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MOORING SYSTEM AND MOTION RESPONSE ANALYSIS OF A GAS IMPORT FLOATING TERMINAL IN OPERATING AND SURVIVAL CONDITIONS

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ABSTRACT

The present work is dealing with the quasi-static motion response analysis of a Gas Import Floating Terminal that is moored through a turret mooring system. The results of the analysis presented here is part of the work undertaken by the Division of Marine Structures, School of Naval Architecture and Marine Engineering, National Technical University of Athens (NTUA-MS), within the GIFT project that is supported by the EU (GIFT, 2005). The results concern the response of the mooring system and the associated behavior of the floating terminal under specific operating and survival conditions. In addition to the quasi-static responses, the slowly varying motions of the vessel are calculated by applying appropriate frequency domain solution techniques. Finally, some first comparisons between the numerical predictions and pertinent experimental data of physical model tests are given and discussed.

INTRODUCTION

The analysis of the dynamic behavior of moored floating structures is of particular importance for their detailed design procedure, especially in cases when active control means, i.e. DP thruster systems, are used to control the orientation and the weathervane ability of multiple interacting floating structures.

This is directly applied to cases of side-by-side loading / unloading operations of large scale LNG terminals moored through a turret system to the sea bed and LNG carriers berthed alongside them. Among the subjects that deserve special attention are the hydrodynamic analysis of the isolated and the interacting floating structures, the evaluation of mean and slowly-varying wind, current and wave loads, the mooring system design, the motion response analysis of the moored terminal with and without having berthed a LNG carrier alongside it, the quasi-static and dynamic analysis of the mooring system, as well as the estimation of the required thrusters' power with their controller design. These topics are among several other ones that are addressed in the on-going European Commission funded project, GIFT (2005). The project is coordinated by Doris Engineering (France), while besides the Laboratory of Floating Structures and Mooring Systems, Division of Marine Structures of NTUA (NTUA-MS, Greece), the other partners are: the Ship Design Laboratory of NTUA (NTUA-SDL, Greece), Chantiers de l' Atlantique (CAT, France), London Marine Consultants (LMC, England) and DnV (Norway).

The present contribution is aiming at presenting some first numerical results concerning the quasi-static motion response analysis of the moored GIFT terminal considered alone under specified operating and survival conditions along with some first comparisons with experimental data.

To this end, first the quasi-static behavior of the terminal in extreme environmental conditions is examined that resemble to survival situations assuming that the translational motions of the structure in the horizontal direction are restricted by a 16 line mooring system. The mean motions are calculated through the static analysis of the mooring arrangement under the action of the mean wind, current and wave forces. The slow-varying maximum excursion is then calculated at a first stage by considering the terminal as a one degree of system oscillator and by solving the corresponding dynamic problem in the frequency domain. The restoring properties offered to the structure are obtained by the quasi-static analysis of the 16line mooring system, while the hydrodynamic characteristics of the terminal are obtained through the solution of the corresponding body - wave interaction problem using sink - source techniques and first-order potential theory.

Finally, some numerical predictions concerning the motions of the moored vessel having its mooring system replaced by an equivalent four – line one are given. In doing this, each of the four - line groups that constitute the full scale mooring system is replaced by one equivalent chain, thus the total system being reduced to a four line one. The numerical calculations with the reduced system have been performed to directly compare numerical predictions and experimental data. The thrusters' action is approximated by inserting two additional mooring lines attached to the stern of the floater, with pretensions and stiffness the ones used in the experiments.

FLOATING TERMINAL, MOORING SYSTEM AND SEA STATES CONSIDERED

Fig.1 depicts the GIFT-LNGC assembly with the grid of panels used for the linearized hydrodynamic calculations and the evaluation of the mean drift forces using potential flow theory. A sufficiently dense grid was used for the terminal that consisted of 2316 elements. In the same figure the reader is able to observe the integrated skirts at the bottom side of the terminal that are used for reducing the excessive rolling motion. The main dimensions of the terminal are listed in Table 1.

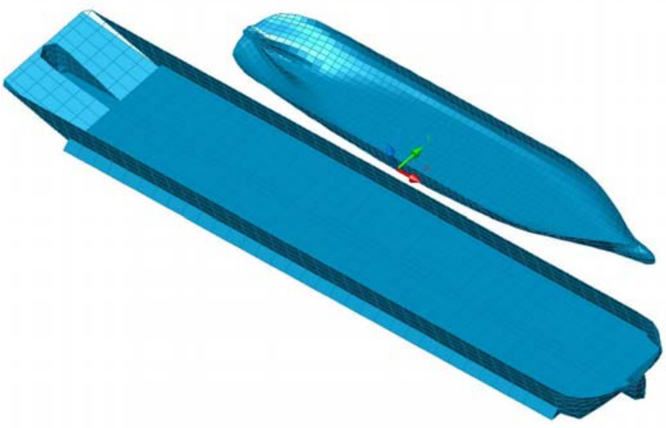

Figure 1: GIFT-LNGC assembly

Table 1: Main dimensions for GIFT

Length overall	410m
Length between perpendiculars	403m
Breadth	55m
Depth at the deck	41.75m
Full load draft	16m
Displacement	335.363 tones

The turret mooring system, designed by LMC, consists of 16 uniform mooring lines (152mm R4S+ Studless Chain). The lines are arranged in four groups with four lines each. The center lines of these groups are spaced by 90°. In each group the spacing of the lines is 5°. The turret is located at 316m from the stern and it is placed at the center plane of the terminal. The depth at the locations of the fairleads is considered equal to 58.5m while the water depth equals to 75m. The characteristics of the mooring lines are given in Table 2. The environmental conditions considered for the calculations concerning the wind, current and wave loads are shown in Tables 3 and 4.

Table 2: Properties of the mooring lines

Total length	(L)	1240m
Mass per unit length	(m)	466.7 kg/m
Nominal diameter	(d)	0.214 m
Added mass per unit length	(m_a)	35.96 kg/m
Cross sectional area	(A)	0.0359 m^2
Elastic stiffness	(EA)	1837869 kN
Equivalent elasticity	(E)	51097202 kN/m^2
Wet weight per unit length	(w)	3979.9 N/m
Breaking Tension	MBL	23437kN
Pretension at the top	(T_{pr})	1250 kN

Table 3: Extreme survival conditions

100 year return period		
Environment		
Wind	*V1h, 10m (m/s)*	48.7
	Spectrum	Harris
Current	*Vsurface (m/s)*	1.1
	Current profile	Constant over depth
Waves	H_s *(m)*	12.6
	T_p *(sec)*	14.8
	Spectrum	JONSWAP, γ=2.6

Table 4: Extreme operating conditions

Environment		
Wind	*V1h, 10m (m/s)*	15
	Spectrum	Harris
Current	*Vsurface (m/s)*	0.4
	Current profile	Constant over depth
Waves	H_s *(m)*	3
	T_p *(sec)*	7-13
	Spectrum	JONSWAP, γ=1.0

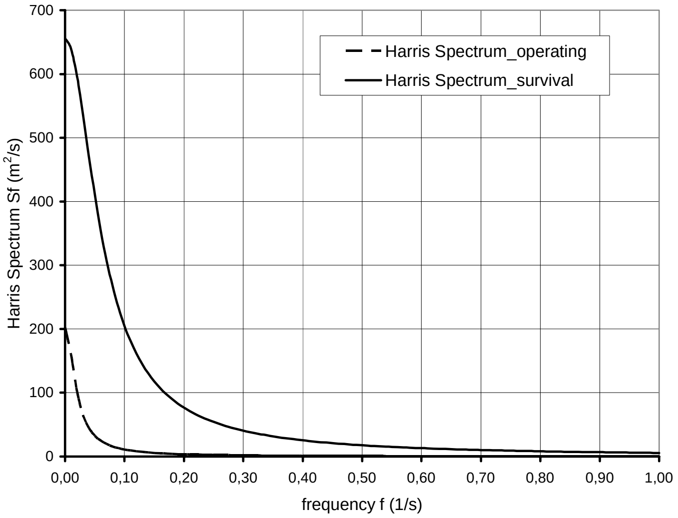

Figure 2: Harris wind spectrum for the sea-states mentioned in Tables 3 and 4.

The JONSWAP wave spectrum formulation recommended by DNV (2004) has been used, while the Harris wind spectrum formulation was taken by Gould and Abu-Sitta (1980). The shape of the Harris wind spectrum for the specified conditions listed in the above tables is shown in Fig. 2.

ENVIRONMENTAL LOADS

The purpose of a mooring system is to reduce the extreme motions of a moored vessel to a certain level determined by safety requirements, by keeping in parallel the maximum tensions along the lines well below of their breaking capacity. The mean structure's excursions are predicted by the mean wind, current and wave drift forces and the mooring system's stiffness. Then, the large amplitude slowly - varying vessel's motions can be obtained by accounting for the mooring system's restoring characteristics around the mean equilibrium position of the floating vessel under the action of the mean environmental loads. In obtaining the mooring system's stiffness, the complete system of governing equations that describe the static equilibrium of extensible lines is solved for each line separately using the 4th order RUNGE - KUTTA method for nonlinear ordinary differential equations. The results are then properly superimposed to predict the final balancing position of the moored vessel under specified loading conditions in surge, sway and yaw using an iteration process (Chatjigeorgiou & Mavrakos, 2003).

Before applying the quasi-static analysis for calculating the mean excursions of the turret, the mean environmental loads are to be predicted. For the mean wind and current calculations use was made of the commercial software *WINDOS* (2004). The corresponding numerical predictions for both sea-states under consideration and for a range of heading from 0 to 180 degrees are given in Figs. 3-6.

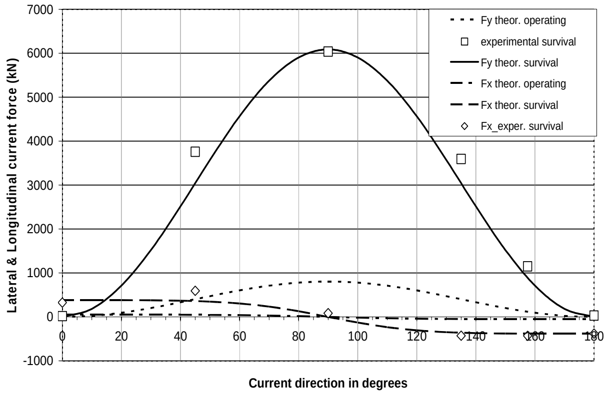

Figure 3: Surge and sway current forces on GIFT

Figs. 3 and 4 depict the calculated data for current forces and moments while Figs. 5 and 6 present the respective results that refer to the wind loadings. In addition, Figs. 3 and 4 depict also the experimental data which were taken during the 1st campaign of experiments carried out by OCEANIDE in Toulon, France. The model that was used for performing the experiments was built with a scaling factor 1:75. As can be seen the agreement between our numerical predictions and the corresponding experiments is favorable.

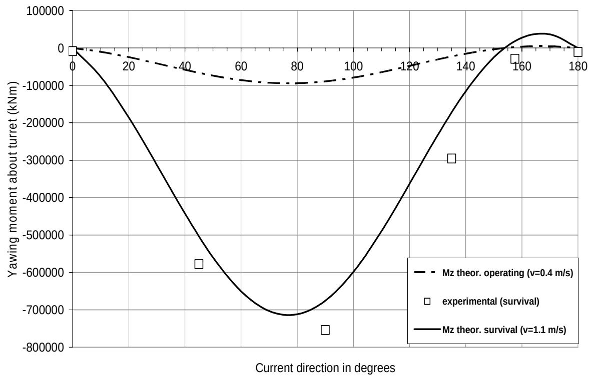

Figure 4: Yaw current moments on GIFT

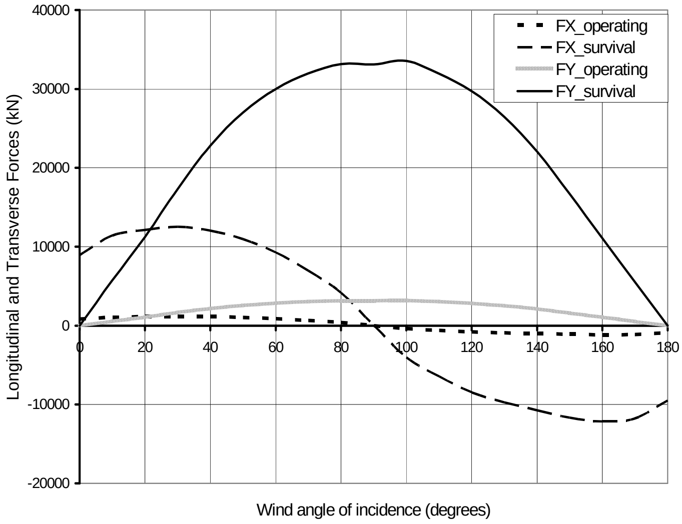

Figure 5: Surge and sway wind forces on GIFT

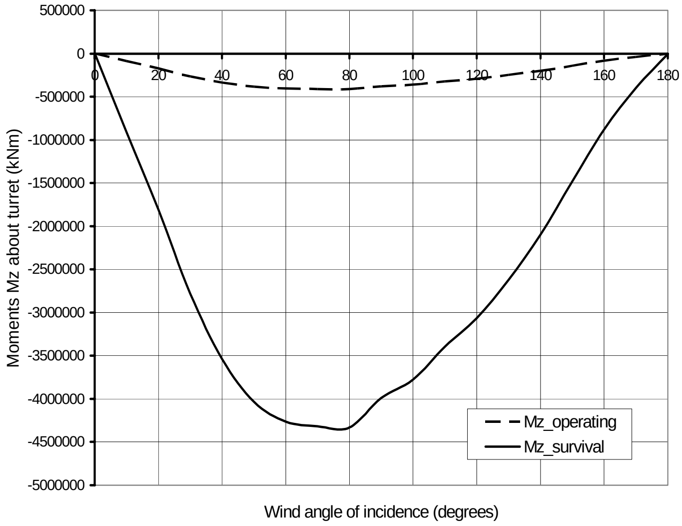

Figure 6: Yaw wind moments on GIFT

As far as the evaluation of the wave drift forces on the floating terminal is concerned, both Far Field (FF) and the Near Filed (NF-Direct Integration) methods have been used. For the implementation of the methods, the computer codes HAQ11 and HAQ12 were used for the FF and the NF, respectively, which are six-degrees of freedom, diffraction – radiation panel codes with zero forward speed suitable for the solution of the linearized body-wave interaction problem around arbitrarily shaped isolated or interacting large volume structures (Kokkinowrachos et. al, 1982; Bardis & Mavrakos, 1984). In the context of the present calculations, the hydrodynamic characteristics of the floating terminal have been derived for wave headings between 0 to 180 degrees with an equal spacing of 30 degrees, while in the range between 150-180 degrees of incidence, additional calculations using an equal spacing of 1 degree for the wave heading have been performed. Indicative results for the Transfer Functions of wave drift forces that refer to 160 degrees are presented in the following Figs. 7-9. The same figures show also the corresponding experimental measurements for three different wave periods.

The above mentioned results were subsequently used for calculating the mean and the slowly varying motions of the moored vessel in survival conditions. The vessel is considered free to rotate around the turret until an angular equilibrium position is reached under the action of the yaw moments due to wind, waves and current. At this position the components of the yaw moments should compensate each other resulting in zero contribution.

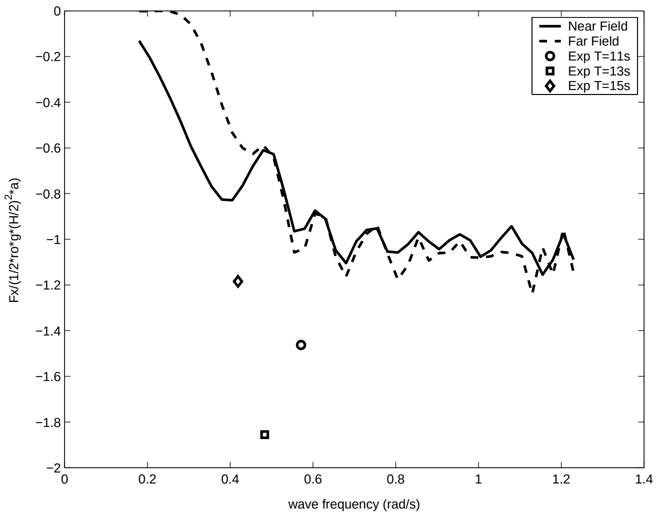

Figure 7: QTFs of the horizontal drift forces on GIFT for 160^o heading

MEAN AND SLOWLY VARYING MOTIONS

For the purposes of GIFT project several survival conditions were examined which are distinguished by the directions of the environmental actions. Fig. 10 depicts an indicative case of loading according to which the vessel has reached an angular equilibrium position where the x-axis of the body's fixed coordinate system is pointing towards 180 degrees while the waves, the wind and the current approach the terminal from 197, 167 and 152 degrees respectively. Some of the loading cases that were examined are defined in Table 5. It is assumed that in the equilibrium position the bow of the vessel is directed as shown in Fig. 10.

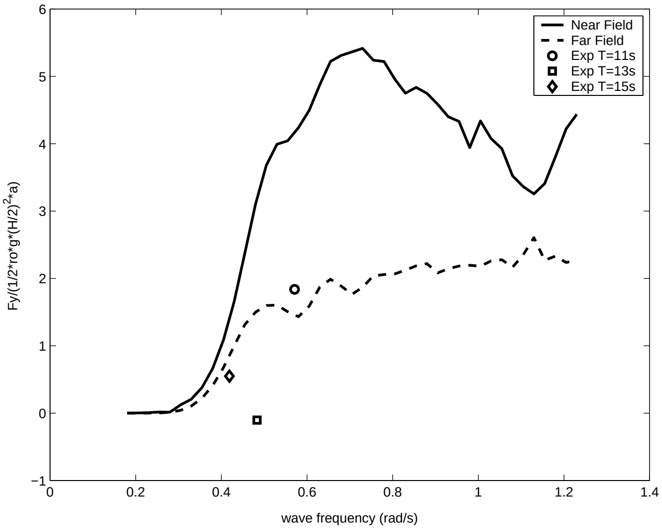

Figure 8: QTFs of the transverse drift forces on GIFT for 160^o heading

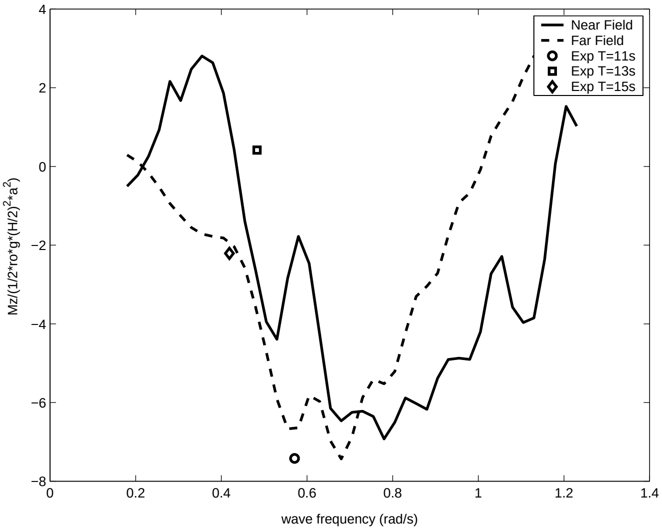

Figure 9: QTFs of the yaw drift moment on GIFT for 160^o heading

Details of the angles of heading at the GIFT's angular equilibrium position around turret are listed in Table 5. Under these conditions, it is considered that the worst case of loading for the mooring system corresponds to the state according to which the centerline of a group of lines is in alignment with the longitudinal axis of the terminal, while the waves which will subsequently cause the slowly varying GIFT's motions hit the terminal from the same direction. The mean excursions for the sea-states listed in Table 5 are given in Table 6. The Δx and Δy mean displacements were obtained by solving the static equilibrium problem of the mooring system using the previously mentioned quasi-static solution technique. The mean wave drift forces that contribute to the total loading shown in Table 5 were derived using the Far Field Method. It should be mentioned that this does not affect seriously the accuracy of the calculations as the dominant contribution to the environmental effects originates from wind and although there are notable differences between the results obtained by the Near Field and Far Field methods (see Figs. 8 and 9), the total mean forces and the resulting mean excursions are comparable.

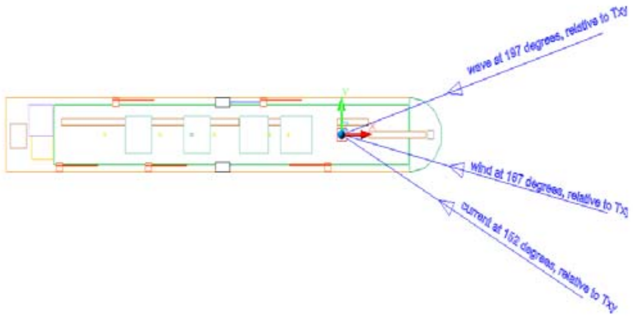

Figure 10: Floating terminal and directions of environmental actions

Table 5: Equilibrium positions and resulting mean forces for various sea-states

Case no	Equil. Pos. (deg)	Wave dir. (deg)	Wind dir. (deg)	Current dir. (deg)	$\bar{F}_x$ (kN)	$\bar{F}_y$ (kN)
1	180	197	167	152	-14350	5215
2	180	197	167	167	-14353	4224
3	180	197	167	182	-14353	3944
4	180	197	167	197	-14352	3379
5	180	189	174	144	-12265	3436
6	180	188	173	158	-12499	2906
7	180	187	172	172	-12738	2894
8	180	188	173	188	-12500	1975
9	180	182	182	137	-11686	7272
10	180	180	180	150	-11466	7317
11	180	180	180	180	-11470	-700

Table 6: Mean excursions and tensions applied at the top of the worst loaded line for the sea-states listed in Table 5

case no	Δx (m)	Δy (m)	T (kN)	%MBL
1/197	-8.32	3.80	4618	19
2/197	-8.33	3.19	4418	18
3/197	-8.33	3.01	4552	19
4/197	-8.34	2.63	4519	19
5/189	-7.53	2.69	3986	17
6/188	-7.63	2.30	4015	17
7/187	-7.72	2.29	4076	17
8/188	-7.63	1.59	3961	16
9/182	-7.25	5.03	4010	17
10/180	-7.16	5.05	3954	16
11/180	-7.21	-0.56	3626	15

Table 7: Slowly varying motions of GIFT in longitudinal and transverse directions for the sea-states listed in Table 5

Case no	$x^{(2)}$ (m)	$y^{(2)}$ (m)	Max Excursion (m)	%D
1/197	-7.66	8.79	20.34	27
2/197	-7.66	8.79	19.98	26
3/197	-7.66	8.79	19.87	26
4/197	-7.66	8.79	19.65	26
5/189	-7.90	4.60	17.06	22
6/188	-7.68	4.14	16.60	22
7/187	-7.62	3.60	16.43	22
8/188	-7.68	4.14	16.15	21
9/182	-7.93	0.79	16.50	22
10/180	-8.01	0.00	15.98	21
11/180	-8.01	0.00	15.23	20

The slowly varying surge and sway motions around the mean position of static equilibrium are given in Table 7. The same table contains the results for the maximum excursions-without including the high frequency motions-as a percentage of the water depth. The mooring system appears to suffer more at the sea state in which the angular differences of the wind and the current directions with respect to the direction of the incoming waves are 30 and 45 degrees respectively. In addition, in all cases where the incoming waves approach the terminal from 197 degrees, the highest turret's maximum excursion is obtained.

For the calculation of the slowly varying motions, the method proposed by Pinkster (1975) has been used, assuming that the floating vessel behaves as a one-degree-of-freedom dynamic system and using the restoring coefficients provided by the mooring arrangement at the mean equilibrium position (see Table 6). An important issue associated with the accurate prediction of the slowly varying motions in surge, sway and yaw, relates to the proper calculation of the linearized damping coefficients. The components, which are considered here when calculating the total damping offered to the structure, are the drag forces, the wave drift damping and the mooring line damping. The latter is usually ignored although it has been reported that it is able to contribute up to 30% to the total damping (Huge, 1986; Brown & Mavrakos, 1997). It should be also mentioned that it has been acknowledged that the wave drift damping, could grow up to 85% of the total damping for extremely high significant wave heights (Faltinsen, 1990). For being as accurate as possible and for including all possible damping contributions, the relevant coefficients that were used for the numerical calculations, were those obtained by the experimental measurements as a percentage of the critical damping. In particular, the mean values of damping measured during the experiments were 1.41% for the surge motion and 6.08% for the sway motion.

COMPARISONS WITH EXPERIMENTS

In this section some results of the above described quasi-static methodology are given for specific loading conditions. For the same conditions, experimental data from the 1st experimental campaign carried out in OCEANIDE (France) are also available. The main difference between the data outlined in the following and those which already discussed is that here an equivalent mooring system is considered that was designed to fit to the dimensions of the basin. The equivalent mooring system consists of 4 equivalent lines representing the 4 groups of the actual mooring arrangement. The replacing system was designed in such a way to properly comply with the physical properties of each group. In addition, the full scale model of the replacing mooring system is considered to consist of truncated lines with reduced length because of the scaling limitations set by the dimensions of the basin. It was determined that the full scale length for each of these lines should be 835m while a spring with an equivalent full scale elasticity k=5921kN/m had to be attached at their bottom end to properly account for the bottom-laying part of the full length chain. Table 8 provides the properties of the truncated lines that were subsequently used for designing the scale-down model with a scaling factor 1:75.

Table 8: Properties of the truncated 835m mooring lines

Total length	(L)	1240m
Mass per unit length	(m)	1866.8 kg/m
Nominal diameter	(d)	0.428 m
Added mass per unit length	(m_a)	143.87 kg/m
Cross sectional area	(A)	0.1438 m^2
Elastic stiffness	(EA)	4*1837869*100 kN
Wet weight per unit length	(w)	15919.9 N/m
Breaking Tension	MBL	4*23437kN
Pretension at the top	(T_{pr})	5000 kN

Some of the properties listed in the above table such as the equivalent diameter, the added mass per unit length and the MBL of the truncated lines were properly calculated in order to account for the lines' equivalent elasticity and their increased breaking load. In addition, it was determined that for the numerical calculations the attached spring could be removed provided that the equivalent elasticity of the truncated lines will be reduced to 4911000kN.

Several numerical runs corresponding to the experimentally investigated heading angles and sea-states conditions were performed. In fact, numerical calculations were carried out for 160°, 120° and 180° of heading. The following figure depicts the moored structure for 160° wave heading.

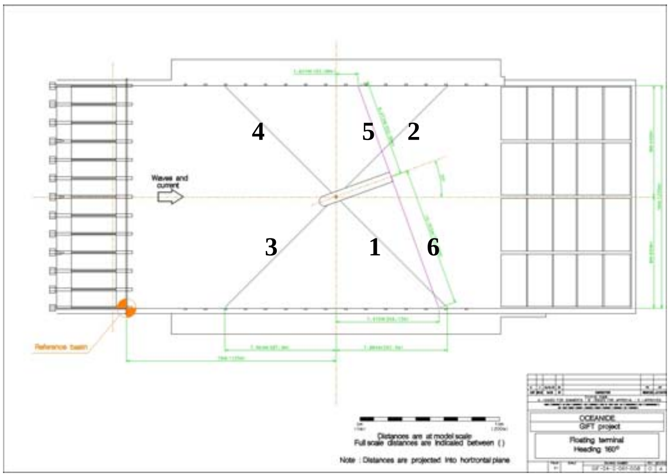

Figure 11: Experimental set-up for 160° heading and line count

The horizontal lines attached at the stern of the structure were used to simulate the operation of the side thrusters. For obtaining the numerical predictions the rear lines were replaced by equivalent moorings taking good care to maintain the equivalent elasticity and the restoring characteristics that originate from the pretensions forces applied at the top. Furthermore, in order to simulate with the best possible way the prevailing conditions during the experimental campaign, the actual pretension forces were used and not the specified ones. These were set equal to 4104kN, 4230kN, 4779kN and 3940kN for lines No 1,2,3 and 4 respectively. In addition the horizontal pretensions used for lines No 5 and 6 were 7242 and 6989 respectively.

The numerical results were derived using quasi-static analysis. Thus, direct comparisons can be made only with the mean values of measurements. As the experimental data refer only to the wave loading without the action of wind or current, the numerical calculations were performed using the corresponding mean drift force obtained through the solution of the first-order hydrodynamic problem of the free floating body. For regular waves, this force is determined directly from the QTFs of the wave drift forces, while its irregular seas counterpart has been evaluated by assuming a JONSWAP sea spectrum (Faltinsen, 1990). All motions shown in the following tables refer to center of gravity of the terminal.

Table 9 shows comparative results for 160° heading and irregular seas with the given characteristics, while Tables 10-17 depict the corresponding numerical and experimental data for regular waves with H=21.3m and H=6m, two directions of the incoming waves (160 and 180 degrees) and three wave periods, i.e. T=11, 13 and 15s. The afore-mentioned heights of the generated waves correspond to survival and operating conditions, respectively.

Table 9: Comparative results for GIFT's quasi-static displacements for irregular waves and 160° heading. $H_{1/3}$=12.6, T_{peak}=14.8s

	Δx (m)	Δy (m)	Δθ (deg)
FF method	-1.662	1.850	-0.05
NF method	-1.972	4.211	0.39
Exp. (min÷max)	-10.7÷7.9	-2.8÷9	-3.8÷1.6
Exp.mean	-2.5	3.1	-0.5

Before proceeding to further comparisons between numerical predictions and experimental data, we should bring to the readers' attention some of the difficulties we had to overcome for setting up a numerical model which could simulate with the best possible way the real conditions of the experiments. First of all the pretension used at each line was different than the specified one. Thus, in real conditions the model had an initial small displacement due to the non symmetric pretension forces. Next, the numerical calculations for the drift forces that subsequently used for predicting the motions of the structure were obtained for the free floating body and not for the body having the mooring installed. Furthermore, during the experiments there was always an intermittent transient interval until the waves were fully developed.

Table 10: GIFT's mean displacements for 160^{o} heading. Drift forces obtained by the Far Field Method. Regular waves H=6m

T(s)	Δx (m)	Δx (m) Exp	Δx (m) Exp Mean	Δy (m)	Δy (m) Exp	Δy (m) Exp Mean	Δθ (deg)	Δθ (deg) Exp	Δθ (deg) Exp Mean
11	-1.1	-2.9÷-0.9	-1.8	1.0	3.8÷4.2	4.0	-0.1	-1.1÷-0.5	-0.9
13	-0.5	-1.6÷-0.9	-1.1	1.2	2.0÷2.3	2.1	0.1	-0.4÷-0.3	-0.4
15	-0.5	-1.8÷-0.7	-1.1	0.8	0.9÷1.4	1.0	0.1	-0.3÷0.2	0.1

Table 11: GIFT's mean displacements for 160^{o} heading. Drift forces obtained by the Near Field Method. Regular waves H=6m

T(s)	Δx (m)	Δx (m) Exp	Δx (m) Exp Mean	Δy (m)	Δy (m) Exp	Δy (m) Exp Mean	Δθ (deg)	Δθ (deg) Exp	Δθ (deg) Exp Mean
11	-0.9	-2.9÷-0.9	-1.8	3.2	3.8÷4.2	4.0	0.3	-1.1÷-0.5	-0.9
13	-0.4	-1.6÷-0.9	-1.1	2.4	2.0÷2.3	2.1	0.2	-0.4÷-0.3	-0.4
15	-0.8	-1.8÷-0.7	-1.1	1.3	0.9÷1.4	1.0	0.3	-0.3÷0.2	0.1

Table 12: GIFT's mean displacements for 160^{o} heading. Drift forces obtained by the Far Field Method. Regular waves H=21.3m

T(s)	Δx (m)	Δx (m) Exp	Δx (m) Exp Mean	Δy (m)	Δy (m) Exp	Δy (m) Exp Mean	Δθ (deg)	Δθ (deg) Exp	Δθ (deg) Exp Mean
11	-11.0	-12.5÷-9.6	-11.5	11.2	16.5÷25.	20.2	-3.0	-8.1÷-4.5	-7.0
13	-6.9	-14.0÷-8.6	-11.6	10.8	15.1÷28.1	20.9	-1.5	-3.7÷-9.8	-7.3
15	-7.3	-14.5÷-10.3	-12.7	6.5	9.4÷11.9	10.5	-0.4	-2.2÷0.9	-1.3

Table 13: GIFT's mean displacements 160^{o} heading. Drift forces obtained by the Near Field Method. Regular waves H=21.3m

T(s)	Δx (m)	Δx (m) Exp	Δx (m) Exp Mean	Δy (m)	Δy (m) Exp	Δy (m) Exp Mean	Δθ (deg)	Δθ (deg) Exp	Δθ (deg) Exp Mean
11	-4.3	-12.5÷-9.6	-11.5	24.1	16.5÷25.	20.2	-3.4	-8.1÷-4.5	-7.0
13	-3.0	-14.0÷-8.6	-11.6	20.0	15.1÷28.1	20.9	-2.6	-3.7÷-9.8	-7.3
15	-8.2	-14.5÷-10.3	-12.7	8.6	9.4÷11.9	10.5	0.5	-2.2÷0.9	-1.3

Table 14: GIFT's mean displacements for 180^{o} heading. Drift forces obtained by the Far Field Method. Regular waves H=6m

T(s)	Δx (m)	Δx (m) Exp	Δx (m) Exp Mean	Δy (m)	Δy (m) Exp	Δy (m) Exp Mean	Δθ (deg)	Δθ (deg) Exp	Δθ (deg) Exp Mean
11	-1.0	-2.1÷-0.9	-1.4	0.5	4.7÷5.4	5.1	0.0	-2.8÷-2.6	-2.7
13	-0.5	-1.7÷-0.8	-1.1	0.5	1.3÷3.8	2.7	0.0	1.9÷-0.8	-1.4
15	-0.6	-1.7÷-0.7	-1.1	0.5	3.4÷4.4	3.9	0.0	-2.2÷-1.9	-2.1

Table 15: GIFT's mean displacements for 180^{o} heading. Drift forces obtained by the Near Field Method. Regular waves H=6m

T(s)	Δx (m)	Δx (m) Exp	Δx (m) Exp Mean	Δy (m)	Δy (m) Exp	Δy (m) Exp Mean	Δθ (deg)	Δθ (deg) Exp	Δθ (deg) Exp Mean
11	-0.9	-2.1÷-0.9	-1.4	0.5	4.7÷5.4	5.1	0.0	-2.8÷-2.6	-2.7
13	-0.5	-1.7÷-0.8	-1.1	0.5	1.3÷3.8	2.7	0.0	1.9÷-0.8	-1.4
15	0.8	-1.7÷-0.7	-1.1	0.5	3.4÷4.4	3.9	0.0	-2.2÷-1.9	-2.1

Table 16: GIFT's mean displacements for 180^{o} heading. Drift forces obtained by the Far Field Method. Regular waves H=21.3m

T(s)	Δx (m)	Δx (m) Exp	Δx (m) Exp Mean	Δy (m)	Δy (m) Exp	Δy (m) Exp Mean	Δθ (deg)	Δθ (deg) Exp	Δθ (deg) Exp Mean
11	-10.3	-14.4÷-12.7	-13.4	1.2	-8.6÷-4.0	-6.5	0.0	1.9÷4.5	3.2
13	-7.2	-14.5÷-12.4	-13.3	1.2	-10.7÷-9.4	-10.3	0.0	4.8÷5.5	5.3
15	-7.9	-14.3÷-11.3	-13.4	1.2	-0.7÷1.3	0.3	0.0	-0.8÷0.2	-0.5

Table 17: GIFT's mean displacements for 180^{o} heading. Drift forces obtained by the Near Field Method. Regular waves H=21.3m

T(s)	Δx (m)	Δx (m) Exp	Δx (m) Exp Mean	Δy (m)	Δy (m) Exp	Δy (m) Exp Mean	Δθ (deg)	Δθ (deg) Exp	Δθ (deg) Exp Mean
11	-9.7	-14.4÷-12.7	-13.4	1.2	-8.6÷-4.0	-6.5	0.0	1.9÷4.5	3.2
13	-7.0	-14.5÷-12.4	-13.3	1.2	-10.7÷-9.4	-10.3	0.0	4.8÷5.5	5.3
15	-9.2	-14.3÷-11.3	-13.4	1.2	-0.7÷1.3	0.3	0.0	-0.8÷0.2	-0.5

During that time, the moored model was displaced from its static pretension position due to the initial waves of small height generated by the wave maker. Finally, the uncertainty regarding the equivalence of the configuration of the two rear mooring lines that were inserted at the model's stern having proper restoring characteristics to replace the horizontal springs in air that were used during the experiments in lieu of the thrusters. The latter were replaced in our numerical model by two equivalent moorings with asymmetrical pretensions applied at the top.

The numerical predictions obtained by the Far Field (FF) and the Near Field (NF) methods that refer to the irregular waves and survival conditions under 160^o heading are in general comparable (Table 9). However, the NF method's results appear to approximate better the mean values of measurements. The fact that the yaw rotation obtained using the NF method has opposite sign than the experimental mean, is insignificant as the angle is almost zero. The good agreement that is observed by inspecting the mean values listed in Table 9 is very encouraging as there is a pronounced variation in motions due to the fact that the stimulation is in irregular seas.

Comparisons for the mean values of motions for regular waves are shown in Figs. 10-17. These correspond to 160^o (Figs. 10-13) and 180^o of incidence (Figs. 14-17). Again the numerical predictions obtained using the drift forces by the NF method are in general better. The most apparent example refers to operating conditions and 160^o heading (Table 11). It is also important to note that the NF method captures with a very good accuracy the extreme sway motions for the same angle of heading and survival conditions (Table 13).

For the cases examined assuming head waves, i.e. (180^o heading) the surge motions which are of particular importance are almost identical regardless the method which was implemented for the drift loads (FF or NF). Also, the values predicted numerically are generally in good agreement with the experimental data.

CONCLUSIONS

In the present work results concerning the quasi-static motion response analysis of a moored LNG terminal obtained during the on-going European Commission funded project GIFT (2005) are reported. Representative results concerning primarily the analysis of a 16line mooring system which was designed for the LNG terminal are given. The calculations refer to numerical predictions of the environmental loading due to wind, waves and current applied to the structure for both operating and survival conditions. For the prediction of wave drift loading both Far Field and Near Field methods were implemented. The structure's slowly-varying motions were obtained assuming that it behaves as a one degree of freedom system, while the restoring characteristics offered by the mooring system were evaluated using quasi-static solution techniques. Finally the work was supplemented with some first comparisons between experimental data and numerical predictions to validate our quasi-static approach for evaluating at a preliminary stage the mean displacements of the structure under specified sea states that resemble to operating and survival conditions.

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