The Nonlinear Roll Damping of a FPSO Hull

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Introduction

The basic mathematical treatment of the roll motion equation was stated by William Froude in the 19th century [1,2] and led to the so-called quadratic dependence. This approach is quite usual in drag-force evaluations, based in a physical content of viscous damping, and should always be tried. Since it works quite well for ship-rounded hulls and small bilge keel width, as observed by several practical comparisons, this treatment has remained a well-established standard until nowadays. It justifies the decay tests widely used by the industry. In fact, the decay test is much easier to perform than forced oscillations. This is, of course, a clear reason to submit the decay tests to criticism, as the present paper does.

Ship design, however, evolved to more squared midship sections since Froude’s age. This new shape of the ship hull has a radical flat bottom and, for floating production storage and offloading (FPSO), a large bilge keel. So it has required new physical interpretation, as shown in this paper. However, the important contribution to establish the roll-damping physical background developed by Ikeda et al. [3] and, likewise, the Himeno [4] publication should be mentioned. According to them, the viscous damping coefficients can be divided into four components related to four effects (friction, lift associated to the ship service velocity, bilge keel local effects, and vortex-shedding influence over the hull). Those publications also have presented methods to estimate the damping coefficients according to ship particulars, achieving good results for typical rounded ship hulls with small bilge keels.

As previously mentioned, since the early 1980s, the roll quadratic dynamics has been reasonably matched for rounded ship sections. However, hulls with large bilge keels behave differently. The last type of hull shape is typical of FPSOs adapted from the very large crude carriers, and it deserves, as also previously mentioned, a closer look. Difficulties when the quadratic model coefficients were bluntly adjusted to a barge hull were also reported, even by Ikeda in a recent publication [5]. In fact, the physical assumptions involved in the quadratic modeling require small damping during the oscillatory cycles. Again, it works fairly well for the analysis of typical ships that use relatively small bilge keels to avoid increasing the resistance when navigating.

In the first FPSO designs, turret moored, the weathervane mooring system characteristics lead to an impression that roll motion would not be a major concern (since the local see is related to the wind). Field operations, however, show that the swell conditions cannot be ignored, implying in large roll amplitudes in some units. The need for a small roll motion in a converted ship has recently stimulated several researches on larger bilge keels (sometimes more than 1.0 m) to minimize this problem. Resistance increase due to the large bilge keel is not a problem for FPSOs, since they are stationary.

To face the new trend, some publications have presented improvements of the numerical modeling by increasing the degree of the polynomial that represents the dependence between the damping load and the velocity going beyond the quadratic model. According to this research line, higher-order polynomials represent better roll-damping behavior. Besides that, the odd functions also avoid working with absolute values (that are not smooth in the origin) when describing the damping behavior. On the other hand, this approach seems to be less linked to the physics of the phenomena than the original quadratic modeling. The present research presents an alternative modeling. It became clear that the vortex generation by the bilge keel rules in this scenario, thus the investigation should provide the information to build a new and reliable numerical approach, as shown next.

Physical Background

As mentioned before, the damping behavior of a ship model depends on the local effects on the hull and bilge keels. It also depends on the vortex effects that change the pressure distribution on the ship hull. Recently, some research (including visualization techniques) have concluded that those vortex effects are dominant for barges (Downie et al. [6]), rolling plates (Yeung and Carmelli [7]), and FPSOs (Oliveira [8]). For rounded hulls, we can refer to Aloisio and Felice [9] and Jung et al. [10]. Typical flows can be visualized in Figs. 1 and 2 for respectively larger and smaller angles of oscillation.

Besides the visualization studies, some computational fluid dynamics (CFD) studies (Wanderley et al. [11] and Kinnas [12]) confirm the presence of the vortex shedding in the roll-damping composition.

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