Vortex Induced Vibrations Analysis Across a Tapered Tower

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Abstract: ***In this paper, 3D flow past a long tapered tower is examined. A tapered tower is described by the taper ratio. Tapered cylinders are a good description of many structures, like wind turbine tower e.t.c. Similar to the flow around cylinders, the Reynolds number is the important flow parameter, and the Strouhal number represents the shedding frequency. These flow patterns are difficult to predict and measure experimentally very time dependent nature. The governing Navier-Stokes equations with suitable boundary conditions are solved by using a CFD solver FLUENT (16.0). The computational mesh is created using ICEM. The flow fields are presented by streamline and velocity magnitude. Vortex induced vibration simulations are performed to capture vortex shedding frequency by using lift coefficient Cl data, drag coefficient and dimensionless strouhal number can also be obtained using viv simulation results .***

Keywords: Tapered, Wind turbine, Shedding Frequency, Strouhal Number

1. Introduction

Vortex induced vibrations (VIV) are known to contribute significantly to fatigue damage of wind turbine tower [1]. However, important uncertainties are still present when it comes to methods for calculation of damage for wind turbine towers. The uncertainties are associated to fundamental understanding of vortex induced vibrations in situations where a large number of frequencies may become active. At least four different approaches are today used [2]:

- One frequency is assumed to dominate, and the response is assumed to be harmonic with a fixed amplitude
- The response is assumed to take place at one frequency, but the amplitude is controlled by a low-frequency envelope process
- A number of response frequencies act simultaneously. Each of these frequencies are harmonic, and the phase between the components are random. This approach might be characterized as "concurrent frequencies", or "space sharing" with reference to the definition of excitation zones on the structure without overlaps.
- A number of response frequencies compete in time and dominates consecutively. The response is always assumed to be harmonic, but the frequency will vary from one period of time to the next. This approach is often referred to as "consecutive frequencies" or "time sharing". Excitation zones on the structure may overlap according to this approach.

2. Simulation Model of the Wind Turbine Tower

A. CFD and fluid model

The flow of fluid and transport process is governed by conservation laws i.e. law of conservation of mass, momentum and energy. Conservation laws are work out collectively according to the physic of problem which results in collection of partial differential equations, that resulting equation are governing equations of the flow. The following part consist of the theoretical knowledge of CFD and the method use for this particular case.

B. Mass conservation principle and equation of continuity

The law of conservation of mass is define as that the rate by which mass is increased in a infinitesimal region of the fluid continuum equalizes the total flow of mass into a infinitesimal region of the fluid continuum. By applying this principle to a flow model resulted in a equation called equation of continuity [20]. The equation of continuity for a compressible flow can be written as follows

$$\frac{\delta P}{\delta t} + div(\rho u) = 0 \qquad (1)$$

where u represents flow velocity ρ represents the density.

C. Motion-induced wind loads

Structural motion induces a feedback to the air flow generating the cross-wind load on the structure. For flexible structures these motion-induced wind loads are significant. The concept of aero elasticity covering these load contributions is discussed below. Structural motion interacts with the wind field in such a way that the dominating vortex shedding frequency synchronizes with the structure’s natural frequency. This phenomenon is called lock-in. Many experiments have been made in order to determine the influence of structural motions on the correlations of the cross-wind loading. The results of these experiments show that increasing vibration amplitudes cause an increase of correlation length. The above-mentioned properties of lock-in and motion-dependent correlations are related to the aerodynamic cross-wind loading caused by the structural vibrations.

D. Different cases of simulation

Initially, models of both flow and solid domains are established with proper dimensions. Design Modeler is used as a for modeling the geometries. The mesh of fluid domain are generated using ICEM and the finite element mesh is created by ANSYS Meshing. The simulation setup includes necessary steps such as defining the material properties, boundary conditions and solver setup for the three different models. At the end of the simulation setup, the fluid model consists of one mediums (air) the wind passes the wind turbine tower, whereas the structure is a tapper cylinder with one ends fixed in ground. A simple sketch of a wind approaching the tapper cylinder is shown in Figure 1.

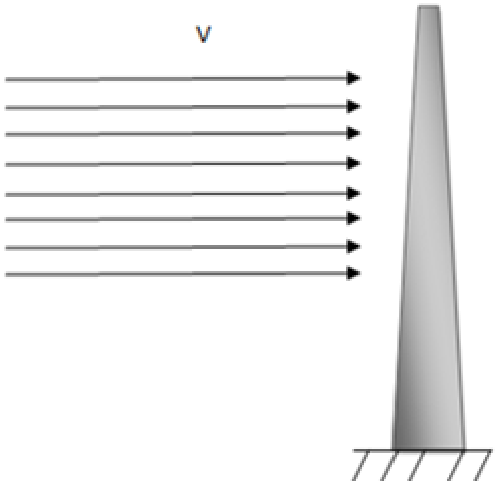

Figure 1: Wind approaching to the tapper tower

These cases are formed by varying the taper angle but keeping the thickness and Young's modulus of the material are same for all case. The following three cases have been finally selected to reach reasonable conclusions from the work.

Table 1: Different cases for VIV Simulations

	Length (m)	*D Down (m)*	*D up (m)*
Case 1	*69*	*5*	*3*
Case 2	*69*	*4.2*	*2.5*
Case 3	*69*	*3.8*	*2.3*

3. Results and Discussion

The Fast Fourier Transform (FFT) is implemented to calculate the frequencies spectrum of f_v as indicated in Figure shown below. Figure (2 to 10) indicates the result of the measurements of the VIV simulation by varying taper angle of wind turbine tower at wind speed V=14,12,10 m/s. According to the VIV simulations, it was found that the peak vortex shedding frequency is (0.833 Hz) at V=14 m/s..Similarly from (Figure 5,6,7), it was found that the peak vortex shedding frequency is (1.33 Hz) at V=14 m/s and from (Figure 8,9,10), it was found that the peak vortex shedding frequency is (1.714 Hz) at V=12 m/s .

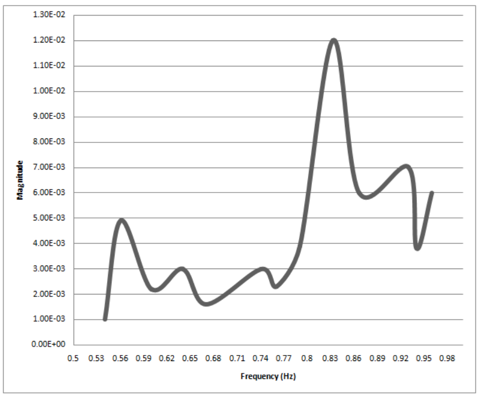

Figure 2: Frequency vs. Magnitude at V=14m/s (case 1)

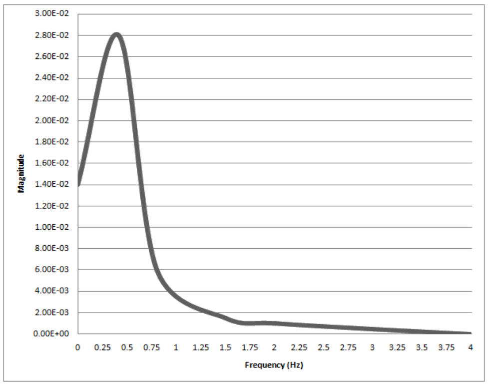

Figure 3: Frequency vs. Magnitude at V=12m/s (case 1)

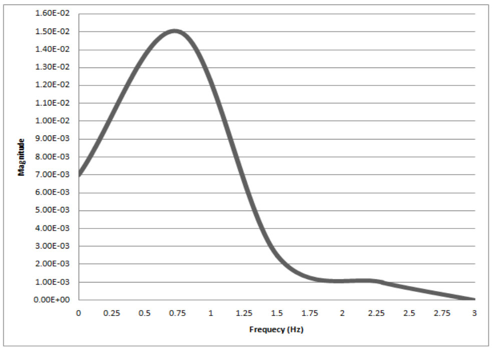

Figure 4: Frequency vs. Magnitude at V=10m/s (case 1)

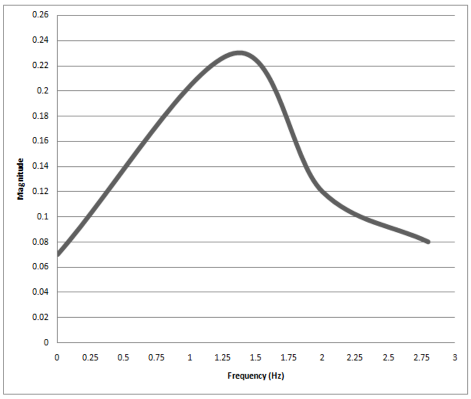

Figure 5: Frequency vs. Magnitude at V=14m/s (case 2)

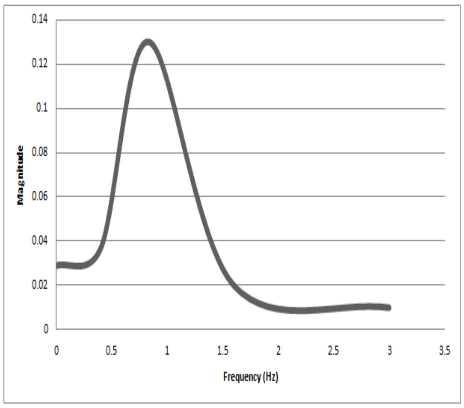

Figure 6: Frequency vs. Magnitude at V=12m/s (case 2)

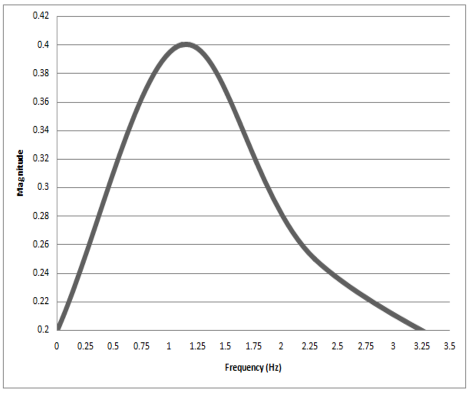

Figure 7: Frequency vs. Magnitude at V=10m/s (case 2)

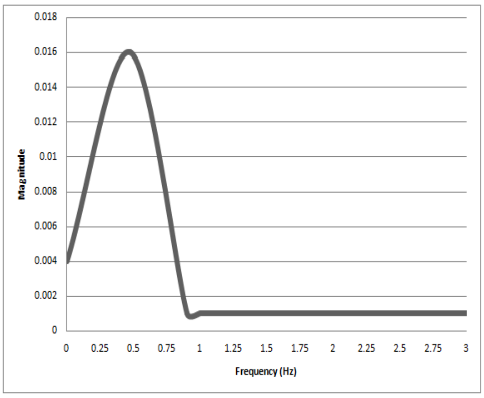

Figure 8: Frequency vs. Magnitude at V=14m/s (case 3)

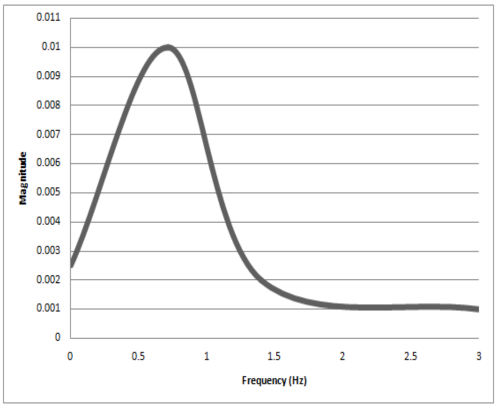

Figure 9: Frequency vs. Magnitude at V=12m/s (case 3)

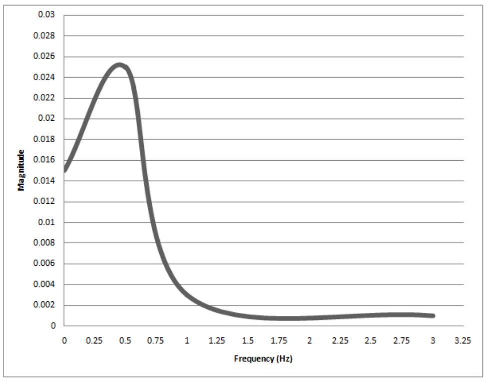

Figure 10: Frequency vs. Magnitude at V=10 m/s (case 3)

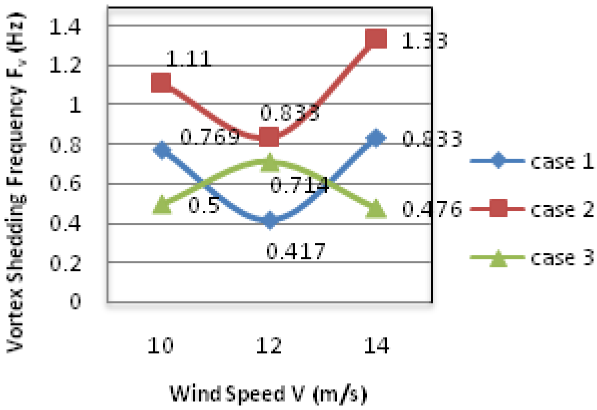

Figure 11: Vortex Shedding Frequency Fv (Hz) Vs Wind Speed

4. Conclusion

The CFD analysis has been carried out on tapper tower to understand the vortex induced vibration behavior by varying tapper angle but keeping the tapper ratio same. As from VIV simulation results shown in figure 11 it can be observed that for case 1 the peak vortex shedding frequency can be seen for V=14 m/s and for case 2 the peak vortex shedding frequency will be observed for V=14 m/s but for case 3 peak vortex shedding frequency will be at V=12 m/s .So from these simulation results it can be concluded that if tapper angle will be decreased than vortex will dislocate at V=14 m/s results in decrease in shedding frequency. These analysis are helpful for further structural simulation as from these analysis we get better understanding about peak vortex shedding cases and further analysis can be done to capture the response of the structure due to wind loads.

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