$ case is similar to $180^\circ$ one and $45^\circ$ similar to $135^\circ$. For $\mu = 0^\circ$ the results are presented below in figure 10, figure 11 and figure 12. For the $45^\circ$ case the results are presented in figure 13 to figure 18.

Figure 9. The coordinate system for motions analysis

Figure 10. RAO’s surge motions; $\mu = 0^\circ$

Figure 11. RAO’s heave motions; $\mu = 0^\circ$

Figure 12. RAO’s pitch motions; $\mu = 0^\circ$
4. Wave induced forces and moments and hull deflections results

The evaluation of the induced forces and moments has been performed using another option of already mentioned computer code [6]. To this purpose, instead of the radii of inertia, the input data are the mass distributions corresponding to the same loading cases used for motions calculations.

The influences of the mass distribution can be identified based on the comparative diagrams. To this purpose only relevant results have been selected, for 0° and 45° heading angles. Mention should be made that the wave induced forces and moments compared with the still water values ratios could lead to the evaluation of a “dynamic effect coefficient”. The diagrams presented below can be also looked as response amplitude operators of the induced forces and moments as far as all results are expressed per unit wave amplitude [7]. The coordinate system for wave induced forces and moments are shown in figure 19.
The results for \( \mu = 0^\circ \) case

The results for the heading angle \( \mu = 0^\circ \) are presented in figure 20 and figure 21. The notation \( \varsigma_a \) represents the amplitude of the regular wave.

![Figure 19. The coordinate system for wave induced forces and moments](image)

**Figure 20.** Vertical shear force, \( F_z \), along ship length (\( \mu = 0^\circ \))

![Figure 21. Vertical bending moment, \( M_y \), along ship length (\( \mu = 0^\circ \))](image)

**Figure 21.** Vertical bending moment, \( M_y \), along ship length (\( \mu = 0^\circ \))

The results of the corresponding hull deflections are presented in figure 22 and the representation for all three loading cases, LC1, LC2 and LC3 in figure 23, figure 24 and figure 25, respectively.
4.2. The results for $\mu = 45^\circ$ case

The results of the evaluations of the induced vertical shear forces, torsional moments and vertical bending moments corresponding to the heading angle $\mu = 45^\circ$ are presented in figure 26, figure 27 and figure 28. The notation $\varsigma_a$ represents the regular wave amplitude. The representation of the hull deflections is presented in figure 29 and the representation in figure 30.
Figure 26. Vertical shear force, $F_z$, along ship length ($\mu = 45^\circ$)

Figure 27. Vertical bending moment, $M_y$, along ship length ($\mu = 45^\circ$)

Figure 28. Torsional moment, $M_x$, along ship length ($\mu = 45^\circ$)
5. Conclusions
All the results presented in the paper have been practically used in order to fulfil the first steps during the preliminary design stages related to the evaluations of the different parameters to be used. The main sections of the paper represent the steps necessary to be followed for a complete analysis, starting with the static analysis, followed by motions calculations, induced forces and moments and continued by hull deflection evaluations.

In order to have a reliable way to understand the influence of weight distribution effects, three different loading cases have been selected. Mention should be made that the first loading case, close to light ship condition, became relevant after ship launching, when a precise evaluation of hull deflections is important. As previously mentioned, such kinds of evaluations are mandatory for docking purposes in order to avoid possible hull deformations. Moreover, the so-called static analysis is an important step required by the classification societies and is an essential tool for the adjustment of ship’s trim when the ballast water could significantly affect the still water shear forces and bending moments.

When dynamic analysis is performed, the wave induced forces and moments and the still water ones ratio could lead to a “dynamic effect coefficient” which gives an important input related to the mass distribution effects on hull deflections. From this point of view, the results are supporting the conclusion that, generally speaking, based on comparative diagrams of motions, induced forces and moments and hull deflections, the higher displacements are leading to lower dynamic effects.

Mention should be made that the values graphically represented in figure 20 and figure 21, for a heading angle of $\mu = 0^\circ$, and figure 26 to figure 28 for a heading angle of $\mu = 45^\circ$, represent, in fact, the amplitudes of the induced forces and moments per 1 m amplitude of the regular wave, which,
moreover, do not appear simultaneously. Practically, similar to the motions analysis, the above mentioned diagrams are the Response Amplitude Operators (RAO’s) of the induced efforts and have to be regarded as the envelope of the maximum amplitudes displayed on the entire range of wave frequency.

It has to be underlined that, in some cases, when the numerical codes fail to provide reliable results or, for a more accurate evaluation, experimental tests to be carried out in towing tanks, on segmented models, are mandatory [9]. Anyway, the experimental tests are always required in order to validate the theoretical approaches.

6. References

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