Prediction of aerodynamic characteristics of cable stayed bridge girder using LES turbulence model

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ABSTRACT: In this study, aerodynamic characteristics of the cross-section of a cable stayed bridge girder are investigated by three-dimensional computational fluid dynamics using LES turbulence model. Flow around streamed lined box girder is analyzed and the effect of section details on the aerodynamic characteristics of bridge section is evaluated. Also dependency of drag coefficient on the mesh near the section details is discussed. In addition, forced vibration is simulated in order to investigate the aero elastic behavior of the cross-section. The flutter characteristics of the bridge section (B/D=11.6) are investigated and compared with the experimental results of generic rectangular cross-sections.

KEYWORDS: LES Model, Aerodynamic coefficients, Flutter analysis, Bridge section details, and Computational fluid dynamics

1 INTRODUCTION

Safe design of large civil engineering structures like cable-stayed bridges requires investigations on the dynamic response under unsteady wind loads. Recently, many studies showed use of CFD in predicting the aerodynamic characteristics of bridge sections. For example, Ishihara et al (2006) reported the successful application of LES model to predict the mean and fluctuating pressure around the square prism. Also, Larsen et al (1998) has reported the applicability of discrete vortex-method in some generic configuration at first and then extended it to some practical bridge cross-sections. Though actual bridge sections include details like handrails, central barrier etc.; previous works have neglected the presence of such details. Such section details, no matter how small in size compared with the size of bridge section, can dramatically affect the aerodynamic characteristics of bridge section not only by controlling the separation point but also by changing the flow characteristics around bridge section. Therefore, it seems necessary at this point to clarify the influence of such details on the overall aerodynamic behavior of such sections.

In this paper, the analysis accuracy of LES model for real bridge cross-section with small details will be investigated. The aerodynamic characteristics of a real bridge section are obtained by employing LES model and effect of small details, e.g., hand rails, inspection rails etc. on these characteristics are investigated and comparison of numerical results with wind tunnel experiments is presented. In addition, forced vibration analysis is done, following the Matsumoto et al.(1994), to investigate the flutter characteristics of real bridge section and a comparison with results for rectangular cylinder is presented. Based on numerical result, application of LES model to the prediction of the flutter is discussed.

2 NUMERICAL APPROACH

LES turbulent model is used for this study in which small eddies are modeled where as large eddies are directly calculated. The Finite Volume Method was used for the descritization of governing equations. QUICK scheme for convective terms and the second order implicit scheme for unsteady terms were used. SIMPLEC method was used to solve the discritized equations. The oscillation of the models is achieved by using the *sliding mesh technique*. FLUENT, CFD software is used as solver.

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3 RESULTS

3.1 *Coefficients of Mean Aerodynamic Forces*

Fig. 1 shows coefficients of mean drag forces, lift forces and the moment with respect to angles of attack for the stream lined girder section, with and without details like handrails, inspection rails, etc.

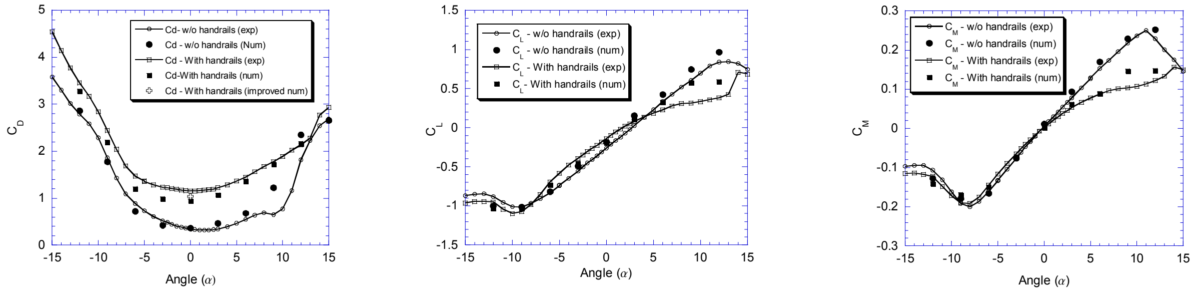

Figure 1. Comparison of Experimental and Numerical Aerodynamic Coefficients of Nanjing Bridge section with and without handrails

In fig. 1, C_D attains the minimum value at about 1° and a moderate increase in C_D is observed in the range of +7° to –7°. Rather rapid increase in C_D is observed with further increase in angle of attack. The drag coefficient of bridge section without details like handrails etc. turns out to be one third of the case with details. For detailed section, some discrepancy is observed in low range of attack angles. To deal with this, more number of computational grids is used at zero angle of attack till grid independent results are obtained; thus reducing the error by half. In case of later section, C_L and C_M increase naturally with the increase of the angle of attack and a maximum value is achieved at about +12° and –9°. However, the peak observed at positive angle of attack for section with no details disappears in the former case. The present calculations well capture the phenomenon of first increase and then reduction in lift and moment coefficients with increase in the angle of attack along with the peak values at the corresponding angles. Overall, a good agreement exists among the predicted force coefficients and the experimental results.

3.2 *Mean flow and pressure distribution around Nanjing Bridge Section*

Looking at the pressure distribution (Fig.2) and flow mechanism (Fig.3) around the section help to identify the characteristics of the mean force coefficients. At attack angle of zero degree, incase of section with no handrails etc., large pressure followed by negative pressure in very small region occurs on the windward side of upper surface. This flow then reattaches to the upper surface and recovers the pressure.

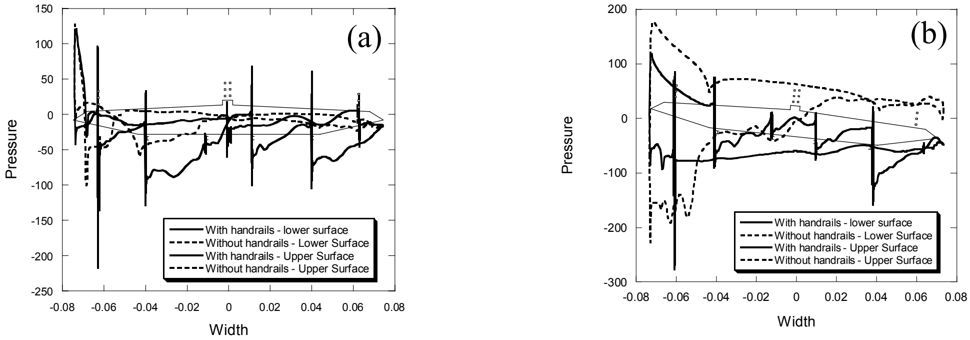

Figure 2. Mean pressure distribution around periphery of bridge section (a) Section with details (b) Section without details

On the lower surface, large negative pressure at the end of lower flap shows the separation of flow, and the following recovery of the pressure indicates the reattachment of flow to lower surface of section towards leeward side. Incase of bridge section with details, large pressure values are observed corresponding to the presence of handrails in addition to that acting on the upper flap surface. However, the observed pressure along the upper surface remains negative and pressure recovery in the vicinity of rear edge of the upper surface indicates flow reattachment. On the other hand, broken pressure pattern on the lower surface is introduced due to the presence of inspection rails on this surface. It should be noted that the difference in the drag coefficient at zero degree, as observed in Fig 1, corresponds to large pressure acting on hand and inspection rails.

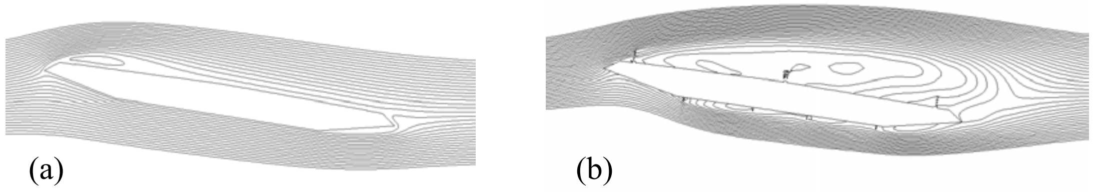
(a) (b)

Figure 3. Mean stream lines around Nanjing Bridge (a) without , and (b) with section details at 9^{o}

The shear layers formed near the corners on lower side disappear by the time angle changes to 9^{o}. In case of bridge section with details, for upper surface, negative pressure intensifies on the windward side with increase in angle of attack and the recovery of pressure towards the leeward side indicates the intermittent reattachment of flow. Whereas on the lower side, the positive pressure acting is changed to negative one by the wakes resulting from the inspection rails. Incase of section without details, the difference in pressure distribution on upper and lower surface maximizes at an angle of nine degree. Thus, indicating the presence of maximum value of the lift coefficient at given angle of attack as discussed in previous section.

3.3 *Estimation of Aerodynamic Derivatives*

In this study, the unsteady aerodynamic forces are simulated using the forced vertical and rotational excitation of single degree of freedom that are later used for evaluating the aerodynamic derivatives. The force time histories obtained by forced vertical and rotational excitation are decomposed into the components corresponding to damping and stiffness by using the Fourier decomposition.

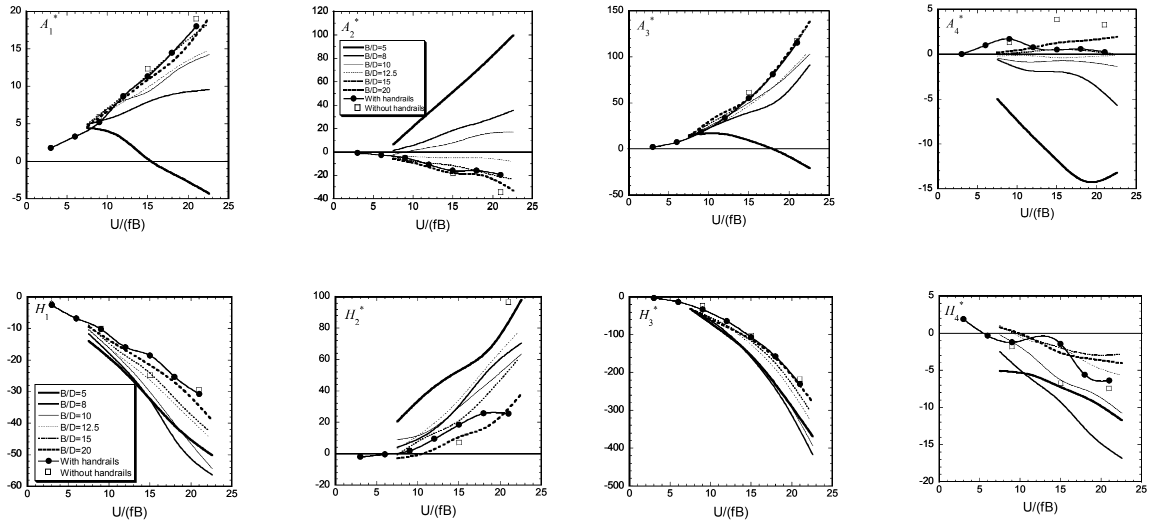

Figure 4. Flutter derivatives of Nanjing Bridge Sections, with and without handrails and inspection rails, compared with the rectangular sections of varying B/D ratio.

Fig. 4 demonstrates that simulated flutter derivatives of bridge section with small details (B/D=11.6) are close to those of the rectangular section with high width to depth ratio, i.e., 20 than that of the rectangular section with B/D=10. This fact can be regarded as a result of the fairings and hand/inspection rails in real bridge section that limits the separation of the wind layer and rather earlier reattachment of flow occurs. Quite good agreement is found among the aerodynamic derivatives of bridge section and those of the rectangles with high B/D ratios. To clarify the effect of the hand/inspection rails, the unsteady aerodynamic force coefficients of bridge section without handrails are evaluated at few reduced velocities as shown in fig (4). A good agreement exits between the moment derivative terms of both bridge sections, with and without small details. However, the flutter derivatives corresponding to heaving of sections show rather large differences as shown in Fig 4. This difference may be attributed to the difference observed for the static lift coefficients at the low angle of attack as shown in fig (1).

3.3 *Flutter Characteristics*

Complex eigen value analysis, proposed by Miyata (1989), was used to determine the circular frequency and logarithmic damping for heaving and torsional branches as shown in fig (5). Both bridge sections follow similar pattern in calculated frequency leading to torsional-branch coupled flutter type which is similar to the flutter characteristics of rectangular prism with B/D=20 (Matsumoto, 1994). The logarithmic damping of the heaving branch remains positive for both sections, with and without handrails and a relatively large difference is observed at higher reduced values. However, the torsional branch of logarithmic damping becomes negative at higher reduced velocity and has similar values for both sections. Though, for both bridge sections, coupling terms of aerodynamic derivatives show some discrepancies; the similarity of torsional branch logarithmic damping shows the predominance of A^*_1, A^*_2 and H^*_3 that was indicated ealier by Matsumoto during his step-by-step analysis. In addition, a comparison of damping ratio of bridge section with that of rectangular section (B/D=20) exhibits good agreement.

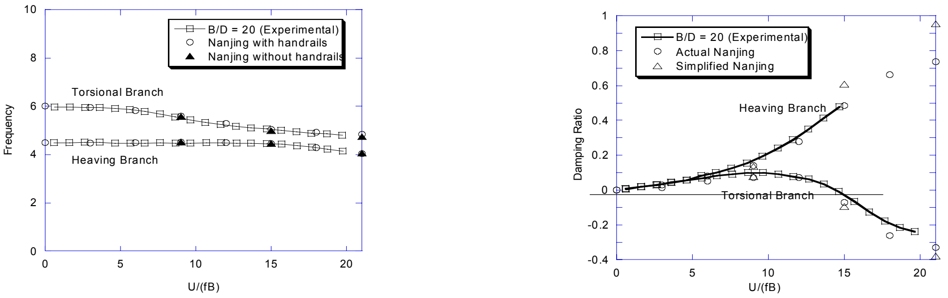

Figure 5 Eigen value loci of Nanjing Bridge with and without handrails along with rectangular section (B/D =20). *$M=1.96kg/m$, $I=4.9X10^{-3}Kgm$, $f_{\eta 0}=4.5Hz$, $f_{\phi 0}=6.0Hz$, $B(=2b)=0.15m$*

4 CONCLUSION

Sections details are found to have strong influence on the aerodynamic coefficients that affects the drag coefficient at low angle of attack and lift & moment coefficients at large angle of attacks. Steady and unsteady characteristics of Nanjing Bridge section are calculated by means of LES turbulence model that are found in good agreement with the experimental results. Thus, concluding the effectiveness of the method for estimating the aerodynamic characteristics of the complex geometrical sections. Finally, the flutter characteristics of stream lined bridge section (B/D=11.6) are found to be near to the rectangular section of B/D=20 than that of B/D=10.

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