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ON THE ANALYTICAL PREDICTION OF BUFFETING RESPONSE FOR AKASHI-KAIKYO BRIDGE

Nguyen Nguyen MINH, Student member
Toshio MIYATA, Hitoshi YAMADA
Member JSCE, Yokohama National University

1. Introduction

Recent need of longer spans has made the buffeting response become the major serviceability problem for long-span bridges. The full-model of Akashi-Kaikyo Bridge in wind tunnel exhibited a very complicated response under gusty wind. So far, there have been many analytical works by various methods to predict the response. However, whereas the torsional and vertical responses were predicted fairly well, the horizontal response was greatly overestimated when compared to those of the experiment. This study presents an approach for buffeting analysis in time-domain, and tries to identify the reasons of the above common error tendency. It is found that the overestimation of horizontal response was contributed by two differences in input: the spatial coherence by exponential forms is greatly stronger, and the spectra of natural wind turbulence is higher than those of the turbulence simulated in wind tunnel in the low-frequency range.

2. Simulation of Turbulence and Buffeting Forces

The numerical simulation of wind turbulence is made by the Auto Regressive-Moving Average (ARMA) method [3]. The new point of this simulation work here is that the spatial correlations of velocity components are fully accounted to improve the accuracy of simulated turbulence. Two velocity components, along-wind (u) and vertical (w), are generated simultaneously and spatially by ARMA model with their statistical characteristics as target inputs. In this study, two cases of turbulence, (a) simulated natural turbulence from proposed characteristics in literature (hereafter called 'literature turbulence'), and (b) turbulence in wind tunnel, are simulated for comparative analysis.

(a) The spectra and cospectra are taken from [2]. The coherence function by exponential forms proposed by Davenport [4] is used. This coherence function equals unit at zero frequency (Fig.4).

(b) Statistical characteristics are extracted from the turbulence records in wind tunnel. After scaled by the similarity rule, the scaled spectra and cospectrum can be expressed as (Fig.3),

$$\frac{S_u(f)}{\bar{u}^2}=\frac{8.7}{(1+12f)^{5/3}};\qquad \frac{S_w(f)}{\bar{u}^2}=\frac{1.11}{1+8.97f^{5/3}};\qquad \frac{Co_{uw}(f)}{\bar{u}^2}=\frac{-2.56}{(1+5f)^{2.4}} \tag{1}$$

The spatial coherence $Coh_u(f)$ and $Coh_w(f)$, however, do not tend to unit at zero frequency (Fig.3), and can be expressed in modified forms as

$$Coh_{u1u2}(f)=(1-.001dy-.0003dy^2)exp(-f\,C_y^u dy/U)\qquad \text{where } C_y^u=12 \tag{2}$$

$$Coh_{w1w2}(f)=(1-.03dy+.0002dy^2)exp(-f\,C_y^w dy/U)\qquad \text{where } C_y^w=8 \tag{3}$$

An approximation of the spatial coherence between u and w is proposed, and well justified:

$$Coh_{u1w2}(f)=\frac{1}{2}\frac{Co_{uw}^2(f)}{S_u(f)S_w(f)}\left[Coh_{u1u2}(f)+Coh_{w1w2}(f)\right] \tag{4}$$

The buffeting force then can be computed by Quasi-Static Assumption from the time-history of the simulated turbulence. Expressions of buffeting lift $L(t)$, drag $D(t)$ and moment $M(t)$ are from [4].

3. Buffeting Analysis in Time Domain

The equation of motion for a 3-D model of a full bridge with the presence of aeroelastic phenomena can be expressed as,

$$\mathbf{M_k}\ddot{\mathbf{u}}+\mathbf{Ku}=\mathbf{w} \tag{5}$$

where **K** is stiffness matrix, **u** is displacement vector, **w** is buffeting force vector. The self-excited forces can be expressed by flutter derivatives, and embedded in $\mathbf{M_k}$. Thus $\mathbf{M_k}$ is a complex function of reduced frequency k. By Mode Tracing Method [1], the modal frequency, modal damping of each mode can be obtained as functions of wind speed U. Thus at a certain wind speed U, the buffeting analysis can be performed by using the corresponding eigenvectors to uncouple Eq.(5). Since $\mathbf{M_k}$ is complex and not symmetric, two biorthogonal sets of complex eigenvectors, the left $\mathbf{v_L}$ and the right $\mathbf{v_R}$, exist for the modal decomposition. The buffeting analysis is then carried out by step-by-step integration. By

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79-5 Tokiwadai, Hodogaya-ku, Yokohama 240 TEL: 045-339-4042 FAX: 045-331-1707

using complex modes, the aerodynamic effects on dynamic characteristics of the system can be effectively incorporated, and coupled responses are accurately captured.

4. Comparative Analysis and Discussion

Buffeting analysis for Akashi-Kaikyo Bridge is performed by the presented scheme. The time step of direct integration is 0.2s and the duration to obtain response is 150 minutes. Number of modes is 32. Turbulence intensity I_u=10%. Mid-span displacements of the main span for 2 cases of turbulence and from experiment are shown in Fig.(1) for comparison. The analytical torsional and vertical responses agree very well with experiment, and the horizontal response, which is highly overestimated for case (a), is greatly improved in case (b). A closer look reveals that the horizontal response is governed mainly by the 1st symmetric sway-dominant mode, which has a very low frequency of around 0.03 Hz. At this frequency, the coherence function proposed by Davenport gives very high coherence for turbulent velocity along the bridge deck, but the analysis of wind-tunnel turbulence gives much smaller values of the coherence as shown in Fig.(3). Comparative check shows that this is the main cause of the overestimation for horizontal response. Moreover, higher values of S_u spectrum of literature turbulence than that of wind-tunnel turbulence at low-frequency range as seen in Fig.(2) also contribute some more errors.

5. Concluding Remarks

The presented scheme for buffeting analysis is effective and practical. By using simulated wind-tunnel turbulence as input, the RMS. of analytical response agrees very well with experiment. However, some errors are still encountered for maximum amplitude. More efforts to include nonlinear effect in structural analysis, and to refine the coherence for natural wind are in progress.

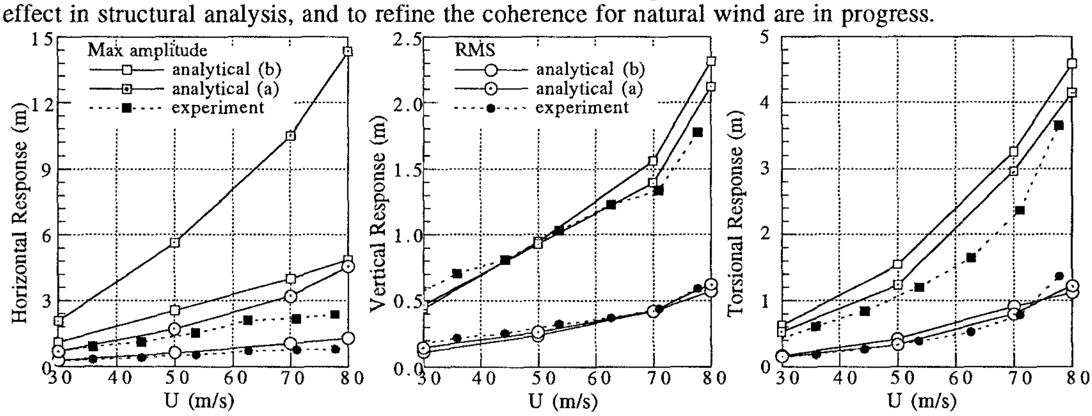

Fig.1: Comparison of analytical and experimental buffeting response (mid-span displacements)

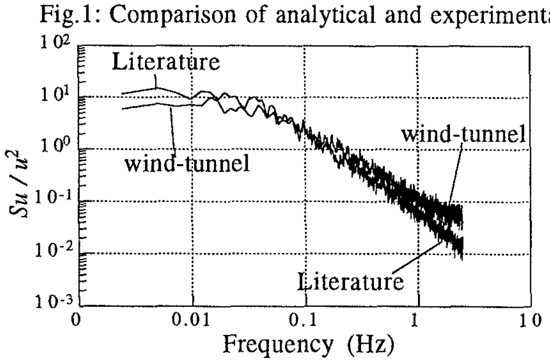

Fig.2: Comparison of spectrum *Su*

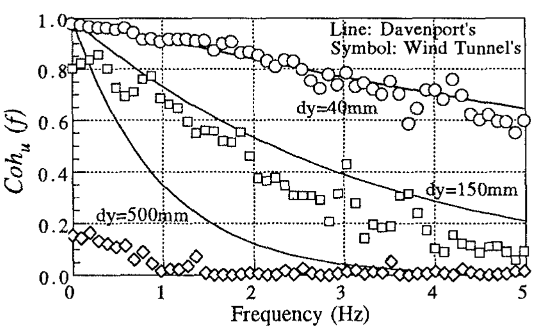

Fig.3: Comparison of Coherence Function

6. Reference

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