CONTROL OF FLUTTER AND BUFFETING BY WINGLETS AND FLAPS

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For flutter and buffeting stability of a long suspension bridge, the active and passive controls using winglets and flaps or being called control surfaces enable a lightweight economic stiffening girder without an additional stiffness for aerodynamic stability. The control using control surfaces for increasing flutter speed and decreasing buffeting response of a suspension bridge is studied numerically and experimentally through a two dimensional bridge deck model. The result shows that the flutter speed is increased and buffeting response is decreased through the adequate motions of the control surfaces. In addition, numerical study is carried out on a 3000m span suspension bridge. The efficiency of the control relates to the method of arrangement of control surfaces, the mode combination and the installed length of control surfaces.

Active control by winglet

Numerical study on the active winglet control of the two dimensional bridge deck in gusty wind were performed and compared with related wind tunnel test results. When winglet width was 10% of the deck width, the critical speed was improved up to 2.7 times compared with no control case. The result of the numerical study matched with the result of experimental study for the flutter and buffeting response. The full span bridge response in gusty wind was analyzed for mode-by-mode, one bending mode and one torsion mode. The numerical study for different winglet arrangements was conducted. The winglets installed about 50% of the span length could increase the flutter speeds of the modes(1-1), modes(2-2) and modes(3-3) up to approximately 2.7 times. The maximum flutter speed of the each mode combination had upper limit which was approximately divergence speed. For divergence, the winglet with 10% of the deck width had small effect. The three dimensional multimode-coupled analysis was also carried out. The first twenty modes were examined. The active winglet control could increase the critical speed of combination of 4 modes up to 2.6 times and of 20 modes up to 1.8 times with the winglets installed about 50% of the span length. The effect of control reduced when the mode number increased. No effect of control on *RMS* of bending is seen. However, *RMS* of torsion is reduced after controlling.

Passive control by winglet

Numerical study on the passive winglet control of the two dimensional bridge deck in gusty wind were also performed and compared with related wind tunnel test results. The winglet is driven just after the pitching motion of the bridge deck mechanically. When winglet width was 10% of the deck width, and the wind ward winglet angle and leeward winglet angle are $\alpha^1 = -4.7\alpha$ and $\alpha^2 = 3.1\alpha$, respectively, the critical speed was improved up to 1.18 times compared with no control case. The result of the numerical study matched with the result of experimental study for the flutter and buffeting response. The full span bridge response in gusty wind was analyzed for mode-by-mode method. The numerical study for different winglet arrangements was conducted with lift and moment coefficients are theorized values. The mode-by-mode analysis showed that the passive control by winglets could increase the flutter speeds of all mode combination. The arrangement method seems effective to mode combination, which correspond to the hoops of the natural vibration torsion mode. For the design purpose, method 2 may be selected because other method may be effected by the short hunger cable near the center of a main span of a suspension bridge. The multimode-coupled analysis was also carried out. With the winglet arrangement method 1, the passive winglet control could increase the critical speed of combination of 4 modes up to 3.2 times and of 20 modes up to 2.4 times with the winglets installed about 50% of the span length. The effect of control of various mode numbers is nearly similar for winglet arrangement method 2 and method 3. *RMS* of torsion is reduced after controlling, but no effect of control on *RMS* of bending is seen.

Passive control by flap

In order to suppress the wind induced motion of a bridge, a bridge deck with mechanically driven flaps are proposed. Flaps are turned mechanically its angle in proportion to the pitching angle of the bridge deck. The mechanically control by flaps with $\beta=-G\alpha,\gamma=G\alpha$ could be better because it is not only got the effective control but also easy to install. Simulation and experiments on flutter and buffeting control of bridge deck by flaps were also performed. In turbulent flow, control by $G = 5$ improved the flutter speed about 1.8 times and suppress the divergence phenomenon up to its wind speed. Buffeting in pitching motion was effectively suppressed but heaving motion is not. The flaps installed about 50% of the span length could increase the flutter speed of the modes(1-1) up to approximately 1.8 times. For divergence, the passive flap control is effective. The multimode-coupled analysis was also carried out. The passive flap control could increase the critical speed up to 1.8 times with the flaps installed about 50% of the span length for various mode numbers. No effect of control on *RMS* of bending is seen. However, *RMS* of torsion is highly effect.

Criterion of control method selection

The aerodynamic forces are very sensitive to the geometry and hence a small change of the section by adding flaps can stabilize the girder, especially the girder has streamline section. With increasing of span length, base on the priority critical speeds are flutter or divergent, the control method should be selected appropriately. If the divergent speed is considered, the passive control by winglet or flap is suitable, because these controls could improve the divergent speed of bridge. Moreover, the active control by winglet with the appropriate winglet size is also effective. If the flutter speed is considered here, the active control by winglet is more effective, especially the span length is super long. If the required energy is considered, naturally the passive control is more attractive than active control. However, the necessary electric power can be generated on the bridge itself by means of small wind-driven generators is available for active control.

This study is very important to real bridge. The multi-box cross section design of the proposed 3,300 m span suspension bridge for the crossing of the Messina Strait and another proposal for Japanese project is 2-box with slot girder are also good solutions for present long span projects. However, the problem of wind stability may not be solved only with cross section, especially if the span length becomes 5, 6 km or more, no experience such a long or super-long span bridge, improving a cross section is still effective. This study shows that the active and passive aerodynamic control by control surfaces can complete a flutter, divergent and buffeting problem for the future bridge which has very long span.