An Overview of Relevant Aspects on VIM of Spar and Monocolumn Platforms

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Vortex-induced motions (VIM) of floating structures are very relevant for the design of mooring and riser systems. In the design phase, spar and monocolumn VIM behavior, as well as semisubmersible and tension leg platform flow-induced motions, is studied and evaluated. This paper provides a checklist of topics and evidence from a number of sources to justify the selection that should be considered when designing spars or monocolumn platforms regarding the VIM phenomenon. An overview of the influential aspects of the VIM is presented such as heading, external appendages of the hull, concomitant presence of waves and currents, motion suppressor, draft condition (immersed portion of the hull), and external damping due to the presence of risers. Previous works concerning the VIM studies on spar and monocolumn platforms are also addressed. Whenever possible, the results of experiments from diverse authors on this matter are presented and compared. [DOI: 10.1115/1.4003698]

Keywords: vortext-induced motion (VIM), monocolumn platform, spar platform, model test

1 Introduction

In general terms, the VIM phenomenon represents a type of fluid-structure interaction, which very much resembles the so-called vortext-induced vibration (VIV) phenomenon. The main peculiarity that distinguishes one phenomenon from the other is the amplitude and period of oscillations. VIM is generally characterized by large amplitudes and long periods, while VIV is normally the opposite. Furthermore, VIM shows to be highly influenced by the restoration characteristic parameters as well as by the system geometry. The exciting current force also plays a role in this characteristic behavior.

This phenomenon is commonly referred to as self-excited, which can be observed occurring on immersed bluff bodies that are free to oscillate in specific fluid flow conditions and present amplitude values in the same order of magnitude as that of the transversal section of the system. Thus, on spar platforms or even on monocolumns, VIM causes great drift on the surface, which reflects on the dimensioning of the mooring lines and riser system regarding both extreme tension and fatigue life.

The study of the VIM phenomenon has been carried out since the beginning of the decade mainly on spar platforms, as reported among others in Refs. [1–3]. Nevertheless, similar VIM studies on monocolumn platforms are more recent. The research development in this field is being carried out by Cueva et al. [4], Fujarra et al. [5], and Gonçalves et al. [6,7]. In general terms, regarding the VIM phenomenon, the relevant difference between spars and monocolumns is that the latter presents a smaller draft/breadth ratio, leading to a greater tridimensionality on the flow, thus differentiating it from the VIV phenomenon on rigid structures with a higher draft/breadth ratio.

The next section presents a brief overview on the influential aspects of the VIM phenomenon. For each influential aspect, the main results published in the literature about the studies of spar and monocolumn platforms are presented.

2 Influence Aspects

2.1 Heading and External Appendages of the Hull. Huang et al. [1] and Yung et al. [8] were the first published works about spar platforms to show the importance of headings in relation to VIM response. The mooring systems are frequently different for each heading for a spar platform; this fact can influence the VIM response. Because of this, van Dijk et al. [9] suggested a study of a large number of different headings for a spar platform.

Furthermore, Yung et al. [10], Finnigan and Roddier [11], and recently Roddier et al. [12] carried out several studies to investigate the sensitivity of the phenomenon regarding the particularities of the geometry of each spar platform type (anodes, chains, pipes, and strakes). Figure 1 shows examples of a spar model with different appendage configurations, as presented in Ref. [12]. Figure 2, as shown by Roddier et al. [12], presents the comparative results for distinct appendage configurations; it is possible to see the large difference for the headings with inclusion of appendages.

In the same line of research, the experimental studies with monocolumn platforms were carried out. Cueva et al. [4] presented results on the VIM of a monocolumn, in particular, the MonoGoM platform, for different headings. The VIM studies of MonoGoM were completed by tests carried out in the NMRI-Japan; these results were published in Ref. [6].

Recently, and similarly, Gonçalves et al. [7] performed extensive research on the influence of headings on VIM of a MonoBR platform. This work has concluded that the impact of the heading is significant on the VIM response and the influence is directly related to the position of the appendages, fairleads, and chains on the hull of the platform.

Figure 3 shows a comparison between the nondimensional amplitudes, cross-flow and in-line, as a function of the reduced velocity for the MonoGoM and MonoBR platforms. According to Fig. 3(*a*), the results of the MonoGoM and MonoBR for the 0 deg incidence are very similar mainly for $Vr_n < 10$. In the range of $Vr_n > 10$, there are some differences that can be associated with the characteristics of the hull appendages.

Concerning the illustrations of the 180 deg incidence in Fig. 3(*b*), a large difference is observed for the range of $Vr_n > 10$. This behavior can be associated with the proximity of the fairleads and chains to the platform hulls; the details can be seen in Fig. 4. As shown in Fig. 5, the MonoBR presents the fairleads and chains more distant from the hull than the MonoGoM, which might promote a turbulent regime of the vortex shedding. Therefore, the smaller nondimensional amplitudes of oscillation observed are due to the loss in the lift force. The same phenomenon that pro-

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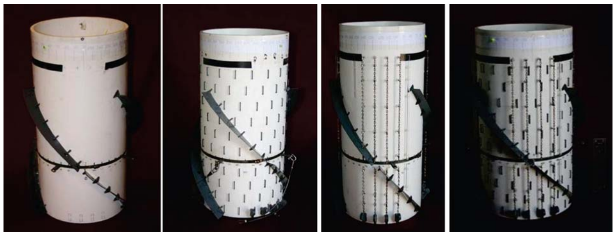

Fig. 1 Pictures of spar model in different appendage configurations with strakes (bare case, anodes only, pipes and chains no anodes, and complete case) by Roddier et al. [12]

moted a turbulent regime or the loss in the correlation of vortex shedding is responsible for the differences in the range of $Vr_n > 10$ for the 0 deg incidence.

The VIM on the XY plane is characterized, in some cases, by an eight shape trajectory. This trajectory represents the existence of a double frequency in the in-line motion and it occurs when the in-line motion coexists with the cross-flow motion, as seen in Fig. 6, which presents VIM on the XY plane for different headings of the MonoBR. The motions on the XY plane for monocolumns are similar to those obtained for spars, as shown in the results presented by Irani and Finn [13] in Fig. 7.

These results consolidate the conclusions about the importance of the geometry and appendages of the hull of the VIM phenomenon found in the literature. Thus, it is very important to try to represent the details of the hull geometry to predict the motions correctly. Obviously, the motions of each unit are unique and need to be better investigated either by using reduced scale model experiments or by numerical simulations, for example, computational fluid dynamic (CFD), or computational models.

2.2 Presence of Waves. Another aspect capable of changing VIM is the simultaneous presence of waves and current. The work by van Dijk et al. [9] alerted about the fact that waves have influence on VIM of a spar.

In the same sense, Irani and Finn [14] also indicated the need to carry out tests with waves. Therefore, Finnigan et al. [15] showed the first results concerning this matter/issue on spar platforms. Figure 8 presents an example of the results obtained. Following these references, Gonçalves et al. [7] presented the results of

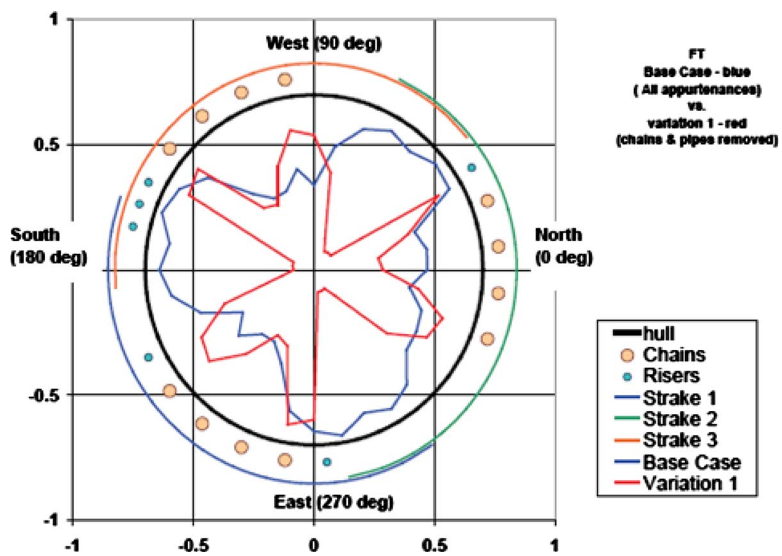

Fig. 2 Comparison between results of spar model with all appendages (base case) and spar model with strakes and chains and pipes (variation 1) by Roddier et al. [12]

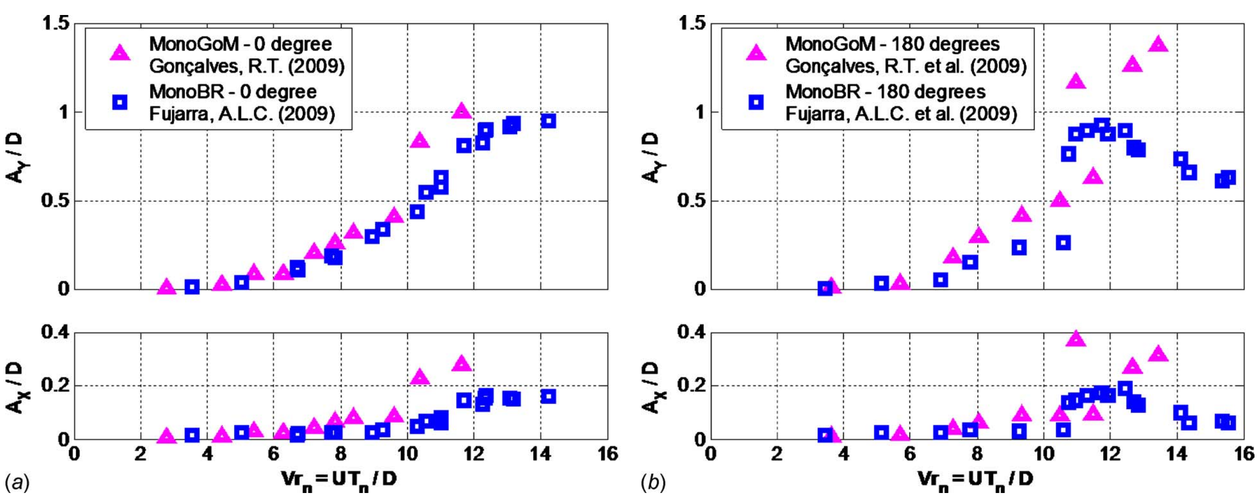

Fig. 3 Comparison between MonoGoM and MonoBR: heading effect: (*a*) 0 deg and (*b*) 180 deg

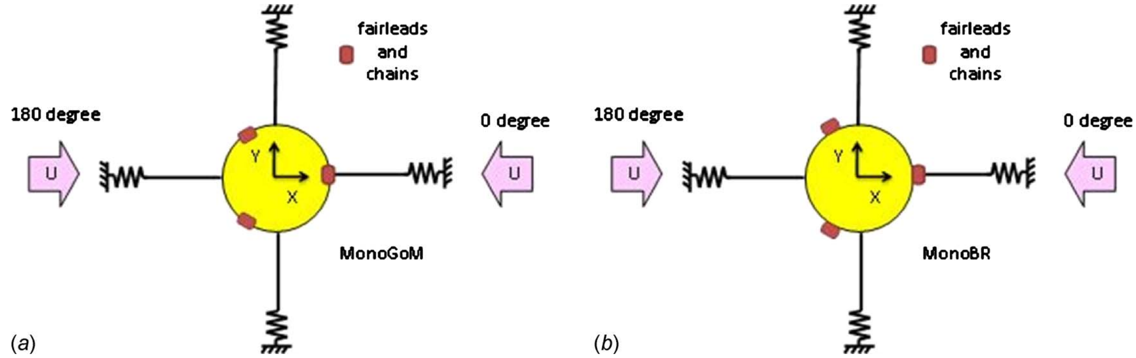

Fig. 4 Layout of the position of fairleads and chains for the (*a*) MonoGoM and (*b*) MonoBR platforms

VIMs with the presence of regular waves on a MonoBR platform.

The time series presented in Fig. 9 shows that the cross-flow is mitigated when the period of the wave is close to the heave natural period of the MonoBR, which is of the order of 20 s. This result is interesting from a scientific standpoint, as this wave period is rather large, not commonly encountered in many sites.

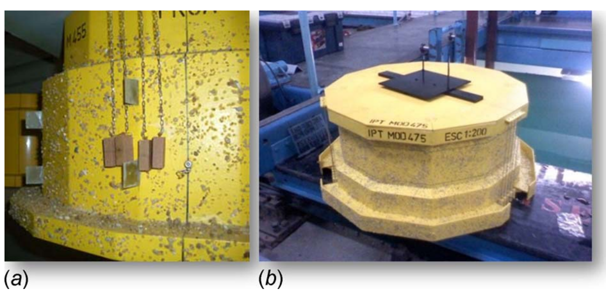

Fig. 5 Comparison between (*a*) MonoGoM by Gonçalves et al. [6] and (*b*) MonoBR by Gonçalves et al. [7]: position of fairleads and chains on the scale model

Such result is similar to the one obtained on spar platforms.

However, these results need careful investigation. Tests with random excitation (for example, irregular sea) are necessary in order to consolidate the results obtained so far.

2.3 Motion Suppressor. The works by Finn et al. [2], van Dijk et al. [3], Irani and Finn [14], and Wang et al. [16] experimentally showed that the use of strakes is capable of minimizing the VIM response of a spar platform. An example of a comparison between VIM of a bare spar hull and straked spar hull is presented in Fig. 10 by Wang et al. [16].

On the other hand, Oakley and Constantinides [17] and Wang et al. [18], among others, demonstrated that CFD can be used to select good configurations of strakes and hull appendages. Nevertheless, the three-dimensionality of the flow field would require a 3D simulation, in which the small scales are important due to the appendages as well as the large scales. Therefore, one should use a direct Navier–Stokes (DNS), a large eddy simulation (LES), or even a detached eddy simulation (DES) with very refined grids and calibrated turbulence models in order to obtain good quantitative solutions. By using DNS, one would get very accurate re-

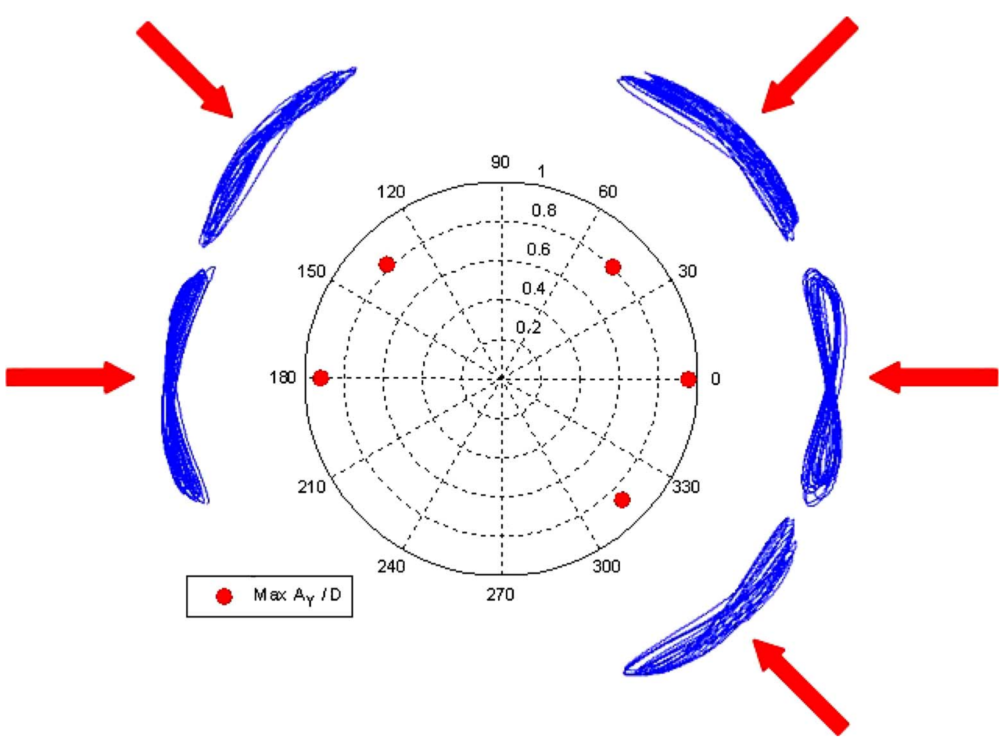

Fig. 6 Trajectories on the XY plane due to the VIM of the MonoBR platform by Gonçalves et al. [7]

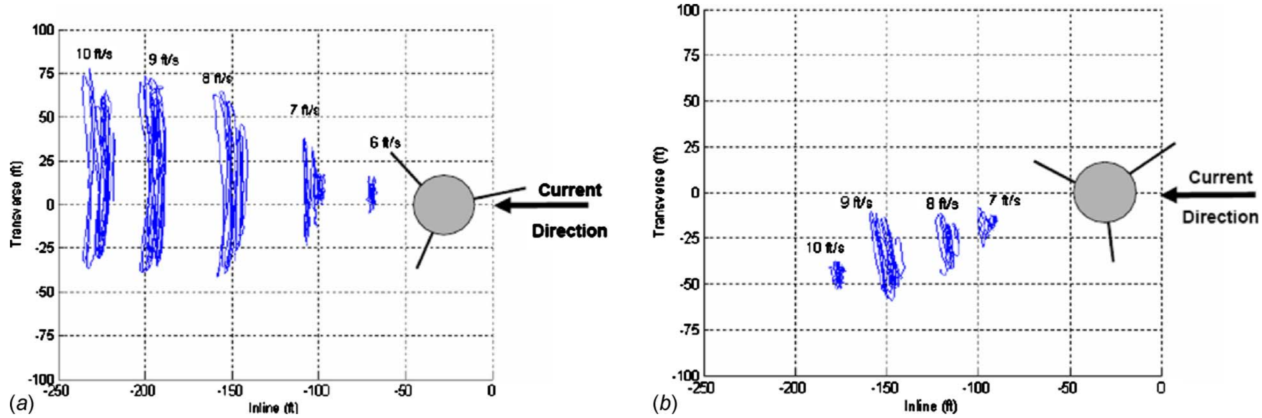

Fig. 7 VIM response of a spar platform for current direction in (*a*) symmetrical and (*b*) asymmetrical with relation to a mooring line system by Irani and Finn [13]. It is important to observe that the position of appendages, mooring lines, etc., relative to the flow direction may change the vortex shedding pattern, thus influencing the amplitude of motions.

sults, but with unfeasible computational effort and time; by using the other approaches, one may get good results depending on a number of factors such as grid and time refinement, turbulence model, and the nature of the problem itself. When it comes to VIV problems, which involve separation and transition points, those matters/issues play a very important role and it is very difficult to obtain an accurate quantitative solution. However, even with some quantitative differences, the overall trends and characteristics are well represented.

Figure 11 presents the results of the use of a motion suppressor (spoiler plates) on a monocolumn platform. The comparison between the results for a MonoGoM, see Ref. [6], and a MonoBR, see Ref. [7], shows that spoiler plates are efficient to mitigate the VIM on a monocolumn, but the spoiler plates on a MonoGoM are more efficient than on a MonoBR. This difference must be due to the distinct configuration of spoiler plates on each platform.

New configurations of the spoiler plates must be evaluated to prove the efficiency of this device. In this case, it would be interesting to use CFD to choose the spoiler plate configuration, as suggested by Oakley and Constantinides [17].

2.4 Draft Condition. The most important element in the mitigation of the VIM phenomenon is the immersed portion of the platform or, as seen in the literature, the ratio L/D, where L is the draft or immersed portion and D is the diameter of the platform. This aspect is not studied on spar platforms because of the large draft.

Figure 12 shows a comparison between the results of VIM of monocolumn platforms, specifically the MonoBR and the SSP Piranema, for different draft conditions. The ratios L/D are 0.39, 0.21, and 0.28, respectively, for the MonoBR in full draft, the MonoBR in light draft, and the SSP Piranema in three operational conditions. Details about the VIM results of the SSP Piranema were presented in Ref. [5].

These results show a large change in the VIM response due to the decrease of the ratio L/D. The decrease of the ratio L/D implies a decrease in the cross-flow motion of the platform; the same conclusion can be found in the results of fundamental studies concerning low aspect ratio cylinders presented by Gonçalves et al. [19].

2.5 External Damping. Model tests with risers are difficult to perform in such a way as to represent the real situation; this was attested to, for example, in VIM tests by van Dijk et al. [9]. In Ref. [10], it is clear that there is the need to establish a procedure to compare the damping in model tests with the real damping due to the risers in VIM.

Gonçalves et al. [7] carried out a battery of VIM tests using a device to represent, in scale, the real damping due to the mooring line and riser system. The results obtained are presented in Fig. 13 and show that the presence of external damping significantly influences the VIM response of the MonoBR platform. The research reaffirmed the importance of the external damping study on VIM response of both spar and monocolumn platforms.

3 Conclusions

A brief overview of the principal effects that could influence the VIM phenomenon was presented. The details of the hull, such as external appendages and the mooring system, impact the VIM response of spar and monocolumn platforms. The VIM response

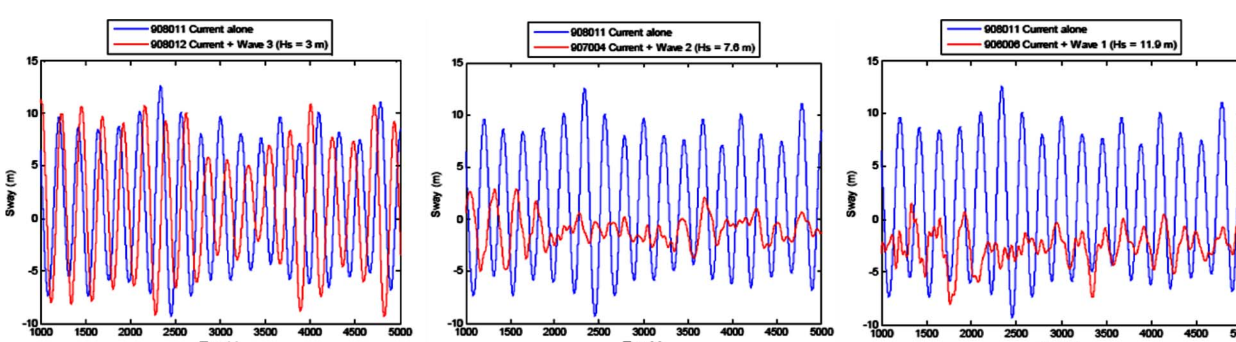

Fig. 8 Temporal series examples of VIMs of a spar with the presence of waves by Finnigan et al. [15]

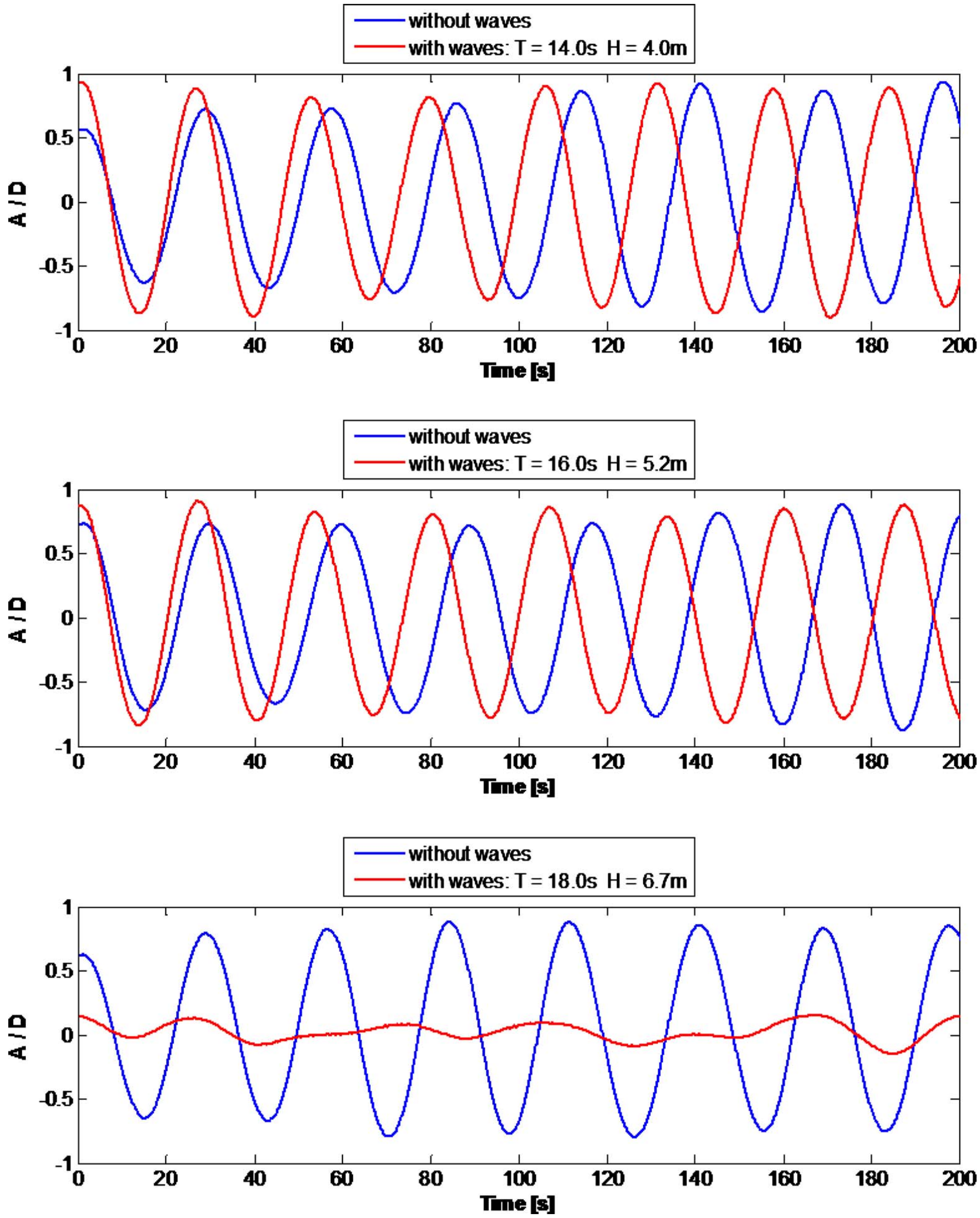

Fig. 9 Example of a time series of VIM of a MonoBR with the presence of regular waves by Gonçalves et al. [7]

for each geometry of the platform is unique. This makes it difficult to use analytical models, but these models are in continuous development.

The use of a motion suppressor on a monocolumn platform is efficient such as on spar platforms, but more studies are required to choose the best geometry of suppressors. These studies can be evaluated by model tests with reduced scale or by using CFD codes.

The results of the concomitant presence of waves and current and also the presence of external damping showed that these should influence VIM response. These studies are in their initial phase and need more time to be consolidated. The loading condition presented the largest impact on VIM response because the low aspect ratio promotes large 3D effects on the vortex shedding, which implies low cross-flow motions.

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Nomenclature

A_Y/D = nondimensional longitudinal amplitude
A_x/D = nondimensional transversal amplitude
D = characteristic diameter of the platform
H = regular wave height
L = immersed length or draft
T = regular wave period
T_0 = natural period of transversal motion in calm waters

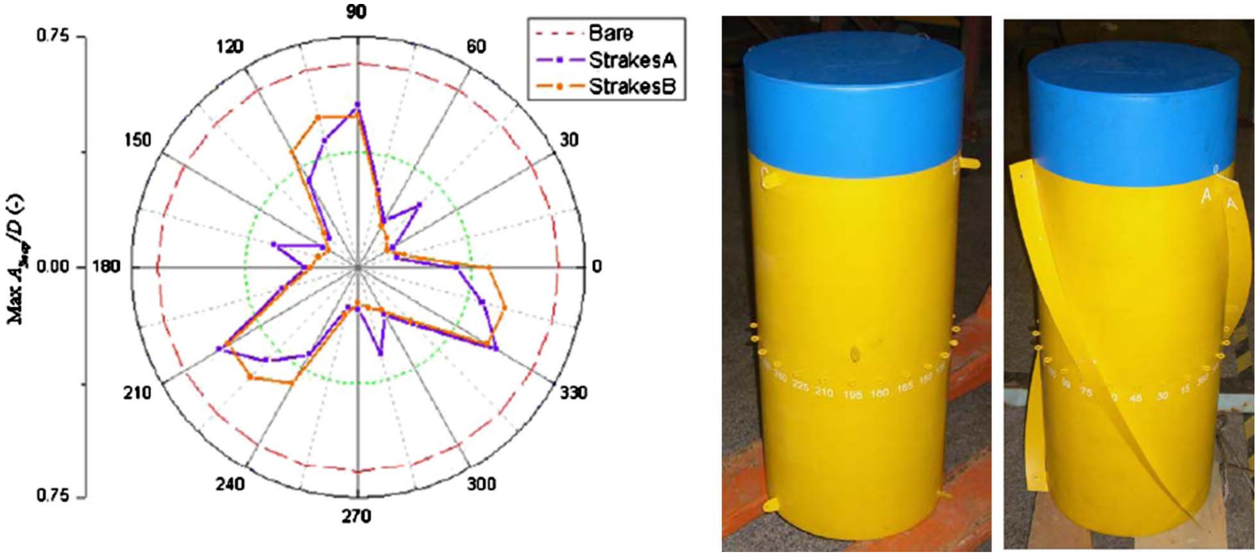

Fig. 10 Comparison between results for spar model bare hull and hull with strakes by Wang et al. [16]

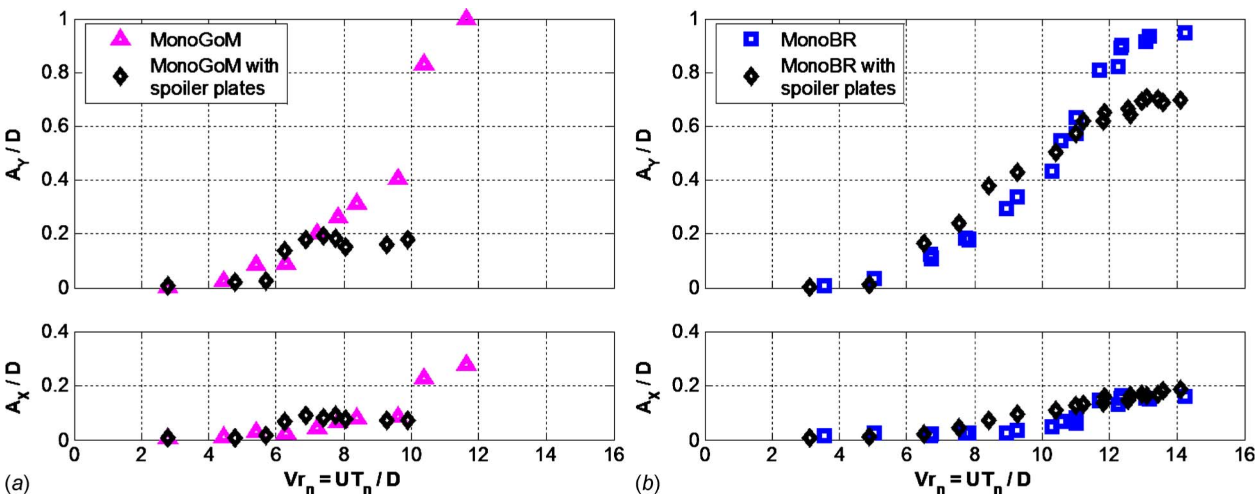

Fig. 11 Comparison between (*a*) MonoGoM by Gonçalves et al. [6] and (*b*) MonoBR by Gonçalves et al. [7]: the effect of suppressor motions (spoiler plates)

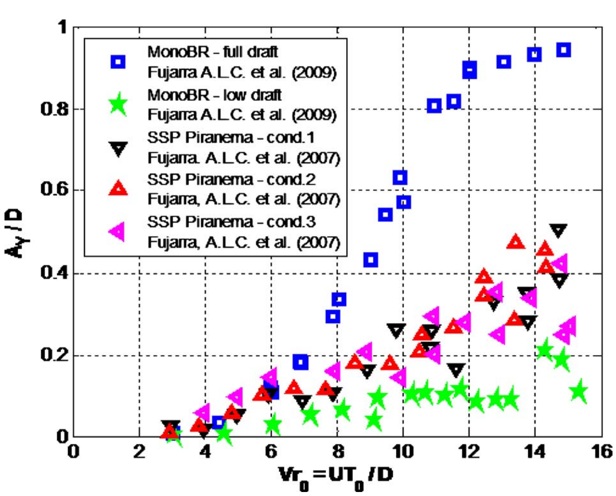

Fig. 12 Comparison between MonoBR and SSP Piranema: immersed portion effect

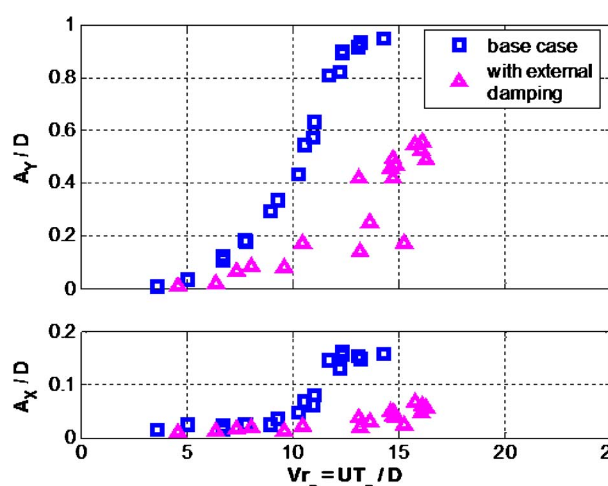

Fig. 13 External damping effect on the VIM response of MonoBR platform by Gonçalves et al. [7]

T_n = natural period of transversal motion in the new offset position
U = flow velocity
Vr_0 = reduced velocity in calm waters
Vr_n = reduced velocity (corrected)

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