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ON THE DEVELOPMENT OF DESIGN SOFTWARE FOR FLOATING DOCK UNITS OPERATING CAPABILITIES ANALYSIS

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ABSTRACT

At shipyards, for ships' production, repairing and launching facility, the floating dock units are currently used. In any design and service stage, the following floating dock main capabilities have to be assessed: floatability, trim, stability and global loads. This paper presents the own developed FDOCK software package that integrates five modules: hydrostatics and draught survey (with dock deflection), sinkage and trim according to the lifting case, transversal stability with trim updated according to heeling angle, still water vertical bending moments and shear forces, having also the option to add small equivalent quasi-static wave loads that can occur in the shipyard basin or at relocation. The floating dock and water system balance in all the computational modules is obtained by iterative non-linear procedures, using a double definition of the off-set lines, external and internal between the two side wing tanks. As numerical study case is considered a floating dock with 60 m length, 20 m breadth, 2 m pontoon height, 8 m height, two constructive versions. Several operation scenarios are analyzed, testing all the software modules. Based on the numerical results, the operation capabilities of the floating dock unit are assessed.

Keywords: development of design software, floating dock unit, operation capabilities analysis.

1. INTRODUCTION

One of the most versatile production unit in a shipyard is the floating dock unit, that requires reduced facilities on land and ensures also the docking and launching operations of the working ship [13], [31], [35].

The floating dock operating capabilities and safety must be assessed at any design and service stages for each working ship project by several criteria, according to the shipbuilding classification society's rules [1], [9], [10], [22]. For this purpose we have developed an own software package FDOCK, making possible to assess the following: the freeboard criterion corresponding to the floating and trim condition, the vertical global strength criteria by yielding stress and ultimate strength limits (global buckling), the general and weather transversal intact stability criteria.

As study case we consider a floating dock unit Dock60 with non-continuous (NWT) and continuous (CWT) side wing tanks [10], [31], overall length 60 m and maximum lifting capacity 828 t. The main operation scenarios are analyzed and the capabilities of the floating dock are obtained. The each operation criterion is first analyzed independent and at the last the coupled criteria are submitted for the floating dock safety assessment.

In the following sections the FDOCK software is presented with theoretical basics, the floating Dock60 characteristics, the two main constructive dock versions assessment by freeboard, strength and stability criteria.

2. THEORETICAL BACKGROUND FOR THE FDOCK SOFTWARE PACKAGE

In this section the modules of the FDOCK software package for operation criteria assessment, with the flowchart in Fig.1, and the theoretical elements in brief are presented. The software modules are developed by free Pascal Programming Language PPL [30].

The **D_DRSU00** module is developed for floating dock draught survey data processing, with trim and hull girder deflection [4],[6],[16],[20]. This module can be used for experimental evaluation of the floating dock displacement, longitudinal gravity centre position and vertical deflection, based on situ draught survey measurements.

Based on the d_A , d_M , d_F aft, amidships, fore measured at draughts survey scales (file *dsfile.dat*) in still water condition, the offset lines external shape (file *dock.dpf*) and the offset lines between the side wing tanks, internal, (file *dock.dpi*), the dock displacement Δ is obtained.

$$d(x)=a_0+a_1\cdot x+a_2\cdot x^2\ ;\ x\in[0,L]\ ;\ \Delta=\rho_w\int_0^L A_t(x)\big|_{z=d(x)}dx\ ;\ x_G=\frac{\rho_w}{\Delta}\int_0^L x\cdot A_t(x)\big|_{z=d(x)}dx \qquad (1)$$

$$a_{0,1,2}=f(d_A,d_M,d_F)\ ;\ w_M=d_M-d_A-trim\cdot(x_M-x_A)\ ;\ trim=(d_F-d_A)/(x_F-x_A);$$

where: L is the length; $d(x)$ is the draught at station x; $A_t(x)|_z$ is the Bonjean diagram; ρ_w is the water density; x_G is the longitudinal gravity centre position (*LGC*); w_M is the dock amidships deflection; *trim* is the dock longitudinal trim; x_A , x_M , x_F are the positions of the draught survey scales.

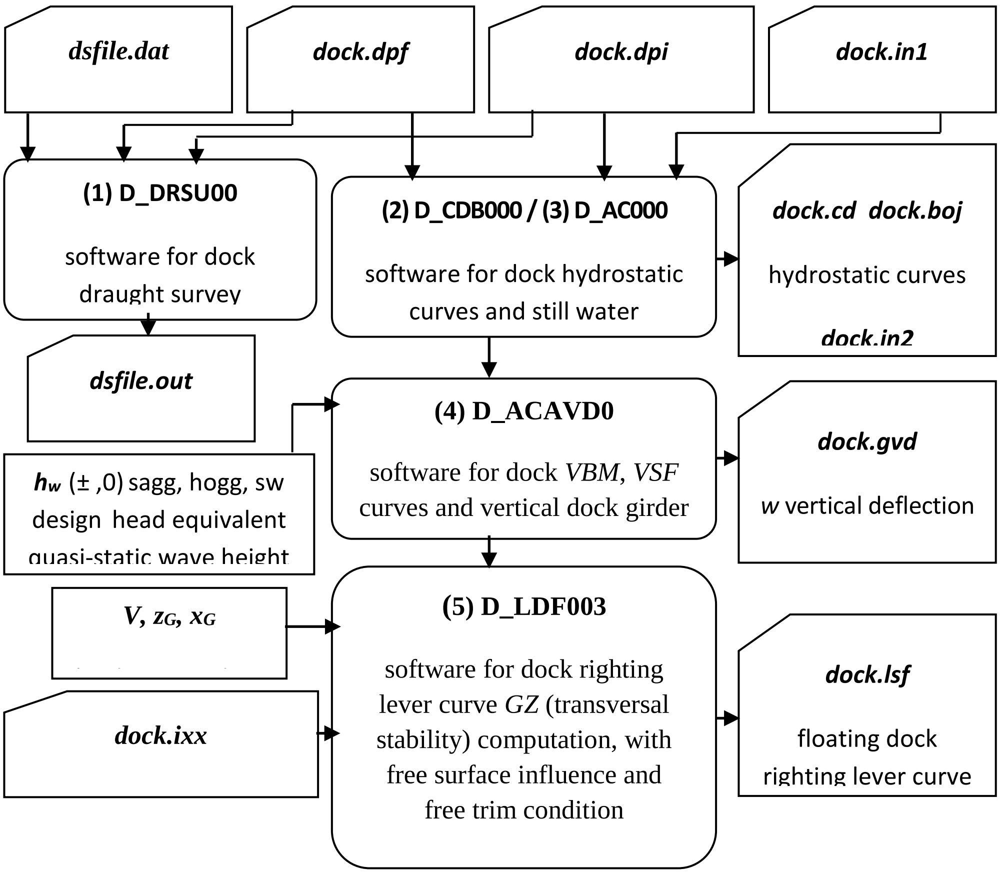

Fig.1 Flowchart of the **FDOCK** software package modules for floating docks capability and operation safety assessment, input and output files

The **D_CDB000** module is developed for the floating dock hydrostatic curves computation (file *dock.cd*) and the Bonjean diagram (file *dock.boj*) [3], [5], [7], [27], [33] used for the initial evaluation of the dock freeboard and initial stability characteristics at each loading case.

The **D_AC000** module is developed for the SW still water equilibrium parameters computation (file *dock.in2*), based on a non-linear iterative procedure for floating (sinkage) and trim equilibrium [11],[12],[14],[17], used for the freeboard criteria check according to *DNVGL RU-FD (Chapter 3, Section 2)* [10]. Besides the offset lines of the dock shape external and between the side wing tanks WT (files *dock.dpf*, *dock.dpi*), as input data is required also the dock mass distribution per unit length m_x (file *dock.in1*).

$$d_{pp}\big|_{x=-L/2} = d_m - (L/2 + x_F)(x_G - x_B)/R \ ;$$
$$d_{pv}\big|_{x=L/2} = d_m + (L/2 - x_F)(x_G - x_B)/R \qquad (2)$$
$$d(x) = d_{pp} + \frac{d_{pv} - d_{pp}}{L}\left(x + \frac{L}{2}\right);\ FB_{PD}(x) = H_p - d(x);$$
$$FB_{UD}(x) = H - d(x);\ x \in \left[-\frac{L}{2}, \frac{L}{2}\right]$$
$$FB_{PD\_adm} \ge 0.075m \text{ for CWT; } FB_{PD\_adm} \ge 0.300m \text{ for NWT; } FB_{UD\_adm} \ge 1.0m \quad [10]$$

where: L is the dock length; d_{pp} , d_{pv} , d_m are the draught at $\pm L/2$ and medium; x_F is the longitudinal position of free surface centre; R is the longitudinal metacentre radius; x_G, x_B are the longitudinal position of the gravity and buoyancy centre; H_p, H are the pontoon deck and upper deck height; FB_{PD}, FB_{UD} are the freeboard at pontoon deck and upper deck; CWT caisson type pontoon with continuous side wing tanks WT; NWT non-continuous side wing tanks WT.

The **D_ACAVD0** module is developed for the still water and design head equivalent quasi-static waves vertical bending moments *VBM* and vertical shear forces *VSF* computation (file *dock.mtf*), based on a non-linear iterative procedure [11],[12]. The input files are the same as the previous module, including also the bending moment of inertia *Iy* and the shear area A_f distributions over the dock length (file *dock.in1*), used for the vertical dock girder deflection computation (file *dock.gvd*). The results from this module are used for the assessment of the global strength criteria according to the *DNVGL RU-FD (Chapter 2, Section 4)* [10] for the yielding stress limit criterion (admissible stress) and the ultimate strength *VBM* criterion *DNVGL RU-SHIPS (Part 3, Chapter 5, Section 4)* [10] (global buckling) [15], [18], [19], [26], [32], [34].

$$Z(x) = d_{pp} + (d_{pv} - d_{pp})\frac{x}{L} \pm \frac{h_w}{2}\cos\left(\frac{2\pi x}{L}\right) \to A_t(x);\ x \in [0, L] \text{ from Bonjean diagram} \qquad (3)$$
$$p_x(x) = g \cdot m_x(x) - \rho_w g \cdot A_t(x) \to VSF(x) = \int_0^x p_x(x)dx \ ;\ VBM(x) = \int_0^x VSF(x)dx$$
$$\sigma_{\max} = 140\, N/mm^2 \to AVBM = \sigma_{\max} \cdot W_D \ ;\ \tau_{\max} = 100\, N/mm^2 \to AVSF = \tau_{\max} \cdot A_f$$
$$USVBM_{sagg,hogg} \to AUSVBM_{sagg,hogg} = USVBM_{sagg,hogg}/c_s \ ;\ c_s = 1.2\,;$$
$$w(x) = w_b(x) + w_t(x);\ w_{adm} = L/400$$
$$w_b(x) = \frac{1}{E}\left[\int_0^x\int_0^x \frac{VBM(x)}{I_y(x)}dx - \frac{x}{L}\int_0^L\int_0^L \frac{VBM(x)}{I_y(x)}dx\right];\ w_t = \frac{1}{G}\left[\int_0^L \frac{VSF(x)}{A_f(x)}dx - \int_0^x \frac{VSF(x)}{A_f(x)}dx\right]$$
$$FB_{PD}(x)\big|_{Z(x)} = H_p - Z(x) \le FB_{PD\_adm} \ ;\ FB_{UD}(x)\big|_{Z(x)} = H - Z(x) \le FB_{UD\_adm}$$

where: $Z(x)$ is the wave free surface elongation; d_{pp}, d_{pv} are the wave medium plane equilibrium parameters; W_D is the section modulus at pontoon or upper deck; *USVBM* is the ultimate strength vertical bending moment and the safety coefficient c_s; w_{adm} is the admissible vertical deflection; *E, G* are Young module and transversal module of the hull girder material [8], [24]; w, w_b, w_t are the total, bending and shearing vertical dock girder deflections.

The **D_LDF003** module is developed for the dock righting lever curve *GZ* (transversal stability) computation, with free surface influence and free trim condition [2],[4],[6],[25], using a non-linear iterative procedure in the case of large heeling angles. Besides the offset lines files (*dock.dpf, dock.dpi*), as input are required also the loading case data (V,z_G,x_G), volume and gravity centre position, and also the onboard tanks free surface data (file *dock.ixx*). The results from this module are used for the assessment of the general transversal stability and weather stability criteria according to *DNVGL RU-FD (Chapter 3, Section 1)* [10] and *DNVGL RU-SHIPS (Part 3, Chapter 15, Section 4.1)* [10].

$$GZ(\varphi) = LSF(\varphi) = y_B(\varphi)\cdot\cos(\varphi) + (z_B(\varphi) - z_G)\cdot\sin(\varphi) \ ;$$
$$\varphi \in [0, 90^0];\quad x_B(\varphi) = x_G \ \forall\varphi \text{ trim condition} \qquad (4)$$
$$GZ_c(\varphi) = LSF_c(\varphi) = GZ(\varphi) - \sin(\varphi)\cdot\Delta^{-1}\sum_k \rho_x^k \cdot i_{xx}^k \ ;\ LDF_c(\varphi) = \int_0^\varphi GZ_c(\varphi)d\varphi$$

$$GM_0 = \frac{dGZ_c}{d\varphi}\Big|_{\varphi=0} \geq 1m \ ; \ \ GZ_c(\varphi_{ref}) \geq GZ_{ref} \ ; \ \ K_{weather}(LDF_{ref}(\varphi)) \geq 1$$

where: $GZ=LSF$, $GZ_c=LSF_c$ are the righting lever curves without and with correction for the free surfaces of onboard tanks; φ heeling angle; y_B,z_B are the transversal and vertical buoyancy centre position; ρ_x, i_{xx} are density and free surface inertial moment of the partial filled onboard tanks; LDF_c is the dynamic stability curve; φ_{ref} reference heeling angle according rules [10]; $K_{weather}$ the weather (wind and roll) dynamic stability criteria according rules [10].

In the next sections the FDOCK software package is used for the assessment of the operation capabilities and safety of a floating dock Dock60 designed for inland harbours. Also the floating dock is tested if is suitable for costal harbour operations and relocation operation. The maximum design equivalent quasi-static wave height [11],[21], [23],[28],[29] is according to the *DNVGL RU-SHIPS (Part 3, Chapter 4, Section 4)* [10] and *DNVGL RU-INV (Part 3 , Chapter 2, Section 4)* [10].

$h_{w\_max} \leq 2m$ SW, IN(0.6), IN(1.2), IN(2.0) the maximum wave height for inland operation; (5)

$h_{w\_max} \leq 0.5 \cdot 0.0856 \cdot L$; $L < 90m$ RE(50%); $h_{w\_max} \leq 2.568m$ for costal harbour operation.

3. FLOATING DOCK60 CHARACTERISTICS

For the numerical study we use a floating Dock60 structure with the main characteristics presented in Table 1. We have considered two main constructive versions: with non-continuous side wing tanks NWT (Fig.2.a) and caisson type with continuous side wing tanks CWT (Fig.2.b). For the two constructive versions, based on the offset lines from Fig.2.a,b and module D_CDB000, the hydrostatic curves (displacement Δ and A_w water plane area) are computed (Figs.3.a,b), putting in evidence significant changes function to the draught level.

The floating dock structural elements dimensions are according to DNVGL RU_FD [10] rules. In the case of NWT version at the centre part the side wing tanks are removed.

Figs.5.a,b present the ultimate strength vertical bending moments *USVBM* [18],[32],[34] computed for the two constructive versions (NWT, CWT), by DNVGL Poseidon software [10]. There are considered 3 cases $a_{Fr} \in [a_0, 2a_0, 4a_0]$ for the frames distance, with regular distance a_0=0.6m. The maxim *USVBM* is obtained for $a_{Fr}=a_0$ but for a better balance between the dock mass and strength we have selected for further analysis the frames distance $a_{Fr}=2a_0$. Based on DNVGL [10] rules (section 2), in Table 2 and Table 3 are presented the admissible limits for strength, deflection and freeboard criteria.

Figs.4.a,b present two constructive versions SB, LB for the docking blocks. Each docking block is placed on the pontoon deck, at the intersection between the frames and the longitudinal girders.

Figs. 6.a,b present the mass diagrams m_x[t/m] for the testing ships, according to the DNVGL RU-FD [10] rules, for the maximum lifting mass Ms=828t capacity of the floating Dock60.

Table 4 presents the displacement cases for the floating Dock60, NWT and CWT constructive cases, with SB short and LB long docking blocks and five loading cases: light, full ballast and the three testing ships (uniform, sagging and hogging mass distribution), resulting a total of 20 main analysis sets.

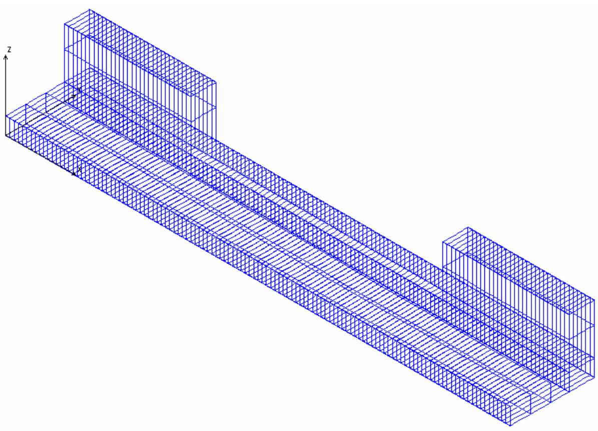

Fig.2.a Dock60_NWT offset lines
non-continuous side wing tanks

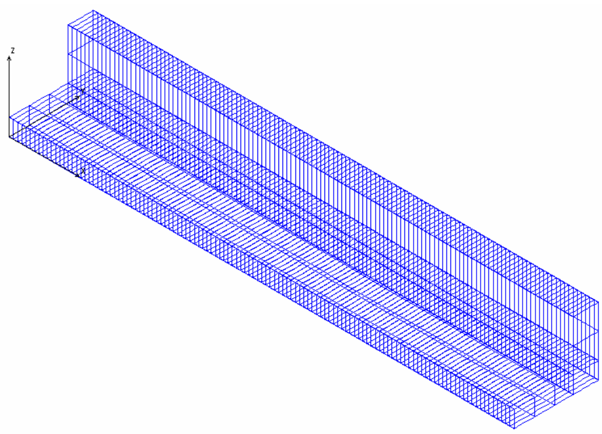

Fig.2.b Dock60_CWT offset lines
continuous side wing tanks

Table 1. Dock60 Floating dock main characteristics

Dock60 main dimensions		NWT (Fig.2.a)		CWT (Fig.2.b)	
$M_s[t]$	maximum lifting mass	828		828	
L[m]	length	60		60	
B[m]	breadth	20		20	
H[m]	upper deck height (UD)	8		8	
H_p[m]	pontoon deck height (PD)	2		2	
Ls[m]	side wing tanks length	15 (aft) + 15 (fore)		60 (continuous)	
Bs[m]	side wing tanks breadth	3		3	
Hs[m]	side wing tanks deck height	5.4		5	
ρ_w[t/m^3]	water density	1.000		1.000	
ρ_m[t/m^3]	material density	7.800		7.800	
a_{Fr}[m]	frames distance a_{Fr}=2a_0	1.200		1.200	
Material type		steel grade A		steel grade A	
Sectional characteristics along the dock [m]		0-15/45-60	15-45	0-15/45-60	15-45
A[m^2]	total area	0.54860	0.34000	0.54700	0.54700
Af[m^2]	shear area	0.23360	0.10000	0.23200	0.23200
Iy[m^4]	bending moment of inertia	3.75842	0.27333	3.75842	3.75842
z_N[m]	neutral axis vertical position	2.75669	1.00000	2.72761	2.72761
WB[m^3]	section modulus at bottom	1.36338	0.27333	1.35274	1.35274
WD[m^3]	section modulus at UD/PD	0.71680	0.27333	0.69982	0.69982

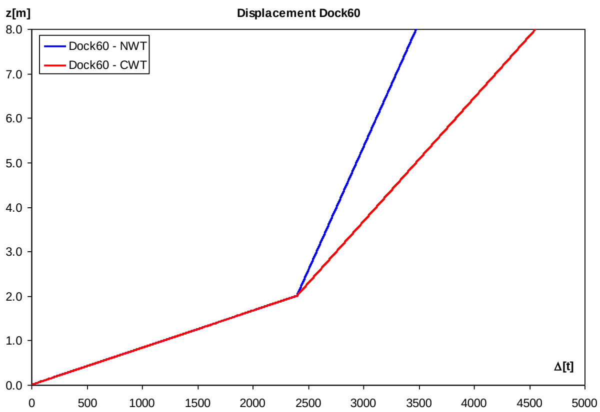

Fig.3.a Dock60 NWT & CWT displacement Δ[t]

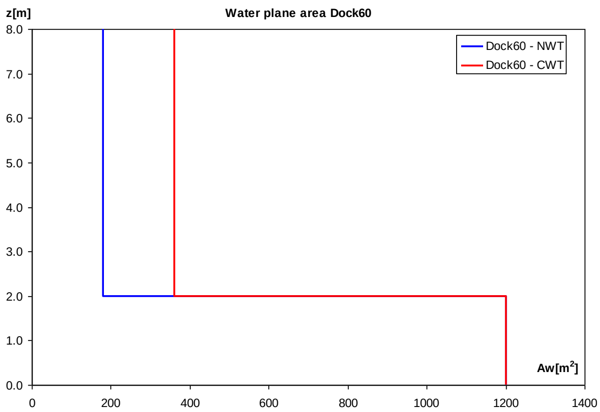

Fig.3.b Dock60 NWT& CWT water plane area A_w[m^2]

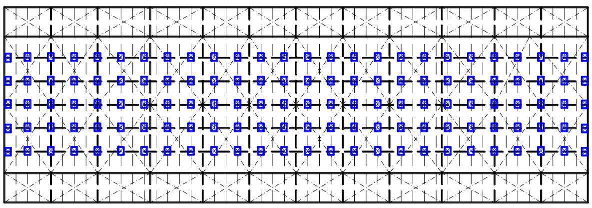

Fig.4.a Docking with short blocks SB (0.6 x 0.8 x 1.25 , 1.212 t), 26 x 5 columns x rows

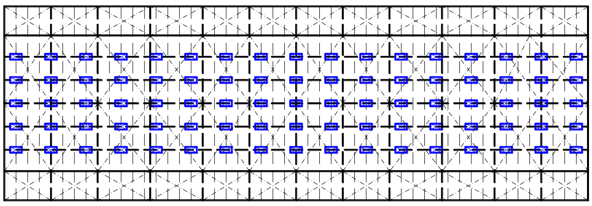

Fig.4.b Docking with long blocks LB (1.2 x 0.6 x 1.25, 1.818 t), 17 x 5 columns x rows

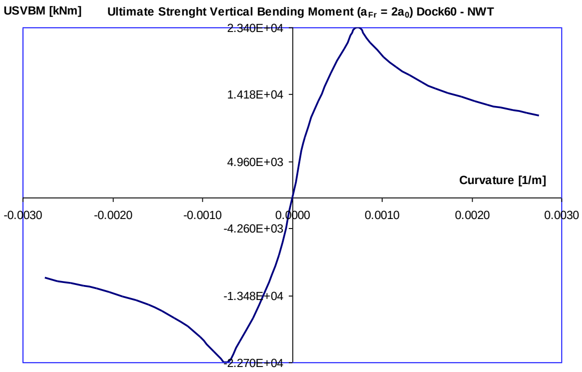

Fig.5.a Dock60_NWT *USVBM* $a_{Fr}=2a_0$

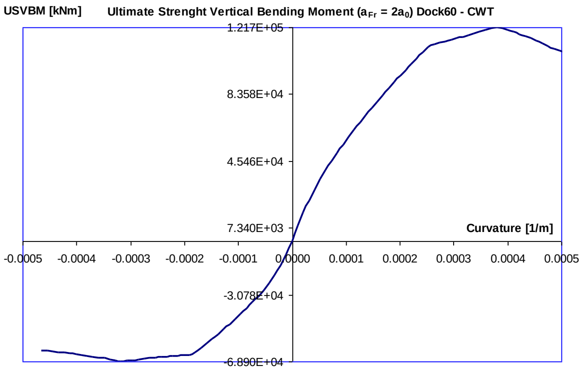

Fig.5.b Dock60_CWT *USVBM* $a_{Fr}=2a_0$

Table 2. Ultimate Strength, Admissible Vertical Bending Moment and Vertical Shear Force

Dock60	a_{Fr}	Hogging		Sagging		*AVBM* [kNm]	*AVSF* [kN]
		USVBM [kNm]	*AUSVBM* [kNm] (cs=1.2)	*USVBM* [kNm]	*AUSVBM* [kNm] (cs=1.2)	(σ_{max}=140 N/mm^2)	(τ_{max}=100 N/mm^2)
NWT	a_0	3.490E+04	2.908E+04	-3.410E+04	-2.842E+04	3.826E+04	1.000E+04
	$2a_0$	2.340E+04	1.950E+04	-2.270E+04	-1.892E+04		
	$4a_0$	1.060E+04	0.883E+04	-1.190E+04	-0.992E+04		
CWT	a_0	1.528E+05	1.273E+05	-9.480E+04	-7.900E+04	9.797E+04	2.320E+04
	$2a_0$	1.217E+05	1.014E+05	-6.890E+04	-5.742E+04		
	$4a_0$	8.620E+04	7.183E+04	-5.810E+04	-4.842E+04		

Table 3 Vertical deflection w_{adm}[m] and displacement d_{adm}[m] admissible limits

w_{adm}=L/400 [m]	$d_{PD\_adm}=H_p-FB_{PD\_adm}$ [m] cases 1,3,4,5		$d_{UD\_adm}=H-FB_{UD\_adm}$ [m] case 2	
0.150	CWT	NWT	CWT	NWT
	1.925	1.700	7.000	7.000

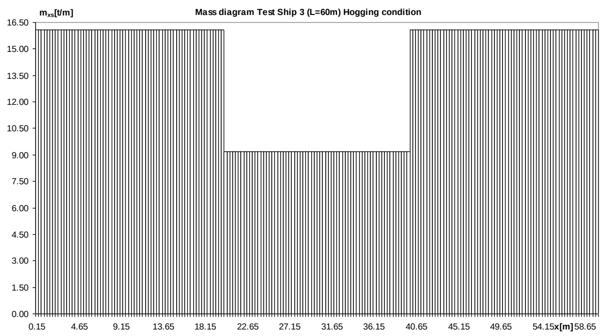

Fig.6.a Mass diagram m_{xs}[t/m] Test Ship Sagging mass distribution (M_s=828 t, x_s=30 m)

Fig.6.b Mass diagram m_{xs}[t/m] Test Ship Hogging mass distribution (M_s=828 t, x_s=30 m)

Table 4. Dock60 NWT and CWT side wing tanks displacement cases

Cases	Blocks	NWT non-continuous side WT					CWT continuous side WT				
		Δ [t]	d_m[m]	x_G[m]	y_G[m]	z_G[m]	Δ [t]	d_m[m]	x_G[m]	y_G[m]	z_G[m]
(1) Light	SB/LB	960	0.800	30	0	1.777	1152	0.960	30	0	3.891
(2) Full ballast	SB/LB	3252	6.733	30	0	1.738	4092	6.700	30	0	2.144
(3)Test ship 1 uniform	SB/LB										
(4)Test ship 2 sagging	SB/LB	1788	1.49	30	0	2.691 ÷ 6.395	1980	1.650	30	0	3.832 ÷ 7.177
(5)Test ship 3 hogging	SB/LB										

4. FLOATING DOCK60 NUMERICAL ANALYSES FOR THE OPERATION CAPABILITIES AND SAFETY ASSESSMENT BY THE STRENGTH AND FREEBOARD CRITERIA

In order to assess the structural capabilities of the floating Dock60, NWT and CWT constructive versions, we have considered only the yielding stress limit (admissible stress) *AVBM*, *AVSF*, the ultimate strength vertical bending moment limit *AUSVBM* and the admissible deflection w_{adm} strength criteria (Table 2 and Table 3), with loads corresponding to the still water SW (h_w=0) sheltered harbour condition, sagging and hogging head equivalent quasi-static waves with the maximum height up to the extreme cases of inland IN(2.0) (h_{wlim}=2 m) and RE(50%) (h_{wlim}=2.568 m) coastal or unsheltered harbour conditions and dock relocation, with δh_w=0.1-0.25 m, according to the DNVGL [10] rules. So, the freeboard limit criterion was initial disregarded, being focused only on the structural safety issue.

From the numerical results, by D_ACAVD0 module, for the 20 displacement cases of the floating Dock60 (Table 4), in the next we have selected the results for testing ship 3 (Fig.6.b, hogging mass distribution, case 5), SB short blocks, when the NWT dock version has reached the limits of the strength capabilities:

- Figs.7.a,b present the floating dock mass diagrams m_x[t/m], for NWT/SB/case5 and CWT/SB/case5;
- Figs.8.a,b present the floating dock girder vertical deflection diagrams w[m], still water, sagging / hogging waves conditions and the admissible deflection w_{adm}[m] (Tab. 3), for NWT/SB/case5 and CWT/SB/case5;

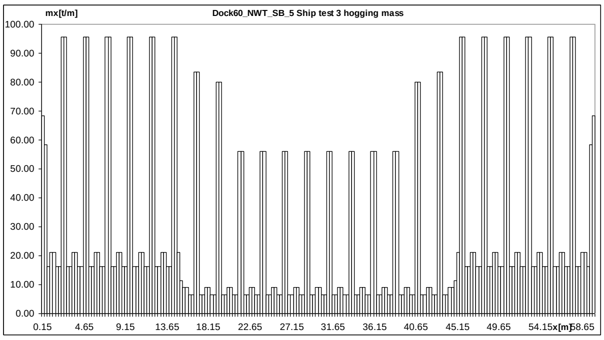

Fig.7.a Dock60_NWT/SB/case5 m_x[t/m]

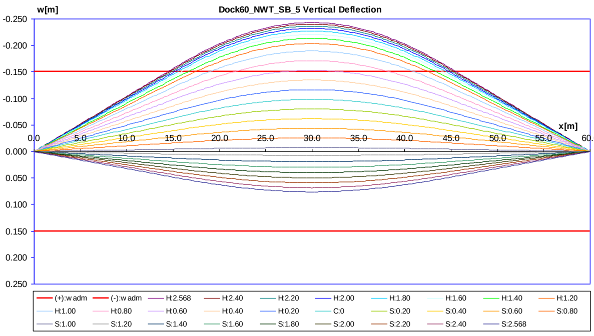

Fig.8.a Dock60_NWT/SB/case5 w[m]

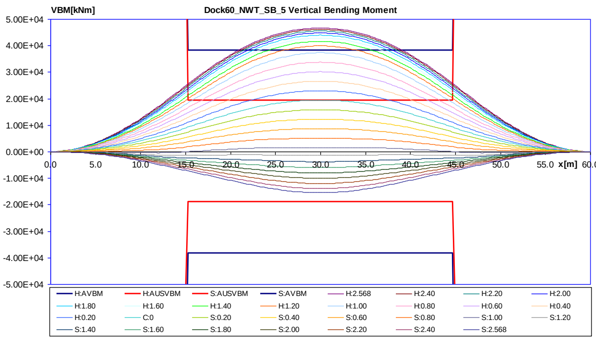

Fig.9.a Dock60_NWT/SB/case5 *VBM*[kNm]

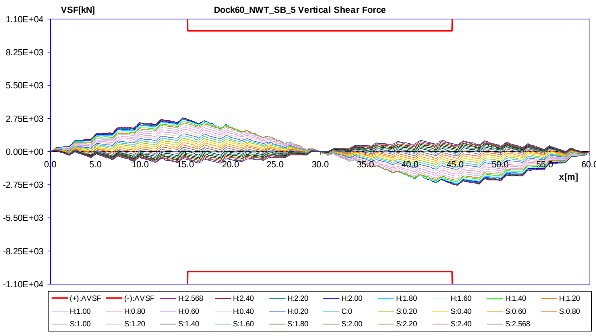

Fig.10.a Dock60_NWT/SB/case5 *VSF*[kN]

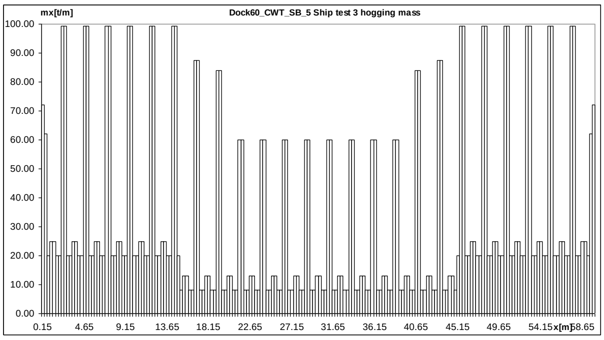

Fig.7.b Dock60_CWT/SB/case5 m_x[t/m]

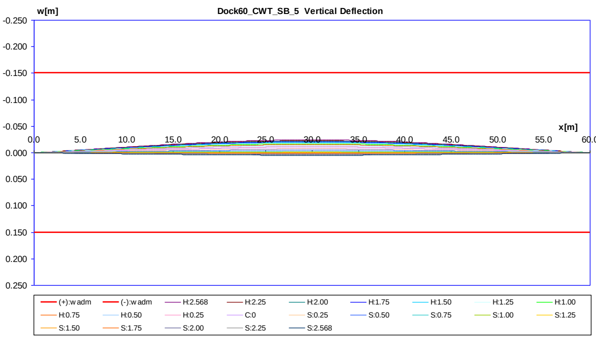

Fig.8.b Dock60_CWT/SB/case5 w[m]

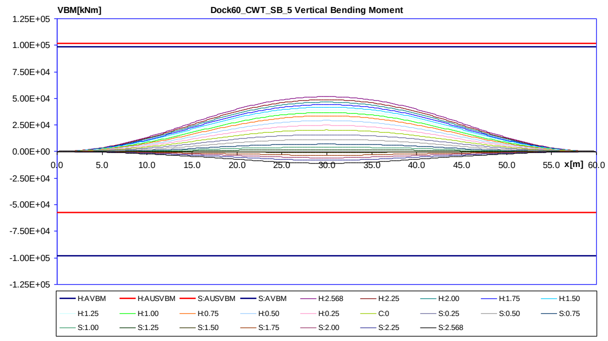

Fig.9.b Dock60_CWT/SB/case5 *VBM*[kNm]

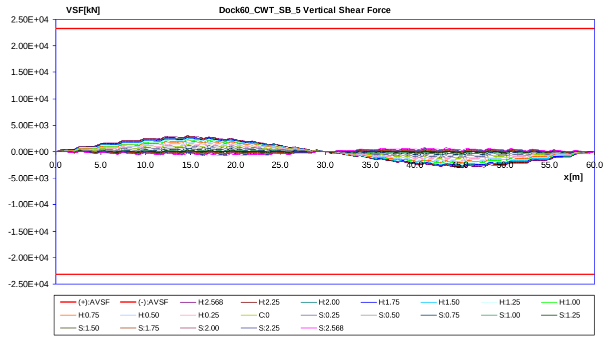

Fig.10.b Dock60_CWT/SB/case5 *VSF*[kN]

- Figs.9.a,b present the floating dock vertical bending moments diagrams *VBM* [kNm], still water, sagging / hogging waves conditions and the admissible limits *AVBM*, *AUSVBM* (Table 2), for NWT/SB/case5 and CWT/SB/case5;
- Figs.10.a,b present the floating dock vertical shear forces diagrams *VSF* [kN], still water, sagging / hogging waves conditions and the admissible limits *AVSF* (Table 2), for NWT/SB/case5 and CWT/SB/case5.

Tables 5.a,b (NWT_SB/LB) and Tables 6.a,b (CWT_SB/LB) present the limit values of the environment condition (waves height limit h_{wlim}) and the strength capabilities in operation of the floating Dock60, based on the strength (*VBM*, *VSF*) and deflection (*w*) criteria (Table 2 and Table 3). Considering only the freeboard criteria (d_m, Tables 5.a,b, Tables 6.a,b), the following restrictions are obtained:

- NWT version: case 1 h_{wlim}=1.85 m and cases 2-5 h_{wlim}=0.33÷0.42 m;
- CWT version: case 1 h_{wlim}=1.93 m and cases 2-5 h_{wlim}=0.55÷0.60 m.

Table 5.a. Limit values according to strength, deflection and freeboard criteria

Dock60_NWT_SB		**Hogging**				**Sagging**			
Criteria	**Limit**	**d_m[m]**	***w*[m]**	***VBM*[kNm]**	***VSF*[kN]**	**d_m[m]**	***w*[m]**	***VBM*[kNm]**	***VSF*[kN]**
Case 1	IN(0.38)	0.776	-0.150	1.95E+04	2.86E+03	0.776	0.128	-1.89E+04	1.347E+03
h_w[m]	0.378	1.848	0.922	0.378	2.568	1.848	2.568	1.844	2.568
Case 2	IN(0.33)	6.837	-0.029	5.41E+03	3.38E+02	6.266	-0.012	2.45E+03	2.55E+02
h_w[m]	0.326	0.326	2.568	2.568	2.568	1.468	2.568	2.568	2.568
Case 3	IN(0.25)	1.490	-0.150	1.95E+04	2.52E+03	1.490	0.095	-1.89E+04	1.28E+03
h_w[m]	0.252	0.420	0.781	0.252	2.568	0.420	2.568	2.476	2.568
Case 4	IN(0.42)	1.490	-0.150	1.95E+04	2.19E+03	1.490	0.135	-1.89E+04	1.57E+03
h_w[m]	0.420	0.420	1.309	0.664	2.568	0.420	2.568	1.724	2.568
Case 5	SW	1.490	-0.150	1.95E+04	2.79E+03	1.490	0.076	-1.54E+04	9.41E+02
h_w[m]	0.000	0.420	0.569	0.000	2.568	0.420	2.568	2.568	2.568
h_w[m]	**0.000**	**Class SW**							

Table 5.b. Limit values according to strength, deflection and freeboard criteria

Dock60_NWT_LB		Hogging				Sagging			
Criteria	**Limit**	**d_m[m]**	***w*[m]**	***VBM*[kNm]**	***VSF*[kN]**	**d_m[m]**	***w*[m]**	***VBM*[kNm]**	***VSF*[kN]**
Case 1	IN(0.39)	0.776	-0.150	1.95E+04	2.84E+03	0.776	0.129	-1.89E+04	1.350E+03
h_w[m]	0.388	1.848	0.933	0.388	2.568	1.848	2.568	1.824	2.568
Case 2	IN(0.33)	6.837	-0.028	5.23E+03	3.26E+02	6.266	-0.011	2.28E+03	2.61E+02
h_w[m]	0.326	0.326	2.568	2.568	2.568	1.468	2.568	2.568	2.568
Case 3	IN(0.34)	1.490	-0.150	1.95E+04	2.47E+03	1.490	0.103	-1.89E+04	1.35E+03
h_w[m]	0.335	0.420	0.871	0.335	2.568	0.420	2.568	2.329	2.568
Case 4	IN(0.42)	1.490	-0.150	1.95E+04	2.17E+03	1.490	0.135	-1.89E+04	1.62E+03
h_w[m]	0.420	0.420	1.325	0.679	2.568	0.420	2.568	1.702	2.568
Case 5	SW	1.490	-0.150	1.95E+04	2.73E+03	1.490	0.077	-1.57E+04	1.00E+03
h_w[m]	0.015	0.420	0.584	0.015	2.568	0.420	2.568	2.568	2.568
h_w[m]	**0.015**	**Class SW**							

Table 6.a. Limit values according to strength, deflection and freeboard criteria

Dock60_CWT_SB		Hogging				Sagging			
Criteria	**Limit**	***d_m*[m]**	***w*[m]**	***VBM*[kNm]**	***VSF*[kN]**	***d_m*[m]**	***w*[m]**	***VBM*[kNm]**	***VSF*[kN]**
Case 1	IN(1.93)	0.958	-0.025	5.40E+04	3.08E+03	0.958	0.012	-2.67E+04	1.394E+03
h_w[m]	1.934	1.934	2.568	2.568	2.568	1.934	2.568	2.568	2.568
Case 2	IN(0.60)	6.700	-0.004	7.54E+03	3.77E+02	6.700	0.009	-2.00E+04	1.16E+03
h_w[m]	0.600	0.600	2.568	2.568	2.568	0.600	2.568	2.568	2.568
Case 3	IN(0.55)	1.650	-0.023	4.73E+04	2.77E+03	1.650	-0.023	-1.54E+04	1.09E+03
h_w[m]	0.549	0.549	2.568	2.568	2.568	0.549	2.568	2.568	2.568
Case 4	IN(0.55)	1.650	-0.019	4.00E+04	2.45E+03	1.650	0.010	-2.28E+04	1.38E+03
h_w[m]	0.549	0.549	2.568	2.568	2.568	0.549	2.568	2.568	2.568
Case 5	IN(0.55)	1.650	-0.024	5.17E+04	3.04E+03	1.650	0.005	-1.10E+04	7.53E+02
h_w[m]	0.549	0.549	2.568	2.568	2.568	0.549	2.568	2.568	2.568
h_w[m]	**0.549**	**Class IN(0.55)**							

Table 6.b. Limit values according to strength, deflection and freeboard criteria

Dock60_CWT_LB		Hogging				Sagging			
Criteria	**Limit**	***d_m*[m]**	***w*[m]**	***VBM*[kNm]**	***VSF*[kN]**	***d_m*[m]**	***w*[m]**	***VBM*[kNm]**	***VSF*[kN]**
Case 1	IN(1.93)	0.958	-0.025	5.38E+04	3.03E+03	0.958	0.013	-2.69E+04	1.393E+03
h_w[m]	1.934	1.934	2.568	2.568	2.568	1.934	2.568	2.568	2.568
Case 2	IN(0.60)	6.700	-0.003	7.37E+03	3.63E+02	6.700	0.009	-2.02E+04	1.19E+03
h_w[m]	0.600	0.600	2.568	2.568	2.568	0.600	2.568	2.568	2.568
Case 3	IN(0.55)	1.650	-0.022	4.59E+04	2.69E+03	1.650	0.007	-1.68E+04	1.16E+03
h_w[m]	0.549	0.549	2.568	2.568	2.568	0.549	2.568	2.568	2.568
Case 4	IN(0.55)	1.650	-0.019	3.98E+04	2.38E+03	1.650	0.010	-2.30E+04	1.43E+03
h_w[m]	0.549	0.549	2.568	2.568	2.568	0.549	2.568	2.568	2.568
Case 5	IN(0.55)	1.650	-0.024	5.15E+04	2.98E+03	1.650	0.005	-1.13E+04	8.05E+02
h_w[m]	0.549	0.549	2.568	2.568	2.568	0.549	2.568	2.568	2.568
h_w[m]	**0.549**	**Class IN(0.55)**							

From the numerical results of this sections (Tables 5.a,b and Table 6.a,b) results that the operation restrictions for the floating Dock60, in terms of environment conditions (waves height limit h_{wlim}), are imposed by the *USVBM* ultimate strength bending moment criterion and *FB* freeboard criterion.

5. FLOATING DOCK60 NUMERICAL ANALYSES FOR THE OPERATION CAPABILITIES AND SAFETY ASSESSMENT BY THE INTACT TRANSVERSAL STABILITY CRITERION

In order to assess the operation capabilities of the floating Dock60, NWT and CWT constructive versions, by the intact transversal stability criterion according to the DNVGL rules [10], we have used the D_LDF003 software module. Due to the same displacement Δ[t] and draught d_m[t] values for cases 3,4,5 on each constructive version (NWT, CWT), we have considered for the testing ships a range of z_{Gs}=0.5÷8.5 m of the docked ship gravity centre vertical position. Also between SB and LB docking blocks conditions, at each case only the mass distribution is different, with influence only on the strength criterion, so that for intact stability assessment of the floating Dock60 the type of docking blocks has no influence. A selection of the numerical results from the intact stability criterion assessment is presented:

- Figs.11.a,b *GZ* the righting lever curve and *LDF* the dynamic stability curve, NWT, cases 1, 2;
- Figs.12.a,b *GZ* the righting lever curve and *LDF* the dynamic stability curve, NWT, cases 3,4,5, z_{Gs} range;
- Table 7 the assessment of the general stability criteria and the weather stability criteria, NWT and CWT versions.

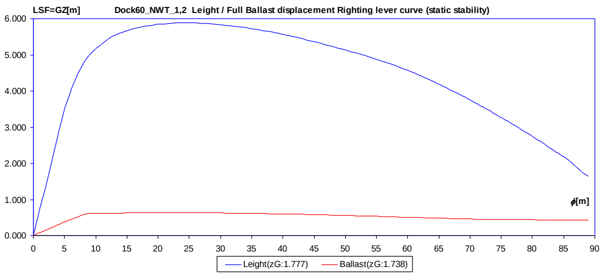

Fig.11.a Dock60_NWT cases 1,2 Righting lever curve

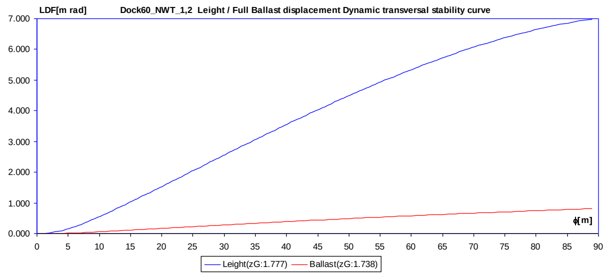

Fig.11.b Dock60_NWT cases 1,2 Dynamic stability curve

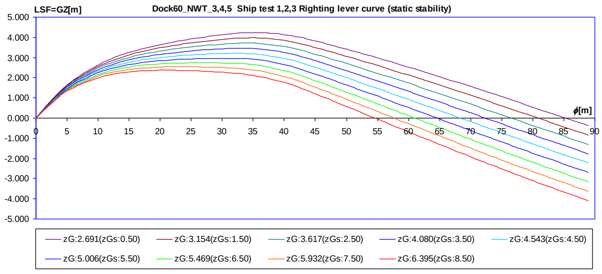

Fig.12.a Dock60_NWT cases 3,4,5 Righting lever curve

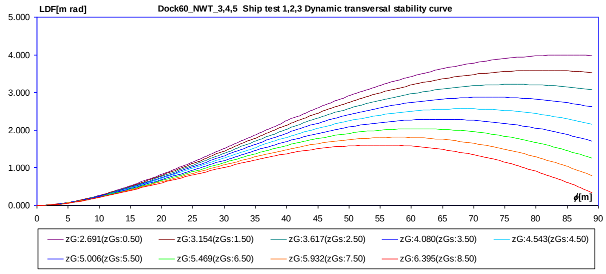

Fig.12.b Dock60_NWT cases 3,4,5 Dynamic stability curve

Table 7 Dock60 NWT and CWT stability criteria assessment

Case	NWT non-continuous side WT					CWT continuous side WT				
	Case 1	Case 2	Cases 3,4,5			Case 1	Case 2	Cases 3,4,5		
□□[t]	960	3252	1788	1788	1788	1152	4092	1980	1980	1980
z_G[m]	1.777	1.738	2.691	5.932	6.395	3.891	2.144	3.832	6.759	7.177
z_{Gs}[m] (test ship 828 t)	-	-	0.5	7.5	8.5	-	-	0.5	7.5	8.5
d_m [m]	0.800	6.733	1.490	1.490	1.490	0.960	6.700	1.650	1.650	1.650
FB_{PD} Pontoon deck freeboard >=0.3 m (initial condition)	1.200 yes	- -	0.510 yes	0.510 yes	0.510 yes	1.040 yes	- -	0.350 yes	0.350 yes	0.350 yes
FB_{UD} Upper deck freeboard >=1 m (initial condition)	7.200 yes	1.267 yes	6.510 yes	6.510 yes	6.510 yes	7.040 yes	1.300 yes	6.350 yes	6.350 yes	6.350 yes
h_0=GM_0[m] >=1 m	40.059 yes	4.080 yes	20.282 yes	17.041 yes	16.578 yes	31.124 yes	6.824 yes	17.086 yes	14.159 yes	13.741 yes
LSF(30deg)=*GZ*(30deg)[m] >=0.20 m	5.838 yes	0.626 yes	4.122 yes	2.501 yes	2.270 yes	5.122 yes	1.019 yes	4.518 yes	3.055 yes	2.846 yes
LDF(15deg)[mrad] >=0.070 mrad	1.02390 yes	0.11632 yes	0.52393 yes	0.41350 yes	0.39772 yes	0.86703 yes	0.18899 yes	0.50547 yes	0.40573 yes	0.39149 yes
LDF(30deg)[mrad] >=0.055 mrad	2.65327 yes	0.29246 yes	1.57821 yes	1.11530 yes	1.04917 yes	2.31400 yes	0.47634 yes	1.66213 yes	1.24407 yes	1.18437 yes
LDF(40deg)[mrad] >=0.090 mrad	3.54984 yes	0.38883 yes	2.23955 yes	1.48132 yes	1.37300 yes	3.08304 yes	0.63307 yes	2.38378 yes	1.69901 yes	1.60121 yes
φ_{st_max}[deg] >=15 deg	25 yes	22 yes	35 yes	24 yes	21 yes	23 yes	20 yes	37 yes	26 yes	25 yes
LSF(φ_{st_max})=*GZ*(f φ_{st_max})[m] >=0.25 m	5.883 yes	0.633 yes	4.242 yes	2.546 yes	2.370 yes	5.241 yes	1.033 yes	4.614 yes	3.091 yes	2.912 yes
LDF(φ_{st_max}) [mrad] if φ_{st_max} < 30 deg limit is	2.03961 0.06 yes	0.19343 0.063 yes	- - -	0.80682 0.061 yes	0.64292 0.064 yes	1.58976 0.062 yes	0.27906 0.065 yes	- - -	0.97603 0.059 yes	0.88294 0.06 yes
$K_{weather}$ (wind & roll) >=1	1.63156 yes	0.44099 no	1.84285 yes	1.05427 yes	0.99187 no	1.10830 yes	0.39641 no	1.57573 yes	1.02522 yes	0.98399 no

6. CONCLUSIONS

Based on this study results the following conclusion came out:

An integrated software package FDOCK (section 2), with five main modules has been developed, for floating docks operation capability and safety assessment by freeboard, yielding stress limit (admissible bending moments and shear forces), ultimate strength vertical bending moment limit, general and weather stability criteria.

A floating Dock60, with 60 m length, numerical model has have developed (section 3), according to the DNVGL rules [10], in two constructive versions NWT and CWT, without and with continuous side wing tanks WT. There are considered 5 displacement cases: light, full ballast, testing ships with uniform, sagging and hogging mass distributions. Also two types of docking blocks SB – short and LB – long are considered.

From the floating Dock60 assessment according to the global strength criteria (section 4), for the range of wave height condition $h_w \leq 2.568$ m, results no restrictions for the dock CWT constructive version. For the dock NWT version, except the case 2 – full ballast, on the other cases result restrictions (cases 1,3,4 $h_{wlim\geq}$.25 m), with the extreme condition for case 5 – testing ship with hogging mass distribution, where $h_{wlim}\approx 0$ (SW-still water). The restrictions occur from the *USVBM* ultimate strength vertical bending moment criterion. For the NWT version at the centre part of pontoon, because the side wing tanks WT are non-continuous, the sections strength is significant reduced in compare to the CWT version caisson type with continuous side WT over the whole dock length.

From the floating Dock60 assessment according to the freeboard criterion (section 4), in the case 1 – light displacement there is a significant reserve of freeboard, so that the relocation operation of the floating dock can be done, corresponding almost to the inland IN(2.0) navigation condition. For the other displacement cases 2÷5 the restrictions are $h_{wlim} \leq 0.42$ m (NWT) and $h_{wlim} \leq 0.55$ m ≈ 0.6 m (CWT) with almost inland IN(0.6) navigation condition.

Table 8. The floating Dock60 operation capabilities in safety conditions

Loading case	Dock60 NWT version (SB/LB blocks) non-continuous side WT	Dock60 CWT version (SB/LB blocks) continuous side WT
Case 1 Light displacement	- operation in sheltered harbour (SW), (h_{wlim}<0.38m) - relocation only on inland waterways with special approval of the inland navigation authorities	- operation in unsheltered ≈IN(2.0) / sheltered harbour (SW), (h_{wlim}<1.93m) - relocation on inland waterways without restrictions and for costal with special approval of the maritime navigation authorities
Case 2 Full ballast displacement	- sheltered harbour (SW) (calm weather conditions due to the stability criterion) - no relocation allowed	- sheltered harbour (SW) (calm weather conditions due to the stability criterion) - no relocation allowed
Case 3 Maximum lifting capacity *Ms*=828 t, $z_{Gs} \leq 7.5$ m testing ship with uniform mass distribution	- operation in sheltered harbour (SW), (h_{wlim}<0.25m) - not designed for relocation operation with lifted ship onboard	- operation in unsheltered harbour ≈IN(0.6) / sheltered harbour (SW), (h_{wlim}<0.55m) - not designed for relocation operation with lifted ship onboard
Case 4 Maximum lifting capacity *Ms*=828 t, $z_{Gs} \leq 7.5$ m testing ship with sagging mass distribution	- operation in sheltered harbour (SW), (h_{wlim}<0.42m) - not designed for relocation operation with lifted ship onboard	- operation in unsheltered harbour ≈IN(0.6) / sheltered harbour (SW), (h_{wlim}<0.55m) - not designed for relocation operation with lifted ship onboard
Case 5 Maximum lifting capacity *Ms*=828 t, $z_{Gs} \leq 7.5$ m testing ship with hogging mass distribution	- operation in sheltered harbour (SW), (h_{wlim}≈0 m), the extreme loading case (strength limits) - not designed for relocation operation with lifted ship onboard	- operation in unsheltered harbour ≈IN(0.6) / sheltered harbour (SW), (h_{wlim}<0.55m) - not designed for relocation operation with lifted ship onboard

From the floating Dock60 assessment according to the general stability criteria (section 5) results no restrictions in any cases. The weather criteria is not satisfied for case 2 – full ballast and also for cases 3,4,5 – testing lifting ships with the ship gravity centre vertical position z_{Gs}>7.5 m.

Taking into account all the floating Dock60 assessed criteria (Tables 5.a,b , Tables 6.a,b , Table 7), in Table 8 the operation capabilities in safety conditions are summarized. The NWT dock version has reached his operation capabilities due to the restrictions induced by *USVBM* criterion. For both dock versions NWT / CWT in case 2 - full ballast, due to the reduced free surface area and righting lever *GZ*, the weather (heel angle and wind) stability criteria is not satisfied and the dock has reached out the operation capability (only SW condition). The freeboard *FB* criterion leads to the main restrictions for all the cases for the CWT dock version.

The floating Dock60 version CWT – caisson type with continuous side wing tanks has higher operation capabilities (no restriction from strengths criteria) in compare to the version NWT – non-continuous side wing tanks WT, which has a lower strength in the centre part of the dock structure.

Further studies shall include the local-global strength assessment using 3D-FEM models, by yielding stress limit and buckling criteria, the environment condition restrictions (h_{wlim}) assessment by dynamic seakeeping criteria in the range inland SW ÷ IN(2.0) and costal up to RE(50%), including the relocation operation for case 1 – light displacement. Also, more complex floating dock structures, especially for constructive versions with non-continuous sided wing tanks (NWT), more sensitive to the extreme operation conditions, shall be analyzed and compared with an effective lifting operation trial from a shipyard, in order to validate the FDOCK iterative equilibrium modules.

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