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ECCENTRIC TMD AS PASSIVE CONTROL OF FLUTTER.

Yokohama National University Member JSCE Nguyen Ngoc DUNG
Yokohama National University Member JSCE Toshio MIYATA
Yokohama National University Member JSCE Hitoshi YAMADA

1. Introduction

The vulnerability to the flutter caused by strong wind has been a serious concern and motivation for research on the application of structure control on long span bridges[1,2]. However, the control method based on the active mean is still impractical while the effectiveness of passive control as it is known does not seem to be impressive. Such poor performance can be attributed to the particularities the self-exited system. In this study the aerodynamic behavior and flutter responses are analyzed by the complex flutter modes in the view of passive control application. From the phase lag and coupling relation between the 3 motions of deck section, it is shown that TMD installed off-center on the windward direction would have better influence on the flutter mode. In fact, eccentricity of TMD such designed will make change in these shapes in favor of stability and greatly improve the flutter resistance with the lower effort. Numerical flutter analysis of the a full model bridge with control is conducted and some aspects are discussed. Results from the analysis show a promising outlook for the TMD devices in flutter control.

2. Passive control by eccentric TMD

In a windy environment, the vibrating structure is found interacting with the flow through the aerodynamic forces. Such forces can be expressed in functions of the structural responses and a set of flutter derivative coefficients. Adding together, the flow and structure can be reduced to a dynamic system with apparent complex mass and stiffness which can be transformed to the modal space[3]. Due to the nature of aerodynamic forces, the system is not symmetric which requires two set of complex eigenvectors for the transformation into modal space. Denoting v,v* as the right and left eigenvector respectively, the modal equation can be written as:

$$\mathbf{m}_i.\ddot{\bar{\mathbf{x}}} + \mathbf{k}_i.\bar{\mathbf{x}} = \mathbf{v}_i^*.\mathbf{w} + \mathbf{v}_i^*.\mathbf{u} \quad \text{where :} \quad \mathbf{x} = \mathbf{v}.\bar{\mathbf{x}} \tag{1}$$

Where the control action **u** is added. It could be observed that while the right eigenvector represents the mode shape of vibration, the left eigenvector is the projection of the modal forces. For the mechanical system, there is no distinction between them since the system is symmetric.

The originally torsional dominant eigenvector of flutter mode is changed to vertical dominant (Fig. 1). The difference of the mode shape and the modal forces shows that while the vibrational motion is mostly vertical, the driving forces behind it is mainly the torsional moment. From the structural control point of view, this implies that the mode is much better observed by the heaving motion while control agent should be more influencing through the twisting forces.

Such strategy on the control can be achieved by installing the TMD device with certain eccentricity (Fig. 2). By analyzing the phase lag between heaving and pitching motions, the best position seems to be in the windward direction. In fact, numerical examples show that positioning the TMD in the opposite direction could have the destabilizing effect.

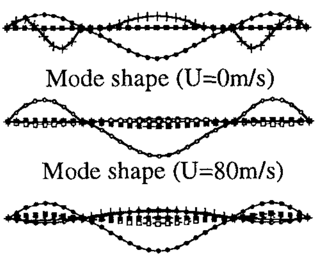

Fig. 1 Mode shape and modal force of flutter mode.

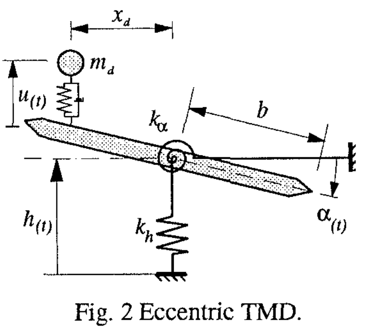

Fig. 2 Eccentric TMD.

3. Numerical example of TMD in 3D bridge model

The 2D section of the bridge deck is far from an ideal model for the flutter response analysis of a full bridge. For this simplified model, the variation of the vibration mode shape along the bridge axis which plays a critical role in the flutter behavior can not be disclosed. The problem is more critical and could

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〒240 Yokohama, Hodogaya-ku, Tokiwadai 79-5. Tel. : 045-339-4042, Fax : 045-331-1707

become unacceptable for the structure with localized controller installed. In the case of eccentric TMD, a limited number of devices are installed and interact at any chosen location while external forces are distributed nature. This advantage which gives the TMD an edge over the aerodynamic forces on taking hold of the vibrations in structure, also makes the flutter mode shape change more radically.

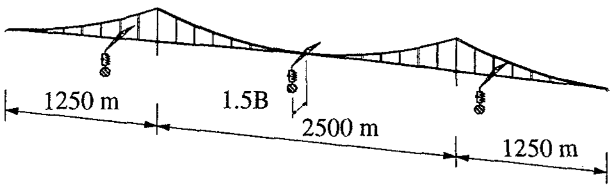

Fig. 3 Three dimensional frame model with eccentric TMD.

Such effects render the control behavior on the 2D model which is only determined by the main frequencies very inaccurate. The design of TMD is first based on the complex flutter mode and once designed, the full system will be analyzed for the stability. This procedure is usually carried on in a few cycle of iteration.

To see how the eccentric TMD could work, an example of suspension bridge with the span length of 2500m is used. The deck of this model is assumed to be a very flat, stream line box girder, where the aerodynamic forces can be calculated by the Theodorsen function. It could be noted that such flatten deck make the bridge vulnerable to flutter at rather low wind speed of 59m/s. The Finite Element Model of the bridge is shown in the Fig. 3. The sum mass of TMD's is about 0.75% of the total mass of cable, girder and the tuned frequencies are 0.108Hz for central TMD, 0.098Hz for the two side span ones.

The result of 3 TMD on the system frequency and damping of the 2500m span bridge are shown in Fig. 4. It can be seen that in this case, the critical wind speed has been dramatically increased. The damping of the structure before flutter is also improved. The wind speed for flutter onset now is more than 80m/s which complies with the design requirement. Comparing with the TMD on 2D case, it should be pointed out that the eccentricity and the controlling mass are smaller but their performance and effectiveness is seemed much better. This highlights the upper hand TMD has over the distributed aerodynamic forces and their effect on the mode shape control.

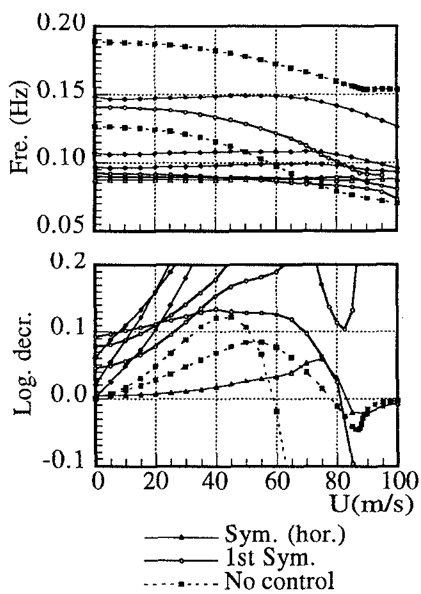

Fig. 4 Frequencies and damping of the full model with 3 TMD.

4. Concluding remarks

The research and result so far have shown the TMD can be used to improved the critical wind speed of the long span bridge. However, to be effective, the flutter characteristics should be taken into account in the control design. By giving the TMD some eccentricity, the TMD is more capable of coping with the coupling motions of flutter mode. Example on the full model of bridge shows that the flutter mode shape is quite sensitive to the control effect which strongly discourages the use of a too simplified model.

The scheme of control suggested is simple. In fact, its manufacture would not require any new technology. Nevertheless, this control have certain responsiveness to the environment, which from the prospective of structural control, could be seen as an intermediate step before a full active control can be integrated into the structure.

References

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