Project 6
Wind-induced Vibrations of Long-span Bridges
Motivation

- Long and slender structures
- Light weight
- Low structural damping
Wind Engineering (Design)

Introduction

Wind load/response → Wind climate → Influence of terrain → Aerodynamic effects → Dynamic effects → Criteria

Bridge Aerodynamics

- Limited Amplitudes
  - Vortex-induced Vibrations
  - Buffeting
  - Wake-induce Vibration, Rain Wind-induced Vibrations, etc.

- Instabilities
  - Galloping
  - Flutter
  - Divergence

Graph showing:
- Vertical displacement, $h$
- Uniform flow
- Turbulent flow
- Buffeting
- Vortex excitation
- First mode
- Higher mode
- Limited amplitudes
- Divergent amplitudes
- Wind speed, $U$
- Instability
- Gust response
- $U_{cr}$
Vortex Induced Vibrations

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Vortex Induced Vibrations

Vortex-induced vibrations (VIV) are resonance phenomena due to matching vortex shedding frequency and the structural frequency.

\[ f_v = (0.8 - 1.2) f_n \]

Vortex Induced Vibrations

- Rectangular cross-section
- Pentagon cross-section
- Rectangular + half-circle cross-section
- Rectangular + deflectors cross-section
Results

Comparison of displacements

Maximum displacement

RMS displacement

Maximum displacement vs Velocity [m/s]

RMS displacement vs Velocity [m/s]
Conclusion

• VIV is self-limiting phenomena, not destructive
• Fatigue problems, comfort issues
• Influence of geometrical shape on VIV

Outlook
• TMD can be studied
• Moveable flaps
Buffeting analysis

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**Buffeting** excitation is caused by fluctuating forces induced by inflow turbulence in the wind field.

**Reference object**
DYNAMICAL PROPERTIES

Structural system and discretization

- $f_V = 0.401 \text{ Hz}$
- $f_L = 0.444 \text{ Hz}$
- $f_T = 0.913 \text{ Hz}$
BUFFETING RESPONSE

Structural Response

$U=55 \text{ m/s}, \quad Tu=Tw=10\%$.

\begin{align*}
\text{RMS - Vertical Displacement} \\
\text{Tip Vertical Displacement} \\
\text{Tip Rotation}
\end{align*}
Flutter

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Flutter

- Coupling of vertical and torsional oscillating mode
- Aeroelastic instability at higher wind speeds
- Can cause ULS if not taken into account
Lillebælt Suspension Bridge, Denmark

- Total length 1080 m
- Steel box girder deck section

0,156 Hz

0,5 Hz

JUTLAND

FUNEN

240m 600m 240m
Methodology

Analysis Methods

1. Fully analytical
2. Forced vibrations
3. Fully coupled CFD simulation

1. Potential flow theory, analytical aerodynamic and structural model
2. Numerical aerodynamic model and analytical structural model
3. Numerical aerodynamic and structural model
Results

Forced Vibrations

Heave

Pitch

Fully coupled CFD – single slice

Critical wind velocities

\[ U_{cr,\text{Theodorsen}} = 94 \text{ m/s} \]
\[ U_{cr,\text{Scanlan}} = 101 \text{ m/s} \]
\[ U_{cr,\text{CFD}} = 98 \text{ m/s} \]
Results

Fully coupled CFD – Multi slice
Conclusion