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COMPARATIVE NATURAL GLOBAL VIBRATION MODES ANALYSIS OF TWO GAS CARRIER MARITIME SHIPS

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ABSTRACT

This technical paper presents a comparative study of two gas carrier maritime ships, focusing on their natural global vibration characteristics. The selected ships are an LPG carrier with a length of 125.6 m and an LNG carrier with a length of 289.3 m, both of which have fully developed structural models, previously used for strength assessment analysis. For both ships, relevant loading conditions are selected, full cargo and ballast cases. The natural global vibration analysis provides the vertical, horizontal, torsional, and longitudinal eigenmodes, with or without the inclusion of the fluid-structure effect. The results emphasize the sensitivity and the differences in the two ships' structures on the modal vibration characteristics.

Keywords: gas carrier maritime ships, natural global vibration modes, 3D-FEM analysis.

1. INTRODUCTION

This approach focuses on the natural global vibration characteristics [1], [6] of two gas carrier maritime ships, with the main data in Table 1, both under full cargo and ballast conditions. The steel material structural models are developed by a 3D-FEM approach [6], [7], for an LPG [3] and an LNG [4] maritime ship, presented in Fig.1 and Fig.2.

The numerical structural analyses and the computation of the added hydrodynamic masses for fluid-structure effect formulation are according to the methods presented in reference [2], for vertical, horizontal, torsional, and longitudinal natural global vibration modes. For the hydrodynamic mass computation, 19 block stations over the two ships' length are considered, the mid-section of each block being the geometry reference.

The numerical modal analysis uses the Femap/NX Nastran [5] application, with the Lanczos eigenvalues method, and also our procedures [2] for onboard and added hydrodynamic masses modelling.

Table 1. The data of LPG and LNG ships [6],[7].

Ship	LPG	LNG
L(m)	125.6	289.3
B(m)	20.5	43.3
$\Delta_{full\ cargo}$(t)	13195	105881
$T_{full\ cargo}$(m)	7.64	11.80
$\Delta_{ballast}$(t)	8412	73167
$T_{ballast}$(m)	5.25	8.5
No. EL	97943	188902
No. ND	37443	53888

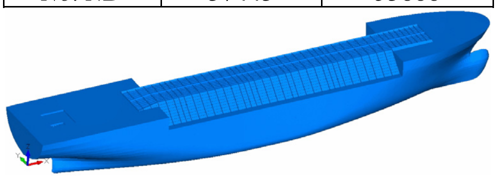

Fig.1 LPG ship, structural model [3].

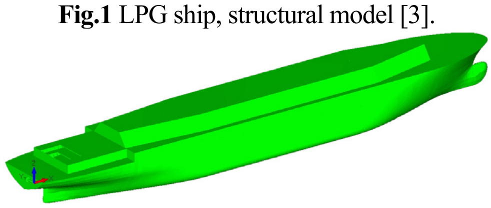

Fig.2 LNG ship, structural model [4].

2. NATURAL GLOBAL VIBRATION MODES OF THE LPG SHIP

The modal analysis by the 3D-FEM LPG full extended model leads to the computation of the natural global vibration modes, without (dry) and with (hyd) the hydrodynamic added masses fluid-structures interaction effect, presented in the following results:
- Figs.3.1-4 vertical hyd. modes, LPG full;
- Figs.4.1-4 vertical hyd. modes, LPG ballast;
- Figs.5.1-4 horizontal hyd. modes, LPG full;
- Figs.6.1-4 horiz. hyd. modes, LPG ballast;
- Figs.7.1-2 torsion hyd. modes, LPG full;
- Figs.8.1-2 torsion hyd. modes, LPG ballast;
- Figs.9.1-2 long. hyd. modes, LPG full, ball;
- Tables 2.1-2 LPG full and ballast onboard masses and hydrodynamic added masses;
- Tables 3.1-2, Figs.10.1-2 LPG full and ballast, dry. and hyd., natural global vibration frequencies.

LPG vertical global vibration modes (hyd)

Fig.3.1 LPG carrier(F),V1(2),1.686Hz.

Fig.4.1 LPG carrier(B),V1(5),1.936Hz.

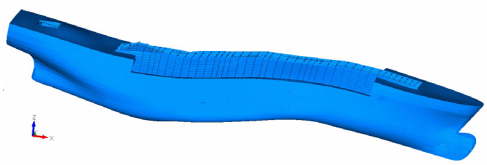

Fig.3.2 LPG carrier(F),V2(9),3.135Hz.

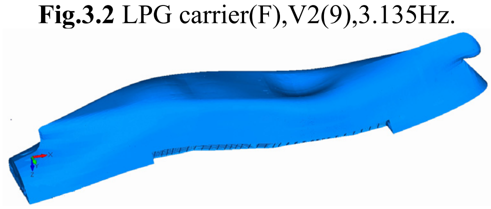

Fig.4.2 LPG carrier(B),V2(17),3.743Hz.

Fig.3.3 LPG carrier(F),V3(18),3.870Hz.

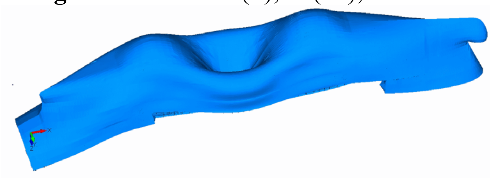

Fig.4.3 LPG carrier(B),V3(21),4.683Hz.

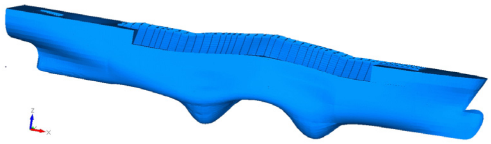

Fig.3.4 LPG carrier(F),V4(34),5.534Hz.

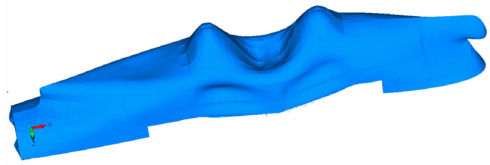

Fig.4.4 LPG carrier(B),V4(43),6.817Hz.

LPG horizontal global vibration modes (hyd)

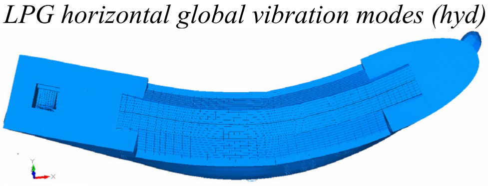

Fig.5.1 LPG carrier(F),H1(7),2.183Hz.

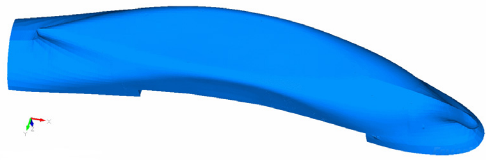

Fig.6.1 LPG carrier(B),H1(8),3.033Hz.

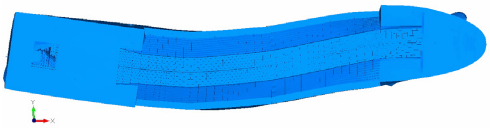

Fig.5.2 LPG carrier(F),H2(18),3.472Hz.

Fig.6.2 LPG carrier(B),H2(33),5.665Hz.

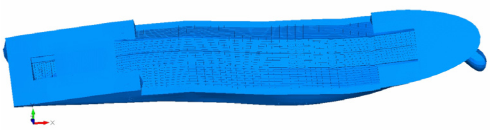

Fig.5.3 LPG carrier(F),H3(23),4.594Hz.

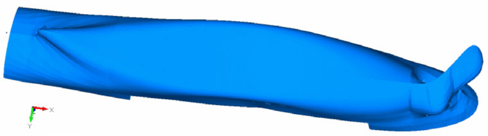

Fig.6.3 LPG carrier(B),H3(49),7.035Hz.

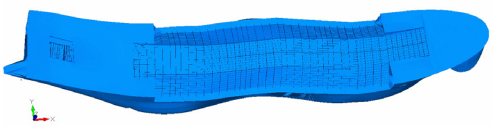

Fig.5.4 LPG carrier(F),H4(38),5.860Hz.

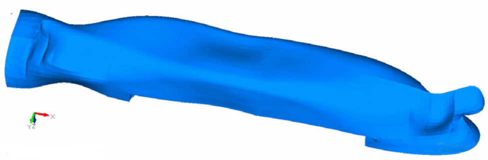

Fig.6.4 LPG carrier(B),H4(71),8.585Hz.

LPG torsional global vibration modes (hyd)

Fig.7.1 LPG carrier(F),T1(17),4.135Hz.

Fig.8.1 LPG carrier(B),T1(20),4.771Hz.

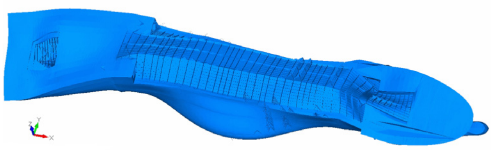

Fig.7.2 LPG carrier(F),T2(56),7.448Hz.

Fig.8.2 LPG carrier(B),T2(68),8.793Hz.

LPG longitudinal global vibration modes (hyd)

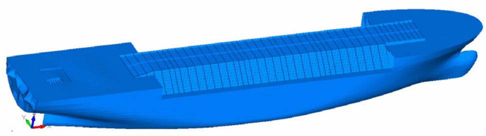

Fig.9.1 LPG carrier(F),L1(57),7.490Hz.

Fig.9.2 LPG carrier(B),L1(68),8.822Hz.

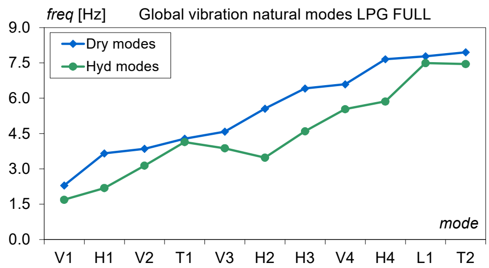

Fig.10.1 LPG(F), natural global vibration freq.

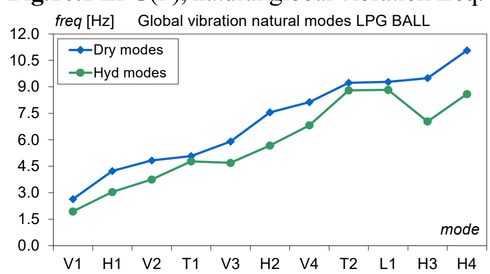

Fig.10.2 LPG(B), natural global vibration freq.

Table 2.1 LPG full cargo, onboard masses and hydrodynamic added masses.

LPG FULL Mode		Equiv. Hyd Mass	Δ(t) $J_{X0}(tm^2)$	Total Equiv. Mass	Eq. / Ship Mass (%)
V1	M33.1 (t)	16202	13195	29397	122.79%
H1	M22.1 (t)	12092	13195	25287	91.64%
V2	M33.2 (t)	11900	13195	25095	90.19%
T1	M44.1(tm^2)	94370	780259	874628	12.09%
V3	M33.3 (t)	10466	13195	23661	79.32%
H2	M22.2 (t)	10970	13195	24165	83.14%
H3	M22.3 (t)	10596	13195	23791	80.31%
V4	M33.4 (t)	9749	13195	22944	73.89%
H4	M22.4 (t)	10409	13195	23604	78.89%
L1	M11.1 (t)	1319	13195	14514	10.00%
T2	M44.2(tm^2)	77727	780259	857985	9.96%

Table 2.2 LPG ballast, onboard masses and hydrodynamic added masses.

LPG BALL Mode		Equiv. Hyd Mass	Δ(t) $J_{X0}(tm^2)$	Total Equiv. Mass	Eq. / Ship Mass (%)
V1	M33.1 (t)	14007	8412	22420	166.51%
H1	M22.1 (t)	5639	8412	14052	67.03%
V2	M33.2 (t)	10288	8412	18701	122.30%
T1	M44.1(tm^2)	98478	459670	558148	21.42%
V3	M33.3 (t)	9048	8412	17461	107.56%
H2	M22.2 (t)	5284	8412	13696	62.81%
V4	M33.4 (t)	8429	8412	16841	100.19%
T2	M44.2 (t)	82680	459670	542350	17.99%
L1	M11.1 (t)	841	8412	9254	10.00%
H3	M22.3 (t)	5165	8412	13578	61.40%
H4	M22.4 (t)	5106	8412	13519	60.70%

Table 3.1 LPG full cargo, dry. and hyd., natural global vibration frequencies.

LPG FULL	Dry Modes		Hyd Modes		Hyd/ Dry	Fig
Mode	No	Freq (Hz)	No	Freq (Hz)	Freq. (%)	
V1	6	2.292	2(V)	1.686	26.45%	Fig.3.1
H1	15	3.654	7(H)	2.183	40.26%	Fig.5.1
V2	16	3.849	9(V)	3.135	18.55%	Fig.3.2
T1	18	4.276	17(T)	4.135	3.31%	Fig.7.1
V3	21	4.578	18(V)	3.870	15.45%	Fig.3.3
H2	32	5.557	18(H)	3.472	37.53%	Fig.5.2
H3	35	6.411	23(H)	4.594	28.33%	Fig.5.3
V4	39	6.590	34(V)	5.534	16.02%	Fig.3.4
H4	56	7.654	38(H)	5.860	23.44%	Fig.5.4
L1	59	7.774	57(L)	7.490	3.65%	Fig.9.1
T2	62	7.951	56(T)	7.448	6.32%	Fig.7.2

Table 3.2 LPG ballast, dry. and hyd., natural global vibration frequencies.

LPG BALL	Dry Modes		Hyd Modes		Hyd/ Dry	Fig
Mode	No	Freq (Hz)	No	Freq (Hz)	Freq. (%)	
V1	6	2.632	5(V)	1.936	26.45%	Fig.4.1
H1	16	4.230	8(H)	3.033	28.28%	Fig.6.1
V2	19	4.827	17(V)	3.743	22.47%	Fig.4.2
T1	20	5.072	20(T)	4.771	5.93%	Fig.8.1
V3	32	5.897	21(V)	4.683	20.59%	Fig.4.3
H2	51	7.549	33(H)	5.665	24.96%	Fig.6.2
V4	59	8.124	43(V)	6.817	16.09%	Fig.4.4
T2	72	9.222	68(T)	8.793	4.66%	Fig.8.2
L1	73	9.275	68(L)	8.822	4.88%	Fig.9.2
H3	75	9.490	49(H)	7.035	25.87%	Fig.6.3
H4	94	11.052	71(H)	8.585	22.32%	Fig.6.4

3. NATURAL GLOBAL VIBRATION MODES OF THE LNG SHIP

Based on the 3D-FEM LNG full extended model modal analysis, the natural global vibration modes, without (dry) and with (hyd) the hydrodynamic added masses fluid structures interaction effect, are computed, resulting in the following modes:
- Figs.11.1-4 vertical hyd. modes, LNG full;
- Figs.12.1-4 vertical hyd. modes, LNG ballast;
- Figs.13.1-4 horizontal hyd. modes, LNG full;
- Figs.14.1-4 horiz. hyd. modes, LNG ballast;
- Figs.15.1-2 torsion hyd. modes, LNG full;
- Figs.16.1-2 torsion hyd. modes, LNG ballast;
- Figs.17.1-2 long. hyd. modes, LNG full, ball;
- Tables 4.1-2 LNG full and ballast onboard masses and hydrodynamic added masses;
- Tables 5.1-2, Figs.18.1-2 LNG full and ballast, dry. and hyd., natural global vibration frequencies.

LNG vertical global vibration modes (hyd)

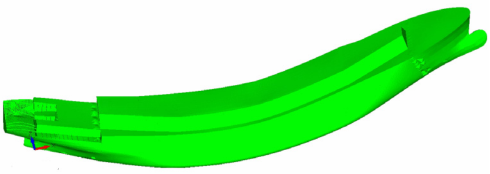

Fig.11.1 LNG carrier(F),V1(6),0.739Hz.

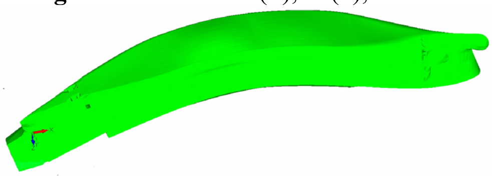

Fig.12.1 LNG carrier(B),V1(7),0.831Hz.

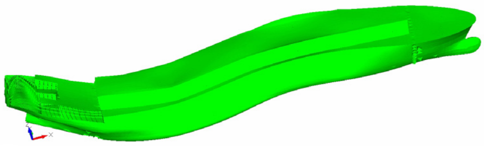

Fig.11.2 LNG carrier(F),V2(22),1.309Hz.

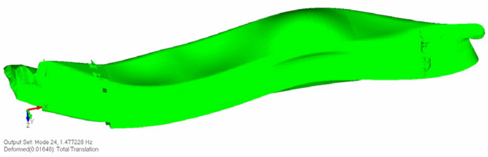

Fig.12.2 LNG carrier(B),V2(24),1.477Hz.

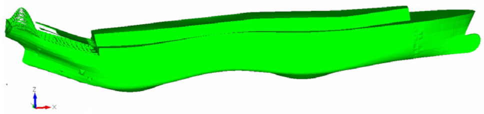

Fig.11.3 LNG carrier(F),V3(28),1.598Hz.

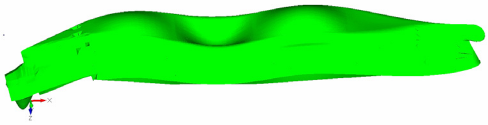

Fig.12.3 LNG carrier(B),V3(34),1.792Hz.

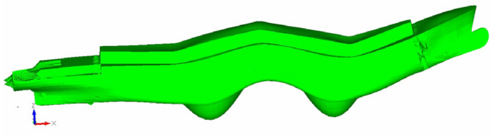

Fig.11.4 LNG carrier(F),V4(48),2.314Hz.

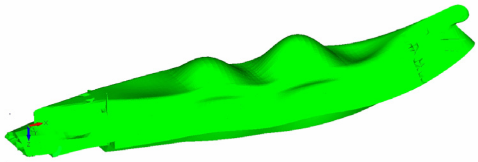

Fig.12.4 LNG carrier(B),V4(59),2.574Hz.

LNG horizontal global vibration modes (hyd)

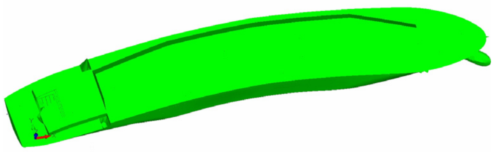

Fig.13.1 LNG carrier(F),H1(14),1.015Hz.

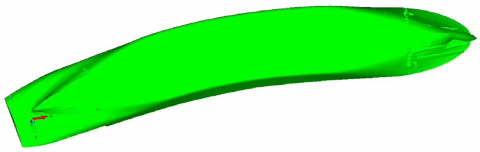

Fig.14.1 LNG carrier(B),H1(19),1.281Hz.

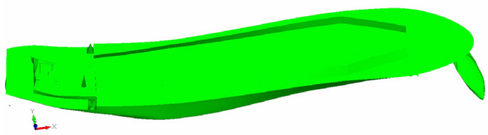

Fig.13.2 LNG carrier(F),H2(27),1.637Hz.

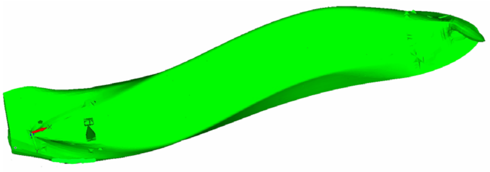

Fig.14.2 LNG carrier(B),H2(39),2.087Hz.

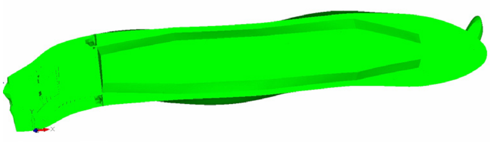

Fig.13.3 LNG carrier(F),H3(65),2.638Hz.

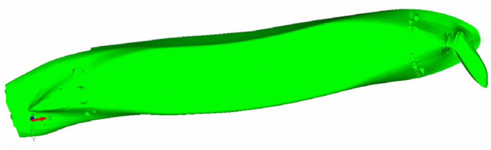

Fig.14.3 LNG carrier(B),H3(86),2.945Hz.

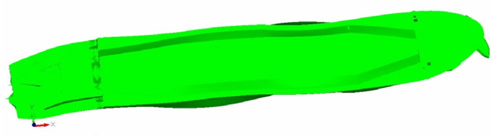

Fig.13.4 LNG carrier(F),H4(108),3.250Hz.

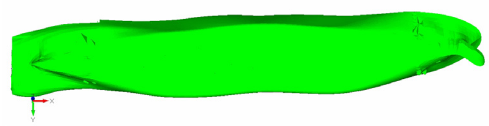

Fig.14.4 LNG carrier(B),H4(144),4.183Hz.

LNG torsional global vibration modes (hyd)

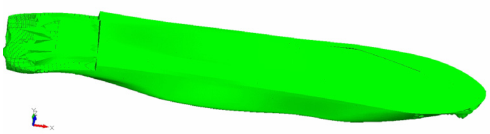

Fig.15.1 LNG carrier(F),T1(96),3.209Hz.

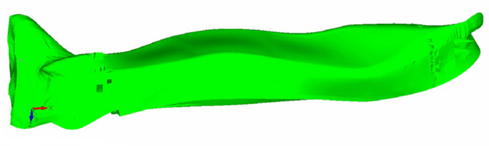

Fig.16.1 LNG carrier(B),T1(106),3.503Hz.

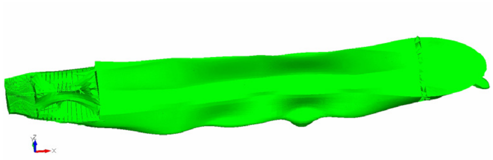

Fig.15.2 LNG carrier(F),T2(405),6.990Hz.

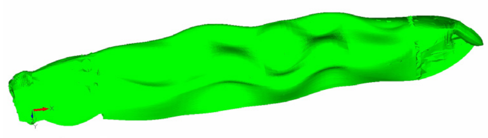

Fig.16.2 LNG carrier(B),T2(423),7.246Hz.

LNG longitudinal global vibration modes (hyd)

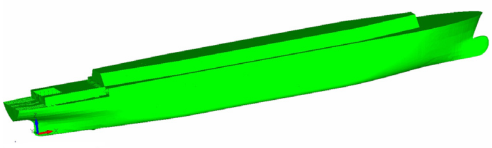

Fig.17.1 LNG carrier(F),L1(108),3.489Hz.

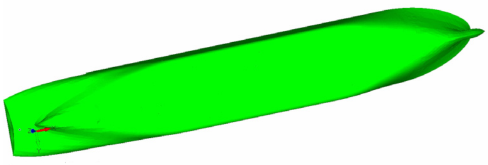

Fig.17.2 LNG carrier(B),L1(144),4.268Hz.

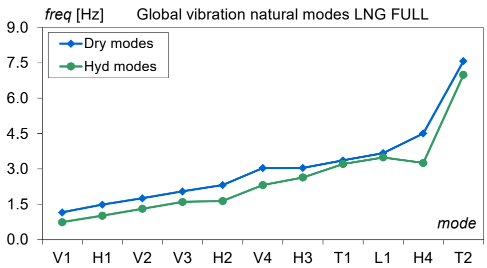

Fig.18.1 LNG(F), natural vibration global freq.

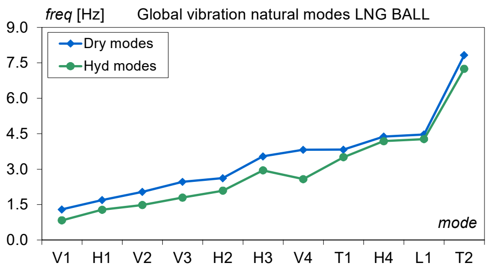

Fig.18.2 LNG(B), natural vibration global freq.

Table 4.1 LNG full cargo, onboard masses and hydrodynamic added masses.

LNG FULL Mode		Equiv. Hyd Mass	Δ(t) $J_{X0}(tm^2)$	Total Equiv. Mass	Eq. / Ship Mass (%)
V1	M33.1 (t)	171738	105881	277619	162.2%
H1	M22.1 (t)	75169	105881	181050	71.0%
V2	M33.2 (t)	130288	105881	236169	123.1%
V3	M33.3 (t)	116471	105881	222353	110.0%
H2	M22.2 (t)	70549	105881	176431	66.6%
V4	M33.4 (t)	109563	105881	215445	103.5%
H3	M22.3 (t)	69009	105881	174891	65.2%
T1	M44.1(tm^2)	5613791	19209425	24823216	29.2%
L1	M11.1 (t)	10588	105881	116470	10.0%
H4	M22.4 (t)	68239	105881	174121	64.5%
T2	M44.2(tm^2)	4780961	19209425	23990386	24.9%

Table 4.2 LNG ballast, onboard masses and hydrodynamic added masses.

LNG BALL Mode		Equiv. Hyd Mass	Δ(t) $J_{X0}(tm^2)$	Total Equiv. Mass	Eq. / Ship Mass (%)
V1	M33.1 (t)	154671	73167	227837	211.4%
H1	M22.1 (t)	40120	73167	113287	54.8%
V2	M33.2 (t)	117340	73167	190507	160.4%
V3	M33.3 (t)	104897	73167	178063	143.4%
H2	M22.2 (t)	38356	73167	111523	52.4%
H3	M22.3 (t)	37768	73167	110935	51.6%
V4	M33.4 (t)	98675	73167	171842	134.9%
T1	M44.1(tm^2)	5235317	12375435	17610753	42.3%
H4	M22.4 (t)	37474	73167	110641	51.2%
L1	M11.1 (t)	7317	73167	80483	10.0%
T2	M44.2(tm^2)	4507737	12375435	16883173	36.4%

Table 5.1 LNG full cargo, dry. and hyd., natural global vibration frequencies.

LNG FULL	Dry Modes		Hyd Modes		Hyd/ Dry	Fig
Mode	No	Freq (Hz)	No	Freq (Hz)	Freq. (%)	
V1	17	1.155	6(V)	0.739	35.97%	Fig.11.1
H1	21	1.485	14(H)	1.015	31.65%	Fig.13.1
V2	27	1.754	22(V)	1.309	25.38%	Fig.11.2
V3	35	2.044	28(V)	1.598	21.82%	Fig.11.3
H2	43	2.317	27(H)	1.637	29.31%	Fig.13.2
V4	85	3.033	48(V)	2.314	23.70%	Fig.11.4
H3	86	3.041	65(H)	2.638	13.28%	Fig.13.3
T1	100	3.359	96(T)	3.209	4.48%	Fig.15.1
L1	117	3.669	108(L)	3.489	4.90%	Fig.17.1
H4	164	4.502	108(H)	3.250	27.80%	Fig.13.4
T2	453	7.572	405(H)	6.990	7.68%	Fig.15.2

Table 5.2 LNG ballast, dry. and hyd., natural global vibration frequencies.

LNG BALL	Dry Modes		Hyd Modes		Hyd/ Dry	Fig
Mode	No	Freq (Hz)	No	Freq (Hz)	Freq. (%)	
V1	18	1.290	7(V)	0.831	35.60%	Fig.12.1
H1	26	1.690	19(H)	1.281	24.23%	Fig.14.1
V2	34	2.036	24(V)	1.477	27.45%	Fig.12.2
V3	48	2.463	34(V)	1.792	27.22%	Fig.12.3
H2	56	2.613	39(H)	2.087	20.13%	Fig.14.2
H3	106	3.540	86(H)	2.945	16.82%	Fig.14.3
V4	120	3.818	59(V)	2.574	32.59%	Fig.12.4
T1	121	3.823	106(T)	3.503	8.37%	Fig.16.1
H4	154	4.374	144(H)	4.183	4.36%	Fig.14.4
L1	159	4.464	144(L)	4.268	4.39%	Fig.17.2
T2	457	7.824	423(T)	7.246	7.39%	Fig.16.2

4. CONCLUSIONS

The ship characteristics and the fluid-structure effect on the gas carrier ships' natural global vibration modes have been analyzed for two selected ships (Table 1, Figs. 1,2).

For the LPG ship the dry global, fundamental natural vibration frequencies are (Tables 3.1, 3.2, Figs.10.1,2): on full cargo 2.292 Hz (V), 3.654 Hz (H), 4.276 Hz (T), 7.774 Hz (L), and on ballast 2.632 Hz (V), 4.230 Hz (H), 5.072 Hz (T), 9.275 Hz (L).

For the LPG ship the hyd global, fundamental natural vibration frequencies are (Tables 3.1, 3.2, Figs.10.1,2): on full cargo 1.686 Hz (V), (Fig.3.1), 2.183 Hz (H) (Fig.5.1), 4.135 Hz (T) (Fig.7.1), 7.490 Hz (L) (Fig.9.1), and on ballast 1.936 Hz (V) (Fig.4.1), 3.033 Hz (H) (Fig.6.1), 4.771 Hz (T) (Fig.8.1), 8.822 Hz (L) (Fig.9.2). The fluid-structure effect (Tables 2.1, 2.2) leads to an average reduction of the natural frequencies 19.12%-21.40% (V), 32.39%-25.36% (H), 4.82%-5.30% (T), 3.65%-4.88% (L), with highest influence on vertical and horizontal global natural modes.

For the LNG ship the dry global, fundamental natural vibration frequencies are (Tables 5.1, 5.2, Figs. 18.1,2): on full cargo 1.155 Hz (V), 1.485 Hz (H), 3.359 Hz (T), 3.669 Hz (L), and on ballast 1.290 Hz (V), 1.690 Hz (H), 3.823 Hz (T), 4.464 Hz (L).

For the LNG ship the hyd global, fundamental natural vibration frequencies are (Tables 5.1, 5.2, Figs. 18.1,2): on full cargo 0.739 Hz (V), (Fig.11.1), 1.015 Hz (H) (Fig.13.1), 3.209 Hz (T) (Fig.15.1), 3.489 Hz (L) (Fig.17.1), and on ballast 0.831 Hz (V) (Fig.12.1), 1.281 Hz (H) (Fig.14.1), 3.503 Hz (T) (Fig.16.1), 4.268 Hz (L) (Fig.17.2). The fluid-structure effect (Tables 4.1, 4.2) leads to an average reduction of the natural frequencies 26.72%-30.72%% (V), 25.51-16.39% (H), 6.08%-7.88% (T), 4.90%-4.39% (L), with semnificative influence on vertical and horizontal global natural modes.

The influence of the fluid-structure effect, modelled by hydrodynamic added masses, is reduced on torsional (6.02%) and longitudinal (4.46%) global vibration modes in comparison to the first four horizontal (24.91%) and vertical (24.49%) global modes.

The LNG ship versus the LPG ship, has lower natural global vibration modes: 43.83%-42.92% (V), 46,50%-42.24% (H), 77.61%-73.42 % (T), 46.58%-48.38% (L), having a more flexible hull girder.

In conclusion, both gas carrier ships have the lowest global natural frequencies on vertical modes, 0.739-0.831 Hz (LNG) and 1.686-1.936 Hz (LPG), under 2 Hz, which proves both have a flexible hull girder, and their sensitivity is suitable for a coupled oscillation-vibration (hydroelastic) structural analysis in irregular waves.

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