Application of Large Eddy Simulation to Predict Aerodynamic Characteristics of Rectangular Cross-Section and Cable Stayed Bridge Girder

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INTRODUCTION

Large civil engineering structures like cable-stayed bridges require investigations on the dynamic response under wind loads for safer design. In this respect, aeroelastic instabilities of rectangular prisms, because of common use of such configurations in bridge industry, have received particular interest from both academic and practical standpoints. Recently, application of the computational fluid dynamics to the two-dimensional simulation of flutter has been reported. κ-ϵ Model was employed for the flutter analysis of the rectangular sections of varying width to depth ratio[1]. Discrete vortex method[2] was used to investigate the two-dimensional flow past five generic bridge decks without any details like handrails etc. However, both methods were found to give conservative prediction of flutter speed. However, Ishihara[3] reported the successful application of LES model to predict the aerodynamic features of 3D square prism. Thus, indicating the necessity to examine the application of LES model for the aeroelastic analysis of bridges.

In this study, flutter analysis of the generic shapes in field is addressed. At first, forced vibration analysis is done, following the Matsumoto[3], to investigate the flutter characteristics of rectangular cross-section with B/D=20 and then comparison with the experimental results is presented. Finally, this analysis is extended to flutter analysis of the Nanjing Bridge cross-section, including the small details like handrails, inspection rails etc.

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; in which small eddies are modeled whereas large eddies are directly calculated. Unstructured finite volume method using collocated grid was used for the calculation purposes. Central difference scheme for convective term and the second order implicit scheme for unsteady term were used to discretize the basic equations to convert algebraic equations. SIMPLE method was used to solve the algebraic equations. The oscillation of the models is achieved by using the *sliding mesh technique*. FLUENT, CFD software is used as solver.

MODELING AND BOUNDARY CONDITIONS

In this study, a rectangular section of B/D=20 and Naning Bridge Section, with B/D=11.6 are used. Fig(1) shows computational domain used in both cases where circular region and rectangular region are subjected to forced oscillations in torsional and heaving modes with amplitudes of y_o/B=0.025 and ϕ_o=2 deg respectively[4]. A sliding mesh technique is employed to allow the forced oscillations. Inflow wind-velocity “U” is kept 14 m/s to avoid any additional phenomenon, if any, arising with change in R_N. Fig (2) shows the definition of the motion and forces acting on the model sections.

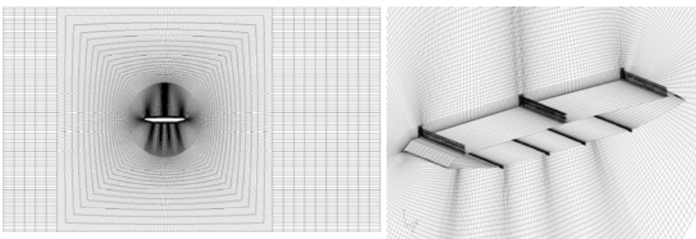

Fig. 1 Computational Domain of Nanjing Bridge cross-section and Rectangular cross-section

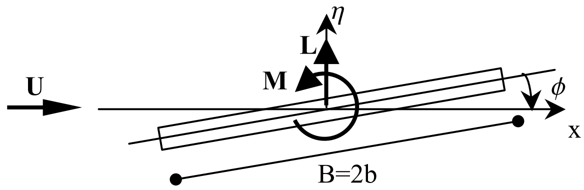

Fig. 2 Definition of motion and force components

RESULTS

Unsteay Aerodynamic Coefficients

In this study, the unsteady aerodynamic forces are simulated using the forced vertical and rotational excitation of single degree of freedom, which are later used for evaluating the aerodynamic derivatives. The force time histories obtained by forced excitation are decomposed into the components corresponding to damping and stiffness by using the Fourier decomposition. Fig (3) shows the comparison between the predicted flutter derivatives of rectangular section with that of experimental ones[4]. Fig (3) also demonstrates the flutter derivatives for the Nanjing Bridge (B/D=11.6) which are closer to that of rectangular section with

Keyword: LES Turbulence Model, Aerodynamic Force, Forced Vibration, Rectangular Prism, Cable Stayed Bridge Girder

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high width to depth ratio, i.e., B/D= 20 than B/D=10, 15. This fact can be regarded as a result of modification, that is use of fairings to get stream lined bridge section, which limits the separation of wind layer and causing rather earlier reattachment of flow.

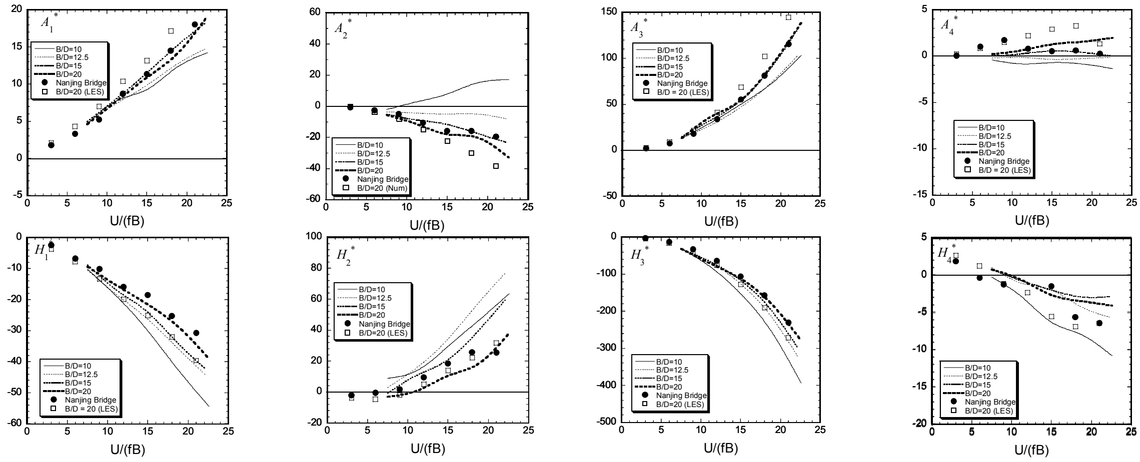

Fig. 3 Comparison of aerodynamic coefficients of Rectangular Section (B/D=20) and Nanjing Bridge Section (B/D=11.6) with the experimental results of different B/D ratios[3]

Flutter Characteristics

Complex eigen value analysis[5] is used to determine the circular frequency and logarithmic damping for heaving and torsional branches as shown in fig (4). Characteristics of torsional-branch coupled flutter type, i.e., both frequency branches gets closer with increase in reduced velocity, of rectangular prism with B/D=20 are clearly recognized in simulated results as shown in fig (4a), and agrees very well with those reported by previous experimental study[4]. Fig 4(b) shows the lograthimic damping of the heaving branch and the torsional branch of rectagular section B/D=20. For torsional branch, damping changes from positive to negative at the reduced velocity higher than in cases of B/D=10, 15. Simula -ted logarithmic damping for B/D=20 show very good agreement with the experimental results for both branches.Forcomparison, the simulation results of κ-ϵ model[1] are also shown, where negative damping is estimated at relatively low reduced velocity leading to conservative prediction of flutter wind speed[1]. In addition, similar procedure is used for the Nanjing section that includes all the section details e.g., handrails, inpsection rails etc. and its characteristics are evaluated. Although increase in B/D ratio shows increase in the flutter speed, flutter characteristics of Nanjing Bridge section (B/D=11.6) are found to agree with those of B/D=20 than that of lower B/D ratios. Thus, indicating the effectiveness of fairings to increase the critical speed for flutter.

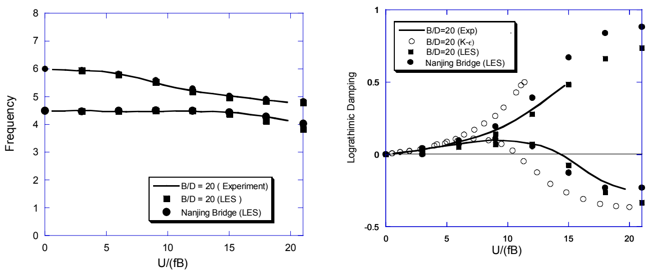

Figure 4 Eigen value loci of Rectangular cross section and Nanjing Bridge. *$M=1.96$kg/m, $I=4.9\times10^{-3}$Kgm, $f_{\eta 0}=4.5$Hz, $f_{\phi 0}=6.0$Hz, $B(=2b)=0.15$m*

CONCLUSIONS

Flutter characteristics of rectangular section with B/D=20 were calculated by means of three-dimensional analysis using the LES model. This method is found to be very efficient for predicting the unsteady aerodynamic forces and flutter characteristics where other model like κ-ϵ leads to conservative results. Further, application to streamline Nanjing Bridge section (B/D=11.6) is extended that show characteristics similar to rectangular section with B/D=20 than the cross-sections with B/D=10 & 15.

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