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ACTIVE AERODYNAMIC CONTROL SYSTEM SYNTHESIS FOR BRIDGE DECK FLUTTER SUPPRESSION

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1. INTRODUCTION

The aerodynamic flutter control methods, by means of additional surfaces, can change the flow-structure interaction. The additional stabilizing forces can be generated on the flaps and the aerodynamic forces exerted on the deck can be modified to suppress flutter. The aim of this paper is to find the optimal flaps configuration and control law for flutter suppression by the deck-flaps system.

2. MODELING OF UNSTEADY AERODYNAMICS OF DECK-FLAPS SYSTEM

The system motion is described by heaving, h, pitching, α, and β, γ denote relative angles of rotation of leading and trailing flap, respectively (Fig. 1).

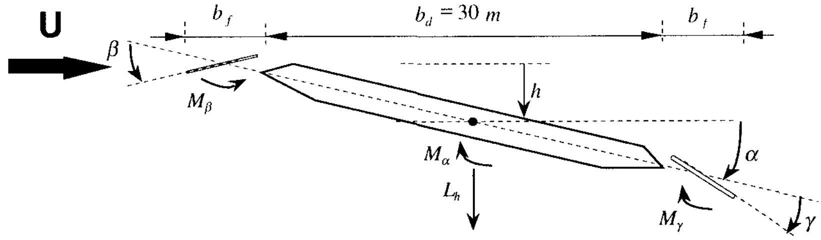

Fig. 1 Geometry and position of coordinate system of bridge deck with additional flaps.

The governing equation of motion for this 4DOF system is:

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{C}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathbf{F}(\ddot{\mathbf{x}}, \dot{\mathbf{x}}, \mathbf{x}, \hat{s}) + \mathbf{u} \tag{1}$$

where $\mathbf{x}^T = [h/b \quad \alpha \quad \beta \quad \gamma]$, $\mathbf{M}$, $\mathbf{C}$, $\mathbf{K}$ are system mass, damping and stiffness matrices, respectively; $\mathbf{u}$ is the vector of control forces for flap motion; and $\mathbf{F}^T = [L_h \quad M_\alpha \quad M_\beta \quad M_\gamma]$ represents the vector of self-excited aerodynamic forces, which depend on the complex reduced frequency $\hat{s}$. The self-excited aerodynamic forces are modeled using rational function approximation[1].

3. OPTIMAL CONFIGURATION OF CONTROL SYSTEM

The optimal configuration of active aerodynamic control of a bridge with main span of 2000 m and deck width of 30 m is studied. Three cases of hinge location in flaps (Fig. 2) are investigated. For each flap configuration four sizes of flaps are considered, namely $1.5\,m$, $3.0\,m$, $4.5\,m$, and $6.0\,m$.

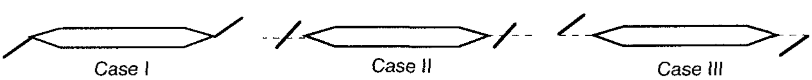

Fig. 2 Location of flaps hinges .

The comparison of different systems is based on the system stability robustness in the wind velocity range of interest, from $U_{low} = 35\ m/s$ to $U_{up} = 80\ m/s$. The proposed performance index is of the form:

$$I_T = q_1 \frac{1}{U_{up} - U_{low}} \int_{U_{low}}^{U_{up}} \min_{0 \le \omega < \infty} (l_U(\omega)) dU + q_2 \min_{U_{low} \le U \le U_{up}} \min_{0 \le \omega < \infty} (l_U(\omega)) \tag{2}$$

$l_U(\omega)$ is the measure of stability robustness used in the control system theory[2], defined as:

$$l_U(\omega) = \underline{\sigma}\left[\mathbf{I} + \mathbf{K}_c \mathbf{G}(i\omega)^{-1}\right] \qquad \text{for } 0 \le \omega < \infty \tag{3}$$

In the above formula $\mathbf{I}$ is an identity matrix of proper dimension, $\mathbf{K}_c$ is the transfer function matrix from measured displacements to control inputs $\mathbf{u}^T = [u_\beta \quad u_\gamma]$, $\mathbf{G}$ is the open loop transfer function, and $\underline{\sigma}$

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denotes the smallest singular value. The subscript U denotes the dependence of the measure on wind velocity. The first term in Eq. (2) gives the average value of stability robustness measure within the design wind velocity range, whereas the second term pick up its smallest value. In the subsequent considerations weighting factors q_1 and q_2 were both set to one.

A simple control law which relates motion of the flaps to the motion of the deck is investigated:

$$\begin{bmatrix} \beta \\ \gamma \end{bmatrix} = \mathbf{T} \begin{bmatrix} h/b \\ \alpha \end{bmatrix} \tag{4}$$

where $\mathbf{T}$ is a gain matrix of size 2×2.

The dynamic parameters describing the sectional model of the bridge are selected as $\omega_h = 0.389\ rad/s$ and $\omega_\alpha = 0.892\ rad/s$. The critical flutter wind speed for this bridge without flaps is $50\ m/s$.

The results of the optimization are shown in Fig 3. It can be noticed that Case I of hinge location gives the highest values of performance index for flaps of width of $1.5\ m$, $3.0\ m$, and $4.5\ m$. The maximum value of $I_T = 0.73$ is obtained for flaps of width of $3.0\ m$, and further increase in flap size cannot improve system performance. The control law which maximizes the performance index (2) is:

$$\begin{bmatrix} \beta \\ \gamma \end{bmatrix} = \begin{bmatrix} 0 & 18 \\ 4 & 20 \end{bmatrix} \begin{bmatrix} h/b \\ \alpha \end{bmatrix} \tag{5}$$

The motion of the flaps for the system subjected to the control law (5) is predominantly govern by the pitching motion of the deck. For the upnose motion of the deck the leading flap is moving downward and the trailing one is rotating in the same direction as the deck. Fig. 4 shows the variation of the robustness measure (3) with wind velocity U for the system subjected to the optimal control law (5). The stability robustness does not differ significantly in the design wind velocity range, deteriorating only slightly as the wind velocity increases.

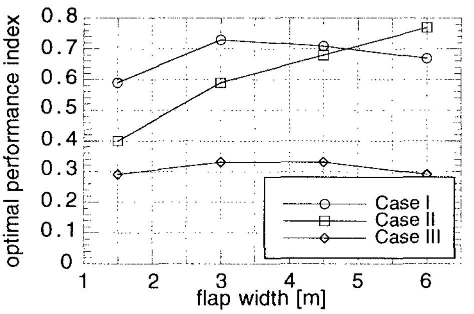

Fig. 3 Optimal performance index for different flap size and hinge location.

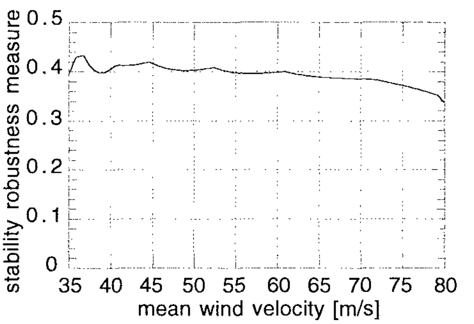

Fig. 4 Variation of the stability robustness measure with wind speed for the optimal control system configuration.

4. CONCLUSIONS

The active aerodynamic control of flutter of the bridge deck with leading and trailing flaps attached to the edges of the deck is studied. The optimal control system configuration is found based on the criterion of maximum stability robustness of the control system in the wind velocity range of interest. It is found that the optimal configuration of flaps is Case I hinge location and flap width of $3.0\ m$. The optimal control system provides system stability in the design wind velocity range with high robustness. The results of this simulations are intended to be used for design of passive aerodynamic method utilizing flaps directly connected to the deck ends.

REFERENCES

1) Wilde K., Omenzetter P., Fujino Y.: Modeling of Unsteady Aerodynamics of Bridge Deck-Flaps System and Optimization of Flaps Motion, Proceedings of the 52nd Annual Conference of JSCE, 1997.

2) Doyle C. D., Stein G.: Multivariable Feedback Design: Concepts for a Classical/Modern Synthesis, IEEE Transactions on Automatic Control, Vol. AC-26, No. 1, 1981.