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IOP Conf. Series: Materials Science and Engineering **591** (2019) 012104 doi:10.1088/1757-899X/591/1/012104

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 o 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.

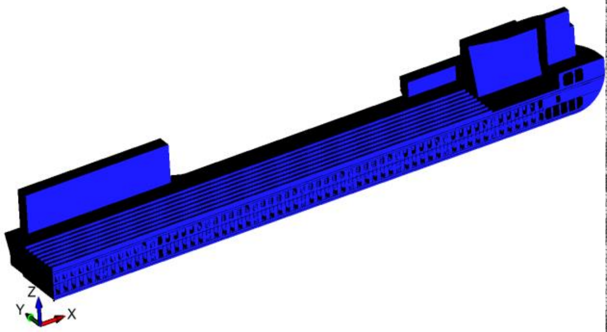


Figure 1. DOCKV 3D-FEM model.

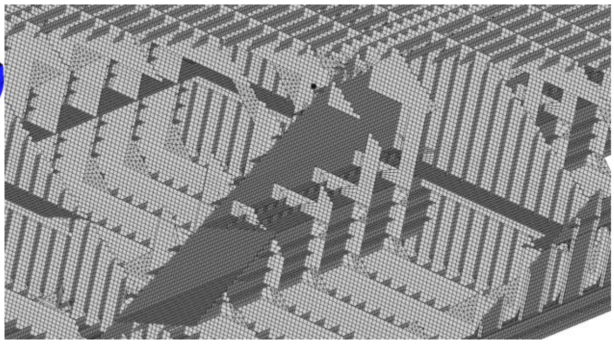


Figure 2. DOCKV 3D-FEM model, detail.

Table 1. The main characteristics of the DOCKV large floating dock [1].

Length overall	LOA (m)	209.20	Material	Steel grade AH36	
Breadth	B (m)	55.13	Yielding stress limit	R_{eH} (MPa)	355
Height pontoon	H_P (m)	10.10	Von Mises stress adm.	σ_{adm}(MPa)	292
Height side wing tanks	H_{WT} (m)	4.90 & 12.66	Elasticity module	E (MPa)	2.1 10^5
No. elements 3D-FEM	N_{EL}	1353139	Poisson ratio	ν	0.3
Element type 3D-FEM	thick shell and lumped mass		Material density	ρ_{mat}(t/m^3)	7.8
No. nodes 3D-FEM	N_{ND}	1834221	Vertical deformation adm.	w_{adm}(mm)	418
Average EL size 3D	ds (mm)	187.5	Freeboard minimum limit	f_s (mm)	300
Main frames distance	a_{Fr} (mm)	3000	Docking draught reference	T (m)	6.20
Simple frames distance	a_0 (mm)	750	Displacement at docking	Δ (t)	66324
No. elements 1D model	N_{EL}	280	Gravity centre and buoyancy	$x_G = x_B$ (m)	100.148
Element type 1D model	beam with 4 DOF		centre long. & trans. position	$y_G = y_B$ (m)	0
No. nodes 1D model	N_{ND}	281	Gravity acceleration	g (m/s^2)	9.81
Average EL length 1D	dx (mm)	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).

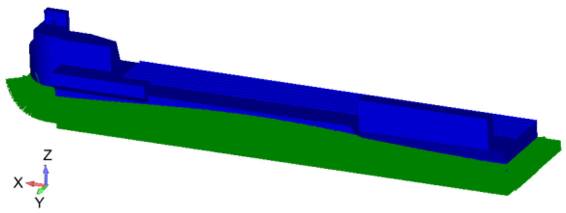


Figure 3. DOCKV 3D-FEM, equivalent design wave pressure, hogging condition, h_w=4.492 m, T=6.2 m.

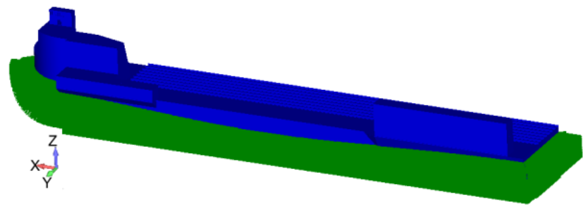


Figure 4. DOCKV 3D-FEM, equivalent design wave pressure, sagging condition, h_w=4.492 m, T=6.2 m.

$$p_w(x,z)=\rho g[\zeta_w(x)-z];\quad \zeta_w(x)=T_{pp}+\left(T_{pv}-T_{pp}\right)\frac{x}{L}\pm\frac{h_w}{2}\cos\left(\frac{2\pi x}{L}\right);\quad x\in[0,L];\quad z\in[0,\zeta_w] \tag{1}$$

$$F_{aft}=H_p-T_{pp}\mp\frac{h_w}{2}\geq f_s;\ x=0\ ;\quad F_m=H_p-\frac{T_{pp}+T_{pv}}{2}\pm\frac{h_w}{2}\geq f_s;\ x=\frac{L}{2}\ ;\quad F_{fore}=H_p-T_{pv}\mp\frac{h_w}{2}\geq f_s;\ x=L \tag{2}$$

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_m, 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 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 m condition; maximum values for von Mises stress and vertical deformation, function to the wave height h_w=0÷4.492 m (figures 8, 9).

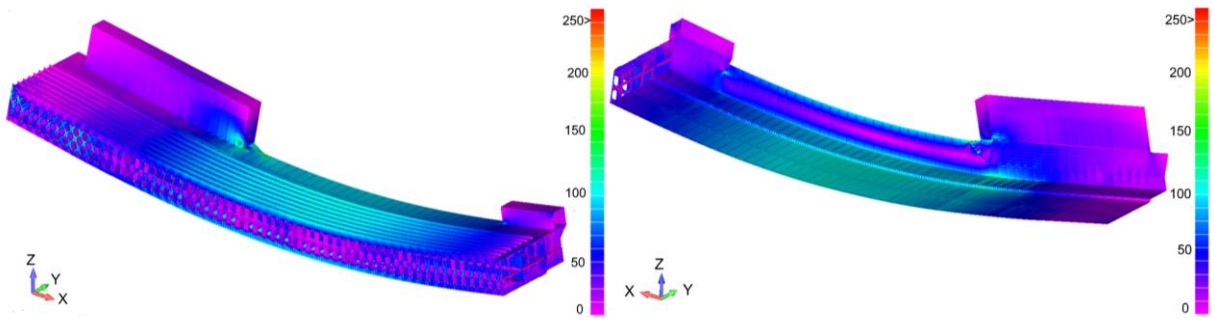
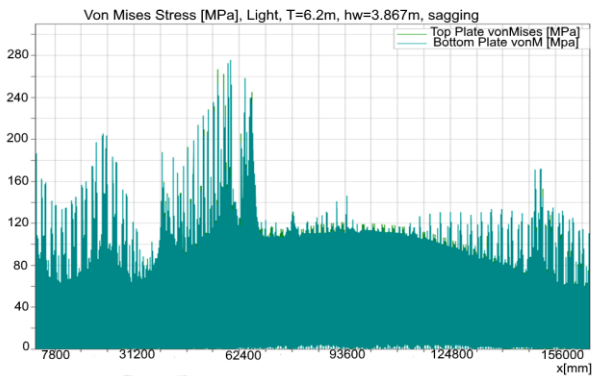


Figure 5. Light, *vonM* (MPa), h_w=3.867m, sagging, views from main deck and from bottom, midship.



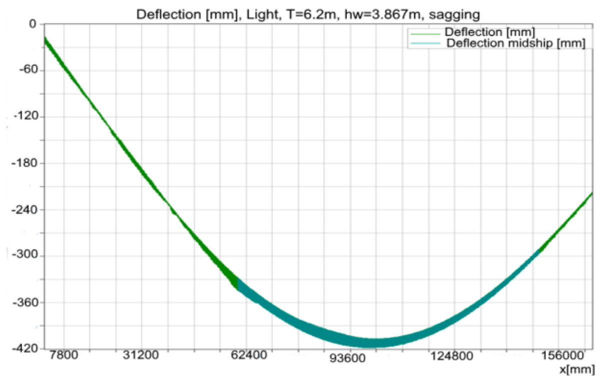


Figure 6. Light, *vonM* , h_w=3.867m, sagg, midhsip. **Figure 7.** Light, deflection w(mm), h_w=3.867m, sagg.

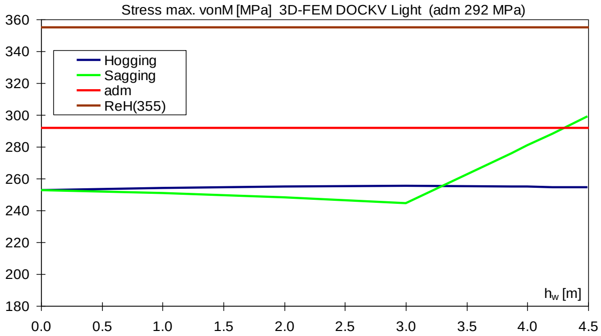


Figure 8. DOCKV light, max. von Mises stress.

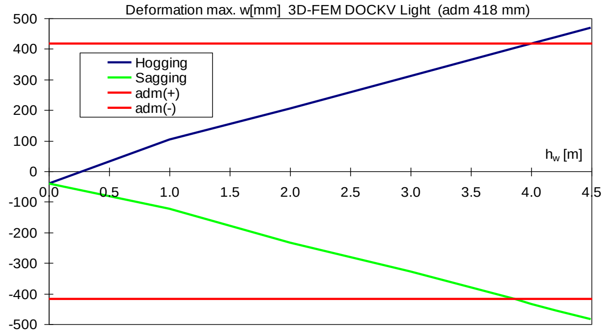


Figure 9. DOCKV light, max. vertical deformation.

Table 2 includes the assessment of freeboard and strength criteria for light case, resulting: at hogging wave h_{wlimit}=4.014m (deformation); at sagging wave h_{wlimit}=3.867m (deformation) and h_{wlimit}= 4.301m (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.

Case	h_w(m)	T_{aft}(m)	T_{fore}(m)	F_{aft}(m)	F_{aft}/adm	F_m(m)	F_m/adm	F_{fore}(m)	F_{fore}/adm	σ_{vM}(MPa)	σ_{vM}/adm	w(mm)	w/adm
sw	0	6.200	6.200	3.900	>1	3.900	>1	3.900	>1	252.790	0.866	-41	0.098
hogging	3.867	6.367	5.873	5.666	>1	2.046	>1	6.160	>1	254.945	0.873	403	0.964
	4.014	6.373	5.861	5.734	>1	1.976	>1	6.246	>1	254.868	0.873	**418**	**1.000**
	4.301	6.386	5.835	5.865	>1	1.839	>1	6.415	>1	254.717	0.872	449	1.074
	4.492	6.394	5.819	5.952	>1	1.748	>1	6.527	>1	254.616	0.872	469	1.122
sagging	**3.867**	6.011	6.520	2.155	>1	5.768	>1	1.647	>1	275.825	0.944	**-418**	**1.000**
	4.014	6.004	6.531	2.089	>1	5.839	>1	1.562	>1	281.286	0.963	-434	1.038
	4.301	5.990	6.554	1.960	>1	5.978	>1	1.395	>1	**292.000**	**1.000**	-464	1.110
	4.492	5.980	6.570	1.874	>1	6.071	>1	1.284	>1	299.137	1.024	-484	1.158

4. The strength analysis at docking mass 19747 t operation case of the large floating dock

The docking case with 19747 t mass has been provided by VARD Tulcea Shipyard [1], with the large floating dock and the docked OSV ship layout presented in figure 10.

There are analyzed 7 transition cases (table 3) of the OSV ship from quay to the floating dock pontoon main deck, using the onboard railway system. Finally, the docked ship with 122.79m length is placed amidships (figure 10). At all transition steps a constant reference draught T=6.2m is preserved, by reducing the water ballast corresponding to the initial light case (section 3) up to 32190 t. The hull steel and final mass distributions are presented in figures 11, 12.

The transfer from quay to dock is done only in still water (h_w=0) condition and the strength criteria are satisfied in any transition step (table 3).

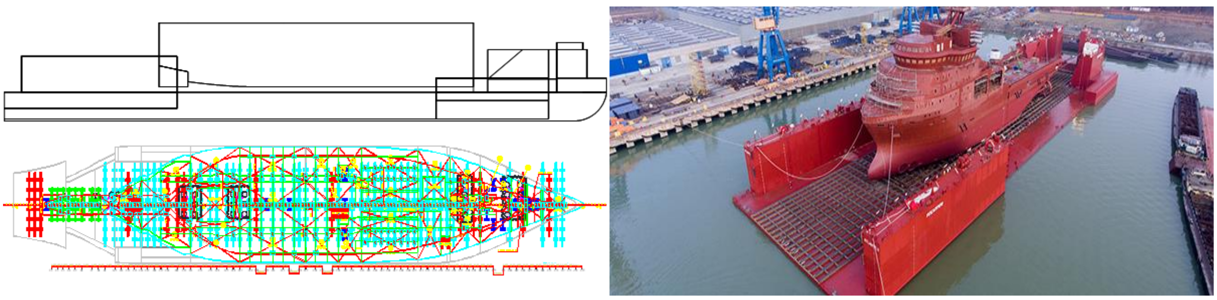


Figure 10. Docking scheme of a 19747 t OSV ship extended over 122.79 m onboard dock railway system, from aft to fore, at VARD Tulcea Shipyard [1].

Table 3. DOCKV docking steps, maximum von Mises stress and vertical deformation.

	L_{docked} (m)	10	20	40	60	80	100	122.79
$T_{aft} = T_{fore} =$ 6.20m; $F_{aft} = F_{fore} =$ 3.900m	σ_{vM} (MPa)	197.835	198.130	197.736	198.390	195.597	197.799	198.965
	σ_{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

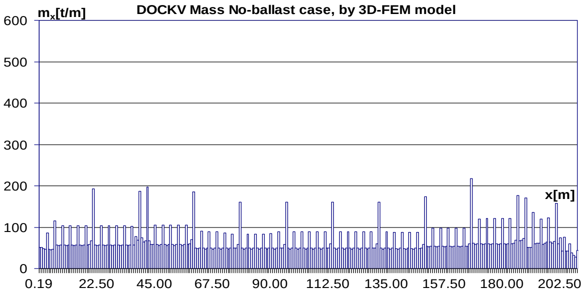


Figure 11. Floating dock hull steel mass distribution.

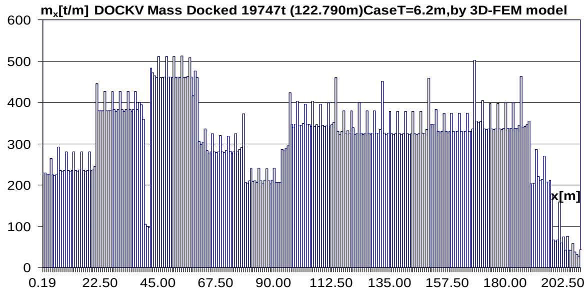


Figure 12. Docked 19747 t (122.79m), mass distribution.

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 case the following results are selected: von Mises stress distribution (figures 13, 14) and vertical deflection (figure 15) for wave hogging h_w=3.851m condition; maximum values for von Mises stress (figure 16) and vertical deformation (figure 17) function to the wave height h_w=0÷4.492m (step 0.5 m).

Table 4 includes the assessment of freeboard and strength criteria for 19747 t docked case, resulting: at hogging wave h_{wlimit}=4.024m (deformation); at sagging wave h_{wlimit}=3.851m (deformation) and h_{wlimit}= 4.284m (stress). For any wave condition, the yielding stress and freeboard limits are not exceeded.

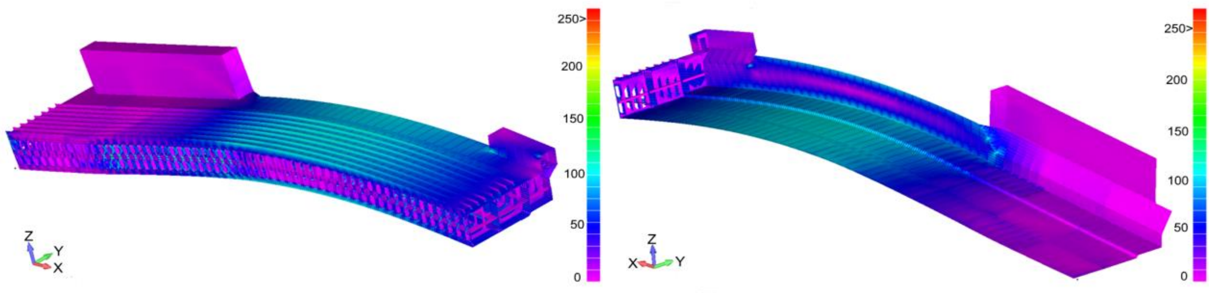


Figure 13. Docked 122.79m, *vonM* (MPa), h_w=3.851m, hogging, main deck and bottom views, midship.

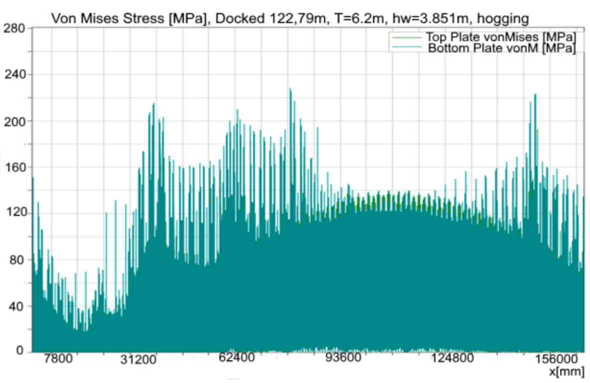


Figure 14. Docked 122.79m, *vonM* , h_w=3.851m, hogg.

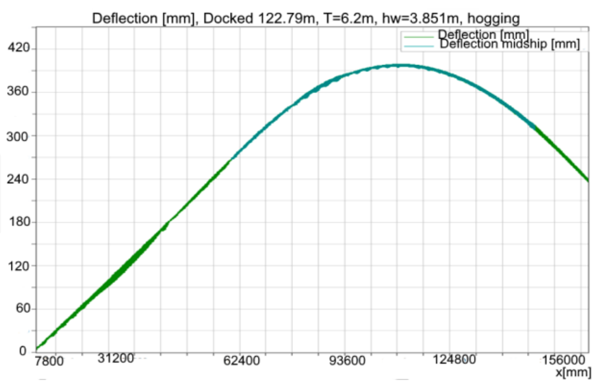
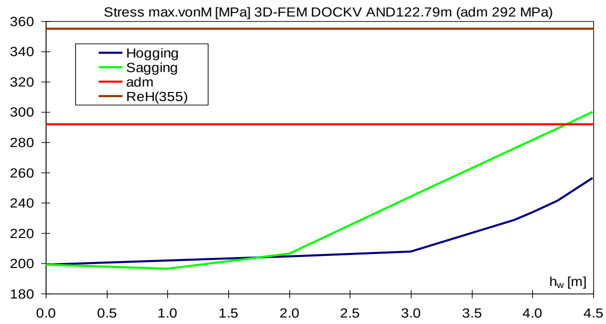


Figure 15. Docked 122.79m, w(mm), h_w=3.851m, hogg.



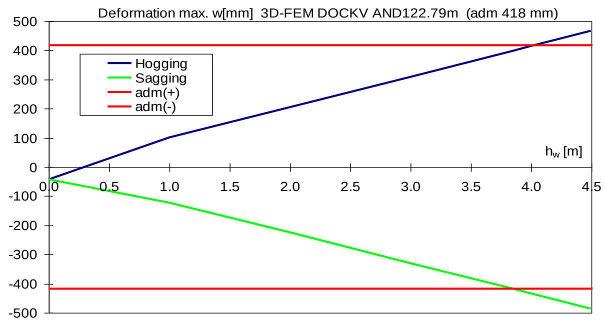


Figure 16. Docked 122.79m, max. von Mises stress. **Figure 17.** Docked 122.79m, max.vertical deformation.

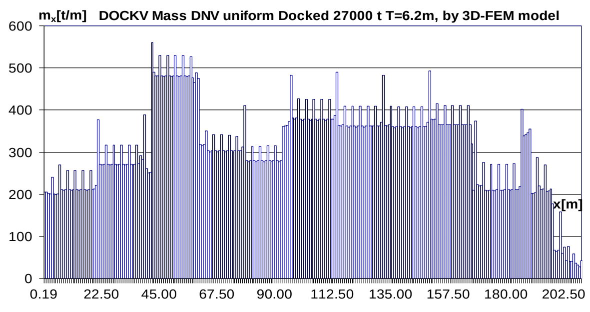
Table 4. Docked 19747 t (122.79m), maximum freeboard, von Mises stress and vertical deformation.

Case	h_w(m)	T_{aft}(m)	T_{fore}(m)	F_{aft}(m)	F_{aft}/adm	F_m(m)	F_m/adm	F_{fore}(m)	F_{fore}/adm	σ_{vM}(MPa)	σ_{vM}/adm	w(mm)	w/adm
sw	0	6.200	6.200	3.900	>1	3.900	>1	3.900	>1	198.965	0.681	-42	0.100
hogging	3.851	6.366	5.875	5.659	>1	2.054	>1	6.151	>1	228.741	0.783	400	0.957
	4.024	6.374	5.860	5.739	>1	1.971	>1	6.252	>1	232.330	0.796	**418**	**1.000**
	4.284	6.385	5.837	5.857	>1	1.847	>1	6.405	>1	245.612	0.841	446	1.067
	4.492	6.394	5.819	5.952	>1	1.748	>1	6.527	>1	256.287	0.878	468	1.119
sagging	**3.851**	6.012	6.518	2.163	>1	5.760	>1	1.656	>1	275.780	0.944	**-418**	**1.000**
	4.024	6.004	6.532	2.084	>1	5.844	>1	1.556	>1	282.140	0.966	-437	1.045
	4.284	5.990	6.553	1.968	>1	5.970	>1	1.405	>1	**292.000**	**1.000**	-464	1.110
	4.492	5.980	6.570	1.874	>1	6.071	>1	1.284	>1	299.925	1.027	-486	1.163

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_{wmax}=4.492m, corresponding 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=6.2m imposed by the shipyard quay layout, the water ballast from initial light case (section 3) is reduced to 24937 t.

For this case the following results are selected: vertical deflection for wave sagging h_w=4.492m 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_w=0÷4.492m, for all three masses.



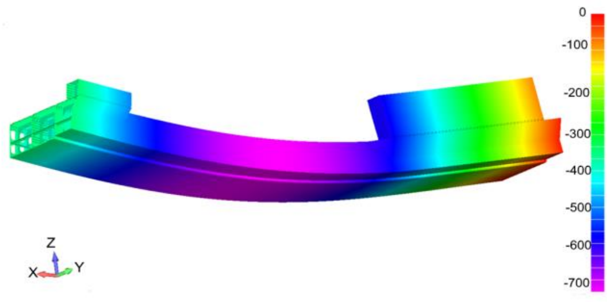
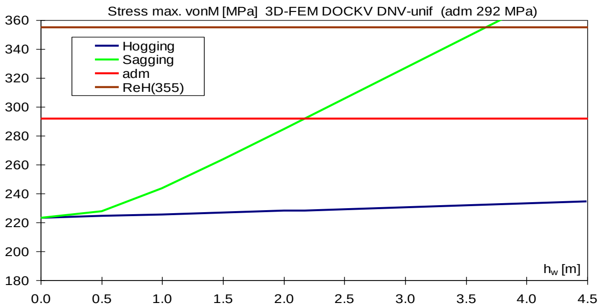


Figure 18. Docked 27000 t unif. mass distribution. **Figure 19.** D27000 t unif , deformation , h_w=4.492m, sagg.

Tables 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_{wlimit}=2.173m (stress), h_{wlimit}= 2.271m (deformation), h_{wlimit}= 3.668m (yielding stress); freeboard limits in range.

- *hogging mass distribution* (table 6): at hogging wave no restrictions; at sagging wave h_{wlimit}=3.048m (deformation), h_{wlimit}= 3.471m (stress); the yielding stress and freeboard limits are not exceeded.
- *sagging mass distribution* (table 7): at hogging wave no restrictions; at sagging wave h_{wlimit}=1.008m (stress), h_{wlimit}= 1.606m (deformation), h_{wlimit}= 2.501m (yielding stress); freeboard limits in range. This case represents the extreme operation condition for the DOCKV large floating dock [1].



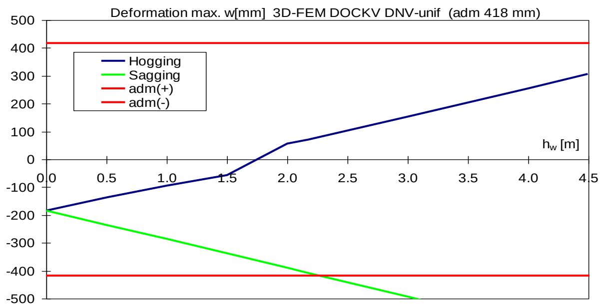
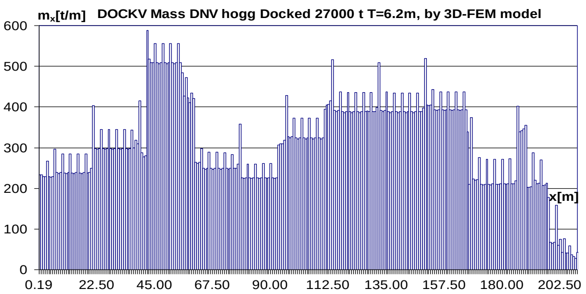


Figure 20. Docked 27000t unif, max. von Mises stress. **Figure 21.** Docked 27000t unif, max. vertical deformation.

Table 5. Docked 27000 t unif. mass, maximum freeboard, von Mises stress and vertical deformation.

Case	h_w(m)	T_{aft}(m)	T_{fore}(m)	F_{aft}(m)	F_{aft}/adm	F_m(m)	F_m/adm	F_{fore}(m)	F_{fore}/adm	σ_{vM}(MPa)	σ_{vM}/adm	w(mm)	w/adm
sw	0	6.200	6.200	3.900	>1	3.900	>1	3.900	>1	223.285	0.534	-185	0.442
hogging	2.173	6.293	6.019	4.893	>1	2.857	>1	5.167	>1	228.389	0.782	71	0.170
	2.271	6.297	6.011	4.938	>1	2.810	>1	5.225	>1	228.643	0.783	81	0.194
	3.668	6.358	5.891	5.576	>1	2.141	>1	6.043	>1	232.337	0.795	221	0.529
	4.492	6.394	5.819	5.952	>1	1.748	>1	6.527	>1	234.604	0.803	307	0.734
sagging	**2.173**	6.095	6.381	2.919	>1	4.949	>1	2.632	>1	**292.000**	**1.000**	-408	0.976
	2.271	6.090	6.389	2.875	>1	4.996	>1	2.575	>1	296.126	1.014	**-418**	**1.000**
	3.668	6.021	6.503	2.245	>1	5.672	>1	1.763	>1	**355.000**	1.215	-564	1.349
	4.492	5.980	6.570	1.874	>1	6.071	>1	1.284	>1	>355	>1	-650	1.555



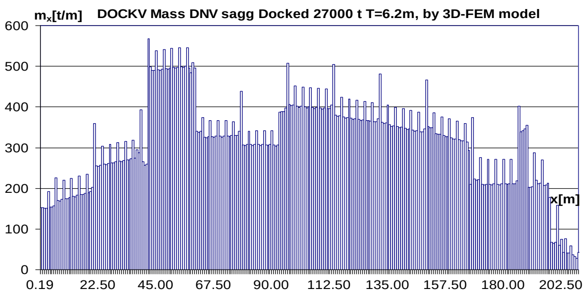
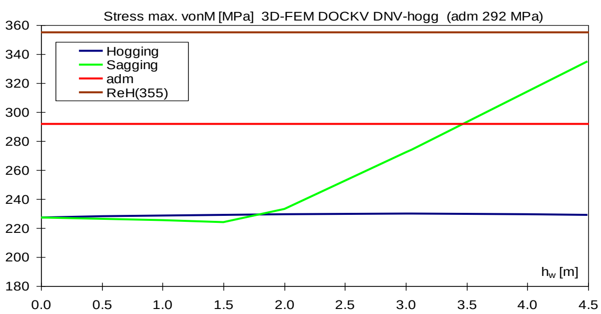


Figure 22. Docked 27000 t hogg. mass distribution. **Figure 23.** Docked 27000 t sagg. mass distribution.



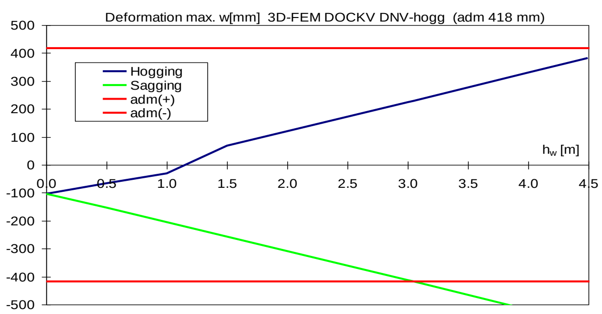
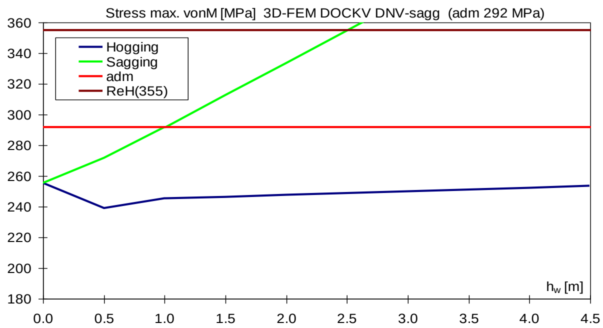


Figure 24. Docked 27000t hogg, max.von Mises stress. **Figure 25.** Docked 27000t hogg, max.vertical deformation.

Table 6. Docked 27000 t hogg. mass, maximum freeboard, von Mises stress and vertical deformation.

Case	h_w(m)	T_{aft}(m)	T_{fore}(m)	F_{aft}(m)	F_{aft}/adm	F_m(m)	F_m/adm	F_{fore}(m)	F_{fore}/adm	σ_{vM}(MPa)	σ_{vM}/adm	w(mm)	w/adm
sw	0	6.200	6.200	3.900	>1	3.900	>1	3.900	>1	227.372	0.778	-105	0.251
hogg	3.048	6.332	5.945	5.292	>1	2.438	>1	5.679	>1	229.814	0.787	229	0.548
	3.471	6.350	5.908	5.486	>1	2.236	>1	5.928	>1	229.663	0.786	274	0.655
	4.492	6.394	5.819	5.952	>1	1.748	>1	6.527	>1	229.206	0.784	383	0.916
sagg	**3.048**	6.051	6.453	2.525	>1	5.372	>1	2.123	>1	274.177	0.939	**-418**	**1.000**
	3.471	6.031	6.487	2.334	>1	5.577	>1	1.877	>1	**292.000**	**1.000**	-463	1.108
	4.492	5.980	6.570	1.874	>1	6.071	>1	1.284	>1	334.966	1.147	-570	1.364



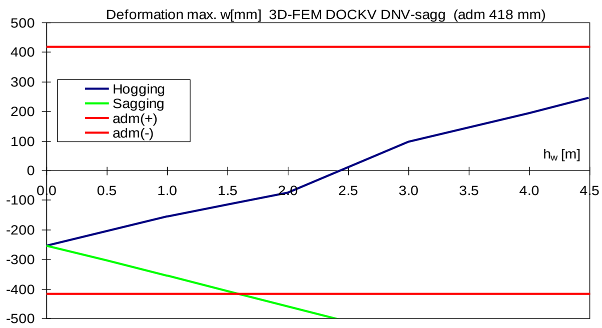


Figure 26. Docked 27000t sagg, max.von Mises stress. **Figure 27.** Docked 27000t sagg, max.vertical deformation.

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

Case	h_w(m)	T_{aft}(m)	T_{fore}(m)	F_{aft}(m)	F_{aft}/adm	F_m(m)	F_m/adm	F_{fore}(m)	F_{fore}/adm	σ_{vM}(MPa)	σ_{vM}/adm	w(mm)	w/adm
sw	0	6.200	6.200	3.900	>1	3.900	>1	3.900	>1	255.514	0.875	-255	0.610
hogging	1.008	6.240	6.119	4.364	>1	3.416	>1	4.485	>1	245.417	0.840	-156	0.373
	1.606	6.268	6.068	4.635	>1	3.129	>1	4.835	>1	246.735	0.845	-106	0.253
	2.501	6.307	5.991	5.043	>1	2.700	>1	5.359	>1	248.821	0.852	11	0.026
	4.492	6.394	5.819	5.952	>1	1.748	>1	6.527	>1	253.706	0.869	245	0.586
sagging	**1.008**	6.152	6.284	3.444	>1	4.386	>1	3.312	>1	**292.000**	**1.000**	-357	0.854
	1.606	6.122	6.334	3.175	>1	4.675	>1	2.963	>1	317.237	1.086	**-418**	**1.000**
	2.501	6.078	6.408	2.771	>1	5.107	>1	2.441	>1	**355.000**	1.215	-511	1.222
	4.492	5.980	6.570	1.874	>1	6.071	>1	1.284	>1	>355	>1	-719	1.720

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 hogging 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 costal 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 hogging, with h_w=3.851 m limit, unrestricted inland IN(2.0) and restricted costal 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_{wlimit}=2.173÷3.048m, unrestricted inland IN(2.0) and restricted costal RE(20÷30%) navigation state. For sagging docked mass results h_{wlimit}=1.008m>0.6m 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 *T*6.2	D19747t *T*6.2	D27000t hogg. *T*6.2	D27000t unif. *T*6.2	D27000t sagg. *T*6.2
$h_{w\ limit}$ (m)	3.867	3.851	3.048	2.173	1.008
criterion	vertical deformation w_{adm}, sagging EDW			eq.von Mises stress σ_{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

7. References

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Acknowledgements
The authors wish to express their thanks to VARD Tulcea Shipyard, who granted us the large floating dock technical data [1]. The research is supported by “Dunarea de Jos” University of Galati.