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Experimental study of the column shape and the roughness effects on the vortex-induced motions of deep-draft semi-submersible platforms

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ABSTRACT

Experiments regarding the VIM of SS platforms with four columns were carried out to investigate the effects of the surface roughness and the column shape. Two different geometry of columns were experimented: rounded-square and circular-cross sections. Each model had the same arrangement of four pontoons in a closed configuration. The range of reduced velocity was from 4 up to 25 covering Reynolds numbers from 7.000 to 80.000. Three angles of incidences for each model were tested, namely 0, 22.5 and 45°. For each model, three different levels of roughness were tested. Regarding roughness effects the results seem to confirm two aspects: the important role played by the separation point near the rounded corners of the rounded-square columns and the roughness effect on the boundary layers of the circular columns. Regarding the effect of the column shape, the results indicated that the heading effects on the VIM of SS strongly depend on the column shape. The characteristic motion periods upheld the resonance behavior for the motions in the transverse direction and yaw motions for the lock-in range. Heave, roll and yaw motions did not impact the VIM behavior in the horizontal plane, and their amplitudes were not considered relevant.

1. Introduction

The study of VIM on semi-submersibles platforms (SS) is more recent than on cylindrical platforms such as monocolumns and spars; see an overview about VIM of single cylindrical structures in Gonçalves et al. (2012a). This fact is due to the geometric dimensions of the new deep-draft (DD) semi-submersibles platforms which have increased significantly, therefore promoting a notable VIM; an extensive review of the VIM topic can be found in Fujarra et al. (2012).

The geometry of the SS implies a more complex VIM phenomenon than that identified for single cylindrical structures. In the case of SS, the vortex shedding occurs around each column, and thus the wake interference characterizes the VIM of the unit, different for each current incidence (platform heading). The shape of the columns, circular, square, diamond or triangle, impacts directly on the vortex-shedding and the wake interference around the columns; consequently, the VIM behavior of the platforms must be affected.

In this context, this study aims to experimentally demonstrate the effects of column shape and surface roughness on the VIM response of a DD-SS with four columns.

Section 2 presents a background of VIM phenomenon as well as a context of the roughness effects on VIV of cylinders. The experimental setup and details about the scale model are described in Section 3. The analysis methodology of the tests is presented in Section 4. The results concerning amplitudes of motions in the transverse and in-line directions, as well as characteristic yaw motion amplitudes are discussed in Section 5. In the same section, force coefficients (drag, lift and added mass) and characteristic motion periods from the spectral analysis are presented. Finally, in Section 6, some conclusions are drawn.

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Nomenclature

Δ	Displacement
β	Blockage effect
ρ	fluid density
θ	Incidence angle of current
A_P	Submerged projected area
A_x/L	Nondimensional characteristic motion amplitude in the in-line direction
A_y/L	Nondimensional characteristic motion amplitude in the transverse direction
A_{yaw}	Characteristic yaw motion amplitude
B	Beam of the platform
C_θ	Structural damping coefficient for the yaw motion
C_a	Added mass coefficient
C_D	Drag force coefficient
C_L	Lift force coefficient
C_m	Yaw moment coefficient
C_x	Structural damping coefficient in the in-line direction
C_y	Structural damping coefficient in the transverse direction
D	Characteristic dimension of the section of the body subjected to a vortex shedding
F_{Hx}	Hydrodynamic force acting on the system in the in-line direction
F_{Hy}	Hydrodynamic force acting on the system in the transverse direction
H	Immersed column height above the pontoon
I_z	Inertia moment of the yaw motion
k	Mean height of the surface protusions
K_x	Total horizontal stiffness in the in-line direction
K_y	Total horizontal stiffness in the transverse direction
L	Column face width
m	Structural mass of the platform
M_{Hz}	Hydrodynamic moment of the yaw motion
P	Pontoon height
Re	Reynolds number
R_{zz}	Yaw radius of gyration
S	Distance between the center of the columns
t	Time
T	Draft
T_0	Natural period in still water
T_{x0}	Natural period of motion in the in-line direction in still water
T_y	Characteristic motion period for the motions in the transverse direction
T_{y0}	Natural period of motion in the transverse direction in still water
T_{yaw}	Characteristic motion period for the yaw motions
T_{yaw0}	Natural period of the yaw motion in still water
U	Incident current velocity
VCG	Vertical center of gravity
V_r	Reduced velocity
X	Axis motion in the in-line direction to the flow
Y	Axis motion in the transverse direction to the flow

2. Background

2.1. Effect of the column design on VIM of offshore floating units

Amplitudes of VIM were observed for DD-SS, as reported in Rijken and Leverette (2009) and Ma et al. (2013) from field measurements. This fact has pushed up the efforts in understanding the VIM behavior of such platforms, and consequently, the number of new solutions to avoid the high VIM amplitudes has been growing up.

The main geometric nondimensional parameters that affect the VIM are H/L, S/L, and H/P; where H is the immersed column height above the pontoon, L is the face width of the column, S is the distance between the center of the columns and P is the pontoon height. These dimensions can be illustrated as in Fig. 1.

Presently, model tests are the preferred method to predict the VIM response of multi-column floater, even the results being conservative compared with field measurement as detached by Koop et al. (2016b).

In this scenario, experimental works focused on VIM of SS platforms with four square columns can be cited, as Rijken et al. (2004, 2011); Waals et al. (2007); Rijken and Leverette (2008), Hong et al. (2008), Magee et al. (2011), Xu (2011), Xu et al. (2012), Gonçalves et al. (2012a, b, 2013), Irani et al. (2015), Kyoung et al. (2015), Sterenborg et al. (2016), Liu et al. (2016a, 2016b) and Maximiano et al. (2016, 2017). All of these works reported relevant motions in certain current conditions, which can reduce the fatigue life of steel catenary risers (SCR) by as much as 50% near the touch-down point (TDP), as noted in Xiang et al. (2010) and Cheng et al. (2011).

Recently, the geometry of the columns has changed. New DD-SS platforms were designed with rectangular, circular or diamond column sections. Naturally, as can be seen in Table 1, the increasing number SS with circular columns is the primary motivation for the present work and the reason why we focus on such a particular geometric arrangement. The works by Tan et al. (2014, 2016), Potanza et al. (2015), Fujiwara et al. (2016) and Kou et al. (2016) presented the VIM results for DD-SS with for circular columns. The results showed that for the DD-SS with circular columns the largest VIM motions in the transverse direction occurred for 0-deg incidence, differently for DD-SS with square columns in which the highest amplitudes occurred for 45-deg incidence.

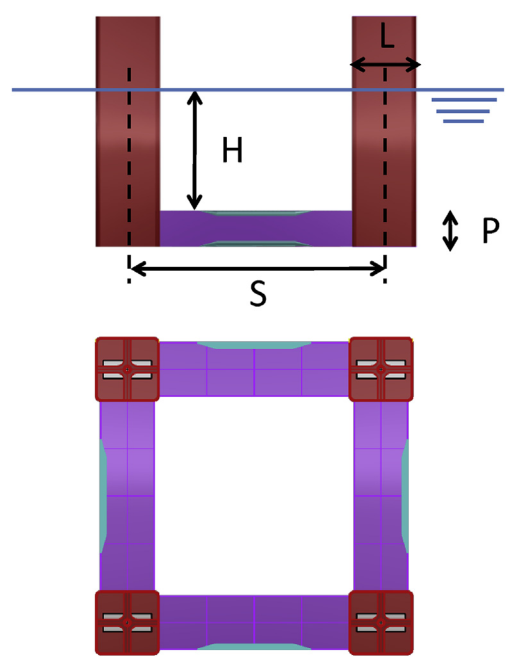

Fig. 1. Characteristic dimensions of a DD-SS unit.