RELEVANT ASPECTS IN VORTEX-INDUCED MOTIONS OF SPAR AND MONOCOLUMN PLATFORMS: A BRIEF OVERVIEW

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Abstract. *Vortex-Induced Motions (VIM) of floating structures are very relevant for the design of mooring and riser systems. In the design phase, SPAR VIM behavior, as well as Semi Submersible and Tension Leg Platform (TLP) flow-induced motions, is studied and evaluated. This paper intends to present an overview of the influential aspects of the VIM phenomenon. These aspects are 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, for example. This paper also addresses previous works concerning the VIM studies on SPAR and monocolumn platforms. Whenever possible, the results of experiments from diverse authors on this matter are presented and compared.*

Keywords*: Vortex-induced motion; monocolumn platform; spar platform; model tests*

NOMENCLATURE

A_Y/D	Non-dimensional longitudinal amplitude (20% of the highest peaks)
A_x/D	Non-dimensional transversal amplitude (20% of the highest peaks)
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
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)

1. INTRODUCTION

In general terms, the VIM phenomenon represents a type of fluid-structure interaction which very much resembles the so-called 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 force itself, namely the marine current, 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 exhibit amplitude values in the same order of magnitude as 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 production ducts regarding both extreme tension and useful life.

The study of the VIM phenomenon has been carried out since the beginning of the decade, mainly on SPAR platforms, as reported in Huang, K. *et al.* (2003), Finn, L.D. *et al.* (2003) and van Dijk, R. *et al.* (2003).

Nevertheless, similar VIM studies on monocolumn platforms are more recent. The research development in this field is being carried out by a research group of the University of Sao Paulo – Brazil, from which the following works can be mentioned: Cueva, M. *et al.* (2006), Fujarra, A.L.C. *et al.* (2007), Gonçalves, R.T. *et al.* (2009) and Fujarra, A.L.C. *et al.* (2009).

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, K., Chen, X. & Kwan, C. T. (2003) and Yung, T.W. *et al.* (2003) were the first published works about SPAR platforms that have shown the importance of headings in relation to VIM response.

Different headings can have influence on the mooring system implying differences in the platform VIM response. Because of this, van Dijk, R.R. *et al.* (2003b) suggested a study of a large number of different headings for a platform.

Furthermore, Yung, T.W. *et al.* (2004) and recently Finningan, T. & Roddier, D. (2007) carried out several studies to investigate the sensibility of the phenomenon regarding the particularities of the geometry of each SPAR platform type (classical, truss and cell).

In the same line of research, the group of the University of São Paulo-Brazil initiated experimental studies with monocolumn platforms. Cueva, M. *et al.* (2006) presented results on the VIM of a monocolumn, in particular the MonoGoM platform, for different headings. The VIM studies of MonoGoM have been completed by tests carried out in the NMRI-Japan; these results were published in Gonçalves, R.T. *et al.* (2009).

Recently, and similarly, Fujarra, A.L.C. *et al.* (2009) performed extensive research on the influence of mooring lines on VIM of a MonoBR platform. This work has concluded that the impact of the heading is significant on the VIM response. The influence is directly related to the position of the appendages, fairleads, and chains on the hull of the platform.

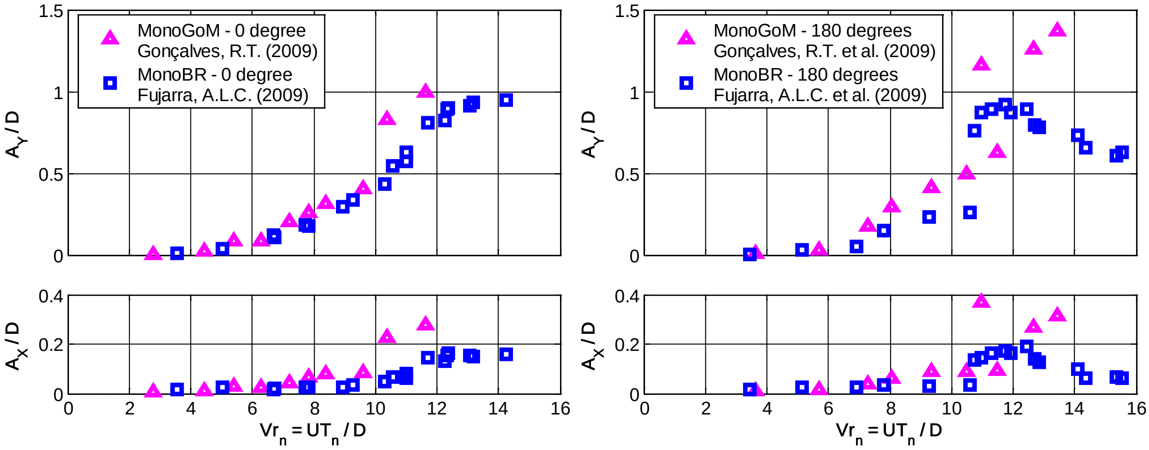

Figure 1 – Comparison between MonoGoM and MonoBR: heading effect (a) 0 degree and (b) 180 degrees.

Figure 1 shows a comparison between the non-dimensional amplitudes, cross-flow and inline, as a function of the reduced velocity for the MonoGoM and MonoBR platforms. According to Figure 1a, the results of the MonoGoM and MonoBR for the 0 degree 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 mooring system characteristics.

Concerning the illustrations of the 180 degrees incidence in Figure 1b, 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 Figure 2. As shown in Figure 3, the MonoBR presents the fairleads and chains more distant from the hull, which might promote a turbulent regime of the vortex shedding. Therefore, the smaller non-dimensional amplitudes of oscillation observed are due to the loss in the lift force.

The same phenomenon that promoted a turbulent regime or the loss in the correlation of vortex shedding is responsible for the differences in the range of $\mathrm{Vr}_n > 10$ for the 0 degree incidence.

The VIM on the XY plane is characterized, in some cases, by an eight (8) shape trajectory. This trajectory represents the existence of a double frequency in the inline motion and it occurs when the inline motion coexists with the cross-flow motion, as seen in Figure 4, which presents VIM on the XY plane for different headings of the MonoBR.

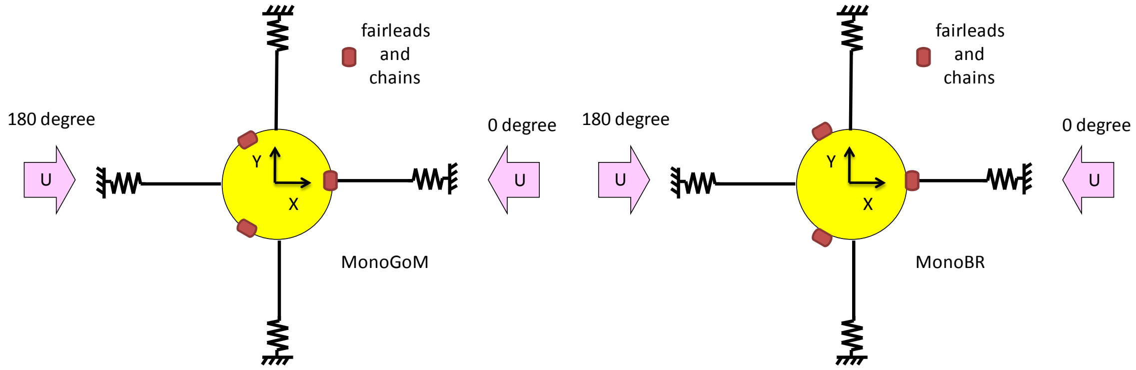

Figure 2 – Layout of the position of fairleads and chains for the (a) MonoGoM and (b) MonoBR platforms.

Figure 3 – Comparison between (a) MonoGoM and (b) MonoBR: position of fairleads and chains on the scale model.

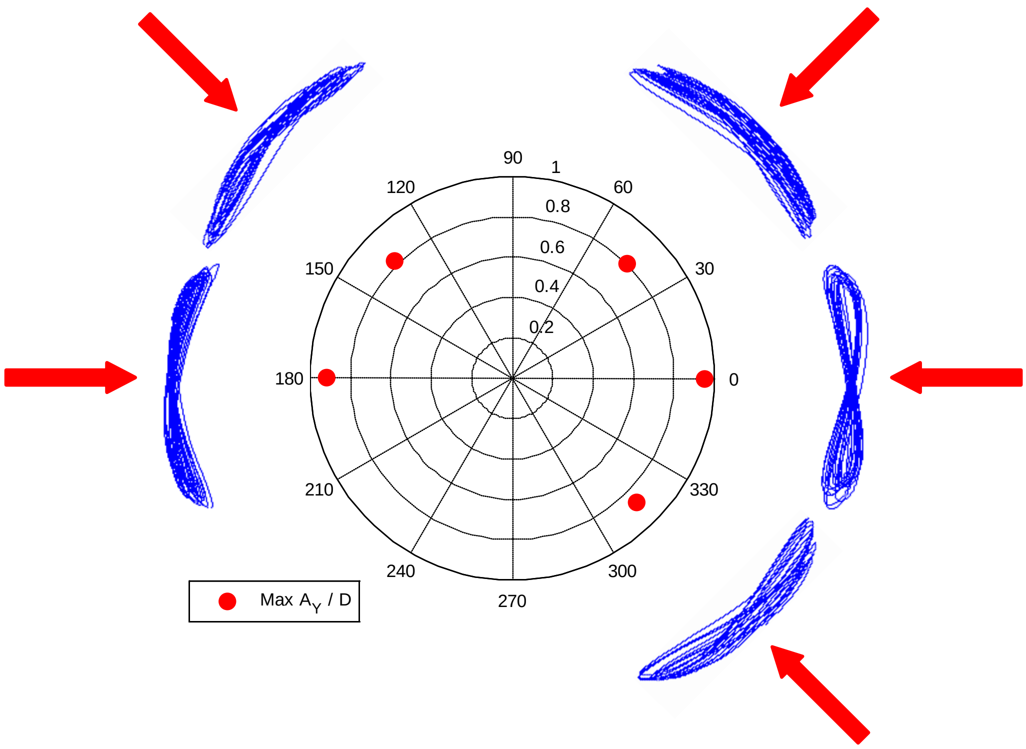

Figure 4 – Trajectories on the XY plane due to the VIM of the MonoBR platform [Fujarra, A.L.C. *et al.* (2009)].

The motions on the XY plane for monocolumns are similar to those obtained for SPARs, as shown in the results presented by Irani, M. and Finn, F. (2004) in Figure 5.

These results consolidate the conclusions about the importance of the geometry and appendages of the hull of the VIM phenomenon found in 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 CFD, or computational models.

However, there is not a robust phenomenological model to consider all the effects that have impact on the VIM phenomenon. The works by Lacerda, T.A.G. *et al.* (2009), Rosetti, G.F. *et al.* (2009a) and Rosetti, G.F. *et al.* (2009b) are a starting point for this study on monocolumn platforms.

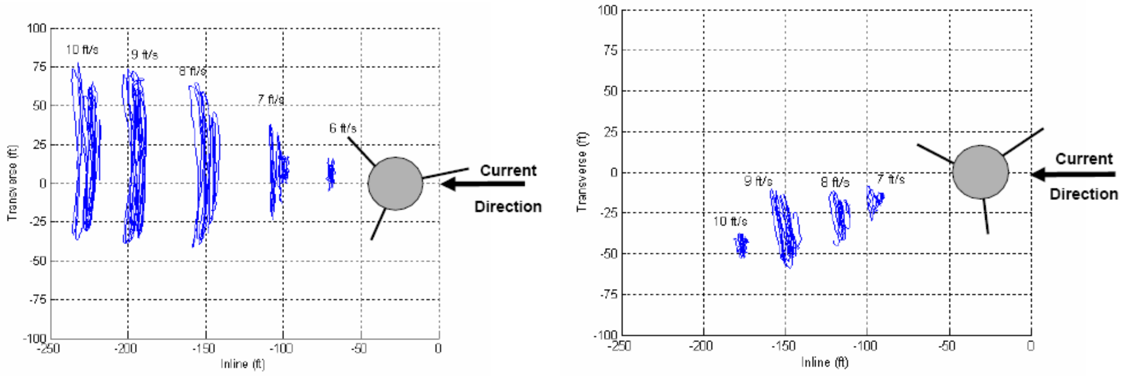

Figure 5 – VIM response of a SPAR platform for current direction in (a) symmetrical and (b) asymmetrical with relation to a mooring line system [Irani, M. & Finn, L. (2004)].

2.2.Presence of Waves

Another aspect capable of changing VIM is the simultaneous presence of waves and current. The work of van Dijk, R.R. *et al.* (2003b) alerted about the fact that waves have influence on VIM of a SPAR.

In the same sense, Irani, M. & Finn, L. (2005) also indicated the need to carry out tests with waves. Therefore, Finnigan, T., Irani, M. & van Dijk, R.R. (2005) showed the first results concerning this matter on SPAR platforms. Figure 6 presents an example of the results obtained.

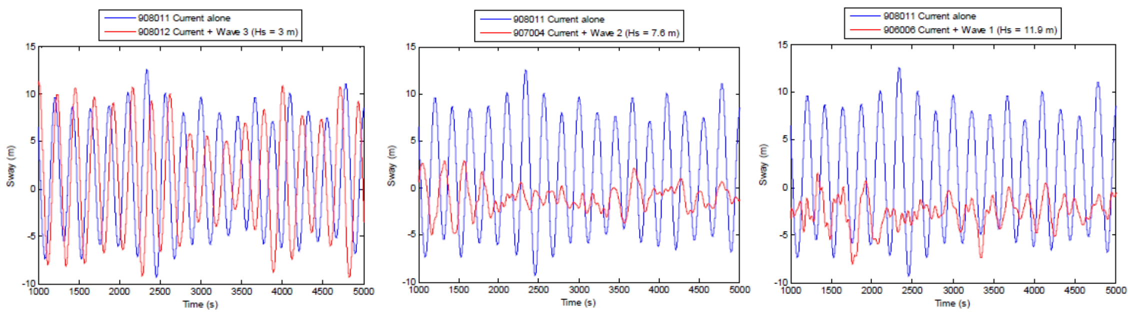

Figure 6 – Temporal series examples of VIM motions of a SPAR with the presence of waves [Finnigan, T., Irani, M. & van Dijk, R.R. (2005)].

Following these references, Fujarra, A.L.C. *et al.* (2009) presented the results of VIM motions with the presence of regular waves on a MonoBR platform.

The time series presented in Figure 7 shows that the cross-flow is mitigated when the period of the wave is close to the natural period of the MonoBR. This 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.

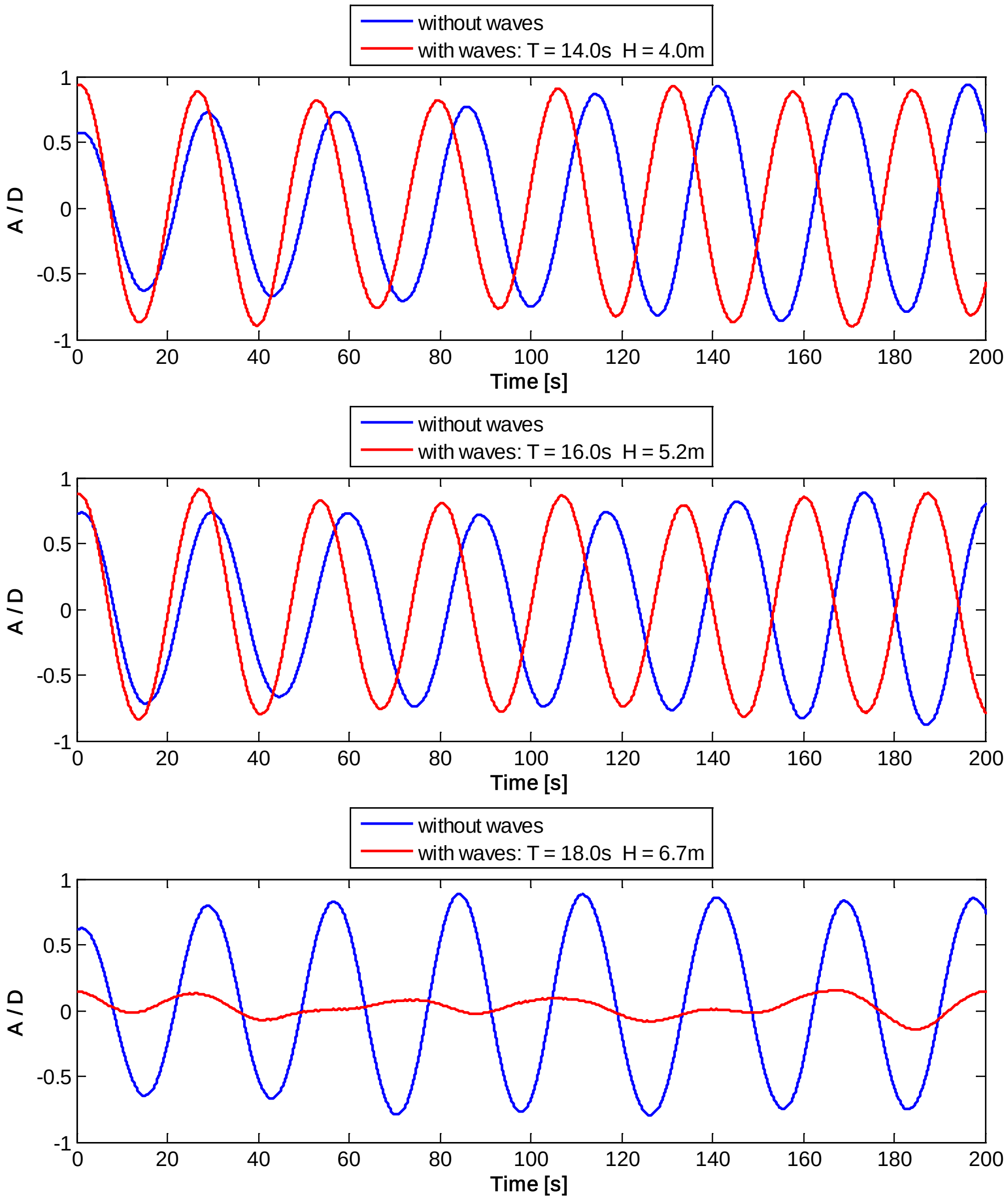

Figure 7 – Example of a time series of VIM of a MonoBR with the presence of regular waves [Fujarra, A.L.C. *et al.* (2009)].

2.3.Motion Supressor

The works by Finn, L.D., Maher, J.V. & Gupta, H. (2003); van Dijk, R.R. *et al.* (2003a) and Irani, M. & Finn, L. (2005) showed experimentally that the use of strakes is capable of minimizing the VIM response of a SPAR platform.

On the other hand, Oakley Jr., O. & Constantinides, Y. (2007) demonstrated that CFD can be used to select the best configuration of strakes and hull appendages and, even though the value of the amplitude results of VIM are not real, the results are qualitatively representative.

Figure 8 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 Gonçalves, R.T. *et al.* (2009), and a MonoBR, see Fujarra, A.L.C. *et al.* (2009), 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 Jr., O. & Constantinides, Y. (2007).

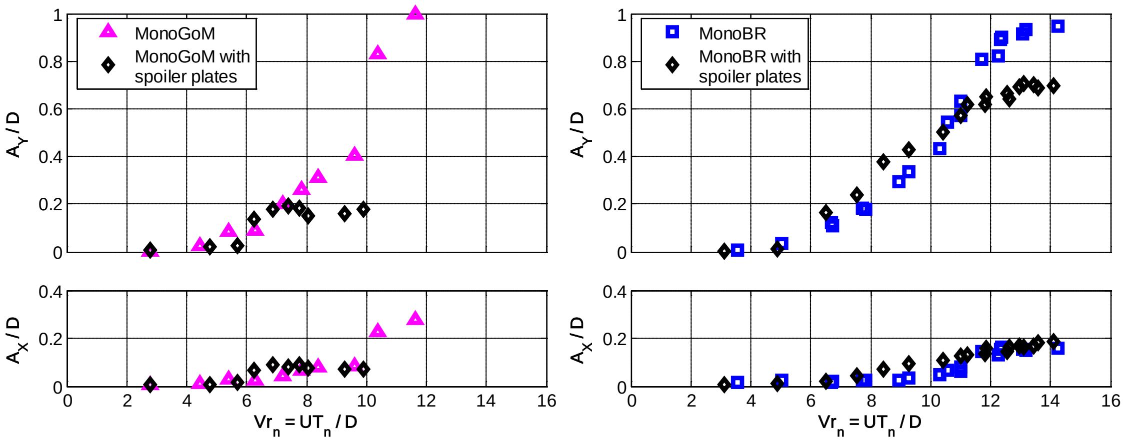

Figure 8 – Comparison between (a) MonoGoM [Gonçalves, R.T. *et al.* (2009)] and (b) MonoBR [Fujarra, A.L.C. *et al.* (2009)]: the effect of suppressor motions (spoiler plates).

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 9 shows a comparison between the results of VIM of monocolumn platforms, in specific the MonoBR and the SSP Piranema, for different draft conditions. The ratios L/D are 0.39, 0.21 and 0.28; respectively, the MonoBR in full draft, the MonoBR in light draft and the SSP Piranema in operational condition. Details about the VIM results of the SSP Piranema were presented in Fujarra, A.L.C. *et al.* (2007).

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.

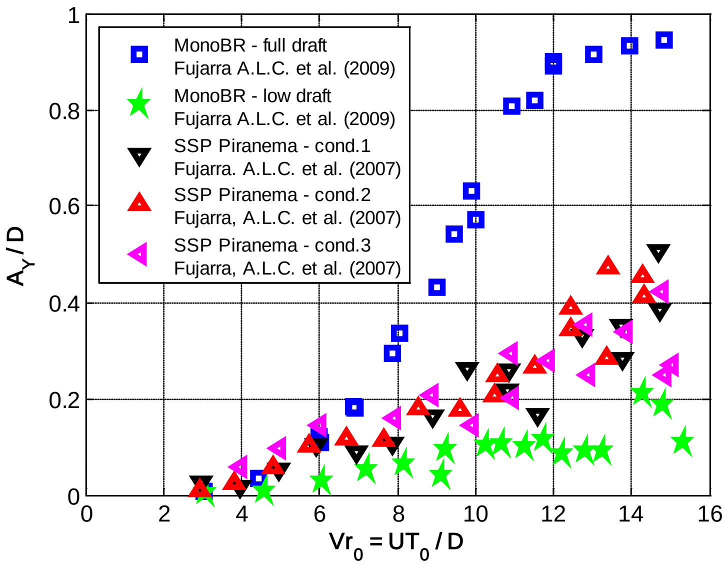

Figure 9 – Comparison between MonoBR and SSP Piranema: immersed portion effect.

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, R.R. *et al.* (2003b). In Yung, T.W. *et al.* (2004) it is clear that there is the necessity to establish a procedure to compare the damping in model tests with the real damping due to the risers in VIM.

Fujarra, A.L.C. *et al.* (2009) carried out a battery of VIM tests using a device to represent, in scale, the real damping due to the mooring line and risers system. The results obtained are presented in Figure 10 and show that the presence of external damping significantly influences the VIM response of the MonoBR platform.

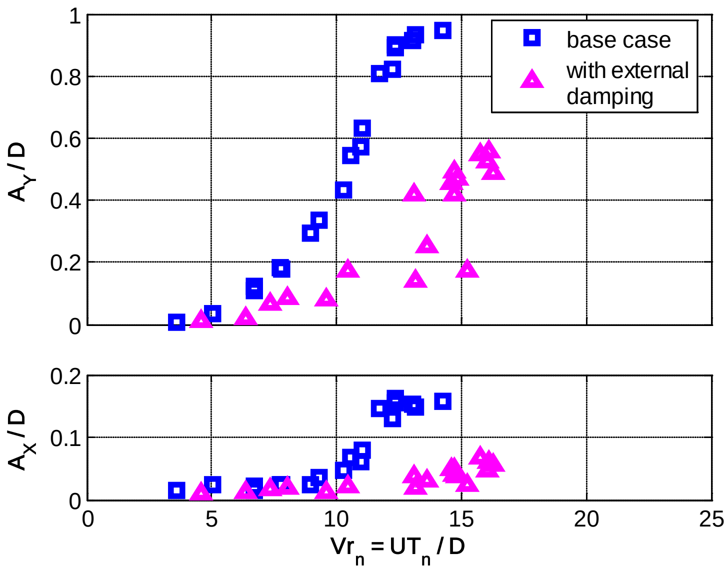

Figure 10 – External damping effect on the VIM response of MonoBR platform [Fujarra, A.L.C. *et al.* (2009)].

The research reaffirmed the importance of the external damping study on VIM response of both SPAR and monocolumn platforms.

3. CONCLUSIONS

This paper has presented a brief overview of the principal effects that could influence the VIM phenomenon.

The details of the hull, such as external appendages and the mooring system, have impact on VIM response of SPAR and monocolumn platforms. The VIM response 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. The research group of USP is performing research on cylinders with different ratios of L/D to explain the physics of this effect. These results will be published soon.

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