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COMBINING EXTREME METOCEAN PARAMETERS ON SPM MOORED TANKERS

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SYNOPSIS

In the design of SPM systems the environmental parameters are of prime importance. In operational condition both the magnitude of the characteristics of wave spectra and the wind and current velocities and their mutual directions may vary. By combining operational metocean parameters in a systematical way insight in the extreme design hawser loads and tanker responses may be gained.

In this paper a systematic number of combinations of wave spectrum, wind and current with regard to mutual directions and different current velocities were applied to a loaded and ballasted tanker moored to a CALM buoy. With these combinations of weather conditions the design hawser loads and tanker responses were studied. The results were obtained by means of time domain computer simulations. The results clearly indicate the most severe combinations of the considered sea states with regard to the extreme design loads.

Some model tests were carried out to support the reliability of the computations.

INTRODUCTION

The metocean parameters are wind, current and waves. Not only the magnitudes of wind and current velocity and (long-crested) wave characteristics are important but also their mutual directions. By combining and varying both wind and current velocities and wave parameters and their mutual directions for both the loaded and ballasted tanker the extreme design loads and responses of a CALM buoy moored tanker may be studied, see for instance Yilmaz et al. (1992).

In this study a resticted number of combinations of metocean parameters, being two basic cases, were considered. For one case the weather condition was combined by varying the internal angle between the parallel directed waves and wind and the direction of the current and applied to a loaded and ballasted tanker moored to a CALM buoy. For another case the weather condition consists of waves and wind directed perpendicular to the current. While the wave spectrum and wind speed were kept constant, the current speed was varied. For these two weather cases the extreme design loads and responses are determined by means of the time-domain computer program TERMSIM.

The technical features of the program are described in the next section. In order to show the reliability of the results some model tests were carried out and compared with the results of the computer program. The description of the measured and the computed results are dealt with in the section "validation". The results of the computations in the combined sea states are given and discussed in the appropriate sections. Finally conclusions have been drawn.

TECHNICAL DESCRIPTION OF THE COMPUTER PROGRAM

Introduction

The SPM moored tanker exposed to an irregular sea, a steady wind and current field performs wave and low frequency motions (respectively wf and lf motions). From observations of many model tests it can be concluded that the lf motions strongly dominate the mooring forces. The lf motions may be induced by both the wind and current (instability of the system) and wave drift excitation. Since the total system is highly non-linear the computations have to be performed in the time-domain. The time-domain computer program as used, is developed to compute the lf motions of the SPM moored tanker. The mooring system is simlated by a "hawser" running from the fairlead of the tanker to the centre of the buoy. The "hawser" represents the non-linear spring of the horzontally projected load-elongation characteristic of the actual hawser and the load-displacement curve of the buoy taking into account the directionality with regard to the chain legs. In irregular (long-crested) waves cobined with wind and current the computer program determines the lf motions of the tanker. The results are besides the lf motions of the tanker also the lf loads in the actual hawser, the lf motions of the buoy in the horizontal plane and the lf chain forces.

For the hawser loads not only the lf part has to be known but also the wf part. Knowing the lf loads, additional techniques were applied to compensate for the wf forces in the hawser. The description of the lf motion model and the applied wf modelling technique are presented below.

Hydrodynamic and aerodynamic modelling of the lf motions of the tanker

For modelling of the lf motions of a tanker in the horizontal plane the magnitudes of the excitation (wave drift forces/moment) and the lf hydrodynamic reaction forces/moment have to be known. The lf hydrodynamic reaction forces/moment consist of lf added mass and lf viscous hydrodynamic damping terms. Although the lf excitation and the reaction forces/moment are in general an order smaller than the well-known first order forces/moment they are responsible for the large amplitude lf motions of the tanker in the horizontal plane introducing high mooring forces. While the wave drift forces/moment and the lf added mass coefficients can be determined by three-dimensional diffraction theory (Pinkster (1980) and Wichers (1988)), the low frequency viscous hydrodynamic damping forces/moment have to determined by model tests. To determine the viscous hydrodynamic damping forces/moment oscillation tests with a set of tankers have been carried out. The description of the low frequency large stroke oscillator and the analysis procedures are described in Wichers (1986, 1988) and de Kat et al. (1991). By means of the measurements in shallow and deep water, data sets are derived in terms of linear and quadratic resistance coefficients in both still water and in current fields and for several ratios of water depth/draft ratios. These data were used for the present computations. For the determination of the relative wind and current forces/moment use is made of the resistance coefficients for wind and current acting on tankers as given by OCIMF (1994-a).

The excitation forces/moment are caused by the wave drift forces/moment. By means of the three-dimensional potential theory the full matrix of the quadratic transfer function of the wave drift forces/moment as function of the wave heading has been computed. For the full description of the equations of motion for the lf motions reference is made to Wichers (1988). Prior to the time-domain simulation by means of the generated wave train and the matrix of the quadratic transfer function of the wave drift forces/moment, the registrations of the wave drift surge and sway forces - and yaw moment have been computed for a range of headings between 0° and 360° (a step of 30° is considered prior to the mean heading of the tanker). The computation of the wave drift force registrations are based on the "impulse response technique" or "Volterra series formulation", see Wichers et al. (1983). In the time domain a linear interpolation is performed on the actual instantaneous heading of the tanker.

Modelling of the wf component to be added to the lf hawser force

As mentioned before besides the lf behaviour of the system, the system is also influenced by the wf forces. The tanker will carry out wf motions in the six degrees of freedom. The fairlead will perform wf surge, sway and heave motions introducing wf force oscillations in the hawser. Furthermore the buoy will introduce wf loads in the hawser. In order to introduce the wf loads in the hawser the following procedure has been applied:

- The maximum lf load in the hawser is known from the lf time-domain computation.
- With the maximum lf load in the hawser the tanker is brought back to the mean tanker heading.
- In the mean tanker heading the wf RAOs of the fairlead are computed.

  In the frequency domain by means of spectral analysis the significant single amplitude of the motion in the direction of the hawser is determined. The computations of the RAOs are based on three-dimensional diffraction theory (wave forces, added mass and damping). Multiplying the significant single amplitude with the associated tangent of the non-linear curve of the total mooring system (spring coefficient) determines approximately the significant wf single load amplitude in the hawser.
- Because the wf hawser loads are based on the maximum lf load in the hawser it is assumed that the buoy is in a taut position in between the chains and the hawser. In this position it is assumed that the motions of the buoy are restricted and that the force as felt by the hawser will be the wave loading on the buoy. In the frequency domain, by means of the three-dimensional diffraction theory applied to the buoy, the significant single amplitude of the horizontal wave force active on the buoy in the wave spectrum will be computed. Now the component of the significant single amplitude of the wave loading in the direction of the hawser will be determined.

Finally the total wf force in the hawser will be determined by taking the square root of the sum of the squares of the two mentioned significant single amplitudes. This value will be added to the associated maximum lf force component in the hawser.

VALIDATION

For the validation use was made of a 200 kDWT tanker. The particulars of the 70% T loaded tanker are given in Table 1. The tanker was moored by means of a hawser to a fixed (stiff) pole. The load-elongation characteristic of the hawser is given in Figure 1.

Table 1. Particulars of tankers

Designation	Symbol	Unit	200 kDWT	140 kDWT	
Draft in % of loaded draft			70	100	40
Length between perpendiculars	Lpp	m	310	286.4	286.4
Breadth moulded	B	m	47.17	43.7	43.7
Depth	H	m	29.70	25.7	25.7
Draft	T	m	13.23	15.8	6.32
Displacement volume	∇	m^3	159,698	164,546	64,070
Centre of buoyancy forward of section 10	$\overline{FB}$	m	9.04	8.37	12.10
Centre of buoyancy above keel	$\overline{KG}$	m	11.55	10.35	10.35
Metacentric height	$\overline{MG_t}$	m	8.66	9.73	16.38
Transverse radius of gyration in air	k_{11}	m	15.02	16.17	16.17
Longitudinal radius of gyration in air	k_{22}	m	77.52	71.47	71.47
Yaw radius of gyration in air	k_{66}	m	83.81	77.28	77.28
Wind area total lateral	A_S	m^2	6028	3435	6150
Wind area total frontal	A_F	m^2	1630	1032	1445
Position bow fairlead forward of section 10	LF	m	158	146.2	146.2
Position bow fairlead wrt to still water (vertical)	h	m	19.47	11.9	21.38

The tanker is moored in 82.5 m water depth. The model tests and the computations were carried out in 2 environmental conditions. The environmental conditions are given in Figure 2. For the quadratic transfer function of the wave drift forces/moment and other input data for the computation, see Wichers (1988). The computations were carried out with the same computer program as described above.

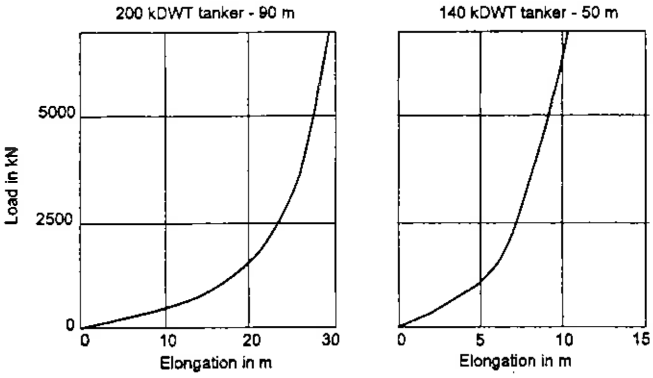


Fig. 1. Load elongation characteristics of bow hawser

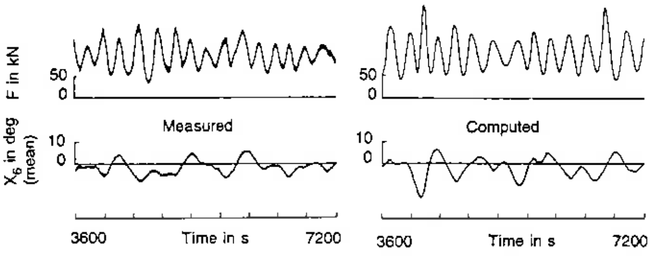


Fig. 3. Measured and computed hawser force and yaw motion of tanker (200 kDWT tanker in 70% T - environment 1)

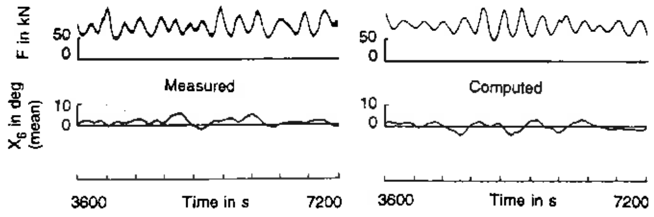


Fig. 4. Measured and computed hawser force and yaw motion of tanker (200 kDWT tanker in 70% T - environment 2)

The results of the measured and computed mean position of the tanker in the two environments are given in Figure 2. The measured and computed registrations of the hawser force and tanker yaw motion are given in Figures 3 and 4. It must be noted that having the same wave spectrum the wave registrations as used for the model tests and computations were different. From the results it can be concluded that the measured and computed results clearly show the same order of magnitude. Furthermore it can be said that the number of peaks of the hawser forces in both registrations were the same. From these results it can be concluded that the computer program may give reliable output.

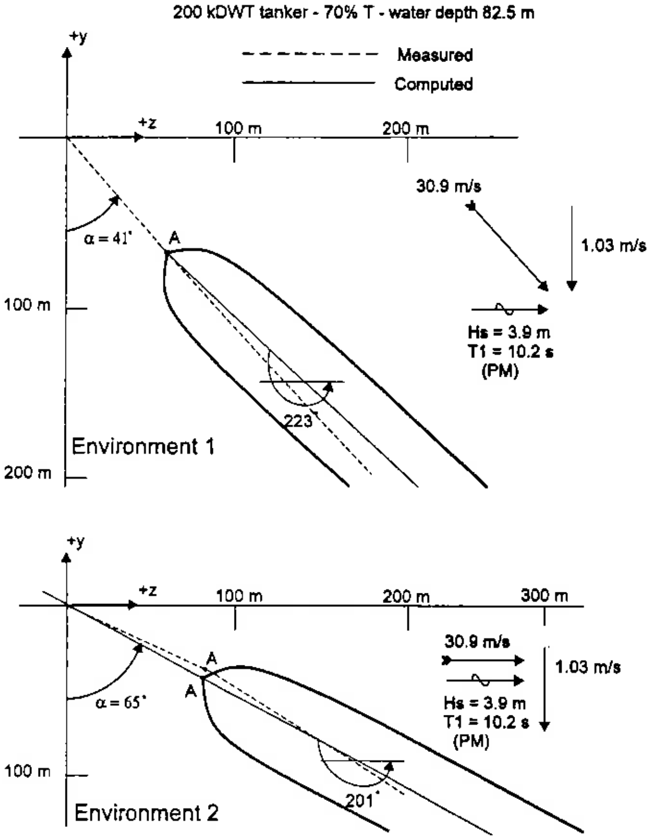


Fig. 2. The measured and computed mean position of the bow hawser moored tanker in wind, waves and current

RESULTS OF COMPUTATIONS IN COMBINED WEATHER CASES

For the study of the SPM in the combined weather cases 1 and 2 a loaded and ballasted 140 kDWT tanker has been used in 23.7 m water depth. The mentioned tanker and water depth have been chosen because this condition is one of the basic cases of the program OCMOTA. OCMOTA, part of the program TERMSIM, is a computer program with a data base giving for instance the matrix of the quadratic transfer functions of the wave drift forces/moment and the ROAs of the tanker for a large range of wave headings, see OCIMF (1994-b). In this program, however, the quadratic transfer function of the wave drift damping and thus the effect of the wave drift forces/moment on the current speed is not taken into account.

The specifications of the weather cases are shown in Figure 5.
The tanker is moored to a CALM-buoy. The particulars of the tanker are given in Table 1. The tanker is moored by means of a hawser to a CALM bouy. The particulars of the CALM-chain system and the hawser are given in Table 2. The load-elongation of the hawser is given in Figure 1.

Table 2. Particulars of mooring system

(140 kDWT tanker - water depth 23.7 m)

Designation	Value	Unit
Nylon double-braided type hawser		
Unstreched (initial) length	50.00	m
Number of grommets	1	-
Diameter	12.13	cm
Breaking strength	2992.05	kN
Total breaking strength	5984.10	kN
Buoy data		
Vertical position of hawser attachement piont	1.50	m
Vertical position of chain attachement points	-3.00	m
Diameter of buoy	12.00	m
Draft of buoy	3.00	m
Chain data		
Number of chains	6	-
Orientation of chains	6*60	deg
Pre-tension	80.50	kN
Length	207.00	m
Breaking strength	7867.75	kN
Elasticity	897795.19	kN
Weight in air	2.24	kN/m
Diameter	102.00	mm
Material grade	NV K3 RIG/ORQ/RQ3	

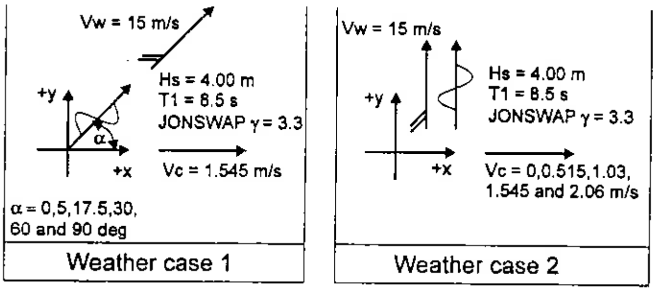


Fig. 5. Review of weather cases applied to the 140 kDWT tanker

For each weather condition the time-domain computations were carried out for a period of 3 hours full scale to ensure a sufficient length for the statistical process. For statistical reasons the maximum peak in the registration of the hawser peaks has been deleted. The maximum peak values as presented are the 2nd highest peaks. In Figure 6 the hawser force as function of the wave/wind direction (weather case 1) for both the loaded and ballasted tanker is presented. In Figure 7 the hawser force as function of current velocity (weather case 2) for both the loaded and the ballasted tanker is depicted.

Further the results of the tanker yaw motion and the hawser direction are presented in the Tables 3 and 4. The results are given as statistical analysis (mean, standard deviation, minimum and maximum). The definition of the mentioned signals are given in Figure 8.

Table 3. Tanker yaw motion and hawser direction in weather case 1 (angles in degrees)

Draft in m	Wave dir.	Signal	Mean	St.dev	Min	Max
15.8	0	ψ_t	180	5.6	166	199
15.8	5	ψ_t	181	5.4	171	196
15.8	17.5	ψ_t	185	3.2	177	195
15.8	30	ψ_t	190	2.4	185	199
15.8	30	ψ_h	140	11.7	103	173
15.8	60	ψ_t	202	3.2	192	212
15.8	60	ψ_h	130	10.6	97	166
15.8	90	ψ_t	212	4.3	200	229
15.8	90	ψ_h	128	17.7	59	208
6.32	0	ψ_t	180	6.3	163	197
6.32	5	ψ_t	183	6.3	167	200
6.32	17.5	ψ_t	192	6.1	176	207
6.32	30	ψ_t	202	4.9	189	218
6.32	30	ψ_h	-169	11	-203	-139
6.32	60	ψ_t	224	4.7	214	241
6.32	60	ψ_h	-159	12	-192	-124
6.32	90	ψ_t	249	5.3	235	266
6.32	90	ψ_h	-136	13.6	-170	-100

Table 4. Tanker yaw motion and hawser direction in weather case 2 (angles in degrees).

Draft in m	Vc in m/s	Signal	Mean	St.dev	Min	Max
15.8	0	ψ_t	269	8.7	249	229
15.8	0	ψ_h	-90	17.1	-138	-38
15.8	0.515	ψ_t	251	4.4	239	261
15.8	0.515	ψ_h	-122	12.8	-157	-96
15.8	1.03	ψ_t	227	5.4	209	241
15.8	1.03	ψ_h	-	-	-	-
15.8	1.545	ψ_t	212	4.3	200	229
15.8	1.545	ψ_h	128	17.7	59	208
15.8	2.06	ψ_t	201	3.8	192	216
15.8	2.06	ψ_h	123	8.7	100	152
6.32	0	ψ_t	268	12.4	237	296
6.32	0	ψ_h	-90	24.3	-157	-229
6.32	0.515	ψ_t	265	7.7	245	284
6.32	0.515	ψ_h	-94	16.2	-141	-41
6.32	1.03	ψ_t	257	5.3	245	273
6.32	1.03	ψ_h	-110	10.6	-152	-80
6.32	1.545	ψ_t	249	5.3	235	266
6.32	1.545	ψ_h	-138	13.9	-172	-101
6.32	2.06	ψ_t	239	5.3	224	259
6.32	2.06	ψ_h	-168	18.2	-219	-120

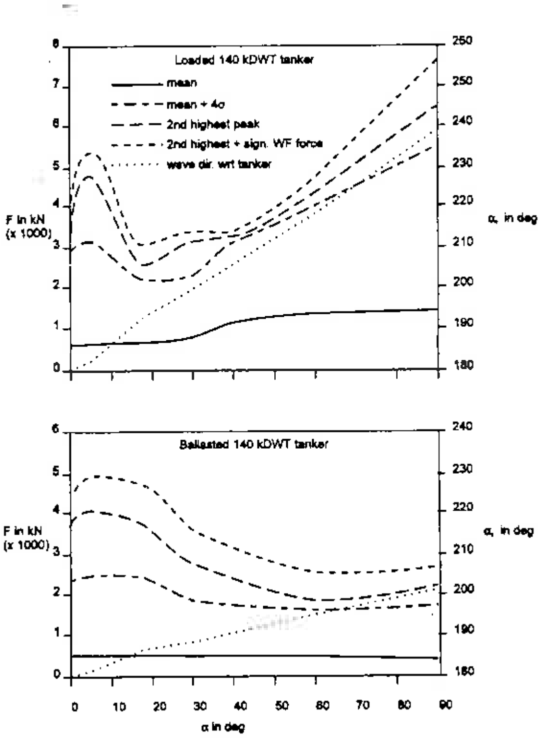


Fig. 6. Hawser force as function of wave/wind direction (weather case 1)

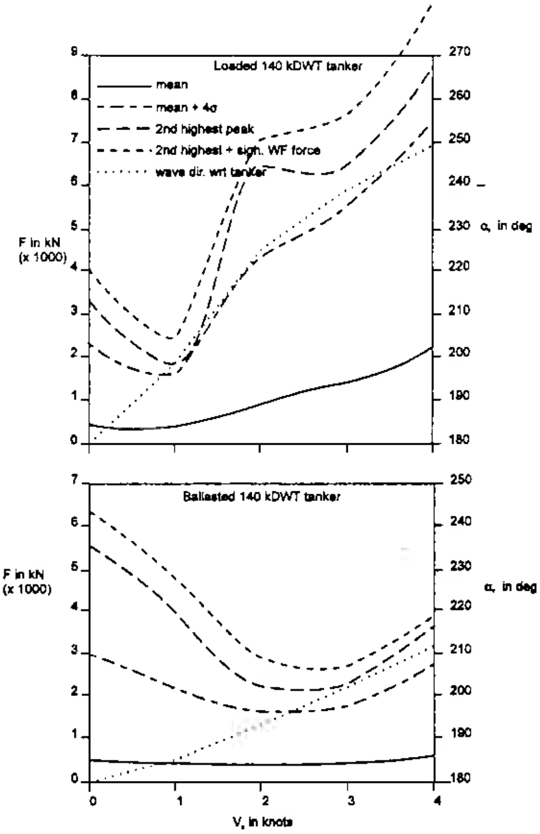


Fig. 7. Hawser force as function of current velocity (weather case 2)

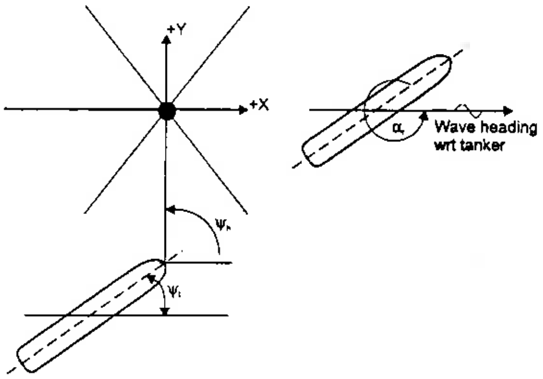


Fig. 8. Definitions of the measured signals

DISCUSSION OF RESULTS

Weather case 1

For the loaded tanker the maximum hawser loads occur for the weather condition where waves, wind and current are approximately co-linearly directed and where the co-linearly directed waves and wind make large angles with the current direction, see Figure 6. The reason for the larger forces in the approximately co-linearly directed weather components is caused by unstable behaviour of the tanker. This instability can be shown by the relatively large standard deviations of the tanker yaw motions for the small mutual angles between the weather components, see Table 3. This conclusion of instability corresponds to earlier work, see Wichers (1976). With increasing angle between the wave/wind direction and the current direction both the mean load in the hawser and the wave heading with regard to the tanker (the relative wave heading) increase, see Figure 6. In these conditions the tanker should be stable. Mainly because of the increased wave heading the lateral wave drift force and the wave drift moment will lead to larger hawser forces. Consequently the largest hawser loads occur in the condition where the co-linearly directed wave/wind is perpendicular to the current direction.

For the ballasted tanker the effect of the wind will dominate the heading of the tanker. Consequently the relative wave heading will be small, see Figure 6. In the approximately co-linearly directed weather condition the tanker performs unstable motions. These unstable motions are shown by the values of the standard deviation of the yaw motion of the tanker, see Table 3. At increasing angles of the co-linearly directed wave/wind direction with regard to the current direction the system becomes more stable. Consequently the maximum hawser forces in the ballast condition occur in the approximately co-linearly directed weather conditions.

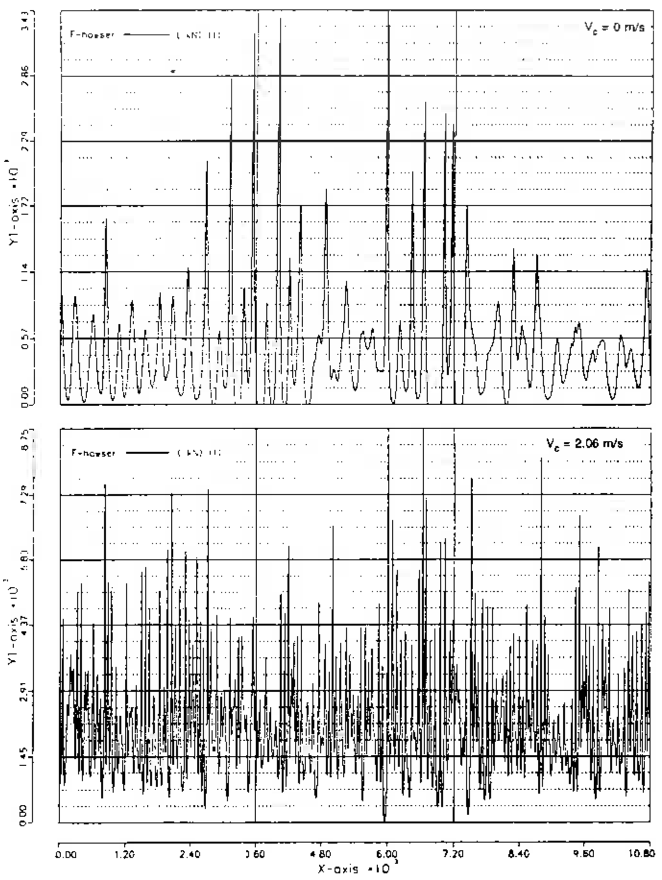
Comparing the hawser loads in the loaded and ballasted condition the highest loads were found in the loaded condition where the current direction is perpendicular to the parallel directed wave/wind direction.

Weather case 2

In the loaded condition the increasing current velocity strongly influences the hawser load, see Figure 7.

Inspite of the relatively high hawser loads in the zero current speed condition (caused by the instability of the system), the hawser loads in higher current speed condition, however, will dominate the force level. The reason for the high hawser loads is not only the increasing mean hawser load but also the relative wave heading, which strongly increase with increasing current speed. Similar as mentioned for weather case 1, due to the increased relative wave heading the lateral wave drift force and wave drift moment may lead to larger peak forces in the hawser. It must be noted that due to the increased pre-tensioning of the system and the non-linear characteristic of the hawser the natural frequencies of the system are significantly changed. This result is shown in Figure 9 where the number of hawser peaks for the loaded tanker in the 0 and 4 knot current condition increased from 42 and 101 respectively. It can be concluded that in case of weak current the zero current case will give the high hawser loads, but that the highest current velocities give the highest load levels.

Similar as was found for weather conditon 1, the effect of the wind will dominate the heading of the tanker in ballast condition. Consequently the relative wave heading is small. In the condition with no or a weak current the tanker will perform unstable motions. This can be concluded by comparing the values of the standard deviation of the yaw motion of the tanker as given in Table 4.



Loaded 140 kDWT tanker - weather case 2

Figure 9. Example of registration of hawser force

At increasing current speed the system becomes more stable. The result is that the maximum hawser force in the ballasted draft occurs in no or weak current condition.

Comparing the hawser loads in the loaded and ballasted condition, the highest loads were found with the loaded tanker and in the highest current velocity directed perpendicular to the parallel directed wave/wind direction.

CONCLUSIONS

The following conclusions can be drawn:

1) The measured and computed results with the 200 kDWT tanker show the same order of magnitude, while the number of peaks of the hawser forces in both registrations were the same. From these results it can be concluded that the computer program may give reliable output.

2) The study shows that by means of combining extreme metocean parameters on SPM moored tankers a realistic selection of the tanker loading and environmental conditions can be obtained and may be applied for model testing.

3) For the mentioned SPM system with the moored 140 kDWT tanker both the co-linearly directed current direction and the perpendicular directed current direction are important metocean parameters to obtain the extreme load in the hawser and tanker responses.

REFERENCES

Kat, de J.O. and Wichers, J.E.W. (1991). *Behavior of a moored ship in unsteady current, wind and waves*, Marine Technology, September.

OCIMF (1994-a). *Prediction of wind and current loads on VLCC's*, OCIMF, 15th floor 96 Victoria street London SWIE 5JW.

OCIMF (1994-b). *Prediction of wave drift forces on and wave frequency motions of VLCC's*, OCIMF, 15th floor 96 Victoria street London SWIE 5JW

Pinkster, J.A. (1980). *Low frequency second order wave exciting forces on floating structures*, Ph.D., University of Technology Delft.

Wichers, J.E.W (1976). *On the slow motions of tankers moored to SPM systems*, OTC Paper No. 2548, Houston.

Wichers, J.E.W. and van den Boom, H.J.J.(1983). *Simulation of the behaviour of SPM moored vessels in irregular waves, wind and current*, Proc. 2nd DOT, Malta.

Wichers, J.E.W. (1986). *Progress in computer simulations of SPM moored vessels*, OTC Paper No. 5175, Houston.

Wichers, J.E.W. (1988). *A simulation model for a single point moored tanker*, Ph.D., University of Technology Delft.

Yilmaz, O. and Incecik, A. (1992). *Identification of non-linear effects in predicting the motion response of a 'CALM' system*, Proc. of the OMAE Conf., Calgary.