Flutter analysis of cable stayed bridge

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Flutter analysis of cable stayed bridge

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Abstract

Aerodynamic stability is one of the most important issues in wind resistance design for long-span bridges; various studies have been carried out on it. One of the most dangerous among various aeroelastic instabilities is flutter, which is the dynamic instability phenomenon wherein at some critical wind speed the bridge will oscillate and collapse. This paper discusses the flutter speed of the cable stayed bridge by means of numerical analysis as well as experimental. Numerical analysis of flutter speed was conducted based on the eight extracted aerodynamic derivatives. The Flutter Margin Method of Zimmerman was used to predict flutter speed of the experimental results. The analysis results showed that the critical flutter velocity based on the flutter derivatives was also confirmed by the experimental test results. It is concluded that the result from numerical analysis is close to that of the experimental test.

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Keywords:Aerodynamic derivatives;flutter speed; cable stayed bridge

1. Introduction

Bridges are very important infrastructures to provide a link across rivers, valleys or other physical obstacles. For long-span bridge designs, the impact of wind loads needs serious attention because the failure of long-span bridges is not necessarily at the maximum wind speed. Like what has happened in the case of Tacoma Narrows Bridge failures in November 1940. Long-span bridges are known to be very susceptible to wind load. There are four main categories of wind effects on bridge decks: (1) flutter, (2) buffeting, (3) vortex excited vibration, and (4) galloping

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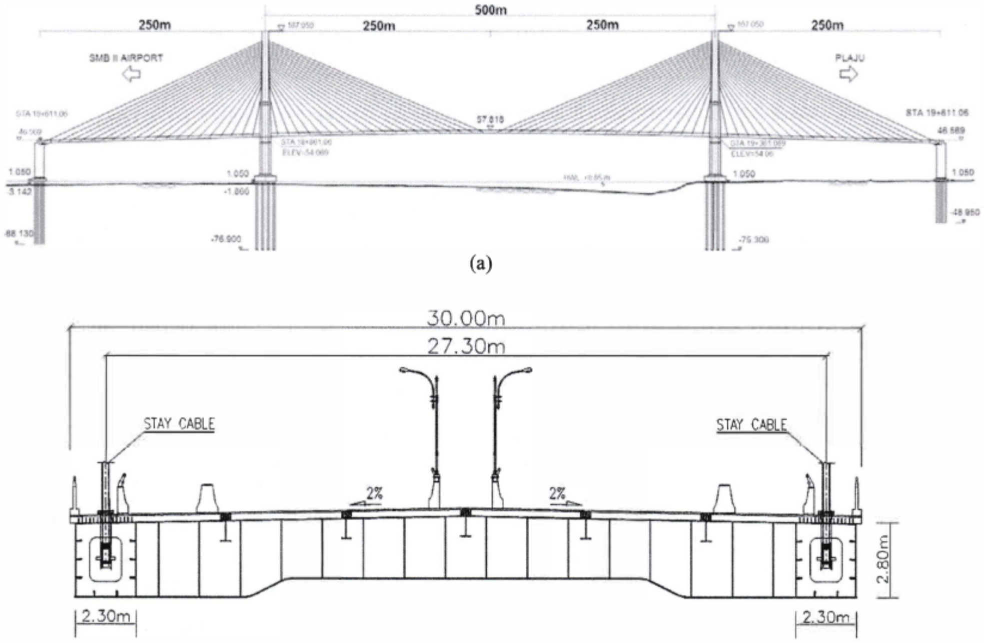
[1]. These four phenomena have been studied extensively by using a wind tunnel test. Flutter is a very important parameter in design of long-span bridges, because it can lead to total failure of the structure. This paper discusses the flutter analysis design of Musi III cable-stayed bridge

2. Bridge Model

The MUSI III bridge is a cable-stayed bridge that was serving for model experimentation and analysis. It is part of the Musi - III highways and bridges in the province of South Sumatera (Palembang) Indonesia. This bridge has a main span length of 500 m and two side spans of 250 m. While the navigational clearance height and width are 51 m and 400 m respectively; and the actual height at midspan is 53,667 m. The deck has a 30m width, supported by two box girders and is separated into two carriageways and two sidewalks by handrails. Basically, the shape of the Musi III bridge deck is similar to the Suramadu cable-stayed bridge, with a two wheeled vehicle lane modifications moved to the inside (Fig. 1).



(a)

(b)

Fig. 1. Prototype of Musi III Bridge. (a) longitudinal section, (b) cross section

The sectional model test was conducted in the Aero-gas Dynamics and Vibration Laboratory, Serpong Indonesia, in a circuit of a closed return type with atmospheric and closed walled test sections of the wind tunnel. The wind tunnel has a working section of 4m in width, 3m in height, and with a total length of 10 m. The maximum attainable wind speed inside the empty test section was 110 meter per second. The reduced scale of 1/50 was chosen, giving a model of width B = 0,592 m. The properties of the structure and model are shown in Table 1. The measurement of the aerodynamic responses of bending and torsional mode for the sectional model was carried out, where the angle of attack is = -3o, 0o and +3o. The center of rotation was assumed to be at the location between the center of gravity and the shear center. The model with a length of 1,2 m and width of 0,592 m was suspended in eight coil springs to enable vertical and torsional motions.

Table 1 Structural properties of prototype and model

Properties	Prototype	Model
Width (m)	30	0,592
Depth (m)	3,0	0.042
Bending natural frequency f_η (Hz)	0,2995	9,5
Torsional natural frequency f_ϕ (Hz)	0,6404	20
f_ϕ/f_η	2,1	2,1

3. Flutter Analysis

Flutter is the dynamic aeroelastic instability phenomenon that is caused by the motion-induced or self-induced force. It is one of the most significant things in long-span bridge design as flutter may lead to excessive vibrational amplitudes or even total collapse of the bridge deck. The interaction between aerodynamic force, stiffness and inertial forces on structures can produce flutter instability. This instability can be realized from the contribution of one or more mode deflections. The deflection components of the bridge are vertical displacement, h, and sway displacement, p, and rotational displacement, α. A single uncoupled torsional mode is usually the most dominant in the response bridge flutter. For very long span bridges, a critical problem will arise when the coupled flutter caused by the coupling among the deflection is in vertical and torsional mode.

Usually, flutter analysis is carried out considering a typical cross section of the bridge. Experimental or analytical techniques can be used to determinate flutter instability. Experimental methods for investigation of aerodynamic stability and aerodynamic properties conducted using a wind tunnel is the standard procedure, where a prototype structure is a scaled model and is tested under the satisfaction of the similarity low. Flutter analysis is subjectedin order to predict the lowest critical wind velocity that induces flutter instability, and the corresponding flutter frequency. Analytical methods are derived based on frequency and time domains.

Over the last four decades, comprehensive studies have been conducted to develop procedures for the analysis of coupled flutter of long span bridges by integrating analysis and determining flutter derivatives. As a pioneer, Bleich [2] analyzed coupled flutters problem for long-span bridges by using a formulation of Theodorsen on unsteady aeroelastic force. Scanlan and Tomko [3] proposed a formula for motion-induced force. The aerodynamic parameters called flutter derivatives were used to define a linear aeroelastic system expressed through aeroelastic force as:

$$m\left(\ddot{h} + \varsigma_h\, \omega_h\, \dot{h} + \omega_h^2\, h\right) = L_{ae} \quad , \qquad I_\alpha\left(\ddot{\alpha} + \varsigma_\alpha\, \omega_\alpha\, \dot{\alpha} + \omega_\alpha^2\, \alpha\right) = M_{ae} \tag{1}$$

Where: m = the mass per unit length, I_α= the mass moment of inertia per unit length, $\zeta_h$and ζ_α are damping ratios-to-critical, ω_h and ω_α are the natural circular frequencies in the h and α degrees-of-freedom, respectively, L_{ae} and M_{ae} are the self-exited aerodynamic lift and moment forces about the rotational axis per unit length, respectively.

The sectional aerodynamic force under vertical displacement h and twist α of the bridge deck section model as:

$$L_{ae} = \frac{1}{2}\rho U^2 B\, L\left(KH_1^* \frac{\dot{h}}{U} + KH_2^* \frac{B\dot{\alpha}}{U} + K^2 H_3^* \alpha \ + K^2 H_4^* \frac{h}{B}\right) \tag{2a}$$

$$M_{ae} = \frac{1}{2}\rho U^2 B^2\, L\left(KA_1^* \frac{\dot{h}}{U} + KA_2^* \frac{B\dot{\alpha}}{U} + K^2 A_3^* \alpha \ + K^2 A_4^* \frac{h}{B}\right) \tag{2b}$$

where: h and α = the vertical and twist deflections, ρ = the air density, U = the mean cross-wind velocity, B = the deck width, L = the deck length, H_i and A_i = flutter derivatives.

The numerical analysis of flutter critical wind speed of the Musi III cable-stayed bridge was estimated by scanlan's flutter analysis method [3] as determined by Dyrbye [4] using flutter derivatives that was determined by Sukamta [5]. The Figure 2 shows the result of the flutter analysis. The critical condition is reached at a number of $u/n\,b = 2{,}51$, which is equivalent to $Up = 48$ m/s.

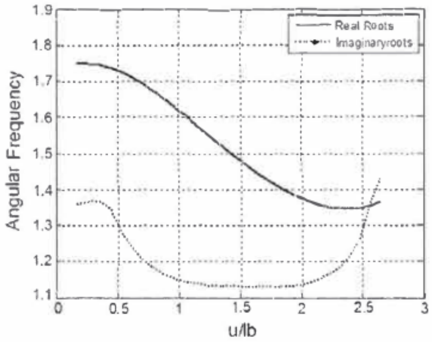


Fig. 2. Determination of critical flutter velocity

The critical flutter (U_f) from the experiment was determined using the Flutter Margin Method of Zimmermann. This method is obtained through direct calculation of the measurement data and damping oscillation frequency of each mode of the model. By using the Flutter Margin Method, predictive potential was determined from the extrapolation curve flutter margin (Fm) to the horizontal axis (X axis) [6].

Figure 3 shows the estimated flutter for a model using the Flutter Margin Method. The predicted flutter speed is reached at a number of q=568 Pa, which is equivalent to about U_p=49 m/s

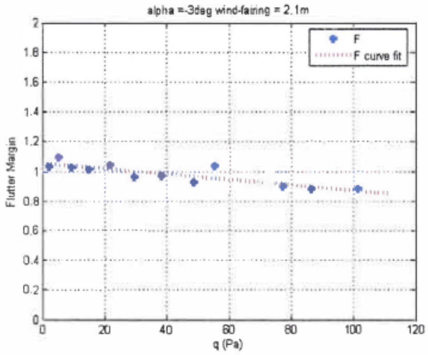


Fig. 3. Flutter Speed prediction using Zimmerman Method

In the case of α=-3 °, there was no oscillation and more stable results were obtained in α=0 ° in comparison with those in α=+3 °. Both methods yield similar values of speed flutter on the prototype bridge, which is about 48 - 49 m/s.

4. Conclusion

The flutter velocity of Musi III has been an analysis. The prediction of critical flutter speed was conducted by means of numerical analysis as well as experimental. The result from numerical analysis is close to that one from the experimental test. To improve the flutter stability of the bridge, the deck should be modified on the shape of the bridge deck.

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