Experimental and Numerical Investigation on Parametrically-Excited Motions of a Mono-Column Platform in Waves

Claudio A. Rodríguez, Julio C. F. Polo, and Marcelo A. S. Neves

Abstract The paper shows results from a comprehensive experimental investigation on a mono-column in regular and irregular waves. Focus is centered on improving the understanding on the occurrence of resonant motions associated with Mathieu instabilities for cylindrical floating platforms. Experimental results with the mono-column showed both roll and pitch parametric amplifications. It is concluded that the instabilities observed in the mono-column experiments were very much influenced by the mooring system configuration. A numerical algorithm is used as a relevant tool for discriminating the role of the different nonlinear contributions to parametric amplifications arising from hydrostatics, Froude-Krylov and mooring loads within the observed diverse patterns of roll and pitch responses.

Keywords Mathieu instability · Parametric resonance · Platform stability · Model tests · Waves

1 Introduction

Mathieu instabilities are nowadays a quite well understood phenomenon which may lead to parametric rolling in ships and literature on the topic is abundant. Recent compilations may be found in Neves et al. [8], Guedes Soares [2] and Fossen and Nijmeijer [1]. However, this may not be the case when reference is made to instabilities in waves of offshore floating platforms. Apparently, dramatic Mathieu instabilities in platforms are rare, an exceptional observation was reported in Haslum and Faltinsen [3], this has much to do with the tendency of these vessels to have vertical walls. Yet, it is noticed from the pertinent literature that there are numerous interpretations on the probable causes of such instabilities, revealing perhaps a gap in the understanding of their main causes. As this understanding may be quite relevant for

C. A. Rodríguez (✉) · J. C. F. Polo · M. A. S. Neves
LabOceano, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: claudiorc@oceanica.ufrj.br

M. A. S. Neves
e-mail: masn@oceanica.ufrj.br

K. J. Spyrou et al. (eds.), *Contemporary Ideas on Ship Stability*, Fluid Mechanics and Its Applications 134, https://doi.org/10.1007/978-3-031-16329-6_41

the best design of such floating structures, the Authors have focused on that topic in the present paper.

An investigation on the occurrence of parametric resonance of spar platforms has been made by Haslum and Faltinsen [3] in which the relevance of Mathieu amplifications has been assessed mainly centered on the heave/pitch coupled motions. They reported on some few test results with a 1:300 model scale, in which large angles were reached. Rho et al. [11, 12], Liu et al. [6] have also reported on numerical and experimental simulations on spar platforms, all papers focusing on the discussion of heave and pitch instabilities. In Rho et al. [11] a 1/400 model was tested. Hong et al. [4] tested a set of spar platforms, models built at 1/160 scale. This last one is one of the few reports encountered in the pertinent literature discussing (albeit on a limited way) the occurrence of heave-roll-pitch instabilities in the case of vertical cylinders.

Neves et al. [7] and Rodríguez and Neves [10] have discussed the mechanisms of heave-roll-pitch parametric excitation for spars, based on an analytical model. They argued that parametric resonance of vertical cylinders is not related to pure hydrostatic pressure variations, but instead to the variations of the nonlinear Froude-Krylov pressure induced by wave passage, vertical motions and the associated attenuation of wave pressure with depth (Smith effect). It was concluded that very deep structures such as spar platforms tend to be more prone to parametric resonance than small-draft platforms as is the case of the mono-column investigated in the present paper. In fact, the tests reported by Hong et al. [4] seen to indicate stronger parametric excitation than the mono-column herein investigated.

Yet, it is still a relevant engineering problem to well ascertain the expected level of parametric resonance in mono-columns in strong seas and to better understand the associated complexities of the coupled responses. Specifically, it will be interesting to understand when pitch and/or roll may find ways of manifesting themselves in high waves. Taking into account the experimental evidence reported in the present paper on the coexistence of roll and pitch parametric amplification and the associated exchange of energy between the two modes, a time domain numerical algorithm is used as a relevant tool for discriminating the different nonlinear contributions involved. Another aim of the paper is to verify whether the parametric amplifications experimentally encountered in regular waves may also occur in irregular waves, in which there is not the pure tuning and regularity that may be found in regular waves.

2 Mono-Column Particulars and Test Set-Up

Figure 1 illustrates the experimental model of the mono-column tested at LabOceano. The model was built to a 1:100 scale. Main dimensions and characteristics of the mono-column at the tested conditions are shown in Table 1 (prototype values).

As the focus of the tests was to investigate vertical motions in longitudinal waves, a simplified horizontal soft mooring system was prescribed. The nominal linear restoring coefficients of the mooring system in surge and sway directions were 750 kN/m and 950 kN/m, respectively. The corresponding expected natural periods in

Fig. 1 Mono-column experimental model

Table 1 Mono-column main particulars

Parameter		Value
Diameter, D	[m]	110
Depth, H	[m]	70
Draught, T	[m]	43
Displacement, Δ	[t]	418 858
Metacentric height, $\overline{GM}_0$	[m]	3.82

surge and sway were 180 s and 160 s. These periods were quite far from the specified wave periods and heave, roll and pitch natural periods so that the influence of the horizontal motions on the vertical motions (heave, roll and pitch) was expected to be minimized. However, during the roll and pitch decay tests, the roll and pitch natural periods showed significant differences compared to their expected free-floating values. These differences were associated to the influence of the mooring restoring system. To assess this influence, two additional mooring lines arrangements were considered in the test program. Under the original mooring configuration (configuration #1), the lines were almost symmetrical such that surge and sway natural periods were close. Under mooring configuration #2 the lines system was aligned with the incident wave direction, resulting in a surge natural period around 180 s and a sway natural period around 380 s, i.e., the mooring system was more complaint in the sway direction than in the surge direction. Under mooring configuration #3 the lines system was aligned normal to the incident wave direction, i.e., normal to configuration #2. The surge and sway natural periods were around 380 s and 180 s, respectively. Graphical sketches of the tested mooring arrangements are shown in Fig. 2.

For all the mooring configurations, decay tests were performed to obtain heave, roll, and pitch natural periods and their corresponding damping coefficients. Table 2 displays the measured natural periods, where Configuration #0 means free-floating body, i.e., without mooring system. Decay tests under this configuration were

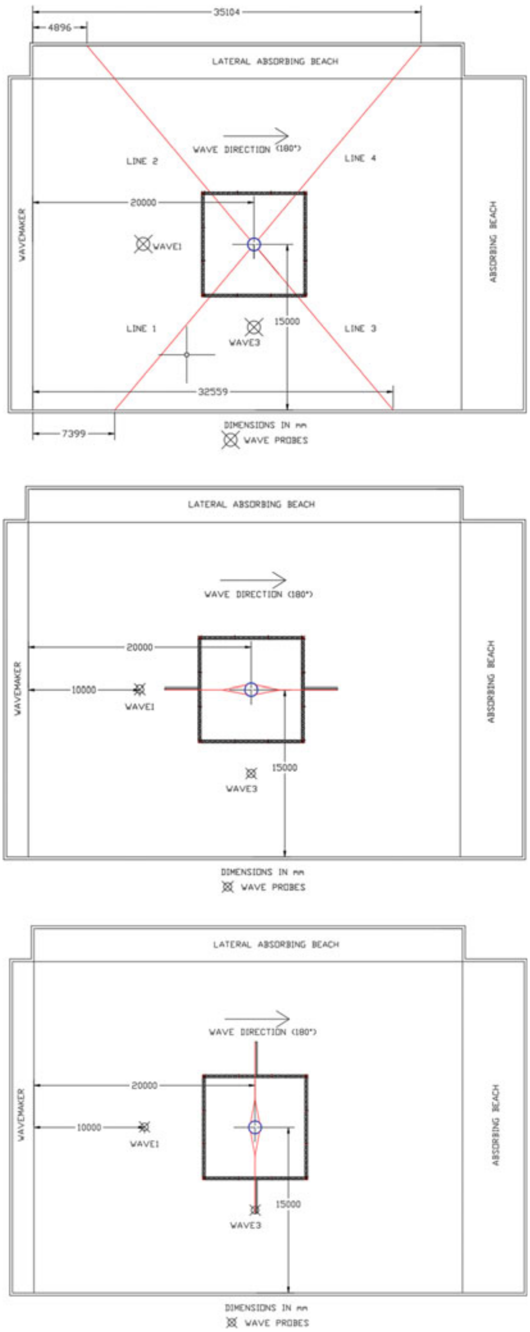

Fig. 2 Tested mooring configurations: #1 (upper), #2 (middle), #3 (lower)—values in model scale

Table 2 Heave, roll and pitch natural periods for different mooring configurations

Configuration #	Heave	Roll	Pitch
0	17.0	38.3	38.3
1	17.0	32.4	32.4
2	17.0	38.0	31.8
3	17.0	32.0	37.8

conducted to estimate the free-floating natural periods, so that the mooring influence on the mono-column dynamics could be assessed.

From Table 2 and Fig. 2, it can be concluded that depending on the mooring arrangement, the values of the roll and pitch natural periods are affected differently by the mooring system when compared to the corresponding free-floating values (configuration #0), i.e., approximately 38 s for both modes. In configuration #2 only the natural pitch period is affected reducing from ~38 s to ~32 s, while in configuration #3 only the roll natural period is affected reducing its value also from ~38 s to ~32 s. In summary, the mooring system introduced additional restoring to the roll and pitch modes.

2.1 Test Matrix

Table 3 summarizes the experimental tests discussed in the present paper. Nine regular and three irregular longitudinal head waves (180° incidence) have been used. Three levels of wave amplitudes ($H = 5$ m, 10 m, and 15 m), and wave frequencies around half the roll and pitch natural periods were considered.

3 Experimental Results and Analyses

3.1 Regular Waves

Configuration #1

Figures 3, 4, 5 and 6 show results in the surge, sway, heave, roll and pitch modes for different wave conditions at configuration #1. Figure 3 shows the responses when the wave period was tuned to the pitch/roll natural period. In this case, since the wave period is far lower from the heave natural period, heave motions are quite low (with amplitudes of approximately 3.1 m). On the other hand, pitch motion is (directly) excited by the wave at its resonant period and reaches 4.3°, while roll motion displayed smaller amplitudes (~1.5°). Pitch responses are typical of first-order motions and occur at the wave period but roll responses (which according to linear

Table 3 Experimental test matrix

Config.	Test code	T [s]	H [m]	Wave type
1	T18-01000	17.0	5.0	Regular
	T18-01300	32.4	5.0	
	T18-01400	16.5	10.0	
	T18-01500	16.5	15.0	
	T18-01700	16.5	5.0	Irregular
2	T18-02400	18.0	10.0	Regular
	T18-02500	18.9	10.0	
	T18-02700	16.5	10.0	
	T18-02800	16.5	10.0	Irregular
3	T18-02000	18.0	10.0	Regular
	T18-02100	18.9	10.0	
	T18-02200	18.9	10.0	Irregular

theory should not be excited by head waves) can be regarded as parametrically excited motions and occur at roll natural frequency). Surge and sway motions basically occurred at the wave frequency without significant drift and low-frequency motions. The surge motion (which is directly excited by the waves) display amplitudes of 2.3 m while the sway response reaches 0.70 m probably due to its coupling with roll.

To investigate the occurrence of parametric resonance, the platform should be excited at a wave period close to half the roll/pitch natural period (in this case, corresponds to approximately the heave natural period). Figures 4, 5 and 6 show

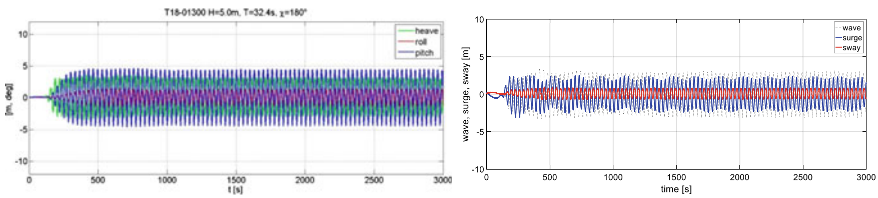

Fig. 3 Config. #1, regular wave ($T = 32.4$ s, $H = 5.0$ m): linear pitch resonance

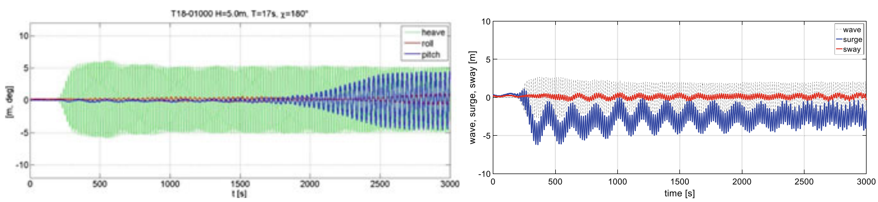

Fig. 4 Config. #1, regular wave ($T = 17.0$ s, $H = 5.0$ m): parametric pitch

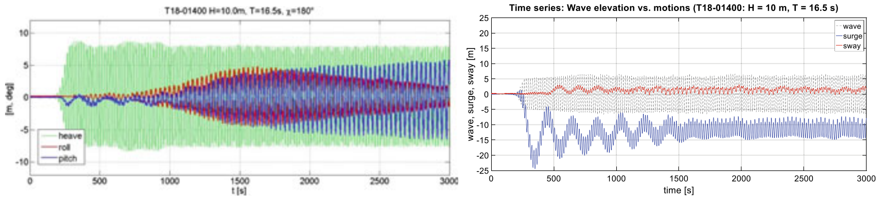

Fig. 5 Config. #1, regular wave ($T = 16.5$ s, $H = 10.0$ m): parametric roll and pitch

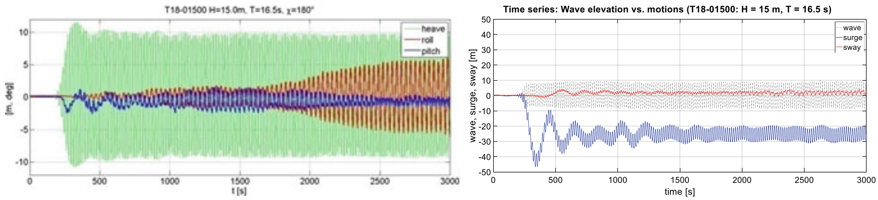

Fig. 6 Config. #1, regular wave ($T = 16.5$ s, $H = 15.0$ m): parametric roll and pitch

the surge, sway, heave, roll and pitch coupled responses for wave heights of 5, 10 and 15 m, respectively. Since the wave is tuned with the heave natural period, heave amplitudes rise to approximately 5.1 m (see Fig. 4). Pitch motions occurred at twice the exciting wave frequency, thus characterizing typical parametric resonance. Pitch amplification started around 1750s, reaching a steady state amplitude of 4.2° (same order of the linear resonant pitch—shown in Fig. 3). After 2400 s, roll amplifications also appeared with twice the wave frequency (thus, also characterizing parametric motions), but with very small amplitudes. In surge, the mono-column displayed, besides the wave-frequency motion, mean and low-frequency oscillations. In sway, both low- and wave-frequency motions are hardly perceptible.

For the wave height of $H = 10$ m (Fig. 5) more energy is fed into the system and (parametric) roll motion amplification occurred earlier, initially stronger than the (parametric) pitch. Later, parametric roll decreases and pitch continues to increase above 7°, probably associated to an exchange of energy between these modes. In the horizontal plane, low-frequency surge motions increased with the larger wave height while no significant motions are observed in sway.

Figure 6 displays the responses for the highest wave height, $H = 15$ m. Heave motion displayed its largest value, and initially both roll and pitch amplifications occur. Later, parametric roll became dominant achieving amplitudes above 6°, and parametric pitch started to decrease—probably associated to an exchange of energy from pitch to roll. Mean drift in surge further increased while the amplitudes of low-frequency oscillations decay with time.

This set of tests (configuration #1) evidenced that at lower levels of energy (lower wave heights), pitch motion, which can be excited either external or internally (parametrically), is more prone to absorb energy from the heave motion. Whereas, the roll motion, which can ONLY be internally (parametrically) excited, requires higher levels of energy (higher waves) to develop. Thus, depending on the level of wave excitation, an interesting interchange of energy between pitch and roll may be postulated: at intermediate levels of wave excitation (Fig. 5), pitch motion is dominant, whereas at higher levels of wave excitation (Fig. 6) roll motion prevails. Regarding the horizontal motions, different from synchronous pitch resonance where only wave-frequency surge motions took place, strong mean and low-frequency oscillations in the surge direction have been observed when parametric pitch occurred. Sway motions were small, even when relatively large parametric roll occurred.

Configuration #2

Under this configuration (see Fig. 2), the natural periods in heave, roll and pitch are, respectively, 17.0 s, 38.0 s and 31.8 s (Table 2). Tests for this configuration try to explore the pattern of responses when roll and pitch have slightly different natural periods. Figure 7 shows responses for $H = 10$ m, $T = 18.9$ s, where roll mode is parametrically excited. This situation may be explained by the fact that, the exciting period is close to half the roll natural period. On the other hand, Fig. 8 shows the responses for another test, where the same wave amplitude was used ($H = 10$ m), but with a lower wave period, $T = 16.5$ s. As observed, roll motion is insignificant, but pitch is parametrically excited (the exciting period is close to half the pitch natural period).

It is worth noting that, heave amplitudes were practically the same in the two tested conditions—around 7.0 m. However, parametric pitch reached amplitudes of 6° (see Fig. 8) and parametric roll achieved only 2.5°. The above feature confirms the experimental evidence observed in configuration #1 (Figs. 4, 5 and 6), i.e., parametric pitch motions are more likely to occur than parametric roll. This characteristic may be explained by the fact that, in longitudinal waves, pitch receives energy both

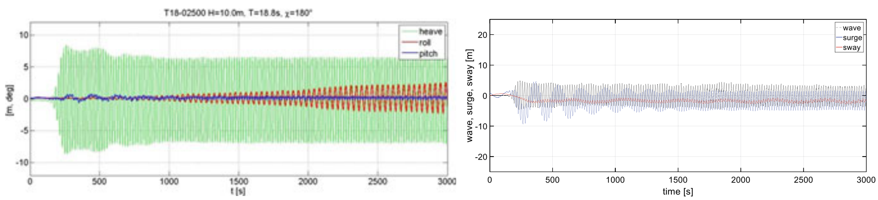

Fig. 7 Config. #2, regular wave ($T = 18.8$ s, $H = 10.0$ m): parametric roll

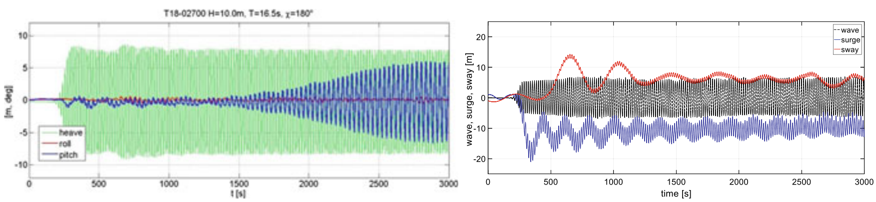

Fig. 8 Config. #2, regular wave ($T = 16.5$ s, $H = 10.0$ m): parametric pitch

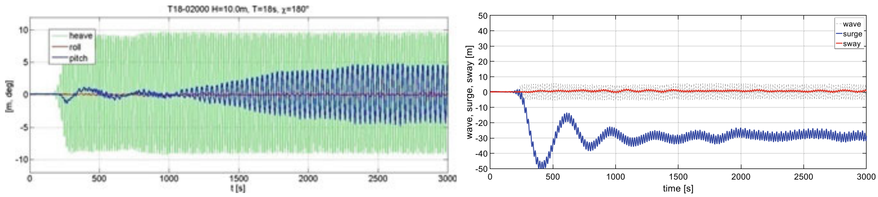

Fig. 9 Config. #3, regular wave ($T = 18.0$ s, $H = 10.0$ m): parametric pitch

from external and internal excitation, while roll only receives internal (parametric) excitation. The results evidence that mean drift in surge direction appears when parametric pitch is present as observed in Fig. 8 (and previously observed in Figs. 4, 5 and 6), however, that relationship is not observed between parametric roll and sway (Fig. 7). An interesting fact in Fig. 8 is the appearance of mean and slow oscillations in sway even with negligible roll motions (however, with significant surge and parametric pitch). Since this behavior has not been observed in the other tests, a possible explanation may be any asymmetric perturbation in the sway direction and the low restoring and damping of this mooring system in that direction.

Configuration #3

Under this mooring arrangement, the roll mode is affected by the mooring restoring, thus affecting the roll natural period. In this case natural periods in heave, roll and pitch were 17.0 s, 32.0 s and 37.8 s, respectively. Figure 9 shows the mono-column responses for a wave height of $H = 10$ m and a wave period of $T = 18$ s. Only parametric pitch was excited, reaching amplitudes of 4.6°. In surge, it is confirmed that when parametric pitch occurs, mean surge drift is also induced. No significant sway motions occurred.

3.2 Irregular Waves

Configuration #1

Tests in irregular waves (JONSWAP spectrum) were also prescribed for each of the mooring configurations of the mono-column. The aim was to verify whether the parametric amplifications observed in regular waves could also appear under irregular waves conditions. Figure 10 shows the heave-roll-pitch responses under a JONSWAP wave with significant wave height and peak period like those values defined for the regular wave in test T18-01,000 (Fig. 4). The same pattern observed for that regular wave test was also observed in the corresponding irregular wave, i.e., prevailing pitch parametric amplifications. Figure 11 shows the spectral densities for the incident wave and for heave, roll and pitch motions.

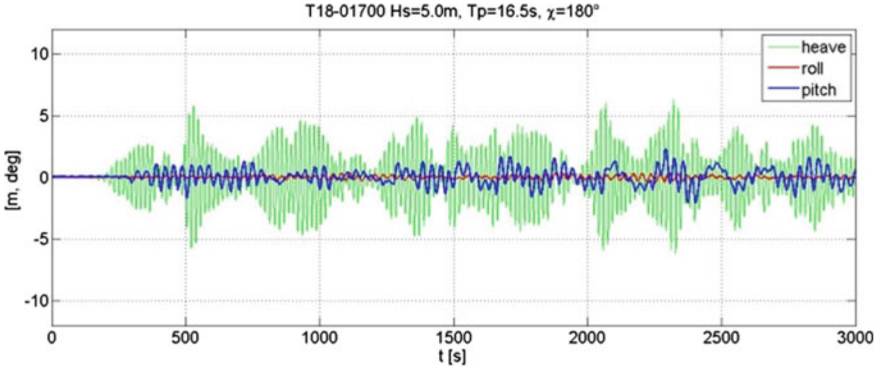

Fig. 10 Config #1, irregular waves: dominant pitch

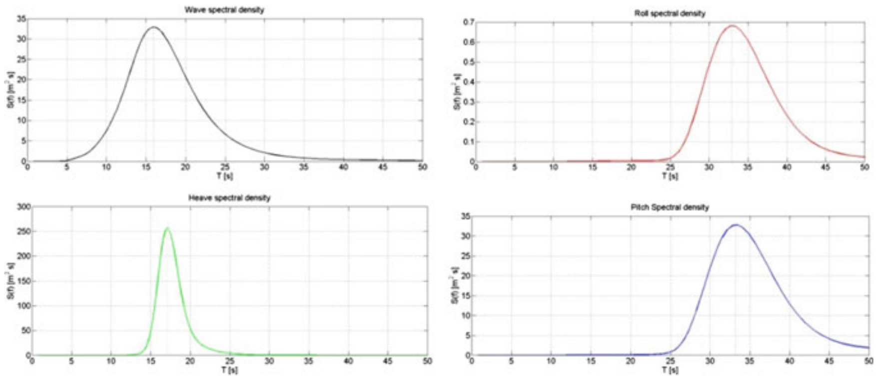

Fig. 11 Config #1, irregular waves, $T = 16.5$ s; $Hs = 5$ m. Wave, heave, roll and pitch spectra

Configuration #2

Figure 12 shows the irregular seas responses under a JONSWAP sea with wave parameters similar to those of the regular wave condition reported in Fig. 8. Again, the same pattern of results observed in regular waves occurred in irregular waves—see response spectra in Fig. 13. Notice that the main energy content for roll and pitch (spectral peaks) do not occur at the same period, but at each mode's natural period, which are different due to influence of the mooring arrangement—pitch natural period being smaller than the roll natural period.

Configuration #3

Figure 14 shows the response time series for a JONSWAP wave with Hs = 10 m, and Tp = 18.9 s, similar to the regular test condition shown in Fig. 9. Again, parametric pitch amplifications are displayed—like what was already observed for the regular test. The spectral densities for the irregular wave responses are shown in Fig. 15.

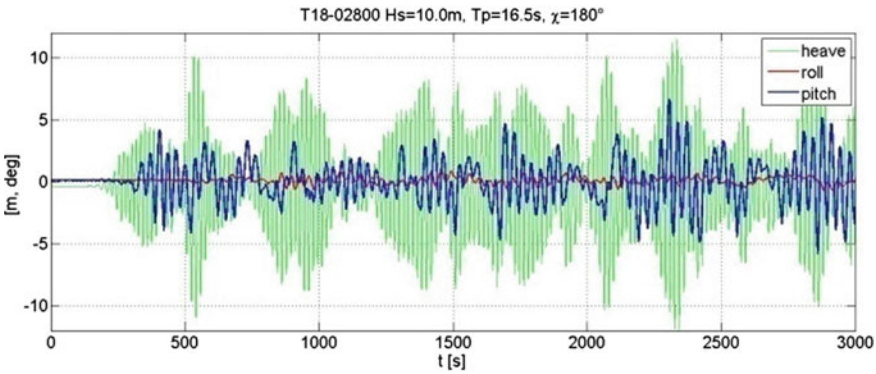

Fig. 12 Config #2, irregular waves: dominant pitch

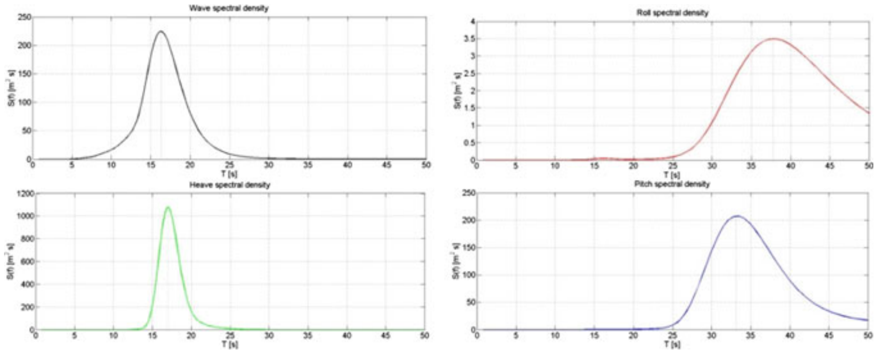

Fig. 13 Config #2, irregular waves, $T = 16.5$ s; $H = 10$ m. Wave, heave, roll and pitch spectra

Roll and pitch motions do not occur at the same period, but at each mode's natural period—now, the roll natural period being smaller than the pitch natural period (due to the influence of the mooring arrangement).

4 Numerical Analysis

A nonlinear algorithm, called DSSTAB, has been used to verify the different parametric roll/pitch motions of the mono-column. DSSTAB is a suite of numerical algorithms for the prediction of the 6-degree-of-freedom rigid-body motions of floating structures in waves. Radiation and diffraction forces are considered linear and are computed based on potential theory using third-party software such as WAMIT®. For the computation of hydrostatic restoring forces and incident (not disturbed) wave forces, a panel method is adopted with direct pressure integration over the

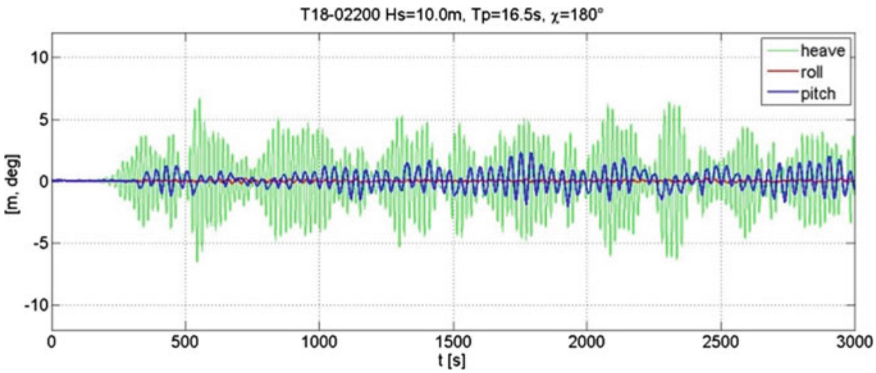

Fig. 14 Config #3, irregular waves: dominant pitch

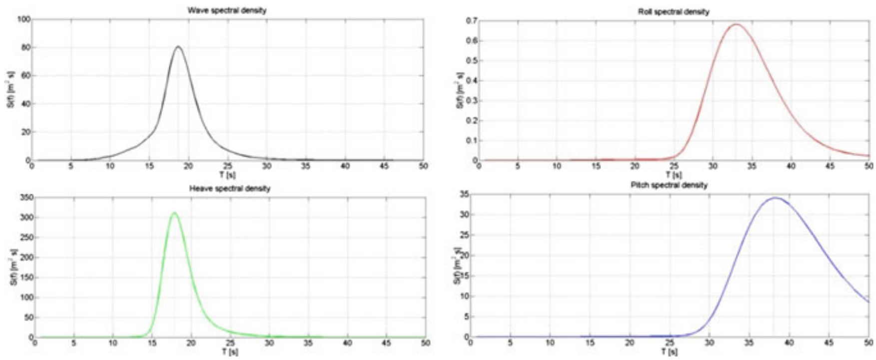

Fig. 15 Config #3, irregular waves, T = 18.9 s; H = 10 m. Wave, heave, roll and pitch spectra

instantaneous wet surface of the body. Besides the nonlinear restoring and Froude-Krylov wave forces, DSSTAB allows the introduction of external linear and nonlinear damping as well as mooring forces. For more details on the algorithm, see Pasquetti et al. [9]. Figure 16 shows the numerical model of the mono-column with mooring lines and incident wave.

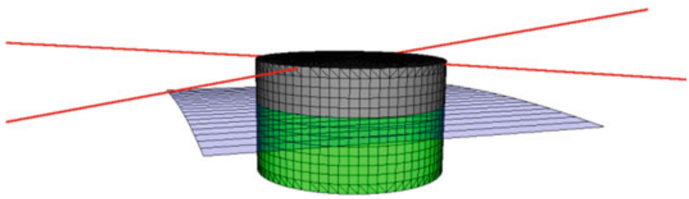

Fig. 16 Mono-column numerical model with mooring lines

The test case reported in Fig. 5 (Config. #1, regular wave: T = 16.5 s and H = 10.0 m) has been chosen for the present limited numerical analyses. Figure 17 indicates that, despite the decaying transients at the beginning of the experimental tests, the numerical simulation captures well the mean surge offset of the body by taking into account the coupling of mooring lines with body responses in waves. Prior to the numerical simulations in waves, calibration of damping coefficients in heave, roll and pitch was performed in the numerical model by comparison of decay tests results between experiments and simulations. After this calibration, the numerical code was capable of reproducing roll and pitch responses in waves very close to the observed ones during the experiments—see, for example, Fig. 18, which should be compared to Fig. 5. Since decay tests were not performed for the surge/sway motions, the calibration of damping coefficients has not been performed for these modes.

One of the main capabilities of the numerical model used here is that it allows the assessment of the different instantaneous contributions on forces and moments coming from: (a) hydrostatics; (b) incident wave field and (c) mooring lines. Typical spectra of these effects are shown in Figs. 19, 20, 21 and 22. Quadratic (2nd order) wave pressures have in general a very small contribution for this hull, for this reason these are not examined further. As the objective here is to assess contributions to parametric excitation, linear restoring moments in roll and pitch ($\Delta\overline{GM}_T\phi$ and $\Delta\overline{GM}_L\theta$,

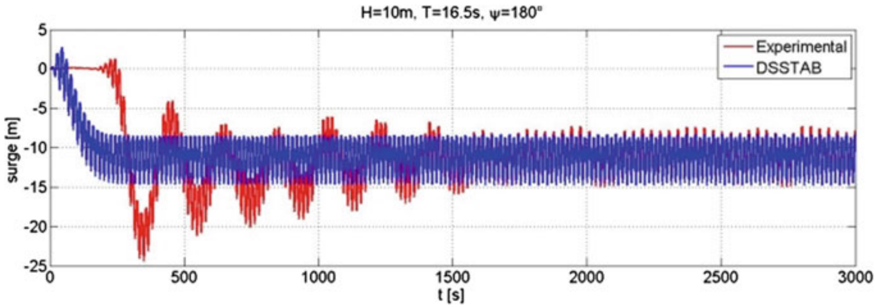

Fig. 17 Surge motion, T = 16.5 s; H = 10 m

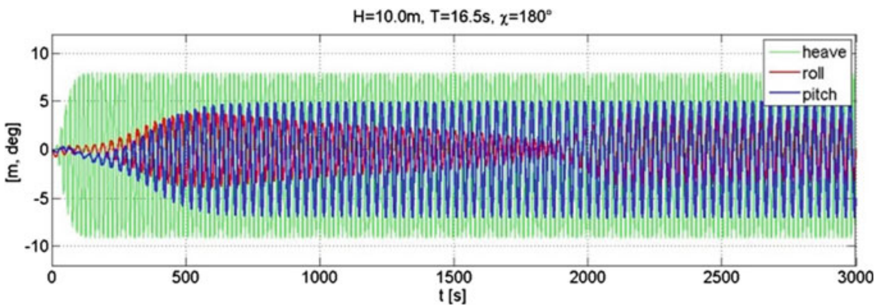

Fig. 18 Heave, roll and pitch motions, numerical simulations, T = 16.5 s; H = 10 m

respectively) have been excluded from the total hydrostatic moments. The non-linear parts of roll and pitch hydrostatic moments are then obtained—spectra being plotted in Fig. 19. It is observed that both moments take place as parametric actions (double wave period), pitch moment being higher. Less relevant super-harmonic contributions are observed at the 1/3 and 1/5 frequency tunings.

It is interesting to observe the qualitative distinct aspects of the Froude-Krylov contributions in the pitch and roll modes: Fig. 20 shows that the instantaneous Froude-Krylov pitch effect takes place mainly at the wave period (comparatively negligible sub-harmonics are also observed between 5 and 10 s), whereas Fig. 21 shows that Froude-Krylov roll moment has its main contribution close to twice the wave period. Then, it may be concluded that, in the pitch mode the wave field does not "notice" the pitch (parametric) motion, which exists as a sub-harmonic at twice the wave period, whereas for the roll mode (which is not externally excited), the wave field does contribute to parametric amplification. Finally, Fig. 22 shows that both roll and pitch moments associated to mooring lines loads act at double the wave period, pitch moment being higher.

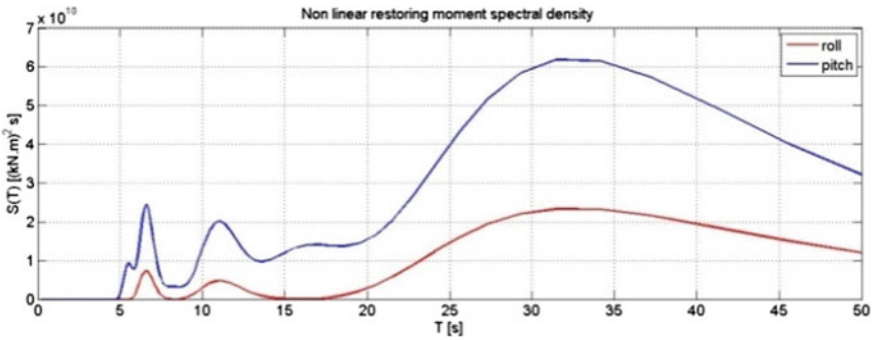

Fig. 19 Spectral density of nonlinear restoring moments, T = 16.5 s; H = 10 m

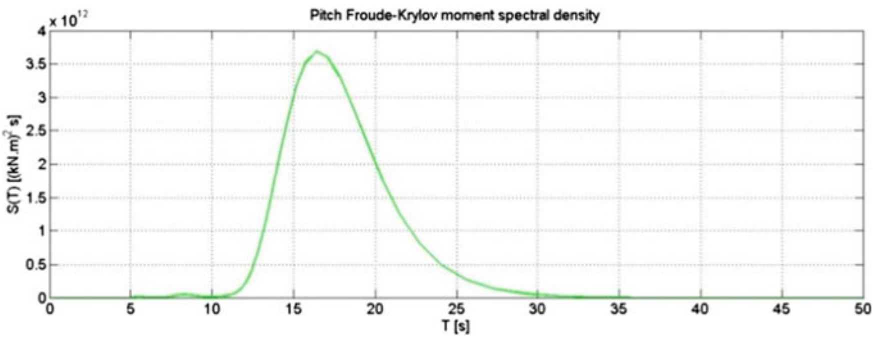

Fig. 20 Spectral density of Froude-Krylov pitch moment, $T = 16.5$ s; $H = 10$ m

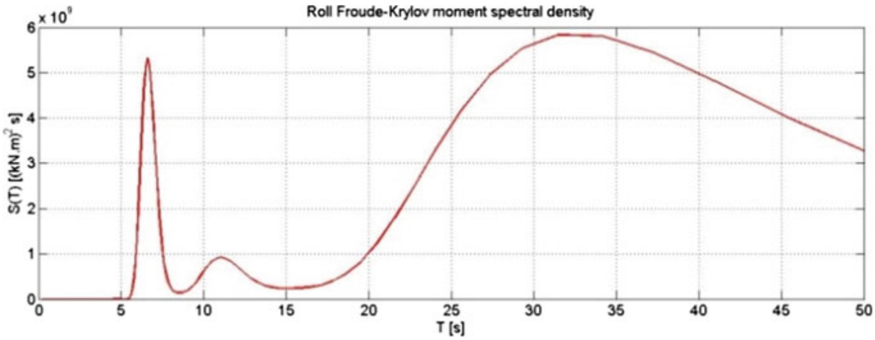

Fig. 21 Spectral density of Froude-Krylov roll moment, $T = 16.5$ s; $H = 10$ m

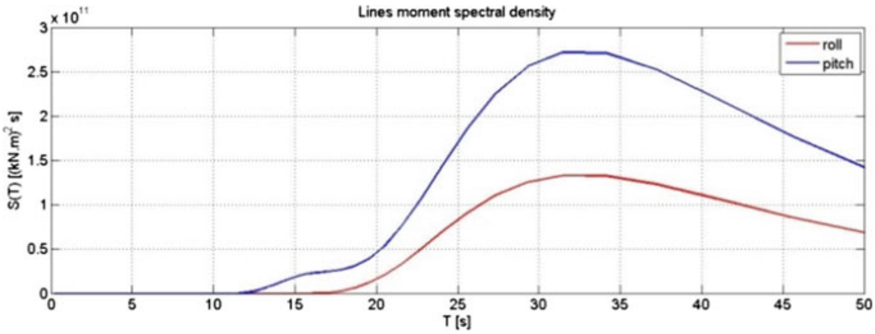

Fig. 22 Spectral density of mooring lines resultant moment, $T = 16.5$ s; $H = 10$ m

A summary of the parametric excitation results in Figs. 19, 20, 21 and 22 indicate that: in pitch the largest moment is introduced by mooring lines; nonlinear hydrostatic contributions comes second (one order of magnitude lower) and there is no Froude-Krylov contribution. Mooring lines moments are again the largest actions in roll, second comes hydrostatic (also one order of magnitude lower) and there exists a Froude-Krylov moment, which is the smallest contribution. In this context it is important to register that without mooring lines, no parametric motions were observed, either in pitch or roll, neither in experiments nor in numerical simulations (see the experimental results in Fig. 23). Notice that under free-floating conditions, the mono-column drifted excessively in surge and sway and reached areas of the basin not covered by the motion measurement system causing a "no visibility" problem in all the 6-dof motions of the body between time 520 s and 680 s.

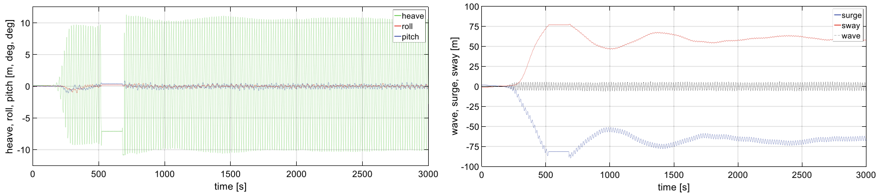

Fig. 23 Config. #0 (free-floating condition), regular wave ($T = 18$ s, $H = 10.0$ m): no parametric motions

5 Conclusions

Tests performed with a mono-column hull under different mooring arrangements in longitudinal regular and irregular waves have been presented and discussed. Tests showed physical evidence on the occurrence of undesirable parametric amplifications not only in pitch but also in roll.

Different patterns of coupled responses have been identified, depending on the mooring system arrangement. In the case of the symmetrical mooring configuration, dependence of angular responses on wave amplitude has been identified. Parametric roll requires higher levels of energy to build up than parametric pitch. Interesting nonlinear exchanges of energy between roll and pitch have been observed.

When the mooring lines are arranged such that roll and pitch natural periods become different (configurations #2 and #3), it is observed that for the same wave height, pitch motion (when tuned, Fig. 9) becomes stronger than roll motion at its respective tuning (Fig. 7). Again, this result confirms that pitch motion is more prone to parametric amplification than roll motion.

The practical relevance of parametric resonance for mono-column structures may be assessed by noting that parametric pitch amplitudes are of the same order of those resulting from direct excitation at its natural period (classical resonance).

Experimental results for the three tested mooring configurations also showed that parametric resonance (pitch and roll) also occurs in irregular waves, displaying the same patterns observed at the corresponding regular tests counterparts.

Numerical analyses of Configuration #1 for H = 10 m showed that mooring lines moments are predominant in establishing the resulting parametrically excited roll and pitch motions. An interesting aspect of the different roles of roll and pitch in the coupled process arises from the Froude-Krylov moments analyses: pitch moment is not internally excited by the waves, its sub-harmonic motion depends mainly on mooring loads.

Mooring loads influence was evident in the different arrangements considered in the experiments. In the limited numerical analysis of the symmetrical configuration, it was also confirmed to be relevant. A general, yet pertinent conclusion is that the mooring arrangement should be carefully considered as an integral part of a testing program on parametric resonance of cylindrical floating platforms.

Acknowledgements The Authors acknowledge the contributions of LabOceano technical staff, especially Prof. Sergio Sphaier and Mr. Joel Sena Sales, for their participation in the planning and execution of the tests reported in the present paper. The Authors also acknowledge financial support from CNPq, ANP, PETROBRAS and LabOceano/UFRJ.

References

1. Fossen TI, Nijmeijer H (Eds) (2012) Parametric resonance in dynamical systems,1st edn. Springer Science International, New York. https://doi.org/10.1007/978-1-4614-1043-0
2. Guedes Soares C, Garbatov Y, Fonseca N, Teixeira AP (eds) (2012) Marine technology and engineering, 1st edn. Taylor and Francis Group, London. ISBN 978-0-415-69808-5
3. Haslum HA, Faltinsen OM (1999) Alternative shape of spar platform for use in hostile areas. In: Proceedings of the offshore technology conference, Paper No. OTC10953, Houston, USA
4. Hong Y, Lee D, Choi Y, Hong S, Kim S (2005) An experimental study on the extreme motion responses of a SPAR platform in the heave resonant waves. In: Proceedings of the 15th international offshore and polar engineering conference (ISOPE'2005), Seoul, Korea
5. LabOceano Report 007-07 (2007) Mono-column Technical Report (in Portuguese)
6. Liu Y, Yan H, Yung T-W (2010) Nonlinear resonant response of deep draft platforms in surface waves, Paper OMAE2010-20823, Shanghai, China
7. Neves MAS, Sphaier SH, Mattoso BM, Rodríguez CA, Santos AL, Vileti V, Torres FGS (2008) Parametric resonance of mono-column structures. In: Proceedings of the 6th Osaka colloquium on seakeeping and stability of ships, 26–28th March, Osaka, Japan
8. Neves MAS, Belenky V, de Kat JO, Spyrou K, Umeda N (eds) (2011) Contemporary ideas on ship stability and capsizing in waves, 1st edn. Springer International, Amsterdam
9. Pasquetti E, Coelho LCG, Neves MAS, Oliveira MC, Esperança PTT, Rodríguez CA, Carbajal MAC, Polo JCF (2012) A nonlinear numerical algorithm for time-domain hydrodynamic simulations of vessel motions in the presence of waves. In: Proceedings of 31st international conference on ocean, offshore and arctic engineering, OMAE 2012, Rio de Janeiro
10. Rodríguez CA, Neves MAS (2012) Investigation on parametrically excited motions of spar platforms in waves. In: Proceedings of STAB 2012 international conference, Athens, Greece
11. Rho J, Choi H, Lee W, Shin H, Park I (2002) Heave and pitch motions of a spar platform with damping plate. In: Proceedings of the 12th international offshore and polar engineering conference (ISOPE'2002), Seoul, Korea
12. Rho J, Choi H, Shin H, Park I (2003) An experimental study for mooring effects on the stability of spar platform. In: Proceedings of the 13th international offshore and polar engineering conference (ISOPE'2003), Seoul, Korea