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ON THE EVALUATION OF TWO DESIGN VERSIONS OF A 23000T OFF-SHORE BARGE BY THE HYDROELASTIC LONG-TERM APPROACH

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Abstract. In this paper the hydroelastic study is developed for a 23000T off-shore barge, with a maximum length of 189 m, focusing on a comparative study for two design versions with 40 m and 50 m breadth. The initial off-shore barge with 40 m breadth has been extended to 50 m breadth by adding a supplementary tank section at the centerline, so making it possible to ensure transport capabilities for cargo structures extra wide. The two versions of the off-shore barges are analyzed at full cargo capacity of 23000 t case, for speed values 0 and 7 knots, corresponding to operation on-site at zero speed and maximum transition speed conditions, under head irregular waves with interference components, for a short-term averaged waves' spectrum. The hull structure of the off-shore barge versions is almost uniform over the whole length, mainly being recorded stress hot-spot at the hull transversal bulkheads connection with the other orthogonal panels and forepeak of the barge, with a maximum of 1.2 hot-spot factor at the prismatic barge hull part. This study is developed by own software DYN-HYD, involving the modules for the hydroelastic long-term approach, applied for the evaluation of the safety limit in the long-term operation conditions.
Keywords: hydroelastic, shore barge, structure.

1. INTRODUCTION

For the floating structures with the first natural frequency less than 1 Hz, on vertical vibration modes, the structural assessment must be done by the hydroelastic long-term approach, involving coupled oscillations and vibrations response computation of the ship's hull body [1- 4].
The numerical study is focused on an initial off-shore barge having 40 m breadth [5] that has been extended by design to 50 m breadth for special operations, as extra-wide cargo structures. The first natural frequencies at vertical hull vibration of the two versions of the off-shore barges are 0.624 Hz and 0.700 Hz (section 3) so that the hull girder vibration response is significant and the hydroelastic long-term approach is required for structural evaluation [6- 8] (sections 4, 5).
The hydroelastic approach includes five interlinked main modules [9]: the solution by the frequency-domain method of the linear dynamic response; the solution by the direct time-domain integration method of the non-linear dynamic response; the total dynamic response in the time-domain and the spectral decomposition analysis delivering the short-term statistical response; the total long-term statistical response computation for a long-term averaged waves' histogram; and finally the long-term fatigue off-shore barge structure evaluation for a reference operation time of 20 years (section 2). The numerical analyses are done by own software DYN-HYD with experimental validation [10].
Both constructive versions of the off-shore barge B40 and B50 are assessed by long-term strength criteria, delivering the operation capabilities comparison of the two design versions (section 6).

2. FUNDAMENTS OF THE OFF-SHORE BARGE HYDROELASTIC LONG-TERM APPROACH

The off-shore barge hydroelastic long-term analysis, in head irregular waves, by eigen algorithm and program DYN-HYD [9, 10] (figure 1), has the next steps:
- (1) *The off-shore barge data.* For the off-shore barge hydroelastic analysis required input data are: masses distribution, shape lines, natural oscillation and vibration modes, first-order averaged ITTC short-term wave power density spectrum (figure 2) and averaged Word Wide Trade wave significant height histogram p$(h_{1/3i})$,i=12 (figure 3).
- (2) *The short-term linear hydroelastic off-shore barge response* with external excitation by head Longuet-Higgins irregular wave model $\zeta_v(x,t)$ [10], with first-order ITTC spectrum and second-order wave interference components (figure 4). The range of wave significant height is $h_{1/3}$=0-12m, $\delta h_{1/3}$=0.5m, and circular wave frequency ω=0-5 rad/s. Using a modal analysis technique on oscillations (heave and pitch, r=0,1) and the first three global vertical vibration modes

2. Fundaments of the off-shore barge hydroelastic long-term term approach

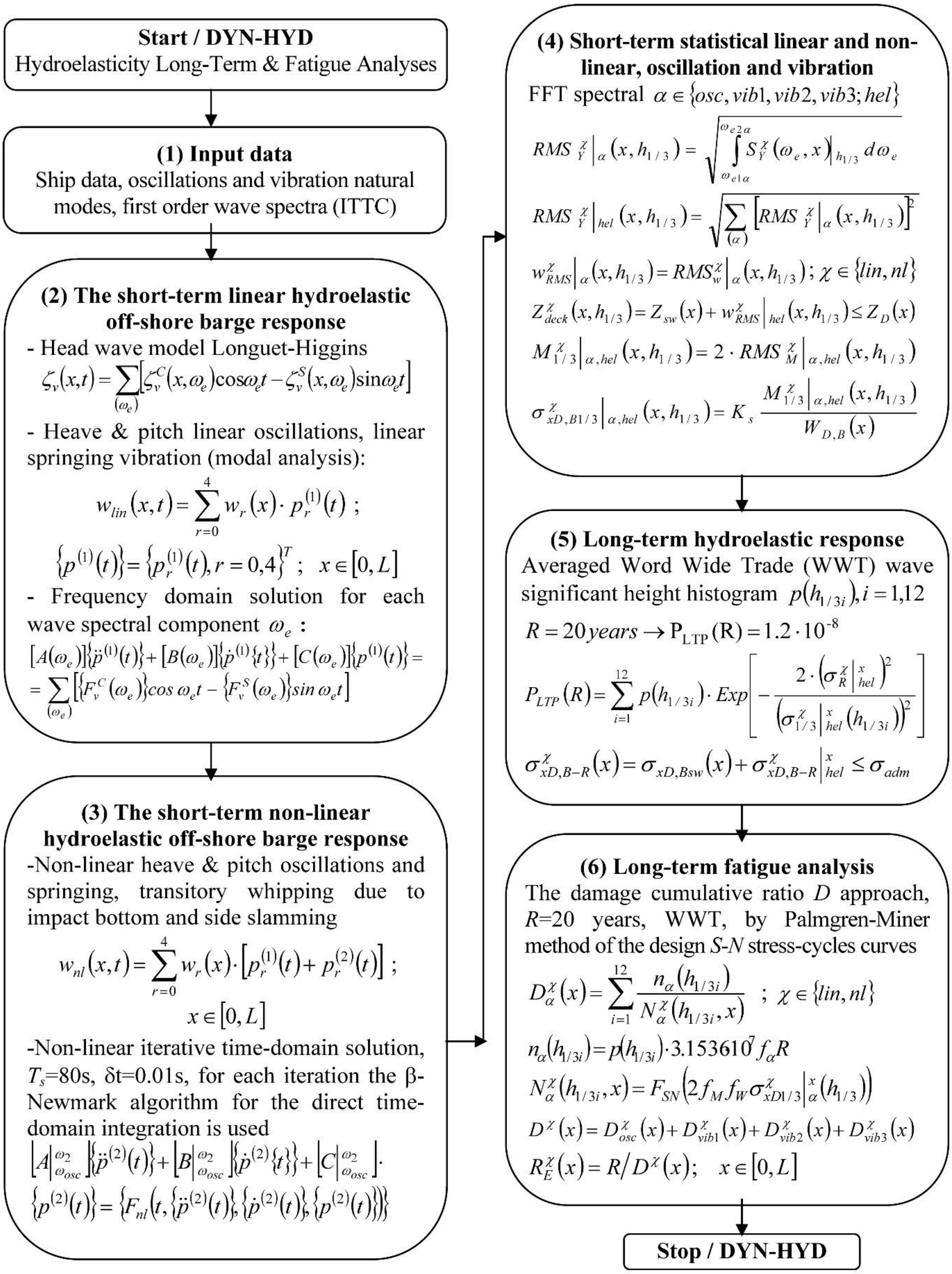

Fig. 1. The algorithm for off-shore barge hydroelastic long-term term approach, with fatigue assessment

(r=2,3,4), results in the frequency domain the linear short-term hydroelastic off-shore barge response $\{p^{(1)}(t)\}$ for each wave spectral components ω_e. The response includes linear oscillations and springing components.

-(3) *The short-term non-linear hydroelastic off-shore barge response* $\{p^{(2)}(t)\}$ with a direct time-domain integration solution, including besides the non-linear oscillations' components also non-linear springing, bottom slamming, side slamming and whipping components.

-(4) *Short-term statistical linear and non-linear, oscillation and vibration.* The most probable response amplitudes *RMS* are obtained by the *FFT* technique [9] applied on total time records for displacement and deflection components w_{RMS}, Z_{deck} and the significant amplitudes of the vertical sectional efforts $M_{1/3}$ and the normal stresses $\sigma_{1/3}$ at deck and bottom. For the off-shore barges structure, the hot-spot stress coefficient is in the range K_s=1÷1.2, being an almost uniform structure over the hull. Using the most probable total displacement the criterion of the freeboard limit is checked.

-(5) *Long-term hydroelastic response* is computed for a maximum reference time *R*=20 years and averaged navigation conditions characterized by WWT long-term histogram (figure 3). Using the long-term stresses σ_R the criteria of the yielding stress limit is checked.

-(6) *Long-term fatigue analysis* by Palmgren-Miner approach of the design *S-N* stress-cycles curves [3] that leads to the assessment of the damage cumulative ratio *D* criteria for a reference period of *R*=20 years and selected structural details as the deck panel. Also, the R_E exploitation life is computed.

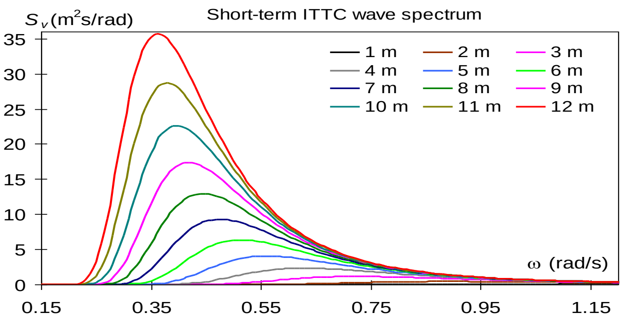

Fig. 2. Short-term ITTC wave spectrum [9]

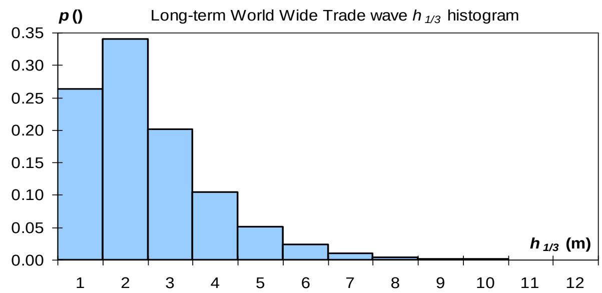

Fig. 3. Long-term WWT wave $h_{1/3}$ histogram [3]

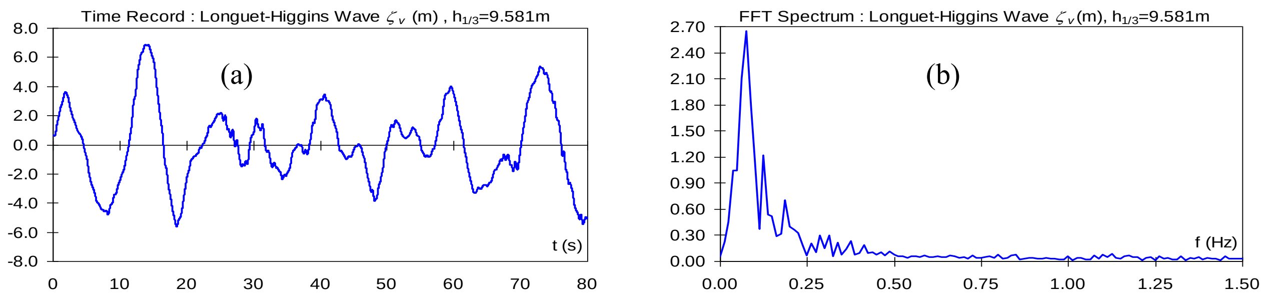

Fig. 4. Longuet-Higgins wave ζ_v (m), (a) time record, (b) FFT spectrum, reference $h_{1/3}$=9.581 m

3. THE OFF-SHORE BARGES B40/B50 (23000T) HYDROELASTIC MODEL MAIN CHARACTERISTICS

The study focuses on a 23000T off-shore barge with two constructive versions B40 and B50, with the main characteristics in table 1 [5]. Figure 5 presents the 3D shape model in the case of barge B40 and the second version barge B50 has an extra 10 m breadth. The off-shore barges shape is prismatic over 179.2 m in length, at forepeak being the only geometric non-linear part (9.8 m).

The off-shore barges' structure is preliminarily designed according to the DNV shipbuilding rules [3] (figure 6), made of steel grade AH36 for bottom and deck panels and steel grade A for the other panels (table 1). The off-shore barge B50 requires a supplementary number of longitudinal bulkheads compare to the initial barge B40 version (figure 6). The off-shore barges hull has a uniformly structure over almost length, being idealized by the 1D-FEM girder model with the equivalent sectional characteristics in table 1. The cargo at maximum capacity 23000 t is uniform distributed over the main deck, with the mass over length distributions in figure 7 for both off-shore barge versions.

Table 1. Off-shore barges B40/B50 (23000T) main characteristics

Main off-shore barges data					Off-shore barges natural frequencies f (Hz)		
L (m)	189	Version	B40	B50	Mode	B40	B50
H (m)	11	B (m)	40	50	osc$_1$ (r=0)	0.119	0.115
F_{aft}(m)	1.5	Δ_{unload}[t]	26586.07	33389.79	osc$_2$ (r=1)	0.120	0.115
F_m(m)	1	Δ_{full}(t)	49586.07	56389.79	vib$_1$ (r=2)	0.624	0.700
F_{fore}(m)	2	x_G (m)	92.467	92.266	vib$_2$ (r=3)	1.668	1.879
Cargo(t)	23000	y_G (m)	0.000	0.000	vib$_3$ (r=4)	3.082	3.481
Stations	270(41)	d_{aft} (m)	6.586	6.000	Off-shore barges steel material data		
ρ_{water} (t/m^3)	1.025	d_m (m)	6.586	6.000	E (kN/m^2)		$2.1\cdot10^8$
g (m/s^2)	9.81	d_{fore} (m)	6.586	6.000	G (kN/m^2)		$8.1\cdot10^7$
v (kn)	0; 7	I_{yy0} (m^4)	105.351	133.530	*structural damping coef.*		0.001
$h_{rules}(m)$	9.581	A_0 (m^2)	6.772	8.614	$\rho_{material}$(t/m^3)		7.85
$h_{1/3max}$(m)	12	A_{fz0} (m^2)	3.219	4.179	R_{eH} (MPa) AH36 & A		355 & 235
Longuet-Higgins head wave		W_{D0} (m^3)	19.340	24.495	σ_{adm} (MPa) AH36		285
ITTC wave spectrum		W_{B0} (m^3)	18.973	24.066	σ_{adm} (MPa) A		205
WWT wave histogram		$1/K_{tnn0}$(m^2)	0.432	0.330	τ_{adm} (MPa) A		120

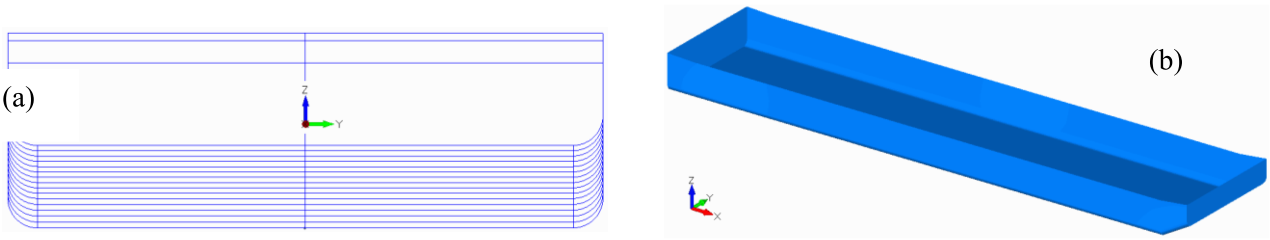

Fig. 5. Off-shore barge B40 (23000T) shape model, (a) transversal off-set lines, (b) 3D view [5].

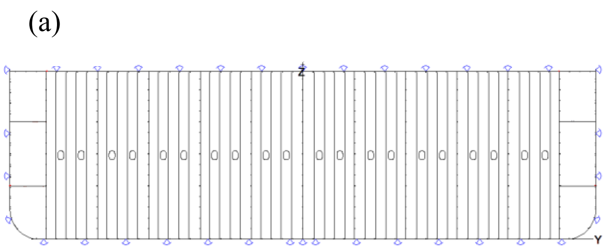

Fig. 6. Off-shore barge B40 (23000T) preliminary design amidships structure

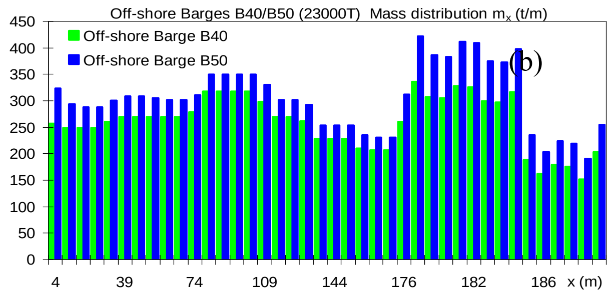

Fig. 7. Off-shore barges versions B40 and B50 (23000T) mass over length distribution m_x (t/m)

4. THE OFF-SHORE BARGES B40/B50 (23000T) HYDROELASTIC SHORT-TERM ANALYSIS

4.1. The short-term hydroelastic off-shore barge B40 response

For the hydroelastic short-term analysis of the off-shore barge B40 in this subsection, a synthesis of the main results is selected.

Figure 8 presents the short-term most-probable vertical non-linear displacement for offshore-barge B40, speed v=7 kn, assessing at deck the green sea and at keel the bottom slamming occurrence.

The green sea phenomenon can occur at both barge ends for a wave with significant height $h_{1/3}$>10.5m, being safe from the freeboard criterion for h_{rules}=9.581m. The bottom slamming does not occur at aft due to U shape and occurs at fore due to the slip shape (figure 5) for $h_{1/3}$>3m. The barge has vertical sides all over the length, so that side slamming cannot occur.

Table 2 presents the assessment of the most-probable vertical linear and non-linear displacement, oscillations (r=0,1) and vibration components (r=2,3,4), for off-shore barge B40, speed v=0; 7 kn, reference wave $h_{1/3}$=9.581m.

The most-probable vibration deflections are reduced in compare to the vertical heave and pitch motion, representing 1.38÷2.30% (vib / osc) for speed v=0 kn and 1.51÷4.68% (vib / osc) for speed v=7 kn. The differences between linear and non-linear displacements and deflections are reduced, +0.27÷+0.61% (nln / lin) v=0 kn and +0.16÷+0.29% (nln / lin) v=7 kn. The speed effect, 0 kn versus 7 kn, on oscillation motion is medium +8.80%÷+8.93% and

on vibration deflections is high, +18.84%÷ +46.07% (*vib2*, *vib3*), and over double (> +100%) for the first mode (*vib1*).
Figures 9 and 10 present vertical non-linear bending moment and shear force, time records and FFT spectrum, for offshore-barge B40, speed v=7 kn, reference wave $h_{1/3}$=9.581m.

Figure 11 presents short-term significant vertical non-linear bending moment and shear force for off-shore barge B40, speed v=7 kn, as the main source for the long-term analysis in the next section.
Table 3 presents the assessment of the significant vertical linear and non-linear bending moment and shear force, oscillations (r=0,1) and vibration components (r=2,3,4), for off-shore barge B40, speed v=0; 7 kn, reference wave $h_{1/3}$=9.581m.

Table 2. Off-shore barge B40, short-term most-probable w_{RMS}(m) vertical displacement, speeds v=0; 7 kn, ITTC & LH head irregular wave $h_{1/3}$=9.581 m

v(kn)	Section	Analysis	w_{oscRMS}(m)	$w_{vibRMS(1)}$(m)	*%vib1/osc*	$w_{vibRMS(2)}$(m)	*%vib2/osc*	$w_{vibRMS(3)}$(m)	*%vib3/osc*
	0.25*L*	Linear	1.5739	0.0324	2.06%	0.0260	1.65%	0.0197	1.25%
0	0.50*L*		1.0773	0.0244	2.27%	0.0196	1.82%	0.0147	1.36%
	0.75*L*		1.5884	0.0405	2.55%	0.0324	2.04%	0.0242	1.53%
Average % :			-	-	**2.29%**	-	**1.84%**	-	**1.38%**
	0.25*L*		1.5776	0.0721	4.57%	0.0416	2.64%	0.0251	1.59%
7	0.50*L*		1.1872	0.0585	4.93%	0.0278	2.34%	0.0172	1.45%
	0.75*L*		1.8420	0.0835	4.53%	0.0442	2.40%	0.0274	1.49%
Average % :			-	-	**4.68%**	-	**2.46%**	-	**1.51%**
speed effect			+8.80%	> +100%	-	+46.09%	-	+19.21%	-
	0.25*L*	Non-linear	1.5750	0.0325	2.07%	0.0261	1.66%	0.0198	1.25%
0	0.50*L*		1.0787	0.0245	2.27%	0.0196	1.82%	0.0147	1.36%
	0.75*L*		1.5937	0.0406	2.55%	0.0325	2.04%	0.0243	1.53%
Average % :			*(+0.27%)*	*(+0.59%)*	**2.30%**	*(+0.60%)*	**1.84%**	*(+0.61%)*	**1.38%**
	0.25*L*		1.5779	0.0722	4.57%	0.0417	2.64%	0.0251	1.59%
7	0.50*L*		1.1902	0.0588	4.94%	0.0278	2.34%	0.0172	1.45%
	0.75*L*		1.8530	0.0837	4.52%	0.0444	2.39%	0.0274	1.48%
Average % :			*(+0.29%)*	*(+0.26%)*	**4.68%**	*(+0.16%)*	**2.46%**	*(+0.16%)*	**1.51%**
speed effect			+8.93%	> +100%	-	+46.07%	-	+18.84%	-

Phenomena		Bottom slamming	Side slamming	Green sea	
aft	0	no	no	$h_{1/3}$ > 10.5 m	*ref.* $h_{1/3}$= *9.581m*
fore	L	$h_{1/3}$ > 3 m	no	$h_{1/3}$ > 10.5 m	

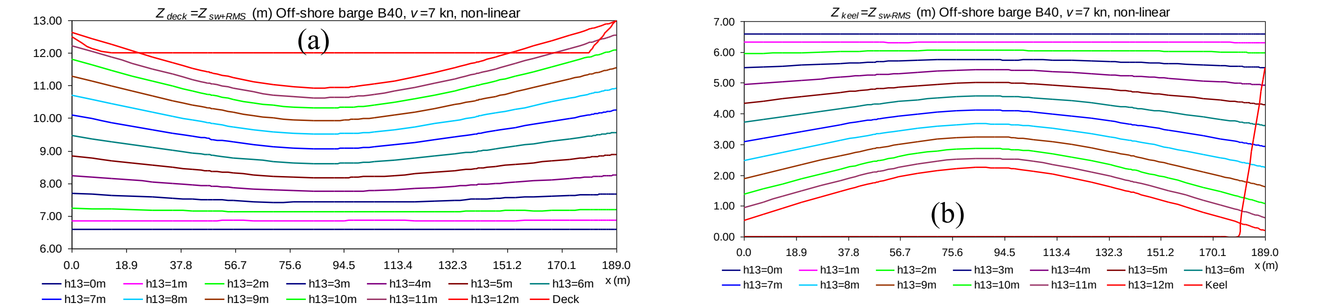

Fig. 8. Off-shore barge B40, short-term vertical non-linear displacement, v=7 kn, Longuet-Higgins irregular head wave $h_{1/3max}$=12 m, (a) deck level, (b) keel level

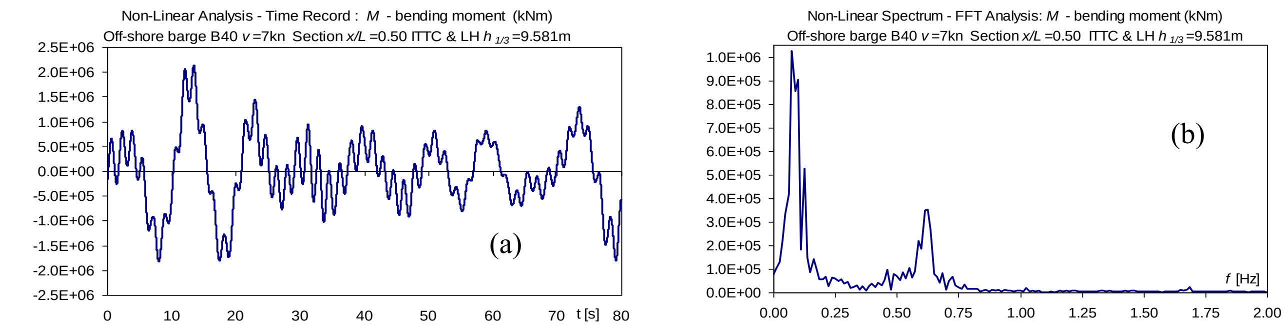

Fig. 9. Off-shore barge B40, vertical non-linear bending moment, v=7 kn, x/L=0.50, Longuet-Higgins irregular head wave $h_{1/3}$=9.581 m, (a) time record T_s=80 s, (b) FFT spectrum ($f_{trigger}$=100 Hz)

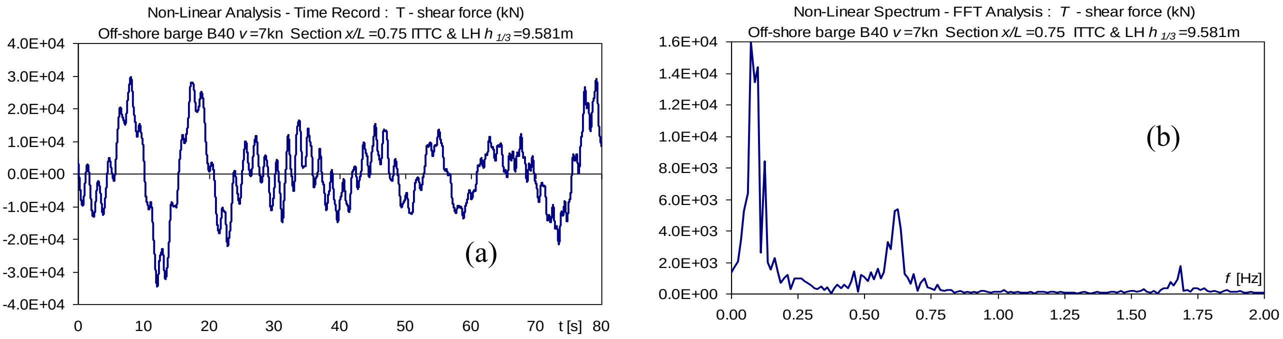

Fig. 10. Off-shore barge B40, vertical non-linear shear force, v=7 kn, x/L=0.75, Longuet-Higgins irregular head wave $h_{1/3}$=9.581 m, (a) time record T_s=80 s, (b) FFT spectrum ($f_{trigger}$=100 Hz)

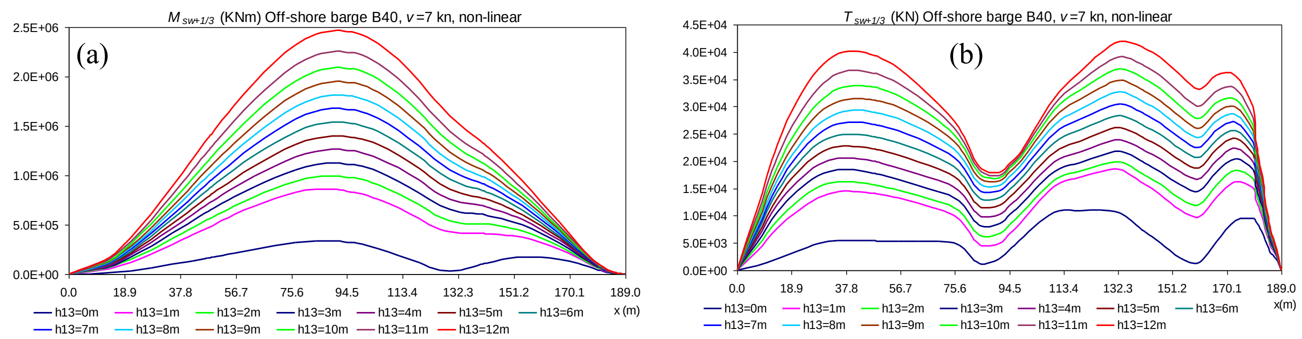

Fig. 11. Off-shore barge B40, short-term vertical non-linear plus still water efforts, v=7 kn, Longuet-Higgins irregular head wave $h_{1/3max}$=12 m, (a) bending moment, (b) shear force

Table 3. Off-shore barge B40, short-term significant sectional efforts $M_{1/3}$(kNm) and $T_{1/3}$(kN), speeds v=0; 7 kn, ITTC & LH head irregular wave $h_{1/3}$=9.581 m

v(kn)	Section	Analysis	$M_{osc1/3}$(kNm)	$M_{vib1/3(1)}$(kNm)	*%vib1/osc*	$M_{vib1/3(2)}$(kNm)	*%vib2/osc*	$M_{vib1/3(3)}$(kNm)	*%vib3/osc*
	0.25L		$8.54\cdot10^{+5}$	$3.37\cdot10^{+5}$	39.42%	$1.85\cdot10^{+4}$	2.16%	$1.08\cdot10^{+4}$	1.26%
0	0.50L		$1.53\cdot10^{+6}$	$6.19\cdot10^{+5}$	40.48%	$3.66\cdot10^{+4}$	2.40%	$2.09\cdot10^{+4}$	1.37%
	0.75L		$8.51\cdot10^{+5}$	$3.26\cdot10^{+5}$	38.32%	$2.14\cdot10^{+4}$	2.51%	$1.21\cdot10^{+4}$	1.42%
Average% :			-	-	**39.41%**	-	**2.36%**	-	**1.35%**
	0.25L	Linear	$8.66\cdot10^{+5}$	$3.45\cdot10^{+5}$	39.89%	$8.26\cdot10^{+4}$	9.54%	$1.21\cdot10^{+4}$	1.39%
7	0.50L		$1.55\cdot10^{+6}$	$6.36\cdot10^{+5}$	40.93%	$2.31\cdot10^{+4}$	1.49%	$2.24\cdot10^{+4}$	1.44%
	0.75L		$8.82\cdot10^{+5}$	$3.35\cdot10^{+5}$	38.00%	$8.00\cdot10^{+4}$	9.07%	$1.52\cdot10^{+4}$	1.73%
Average% :			-	-	**39.61%**	-	**6.70%**	-	**1.52%**
speed effect			+2.12%	+2.63%	-	> +100%	-	+14.94%	-
	0.25L		$8.59\cdot10^{+5}$	$3.48\cdot10^{+5}$	40.57%	$1.88\cdot10^{+4}$	2.19%	$1.10\cdot10^{+4}$	1.28%
0	0.50L		$1.54\cdot10^{+6}$	$6.41\cdot10^{+5}$	41.69%	$3.73\cdot10^{+4}$	2.43%	$2.13\cdot10^{+4}$	1.38%
	0.75L		$8.62\cdot10^{+5}$	$3.39\cdot10^{+5}$	39.39%	$2.16\cdot10^{+4}$	2.51%	$1.23\cdot10^{+4}$	1.43%
Average% :			*(+0.81%)*	*(+3.74%)*	**40.55%**	*(+1.65%)*	**2.38%**	*(+1.69%)*	**1.36%**
	0.25L	Non-linear	$8.71\cdot10^{+5}$	$3.51\cdot10^{+5}$	40.29%	$8.27\cdot10^{+4}$	9.49%	$1.23\cdot10^{+4}$	1.41%
7	0.50L		$1.57\cdot10^{+6}$	$6.48\cdot10^{+5}$	41.38%	$2.35\cdot10^{+4}$	1.50%	$2.26\cdot10^{+4}$	1.44%
	0.75L		$8.90\cdot10^{+5}$	$3.44\cdot10^{+5}$	38.71%	$8.00\cdot10^{+4}$	9.00%	$1.54\cdot10^{+4}$	1.73%
Average% :			*(+0.79%)*	*(+2.13%)*	**40.13%**	*(+0.55%)*	**6.66%**	*(+1.22%)*	**1.53%**
speed effect			+2.20%	+1.14%	-	> +100%	-	+14.37%	-
v(kn)	Section	Analysis	$T_{osc1/3}$(kN)	$T_{vib1/3(1)}$(kN)	*%vib1/osc*	$T_{vib1/3(2)}$(kN)	*%vib2/osc*	$T_{vib1/3(3)}$(kN)	*%vib3/osc*
	0.25L		$2.47\cdot10^{+4}$	$9.81\cdot10^{+3}$	39.77%	$5.63\cdot10^{+2}$	2.28%	$3.23\cdot10^{+2}$	1.31%
0	0.50L		$1.40\cdot10^{+4}$	$1.46\cdot10^{+3}$	10.41%	$3.11\cdot10^{+2}$	2.21%	$1.85\cdot10^{+2}$	1.31%
	0.75L		$2.43\cdot10^{+4}$	$9.60\cdot10^{+3}$	39.52%	$6.06\cdot10^{+3}$	2.49%	$3.45\cdot10^{+2}$	1.42%
Average% :			-	-	**29.90%**	-	**2.33%**	-	**1.35%**
	0.25L	Linear	$2.49\cdot10^{+4}$	$1.01\cdot10^{+4}$	40.53%	$9.83\cdot10^{+2}$	3.95%	$3.08\cdot10^{+2}$	1.24%
7	0.50L		$1.41\cdot10^{+4}$	$1.55\cdot10^{+3}$	11.02%	$3.45\cdot10^{+3}$	24.47%	$2.42\cdot10^{+2}$	1.71%
	0.75L		$2.47\cdot10^{+4}$	$9.86\cdot10^{+3}$	39.92%	$1.08\cdot10^{+3}$	4.38%	$3.44\cdot10^{+2}$	1.39%
Average% :			-	-	**30.49%**	-	**10.93%**	-	**1.45%**

speed effect			+1.06%	+3.94%	-	> +100%	-	+8.63%	-
0	0.25*L*	Non-linear	$2.48 \cdot 10^{+4}$	$1.02 \cdot 10^{+4}$	41.00%	$5.74 \cdot 10^{+2}$	2.32%	$3.29 \cdot 10^{+2}$	1.33%
	0.50*L*		$1.41 \cdot 10^{+4}$	$1.49 \cdot 10^{+3}$	10.61%	$3.17 \cdot 10^{+2}$	2.25%	$1.87 \cdot 10^{+2}$	1.33%
	0.75*L*		$2.45 \cdot 10^{+4}$	$9.96 \cdot 10^{+3}$	40.70%	$6.16 \cdot 10^{+2}$	2.52%	$3.15 \cdot 10^{+2}$	1.43%
Average% :			*(+0.46%)*	*(+3.14%)*	**30.70%**	*(+1.96%)*	**2.36%**	*(+1.58%)*	**1.36%**
7	0.25*L*		$2.45 \cdot 10^{+4}$	$1.03 \cdot 10^{+4}$	40.90%	$9.96 \cdot 10^{+2}$	3.97%	$3.12 \cdot 10^{+2}$	1.24%
	0.50*L*		$1.41 \cdot 10^{+4}$	$1.64 \cdot 10^{+3}$	11.65%	$3.45 \cdot 10^{+3}$	24.48%	$2.45 \cdot 10^{+2}$	1.74%
	0.75*L*		$2.49 \cdot 10^{+4}$	$1.01 \cdot 10^{+4}$	40.45%	$1.09 \cdot 10^{+3}$	4.37%	$2.45 \cdot 10^{+2}$	1.38%
Average% :			*(+0.57%)*	*(+3.20%)*	**31.00%**	*(+0.73%)*	**10.94%**	*(+1.01%)*	**1.46%**
speed effect			+0.14%	+4.15%	-	> +100%	-	+1.21%	-
Phenomena			Linear springing medium		Non-linear springing small		Whipping small		*ref.* $h_{1/3}$= *9.581m*

Because the bottom slamming occurs only at the fore, over a reduced length of 9.8 m (5.19%L), with a small integration area for impact slamming pressure, and no side slamming occurrence due to vertical sides, the non-linear springing and whipping phenomena have a very reduced intensity.
The significant vibration efforts are high on first mode (vib1) in comparison to the vertical oscillation efforts, representing 29.90÷40.55% (vib1/osc), medium on second mode 2.33÷10.94% (vib2/osc) and small on the third mode 1.35÷1.53% (vib3/osc). The differences between linear and non-linear efforts are small, +0.46÷+3.74% (nln / lin). The speed effect on efforts, 0 kn versus 7 kn, is reduced on oscillations +0.14%÷+2.20% and on vibration is small for vib1, +1.14%÷ +4.15%, medium for vib3 +1.21%÷ +14.94% and over double (> +100%) for the second mode (*vib2*).

4.2. The short-term hydroelastic off-shore barge B50 response

The synthesis for the hydroelastic response of the off-shore barge B50 includes the next results.
Figure 12 presents short-term most-probable vertical non-linear displacement for offshore-barge B50, speed v=7 kn, assessing at deck the green sea and at keel the bottom slamming occurrence.
The green sea phenomenon can occur only at the fore for a wave with significant height $h_{1/3}$>11.5m so that the freeboard criterion for h_{rules}=9.581m is satisfied. Similar to the initial barge version, the bottom slamming occurs only at aft for h1/3>1.5m, correlated to the decrease of the draught. No side slamming occurs, due to the vertical sides of the barge shape.
Table 4 presents the assessment of the most-probable vertical linear and non-linear displacement, oscillations and vibration, for off-shore barge B50, speed v=0; 7 kn, reference wave $h_{1/3}$=9.581m.
The most-probable vibration deflections are small in comparison to the vertical heave and pitch motion, representing 1.42÷4.23% (vib/osc). The linear and non-linear displacements and deflections have small differences, +0.21÷+1.08% (nln / lin). The speed effect, 0 kn versus 7 kn, on oscillation motion is medium +10.92%÷+11.00% and on vibration deflections are also medium, +8.13%÷+10.76%.
Comparing the two constructive versions, the off-shore barge B50, due to the larger total mass (table 1), has larger oscillation displacement (average +10.03%) and vibration deflections (average +27.23%), especially on the linear vibration components (tables 2, 4).
Figures 13 and 14 present vertical non-linear bending moment and shear force, time records and FFT spectrum, for offshore-barge B50, speed v=7 kn, reference wave $h_{1/3}$=9.581m.
Figure 15 presents short-term significant vertical non-linear bending moment and shear force for off-shore barge B50, speed v=7 kn, as the main source for the long-term analysis in the next section.
Table 5 presents the assessment of the significant vertical linear and non-linear bending moment and shear force, oscillations (r=0,1) and vibration components (r=2,3,4), for off-shore barge B50, speed v=0; 7 kn, reference wave $h_{1/3}$=9.581m.
The shape of off-shore barge B50 is similar to the barge B40 (figure 5), having an extra 10 m breadth. For this version, the bottom slamming occurs only at the fore over a reduced length and no side slamming occurs. The non-linear springing and whipping phenomena have a small intensity.

Table 4. Off-shore barge B50, short-term most-probable w_{RMS}(m) vertical displacement, speeds v=0; 7 kn, ITTC & LH head irregular wave $h_{1/3}$=9.581 m

v(kn)	Section	Analysis	w_{oscRMS}(m)	$w_{vibRMS(1)}$(m)	*%vib1/osc*	$w_{vibRMS(2)}$(m)	*%vib2/osc*	$w_{vibRMS(3)}$(m)	*%vib3/osc*
0	0.25*L*	Linear	1.7291	0.0765	4.42%	0.0423	2.45%	0.0261	1.51%
	0.50*L*		1.1763	0.0516	4.38%	0.0279	2.37%	0.0171	1.46%
	0.75*L*		1.7126	0.0646	3.77%	0.0368	2.15%	0.0224	1.31%
Average % :			-	-	**4.19%**	-	**2.32%**	-	**1.43%**

7	0.25L		1.7579	0.0728	4.14%	0.0428	2.44%	0.0260	1.48%
	0.50L		1.3463	0.0560	4.16%	0.0312	2.32%	0.0191	1.42%
	0.75L		1.9978	0.0793	3.97%	0.0437	2.19%	0.0271	1.36%
Average % :			-	-	**4.09%**	-	**2.31%**	-	**1.42%**
speed effect			+10.92%	+8.82%	-	+10.59%	-	+10.76%	-
0	0.25L	Non-linear	1.7301	0.0771	4.46%	0.0425	2.46%	0.0261	1.51%
	0.50L		1.1781	0.0521	4.42%	0.0281	2.38%	0.0172	1.46%
	0.75L		1.7199	0.0654	3.80%	0.0371	2.16%	0.0226	1.31%
Average % :			*(+0.21%)*	*(+1.08%)*	**4.23%**	*(+0.60%)*	**2.33%**	*(+0.27%)*	**1.43%**
7	0.25L		1.7581	0.0730	4.15%	0.0429	2.44%	0.0260	1.48%
	0.50L		1.3527	0.0561	4.15%	0.0313	2.31%	0.0191	1.42%
	0.75L		2.0049	0.0798	3.98%	0.0440	2.19%	0.0273	1.36%
Average % :			*(+0.28%)*	*(+0.30%)*	**4.09%**	*(+0.32%)*	**2.32%**	*(+0.30%)*	**1.42%**
speed effect			+11.00%	+8.13%	-	+10.31%	-	+10.49%	-

Phenomena		Bottom slamming	Side slamming	Green sea	
aft	0	no	no	no	*ref.* $h_{1/3}$= 9.581*m*
fore	L	$h_{1/3}$ > 1.5 m	no	$h_{1/3}$ > 11.5 m	

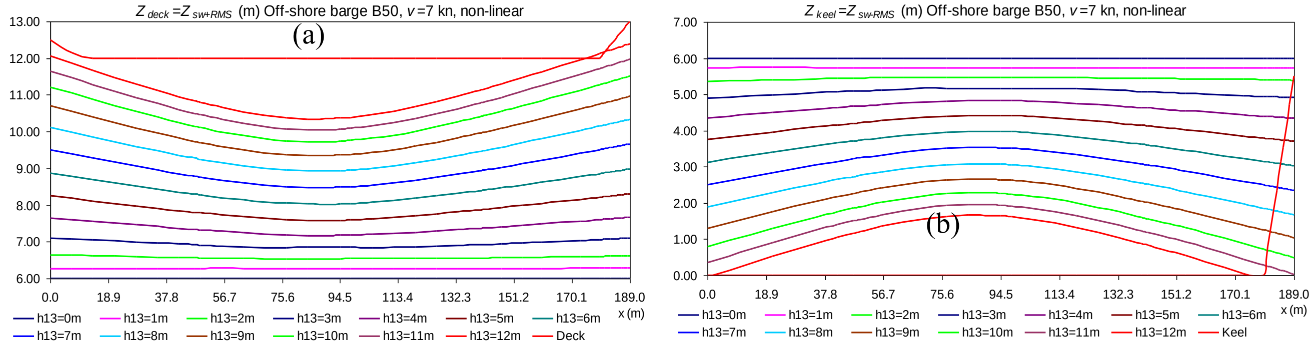

Fig. 12. Off-shore barge B50, short-term vertical non-linear displacement, v=7 kn, Longuet-Higgins irregular head wave $h_{1/3max}$=12 m, (a) deck level, (b) keel level

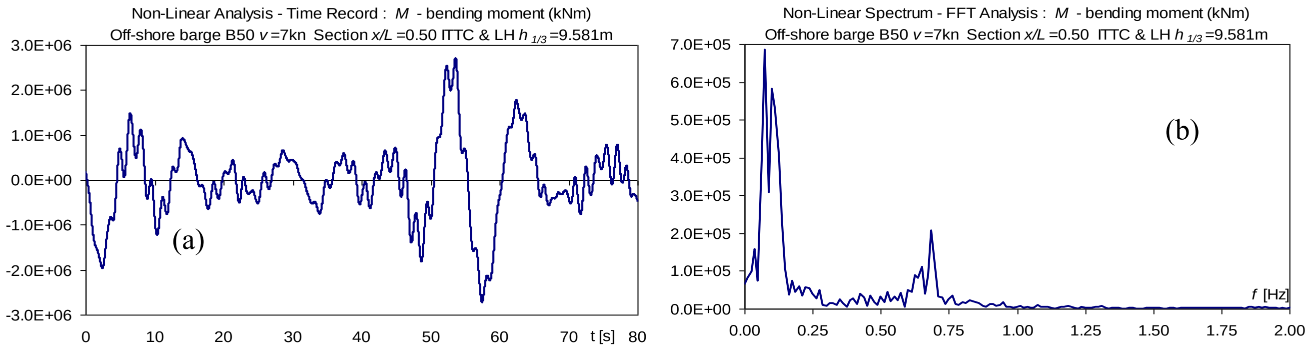

Fig. 13. Off-shore barge B50, vertical non-linear bending moment, v=7 kn, x/L=0.50, Longuet-Higgins irregular head wave $h_{1/3}$=9.581 m, (a) time record T_s=80 s, (b) FFT spectrum ($f_{trigger}$=100 Hz)

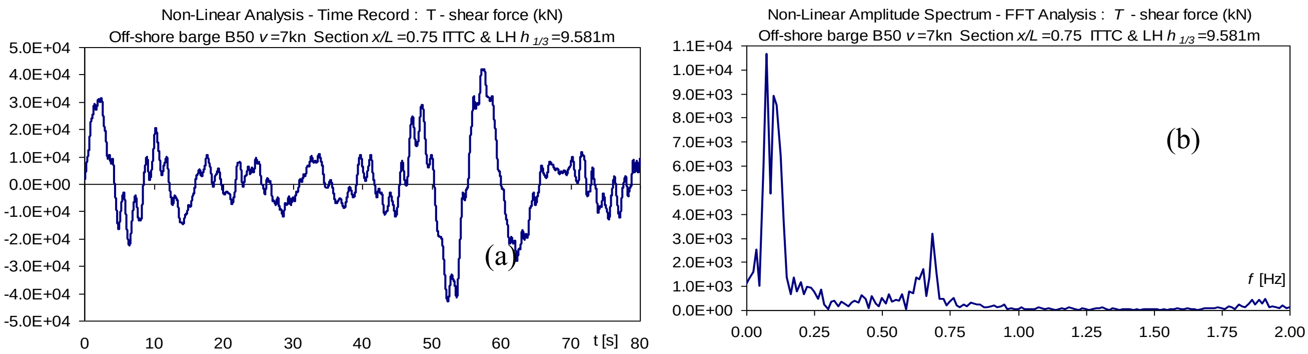

Fig. 14. Off-shore barge B50, vertical non-linear shear force, v=7 kn, x/L=0.75, Longuet-Higgins irregular head wave $h_{1/3}$=9.581 m, (a) time record T_s=80 s, (b) FFT spectrum ($f_{trigger}$=100 Hz)

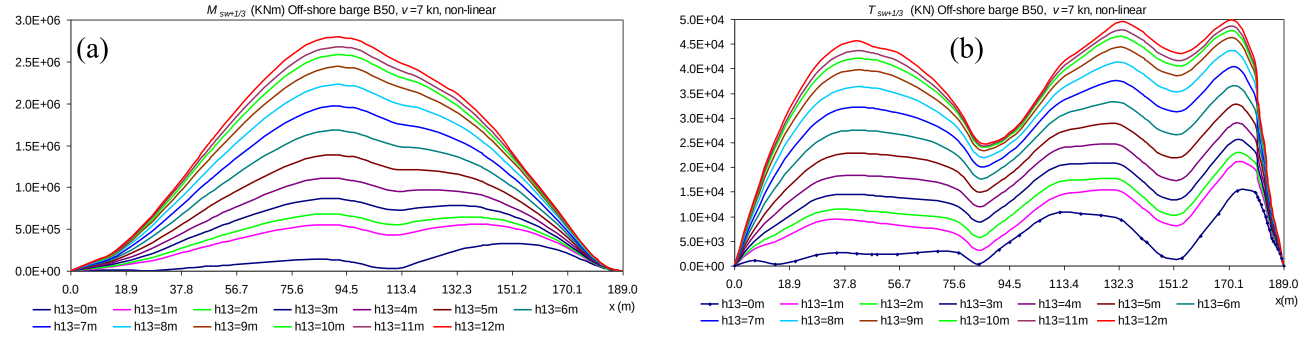

Fig. 15. Off-shore barge B50, short-term vertical non-linear plus still water efforts, v=7 kn, Longuet-Higgins irregular head wave $h_{1/3max}$=12 m, (a) bending moment, (b) shear force

Table 5. Off-shore barge B50, short-term significant sectional efforts $M_{1/3}$(kNm) and $T_{1/3}$(kN), speeds v=0; 7 kn, ITTC & LH head irregular wave $h_{1/3}$=9.581 m

v(kn)	Section	Analysis	$M_{osc1/3}$(kNm)	$M_{vib1/3(1)}$(kNm)	*%vib1/osc*	$M_{vib1/3(2)}$(kNm)	*%vib2/osc*	$M_{vib1/3(3)}$(kNm)	*%vib3/osc*
	0.25L		$1.19\cdot10^{+6}$	$3.19\cdot10^{+5}$	26.83%	$2.76\cdot10^{+4}$	2.32%	$1.66\cdot10^{+4}$	1.40%
0	0.50L		$2.16\cdot10^{+6}$	$5.90\cdot10^{+5}$	27.28%	$5.39\cdot10^{+4}$	2.50%	$3.25\cdot10^{+4}$	1.51%
	0.75L		$1.19\cdot10^{+6}$	$3.15\cdot10^{+5}$	26.51%	$2.97\cdot10^{+4}$	2.50%	$1.81\cdot10^{+4}$	1.53%
Average% :			-	-	**26.87%**	-	**2.44%**	-	**1.48%**
	0.25L	Linear	$1.26\cdot10^{+6}$	$3.35\cdot10^{+5}$	26.60%	$1.35\cdot10^{+5}$	10.69%	$2.21\cdot10^{+4}$	1.76%
7	0.50L		$2.31\cdot10^{+6}$	$6.13\cdot10^{+5}$	26.52%	$4.20\cdot10^{+4}$	1.82%	$3.23\cdot10^{+4}$	1.40%
	0.75L		$1.32\cdot10^{+6}$	$3.28\cdot10^{+5}$	24.92%	$1.30\cdot10^{+5}$	9.89%	$2.00\cdot10^{+4}$	1.52%
Average% :			-	-	**26.01%**	-	**7.46%**	-	**1.56%**
speed effect			+7.92%	+4.35%	-	> +100%	-	+14.34%	-
	0.25L		$1.19\cdot10^{+6}$	$3.26\cdot10^{+5}$	27.44%	$2.77\cdot10^{+4}$	2.33%	$1.67\cdot10^{+4}$	1.40%
0	0.50L		$2.16\cdot10^{+6}$	$6.01\cdot10^{+5}$	27.79%	$5.40\cdot10^{+4}$	2.50%	$3.26\cdot10^{+4}$	1.51%
	0.75L		$1.19\cdot10^{+6}$	$3.18\cdot10^{+5}$	26.71%	$3.01\cdot10^{+4}$	2.53%	$1.83\cdot10^{+4}$	1.54%
Average% :		Non-linear	*(+0.06%)*	*(+1.69%)*	**27.31%**	*(+0.61%)*	**2.45%**	*(+0.51%)*	**1.48%**
	0.25L		$1.26\cdot10^{+6}$	$3.55\cdot10^{+5}$	28.06%	$1.35\cdot10^{+5}$	10.68%	$2.30\cdot10^{+4}$	1.82%
7	0.50L		$2.32\cdot10^{+6}$	$6.45\cdot10^{+5}$	27.81%	$4.38\cdot10^{+4}$	1.89%	$3.41\cdot10^{+4}$	1.47%
	0.75L		$1.32\cdot10^{+6}$	$3.40\cdot10^{+5}$	25.75%	$1.30\cdot10^{+5}$	9.87%	$2.06\cdot10^{+4}$	1.56%
Average% :			*(+0.34%)*	*(+4.92%)*	**27.21%**	*(+1.56%)*	**7.48%**	*(+4.21%)*	**1.62%**
speed effect			+8.07%	+7.71%	-	> +100%	-	+18.30%	-
v(kn)	Section	Analysis	$T_{osc1/3}$(kN)	$T_{vib1/3(1)}$(kN)	*%vib1/osc*	$T_{vib1/3(2)}$(kN)	*%vib2/osc*	$T_{vib1/3(3)}$(kN)	*%vib3/osc*
	0.25L		$3.48\cdot10^{+4}$	$9.28\cdot10^{+3}$	26.70%	$8.52\cdot10^{+2}$	2.45%	$5.14\cdot10^{+2}$	1.48%
0	0.50L		$1.90\cdot10^{+4}$	$1.49\cdot10^{+3}$	7.86%	$4.49\cdot10^{+2}$	2.37%	$2.74\cdot10^{+2}$	1.44%
	0.75L		$3.40\cdot10^{+4}$	$9.12\cdot10^{+3}$	26.80%	$8.62\cdot10^{+2}$	2.53%	$5.21\cdot10^{+2}$	1.53%
Average% :			-	-	**20.45%**	-	**2.45%**	-	**1.48%**
	0.25L	Linear	$3.70\cdot10^{+4}$	$9.63\cdot10^{+3}$	26.00%	$1.63\cdot10^{+3}$	4.39%	$4.93\cdot10^{+2}$	1.33%
7	0.50L		$2.07\cdot10^{+4}$	$1.95\cdot10^{+3}$	9.41%	$5.51\cdot10^{+3}$	26.67%	$4.65\cdot10^{+2}$	2.25%
	0.75L		$3.69\cdot10^{+4}$	$9.41\cdot10^{+3}$	25.54%	$1.67\cdot10^{+3}$	4.53%	$4.43\cdot10^{+2}$	1.20%
Average% :			-	-	**20.31%**	-	**11.86%**	-	**1.59%**
speed effect			+7.93%	+12.61%	-	> +100%	-	+16.88%	-
	0.25L		$3.48\cdot10^{+4}$	$9.50\cdot10^{+3}$	27.32%	$8.53\cdot10^{+2}$	2.45%	$5.14\cdot10^{+2}$	1.48%
0	0.50L		$1.91\cdot10^{+4}$	$1.57\cdot10^{+3}$	8.22%	$4.57\cdot10^{+2}$	2.40%	$2.78\cdot10^{+2}$	1.46%
	0.75L		$3.41\cdot10^{+4}$	$9.27\cdot10^{+3}$	27.20%	$8.65\cdot10^{+2}$	2.54%	$5.23\cdot10^{+2}$	1.54%
Average% :			*(+0.21%)*	*(+3.01%)*	**20.91%**	*(+0.70%)*	**2.46%**	*(+0.67%)*	**1.49%**
	0.25L	Non-linear	$3.72\cdot10^{+4}$	$1.02\cdot10^{+4}$	27.39%	$8.65\cdot10^{+3}$	4.38%	$5.19\cdot10^{+2}$	1.40%
7	0.50L		$2.07\cdot10^{+4}$	$2.05\cdot10^{+3}$	9.92%	$5.52\cdot10^{+3}$	26.67%	$4.73\cdot10^{+2}$	2.29%
	0.75L		$3.70\cdot10^{+4}$	$9.86\cdot10^{+3}$	26.68%	$1.70\cdot10^{+3}$	4.60%	$4.58\cdot10^{+2}$	1.24%
Average% :			*(+0.26%)*	*(+5.38%)*	**21.33%**	*(+0.73%)*	**11.89%**	*(+3.46%)*	**1.64%**
speed effect			+7.93%	+14.77%	-	> +100%	-	+19.56%	-
Phenomena			Linear springing medium			Non-linear springing small		Whipping small	*ref.* $h_{1/3}$= *9.581m*

The significant vibration efforts are high on first mode (vib1) in comparison to the vertical oscillation efforts, representing 20.31÷27.31% (vib1/osc), medium on second mode 2.44÷11.89% (vib2/osc) and small on the third mode 1.48÷1.64% (vib3/osc). The differences between linear and non-linear efforts are small, +0.06÷+5.38% (nln / lin). The speed effect on efforts, 0 kn versus 7 kn, is medium on oscillations +7.92%÷+8.07%; on vibration is medium for vib1, +4.35%÷ +14.77% and for vib3 +14.34%÷ +19.56% and over double (> +100%) for the second mode (*vib2*).

Comparing the two constructive versions, the off-shore barge B50, due to the larger total mass (table 1), has larger short-term oscillation efforts (average +43.57%) and vibration efforts on vib2 and vib3 modes (average +53.85%); similar vibration efforts on vib1 mode (tables 3, 5, figures 11, 15).

5. THE OFF-SHORE BARGES B40/B50 (23000T) HYDROELASTIC LONG-TERM AND FATIGUE ASSESSMENT

5.1. The long-term hydroelastic off-shore barge B40 analysis and fatigue assessment

For the hydroelastic long-term analysis and fatigue assessment of the off-shore barge B40 in this subsection, a synthesis of the main results is selected.

Figure 16 presents the off-shore barge B40 long-term non-linear hydroelastic stresses, speed v=7 kn, WWT wave histogram, K_s=1.0, R≤20 years, at main deck $\sigma_{xD\text{-}R}$ and side neutral-axis $\tau_{xzNN\text{-}R}$.

Table 6 presents the off-shore barge B40 long-term linear and non-linear stresses assessment by yielding stress criteria (table 1), speeds v=0; 7 kn, WWT wave histogram, K_s=1.0, 1.1, 1.2, reference period R=20 years, at the main deck, bottom and side panels.

Table 7 presents the off-shore barge B40 fatigue long-term assessment, speeds v=0; 7 kn, K_s=1.0, 1.1, 1.2, oscillations and hydroelastic stresses, at amidships deck panel detail, for the R_E exploitation life computation, considering the standard and high-quality welding state.

Similar to the short-term sectional efforts' distributions (figure 11), the main deck panel stresses are maximum around the amidships sections and the side panel stresses are maximum at the aft and fore- quarter sections (figure 16), with significant influence of the R period. For K_s=1.0 the yielding stress criterion is satisfied in any cases (table 6). For K_s=1.1 strength restrictions occur at the bottom panel, non-linear response, speed v=7kn (table 6). For K_s=1.2 the strength restrictions (R_E<20 years) are extended to the main deck and bottom panel, linear and non-linear response, all range of speeds v= 0; 7kn (table 6).

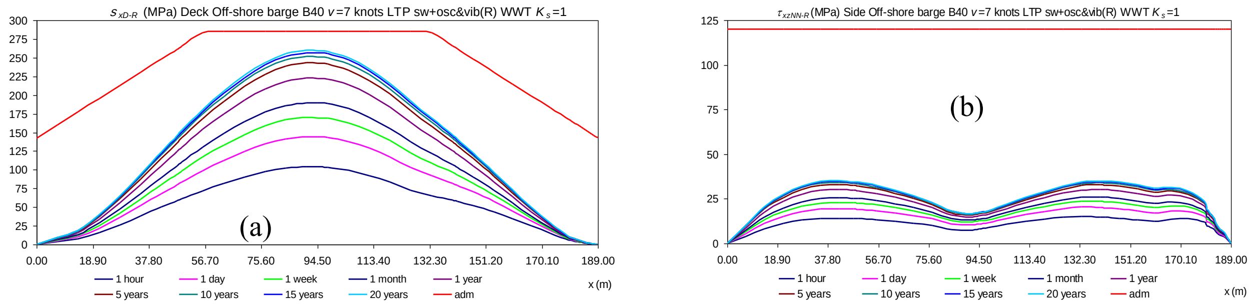

Fig. 16. Off-shore barge B40, long-term non-linear hydroelastic stresses, v=7 kn, WWT histogram, K_s=1.0, (a) deck $\sigma_{xD\text{-}R}$ (MPa), (b) side neutral-axis $\tau_{xzNN\text{-}R}$ (MPa)

Table 6. Off-shore barge B40, long-term stresses (MPa) analysis, WWT histogram, speeds v=0; 7 kn, hydroelastic analysis, K_s=1.0, 1.1, 1.2, reference period R=20 years

Panel reference	Speed (kn)		K_s	1.0			1.1			1.2		
Stress (MPa)		Analysis	adm	S(MPa)	S/adm	R(years)	S(MPa)	S/adm	R(years)	S(MPa)	S/adm	R(years)
$\sigma_{xD\text{-}R}$ deck	0	Linear	285	243.76	0.855	>20	268.14	0.941	>20	292.52	1.026	**<20**
$\sigma_{xB\text{-}R}$ bottom			285	248.49	0.872	>20	273.34	0.959	>20	298.19	1.046	**<20**
$\tau_{xzNN\text{-}R}$ n-n axis			120	33.27	0.277	>20	36.59	0.305	>20	39.92	0.333	>20
$\sigma_{xD\text{-}R}$ deck	7		285	255.91	0.898	>20	281.50	0.988	>20	307.09	1.078	**<20**
$\sigma_{xB\text{-}R}$ bottom			285	260.87	0.915	>20	286.96	1.007	**≈20**	313.05	1.098	**<20**
$\tau_{xzNN\text{-}R}$ n-n axis			120	34.71	0.289	>20	38.19	0.318	>20	41.66	0.347	>20
$\sigma_{xD\text{-}R}$ deck	0	Non-linear	285	247.46	0.868	>20	272.21	0.955	>20	296.95	1.042	**<20**
$\sigma_{xB\text{-}R}$ bottom			285	252.26	0.885	>20	277.49	0.974	>20	302.71	1.062	**<20**
$\tau_{xzNN\text{-}R}$ n-n axis			120	33.69	0.281	>20	37.06	0.309	>20	40.43	0.337	>20
$\sigma_{xD\text{-}R}$ deck	7		285	260.26	0.913	>20	286.28	1.004	**≈20**	312.31	1.096	**<20**

σ_{xB-R} bottom	285	265.30	0.931	>20	291.83	1.024	**<20**	318.37	1.117	**<20**
τ_{xzNN-R} n-n axis	120	35.29	0.294	>20	38.82	0.323	>20	42.35	0.353	>20

The fatigue criteria lead to restrictions in some cases for the predicted R_E exploitation life, speed v=0 kn (table 7), as follows: 6.5÷15.1 years (hydroelastic, standard), 15.1÷20 years (hydroelastic, high quality), 8.6÷ 20 years (oscillation, standard) and 19.1÷20 years (oscillation, high quality). In the case of speed v=7 kn (table 7), the fatigue criteria lead to restrictions in any cases for the predicted R_E exploitation life, as follows: 2.4÷6.0 years (hydroelastic, standard), 5.8÷15.4 years (hydroelastic, high quality), 5.3÷ 11.9 years (oscillation, standard) and 11.8÷20 years (oscillation, high quality).

Table 7. Off-shore barge B40, fatigue long-term assessment, WWT histogram, speeds v=0; 7 kn, oscillation and hydroelastic response, K_s=1.0, 1.1, 1.2, x/L=0.50, deck panel

Model type	Welding quality	D_{osc}	D_{vib1}	D_{vib2}	D_{vib3}	D_{hel}	R_{Ehel} (year)	R_{Eosc} (year)	D_{osc}	D_{vib1}	D_{vib2}	D_{vib3}	D_{hel}	R_{Ehel} (year)	R_{Eosc} (year)
K_s =1.0		v=0 kn							v=7 kn						
Linear	standard	1.047	0.276	$2.5\cdot10^{-7}$	$2.7\cdot10^{-8}$	1.322	**15.1**	**19.1**	1.682	1.631	$3.1\cdot10^{-8}$	$5.8\cdot10^{-8}$	3.312	**6.0**	**11.9**
	h.quality	0.437	0.103	$9.5\cdot10^{-8}$	$1.0\cdot10^{-8}$	0.540	>20	>20	0.692	0.610	$1.1\cdot10^{-8}$	$2.2\cdot10^{-8}$	1.302	**15.4**	>20
Non-linear	standard	1.083	0.290	$2.7\cdot10^{-7}$	$2.9\cdot10^{-8}$	1.372	**14.6**	**18.5**	1.749	1.840	$3.5\cdot10^{-8}$	$7.4\cdot10^{-8}$	3.589	**5.6**	**11.4**
	h.quality	0.456	0.108	$1.0\cdot10^{-7}$	$1.1\cdot10^{-8}$	0.564	>20	>20	0.722	0.688	$1.3\cdot10^{-8}$	$2.8\cdot10^{-8}$	1.410	**14.2**	>20
K_s =1.1		v=0 kn							v=7 kn						
Linear	standard	1.586	0.451	$4.1\cdot10^{-7}$	$4.4\cdot10^{-8}$	2.037	**9.8**	**12.6**	2.526	2.665	$5.0\cdot10^{-8}$	$9.5\cdot10^{-8}$	5.191	**3.9**	**7.9**
	h.quality	0.684	0.169	$1.6\cdot10^{-7}$	$1.7\cdot10^{-8}$	0.853	>20	>20	1.090	0.998	$1.9\cdot10^{-8}$	$3.6\cdot10^{-8}$	2.089	**9.6**	**18.3**
Non-linear	standard	1.631	0.474	$4.5\cdot10^{-7}$	$4.7\cdot10^{-8}$	2.106	**9.5**	**12.3**	2.624	3.008	$5.8\cdot10^{-8}$	$1.2\cdot10^{-7}$	5.632	**3.6**	**7.6**
	h.quality	0.711	0.177	$1.7\cdot10^{-7}$	$1.8\cdot10^{-8}$	0.888	>20	>20	1.133	1.127	$2.2\cdot10^{-8}$	$4.5\cdot10^{-8}$	2.260	**8.8**	**17.6**
K_s =1.2		v=0 kn							v=7 kn						
Linear	standard	2.255	0.708	$6.5\cdot10^{-7}$	$7.0\cdot10^{-8}$	2.963	**6.7**	**8.9**	3.621	4.180	$7.9\cdot10^{-8}$	$1.5\cdot10^{-7}$	7.801	**2.6**	**5.5**
	h.quality	1.014	0.265	$2.4\cdot10^{-7}$	$2.6\cdot10^{-8}$	1.278	**15.6**	**19.7**	1.625	1.567	$2.9\cdot10^{-8}$	$5.6\cdot10^{-8}$	3.192	**6.3**	**12.3**
Non-linear	standard	2.319	0.745	$7.1\cdot10^{-7}$	$7.4\cdot10^{-8}$	3.064	**6.5**	**8.6**	3.762	4.718	$9.0\cdot10^{-8}$	$1.9\cdot10^{-7}$	8.480	**2.4**	**5.3**
	h.quality	1.048	0.278	$2.7\cdot10^{-7}$	$2.8\cdot10^{-8}$	1.327	**15.1**	**19.1**	1.690	1.769	$3.4\cdot10^{-8}$	$7.1\cdot10^{-8}$	3.459	**5.8**	**11.8**

5.2. The long-term hydroelastic off-shore barge B50 analysis and fatigue assessment

For the off-shore barge B50 hydroelastic long-term analysis and fatigue assessment in this subsection, a selection of the main data results is included.

Figure 17 presents the off-shore barge B50 long-term non-linear hydroelastic stresses, speed v=7 kn, WWT wave histogram, K_s=1.0, R≤20 years, at main deck σ_{xD-R} and side neutral-axis τ_{xzNN-R} .

Table 8 presents the off-shore barge B50 long-term linear and non-linear stresses assessment by yielding stress criteria (table 1), speeds v=0; 7 kn, WWT wave histogram, K_s=1.0, 1.1, 1.2, reference period R=20 years, at the main deck, bottom and side panels.

Table 9 presents the off-shore barge B50 fatigue long-term assessment, speeds v=0; 7 kn, K_s=1.0, 1.1, 1.2, oscillations and hydroelastic stress, at amidships deck panel detail, for the R_E exploitation life computation, considering the standard and high-quality welding state.

The stresses distributions over the barge B50 (figure 17) are similar to the barge B40 version (figure 16), being significantly influenced by the reference R period. For K_s=1.0 and K_s=1.1 the yielding stress criterion is satisfied in any cases (table 6). For K_s=1.2 the strength restrictions (R_E<20 years) are recorded at the main deck and bottom panel, linear and non-linear response, for the transit speed v=7 kn and without strength restrictions (R_E≥20 years) on-site operation v=0 kn (table 6).

For speed v=0kn the restrictions by the fatigue criteria for the R_E exploitation life are as follows: 7.4÷14.9 years (hydroelastic, standard), 15.5÷20 years (hydroelastic, high quality), 7.5÷ 20 years (oscillation, standard) and 15.7÷20 years (oscillation, high quality). In the case of speed v=7 kn the fatigue criteria lead to the following restrictions for the predicted R_E exploitation life: 6.5÷13.4 years (hydroelastic, standard), 13.8÷20 years (hydroelastic, high quality), 7.4÷14.8 years (oscillation, standard) and 15.4÷20 years (oscillation, high quality).

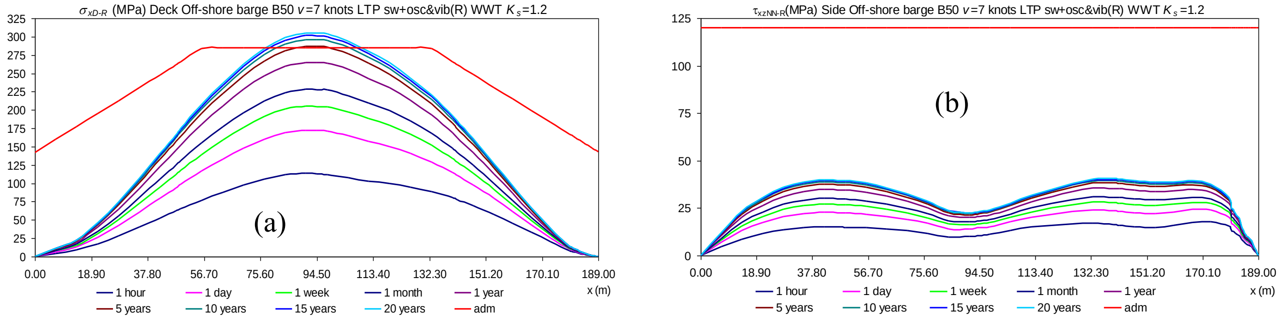

Fig. 17. Off-shore barge B50, long-term non-linear hydroelastic stresses, v=7 kn, WWT histogram, K_s=1.2, (a) deck σ_{xD-R} (MPa), (b) side neutral-axis τ_{xzNN-R} (MPa)

Table 8. Off-shore barge B50, long-term stresses (MPa) analysis, WWT histogram, speeds v=0; 7 kn, hydroelastic analysis, reference period R=20 years

Panel reference	Speed (kn)		K_s	1.0			1.1			1.2		
Stress (MPa)	Analysis		adm	S(MPa)	*S/adm*	*R*(years)	S(MPa)	*S/adm*	*R*(years)	S(MPa)	*S/adm*	*R*(years)
σ_{xD-R} deck	0	Linear	285	232.71	0.817	>20	255.99	0.898	>20	279.26	0.980	>20
σ_{xB-R} bottom			285	236.86	0.831	>20	260.55	0.914	>20	284.23	0.997	**≈20**
τ_{xzNN-R} n-n axis			120	30.92	0.258	>20	34.01	0.283	>20	37.11	0.309	>20
σ_{xD-R} deck	7		285	251.64	0.883	>20	276.81	0.971	>20	301.97	1.060	**<20**
σ_{xB-R} bottom			285	256.13	0.899	>20	281.74	0.989	**≈20**	307.35	1.078	**<20**
τ_{xzNN-R} n-n axis			120	33.55	0.280	>20	36.91	0.308	>20	40.26	0.336	>20
σ_{xD-R} deck	0	Non-linear	285	233.14	0.818	>20	256.46	0.900	>20	279.77	0.982	>20
σ_{xB-R} bottom			285	237.30	0.833	>20	261.03	0.916	>20	284.76	0.999	**≈20**
τ_{xzNN-R} n-n axis			120	31.01	0.258	>20	34.11	0.284	>20	37.21	0.310	>20
σ_{xD-R} deck	7		285	254.41	0.893	>20	279.85	0.982	>20	305.29	1.071	**<20**
σ_{xB-R} bottom			285	258.94	0.909	>20	284.84	0.999	**≈20**	310.73	1.090	**<20**
τ_{xzNN-R} n-n axis			120	33.73	0.281	>20	37.10	0.309	>20	40.47	0.337	>20

Table 9. Off-shore barge B50, fatigue long-term assessment, WWT histogram, speeds v=0; 7 kn, oscillations and hydroelastic response, K_s=1.0, 1.1, 1.2, x/L=0.50, deck panel

Model type	Welding quality	D_{osc}	D_{vib1}	D_{vib2}	D_{vib3}	D_{hel}	R_{Ehel} (year)	R_{Eosc} (year)	D_{osc}	D_{vib1}	D_{vib2}	D_{vib3}	D_{hel}	R_{Ehel} (year)	R_{Eosc} (year)
K_s =1.0		v=0 kn							v=7 kn						
Linear	standard	1.323	0.018	$3.2\cdot10^{-7}$	$4.7\cdot10^{-8}$	1.341	**14.9**	**15.1**	1.350	0.143	$3.1\cdot10^{-7}$	$2.1\cdot10^{-7}$	1.492	**13.4**	**14.8**
	h.quality	0.586	0.007	$1.2\cdot10^{-7}$	$1.7\cdot10^{-8}$	0.593	>20	>20	0.611	0.053	$1.2\cdot10^{-7}$	$7.9\cdot10^{-8}$	0.664	>20	>20
Non-linear	standard	1.333	0.020	$3.4\cdot10^{-7}$	$4.8\cdot10^{-8}$	1.353	**14.8**	**15.0**	1.361	0.155	$3.6\cdot10^{-7}$	$2.4\cdot10^{-7}$	1.516	**13.2**	**14.7**
	h.quality	0.591	0.007	$1.3\cdot10^{-7}$	$1.8\cdot10^{-8}$	0.599	>20	>20	0.618	0.058	$1.4\cdot10^{-7}$	$8.9\cdot10^{-8}$	0.676	>20	>20
K_s =1.1		v=0 kn							v=7 kn						
Linear	standard	1.892	0.029	$5.2\cdot10^{-7}$	$7.6\cdot10^{-8}$	1.921	**10.4**	**10.6**	1.919	0.231	$5.1\cdot10^{-7}$	$3.4\cdot10^{-7}$	2.150	**9.3**	**10.4**
	h.quality	0.876	0.011	$2.0\cdot10^{-7}$	$2.8\cdot10^{-8}$	0.887	>20	>20	0.900	0.086	$1.9\cdot10^{-7}$	$1.3\cdot10^{-7}$	0.986	**≈20**	>20
Non-linear	standard	1.908	0.032	$5.4\cdot10^{-7}$	$7.8\cdot10^{-8}$	1.941	**10.3**	**10.5**	1.935	0.252	$5.9\cdot10^{-7}$	$3.9\cdot10^{-7}$	2.186	**9.1**	**10.3**
	h.quality	0.884	0.012	$2.0\cdot10^{-7}$	$2.9\cdot10^{-8}$	0.896	>20	>20	0.909	0.094	$2.2\cdot10^{-7}$	$1.4\cdot10^{-7}$	1.003	**≈20**	>20
K_s =1.2		v=0 kn							v=7 kn						
Linear	standard	2.644	0.045	$8.1\cdot10^{-7}$	$1.2\cdot10^{-7}$	2.689	**7.4**	**7.6**	2.667	0.359	$7.9\cdot10^{-7}$	$5.3\cdot10^{-7}$	3.026	**6.6**	**7.5**
	h.quality	1.262	0.017	$3.0\cdot10^{-7}$	$4.4\cdot10^{-8}$	1.279	**15.6**	**15.8**	1.289	0.134	$2.9\cdot10^{-7}$	$2.0\cdot10^{-7}$	1.423	**14.1**	**15.5**
Non-linear	standard	2.668	0.050	$8.4\cdot10^{-7}$	$1.2\cdot10^{-7}$	2.718	**7.4**	**7.5**	2.688	0.390	$9.2\cdot10^{-7}$	$6.0\cdot10^{-7}$	3.078	**6.5**	**7.4**
	h.quality	1.273	0.019	$3.2\cdot10^{-7}$	$4.5\cdot10^{-8}$	1.292	**15.5**	**15.7**	1.300	0.146	$3.4\cdot10^{-7}$	$2.2\cdot10^{-7}$	1.446	**13.8**	**15.4**

6. CONCLUSIONS

This study includes a comparative analysis between two constructive versions of a large off-shore barge 23000T, with different breadths B40 and B50 (section 3), based on short and long-term hydroelastic approaches and fatigue evaluation for the operational safety assessment (section 2). The hydroelastic formulation implemented in own code DYN-HYD [9, 10] makes it possible to have an advanced solution for the off-shore barge dynamic response in irregular waves, involving oscillations and vibrations components, according to the shipbuilding classification societies requirements [2, 3, 4].

For both off-shore 23000T barges constructive versions, the short-term response (section 4) reveals that the linear components, oscillation and first vibration (linear springing) modes, are dominant in the total hydroelastic response because they have geometric and hydrodynamic non-linearities very reduced, due to the prismatic forms for almost 95% over the barges' length and with vertical sides. Bottom slamming occurs only at the barges forepeak, without side slamming, resulting in whipping and non-linear springing responses with a small intensity. The green sea can occur in extreme sea conditions.
In terms of short-term most probable vertical displacements, the barges speed effect is medium on oscillation motions for both barges constructive versions and higher on vibration deflections for the initial barge B40 in comparison to second barge B50.
In terms of short-term significant sectional efforts, for the initial barge B40, the barges speed effect is small for oscillation and first vibration modes, high on second vibration mode and medium on third vibration mode. For the second version barge B50, the barges speed effect is medium for oscillation, first and third vibration modes, high on second vibration mode. The second off-shore barge B50, in comparison to the initial off-shore barge B40, has higher predicted hydroelastic short-term response, most probable vertical displacements and significant sectional efforts, due to the increase of the total onboard mass (table 1).
The long-term stress distributions are similar for both off-shore barges (section 5), due to the dominant prismatic shape and uniform 23000 t cargo mass distribution (section 2). Though the barge B50 has a total mass larger than barge B40, due to the hull steel mass, it compensates by a better rigidity (table 1), so that the long-term stresses for the second barge are slightly smaller as for the initial barge. The long-term strength restrictions by yielding stress criterion occur on both off-shore barges for K_s=1.2, at main deck and bottom panels, without restrictions on 0 kn speed for barge B50. According to the long-term fatigue criteria (section 5), both off-shore barges must have a high-quality welding process implemented to improve the predicted R_E exploitation life, being not acceptable for practical purposes the standard welding case. The differences between fatigue assessment with or without vibration response components point out that the long-term hydroelastic approach leads to higher restrictions in comparison to the standard long-term oscillations approach (section 5), being specific for large elastic floating structures. For both off-shore barges, the restriction differences by fatigue criteria between linear and non-linear long-term hydroelastic formulations are small, preserving the trends from previous short-term off-shore barges dynamic analysis. As the hot-spot factor increases, the restrictions by fatigue criteria increase too. Taking as reference the non-linear hydroelastic formulation, high-quality welding, for barge B40 the predicted exploitation life is 15.1÷20 years (v=0 kn) and 5.8÷14.2 years (v=7 kn), and for barge B50 the predicted exploitation life is 15.5÷20 years (v=0 kn) and 13.8÷20 years (v=7 kn). So, both off-shore barges constructive versions can have the predicted exploitation life larger than the reference R_E >5 years between two inspection periods, according to the shipbuilding classification societies rules [2, 3, 4].
In conclusion, the comparative hydroelastic long-term analysis of the two design versions of the 23000T off-shore barge points out that the second barge B50 has fewer operational restrictions than the initial barge B40 in the transition state (v=7 kn), and both have similar restrictions at on-site operation at zero speed. The second off-shore barge B50 has as its main advantages lower draught and wider operational area on the main deck, but requires supplementary steel mass, larger displacement, and construction costs, in comparison to the initial off-shore barge B40 (table 1). Further hydroelastic long-term studies will be extended to other off-shore-like floating structures, with flexible hull and non-linearities, which can be more sensitive to extreme operating conditions.

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