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# Experimental investigation of the suppression of vortex induced vibration of two interfering risers with splitter plates

Min Lou [a,*], Zhiwei Chen [a], Peng Chen [b]

[a] *College of Petroleum Engineering, China University of Petroleum (East China), China*
[b] *Yantai CIMC Raffles Offshore Limited, China*

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A B S T R A C T

Marine risers are key equipment in deep-water oil and gas development. They are prone to vortex induced vibration (VIV) in deep water and in strong current environments, and the vibration mechanism becomes more complicated when there is wake interference. Long term VIV causes fatigue damage to the structure. A series of tests were conducted to study the effectiveness of splitter plates in different arrangements in suppressing riser VIV under wake interference conditions. Strain responses in the cross-flow (CF) and in-line (IL) directions were measured and showed a significant reduction in VIV, indicating that the presence of the splitter was effective in suppressing both CF and IL response of the riser. The arrangement of splitter plates plays an important role in VIV suppression, with better suppression effects occurring where $L/D = 1.0$, 1.25, and 1.5 (where L is the transverse length of the splitter plate and D is the diameter of the riser). The spacing ratio is also important for VIV suppression, but the influence varied for different splitter plate arrangements.

## 1. Introduction

With the growing shortage of available oil and gas resources on land, deep-sea oil and gas fields are increasingly being exploited. The marine riser is key equipment in the development of deep-water oil and gas platforms. Ocean currents exert a drag force on the riser due to different pressures upstream and downstream of the riser. Periodic vortex shedding in the wake due to sea currents leads to vortex induced vibration (VIV). VIV in flexible marine pipes is presently receiving considerable research attention as production operations move into deeper waters where structures become more flexible and more sensitive to VIV due to the increase in their length to diameter ratio. VIV is a typical flow/structure interference phenomenon that can cause significant structural fatigue failure and potentially cause catastrophic damage to the integrity of the system and environment. VIV in marine risers is one of the most challenging issues in offshore oil engineering development, and it is essential to use special devices to suppress VIV and improve the fatigue life of the riser.

Increasing attention has been paid to VIV in recent years, both in engineering practice and academia. Iwan (1975) used a semi-empirical method to study the prediction of VIV response. Vandiver (1983) and Vandiver and Chung (1988) discussed VIV of deep-water risers, and investigated methods of VIV suppression. A number of research institutes have performed VIV laboratory and field studies, including the Norwegian Marine Technology Research Institute (MARINTEK) and the Maritime Research Institute Netherlands (MARIN). Many oil companies have also performed independent and in-depth VIV research, including Shell, BP, and ExxonMobil, among others.

Wake interference between multiple risers complicates VIV and aggravates fatigue damage to the riser. In an experimental study, Igarashi (1981) analyzed the flow field of wake interference for different vertical tube spacings and different Reynolds numbers. Other experimental studies (e.g. Sumner, 2010) have found that flow patterns caused by parallel vertical tubes fall into three categories depending on the tube spacing: single vortex street, biased gap flow, and coupled vortex street.

The importance of finding VIV suppression measures is becoming increasingly recognized. Two approaches to VIV suppression in common use are active and passive control. Active control includes real-time monitoring of the flow field and force structure, the use of automated computerized control technology, or the introduction of external disturbance to the flow to control

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[*] Corresponding author.
*E-mail address:* shidaloumin@163.com (M. Lou).

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vortex shedding (e.g. acoustic excitation, suction and injection, cylinder rotation vibration, etc.). Passive control involves changing the surface shape of the structure itself, or adding devices to alter the flow field around the riser to modify the formation and development of vortices or suppress vortex shedding. Zdravkovich (1981) suggested that passive control methods may be divided into three categories: surface protrusions, affecting the separation line or separation of shear layers (e.g. threads, lines, wings, bolts, hemispherical surfaces, etc.); coatings to affect the coil suction layer (e.g. perforations, wire mesh, control rods, axial strips, etc.); and near-wake stabilizers to prevent interaction of the entrainment layer (e.g. banderoles, fairings, splitter plates, guide wings, base bleed, slits, etc.).

One mechanism for VIV suppression for fluid flow past a bluff body is to modify the shear layer interaction in the near wake of the body by attaching a splitter plate in the wake, as explained by Roshko (1955) and Bearman (1965). Apelt et al. (1973) performed experiments with a static cylinder fitted with a splitter plate of length L to a cylinder of diameter D with ratio $L/D \leq 2.0$ in water, in the Reynolds number range of $10^4 \leq Re \leq 5 \times 10^4$. Unal and Rockwell (1987) performed similar experiments in the range $140 \leq Re \leq 3600$ to investigate wake control by a splitter plate. Hwang et al. (2003) studied stationary cylinders with detached splitter plates and showed decreases in lift and drag forces. Assi et al. (2009) demonstrated that control plates allowed to rotate around the axis of an elastically mounted rigid cylinder could be used for suppressing VIV if an adequate rotary stiffness was used. Stappenbelt (2010) studied VIV suppression with splitter plates of different lengths. Gu et al. (2012) researched the stable positions, forces, correlations, and flow structures in the wake of a rigid cylinder fitted with splitter plates of different lengths. Huera-Huarte (2014) showed that VIV amplitude is reduced along with the drag coefficient by up to 50% for the lower velocities investigated.

More recent studies of the use of splitter plates have focused on an isolated riser model, with few considering riser arrays where VIV is complicated by wake interference with the risers themselves. The present study reports a series of experiments investigating VIV suppression by splitter plates attached to two interfering risers. In particular, the influence of the splitter arrangement, the transverse length of the splitter, and the distance between the risers (the ‘spacing distance’).

## 2. Experimental set-up

Model tests were performed in a current flume (Fig. 1) at the Hydrodynamics Laboratory at China University of Petroleum (UPC), Qingdao, to investigate the extent of VIV suppression using splitter plates considering wake interference. The glass sided wave-current tank facility produced well controlled steady flows and gave a complete view of the model.

Two identical riser models were constructed from PMMA tubing with outer diameter $D = 15$ mm, wall thickness $t = 1$ mm, and length $L = 1200$ mm. The underwater length of the riser was 700 mm. The risers were filled with water, providing a mass ratio $m^* \approx 1.1$, the ratio of mass per unit length of the riser model to mass of displaced water. Both risers were positioned vertically with both ends firmly fixed to an aluminum alloy post, allowing the riser to oscillate within two degrees of freedom, i.e., in the in-line (IL) (X) and cross-flow (CF) (Y) directions. Strain gauges were positioned to measure the dynamic strains in each cylinder in both directions (Fig. 2). Changes in the strain signal due to the axial force were canceled out by placing four strain gauges (two in each direction) symmetrically on the outer surface of each cylinder. A waterproof coating was then applied to the instrumented cylinders to protect the strain gauges. The experimental parameters are listed in Table 1.

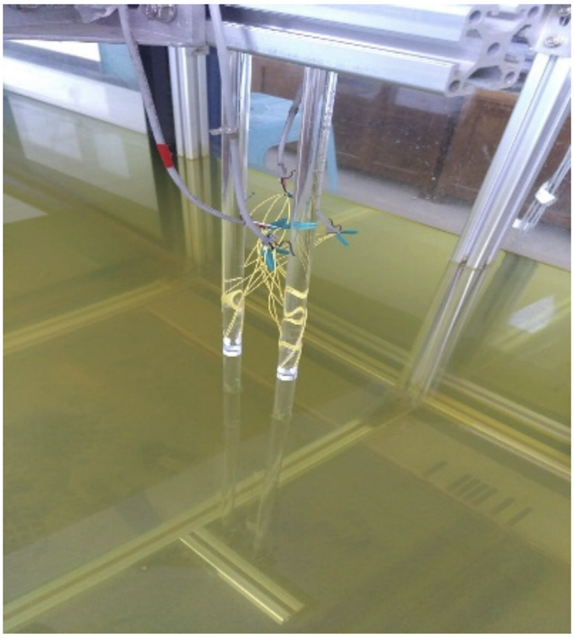

**Fig. 1.** Model test set-up.

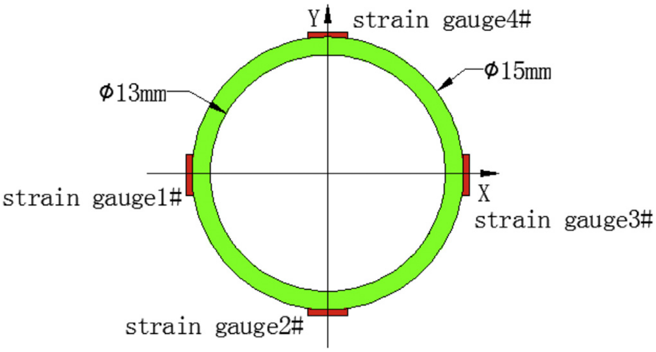

**Fig. 2.** Cross-section of riser model.

**Table 1**
Physical properties of the riser model.

| | |
|---|---|
| Length (m) | 1.2 |
| Outer diameter (m) | 0.015 |
| Inner diameter (m) | 0.013 |
| Wall thickness (m) | 0.001 |
| Modulus of elasticity ($N/m^2$) | $3 \times 10^9$ |
| Mass ratio | 1.1 |
| Length/diameter ratio | 80 |

Prior to the VIV experiment, a free vibration test was performed to determine the natural frequency, $f_n$, of the riser in calm water. An initial displacement was applied to the riser and released, and its subsequent movement in the water recorded. Fig. 3 shows the time history of the free vibration and the corresponding power spectral density (PSD) of the transverse strain. The natural frequency was 3.9 Hz (Fig. 3b).

Fig. 4 shows the arrangement of splitter plates and the main risers. The splitter plates were thin plates (1 mm) positioned centrally on the downstream side of the risers. Their longitudinal length (i.e., in the axial direction of the riser) was 30 cm. Their transverse lengths, L, are given in Table 2. To assess the accuracy of