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A Comprehensive Study on FPSO Roll Decay Tests with the Aid of 3D CFD Modeling

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This study delves into computational fluid dynamics (CFD) applied to roll decay tests for Floating Production, Storage, and Offloading units. The main objective of this work is to investigate complexities of the corresponding CFD simulations and aspects of the numerical setup optimization to enhance understanding of factors influencing precision, computational efficiency, and reliability in such numerical applications. Moreover, different bilge keel configurations along with the presence of other submerged appendages are studied and assessed in a compendious manner.

NOMENCLATURE

BK	Bilge Keels
BM	Metacentric Radius
CFD	Computational Fluid Dynamics
CFL	Courant Friedrichs Lewy
CPU	Central Processing Unit
DES	Detached Eddy Simulation
DOF	Degree of Freedom
FEED	Front End Engineering and Design
FPSO	Floating, Production, Storage and Offloading
GM	Metacentric Height about Longitudinal Axis
LRB	Lower Riser Balcony
LC	Loading Conditions
(U)RANS	(Unsteady) Reynolds Averaged Navier-Stokes
VOF	Volume of Fluid
VCG (KG)	Vertical Center of Gravity (w.r.t Keel)
VCB (KB)	Vertical Center of Buoyancy (w.r.t Keel)

INTRODUCTION

In floating production, storage, and offloading units (FPSOs), the structural integration of topside processing units and the safe operation of risers relies heavily on vessel motions and accelerations. However, from all six degrees of freedom, only roll motion is possible to mitigate. Anti-roll tanks, as shown in Diebold et al. (2018) and Chen et al. (2023), can make it possible to reduce roll amplitude, but such an approach is not easily applicable on FPSOs or large displacement vessels in general and is hence avoided.

More practical in terms of integration and operation, is the placement of bilge keels (BKs) which are considered industry standard practice. On the other hand, the hydrodynamic performance of BKs and their contribution to roll (viscous) damping has been thoroughly investigated, numerically and experimentally.

Several works on the effect of BKs have been conducted, with some of the earliest being the studies performed by Tanaka and Hishida (1957), Martin (1958), and Watanabe et al. (1964). Himeno (1981) presented a thorough state of the art on the calculation methods for roll damping. Ikeda (1979) performed experiments on 2D cylinders and comparisons with BKs on ship models, proposing a prediction method for estimating the pressure component of BK damping. Ikeda (1983) presented the requirement to associate roll damping with the appropriate nonlinear attributes, especially when nonlinear roll under random seas is the problem at hand. Focusing on roll damping estimation by means of computational fluid dynamics (CFD) with forced oscillations or freely floating decay testing, Gu et al. (2019) examined the influence of several numerical parameters (e.g., boundary condition, wall function). Koop et al. (2019) examined via 2D hull sections and forced oscillation tests, the sensitivity of the computed roll damping with respect to scale ratio, roll amplitude, center of rotation, and other elements. Van't Veer and Fathi (2011), using 2D CFD analysis, examined the roll damping attributes of a converted FPSO with a riser balcony and BKs. Van't Veer et al. (2012) calculated the Keulegan-Carpenter (KC) dependent drag coefficient of the BK geometry by 2D CFD forced harmonic oscillations to further feed the coupling with velocities from potential flow for operation in irregular sea states.

An extensive investigation on 3D freely floating roll decay tests for a barge-type FPSO was performed by Lee and Huang (2019), where the influence of numerical parameters, e.g., domain size, time step, turbulence model, and mesh size, was examined along with benchmarking between numerical and experimental results. Kwon et al. (2017) compared results from CFD analysis with experiments to assess the effect of vessel-stability parameters and BK height on the roll damping of box-shaped FPSOs.

From the FPSO industry's perspective, pre-FEED or FEED stages can present challenges with roll motion or roll-induced transverse accelerations. Physical model testing can be costly and cause delays, making CFD a significant alternative. CFD roll decay testing provides valuable insights into variations in BK geometries, the effects of submerged appendages, like lower riser balconies and/or sponsons, vessel drafts, and more.

With an initial calm water surface and no incoming waves, roll damping will be underestimated. However, roll decay tests can still provide valuable comparisons and assessments of roll damping. Therefore, the demand for accurate and efficient roll decay simulations of barge-type FPSOs can be met using CFD-aided numerical analyses.

In contrast to diffraction/radiation potential flow software, CFD analysis doesn't require any pre-calculation of damping coefficients. However, CFD comes with a significant drawback, as it can

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