Applied Ocean Research 51 (2015) 93–116

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Numerical evaluation of passive control of VIV by small control rods

Hongjun Zhu*, Jie Yao

State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu, Sichuan 610500, China

ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form 22 March 2015
Accepted 24 March 2015
Available online 10 April 2015

Keywords:
VIV suppression
Control rod
Vortex shedding
CFD
Simulation

ABSTRACT

Flow past a circular cylinder with multiple small control rods is studied by numerical simulation for $\mathrm{Re_D}$ ranging from 1161.3 to 6387.1. The Reynolds-Averaged-Navier–Stokes (RANS) equations and shear stress transport (SST) $k-\omega$ turbulence model are used to calculate the vortex field, while a fourth-order Runge–Kutta method is employed for evaluating the structure dynamics of the cylinder group. Comparisons with experimental results demonstrate the validation of this method. This study is concerned with the vortex induced vibration (VIV) suppression efficacy of small control rods placed around a main cylinder. The effects of control rod number, diameter ratio, spacing ratio and Reynolds number on the hydrodynamics and vibration responses of the main cylinder are investigated. The reduced percents of in-line and cross-flow amplitudes and the increased percents of the whole cross-sectional area of cylinders and the drag coefficient are used to give a comprehensive evaluation. Results of simulation indicate that placing small rods with appropriate number at appropriate locations can achieve good suppression effectiveness at a wide range of Reynolds number. The numerical result for the case with nine control rods, diameter ratio of 0.15 and spacing ratio of 0.6 shows the best suppression effect among the cases investigated in this study.

1. Introduction

Flow over a circular cylinder is of great importance in many applications such as risers, oil and gas pipelines in deep water, tall buildings, high voltage lines and bridges. A large number of numerical and experimental investigations have been conducted on the wake flows behind circular cylinders, as shown in the reviews by King [1], Sarpkaya [2,3], Bearman [4,5], Sumer and Fredsoe [6], Gabbai and Benaroya [7], Williamson and Govardhan [8,9], and Wu et al. [10], Wu et al. [11]. Alternating vortex shedding presents in the wake over a wide range of Reynolds numbers, resulting in structural vibration, acoustic noise, and significant increases in the drag and lift fluctuations [12–15]. This kind of fluctuations may cause fatigue in the structures and then sometimes lead to failure. Therefore, vortex induced vibration of cylindrical structures is the most interesting concern for engineers.

Many methods have been proposed in order to manipulate the wake flows behind circular cylinders and suppress VIV responses, which are classified as passive, active open-loop and active closed-loop controls [16–18]. Whether there is power input is used to distinguish passive and active controls. While active open-loop and active closed-loop controls are distinguished by whether there are sensors to active feedback. Rotating a cylinder at a certain speed [19,20], oscillating a cylinder in in-line or cross-flow at an appropriate frequency [21,22], steady or time-periodic blowing and suction [23,24], electromagnetic forcing [25], and distributed forcing controls [26] are typical examples for active controls. However, extra energy and relatively complex actuators are needed in active controls, which make it more difficult to implement in real situations. During the past 20 years, passive control methods have been further developed, such as helical strake [27], surface protrusions [28], shrouds [29], splitter plate [30], rear-wake stabilizer [31], and small rods [32,33]. Geometric modifications of cylinder wall are the main methods for these passive controls, which inevitably increase the mass ratio and sometimes increase the drag coefficient (e.g., helical strake). Therefore, few of them are applied on a large scale in practice.

For cylindrical risers in offshore oil and gas engineering, they are generally attached by several auxiliary smaller lines such as water and chemical supply pipes, kill and choke lines, hydraulic control lines, blowout preventer lines and electric cables [34]. These lines can be referred to as small control rods, which may suppress VIV if their arrangement is optimized. Due to its convenient and low-cost merits, flow over multiple cylinders has attracted the interest of a number of investigators. Uniform flow past two identical circular cylinders in tandem [35,36], side-by-side [37] or generally staggered arrangements [38] have been studied extensively using either numerical or experimental methods. Reynolds number and the gap between the cylinders are the two main parameters determining the fluid forces and flow regimes. Wakes behind three

---

* Corresponding author. Tel.: +86 28 83032206.
E-mail address: ticky863@126.com (H. Zhu).

0141-1187/$ – see front matter © 2015 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apor.2015.03.003

identical cylinders arranged in triangular configuration [39], and four identical cylinders arranged in-line [40] or in square configuration [41] are also investigated in the past 20 years. Compared with multiple identical cylinders, little attention is paid to flow past a main cylinder attached by small control cylinders. Zhao et al. [32] have performed numerical simulation of flow past a main circular cylinder with one small control cylinder. The effects of the position angle of the small cylinder and the gap ratio between the two cylinders on force coefficients, pressure distributions and flow patterns are discussed. They found that the mean drag force and the root mean square lift force can be reduced if the small rod is placed in an appropriate position. Rahmanian et al. [42] have conducted similar simulations of two-degree-of-freedom vortex-induced vibration of two mechanically coupled cylinders with a diameter ratio of 0.1. The gap ratio and the angular position of small rod when the maximum and minimum vibration amplitudes occur are identified. Recently, Wu et al. [10] and Wu et al. [11] have performed experimental tests of vibration amplitude of a main circular cylinder attached by four identical small rods. VIV responses are reduced for Reynolds numbers ranging from 2400 to 7600. However, due to the complication in arranging small rods and difficulties in measuring vibration amplitude, the experiment is limited to only one diameter ratio, three gap ratios and four control rods.

In order to further understand VIV suppression by multiple control rods, in the present study, comprehensive numerical simulations of two-degree-of-freedom VIV are conducted to investigate VIV suppression efficacy of small control rods placed around a main cylinder using computational fluid dynamics (CFD) models coupling with a fluid–structure interaction (FSI) computational method. The effects of the control rod number, the diameter ratio, the gap ratio and Reynolds number are discussed in detail.

2. Problem description

Fig. 1 shows the configuration sketch of flow over a main circular cylinder with small control cylinders arranged circumferentially uniformly. A rectangle computational domain ($30D \times 16D$, D is the diameter of the main circular cylinder) is adopted for the numerical simulations. The main cylinder ($D = 38.1$ mm) is placed at $8D$ downstream the inlet boundary and $22D$ upstream the outlet boundary. Both lateral boundaries are located 8 times the diameter of the main cylinder. An $8D \times 8D$ square accompanying moving zone around the main cylinder is defined as shown in Fig. 1. Small control rods with the same diameter of d are placed around the main cylinder with uniform angle interval (α) and gap spacing (the surface-to-surface distance between the main cylinder and each control rod, G). For three control rods, the angle interval is 120°, which is 90° for four control rods, and the rest can be deduced by analogy. Fig. 1(b) shows the cases of three, four, eight and nine control rods. No matter how

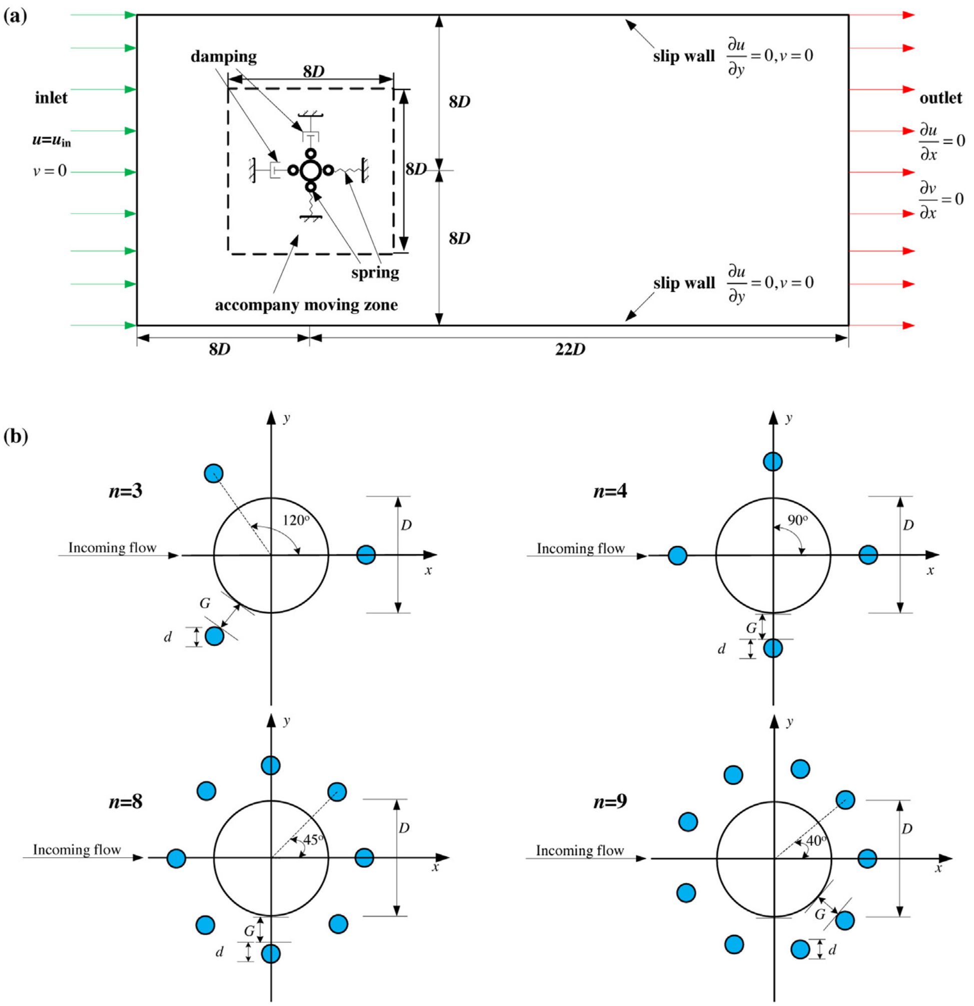

Fig. 1. Sketch of fluid flow over a circular cylinder with small control cylinders: (a) computational domain with boundary conditions; (b) the relative location of the control cylinders and the main cylinder at different number of small rods (n is the number of rods).