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Hydrodynamic Forces on Vertical Piggyback Cylinders in Regular Waves

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ABSTRACT

The wave-induced hydrodynamic forces on a pair of vertical cylinders of different diameters in close proximity are investigated experimentally. The smaller cylinder is placed at various circumferential positions around the larger one. The effects of the wall-to-wall gap between the 2 cylinders are also investigated. The wave forces, including drag, inertia forces and mean lift, are measured on each cylinder independently and at 2 different depths below the mean water level for each cylinder. The Keulegan-Carpenter numbers vary from 0.4 to 14 based upon the larger cylinder diameter, and the Reynolds numbers are in the subcritical regime. It is found that there is significant interference effect upon the cylinder drag and inertia coefficients.

INTRODUCTION

As the search for oil extends into ever deeper water environments, floating production systems are increasingly adopted. In particular, FPSOs, with purposely built vessels and improvements in internal turret mooring technology, have shown to be cost-effective for medium and even large field developments. Conventional flexible risers are generally used in conjunction with the production vessel in various buoyant catenary shapes, although rigid steel pipe risers are becoming increasingly attractive.

The main advantage of an FPSO development over other development options, such as TLPs and compliant towers, is that it can offer a fast-track schedule and low CapEx, which is an important factor in the current economic climate. However, unlike a TLP development where direct downhole access is possible, an FPSO development relies upon independent workover operations using either a drilling semisubmersible or a DSV-like vessel offering a cheaper alternative. It can be expected that in the coming years such independent workover activities will be increased. A typical downhole workover system consists of a surface support vessel, a vertically tensioned riser and a subsea well head connector. The riser extends from its top connection at the vessel to a few metres above the seabed where it is connected to the well head system. The riser usually has a main circular cylinder and one or several smaller piggyback lines clamped to the main one for control and other purposes. For such a workover riser system, one of the key design issues is the requirement of top tension. The top tension is affected primarily by the riser's own weight and hydrodynamic forces.

There are other applications in offshore industry where 2 pipes of dissimilar diameters are clapped together with a gap in between. The present design practice, however, often ignores the piggyback line and uses the drag coefficients derived for an isolated circular cylinder. The mean lift force due to the asymmetric orientation of the piggyback riser with respect to waves is entirely unaccounted for. It can be said that for a typical piggyback cylinder system, where the diameter of the larger cylinder is greater than that of the smaller cylinder and the cylinder gap is of the order of the smaller diameter, information on the hydrodynamic forces is particularly limited.

Limited work has been done in the past on 2 cylinders in steady flows. Bearman and Wadcock (1973) carried out an experiment in a wind tunnel on 2 cylinders side by side in a cross flow. The 2 cylinders have the same diameter, and the emphasis of the experiment is on the effect of the cylinder gap on vortex shedding. The Reynolds number is somewhat low at 2.5×10^4. The work concludes that a repulsive mean force acts between the 2 cylinders, and at very small gaps the drag of the cylinders in combination is less that the sum of the drag of the cylinders in isolation. Zdravkovich (1987) reviewed and categorised the disorderly state of various test data on the effects of interference between circular cylinders, concluding that only for 2 cylinders of equal diameter, either in tandem or side by side in cross flow, is there a reasonably complete picture. The amount of information decreases rapidly as the number of cylinders increases or 2 cylinders of different sizes are involved. Baxendale et al. (1985) investigated the hydrodynamic interaction of 2 cylinders having different diameters. The experiment was carried out in a wind tunnel with the 2 cylinder diameters at 8 and 16 mm, respectively, and the Reynolds number based upon the larger cylinder diameter at 1.45×10^4. A series of cylinder gaps are investigated with the minimum distance at 9 mm between cylinder surfaces. The work shows that the orientation and cylinder gap have significant effect upon drag and lift force coefficients.

In contrast to its wide application in the offshore industry, drag and inertia forces on a piggyback cylinder system in oscillatory flows has only been investigated sporadically. Chakrabarti (1982) tested rows of cylinders in oscillatory cross flows and found significant force amplification when the cylinder wall-to-wall gaps are small. Jakobsen (1994) measured the forces on a piggyback pipeline where it is forced to undergo sinusoidal motions in calm water. The results indicate that, due to the cylinder interference, the total force can be increased by as much as 100% in comparison to a simple addition of the forces acting on the 2 cylinders in isolation.

This paper represents an attempt to ascertain the hydrodynamic interference between 2 cylinders in a piggyback arrangement, and

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