Strength investigation of a small size floating dock unit by 3D-FEM models in head design waves

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Abstract. This study is focused on floating docks strength analysis by 3D finite element models, full extended over the dock length. The equilibrium position of the dock in the design equivalent quasi-static waves environment is obtained by own code, based on a non-linear iterative procedure. For the surrounding water and ballast tank water loads we have developed user procedures and functions implemented in the finite element programs. Also the still water conditions are analysed. The numerical study is developed for a small size floating dock, designed for multiple shipyards operation, with 60 m length and two constructive versions, having continuous and non-continuous side ballast tanks. As main operation cases of the small size floating dock are considered: light without docking ship, full ballast at maximum upper deck limit, three docking ship tests, with ship mass uniform, sagging and hogging type distributions, according to the shipbuilding classification societies rules. As assessment criteria, the 3D model yielding stress limit for global and local strength, buckling factor and maximum vertical deflection are considered. Also the freeboard criterion is considered. The results of the study are delivering the operation limits, in terms of design wave height, in order to ensure the strength safety rules requirements.

1. Introduction
The floating dock units are widely used in shipyards in many operation conditions [1]. At any floating dock design stage, for the main operating cases, the global and local strength in head equivalent design waves (EDW) has to be assessed, according to shipbuilding rules [2,3].

The floating dock strength by finite element method requires the development of 3D-FEM models, full extended over the length [4], and accurate procedures for the computation of the equilibrium position between the dock and the equivalent design wave [5]. A combination between Femap/NX Nastran program [6] and user procedures, functions and own developed codes for the dock-EDW equilibrium position are used. Section 2 presents the analysis linked codes and the strength criteria.

As study case we have developed the 3D-FEM models for a small size floating dock of 60 m length, with continuous (CWT) and non-continuous (NWT) side ballast tanks, placed on the dock pontoon [2,7]. Also a 1D model, by the equivalent beam method [5], is developed for the equilibrium position dock-EDW codes. Five main operation of the floating dock are considered, light, ballast and three docking ship types, according to the shipbuilding classification societies rules [2] (table 1). The numerical model details and the floating dock main characteristics are presented in section 3.

Section 4 presents the strength numerical analysis by 3D-FEM models of the two constructive versions of the floating dock. The dock structure is assessed by global - local admissible stress and buckling criteria, global vertical deflection and freeboard criteria. For each operation case a set of
EDW wave height is considered. Finally the operation limits of the floating dock, by strength safety criteria (table 2) [2, 3], are formulated in terms of the EDW equivalent design wave height.

2. Theoretical basis for the floating dock strength analysis by 3D-FEM and 1D-beam models
For global and local strength analysis of the small size dock we have used several own program codes and user procedures implemented in Femap/NX Nastran [6], linked as in the flowchart from figure 1.

![Flowchart](image_url)

Figure 1. The flowchart for the floating dock strength analysis by 3D-FEM and 1D-beam models.

The global-local strength analysis of the dock by 3D/1D models has the next steps (figure 1):
- (1) the floating dock design concept data includes: the external shape and between the side tanks offset lines, the onboard tanks scheme and the general arrangement plan, the technical project for the structural design and the loading case, according to dock operation condition selected by rules [2].

- (2) the 3D-FEM model. Based on the Femap/NX Nastran [6] CAD modelling facilities, the offset lines for the floating dock are first imported. Using the data from the dock design concept, a 3D-CAD structural model is developed, including the main longitudinal panels, main and simple frames, longitudinal girders, stiffeners, brackets, etc. Based on the Femap/NX Nastran [6] FEM meshing facilities, the numerical 3D-FEM model of the small size dock is obtained, including two main parts: the dock pontoon and the side wing tanks (figures 2,3).

- (3) the masses on 3D-FEM model. Using the floating dock and the operation loading case data, the required on board masses, ballast and docking ship type mass are obtained. Using lumped masses or un-structural mass elements from Femap/NX Nastran [6], the mass distribution on the 3D-FEM model is done. By own user procedures (group_selection.prg; mass_selection.prg) developed for Femap/NX Nastran [6], the mass distribution per unit length for the 1D-beam model is extracted.

- (4) the equivalent 1D-beam model. Based on the floating dock data the 1D equivalent beam numerical model is developed. The 1D model includes: external and between side tanks offset lines (geometric 3D) imported from dxf files using OFF_DYN code, the dock hydrostatic curve by D_CD code, the transversal sections strength characteristics, A, A_I, J_w, W_w, W_b, K_m (table 3) by SH_GECH code.

- (5) import of the mass distribution from the 3D-FEM. A special care is to ensure the best correlation for the external hull shape and mass distributions between the 3D and 1D models used for the dock waves equilibrium parameters. Also the still water equilibrium condition is obtained by D_AC code, in order to check out the accuracy of the loading case idealization using the 3/1D models.

- (6) 1D-model: equilibrium parameters. Using an iterative non-linear algorithm with two parameters, vertical position and trim angle [8,9] of the medium plane of the head equivalent design wave [5], the dock-EDW equilibrium position is obtained. The algorithm is implemented in D_AC_AVD code, a subset of the code P_QSW [10] developed as a three parameters iterative algorithm for oblique equivalent design wave. Using the 1D-model equivalent beam [5], besides the T_p, T_v, vertical position of the medium plane of the EDW head wave, at aft and fore of the dock, also the vertical bending moments (VBM) and shear forces (QSF), the normal stresses at bottom and upper deck, tangential side stress at neutral axis level are obtained. Equation (1) presents the EDW head wave free surface equation and the EDW wave pressure at x and z positions over the external and between sides dock shells.

\[
\zeta_w(x) = T_{pp} + \left(T_v - T_{pp}\right) \frac{x \pm h_w}{L} \frac{2\pi}{L}; T_m = \frac{T_{pp} + T_v}{2}; p_w(x, z) = p_g(\zeta_w(x) - z); x \in [0, L]; z \in [0, H] \tag{1}
\]

where: T_pp, T_v, T_m are the aft, fore, average vertical positions of EDW head wave medium plane and represent the draught values in the case of SW still water; \(\zeta_w\), \(p_w\), \(h_w\) are the EDW head equivalent design wave elongation, pressure and height; XEL, ZEL are Femap/NX Nastran [6] functions for element EL centre longitudinal x and vertical z positions selection; L, H are the dock length and height.

- (7) 3D-model wave pressure. Based on the user function from equation 2 and the equilibrium parameters from step 6, corresponding to a wave height \(h_w\) in sagging (+) or hogging (-) conditions, by Femap/NX Nastran [6] program loading menu on each element from the external and between side tanks shells the EDW wave pressure (equation (1)) is applied automatically. Using the NX Nastran solver [6] with static linear option, the 3D-FEM model is analysed.

- (8) 3D-FEM strength analysis results assessment. For each operation case, the maximum EDW head wave height \(h_w\) is selected according to the limits imposed by the freeboard criteria [2] (table 2). Then the 3D-FEM model analysis results are assessed by the global-local strength criteria according to the rules [2] (table 2): the admissible stresses to the yield stress limit, the admissible buckling factor and the admissible global vertical deflection of the floating dock hull. The results are presented in section 4.
3. The small size floating dock 3D-FEM and 1D-beam models
The main characteristics of the small size floating dock, with the two constructive versions (figures 2,3), are presented in table 3. In order to ensure the local buckling strength, the structural initial design concept [7] of the small floating dock has been enhanced by adding longitudinal and horizontal stiffeners (FB400x5, figures 6, 4) and simple frames (figure 5) between the main frames (figure 6). The onboard ballast mass has been reconfigured in order to preserve the initial displacement cases (table 1).

The 3D model is developed by Femap/NX Nastran [6] program (steps 1-3) and includes the internal and external shell plates, main longitudinal girders and frames, with the corresponding cut-holes, longitudinal and transversal stiffeners, and also local brackets. The 3D-FEM model has shell, membrane and plate (Mindlin) elements, with an average element size of 200 mm, suitable for global and local stress investigation, plus the mass elements for onboard mass groups (step 3). Figures 4, 5 present details of the 3D-FEM model. Table 1 presents the operation cases of the small floating dock, according to rules [2].

The 1D-beam model, developed by the equivalent beam method [5] (steps 1, 4, 5), has the characteristics in table 3. The mass diagrams are imported from the 3D-FEM models (steps 3 to 5).

Table 2 presents the strength criteria (step 8) used for the dock structure analysis (steps 6, 7) assessment. Figure 7 presents the pressure from EDW wave sagging and hogging, on the NWT floating dock hull.

Figure 2. 3D-FEM model, CWT floating dock.  
Figure 3. 3D-FEM model, NWT floating dock.

Figure 4. 3D-FEM model, longitudinal elements.  
Figure 5. 3D-FEM model, simple frames elements
Table 1. CWT and NWT operation cases [7].

|          | LCG = 30 m | Light | Ballast | Ships 1-3* |
|----------|------------|-------|---------|------------|
| CWT      |            |       |         |            |
| $\Delta$ [t] | 1152       | 4092  | 1980    |            |
| $T_{mSW}$ [m] | 0.960      | 6.700 | 1.650   |            |
| NWT      |            |       |         |            |
| $\Delta$ [t] | 960        | 3252  | 1788    |            |
| $T_{mSW}$ [m] | 0.800      | 6.733 | 1.490   |            |

Table 2. The strength and freeboard criteria [2].

|                  | $\alpha_{adm}$ [MPa] | $e_{adm}$ [MPa] | $B_{adm}$ [MPa] | $w_{adm}$ [mm] |
|------------------|----------------------|-----------------|-----------------|----------------|
| CWT NWT          | 175                  | Freeboard       | 1.925 1.700     | 150            |
|                  | 110                  | light dock      | 7.00            |                |
|                  | 1.50                 | ballast dock    |                |                |
|                  | 1.50                 | docking 1,2,3   | 1.925 1.700     |                |

*Docking ships: uniform, sagg. & hogg. mass types

Figure 6. Small floating dock structure dimensions [7]

Figure 7. The EDW pressure on NWT, sagg., hogg.

Table 3. The main characteristics of the small size floating dock [7].

| Floating dock type (side WT type) | CWT | NWT | Yielding stress limit $R_{el}$ [MPa] | 235 |
|-----------------------------------|-----|-----|--------------------------------------|-----|
| Length overall $LOA$ [m]          | 60  | 150 | 2.1 $10^5$                           |     |
| Breadth $B$ [m]                   | 20  | 30  | 0.3                                  |     |
| Height pontoon $H_F$ [m]          | 2   |     | 7.8                                  |     |
| Height side wing tank $H_{WT}$ [m]| 8   |     |                                      |     |
| Aft and fore part length $L(1)$ [m]| 0-15 & 45-60 |  |
| Middle part length $L(2)$ [m]     | 15-45 |     |                                      |     |
| No. elements 3D-FEM $N_{EL}$      | 237928 | 162065 |                                      |     |
| Element type 3D-FEM               | shell (plate Mindlin) and mass | Area of sections | 1 | 0.80700 0.80860 |
| No. nodes 3D-FEM $N_{ND}$         | 201153 | 190618 | 2 | 0.50400 |
| Average EL length 3D $dx$ [mm]    | 200 |     | 3.6960 | 2.0400 |
| Main frames distance $a_{F}$ [mm] | 1200 |  | 0.36800 | 0.20400 |
| Simple frames distance $d_{F}$ [mm]| 600 |  | 5.29335 | 5.29335 |
| Bending moment of inertia $I_y$ [m^4] |  |  | 5.3698 | 0.34768 |
| Section modulus bottom $W_{bb}$ [m^3] |  |  | 1.94078 | 1.94811 |
| Section modulus deck $W_D$ [m^3] | 1.00181 |  |  |  |
| Shearing coefficient $K_{non}$ [m^2] |  |  | 6.86436 | 11.1942 |

4. The small size floating dock strength analysis by 3D-FEM and 1D-beam models

Based on the analysis flowchart from figure 1, the strength analyses by 3D-FEM and 1D-beam models for the small size floating dock, with the two constructive versions CWT and NWT, are done.

Figures 8 and 12 present the equivalent von Mises stress ($\sigma_{eq}$) [MPa] values for hogging condition, $h_w=0.550$ m (CWT) and $h_w=0.186$ m (NWT), in the case of docking ship 3, for 3D-FEM model.

Figures 9 and 13 present the buckling collapse mode and factor (B) values for hogging condition, $h_w=0.550$ m (CWT, frame) and $h_w=0.186$ m (NWT, bottom), in the case docking ship 3, 3D-FEM model.
Figures 10,14 and 11,15 present the normal stresses distributions in upper deck / deck ($\sigma_x$) [MPa] on still water, sagging and hogging conditions, for CWT and NWT floating dock constructive versions, in the case of docking ship 3, for 3D-FEM and 1D-beam models.

Tables 4 and 6 present the maximum equivalent von Mises stress ($vonM$), buckling factor ($B$), freeboard and the assessment by criteria from table 2, for CWT and NWT floating dock constructive versions, for all the five operation cases (table 1), by 3D-FEM model.

Tables 5 and 7 present maximum normal deck stress ($\sigma_x$) and vertical deflection ($w$) and the assessment by criteria from table 2, both dock versions (CWT, NWT), for all five operation cases (table 1), by 3D-FEM and 1D-beam models.

Table 4. CWT 3D-FEM model, maximum equivalent von Mises stress and buckling factor, freeboard.

| No | case       | wave | $h_w$ [m] | $T_m$ [m] | $Z_m$ = $T_m$ $h_w$ / $T_m^2$ | $\sigma_{M}$ [MPa] | $\sigma_{M}$/adm $\leq 1$ | $B_{Buckling}$ | $B$/adm $\geq 1$ |
|----|------------|------|-----------|-----------|-------------------------------|-------------------|--------------------------|----------------|----------------|
| 1  | Light      | sagg.0.96 | 1.93      | -0.005    | 0.499                         | 18.92             | 0.108                    | 5.550          | 3.700          |
|    |            | 1.93    |           |           | 1                               | 48.30             | 0.276                    | 2.828          | 1.885          |
| 2  | Ballast    | sagg.0.60 | 6.70      | 6.700     | 0.957                         | 43.78             | 0.250                    | 3.102          | 2.068          |
|    |            | 0.60    |           |           | 6.400                         | 46.45             | 0.265                    | 2.928          | 1.952          |
| 3  | Docking ship1 | sagg.0.55 | 1.65     | 1.650     | 0.857                         | 31.20             | 0.178                    | 4.511          | 3.007          |
|    |            | 1.925   |           |           | 31.26                         | 0.179             | 2.849                    | 1.899          |                |
| 4  | Docking ship2 | sagg.0.55 | 1.65     | 1.650     | 0.857                         | 30.56             | 0.175                    | 4.377          | 2.918          |
|    |            | 1.925   |           |           | 30.81                         | 0.176             | 3.606                    | 2.404          |                |
| 5  | Docking ship3 | sagg.0.55 | 1.65     | 1.650     | 0.857                         | 30.63             | 0.175                    | 3.909          | 2.606          |
|    |            | 1.925   |           |           | 31.08                         | 0.178             | 2.411                    | 1.607          |                |
Table 5. CWT 3D and 1D models, maximum normal deck stress and vertical deflection.

| No | case | wave | $h_0$[m] | $\sigma_{\text{MPa}}$ [MPa] | $\sigma_{\text{MPa}}$ [MPa] | $3D/ID$ | $\sigma_{\text{MPa}}$/adm | $w$[mm] | $w$[mm] | $3D/ID$ | $w$[mm] | $3D/ID$ | $w$/adm | $w$/adm |
|----|------|------|----------|-----------------|-----------------|--------|-----------------|--------|--------|--------|--------|--------|--------|--------|
| 1  | Light | sw.  | 0        | 10.440          | 9.567           | 1.091  | 0.060           | 3.166  | 3.124  | 1.157  | 0.047  | 3.124  | 1.157  | 0.123  |
|    |      | sagg. | 1.93     | 29.190          | 25.349          | 1.152  | 0.167           | 11.77  | 7.960  | 1.479  | 0.078  | 11.77  | 7.960  | 0.123  |
|    |      | hogg. | 1.93     | 49.910          | 44.543          | 1.053  | 0.268           | 18.47  | 14.21  | 1.300  | 0.123  | 2.841  | 1.894  |
| 2  | Ballast | sw.  | 0        | 15.085          | 12.782          | 1.180  | 0.086           | 4.428  | 4.020  | 1.101  | 0.024  | 1.101  | 0.024  | 0.024  |
|    |      | sagg. | 0.60     | 18.617          | 16.042          | 1.161  | 0.106           | 5.932  | 5.054  | 1.067  | 0.036  | 5.932  | 5.054  | 0.036  |
|    |      | hogg. | 0.60     | 11.579          | 9.522           | 1.216  | 0.066           | 3.472  | 2.986  | 1.163  | 0.023  | 3.472  | 2.986  | 0.023  |
| 3  | Docking | sw.  | 0        | 13.198          | 12.032          | 1.097  | 0.075           | 5.523  | 4.007  | 1.378  | 0.037  | 5.523  | 4.007  | 0.037  |
|    |      | sagg. | 0.55     | 4.706           | 2.293           | 2.052  | 0.027           | 1.434  | 0.858  | 1.671  | 0.009  | 1.434  | 0.858  | 0.009  |
|    |      | hogg. | 0.55     | 23.400          | 21.994          | 1.064  | 0.134           | 9.717  | 7.176  | 1.259  | 0.065  | 9.717  | 7.176  | 0.065  |
| 4  | Docking | sw.  | 0        | 6.962           | 4.545           | 1.532  | 0.040           | 1.780  | 1.452  | 1.226  | 0.012  | 1.780  | 1.452  | 0.012  |
|    |      | sagg. | 0.55     | 9.346           | 5.501           | 1.699  | 0.053           | 2.978  | 2.560  | 1.163  | 0.020  | 2.978  | 2.560  | 0.020  |
|    |      | hogg. | 0.55     | 15.623          | 14.506          | 1.077  | 0.089           | 5.880  | 4.612  | 1.275  | 0.039  | 5.880  | 4.612  | 0.039  |
| 5  | Docking | sw.  | 0        | 17.949          | 16.455          | 1.091  | 0.103           | 7.133  | 5.147  | 1.386  | 0.048  | 7.133  | 5.147  | 0.048  |
|    |      | sagg. | 0.55     | 7.670           | 6.493           | 1.181  | 0.044           | 2.941  | 1.988  | 1.479  | 0.020  | 2.941  | 1.988  | 0.020  |
|    |      | hogg. | 0.55     | 28.379          | 26.416          | 1.074  | 0.162           | 11.330 | 8.306  | 1.364  | 0.076  | 11.330 | 8.306  | 0.076  |

Figure 12. NWT, 3D-FEM, ship3, vonM, H0.186m
Figure 13. NWT, 3D-FEM, ship3, B=1.501, H0.186 m

Table 6. NWT 3D-FEM model, maximum equivalent von Mises stress and buckling factor, freeboard.

| No | case | wave | $h_0$[m] | $T_0$[m] | $Z$[m]= $T_0$+$x$/$l$ | $Z$/adm | $\sigma_{\text{MPa}}$ [MPa] | $\sigma_{\text{MPa}}$/adm | $B_{\text{buckling}}$ | $B$/adm |
|----|------|------|----------|----------|-----------------------|--------|-----------------|-----------------|--------|--------|
| 1  | Light | sw.  | 0        | 0.800    | 0.847                 | 46.66  | 0.267           | 2.841           | 1.894  |
|    |      | sagg. | 0.82     | 0.800    | 0.847                 | 46.66  | 0.267           | 2.841           | 1.894  |
|    |      | hogg. | 0.82     | 0.800    | 0.847                 | 46.66  | 0.267           | 2.841           | 1.894  |
| 2  | Ballast | sw.  | 0.6333   | 6.7333   | 6.7333                | 0.962  | 107.3           | 0.613           | 2.395  | 1.597  |
|    |      | sagg. | 0.6333   | 6.7333   | 6.7333                | 0.962  | 107.3           | 0.613           | 2.395  | 1.597  |
|    |      | hogg. | 0.6333   | 6.7333   | 6.7333                | 0.962  | 107.3           | 0.613           | 2.395  | 1.597  |
| 3  | Docking ship1 | sw.  | 0.420    | 1.49     | 1.490                | 0.876  | 68.11           | 0.389           | 2.278  | 1.519  |
|    |      | sagg. | 0.420    | 1.49     | 1.490                | 0.876  | 68.11           | 0.389           | 2.278  | 1.519  |
|    |      | hogg. | 0.420    | 1.49     | 1.490                | 0.876  | 68.11           | 0.389           | 2.278  | 1.519  |
| 4  | Docking ship2 | sw.  | 0.420    | 1.49     | 1.490                | 0.876  | 68.11           | 0.389           | 2.278  | 1.519  |
|    |      | sagg. | 0.420    | 1.49     | 1.490                | 0.876  | 68.11           | 0.389           | 2.278  | 1.519  |
|    |      | hogg. | 0.420    | 1.49     | 1.490                | 0.876  | 68.11           | 0.389           | 2.278  | 1.519  |


Table 7. NWT 3D and 1D models, maximum normal deck stress and vertical deflection.

| No | case | wave | $h_w$[m] | $\sigma_{D}(3D)$[MPa] | $\sigma_{D}(1D)$[MPa] | $\sigma_{D}(1D)/\sigma_{D}(3D)$ | $w_{adm}\leq[3D]$[mm] | $w_{adm}\leq[1D]$[mm] |
|----|------|------|----------|----------------|-----------------|------------------------|-----------------|-----------------|
| 1  | Light| sw.  | 0        | 36.092 | 32.461 | 1.112 | 0.206 | 48.55 | 45.88 |
|    |      | sagg.| 0.582   | 6.016  | 3.031  | 1.985 | 0.034 | 3.866 | 3.52 | 1.098 | 0.026 |
|    |      | hogg | 0.582   | 66.846 | 62.410 | 1.071 | 0.382 | 93.54 | 87.34 | 1.071 | 0.535 |
| 2  | Ballast| sw.  | 0        | 21.400 | 6.933  | 3.087 | 0.122 | 17.37 | 10.06 | 1.727 | 0.116 |
|    |      | sagg.| 0.326   | 19.909 | 6.393  | 3.114 | 0.114 | 15.54 | 9.18 | 1.693 | 0.104 |
|    |      | hogg | 0.326   | 22.904 | 7.473  | 3.065 | 0.131 | 19.23 | 10.95 | 1.756 | 0.128 |
| 3  | Dock-| sw.  | 0        | 43.781 | 39.380 | 1.118 | 0.230 | 64.20 | 56.33 | 1.140 | 0.428 |
|    |      | sagg.| 0.420   | 21.578 | 17.767 | 1.214 | 0.123 | 31.71 | 26.38 | 1.202 | 0.111 |
|    |      | hogg | 0.420   | 65.938 | 60.992 | 1.081 | 0.377 | 96.68 | 86.23 | 1.121 | 0.645 |
| 4  | Dock-| sw.  | 0        | 22.304 | 18.108 | 1.232 | 0.127 | 29.88 | 25.33 | 1.180 | 0.199 |
|    |      | sagg.| 0.420   | 12.361 | 6.062  | 2.039 | 0.071 | 4.17  | 3.68 | 1.133 | 0.028 |
|    |      | hogg | 0.420   | 44.461 | 39.720 | 1.119 | 0.254 | 62.35 | 55.25 | 1.141 | 0.416 |
| 5  | Dock-| sw.  | 0        | 56.296 | 51.946 | 1.084 | 0.321 | 79.39 | 71.34 | 1.113 | 0.529 |
|    |      | sagg.| 0.186   | 46.465 | 42.375 | 1.097 | 0.266 | 64.99 | 58.09 | 1.119 | 0.433 |
|    |      | hogg | 0.186   | 66.110 | 61.517 | 1.075 | 0.378 | 93.79 | 84.59 | 1.109 | 0.625 |

5. Conclusions

The strength analysis of the floating dock [7] (section 4), with two versions section 3 (figures 2,3), based on the algorithm in section 2 (figure 1), for five operation cases (table 1), leads to the next conclusions:

1. A complex algorithm (figure 1) for the floating docks global and local strength analysis using 3D-FEM and 1D-beam models has been developed, including iterative numerical methods for dock-EDW equilibrium by own codes and user procedures & functions implemented into the Femap/NX Nastran [6].

2. In order to ensure the local buckling strength, the initial dock structure [7] has been enhanced (figure 6), by adding horizontal & longitudinal stiffeners (figure 4) and simple frames (figure 5).

3. Both floating dock versions, CWT, NWT, are initial loaded with EDW head wave pressure, sagging and hogging conditions, up to the wave height $h_w$ limits imposed by the freeboard criterion (table 2). The most restrictive operations are on the three docking ships and ballast cases (tables 4, 6), resulting the following limits $h_w=0.550-0.600$ m (CWT) and $h_w=0.326-0.420$ m (NWT), which are around or under the IN(0.6) navigation area, requiring sheltered harbour conditions. At light case, by freeboard criterion, the limits (tables 4, 6) are $h_w=1.930$m (CWT) and $h_w=1.829$m (NWT), which are around the IN(2.0) navigation area, being suitable for relocation operation of the floating dock.

4. In the case of CWT dock, the buckling criterion adds no supplementary restrictions, only being overlapped with freeboard criterion in the case of light operation, hogging $h_w=1.930$m (table 4). The admissible stress and vertical deflection criteria (tables 4, 5) induce no restrictions.

5. In the case of NWT dock, the buckling criterion induces significant limits for the light case, hogging $h_w=0.582$m, and docking ship 3 case, hogging $h_w=0.186$m (table 6). There are no buckling restrictions for docking ship 2 case and is overlapped with the freeboard criterion on docking ship 1 case. For the wave conditions already reduced by the freeboard and buckling criteria, the admissible stress and vertical deflection criteria (tables 6, 7) induce no extra restrictions in the case of the NWT dock.

6. The comparison between 3D&1D models (tables 5,7; figs.10,11,14,15) points out the deck hotspots stresses.

7. By combined criteria, table 8 presents the operation restrictions for the small size floating dock. The operation of NWT dock is more restrictive in compare to the CWT, having less strength. Further study shall include also the case of oblique EDW waves [10] for the assessment of the floating dock strength.

Table 8. CWT and NWT floating dock analysis results by 3D &1D models and combined criteria.

| Type   | Light | Ballast | D-Ship 1 | D-Ship 2 | D-Ship 3 |
|--------|-------|---------|----------|----------|----------|
| CWT    | $h_w$ limit [m] | 1.930 | 0.600 | 0.550 | 0.550 | 0.550 |
criteria | freeboard & buckling | freeboard | freeboard | freeboard | freeboard |
----------|----------------------|----------|-----------|-----------|-----------|
inland    | ≈ IN(2.0)            | IN(0.6)  | ≈ IN(0.6) | ≈ IN(0.6) | ≈ IN(0.6) |

costal    | special approval     | unsheltered / sheltered harbour |

$NWT$ $h_w \text{ limit [m]}$ | 0.582 | 0.326 | 0.420 | 0.420 | 0.186 |

6. References

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