New Approach on Buffeting Response Prediction of Cable-stayed Bridges

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Abstract. Buffeting response of bridges, known as randomly vibrational response due to atmospheric turbulent winds is prone among aerodynamic responses, especially in medium and strong wind velocities. This paper will present new and comprehensive approach on buffeting response prediction of cable-stayed bridges using the Proper Orthogonal Decomposition in which its Proper Transformations is combined with the Structural Modal Transformation to estimate the buffeting response. The former is used to decompose multi-variate random loading processes into orthogonal loading modes, then associated with orthogonal structural modes in generalized structural coordinates decomposed by the later. Thus, buffeting response prediction of cable-stayed bridges will be formulated in both the time and frequency domains with numerical example of cable-stayed bridges.

1. Introduction

Buffeting response prediction of structures subjected to the random turbulent loading proposed firstly by Davenport, 1963 in the frequency domain. The time domain analysis has been developed by some authors (Chen et al., 1999). As a principle, MDOF motion equations of bridges were decoupled into generalized coordinates and orthogonally structural modes using the modal transformation. However, inevitably difficulty is to decompose the spatially-correlated turbulent loading, which is associated with generalized structural coordinates. In the conventional approaches, the so-called Joint Acceptance Function technique has been used (Davenport, 1963; Chen et al., 1999).

The Proper Orthogonal Decomposition (POD), known as the Karhunen-Loeve decomposition, was firstly applied for random turbulent fields by Lumley, 1970 as a stochastic decomposition to decouple multi-variate random turbulent fields. POD also has been used for the simulation of turbulent field (Paola and Gullo, 2001; Chen and Kareem, 2005; Le and Nguyen, 2006), the pressure field analysis and the physical phenomenon identification. The proper transformations have been branched by either covariance-based or spectral-based proper transformations, which depend on basic matrix formed from either covariance or cross spectral matrices. New approach for dynamic and buffeting response analysis of structures, so-called Dual Modal Transformations, has been proposed recently by Carassale et al., 1999 by which the structural modes can be
associated with the turbulent modes decomposed by the proper transformations. The spectral-based double modal transformation has been applied for gust response prediction of tall building (Chen and Kareem, 2005), and for that of bridge (Solari and Tubino, 2005; Le and Nguyen, 2006). The buffeting forces using the quasi-steady theory have not been accounted the frequency-dependant correction function such as an Aerodynamic Admittance Function. The buffeting response of structures, furthermore, has not been formulated in the time domain using the covariance proper transformation that is promising due to its comprehensive solutions for nonlinear and unsteady aerodynamics.

In this paper, the Proper Orthogonal Decomposition-based covariance and spectral proper transformations will be presented with emphasis on their applications to decoupling the spatially-correlated turbulent loading, and in combination with the Structural Modal Transformation to formulate the buffeting response prediction of structures in both the time and frequency domains. Numerical example of cable-stayed bridge is taken for investigation.

2. Theoretical background on bridge buffeting response

It is generally agreed that the buffeting response prediction of bridges can be treated analytically in either the frequency domain or the time domain. In the frequency-domain approach (indirect buffeting analysis), the Fourier transform is applied in associated with statistical computation and spectral analysis technique. The correction functions and the coherence ones have been used in transformation steps. Furthermore, the modal analysis technique in generalized coordinates has been applied for decomposition from the multi-degree-of-freedom motion system into the single-degree-of-freedom. Thus, the core of the computational frequency-domain buffeting analysis relates to modal decomposition method and modal-based response superposition technique that are associated with the spectral analysis method. Stepwise procedure for the frequency-domain buffeting response prediction of bridges is expressed in Figure 1.

![Figure 1. Stepwise flow for buffeting response prediction in the frequency domain](image)
In the branch of the time-domain approach (direct buffeting analysis), the turbulent loading can be treated as multi-variate random Gaussian processes and acting on discrete structural nodes. Simulation techniques are usually used in many cases to generate the turbulent loading at structural nodes. Either unsteady buffeting forces (using aerodynamic admittance and coherence functions) or complete unsteady buffeting forces (using the indicial response functions or the impulse response function) are formulated in the time and frequency domain. Discrete frequency-dependant functions can be transformed into the continuous time functions using some techniques as the rational function approximation. Direct integration methods are applied to obtain time-history solutions of the generalized responses, and time-histories of global responses can be estimated accordingly. Time domain procedure is shown in Figure 2.

The commonly buffeting theory of the bridges can be formulated briefly as follows. Uniform buffeting forces per unit deck length (consisting of Lift, Drag, Moment: \(L_b(t), D_b(t), M_b(t)\)) are normally determined in the time domain from the turbulent fields \(u(t), w(t)\) due to the quasi-steady theory (Davenport 1963):

\[
L_b(t) = \frac{1}{2} \rho U^2 [B(C_L(\alpha_0))X_L(n) \frac{2u(t)}{U} + (C_L(\alpha_0) + C_D(\alpha_0))X_L(n) \frac{w(t)}{U}] \quad (1a)
\]

\[
D_b(t) = \frac{1}{2} \rho U^2 [B(C_D(\alpha_0))X_D(n) \frac{2u(t)}{U} + (C_D(\alpha_0) - C_L(\alpha_0))X_D(n) \frac{w(t)}{U}] \quad (1b)
\]

\[
M_b(t) = \frac{1}{2} \rho U^2 \frac{2M_u(n)}{U} + C_M(\alpha_0)X_M(n) \frac{w(t)}{U} \quad (1c)
\]

where \(C_L, C_D, C_M\) : aerodynamic static coefficients at balanced angle of attack \(\alpha_0\) (usual \(\alpha_0 = 0^\circ\)); \(C_L', C_D', C_M'\) : first derivatives with respect to angle of attack at balanced angle \(C_f = \frac{dC_f(\alpha)}{d\alpha} \bigg|_{\alpha = 0}, \quad F = L, D, M; \quad X_{Fu}(n) (F = L, D, M; u = u, w) : \)
aerodynamic transfer functions between turbulent components and turbulent-induced forces (their absolute magnitudes refer as aerodynamic admittance functions); \( \rho \), B, U: air density, width and mean velocity, respectively.

Then, power spectral densities of the uniform buffeting forces (point-like forces) can be obtained in the frequency domain thanks to second-order Fourier transformation:

\[
S_L(n) = \left( \frac{1}{2} \rho U^2 B \right)^2 \left[ C_L^2 \mathcal{X}_L(n) \frac{4S_{uu}(n)}{U^2} + (C_L + C_D)^2 \mathcal{X}_L(n) \frac{S_{uw}(n)}{U^2} \right] \tag{2a}
\]

\[
S_D(n) = \left( \frac{1}{2} \rho U^2 B \right)^2 \left[ C_D^2 \mathcal{X}_D(n) \frac{4S_{uu}(n)}{U^2} + (C_D - C_L)^2 \mathcal{X}_D(n) \frac{S_{uw}(n)}{U^2} \right] \tag{2b}
\]

\[
S_M(n) = \left( \frac{1}{2} \rho U^2 B^2 \right)^2 \left[ C_M^2 \mathcal{X}_M(n) \frac{4S_{uu}(n)}{U^2} + C_M^2 \mathcal{X}_M(n) \frac{S_{uw}(n)}{U^2} \right] \tag{2c}
\]

where \( S_L(n), S_D(n), S_M(n) \): power spectra of lift, drag and moment, respectively; \( S_{uu}(n), S_{uw}(n) \): auto power spectra of uni-variate turbulent processes \( u(t), w(t) \).

Finally, the power spectral densities of full-scale buffeting forces (line-like forces) associated with the \( i \)-th generalized coordinate can be obtained as follows:

\[
S_{L_i}(n) = \left| \frac{4L_i}{U^2} \right| J_{L_i}(n) \left| \mathcal{X}_L(n) \right|^2 S_{uu}(n) + \left| \frac{L_i}{U^2} \right| J_{L_i}(n) \left| \mathcal{X}_L(n) \right|^2 S_{uw}(n) \tag{3a}
\]

\[
S_{D_i}(n) = \left| \frac{4D_i}{U^2} \right| J_{D_i}(n) \left| \mathcal{X}_D(n) \right|^2 S_{uu}(n) + \left| \frac{D_i}{U^2} \right| J_{D_i}(n) \left| \mathcal{X}_D(n) \right|^2 S_{uw}(n) \tag{3b}
\]

\[
S_{M_i}(n) = \left| \frac{4M_i^2}{U^2} \right| J_{M_i}(n) \left| \mathcal{X}_M(n) \right|^2 S_{uu}(n) + \left| \frac{M_i^2}{U^2} \right| J_{M_i}(n) \left| \mathcal{X}_M(n) \right|^2 S_{uw}(n) \tag{3c}
\]

where \( L_i, D_i, M_i \): force coefficients defined as

\[
L_i = \frac{1}{2} \rho U^2 C_{L_{10}} B^2 \quad D_i = \frac{1}{2} \rho U^2 C_{D_{10}} B^2 \quad M_i = \frac{1}{2} \rho U^2 C_{M_{10}} B^2
\]

\[
L_1 = \frac{1}{2} \rho U^2 C_{L_{10}} B^2 \quad L_2 = \frac{1}{2} \rho U^2 C_{L_{10}} B^2 \quad D_1 = \frac{1}{2} \rho U^2 C_{D_{10}} B^2 \quad D_2 = \frac{1}{2} \rho U^2 C_{D_{10}} B^2 \quad M_1 = \frac{1}{2} \rho U^2 C_{M_{10}} B^2
\]

In Eqs.(2a,2b,2c), the \( J_{F_i}^2 \) are called as Joint Acceptance Functions, defined as:

\[
| J_{L_i}(n) |^2 = \int_0^L \int_0^L \text{COH}_u(x_A, x_B, n) h_i(x_A) h_j(x_B) dx \tag{4a}
\]

\[
| J_{D_i}(n) |^2 = \int_0^L \int_0^L \text{COH}_v(x_A, x_B, n) p_i(x_A) p_j(x_B) dx \tag{4b}
\]

\[
| J_{M_i}(n) |^2 = \int_0^L \int_0^L \text{COH}_o(x_A, x_B, n) \alpha_i(x_A) \alpha_j(x_B) dx \tag{4c}
\]
where $COH_v(x_A, x_B, n)$: spanwise coherence function of turbulent component $v(t)$ between two points $x_A$ and $x_B$, $v(t) = u(t)$ or $w(t)$.

It is noted that in the practical applications, some empirical formulae are available to determine: (i) Auto spectral density functions of the longitudinal and vertical turbulent components $S_{uu}(n), S_{ww}(n)$; (ii) Aerodynamic Admittance Functions $\chi_{F_0}(n), F = L, D, M$ and $v = u, w$; (iii) Spanwise coherence functions $COH_v(x_A, x_B, n)$.

Power spectral densities of the $i$-th generalized response can be determined from the power spectral densities of full-scale buffeting forces as follows:

$$S_{xx}(n) = \|H(n_i)\|^2 \phi_i^T S_{F_F}(n) \phi_i$$

where $\|H(n_i)\|^2$: Mechanical Admittance Function (Frequency Response Function) corresponding to natural frequency $n_i$ of the $i$-th structural mode as

$$\|H(n_i)\|^2 = \left[1 - n_i^2/\zeta_i^2 \right]^2 + 4\zeta_i^2 n_i^2/\zeta_i^2$$

New approach for the buffeting response prediction of cable-stayed bridges in both the frequency domain and the time domain with comprehensive model of the 3D wind fields, the buffeting forces, the wind loading modes as well as new way in combination between wind modes and structural modes using the Proper Orthogonal Decomposition and its Proper Transformation is going to be presented hereafter (Carassale et al., 2000; Le et al., 2006, Matsumoto, Shirato, Le, 2007)

### 3. Proper Orthogonal Decomposition and its proper transformations

The main idea of the Proper Orthogonal Decomposition is to find out a set of orthonormal basic vectors which can expand a multi-variate random process into a sum of products of these basic orthogonal vectors and single-variant uncorrelated random processes. Proper Orthogonal Decomposition-based proper transformations are summarized as follows:

#### 3.1. Covariance-based proper transformation

The covariance matrix-based orthogonal vectors are found as the eigenvector solutions of the zero-time-lag covariance matrix $C_v(n)$ of the N-variate random turbulent field $v(t)$:

$$C_v \Theta_v = \Gamma_v \Theta_v$$

where $\Theta_v = [\theta_{v1}, \theta_{v2}, \ldots, \theta_{vN}]$, $\Gamma_v = \text{diag}(\gamma_{v1}, \gamma_{v2}, \ldots, \gamma_{vN})$ : covariance eigenvalue and eigenvector (turbulent mode) matrices, which satisfy the orthonormal conditions: $\Theta_v \Theta_v^T = I$; $\Theta_v C_v \Theta_v^T = \Gamma_v$
Accordingly, the turbulence field and its covariance matrix can be expressed due to the covariance proper transformation as summed approximation as follows:

\[ \mathbf{v}(t) = \Theta_v \mathbf{x}_v(t) \approx \sum_{j=1}^{\tilde{M}} \Theta_{v,j} \mathbf{x}_v(t) ; \quad \mathbf{C}_v = \Theta_v \Gamma_v \Theta_v^T (n) \approx \sum_{j=1}^{\tilde{M}} \Theta_{
u,j} \Gamma_{v,j} \Theta_{v,j}^T \]  \hspace{1cm} (8)

where \( \mathbf{x}_v(t) = [\mathbf{x}_{v,1}(t), \mathbf{x}_{v,2}(t), \ldots, \mathbf{x}_{v,j}]^T \): covariance-based turbulent principal coordinates as the N-variate uncorrelated Gaussian random process; \( \tilde{M} \): number of truncated turbulent modes (\( \tilde{M} < N \)). Covariance principal coordinates can be determined from observed data:

\[ \mathbf{x}_v(t) = \Theta_v^{-1} \mathbf{v}(t) = \mathbf{v}(t) \Theta_v = \sum_{i=1}^{N} \nu_i(t) \theta_i \] \hspace{1cm} (9)

3.2. Spectral-based proper transformation

Similarly, the spectral eigenvalues and eigenvectors are found based on to the eigen problem of the cross spectral matrix \( S_v(n) \) of random turbulent process \( \mathbf{v}(t) \):

\[ S_v(n) \Psi_v(n) = \Lambda_v(n) \Psi_v(n) \] \hspace{1cm} (10)

where \( \Lambda_v(n) = \text{diag}(\lambda_{v,1}(n), \lambda_{v,2}(n), \ldots, \lambda_{v,N}(n)) \), \( \Psi_v(n) = [\psi_{v,1}(n), \psi_{v,2}(n), \ldots, \psi_{v,N}(n)] \): spectral eigenvalue and eigenvector (turbulent mode) matrices, which also satisfy the orthonormal conditions

\[ \Psi_v^T(n) \Psi_v(n) = I ; \quad \Psi_v^T(n) S_v(n) \Psi_v(n) = \Lambda_v(n) \] \hspace{1cm} (11)

Thus, the Fourier transform and the cross spectral density matrix \( S_v(n) \) can be represented under the spectral proper transformation as follows:

\[ \hat{\mathbf{v}}(n) = \Psi_v(n) \hat{\mathbf{x}}_v(n) \approx \sum_{j=1}^{\tilde{M}} \psi_{v,j}(n) \hat{\mathbf{x}}_v(n) ; \quad S_v(n) = \Psi_v(n) \Lambda_v(n) \Psi_v^T(n) \approx \sum_{j=1}^{\tilde{M}} \psi_{v,j}(n) \lambda_{v,j}(n) \psi_{v,j}^T(n) \] \hspace{1cm} (12)

where \( \hat{\mathbf{x}}_v(n) \): spectral-based turbulent principal coordinates as Fourier transforms of uncorrelated single-variate random processes; \( \tilde{M} \): number of truncated turbulent modes (\( \tilde{M} < N \)); \*\,T: complex conjugate and transpose operation, respectively.

4. New approach on buffeting response formulation

4.1. Structural modal transformation

MDOF motion equations of structures subjected to the buffeting forces:

\[ M\ddot{U} + C\dot{U} + KU = F_b(t) \] \hspace{1cm} (13)

where \( M, C, K \): mass, damping and stiffness matrices, respectively; \( U, \dot{U}, \ddot{U} \): deflection and its first-, second-order derivatives; \( F_b(t) \): full-scale buffeting forces.

Decomposing into the generalized structural coordinates using the mass matrix-based normalized structural modal transformation as follows:

\[ U = \Phi \xi \approx \sum_{i=1}^{M} \phi_i \xi_i \; ; \; \Phi^T M \Phi = I \; ; \; \Phi^T C \Phi = \Xi \; ; \; \Phi^T K \Phi = \Omega \] \hspace{1cm} (14)
where $\Phi$: modal matrix $\Phi = [\phi_1, \phi_2, \ldots, \phi_T \ldots]$; $M$: number of truncated structural modes; $I$: unit matrix; $\Omega$: diagonal matrix containing structural eigenvalues; $\Xi$: diagonal matrix containing structural frequencies and damping ratios.

Thus, the 1DOF motion equation in the $i$-th generalized structural coordinate due to the generalized buffeting forces can be obtained:

$$\ddot{\xi}_i + 2\zeta_i \omega_i \dot{\xi}_i + \omega_i^2 \xi_i = \phi_i^T F_b(t)$$

(15)

where $\omega_i, \zeta_i$: circular frequency, damping ratio.

4.2. Time-domain buffeting response

The full-scale buffeting forces in Eq.(5) are used in which the two $N$-variate turbulent processes $u(t), w(t)$ are decomposed into uncorrelated turbulent principal coordinates using the covariance proper transformation as Eq.(8) and Eq.(9):

$$u(t) \approx \tilde{u}(t) = \Theta_u \tilde{x}_u(t) = \sum_{j=1}^{M} \theta_{uj} \tilde{x}_j(t); \quad w(t) \approx \tilde{w}(t) = \Theta_w \tilde{x}_w(t) = \sum_{j=1}^{M} \theta_{wj} \tilde{x}_j(t)$$

(16)

Thus, the 1DOF motion equation eq.(15) is rewritten:

$$\ddot{\xi}_i(t) + 2\zeta_i \omega_i \dot{\xi}_i(t) + \omega_i^2 \xi_i(t) \approx \frac{1}{2} \rho UB \left[ \phi_i^T C_u \sum_{j=1}^{M} \theta_{uj} \tilde{x}_j(t) + \phi_i^T C_w \sum_{j=1}^{M} \theta_{wj} \tilde{x}_j(t) \right]$$

(17a)

$$\ddot{\xi}_i(t) + 2\zeta_i \omega_i \dot{\xi}_i(t) + \omega_i^2 \xi_i(t) \approx \frac{1}{2} \rho UB \left[ \tilde{P}_u(t) \tilde{x}_u(t) + \tilde{P}_w(t) \tilde{x}_w(t) \right]$$

(17b)

where $\tilde{P}_u(t) = \sum_{j=1}^{M} P_{uj}(t); \quad \tilde{P}_w(t) = \sum_{j=1}^{M} P_{wj}(t)$: cross modal coefficient matrices accounting for interrelation between the turbulent modes and the structural modes.

Time series and its derivatives of the generalized responses can be obtained by using direct integration methods such as the Newton-$\beta$ method ($\gamma = 1/2, \alpha = 1/4$). Finally, the global responses are determined.

4.3. Frequency-domain buffeting response

Power spectra of the generalized responses can be obtained due to second-order Fourier transform with the spectral proper transformation as Eq.(12):

$$S_i(n) = \frac{1}{2 \pi} \rho UB \left[ H(n) \Phi C_u \psi_u(n) \Lambda_u(n) \psi_u^T(n) K(n)^2 \Phi^T H(n)^T + H(n) \Phi C_w \psi_w(n) \Lambda_w(n) \psi_w^T(n) K(n)^2 \Phi^T H(n)^T \right]$$

(18a)

$$S_i(n) = \frac{1}{2 \pi} \rho UB \left[ H(n) \tilde{P}_u(n) \Lambda_u(n) \tilde{P}_u^T(n) H(n) + H(n) \tilde{P}_w(n) \Lambda_w(n) \tilde{P}_w^T(n) H(n) \right]$$

(18b)

where $\tilde{P}_u(n) = \sum_{j=1}^{M} \tilde{P}_{uj}(n); \quad \tilde{P}_w(n) = \sum_{j=1}^{M} \tilde{P}_{wj}(n)$: spectral cross modal coefficient matrices in which their elements
\[ \hat{P}_{uj}(n), \hat{P}_{uj}(n) \text{ imply for interrelation between } j\text{-th turbulent mode on } i\text{-th structural one; } H(n) : \text{ frequency response function (FRF) matrix} \]
\[ H(n) = \operatorname{diag}(\{ H_1(n), \ldots, H_{29}(n) \}) \]

in which term of \( |H_i(n)| \) denotes to FRF at natural frequency \( n_i \). \( K(n)^2 \): squared aerodynamic admittance function.

Spectra and mean square (RMS) of the global responses are obtained respectively. Finally, the root mean square of global responses with respect to vertical, longitudinal and rotational directions can be combined from single-modal responses due to the SRSS principle
\[ S_u(n) = \Phi S_z(n) \Phi^T; \quad \sigma_u^2 = \int S_u(n) dn; \quad \sigma_r(n) = \sqrt{\sum_{i=1}^{29} \sigma_{r,i}^2}; \quad r = h, p, a \]

where \( r \) denotes to displacement components: vertical (h), longitudinal (p), rotational (a); \( M_r \): number of component modes in response combination;

5. Numerical example and discussions

A cable-stayed bridge was taken to investigate the above-presented computational procedures. 3D frame model was built using FEM, totally 30 discrete nodes on bridge deck (nodes 8, 23 at pylons). First ten modes were analyzed and given in Figure 1, in which vertical modes are modes 1, 2, 5, 6 and 8, whereas torsional modes are modes 3, 4, 7, 9 and 10. Lateral modes were omitted.

Figure 3. Normalized structural modes: vertical (left) and rotational (right)

At first, the response analysis of bridges in the time domain has been carried out using Covariance Proper Transformation. Time series of turbulent fields \( u(t), w(t) \) were simulated at deck nodes at mean velocities with sampling frequency of 1000Hz for time interval of 100 seconds. Targeted spectral density functions of \( u \), \( w \)-turbulences used the Kaimail’s and Panofsky’s models. Coherence function used
the Davenport’s function, admittance functions was due to the Liepmann’s approximation.

Figure 4 shows the simulated time series of \( u(t) \), \( w(t) \) at node 5 (mid of side span) and node 15 (mid of main span) at mean velocities \( U=20\text{m/s} \) & \( U=30\text{m/s} \). The power auto spectra (PSD) of simulated time series of \( u(t) \), \( w(t) \) in some deck nodes must be checked for a good agreement with targeted auto spectra. Figure 5 expresses time histories of turbulent-induced lift, moment and those of vertical displacement, rotational displacement in nodes 5 and 15 at also mean velocity \( U=20\text{m/s} \). Newton-beta integration method is used to solve the generalized differential equation in the time domain.

**Figure 4.** Simulated time series in nodes 5&15 at \( U=20\text{m/s} \)(left) & \( U=30\text{m/s} \)(right)

**Figure 5.** Time histories of forces and global response in nodes 5 & 15 at \( U=20\text{m/s} \)
In the next step, response analysis of bridge in the frequency domain has been implemented using the Spectral Proper Transformation. Figure 6 and Figure 7 show the first five spectral eigenvalues and first three spectral turbulent modes on 0.01±10Hz, respectively. It notes that first spectral eigenvalue $\lambda_1(n)$ exhibits much higher than the others on low frequency band 0.01±0.2Hz of $u$-turbulence, 0.01±0.5Hz of $w$-turbulence.

Spectral turbulent modes of $u$-, $w$-turbulences look like symmetrically and asymmetrically sinusoidal waves, moreover, shapes of the turbulent modes are unchanged among the natural frequencies of 0.61±1.85Hz (see Figure 7).

![Figure 6](image1.png)  
Figure 6. First five spectral eigenvalues of $S_u(n)$ (left) and $S_w(n)$ (right)

![Figure 7](image2.png)  
Figure 7. First three turbulent modes of $S_u(n)$ (upper) and of $S_w(n)$ (lower)
Figure 8. Spectra of global responses (vertical & rotational) at node 15 (middle of main span) vs. number of turbulent modes

Figure 8 shows the power spectra of the global responses (vertical and rotational displacements) at middle node 15 and also effect of number of truncated turbulent modes on global response has been investigated. Resonant and background responses can be seen in the Figure 8. Moreover, the vertical structural modes (modes 1,2,6,8) contribute on the vertical displacement, whereas the torsional modes on the rotational one. For contribution of number of the turbulent modes on the global responses, it is observed that no much different among cases of truncated turbulent modes, the first turbulent mode significantly contributes on spectra of global responses, except difference from the background response can be observed.
Figure 9. Global responses (vertical & rotational) on all deck nodes vs. number of turbulent modes

Figure 9 shows the root mean square of vertical and rotational displacements on whole bridge deck in comparison between time domain and frequency domain analyses as well as effect of number of turbulent modes. As seen that the first turbulent mode and the lowest modes in the frequency domain formulation contributes significantly on the global responses and play more important role than that in the time domain one.
6. Conclusion

In this paper, new approach on the buffeting response prediction of cable-stayed bridges based on the Proper Orthogonal Decomposition and Dual Modal Transformations has been discussed. Multi-variate spatially-correlated turbulent fields have been represented on comprehensive form of the covariance matrix and the cross spectral one. It is found that only limited number of low-order turbulent modes dominantly contributes on structural buffeting response. The first spectral turbulent mode seems accuracy enough to predict the buffeting response in the frequency domain, however more number of the covariance turbulent modes should be required in the time domain.

References