Marine Structures 52 (2017) 94–107

Contents lists available at ScienceDirect

Marine Structures

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

A numerical investigation on capturing the maximum transverse amplitude in vortex induced vibration for low mass ratio

Zhuang Kang, Wenchi Ni*, Liping Sun

Deepwater Engineering Research Center, Harbin Engineering University, Harbin 150001, China

ARTICLE INFO

Article history:
Received 7 June 2016
Received in revised form 19 November 2016
Accepted 28 November 2016

Keywords:
Two degrees of freedom
VIV
Turbulence model
Acceleration
Numerical simulation

ABSTRACT

According to Jauvtis and Williamson's experiment, when the mass ratio is 2.6, the maximum transverse amplitude of the cylinder reaches 1.5 *D* in the super-upper branch. Many researchers have tried to capture the maximum transverse amplitude in numerical simulation. However, according to the existing references, few of the numerical results can reach such amplitude and the maximum vibration amplitudes are obviously smaller than the experimental values. In order to get more accurate results, a modified SST turbulence model is applied for the numerical simulations based on OpenFOAM. The influence of the magnitude of inflow acceleration in numerical simulation is also investigated. Firstly, the performance of modified SST model is tested by example of flow around a circular cylinder. Secondly, the appropriate inflow acceleration magnitude is determined by analyzing the numerical response under different acceleration magnitudes, finding that the inflow acceleration must be less than 0.017 per normalization time in order to capture the maximum transverse amplitude. Then, the two degrees of freedom vortex induced vibration of a cylinder with a mass ratio of 2.6 and reduced velocity from 2 to 14 is simulated. The numerical results are compared in detail with the experimental data and the maximum transverse amplitude, mutations of phase angle between lift force and displacement, the characteristics and change trends of the trajectory as well as the "2T" vortex model are captured clearly. The results show that the maximum transverse amplitude can be captured more accurately with modified SST turbulence model and appropriate inflow acceleration value.

1. Introduction

Vortex-induced vibration continues to receive much attention due to its frequent occurrence in engineering practice, especially in marine and coastal applications, such as marine cables, risers, hawsers and mooring lines. From an engineering perspective, a practical and reliable forecast method is required for the economic and safe design of such structures for estimating the amplitudes, frequencies and forces in the in-line and transverse directions as well as the vortices shedding from these structures [1], thus providing valuable basis for dynamic response, nonlinear impact, fatigue analysis and reliability assessment of marine slender bodies [2,3].

* Corresponding author. College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, Heilongjiang, China.
E-mail address: niwenchi@hrbeu.edu.cn (W. Ni).

http://dx.doi.org/10.1016/j.marstruc.2016.11.006

With the improvement of computer performance, the research on numerical simulation of vortex induced vibration has been deeply studied. There are many factors that affect the accuracy of numerical simulation, and the turbulence model is one of the most important factors. According to the different methods to solve Navier-Stokes equations, the method of numerical simulation can be divided into Direct Numerical Simulation (DNS), Large Eddy Simulations (LES) and Reynolds Averaged Navier-Stokes (RANS). DNS and LES methods have higher calculation accuracy. Although gigantic progress using these methods has already been achieved in numerical simulation of unsteady separated flows at low Reynolds number [4,5], its application as tools for engineering predictions has been restricted due to the high cost inherent in being limited by the need to use very fine grids and small size of time steps to simulate a significant portion of the turbulence energy spectrum [6]. RANS is still considered to be the practical approach for engineering problem among which, SST turbulence model has higher precision and reliability of the calculated results compared to other Reynolds averaged model. However, its performance seems to be underperforming in computing flows where vortex shedding occurs. In engineering practice, the maximum amplitude is one of the most concerned parameters for designers, but the existing numerical simulation method often fail to accurately capture it.

Celik and Shaffer [7] calculated the long time averaged flow past a circular cylinder using the standard $k-\varepsilon$ model and got poor agreement with experimental data. Franke [8] simulated the vortex-shedding flow past a square cylinder at $Re = 22000$ with the $k-\varepsilon$ eddy-viscocity model and a Reynolds-stress equation model. He found that vortex shedding was ultimately suppressed and a steady−state solution obtained instead. Atlar [9] evaluated four well-known RANS-based turbulence models on the computation of the near-wake flow of a circular cylinder, pointed out that SST turbulence model appears to be rather encouraging to produce more realistic results, but till not satisfying enough. Stringer [10] also reported poor agreement with circular cylinder data when using SST turbulence model. Numerical simulation results of vortex induced vibration seem to be worse. According to Jauvtis and Williamson's experiment [11], when the mass ratio is 2.6, the maximum transverse amplitude of the cylinder reaches $1.5D$, which has been seldom captured in numerical simulation. Pan [12] failed to capture the upper branch in simulating the response of an elastically mounted rigid cylinder at low mass damping constrained to oscillate transversely to a free stream with the SST k-ω turbulence model. Similarly, the upper branch is also not observed in Sanchis' report [13]. Srinil [14] carried out an experimental and numerical investigation of a two-degree-of-freedom VIV of a flexibly mounted circular cylinder with variable in-line-to-cross-flow natural frequency ratio, and the lateral amplitude of the numerical simulation is much smaller than the experimental value.

Reasons for RANS-based turbulence model to perform poorly in predicting the separation flow has been deeply investigated. Medic [15] found that the standard turbulence closure have shortcomings in the prediction of unsteady separated flows due to their origins in the use of dissipative discretization schemes, which leads to numerical diffusion errors that are sufficiently large as to suppress the vortex shedding process. Furthermore, Younis [16] put forward that turbulence model should take into account the effects of the interactions between the large-scale organized periodicity of the mean flow and the random, small scale high-frequency motions that characterize turbulence, which is reflected in none of the standard form of RANS-based turbulence models. According to the above theories, an improved SST turbulence model which explicitly accounts for these interactions is proposed.

Besides, research show [17,18] that there is hysteresis in the vortex induced vibration response, and the maximum amplitude of vortex induced vibration will occur in the acceleration process. Therefore, a self-compiled script is adopted to make the flow velocity increases continuously in the process of simulation, with purpose to capture the maximum amplitude. Till now, little research has been done in investigating the relationship between acceleration magnitude and transverse amplitude response. In order to search the proper inflow acceleration magnitude, the acceleration process of two degrees of freedom vortex induced vibration of a cylinder with velocity from 0 to 6 under different inflow acceleration magnitude is simulated and the transverse amplitudes and frequencies are analyzed.

Generally, in this paper, a modified SST turbulence model is applied for the numerical calculations based on OpenFOAM. Considering that the risers, most frequently suffered from vortex induced vibration are always with low mass ratio, a cylinder with low mass ratio is investigated. Firstly, the performance of modified SST model is tested by example of flow around a circular cylinder. Secondly, the appropriate inflow acceleration magnitude is determined by analyzing the numerical response under different acceleration value, finding that the acceleration must be less than 0.017 per normalization time in order to capture the maximum amplitude. Then, the two degrees of freedom vortex induced vibration of a cylinder with a mass ratio of 2.6 and reduced velocity from 2 to 14 is simulated. The numerical results are compared in detail with the experimental data including lift and drag coefficients, amplitude, frequency ratio, phase angle, trajectory and vortex model.

2. Numerical method

2.1. Modified method

The dimensionless form of standard SST model [19] can be expressed as follows:

Kinematic Eddy Viscosity