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SUPPRESSION OF FLUTTER OF LONG SPAN SUSPENSION BRIDGES BY ECCENTRIC MASS METHOD

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1. INTRODUCTION

Long span suspension bridges are very sensitive and flexible towards wind forces. For the design of such bridges, flutter is one of the most important criterion since it can lead to a total collapse of the structure. In this paper, suppression of flutter by eccentric mass method is studied. The auxiliary mass is placed on the windward side of the deck to shift the center of gravity, and thus, reduce the aerodynamic moment acting on the deck. The flutter suppression by eccentric mass method both in sectional and full bridge model in time domain by using rational function approximation (RFA) are presented in this paper.

2. SECTIONAL MODEL ANALYSIS

In the analysis, the bridge deck is modeled as a 2 DOF system. The natural frequency of heaving mode, ω_h, and pitching mode, ω_α, are equal to 0.355 rad/s and 0.845 rad/s, respectively. The bridge deck has width of 30 m. The equation of motion is written in time domain by using RFA[1]. For this study, the aerodynamic data obtained from the experiment of Kurushima bridge model of a scale 1:60 in different angles of attack are used.

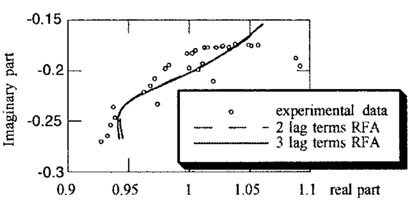

Fig.1 Approximation of moment due to pitching mode

It is found that, for the case of zero degree angle of attack, RFA with different lag terms provides similar approximation of wind forces (Fig.1). Nonetheless, when the angle of attack is more than zero, larger approximation function is found to be necessary.

The critical wind speed (U_f) for the case of bridge without eccentric mass is 35.3 m/s. Fig.2 shows the relation between the critical wind speed and mass ratio of the eccentric mass with respect to mass of the deck for aerodynamic data for different angle of attack. It can be seen that the critical wind speed can be increased from 35.3 m/s to around 60 m/s by using 30% mass ratio. Moreover, when the mass ratio is approximately less than 10%, the critical wind speeds are similar regardless to used aerodynamic data. But for the higher mass ratio, both approximations through different angles of attack and RFA with different lag terms provide different results. For the higher mass ratio range, it is found that the system becomes unstable due to divergence (non-harmonic instability), not flutter. According to this sectional model, it can be seen that the eccentric mass can significantly improve the critical flutter wind speed.

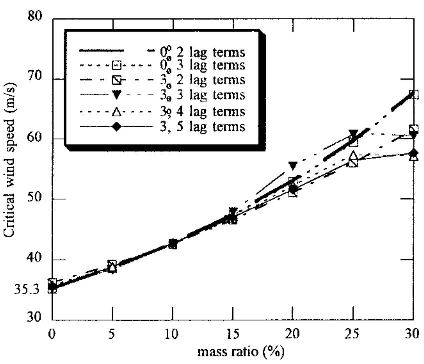

Fig.2 Increasing of critical wind speed with eccentric mass

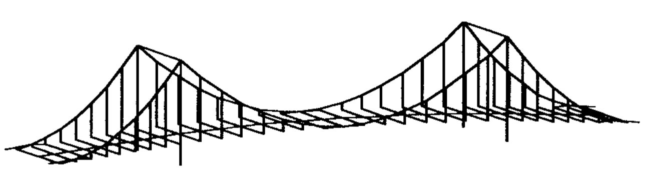

Fig.3 Full Bridge model

3. FULL BRIDGE MODEL ANALYSIS

The full bridge model has a 2,500 m center-span and 1,000 m side-spans and the deck width is 30 m (Fig.3). The full bridge model has the same natural frequencies of the first vertical bending mode and the first torsional mode as in the sectional model. In the simulations, the aerodynamic data from the approximation through RFA from the sectional model are used. The eccentric mass is limited to 5% of deck

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per unit length because the application of large mass ratio is not practical due to significant increase of dead load of the deck. Since mass ratio is limited to 5%, only RFA model of the unsteady aerodynamics for zero degree angle of attack with two lag terms is used in this simulations. The effects from the eccentric mass distribution along the bridge deck is studied in four cases: eccentric mass on the whole bridge, 100% length of center-span, 60% length of center-span and 30% length of center-span.

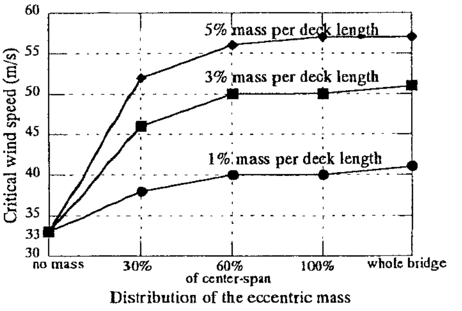

Fig.4 Effect of eccentric mass to critical wind speed

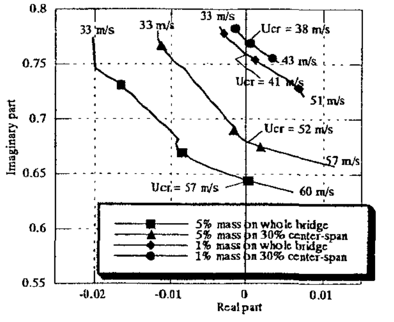

Fig.5 Pole positions of Torsional mode

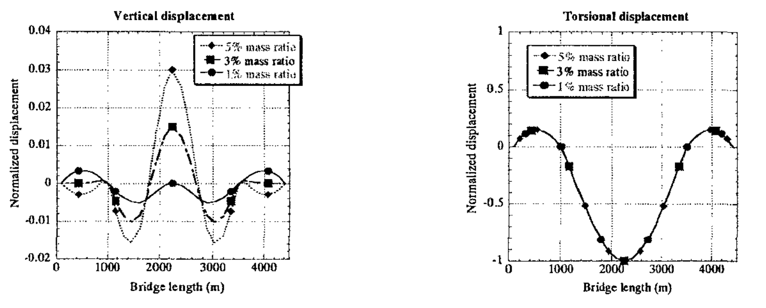

Fig.6 Mode shape of Torsional mode (flutter mode), using 60% center-span mass distribution with different mass ratio

The critical wind speed (U_f) of bridge without additional mass is 33 m/s. Fig.4 shows an increase in the critical wind speed due to different eccentric mass ratio and distribution. It can be seen that the critical wind speed increases greatly when the mass distribution is between 30%-60% of the center-span. However, for the distribution of the mass on whole main span and whole bridge, the critical wind speed shows smaller increase. Fig.5 illustrates pole positions of the torsional dominant mode (flutter) of the system with different eccentric masses. Each complex pole (oscillatory mode) appears to have a positive value of its real part, implying that the structure becomes unstable due to flutter. It also shows that the usage of higher mass ratio, as well as the more distribution, makes the pole shift further from the imaginary axis. This leads to the larger wind speed the system takes for being unstable, and, therefore, the higher critical wind speed. Moreover, when the critical wind speeds are comparatively considered between Fig.2 (sectional model) and Fig.4 (full bridge model), it can be seen that the critical wind speed of the latter is higher because there is a coupling between the first torsional mode and the third vertical bending mode in the full bridge analysis as shown in Fig.6. The figure illustrates the mode shape of the flutter mode of the vertical and torsional displacements for the case of 60% eccentric mass distribution.

4. CONCLUSIONS

For the studied full bridge model, the eccentric mass method proves to be efficient as it can enhance the critical wind speed for approximately 70% when the 5% mass ratio is attached on a whole bridge (Fig.4). The study concerning the mass distribution implies that the important range that significantly affects an improvement of the critical wind speed is the center-span, while there is no need to consider any control device in the side-spans. The full bridge model study shows higher critical wind speed comparing with the results obtained from the sectional model. The full bridge model describes whole complex coupling between all elements of the bridge which cannot be captured by sectional model.

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