ANALYSIS OF LONG SPAN SUSPENSION BRIDGE BY TIME DOMAIN TECHNIQUE

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Introduction

Continuously monitored ambient vibration measurement is used to study the dynamic behavior of suspension bridge, such as, natural frequencies, the modal vectors, and modal damping ratio. Ambient vibration measurement is a simple technique to identify the dynamic properties of a suspension bridge because there are situations where controlled excitation or initial excitation cannot be used. In this paper, the Random Decrement Method [1] with the Ibrahim Time Domain Method was used to find the higher frequencies mode vectors of Hakucho Bridge [2]. Hakucho Bridge is a suspension bridge with a 720 m span and two symmetric side spans with 330 m and the total length is 1380 m. Each span is discontinuous and the center span is simply supported at the towers.

Theory

By using the Random Decrement Technique, the very high noise in the ambient vibration data can be reduced or eliminated. So by this technique the ambient vibration with very high noise can be changed to free vibration with very low noise.

The equation of motion of the free vibration response is:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{0\}$$

Where [M], [C], and [K] are n x n matrices, while x, $\dot{x}$, and $\ddot{x}$ are n-dimensional vectors. By using Ibrahim Time Domain Method the dynamic parameters of this system can be identified as in the following equation:

$$\begin{Bmatrix} x_1(t) \\ x_2(t) \\ \vdots \\ x_N(t) \end{Bmatrix} = \sum_{r=1}^{2N} \begin{Bmatrix} \Psi_{1r} \\ \Psi_{2r} \\ \vdots \\ \Psi_{Nr} \end{Bmatrix} \exp((-z_r w_r + \sqrt{1-z_r^2}\, w_r)t)$$

By this equation, at any instant of time (t), $2N$ conjugate modes are identified. But only the first few modes can be identified with high accuracy.

After time shift τ, the same $2N$ modes are identified.

$$\begin{Bmatrix} x_1(t+t_1) \\ x_2(t+t_1) \\ \vdots \\ x_N(t+t_1) \end{Bmatrix} = \sum_{r=1}^{2N} \begin{Bmatrix} \Psi_{1r} \\ \Psi_{2r} \\ \vdots \\ \Psi_{Nr} \end{Bmatrix} \exp((-z_r w_r + \sqrt{1-z_r^2}\, w_r)(t+t_1))$$

This equation can be rewritten after changing the notation as:

$$\begin{Bmatrix} x_1(t+t_1) \\ x_2(t+t_1) \\ \vdots \\ x_N(t+t_1) \end{Bmatrix} = \sum_{r=1}^{2N} \begin{Bmatrix} \Phi_{1r} \\ \Phi_{2r} \\ \vdots \\ \Phi_{Nr} \end{Bmatrix} \exp((-z_r w_r + \sqrt{1-z_r^2}\, w_r)t)$$

Then the number of measurement points increased from N To $2N$ and the number of modes also increased from $2N$ to $4N$.

By making the same time shift many times and combining all equation in one equation, the number of modes extended from $2N$ to $2L$ as shown:

$$\begin{Bmatrix} x_1(t) \\ x_2(t) \\ \vdots \\ x_N(t) \\ x_1(t+t) \\ x_2(t+t) \\ \vdots \\ x_M(t+t) \end{Bmatrix} = \sum_{r=1}^{2N} \begin{Bmatrix} \Psi_{1r} \\ \Psi_{2r} \\ \vdots \\ \Psi_{Nr} \\ \Psi_{(N+1)r} \\ \Psi_{(N+2)r} \\ \vdots \\ \Psi_{Lr} \end{Bmatrix} \exp((-z_r w_r + \sqrt{1-z_r^2}\, w_r)t)$$

In this study, for vertical mode, the number of measurement points are 19, 5 at the side span and 14 at the main span, so the number of modes which can identify equal to 19. By using the time shift technique four times for the main span only, the number of modes extended to 61 mode. By this procedure the first 19th mode can identify with very high accuracy.

Keyword: Ambient vibration, Random Decrement, Time Domain, Long span bridge
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Analysis and Results

In this study ambient vibration data from 4th June 1998 until 12th June 1998 are analyzed. This data are divided into 10 ranks according to the rms of the acceleration od the station number 17, which locates at the mid point of the main spain. By the persented new method the dynamic parameters of 28 modes, 10 symmetric vertical modes, 9 anti-symmetric vertical modes, 5 symmetric torsion modes, and 4 anti-symmetric torsion modes are identified. The following figures show the variation of the dynamic parameters of two modes, as examples, with the wind speed or rank level starting with real part of mode vector, natural frequency, and after that the damping ratio.

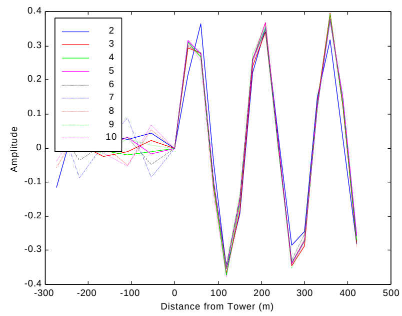

Figure (1): Mode shape

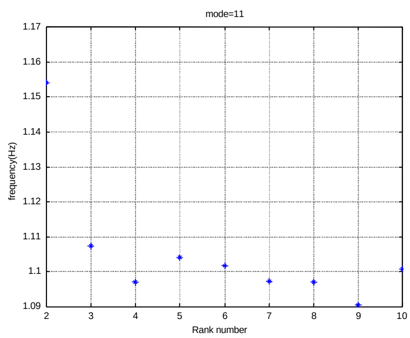

Figure (2): Natural frequency

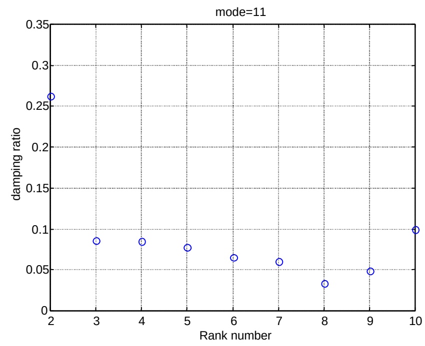

Figure (3): Damping ratio

Figure (4) shows the comparison of the natural frequencies of all the 19th vertical modes. This new method give excellent results comparing with the finite element method and the forced vibration test.

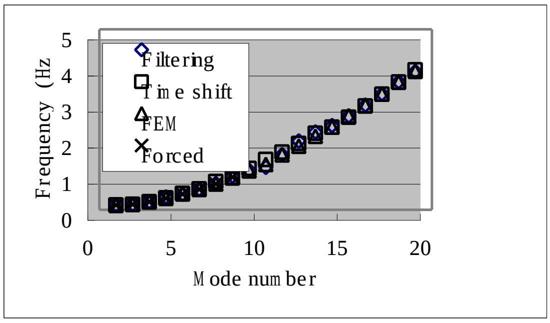

Figure (4): The comparison of the natural frequencies

Conclusion

Random decrement vibration analysis technique with Ibrahim time domain method was used to identify the dynamic parameters of the higher frequencies modes. This study also shows the variation of natural frequencies, damping ratios, and mode shapes due to change in wind velocity, which can be used efficiently in health monitoring of the bridge.

Reference

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2. S.R. Ibrahim and E.C. Mikulcik, "*A Time Domain Modal Vibration Test Technique*" The Shock and Vibration Bulletin, Bulletin 43, Part 4, June 1973.

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