Numerical study on Modal Analysis of a typical bridge section with the influence of Aeroelastic effect

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Abstract: *Due to the increase in the number of vehicles, transportation management is achieved through the construction of bridges. This article discusses the vibrational effect in the design of bridges. In the structural design of the bridges proper planning is necessary, as gusts may occur, leading to aeroelastic instabilities. In this article a typical bridge is designed using the design software CATIA and a numerical simulation using analysis software ANSYS. Further, the aeroelastic phenomenon involved in coupling of Fluid Structure Interaction is discussed. The results of Mode shape show vortex-induced vibrations which can lead to Flutter.*

Key Words: *Bridges, Numerical analysis, Fluid Structure Interaction, Aeroelasticity*

1. INTRODUCTION

Bridges play a major role in the field of transportation, so constructing them in a more efficient manner also plays a major role by taking into consideration of all the external and internal factors that can damage the constructed bridge. Proper analysis and other precautions should be taken before constructing one. One of the factors that can damage or even collapse the bridge is the aeroelastic phenomenon. A bridge should be capable of withstanding all kinds of loads that happen when a strong wind blows over it. Due to aero elastic loads the bridge tends to vibrate and the end result will be similar to Tacoma bridge disaster.

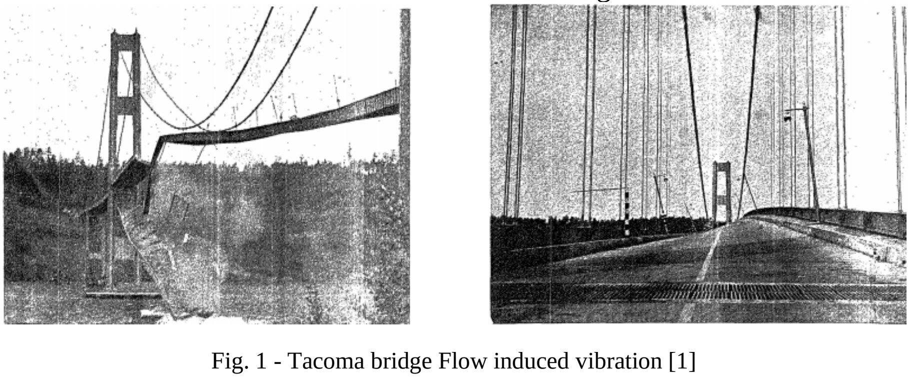


Fig. 1 - Tacoma bridge Flow induced vibration [1]

During 1940 a bridge called Tacoma Narrows Bridge, has been affected due to vibrations, [2]. The image is shown in the figure above. Primary stress and vibration due to flow-induced aerodynamic forces is the main reason. The main reason is stress and vibration due to flow-induced aerodynamic forces. The phenomenon known as the aerodynamic flutter is the major cause for the collapse of the bridge. The response characteristic of heavy gust induced vibrations on the bridges has been investigated [3]. Further the investigation of frequencies, vibration and mode shapes has been carried out [4]. In real time the bridge is fixed at either ends likewise in this analysis the bridge in fixed at both the ends. Then analytical and experimental modal analysis and its applications were proposed [5]. Due to the development in composite materials, fiber-reinforced polymer composite bridge has been studied using experimental set up modal tests and simulation using finite element models [6]. The aeroelastic response of bridge has been carried using computer modeling and reported [7]. The utilization of mass dampers to suppress flow-induced vibration on bridges was studied [8]. The linear aeroelastic analysis on bridges was discussed [9].

2. VIBRATION OF BRIDGES

In this article a typical bridge with truss support is designed and simulated for aerodynamic flutter and analyzed for various modes of vibration.

$$m\ddot{x} + c\ddot{x} + kx = F\,cos(\omega t) \quad (1)$$

The vibration analysis of a bridge is based on the linearization of the equation of motion. This analysis includes eigenvalue analysis and the natural frequencies of the bridge are found, so-called fundamental modes. The natural frequency of the induced vortices in the von Karman vortex street is called the Strouhal frequency, which is given by

$$\frac{f_s D}{U} = S \quad (2)$$

Here, U is flow velocity, D is a characteristic length and S is the dimensionless Strouhal number, which depends on the body. If Strouhal frequency is equal to one of the natural vibration frequencies of the bridge it leads to resonance. The natural frequencies of the bridge is given by

$$2\pi f_s = \omega \quad (3)$$

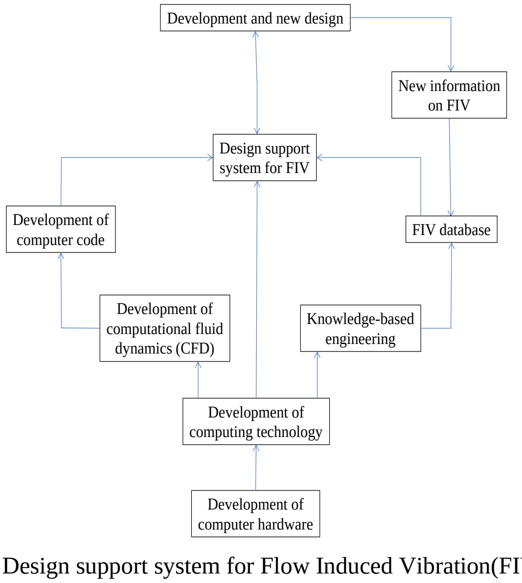


Fig. 2 - Design support system for Flow Induced Vibration(FIV) [10]

The methodology in Figure 2 represents the design support of the flow induced vibrations, which is a major problem due to the aeroelastic instabilities.

The evolution in Computational Fluid Dynamics(CFD) plays a major role in flow induced vibrations.

3. CONDITIONS FOR FAILURE

The failure of a bridge may cause in various ways but the most noted fact is due to the aeroelastic flutter and resonance.

Flutter [11] is a phenomenon encountered in flexible structures subjected to aerodynamic forces and elastic force.

This includes the multiple application such as aircraft, buildings, telegraph wires, stop signs, and bridges.

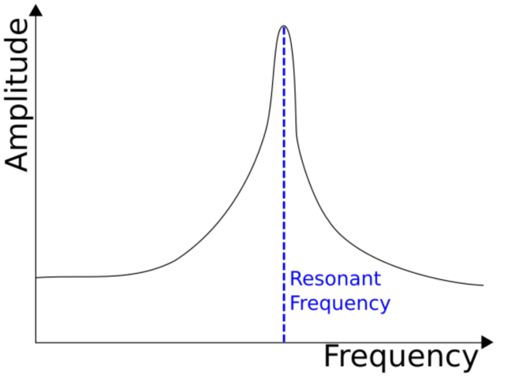


Fig. 3 - Resonance amplitude

Another factor is the resonance, which is a phenomenon in which a vibrating system oscillates with greater amplitude at specific frequencies.

Frequencies [12] at which the response amplitude is a relative maximum are known as the resonance frequencies of the system.

The applications such as the areas of MEMS, clock oscillators and ultrasound transducers were used [13].

4. DESIGNING AND NUMERICAL ANALYSIS

For the analysis of the bridge a typical bridge of length 100mm and height 50mm is designed using CATIA software, as shown in figure 4; it is assumed to be a prototype of a real time bridge.

ANSYS 18.1 is used for the analysis, the bridge is loaded into the analysis software and as mentioned earlier both the ends of the bridge are fixed.

The bridge is simulated under aeroelastic force and then allowed to vibrate. During this vibration the bridge is noted for various modes of vibration.

Monte Carlo approach is utilized to find the natural frequency that encompass model simulations [14].

The evaluation of an extended set of experimental data on flutter derivatives were validated [11]. Figure 5 depicts the flutter calculation procedure with Fluid and Structural Interaction.

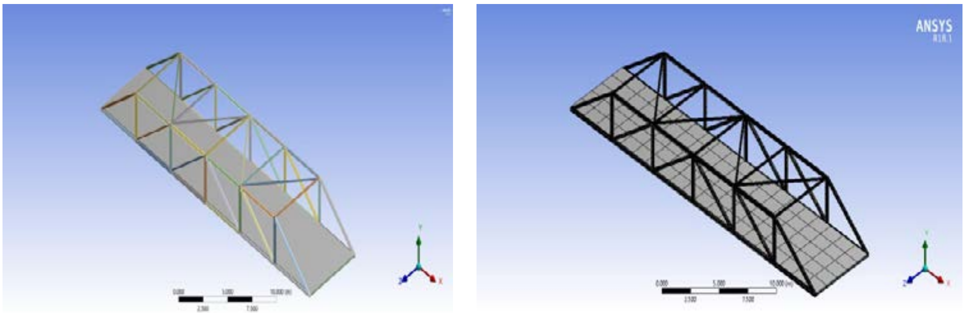


Fig. 4 - Computer Aided Design of a Typical bridge structure and grid generation

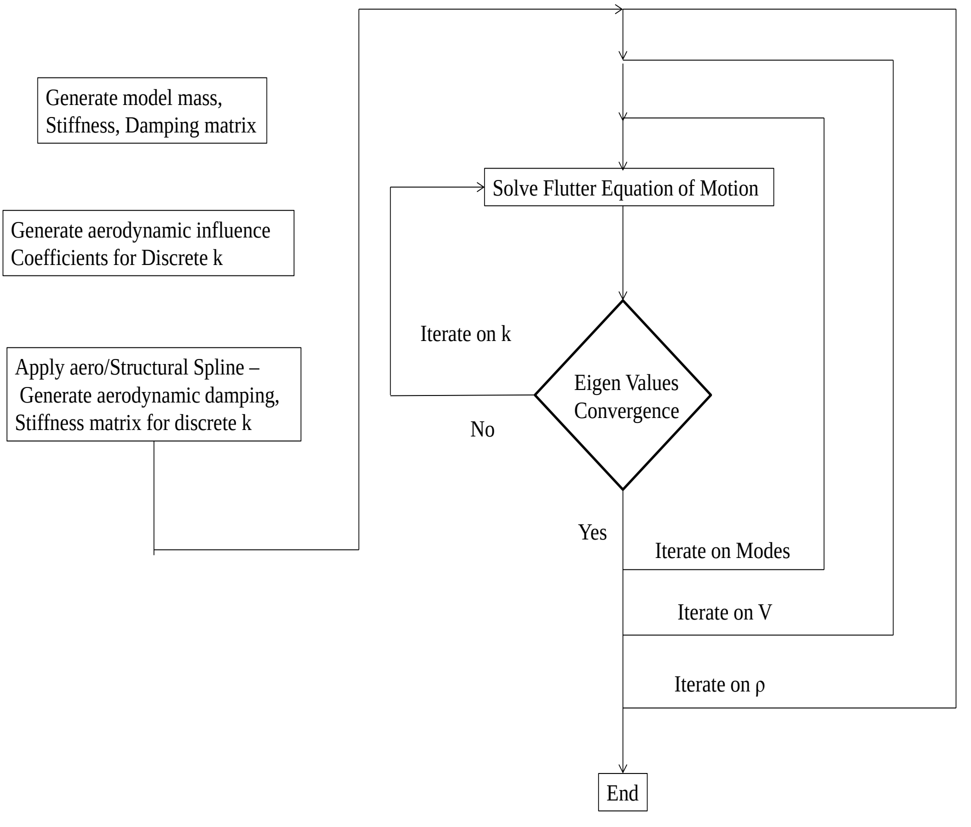
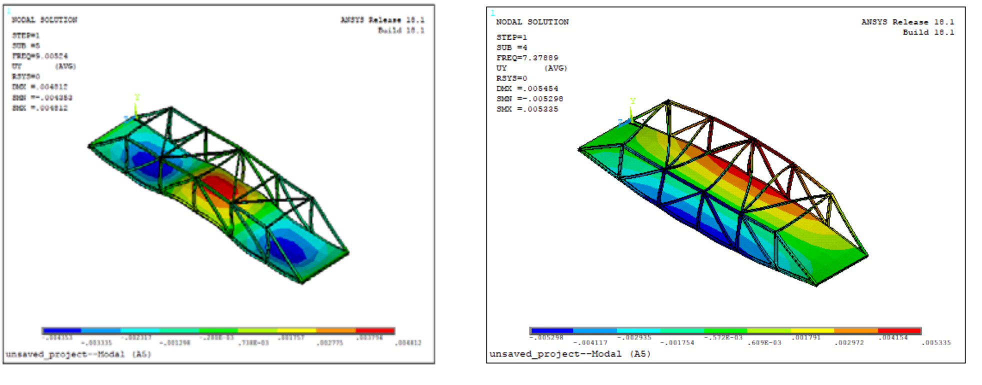


Fig. 5 - Flow diagram for Solution of Flutter Equations of Motion [10]



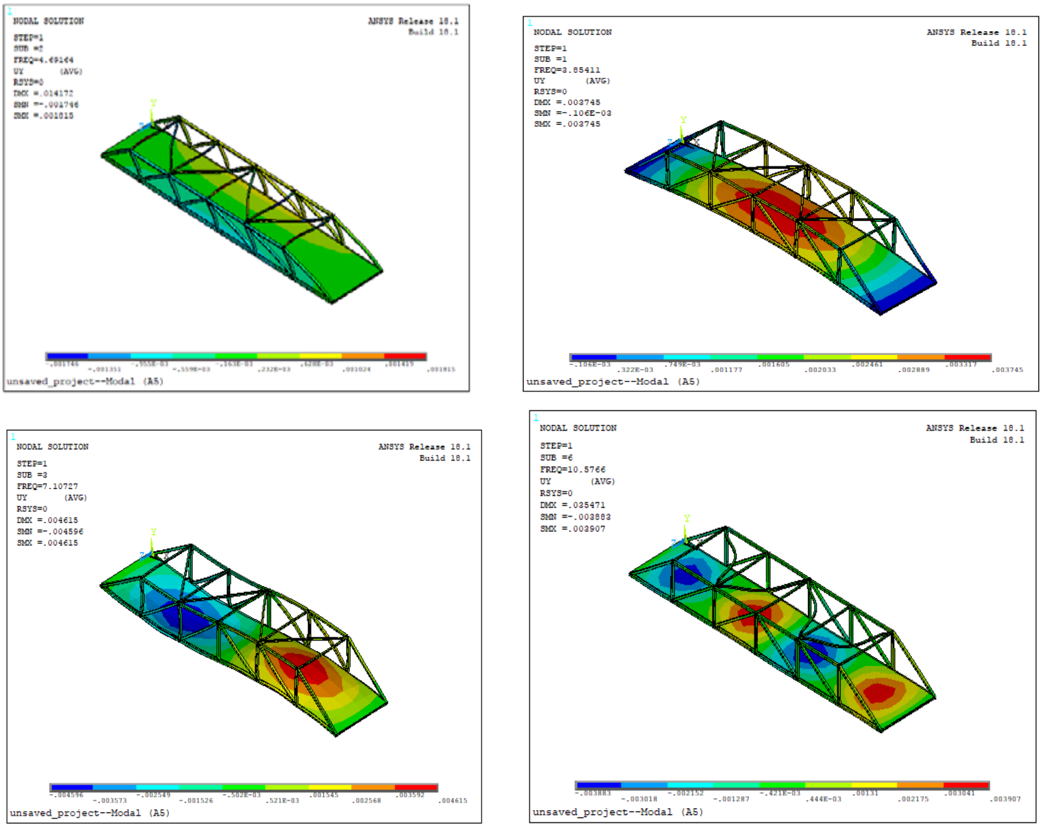


Fig. 6 - Mode Shapes of the bridge design

The results shown above are the Mode shape of the typical bridge design. The design of the bridge is largely influenced by the flow-induced vibration. Further, when the exiting frequency matches with the natural frequency, the resonance occurs. 3D Large Eddy Simulation of turbulence model has been used for the basic configuration of the bridge section [12]. Aerodynamic instability of a bridge section model has been analyzed [15]. The figure shows the maximum stress at the various points for different mode shapes.

5. CONCLUSIONS

In practice it is not always possible to prevent or eliminate flutter by the use of coupling terms. However, by increasing structural stiffness of the bridge by dampers, although carrying the penalty of increased weight, we can raise the value of flutter speed. Further, the design of bridge should be carried considering the influence of the effect of aeroeleasicity.

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