土木学会第53回年次学術講演会（平成10年10月）

I - B 47

DISCUSSION ON THE CONVENTIONAL ADMITTANCE SINGLE-MODE METHOD FOR GUST RESPONSE OF BRIDGES IN MODERN VIEWPOINT

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1. Introduction

Akashi-Kaikyo Bridge, the first of 2000m-main-span class of bridges, has been successfully realized. It is the time to review the design methods to prepare for the next generation of longer-span bridges. Beside flutter prediction, gust response has been experienced as the next most important issue to consider. There have been many sophisticated gust response analysis methods in literature. However, there is actually a need of simple, practical and effective enough for the preliminary design stage. In this sense, the conventional Admittance Single-Mode (ASM) method developed by Davenport [1] is the common choice, although many limitations inherent in this method have been well known. Here comes up a question that to which extent this method is still effective. In this paper, ASM method will be reviewed and justified by a modern approach, which is called Aeroelastic Complex-Mode (ACM) method developed by the authors [3]. Discussions on the still-effective points of ASM method, and some suggestions on how to use of ASM method for long-span bridges will be made. A clearer representation of the limitation of ASM method will also be provided.

2. Aeroelastic Complex-Mode (ACM) Method versus Admittance Single-Mode (ASM) Method

The ACM method has been well described in [3]. The method is originated by the framework of Direct FEM Flutter Analysis [4]. The complex eigen-analysis for the full 3-D FEM model of bridges integrated with the aeroelastic unsteady forces (determined by Flutter Derivatives) is carried out directly. The effects of aeroelastic phenomenon then can be effectively incorporated into the modal properties. By Mode Tracing Method [2], which is a development of the Direct FEM Flutter Analysis, necessary aeroelastic modal properties at a certain mean wind speed can be computed and collected to facilitate the gust response analysis. The modal frequencies and aerodynamic dampings can be determined by the complex eigenvalues as function of wind speed for any intended mode. Aeroelastic and structural couplings between many modes can be captured. Coupled response then can be effectively analyzed. Therefore, in methodology viewpoint, the ACM method has included all the modern concepts of aeroelastic phenomena on bridge's decks.

On the contrary, the ASM method [1] is much simpler due to many assumptions. The method is just applied one-by-one for each chosen mechanical mode (mode at zero mean wind speed), and then the response spectra of many modes are summed following the 'Square Root of Sum of Square' (SRSS) rule. There is no consideration of coupled responses, neither aeroelastic nor structural couplings. There is no concept of aeroelastic effects, except the logarithmic decrements of modal aerodynamic dampings are determined by very simple proposed formula based on quasi-static theory as follows,

Horizontal: $\delta_r^h = \dfrac{1}{2}\dfrac{\rho U C_D B}{n_r m}$ (1); Vertical: $\delta_r^v = \dfrac{1}{4}\dfrac{\rho U C_L' B}{n_r m}$ (2) Torsional: $\delta_r^t = \dfrac{1}{4}\dfrac{\rho U C_M' B^2}{n_r m k}$ (3)

where ρ: air density, U: mean wind speed, C_D, C_L, C_M: static coefficients, B: deck's width, n_r: frequency of r-th mode, m: mass per unit length, k: radius of gyration.

3. Justification for ASM Method by ACM Method

The gust responses at the midspan of the main span of Akashi-Kaikyo Bridge are calculated by both methods under the same condition of wind-tunnel turbulence inputs [3]. The first 10 modes of the bridge, which will yield reasonable results as experienced from [3], is considered for ACM method. Among these respective mechanical modes, significant modes for the responses at the midspan are: Mode #1 is the 1st horizontal mode; Mode #2 is the 1st vertical mode; Mode #8 is the 3rd vertical mode; Mode #9 is a coupling mode between the 1st torsional and the 3rd horizontal; Mode #10 is also a coupling mode between the 1st torsional and the 3rd horizontal but in opposite sign. Then, for ASM method, modes #1, #9, #10 is selected for calculating horizontal response; modes #2 and #8 are chosen for calculating vertical response; and modes #9, #10 is selected for calculating torsional response.

Fig.1 shows the comparison of aeroelastic dampings calculated by ASM and ACM methods. Good agreements can be seen for mode #1, #2, #8. Note that these modes are purely one-motion modes (mode with only one motion component). On the other hand, the ASM aerodynamic dampings fail to agree with those of ACM for motion-coupling modes as mode #9 and #10, especially the nonlinear trend in the development of the damping with wind speed.

Fig.2 presents the response spectra at the design wind speed of 60m/s. A common different is that all the peaks of ACM are at smaller frequencies than those of ASM. Then the amplitudes of ASM peaks are smaller than those of ACM. For vertical response, the ASM method can not gives the peak at frequency of modes #9 and #10 as seen for ACM result. Note that the response spectra of ACM is very similar to those observed from experiment. These are due to aeroelastic effects that only captures by ACM method. Therefore, ASM result is smaller than ACM result. For horizontal response, since mode #1, which is not so much affected by aeroelastic phenomena, exclusively dominates the response, very good agreement between the two methods is observed. This response of bridges is actually more affected by the spatial coherence of turbulence along the deck. For torsional response, the ASM method very much underestimates the response due to its overestimation of the aerodynamic damping as seen in Fig.1 for modes #9 and #10. One alternative is to assume this damping to be zero, which will give the rather overestimation of the response for conservative design. Fig.3 shows the RMS of the responses at wind speeds of 30, 40, 50, 60, 70 m/s. These responses reflect the observations in Fig.2 very well. As wind speed increases, the aeroelastic

Keyword: gust response, aerodynamic damping, response spectra
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phenomena is more pronounced, makes the vertical response increases quickly as for ACM method. Then the discrepancies between the two methods increase as well. The horizontal responses agree very well to each other. In the torsional response, ASM underestimates the response, and give conservative results by assuming the torsional aerodynamic damping to be zero.

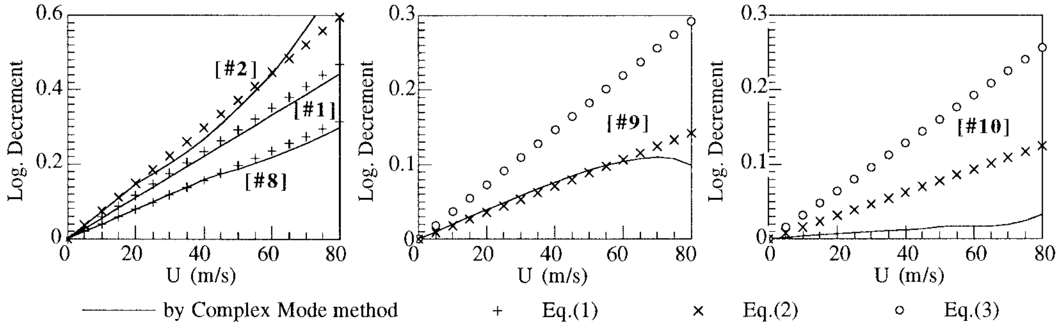

Fig. 1: Comparison of aerodynamic damping by Complex Mode method and Quasi-Static formula

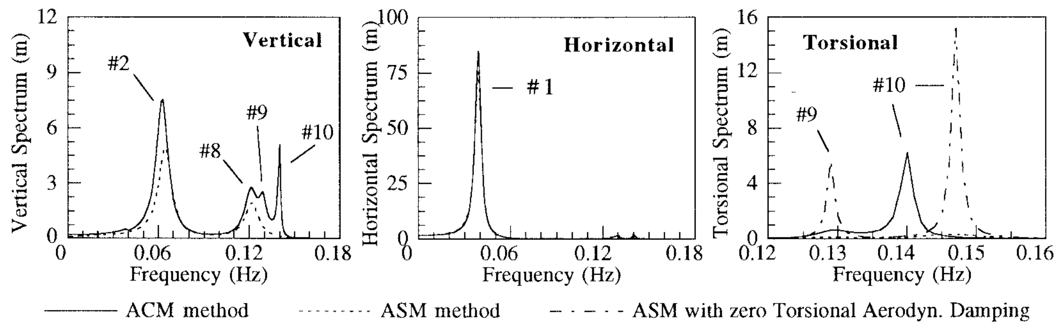

Fig.2: Comparison of response spectra from ACM and ASM method

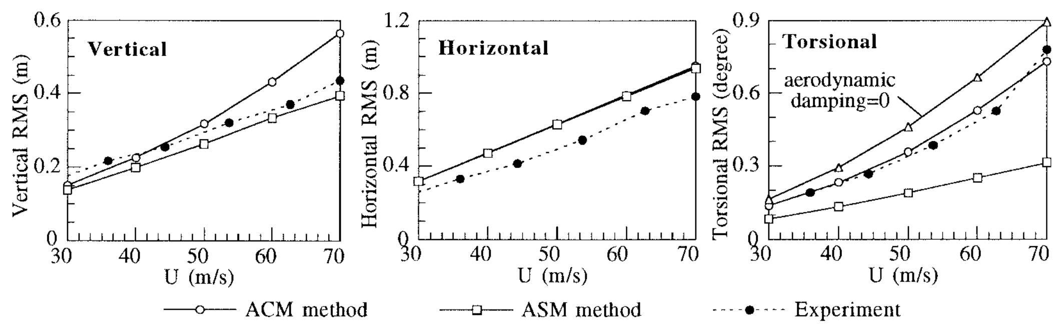

Fig.3: Comparison of RMS of responses from ACM and ASM method at different wind speeds

4. Concluding Remarks

The quasi-static formula for aerodynamic damping are still applicable for purely-one-motion modes, and invalid for motion coupling modes. Therefore, as in case of Akashi-Kaikyo Bridge, the vertical and horizontal dampings are still reasonable, but the torsional dampings is not valid anymore. Assuming zero for the torsional damping is suggested for conservative results. Neglecting coupled response and aeroelastic effects can be seen clearly as the serious shortages of ASM method. However, in the preliminary stage of design, ASM method could be used with some notes presented above. It would underestimate vertical response due to neglecting aeroelastic effects, underestimate torsional response due to overestimation of torsional damping, and give fair result for horizontal response, which exclusively depends on spatial coherence of turbulence.

5. References

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