Mitigation of Wind-Induced Vibrations in Long-Span Bridges using a Distributed Flap System

Maria Boberg
Early civilization...

The future of civilization is dynamic!

Long-span bridges are sensitive to wind loads.

Mitigation of wind-induced vibrations by arrays of actively controlled flaps.
Early civilization...

- Suppress flutter of long-span bridges
- Enable longer bridge spans
- Reduce fatigue of structure

Long-span bridges are sensitive to wind loads.

Mitigation of wind-induced vibrations by arrays of actively controlled flaps.
Approach

Real System

Physical abstraction

Mathematical abstraction

Control

\[ m(\ddot{h} + 2\zeta_h \omega_h \dot{h} + \omega_h^2 h) = L \]
\[ I(\dddot{\alpha} + 2\zeta_\alpha \omega_\alpha \dot{\alpha} + \omega_\alpha^2 \alpha) = M \]
Scope of the Thesis
Active Section Model - SmartBridge

- Laser Sensor
- Spring
- Control Flap
- Motor Controller
- DC Motor
- Spar
- Rib
- 5 cm
- 180 cm
- 74 cm
- 400 mm
Wind Tunnel

- Closed-loop boundary layer wind tunnel
- Channel dimensions: 1.5x2x10 m
- Max wind speed 16 m/s
What is Flutter?

• **Aeroelastic** phenomena:
  • strong interaction between **structural** motion and **aerodynamic** forces

• **Flutter**:
  • unstable self-excited oscillations

1916: 1\textsuperscript{st} observation (airplane)
1940: 1\textsuperscript{st} observation (bridge)
1935: Analytical description of wing flutter
1960’s: Analytical description of bridge flutter (wind tunnel tests)
1992: 1\textsuperscript{st} active bridge flutter control with flaps (section model)
Analytical Flutter Model

[Theodorsen et al., 1943]

[Kobayashi et al., 1992]
Analytical Flutter Model

\[ m(\ddot{h} + 2\zeta_h \omega_h \dot{h} + \omega_h^2 h) = L_h + L_l + L_t \]
\[ I (\ddot{\alpha} + 2\zeta_\alpha \omega_\alpha \dot{\alpha} + \omega_\alpha^2 \alpha) = M_\alpha + M_l + M_t \]

Structural part  Aerodynamic part

[Theodorsen et al., 1943]  [Kobayashi et al., 1992]
Control Law

Control law:
\[ \alpha_t(t) = A_t e^{-i\varphi} \alpha(t) \]
\[ \alpha_l(t) = A_l e^{-i\varphi} \alpha(t) \]

- Synchronized Flap Control
- Amplitude-gain and phase-shift control of deck pitch
- Trailing or leading flap individually, or in coordination

Wind
Control Parameter Analysis

Control leading flap only

U_f [m/s] vs. Phase-shift [°] for varying amplitudes.

- Amplitude 0
- Amplitude 0.2
- Amplitude 0.42
- Amplitude 0.8
- Amplitude 1.19
- Amplitude 1.6
- Amplitude 2
Control Parameter Analysis

Identify good control parameters

Control leading flap only

Control trailing flap only
Wind Tunnel Experiment
Wind Tunnel Experiment
Approach

- Add structural contribution of flap motion to model
- Experimental estimation of model parameters
Improving Analytical Model

- Consider structural effects of flap motion
- Experimental estimation of model parameters
Take home message

- SmartBridge - Actively controlled structure capable of reducing wind-induced vibrations
- Methodological framework (layers of abstraction) is a powerful tool for analyzing, designing and controlling dynamic structures
Acknowledgements

Previous collaborators:
• Pascal Gilbert
• Shravan Kumar Sajja
• Albrecht Lindner

Students:
• Nicolo Valigi
• Vincent Mazoyer
• Tiago Morais

Alcherio

Glauco

Emmanuel
Thank you for your attention