The structural evaluation of a large floating dock in head design waves by strength criteria

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Abstract. This study is developed for the strength analysis of a large floating dock, with length over all of 209.2 m, obtained from a conversion of an off-shore barge. The docking operations are evaluated by global and local strength criteria. The first operation scenario includes an entire translation process of a ship from the quay to the floating dock railway system, in a river shipyard location, including the main intermediate steps. A second set of operation scenarios include several trial docking cases, at full capacity, considering also the initial state without docking ship that is specific for transit condition between ports. The structural numerical analysis is developed on a very large 3D-FEM model, one sided, full extended over the length, involving an own iterative algorithm for the dock and head design wave equilibrium parameters computation and user functions for the quasi-static head wave pressure application on the external dock shell. The large floating dock has operations in sheltered and unsheltered environments and can be relocated on river and costal waterways, under specific wave’s conditions, according to the shipbuilding classification societies design rules. The numerical results are making possible to evaluate the several operations of the large floating dock by strength criteria.

1. Introduction
The large floating docks, designed for maritime and river shipyards, request structural assessment for a wide operation conditions [1, 2]. The floating docks assessment in head equivalent quasi-static design waves EDW, by strength criteria [3, 4], involves complex 3D-FEM structural models [5].

This study is focused on the local and global strength analysis of large floating dock (DOCKV), which is in service at VARD Tulcea Shipyard [1], with the structure obtained from a conversion of an off-shore barge, by adding supplementary ballast tanks at sides and non-continuous on the main deck. In addition, a special railway system and extra strengthen elements have been added on the main deck structure for docking processes (figure 1, section 2).

The numerical analyses for the large floating dock [1], based on own algorithm [6], include three main operation scenarios: without docked mass (section 3) typical for relocation between two shipyards, docking mass according to a set of cases provided by VARD Tulcea Shipyard [1] (section 4), docking at full design capacity of 27000t, with three sub-cases of mass distributions on the pontoon main deck (section 5), for structural capabilities evaluation in extreme conditions, according to the shipbuilding rules [3, 4]. As results, the large floating dock operation limits by strength criteria are obtained, providing the safety limits for navigation conditions, at inland and coastal areas (section 6).
2. The large floating dock numerical 3D-FEM model

As study case we have considered a large floating dock (DOCKV), with the technical data granted by VARD Tulcea Shipyard [1], having non-continuous side ballast tanks on the pontoon main deck (figure 1).

The 3D-FEM model of the whole dock structure, one sided, has been developed by Femap/NX program [7] (figures 1, 2), using quad and triangle shell elements, with Mindlin formulation, for the steel hull part, and lumped mass elements, for the onboard equipments, ballast and docked masses modelling. The 3D-FEM model average mesh size is less then 200 mm (detail in figure 2), so that the sensitivity of the numerical model is suitable for global and local dock strength analysis. The boundary conditions are modelling the symmetry at centre line and two control master nodes at both extremities.

For each operation case the ballast docking scheme has to ensure the same reference draught of \(T=6.2\) m, without any trim, in order to ensure the transfer from quay, so that the floating dock onboard masses adjustments in the 3D-FEM model are done and checked by hydrostatic procedures [8].

For each docking operation we have used an own non-linear iterative algorithm, for the floating dock and head design wave equilibrium parameters computation \((T_{pp}, T_{pv})\), and user functions for the quasi-static head wave pressure \((p_{w})\), as in equation (1), applied on the external dock shell [6] (figures 3, 4). For equilibrium computation also an equivalent 1D-beam floating dock model is required [6, 9].

Table 1 includes the main characteristics of the 3D and 1D large floating dock [1] numerical models.

![Figure 1. DOCKV 3D-FEM model.](image1.png)

![Figure 2. DOCKV 3D-FEM model, detail.](image2.png)

| Table 1. The main characteristics of the DOCKV large floating dock [1]. |
|-----------------|-----------------|-----------------|=-----------------|
| Length overall | 209.20 | Material | Steel grade AH36 |
| Breadth | 55.13 | Yielding stress limit | 355 |
| Height pontoon | 5.10 | Von Mises stress adm. | 292 |
| Height side wing tanks | 4.90 & 12.66 | Elasticity module | 2.1 10³ |
| No. elements 3D-FEM | 1353139 | Poisson ratio | 0.3 |
| Element type 3D-FEM | steel shell and lumped mass | Material density | 7.8 |
| No. nodes 3D-FEM | 1834221 | Vertical deformation adm. | 418 |
| Average EL size 3D | 187.5 | Freeboard minimum limit | 300 |
| Main frames distance | 3000 | Docking draught reference | 6.20 |
| Simple frames distance | 750 | Displacement at docking | 66324 |
| No. elements 1D model | 280 | Gravity centre and buoyancy | 100.148 |
| Element type 1D model | beam with 4 DOF | centre long. & trans. position | 0 |
| No. nodes 1D model | 281 | Gravity acceleration | 9.81 |
| Average EL length 1D | 750 | Wave condition | head equivalent design waves |

A special user procedure for data transfer from the 3D-FEM model to the 1D-beam model has been developed [6], in order to ensure the accuracy of the dock-wave equilibrium parameters computation.

The large floating dock can have operations on river and costal waterways, so that the reference head design wave height is 2 m extended up to 4.942 m, according to the shipbuilding rules [3, 4].

The floating dock strength criteria [3, 4] are formulated in terms of admissible von Mises stress and vertical deformation (table 1). The freeboard limit criterion is assessed as in equation (2) (table 1).
Figure 3. DOCKV 3D-FEM, equivalent design wave pressure, hogging condition, \( h_w = 4.492 \text{ m}, \ T = 6.2 \text{ m} \).

Figure 4. DOCKV 3D-FEM, equivalent design wave pressure, sagging condition, \( h_w = 4.492 \text{ m}, \ T = 6.2 \text{ m} \).

\[ p_u(x,z) = \rho g \left[ \xi_u(x) - z \right] \; ; \; \xi_u(x) = T_{pp} + \left( T_{pv} - T_{pp} \right) \frac{x}{L} \pm \frac{h_w}{2} \cos \left( \frac{2\pi x}{L} \right) ; \; x \in [0,L] ; \; z \in [0,\xi_u] \]  

(1)

\[ F_{aft} = H_p - T_{pp} + \frac{h_w}{2} \geq f_i ; \; x = 0 ; \; F_{se} = H_p - \frac{T_{pp} + T_{pv}}{2} \pm \frac{h_w}{2} \geq f_i ; \; x = L \; ; \; F_{fore} = H_p - T_{pv} + \frac{h_w}{2} \geq f_i ; \; x = L \]  

(2)

where: \( h_w \) and \( p_w \) are the head equivalent design wave EDW height and pressure; \( T_{pp}, T_{pv} \) are the floating dock and EDW wave equilibrium parameters; \( F_{aft}, F_{se}, F_{fore} \) are the freeboard values.

3. The strength analysis at light operation case of the large floating dock

The light case corresponds to the situation without docked masses, preliminary for quay transfer, with 51937 t water ballast for reference draught \( T = 6.2 \text{ m} \). Also, the case is suitable for dock relocation.

From the light case analysis the following results are selected: von Mises stress distribution (figures 5, 6) and vertical deflection (figure 7) for wave sagging \( h_w = 3.867 \text{ m} \) condition; maximum values for von Mises stress and vertical deformation, function to the wave height \( h_w = 0 \div 4.492 \text{ m} \) (figures 8, 9).

Figure 5. Light, vonM (MPa), \( h_w = 3.867\text{m}, \) sagging, views from main deck and from bottom, midship.

Figure 6. Light, vonM , \( h_w = 3.867\text{m}, \) sagg, midship.  

Figure 7. Light, deflection w(mm), \( h_w = 3.867\text{m}, \) sagg.
Figure 8. DOCKV light, max. von Mises stress. Figure 9. DOCKV light, max. vertical deformation.

Table 2 includes the assessment of freeboard and strength criteria for light case, resulting: at hogging wave $h_{u,min}=4.014\text{m}$ (deformation); at sagging wave $h_{u,max}=3.867\text{m}$ (deformation) and $h_{u,min}=4.301\text{m}$ (stress). For any wave condition, the yielding stress and freeboard limits are not exceeded.

Table 2. DOCKV light case, maximum freeboard, von Mises stress and vertical deformation.

| $T_{sw}$ | $T_{fore}$ | $F_{u,ad}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adm}$ | $F_{u,adr}
Table 3. DOCKV docking steps, maximum von Mises stress and vertical deformation.

| $L_{docked}$ (m) | 10 | 20 | 40 | 60 | 80 | 100 | 122.79 |
|-------------------|----|----|----|----|----|-----|--------|
| $\sigma_{vM}$ (MPa) | 197.835 | 198.130 | 197.736 | 198.390 | 195.597 | 197.799 | 198.965 |
| $\sigma_{vM}$/adm | 0.6775 | 0.6785 | 0.6772 | 0.6794 | 0.6698 | 0.6774 | 0.6813 |
| $w$ (mm) | -39 | -38 | -38 | -38 | -38 | -38 | -42 |
| $w$/adm | 0.0933 | 0.0909 | 0.0909 | 0.0909 | 0.0909 | 0.0909 | 0.1005 |

For the final step of OSV transfer, the possibility of operating in unsheltered conditions and even relocation cases are considered, so that the wave conditions have to be assessed. From this analysis the following results are selected: von Mises stress distribution (figures 13, 14) and vertical deflection (figure 15) for wave hogging $h_w=3.851$ m condition; maximum values for von Mises stress (figure 16) and vertical deformation (figure 17) function to the wave height $h_w=0$ to $4.492$ m (step 0.5 m).

Table 4 includes the assessment of freeboard and strength criteria for 19747 t docked case, resulting: at hogging wave $h_{w,limit}=4.024$ m (deformation); at sagging wave $h_{w,limit}=3.851$ m (deformation) and $h_{w,limit}=4.284$ m (stress). For any wave condition, the yielding stress and freeboard limits are not exceeded.
5. The strength analysis at maximum docking capacity operation case of the large floating dock

The large floating dock maximum design lifting capacity is 27000 t [1]. According to the shipbuilding rules [3, 4], the structure of the large floating dock has to be evaluated at maximum docking capacity and in extreme equivalent design waves EDW. For this study case the maximum wave height is \( h_{w,max} = 4.492 \) m, correspondingly to a costal restricted navigation condition class RE(50%). Also from rules [3, 4], the docked maximum mass is considered with three testing mass distributions over the onboard railway system (figure 1): uniform (figure 18), hogging (figure 22) and sagging (figure 23) type. At maximum docking capacity case, in order to preserve the reference draught \( T=6.2 \) m imposed by the shipyard quay layout, the water ballast from initial light case (section 3) is reduced to 24937 t.

This case the following results are selected: vertical deflection for wave sagging \( h_s=4.492 \) m condition and uniform mass (figure 19); maximum values for von Mises stress (figures 20, 24, 26) and vertical deformation (figures 21, 25, 27) function to the wave height \( h_s=0+4.492 \) m, for all three masses.

Table 4. Docked 19747 t (122.79m), maximum freeboard, von Mises stress and vertical deformation.

| Case | h_s (m) | T_s (m) | T_max (m) | F_max/adm | F_max/adm | F_max/adm | F_max/adm | \( \sigma_{max} \) (MPa) | \( \sigma_{max} \) (MPa) | w_max (mm) | w_max (mm) |
|------|---------|---------|-----------|-----------|-----------|-----------|-----------|----------------|----------------|-------------|-------------|
| sagging | 3.851 | 6.366 | 5.875 | 5.659 | 1 | 3.900 | 1 | 3.900 | \( 198,965 \) | \( 0.81 \) | \( 42 \) | \( 1.000 \) |
| hogging | 4.024 | 6.374 | 5.860 | 5.739 | 1 | 3.900 | 1 | 3.900 | \( 232,330 \) | \( 0.796 \) | \( 418 \) | \( 1.000 \) |
| sagging | 4.284 | 6.385 | 5.837 | 5.857 | 1 | 3.900 | 1 | 3.900 | \( 245,612 \) | \( 0.841 \) | \( 446 \) | \( 1.067 \) |
| hogging | 4.492 | 6.394 | 5.819 | 5.952 | 1 | 3.900 | 1 | 3.900 | \( 256,287 \) | \( 0.878 \) | \( 468 \) | \( 1.119 \) |

Table 5-7 include the assessment of freeboard and strength criteria for 27000 t docking cases.

- uniform mass distribution (table 5): at hogging wave no restrictions; at sagging wave \( h_{wlim}=2.173 \) m (stress), \( h_{wlim}=2.271 \) m (deformation), \( h_{wlim}=3.668 \) m (yielding stress); freeboard limits in range.

Figure 18. Docked 27000 t unif. mass distribution. Figure 19. D27000 t unif. deformation, \( h_s=4.492 \) m, sagg.
- hogging mass distribution (table 6): at hogging wave no restrictions; at sagging wave $h_{\text{hogg}} = 3.048 \text{m}$ (deformation), $h_{\text{sagg}} = 3.471 \text{m}$ (stress); the yielding stress and freeboard limits are not exceeded.

- sagging mass distribution (table 7): at hogging wave no restrictions; at sagging wave $h_{\text{hogg}} = 1.008 \text{m}$ (stress), $h_{\text{sagg}} = 1.606 \text{m}$ (deformation), $h_{\text{hogg}} = 2.501 \text{m}$ (yielding stress); freeboard limits in range. This case represents the extreme operation condition for the DOCKV large floating dock [1].
Table 6. Docked 27000 t hogg. mass, maximum freeboard, von Mises stress and vertical deformation.

| Case $h_w$(m) | $T_{opp}$(m) | $T_{fore}$(m) | $F_{opp}$/adm | $F_{aft}$/adm | $F_{fore}$/adm | $F_{fore}$/adm | $\sigma_M$(MPa) | $\sigma_M$/adm | $w$(mm) | $w$/adm |
|---------------|--------------|---------------|----------------|---------------|----------------|----------------|----------------|--------------|-------------|-----------|
| $sw$          | 6.200        | 6.200         | 3.900          | >1            | 3.900          | >1             | 3.900          | >1           | 227.372     | 0.778     | -105.0    | 0.251     |
| hogg          | 3.048        | 6.332         | 5.945          | 5.292         | >1             | 2.438          | >1             | 5.679         | >1          | 229.814   | 0.787     | 229.0     | 0.548     |
| sagg          | 3.471        | 6.350         | 5.908          | 5.486         | >1             | 2.236          | >1             | 5.928         | >1          | 229.663   | 0.786     | 274.0     | 0.655     |
|               | 4.492        | 6.394         | 5.819          | 5.952         | >1             | 1.748          | >1             | 6.527         | >1          | 229.206   | 0.784     | 383.0     | 0.916     |

Figure 26. Docked 27000t sagg. max. von Mises stress. Figure 27. Docked 27000t sagg. max. vertical deformation.

Table 7. Docked 27000 t sagg. mass, maximum freeboard, von Mises stress and vertical deformation.

| Case $h_w$(m) | $T_{opp}$(m) | $T_{fore}$(m) | $F_{opp}$/adm | $F_{aft}$/adm | $F_{fore}$/adm | $F_{fore}$/adm | $\sigma_M$(MPa) | $\sigma_M$/adm | $w$(mm) | $w$/adm |
|---------------|--------------|---------------|----------------|---------------|----------------|----------------|----------------|--------------|-------------|-----------|
| $sw$          | 6.200        | 6.200         | 3.900          | >1            | 3.900          | >1             | 3.900          | >1           | 255.514     | 0.875     | -255.0    | 0.610     |
| hogg          | 1.008        | 6.240         | 6.119          | 4.364         | >1             | 3.416          | >1             | 4.485         | >1          | 245.417   | 0.840     | -156.0    | 0.373     |
| sagg          | 1.606        | 6.268         | 6.068          | 4.635         | >1             | 3.129          | >1             | 4.835         | >1          | 246.735   | 0.845     | -106.0    | 0.253     |
|               | 2.501        | 6.307         | 5.991          | 5.043         | >1             | 2.700          | >1             | 5.359         | >1          | 248.821   | 0.852     | 11.0      | 0.026     |
|               | 4.492        | 6.394         | 5.819          | 5.952         | >1             | 1.748          | >1             | 6.527         | >1          | 253.706   | 0.869     | 245.0     | 0.586     |

6. Conclusions
The strength analyses result of the large floating dock DOCKV [1] (section 2), by the theoretical and numerical approach for head equivalent design wave loads [6], on several docking operation cases (sections 3, 4, 5), are synthesized in table 8 and the next conclusions:

1. A 3D-FEM structural model, full extended over the length, one sided, of the large floating dock [1] has been developed (figures 1, 2), by Femap/NX Nastran [7], involving 11 millions of degrees of freedom. For the dock and EDW wave equilibrium parameters computation, a 1D-beam model has been developed (table 1), using own code and user subroutines for 1D and 3D models data transfer [6].

2. For the light case (section 3, figures 5-9, table 2), corresponding to the condition without onboard docking mass, ballasted for reference draught $T = 6.2$ m, on both sagging and hoggging wave conditions the vertical deformation criterion is first not satisfied, resulting a $h_w = 3.867$ m limit, that corresponds to unrestricted inland navigation IN(2.0) and restricted coastal navigation RE(40%). This case is suitable for relocation of the floating dock, but with special approval of the navigation authority.

3. For the docking operation case, provided by VARD Tulcea Shipyard [1], mass 19747 t, during the 7 steps (section 4, table 3, figure 10), still water state, no restrictions occur. In head waves condition (table 4, figures 13-17), the vertical deformation criterion is first not satisfied, sagging and hoggging, with $h_w = 3.851$ m limit, unrestricted inland IN(2.0) and restricted coastal RE(40%) navigation state.
4. For the extreme docking operation case, mass 27000 t, with docked mass distribution according to shipbuilding rules [3, 4], uniform, hogging and sagging (section 5, tables 5-7, figures 18-27), the restrictions are significant in sagging wave conditions, from deformation or stress criteria. In case of uniform and hogging docked mass results $h_{\text{limit}}=2.173\\text{\textbar}3.048\text{m}$, unrestricted inland IN(2.0) and restricted coastal RE(20\%\textbar30\%) navigation state. For sagging docked mass results $h_{\text{limit}}=1.008\text{m}>0.6\text{m}$ IN(1.0) that can be operated unrestricted at VARD Tulcea Shipyard, having costal significant restrictions.

5. For all cases the maximum stress hotspots are recorded at the end of the non-continuous side ballast tanks coupling to the pontoon main deck (figures 5, 6, 13, 14), where supplementary local strengthen elements have been added.

6. Further studies shall include also other assessment criteria, as buckling and transversal stability, and seakeeping analysis, when the floating dock relocation operations can be considered.

**Table 8.** DOCKV large floating dock results by 3D-FEM models and head design waves.

| Docking case | Light T6.2 D19747t | T6.2 D27000t hogg. T6.2 | D27000t unif. T6.2 | D27000t sagg. T6.2 |
|--------------|------------------|-----------------------|------------------|-------------------|
| $h_{\text{lim}}$ (m) | 3.867 | 3.851 | 3.048 | 2.173 | 1.008 |
| criterion | vertical deformation $w_{\text{adm}}$, sagging EDW | eq. von Mises stress $\sigma_{\text{adm}}$, sagging EDW | |
| inland | IN(2.0) | IN(2.0) | IN(2.0) | IN(2.0) | IN(1.0) |
| costal | =RE(40\%) | =RE(40\%) | =RE(30\%) | =RE(20\%) | sheltered operation |

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