Dynamic response investigation of a small size floating dock unit in irregular oblique waves

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Abstract. The floating dock units, according to the operation schedules, from time to time have to be relocated to different shipyards, involving river or coastal routes. In this study, the dynamic behaviour of a small size floating dock during relocation is analyzed, with two constructive types of the floating structure above the dock pontoon deck and a maximum length of 60 m. By the floating dock and tug ship system resistance prediction, results a maximum towing speed around 18 km/h (9.72 kn). So, the numerical analysis is carried on for a set of five speed values, between 0 and 18 km/h. The dynamic response in irregular waves of the floating dock, full heading angle set, is computed by own program code. The irregular waves intensity is prescribed in terms of statistical wave significant height, with the maximum values corresponding to the Lower Danube River way and the Black Sea Coastal on Romanian area. The statistical dynamic responses, in terms of motion and acceleration significant amplitudes, are checked out against the short-term seakeeping criteria, in order not flood the dock pontoon deck. The study results are pointing out the limit navigation conditions for safety during the small size floating dock relocation operation.

1. Introduction
In many shipyards the hull assembling process is done using floating dock units [1]. According to their operation schedules the floating docks are relocated between working places using river–costal routes. For the relocation operation the dynamic behaviour of the floating dock must be analyzed, considering realistic environment conditions, with oblique irregular waves [2,3,4].

The floating dock dynamic response is obtained by the own program DYN-OSC [5], solving first the motion equations in regular waves for response amplitude operator’s computation and second the statistical short-term response in irregular oblique waves [3,6]. The safety of the dock relocation operation is assessed by seakeeping criteria, formulated as statistical significant limit values of motion and acceleration amplitudes, selected in order to avoid the flooding of the dock pontoon deck. The theoretical bases for the program code are presented in section 2.

This study is developed for the relocation analysis of a small size floating dock with maximum length of 60 m and two constructive versions with (CWT) and without (NWT) continuous wing tanks above the dock pontoon deck [7,8]. In the case of relocation, the floating dock is considered in the light displacement case, without a docking ship on the dock pontoon deck. Section 3 presents the main characteristics of the floating dock for the two constructive versions.

The response amplitude operators RAO, for the main motion components, heave, pitch and roll, are computed by DYN-OSC [5] program, under the regular wave excitation. The comparison of the RAO
functions for the two floating dock constructive versions is presented in section 4, considering the influence of the dock towing speed and heading angle.

For the dynamic response in oblique irregular waves, the Lower Danube and the Black Sea Coast routes are considered, resulting specific limits of the waves intensity [2]. In the analysis a set of five trial speeds and a full range of heading angle are considered. Imposing the seakeeping criteria, the safety navigation limits for the floating dock result. The comparison of the navigation capabilities during relocation of the two floating dock versions is presented in section 5.

2. Theoretical basis of the floating dock dynamic response analysis method

For the analysis of the floating dock dynamic response during relocation, the own program DYN-OSC [5] has been used, with the main algorithm presented in figure 1.

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Figure 1. The algorithm of the DYN-OSC [5] program for floating dock dynamic response analysis.
The algorithm for the dynamic response analysis includes the following main steps (figure 1).

- **(1) the floating dock model data selection** includes the offset lines for the external shape up to the dock pontoon deck which must be not flooded (figures 3.a,b), mass distribution over the dock length (figures 4.a,b), main characteristics of the hull (table 2) as $\Delta$, LCG, KG displacement, longitudinal and vertical ship’s gravity centre (section 3). As input data, also the limits for the irregular waves’ intensity have to be provided, in terms of the statistical significant wave height. For the river route on the Lower Danube way the wave limits are $H_s = 0.6, 1.2, 2.0$ m and near the coast of the Black Sea the wave limit is $H_s = 2.568$ m, correlated to the dock length according to the rules [2].

- **(2) the floating dock still water equilibrium.** Based on an iterative non-linear approach, the still water equilibrium parameters [9,10] are obtained for each floating dock version (table 2). Also based on an iterative non-linear approach, with trim correction, the transversal stability diagram [9,10] is obtained for the floating dock (figure 5).

- **(3) the RAO response amplitude operators.** Considering a potential flow hydrodynamic model by a 2D strip theory model and conformal transformation of the transversal stations parameterization by Lewis method, the hydrodynamic masses and damping are obtained [5,6,10]. The time domain motion equations are linearized and the dynamic response is obtained directly in the frequency domain [3,5,10]. The heading angle covers a full range of 360 deg., with a 5 deg. searching step, $\omega = 0-3$ rad/s and $\sigma = 0.001$ rad/s, for each towing speed. So, the response RAO functions on heave, pitch and roll motions, corresponding to the case of regular unit amplitude wave excitation, are obtained (section 4).

- **(4) the statistical short-term response.** For the irregular waves modelled statistically by the power density ITTC spectrum [2,3,5] (figure 2) and maximum wave significant height $H_{\text{rms}} = 2.568$ m, the response spectra and moments are obtained for heave, pitch and roll motions [5,6]. The most probable amplitude response is equal with the RMS root mean square value [3,5], being the reference used for the seakeeping criteria assessment.

- **(5) polar diagrams by seakeeping criteria.** The motion and acceleration amplitude limits (equations 1-3, table 1) are selected according to the constructive type of the floating dock, in order not flood the dock pontoon deck. The seakeeping criteria are formulated in terms of the evaluation of the maximum most probable dynamic response RMS, resulting the polar diagrams for limit waves intensity, as significant height $H_{\text{rms}}$ and $B_{\text{limit}}$ Beaufort level [3,5], for the assessment of the navigation capabilities of the floating dock with the two constructive versions (section 5).

\[
\text{heave: } RMS_{\text{z,max}} = H_{\text{ide}} - f_s \cdot T_{\text{fore,aft}} \geq RMS_{\text{z}} ; RMS_{\text{ac}}z_{\text{max}} = 0.05g \geq RMS_{\text{ac}}z 
\]  

\[
\text{where } RMS_{\text{z}} = RMS_{\text{z}} + 0.5 \cdot L \cdot RMS_{\text{g0}} + 0.5 \cdot B \cdot RMS_{\text{g}} + 0.25 \cdot H_{\text{s}} ; f_s = 0.075, 0.3 m 
\]

\[
\text{pitch: } RMS_{\psi_{\text{max}}} = 1^{\circ} \geq RMS_{\psi} ; RMS_{\text{ac}}\psi_{\text{max}} = 0.1g/(L/2) \geq RMS_{\text{ac}}\psi 
\]

\[
\text{roll: } RMS_{\phi_{\text{max}}} = 4^{\circ} \geq RMS_{\phi} ; RMS_{\text{ac}}\phi_{\text{max}} = 0.15g/(B/2) \geq RMS_{\text{ac}}\phi 
\]

![ITTC Wave Spectrum](image1)

Figure 2. Wave spectrum, $H_s \leq 2.568$ m.[2,3,5].

| Criteria / Version | CWT | NWT |
|-------------------|-----|-----|
| Motions criteria (heave, pitch, roll) | | |
| $RMS_{z_{\text{max}}}$ [m] | 0.965 | 0.900 |
| $RMS_{\psi_{\text{max}}}$ [rad] | 0.01745 | |
| $RMS_{\phi_{\text{max}}}$ [rad] | 0.06981 | |
| Accelerations criteria (heave, pitch, roll) | | |
| $RMS_{ac}z_{\text{max}}$ [m/s²] | 0.49050 | |
| $RMS_{ac}\psi_{\text{max}}$ [rad/s²] | 0.03270 | |
| $RMS_{ac}\phi_{\text{max}}$ [rad/s²] | 0.14715 | |
3. The small size floating dock with two constructive versions

Table 2 presents the main characteristics of the small size floating dock and the still water equilibrium draught [7]. There are considered two constructive versions, with (CWT) or without (NWT) continuous side wing tanks on pontoon deck. Figures 3.a,b and figures 4.a,b present the offset-lines and the mass diagrams for the two versions of the small size floating dock. Figure 5 presents the transversal stability diagram GZ for the floating dock versions. The maximum possible towing speed is around 18 km/h, based on the dock-tug 4000 HP resistance analysis [3] (figure 6), with trial speeds \( v = 0.5, 10, 15, 18 \) km/h.

![Figure 3.a CWT offset-lines (continuous WT)[7].](image1)
![Figure 3.b NCWT offset-lines (non-cont. WT) [7].](image2)

![Figure 4a. CWT mass diagram (continuous WT) [7].](image3)
![Figure 4b. NCWT mass diagram (non-cont. WT) [7](image4)

![Figure 5. GZ[m] stability diagram CWT & NWT](image5)

![Figure 6. DOCK – TUG resistance prediction.](image6)

**Table 2.** The main characteristics of the small size floating dock [7].

| Floating dock type (WT type) | CWT | NWT | Length overall \( LOA \) [m] | Long. centre of gravity \( LCG \) [m] | Vert. centre of gravity \( KG \) [m] |
|-----------------------------|-----|-----|-------------------------------|---------------------------------|------------------|
| 60                          |     |     | 30                           | 3.891                          | 1.777            |
Breadth \( B [m] \) 20  Number of elements \( Ne \) 200
Height pontoon \( H_P [m] \) 2  Average element length \( \Delta x [m] \) 0.300
Height side wing tank \( H_{WT} [m] \) 8  Inertial mass moment \( J_c [m] \) 57260 47656
Displacement \( \Delta [t] \) 1152 960  Metacentre height \( GM_{T0} [m] \) 31.124 40.059
Draught mean, fore, aft \( T [m] \) 0.960 0.800  Max. GZ ref. angle \( \phi_{GZ} [\text{deg}] \) 23 25

4. The small size floating dock response amplitude operator for the two constructive versions

Based on the own program DYN_OSC (figure 1), the response amplitude operators for the small size floating dock are obtained. Figures 7,8 present the heave \( RAO_z \) and pitch \( RAO_{\theta} \) for CWT, \( v=0 \) km/h, and for NWT the \( RAO's \) are similar due to the prismatic dock pontoon. Figures 9,a,b present roll \( RAO_{\phi} \), \( v=0.18 \) km/h, with significant differences between the two versions due to the stability data (figure 5).

![Figure 7. RAO_z [m/m] heave, CWT, \( v=0 \) and 18 km/h.](image)

![Figure 8. RAO_{\theta} [rad/m] pitch, CWT, \( v=0 \) and 18 km/h.](image)
The differences of RAO roll functions and the heave and pitch RAO similar functions are justified also by the resulting natural oscillations frequencies of the floating dock from table 3.

**Table 3.** The small size floating dock natural oscillations frequencies and periods.

| Motion | CWT continuous side wing tanks | NWT non-continuous side wing tanks |
|--------|--------------------------------|-----------------------------------|
|        | Heave $\zeta$ | Pitch $\theta$ | Roll $\phi$ | Heave $\zeta$ | Pitch $\theta$ | Roll $\phi$ |
| $\omega_p$ [rad/s] | 0.860 | 0.825 | 2.428 | 0.862 | 0.825 | 2.790 |
| $T_p$ [s] | 7.306 | 7.616 | 5.188 | 7.289 | 7.616 | 2.252 |

5. The small size floating dock short-term statistical response for the two constructive versions

Based on the RAO’s functions (section 4) and the irregular waves spectrum (figure 2), the short-term statistical response most probable motion and acceleration amplitudes for the small size dock are obtained, versions CWT (figures 10.a-f) and NWT (figures 11.a-f). Table 4 presents a synthesis of maximum RMS values. Imposing the seakeeping criteria (equations 1-3, table 1) the polar diagrams for navigation safety limits $H_s \text{limit}$ & $B \text{limit}$ assessment are obtained, versions CWT (figure 12.a) and NWT (figure 12.b). Table 5 presents a synthesis of the waves intensity limits for the navigation safety fulfillment.

**Table 4.** The maximum RMS amplitudes for the floating dock (units same as table 1), ref. $H_s=2.568$ m

| Version | CWT continuous side wing tanks | NWT non-continuous side wing tanks |
|---------|--------------------------------|-----------------------------------|
| mot/acc | RMSZ | RMSG | RMSG | RMSacZ | RMSacG | RMSacG | RMSZ | RMSG | RMSacZ | RMSacG | RMSacG |
| adm. | 0.965 | 0.017 | 0.070 | 0.491 | 0.033 | 0.147 | 0.900 | 0.017 | 0.070 | 0.491 | 0.033 | 0.147 |
| 0 km/h | 1.846 | 0.022 | 0.050 | 0.425 | 0.018 | 0.149 | 1.775 | 0.022 | 0.035 | 0.430 | 0.018 | 0.151 |
| (max) | 91.27% | 25.54% | -28.2% | -13.3% | -46.3% | 1.55% | 97.19% | 25.34% | -49.3% | -12.3% | -45.8% | 2.31% |
| 18 km/h | 2.007 | 0.023 | 0.050 | 0.487 | 0.031 | 0.173 | 2.073 | 0.023 | 0.070 | 0.494 | 0.031 | 0.187 |
| (max) | 108.0% | 32.55% | -28.2% | -71% | -5.35% | 17.31% | 130.3% | 32.46% | 0.45% | 0.75% | -3.95% | 27.25% |

![Figure 9a. $RAO_\phi$ [rad/m] roll, CWT, $v=0.18$ km/h](image1)

![Figure 9b. $RAO_\phi$ [rad/m] roll, NWT, $v=0.18$ km/h.](image2)
Figure 10. \(RMS_{\text{max}}\) heave, pitch, roll motions maximum most probable amplitudes, CWT & NWT.

Figure 11. \(RMS_{\text{max}}\) heave, pitch, roll accelerations maximum most probable amplitudes, CWT & NWT.
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Table 5. The wave’s intensity limits for the navigation safety of the small size floating dock.

| $v$ [km/h] | $H_s$ limit [m] | $B$ limit | $H_s$ limit [m] | $B$ limit |
|------------|----------------|-----------|----------------|-----------|
| CWT        | 1.456          | 3.09      | 1.418          | 2.93      |
|            | 1.382          | 2.75      | 0.990          | 0.89      |
|            | 1.981          | 0.89      | 1.915          | 0.59      |
| NWT        | 1.071          | 0.97      | 0.938          | 0.85      |
|            | 0.708          | 0.64      | 0.708          | 0.56      |
|            | 1.285          | 0.626     | 1.899          | 0.45      |
|            | 1.739          | 4.04      | 1.825          | 4.35      |
|            | 1.889          | 4.45      | 1.939          | 4.25      |

Figure 12a. Polar diagrams for navigation safety limits $H_s$ limit & $B$ limit, CWT floating dock version.

Figure 12b. Polar diagrams for navigation safety limits $H_s$ limit & $B$ limit, NWT floating dock version.

6. Conclusions
Based on the own program DYN [5] (figure 1), the safety of a small size floating dock (figures 3.a,b, table 2) during relocation operation in irregular waves has been analyzed and the next conclusions result: 1. Due to the prismatic shape of the pontoon, the heave and pitch $RAO$’s (figures 7,8) are similar for the two dock versions. Also the heave and pitch natural frequencies are similar (table 3).
2. Due to the transversal stability characteristics (figure 5, table 2), the roll RAO’s (figures 9.a,b) of the two dock versions are recording significant differences. Because the roll natural frequencies are larger than 2 rad/s (table 3) the roll hydrodynamic damping is reduced, resulting higher roll RAO peaks.

3. On any motion component, due to the changes of the wave encountering frequency $\omega_e$ (figure 1, SSTR block), heading angle $\mu$ and towing speed $v$ have a significant influence on RAO’s (section 4).

4. For wave reference $H_s=2.568$ m the maximum most probable response amplitudes RMS’s (table 4) are compared to the seakeeping criteria limits (equations 1-3, table 1). The excessive response results on heave at side, aft or fore, combined motions (figures 10.a,b) over 91.19-130.3%, pitch motion (figures 10.c,d) over 25.34-32.55% and roll acceleration (figures 11.e,f) over 1.55-27.25% (more on NWT and beam sea). The roll motion (figure 10.e,f) and heave acceleration (figures 11.a,b) have a small overvalue 0.45-0.75% for NWT and none for CWT. The pitch accelerations criterion (figures 11.c,d) is satisfied in any case.

5. From the polar diagrams (figures 12.a,b, table 5) the navigation limits result, $H_s=0.626-2.003$ m, due mainly to the reduced freeboard at head, follow, oblique sea and excessive roll accelerations due to small roll period (table 3, $T_\phi \leq 2.6$ s) at beam sea. For dock relocation safety, there must be considered: a reduced towing speed, avoid the beam sea condition and a special approval for costal route is required.

7. References

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