Eccentric-wing flutter stabilizer
Analysis and wind tunnel tests

Uwe Starossek, Hannah Ziems, Tamas Ferenczi
Eccentric-wing flutter stabilizer

... a device for increasing the critical wind speed for bridge flutter

Bridge deck with rigidly attached eccentric-wing flutter stabilizer (cross section)
Competing designs

Twin or multiple bridge decks connected by cross beams (Richardson 1981)
- passive aerodynamic measure
- additional costs due to cross beams

Active control surfaces (winglets, flaps) (Ostenfeld, Larsen 1992)
- movable device
- requires energy supply and control

Pictures taken from "Li, Ge, Guo, Zhao: Theoretical framework of feedback aerodynamic control of flutter … by the twin-winglet system. J. Wind Eng. Ind. Aerodyn. 145 (2015)"
Reasons of effectiveness

► Consider a rotational displacement $\alpha$.
► $F = \text{lift forces on wings are proportional to } \alpha$ (quasi-stationary flow assumption).
► Lift forces on wings produce deck moments proportional to $\alpha a_c$.
► corresponding to a rotational aero-dynamic stiffness proportional to $a_c$.
► Leeward wing: positive stiffness, windward wing: negative stiffness.

► Consider a rotational velocity $\dot{\alpha}$.
► Vertical velocity of wings $v = \dot{\alpha} a_c$ leads to quasi-static apparent angle of attack $\varphi = v/u$ resulting in lift forces proportional to $\varphi$, that is, proportional to $\dot{\alpha} a_c$.
► Lift forces on wings produce deck moments proportional to $\dot{\alpha} a_c^2$,
► corresponding to a rotational aero-dynamic damping proportional to $a_c^2$.
► Leeward wing: positive damping, windward wing: positive damping.
Flutter analysis: Methodology

Assumption: no aerodynamic interference between bridge deck and wings.

Bridge deck is modelled with 6-DOF aeroelastic finite beam elements. (*)

Wings are rigidly attached to the deck. Therefore, their DOFs are cinematically related to the DOFs of the deck (dependent variables, no additional independent variables).

Aerodynamic forces on deck and wings are individually described by Theodorsen's theory with complex flutter derivatives.

Flutter speed results from eigenvalue analysis of MDOF complex system matrix. (*)

Flutter analysis: Results

\[ \frac{a_c}{b} = 2.00 \]
\[ \frac{b_c}{b} = 0.100 \]

\( L = 3,000 \text{ m} \)
\( 2b = 38.0 \text{ m} \)
\( \frac{f_a}{f_h} = 1.76 \)

\( b \)
Flutter analysis: Flutter speed increase

\[ \frac{a_c}{b} = 2.00 \]
\[ \frac{b_c}{b} = 0.100 \]

+64 %

+28 %
Wind tunnel tests

Sectional model of bridge deck, support structures, and wings

Spring-supported sectional model of bridge deck, support structures, and wings installed in wind tunnel
Wind tunnel tests

► 24 different setups were tested: 3 different eccentricities, 2 different wing width, 4 different wing arrangements (no wings / windward wing / windward and lee wings / lee wing).

► If a wing is absent, its mass is substituted by a ballast mass.

► Setups 1 to 4 refer to $a_c/b = 2.00$ and $b_c/b = 0.100$ but differ in wing arrangement.

► The table shows the flutter speed measured in the wind tunnel for setups 1 to 4.

► For comparison, the computed flutter speeds (Theodorsen) and the respective flutter speed increases compared to setup 1 (no wings) are shown.

<table>
<thead>
<tr>
<th>Setup</th>
<th>Windward side</th>
<th>Lee side</th>
<th>Wind tunnel [m/s]</th>
<th>Increase compared to setup 1</th>
<th>Analysis (Theod.) [m/s]</th>
<th>Increase compared to setup 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ballast</td>
<td>ballast</td>
<td>5.95</td>
<td>–</td>
<td>6.97</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td><strong>wing</strong></td>
<td>ballast</td>
<td>6.0</td>
<td>+1 %</td>
<td>6.61</td>
<td>-5 %</td>
</tr>
<tr>
<td>3</td>
<td><strong>wing</strong></td>
<td><strong>wing</strong></td>
<td>8.0</td>
<td>+34 %</td>
<td>10.1</td>
<td>+45 %</td>
</tr>
<tr>
<td>4</td>
<td>ballast</td>
<td><strong>wing</strong></td>
<td>8.5</td>
<td>+43 %</td>
<td>12.6</td>
<td>+81 %</td>
</tr>
</tbody>
</table>

$(2b = 0.80 \text{ m}; f_a/f_h = 1.11)$
Cost-efficient placement of wings

Bridge with eccentric-wing flutter stabilizer around center of main span (plan view, not to scale)

(when flutter governed by symmetrical modes)

Bridge with eccentric-wing flutter stabilizer around quarter points of main span (plan view, not to scale)

(when flutter governed by anti-symmetrical modes)
Alternative wing layouts

Single wing replaced by group of wings stacked vertically
► easier assembly, lower cost
► shielding against buffeting

Continuous wing replaced by many short wings supported on rotating bearings
► leeward wing aligns horizontally making it aerodynamically effective
► windward wing aligns vertically making it aerodynamically ineffective
Open questions and ongoing work

► Improving the cost estimate, based on
► Structural design of support structures and wings, based on
► Verification of local flutter
► Verification of local buffetting
► Verification of vortex-induced vibrations
Conclusions

► The flutter speed of a bridge can be increased by lateral wings that are rigidly and eccentrically attached to the bridge deck.

► The flutter speed increases over-proportionally with the eccentricity of the wings.

► The effect is mainly due to aerodynamic damping.

► The eccentric-wing flutter stabilizer seems cost-efficient because it can consist of light structural elements.

► The cost efficiency of the device can further be enhanced by placing it only at regions of large vibrations.
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Thank you