Numerical Prediction of Vortex Induced Vibration and Control of Box Girder Bridge Section Using Aerodynamic Countermeasures

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INTRODUCTION

Safety of long span bridges against wind loads is being of primary concern during design process. Wind-induced phenomena, particularly the vortex-induced vibration (VIV) becomes critical for the safety and serviceability of long span bridges[1]. The selection of basic girder shapes is based on structural and economical issues that may not have optimal aerodynamic efficiency. As a consequence, long span bridges are often subjected to VIV, examples of which are Trans-Tokyo Bay Bridge[2] and Storebælt Suspension Bridge[3]. A large number of aerodynamic countermeasures (ADMs) are often tested to choose suitable measures[3] because the efficiency of such measures is dependent upon geometrical configuration of bridge sections[2]. Previous experimental studies[2,3] lack information on vibration suppression mechanism of such measures and don't provide any guidance to select countermeasure for bridges experiencing similar problem. Recently, some numerical works have shown prediction of VIV of bridge sections. However, in these studies[4,5],section details were ignored due to their smaller sizes, i.e., 1:100 of section depth. At present, inclusion of such small details is highly desirable to i) investigate the influence of aerodynamic counter measures on the flow condition around bridge sections and, ii) clarify the vibration control mechanism. This study aims to provide a comprehensive investigation to clarify the mechanism of reduction in amplitude of VIV by ADMs for box girder bridge section using LES model. The influence of aerodynamic measures on unsteady aerodynamic characteristics of bridge section is analyzed, and flow visualization is employed to examine the modified flow conditions around bridge section in presence of ADM.

NUMERICAL APPROACH

Large Eddy Simulation (LES) turbulence model that can capture turbulence characteristics, which are unsteady and three-dimensional in nature, is used in this study. Unstructured finite volume method using collocated grid was used for the calculation purposes. Central difference scheme for convective term and second order implicit scheme for unsteady term were used to discretize the basic equations. The oscillation of models is achieved by using the sliding mesh technique.

MODELING AND BOUNDARY CONDITIONS

The computational domain used in this study for box girder section (B/D=3.84) with different counter measures is shown in Fig. 1. An enlarged view of the geometrical configuration and meshing in vicinity of countermeasures are summarized in Fig 2. To capture the flow characteristics, fine mesh size is required in regions close to bridge section where ADM and other attachments are installed. Therefore, the domain is divided into several zones to deal with the complexity of geometry as shown in Fig 2d. Model sections are subjected to heaving oscillations to simulate unsteady lift force and free vibration cases. A sliding mesh technique with non-periodic grid interface is employed to allow heaving oscillations of bridge sections.

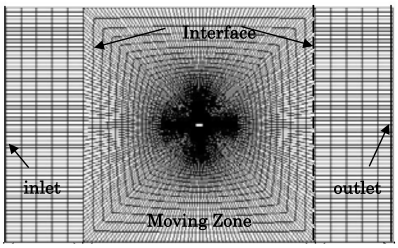

Figure 1 Computational domain around the bridge section

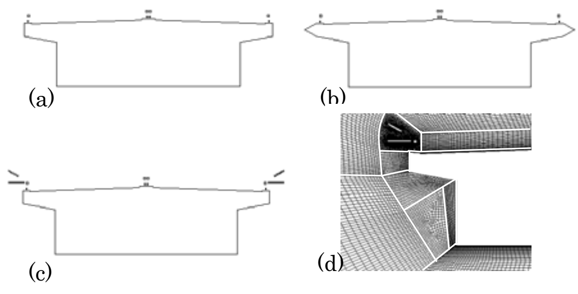

Figure 2 Geometry of section a) Sec, b) Sec+ F, c) Sec+DF and, d) mesh around complex geometry of Sec+DF

RESULTS AND DISCUSSION

Unsteady Lift force in Presence of countermeasures

Forced oscillation simulations were carried out by subjecting moving zone to the sinusoidal amplitude at desired frequency. The amplitude of oscillation was kept 0.02D for all cases. In addition, to avoid any effect arising from change in Reynolds number (R_N), the oscillatory frequency is changed to increase the reduced velocity. The unsteady lift history is decomposed using frequency response analysis (FRA) into real (C_{LR}) and imaginary (C_{LI}) components that corresponds to negative aerodynamic damping. Then lift component (C_L) represents the FRC corresponding to occurrence of VIV. Fig 3(a,b) shows that negative aerodynamic damping occurs for bridge section with and w/o fairings, and a spike is observed for C_L. Whereas, use of double flap did not show sharp spike for C_L that represents a rather smaller negative aerodynamic damping (Fig 3c). This decrease in FRC for different ADM also indicates the severity of the instability caused by VIV. The reduced velocity corresponding to maximum negative aerodynamic damping, obtained by FRA of unsteady lift force, is identified as U_{cr} and the free vibration analysis is carried out for the velocities close to identified reduced velocities.

Keyword: Vortex induced vibrations, Aerodynamic counter measures, Aerodynamic damping , Box girder bridge, LES

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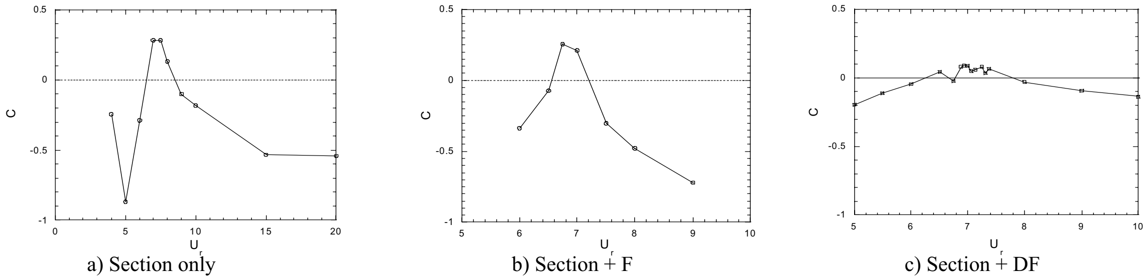
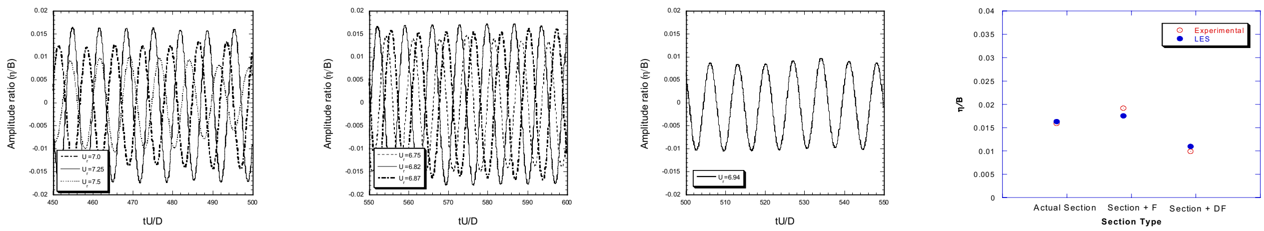


a) Section only b) Section + F c) Section + DF

Figure 3 Variation of unsteady lift components with reduced velocity for various bridge sections

Reduction in amplitude of vibration by aerodynamic measures

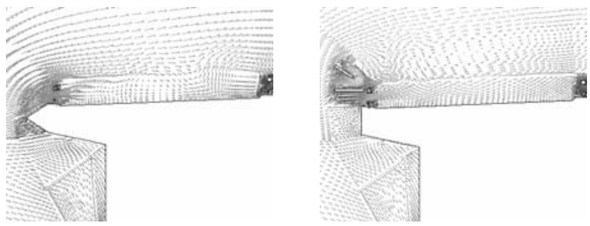
For the bridge sections with and without fairing, rather large number of free vibration tests was required to obtain the maximum amplitude of vibration within the identified range of reduced velocities. For section only case, maximum amplitude of vibration occurred at U_r=7.25 as shown in Fig 4a. For section with fairing (F), large amplitude of vibrations are observed for the identified range of U_r, where maximum amplitude occurs at U_r=6.82. Comparison of normalized amplitude history, Fig 4b, shows that even a small change in reduced velocity results in smaller amplitude. However, for bridge section with DF, the identified reduced velocity resulted in maximum amplitude of vibration, which is almost half of amplitude of section with and w/o fairing, as shown in Fig 4c. The use of fairing tends to increase amplitude of vibration, while double flap has helped controlling such vibrations. Figure 4d shows a good agreement between the experimental and numerically predicted amplitude of vibrations.



a) Bridge section only b) Bridge Section + F c) Bridge Section + DF d) Maximum amplitude ratio(Exp[2])

Figure 4 Amplitude of Bridge Section under VIV with and without aerodynamic measures

The reduction in amplitude by the double flap can be explained by examining the velocity flow vectors around the bridge sections with ADMs. The wind velocity at the leading edge increases in presence of fairing. Thus intensifying the shear layer, and strong vortex formation is observed on upper surface (Fig 5a). In addition, handrails disturbed the on coming flow, and velocity jet formation between handrails is observed. On the other hand, use of the double flap has forced air flow towards upper surface and suppresses generation of vortex on the upper surface by disturbing the formation of shear layer and thus reducing lift force acting on the section (Fig 5b).



a) Section + F *(η=0,U_r=U_{cr})* b) Section + DF

Figure 5 Velocity vectors on wind ward side of bridge section

CONCLUSIONS

Investigation on vortex induced vibrations and suppression mechanism of box girder bridge section in presence of aerodynamic countermeasures is pursued by means of 3D LES model. The predicted amplitudes of vibration in presence of aerodynamic countermeasures are found in very good agreement with those of experimental studies. Flow visualization has shown that use of double flap caused disturbance to the shear layer and generation of strong vortex on upper edge diminishes. However, use of fairing helps intensifying the vortex formation on upper surface leading to large amplitude of vibration. Forced vibration testing has shown that aerodynamic measures drastically alter the aerodynamic characteristics of the bridge section. And introduction of double flap results in small negative aerodynamic damping that is basically responsible for vortex induced vibrations. In short, LES is an effective technique for estimating aerodynamic characteristics of the complex geometrical sections.

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