Experimental evidences of high frequency and short wavelength VIV on long stay cables

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Seminar on: Modelling Vortex Resonance
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Context

\[ f_s = \frac{US't}{D} \]

\[ S_L(f, z) \sim \exp \left[ -\frac{1}{B^2(z)} \left( 1 - \frac{f}{f_s(z)} \right)^2 \right] \]

relative bandwidth

Shedding frequency

\( g(s) \) in eqn. (28) was generated as a narrow-band Gaussian random variable with zero mean, unit variance and a relative bandwidth of 0.1; the centre wavenumber was set equal to \( S/D \). The relative bandwidth of 0.1 is representative of smooth flow.

(This number has been adjusted for chimneys.)

Model by Vickery and Clark, ASCE, 1972
Context

Former NATO antenna
254-m high
3m x 3m Truss tower & 20 pairs of stay cables
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Description of the pylon

Plan view: 8 foundations blocks

Each cable is actually a pair of cables

Layers 1 & 2

Layers 3-4-5
Description of the pylon

The 8 blocks of foundation are protected by bunkers.

Re-tensioning is performed with screws and filleted anchorages.

Layers 1 & 2

Layers 3-4-5
Description of the pylon

Very low sag-to-span ratios, ~1%

Layer 3
Layer 4
Layer 5
Some numbers

- Longest cable, almost 300 meters long
- Diameters from 24 mm to 42 mm
- Sub-crossover regime (low Irvine parameter, from 0.45 to 9)
- Low fundamental natural frequency (0.28 Hz to 0.88 Hz)

<table>
<thead>
<tr>
<th></th>
<th>Cable 1</th>
<th>Cable 2</th>
<th>Cable 3</th>
<th>Cable 4</th>
<th>Cable 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal pretension [kN]</td>
<td>111.2</td>
<td>163.6</td>
<td>150</td>
<td>192</td>
<td>237</td>
</tr>
<tr>
<td>Top anchorage height [m]</td>
<td>47</td>
<td>95</td>
<td>143</td>
<td>185</td>
<td>227</td>
</tr>
<tr>
<td>Anchorage foot offset [m]</td>
<td>102.1</td>
<td>102.1</td>
<td>182.9</td>
<td>182.9</td>
<td>182.9</td>
</tr>
<tr>
<td>Cable length [m]</td>
<td>112.4</td>
<td>139.5</td>
<td>232.2</td>
<td>260.1</td>
<td>291.5</td>
</tr>
<tr>
<td>Cable angle [°]</td>
<td>24.7</td>
<td>42.9</td>
<td>38.0</td>
<td>45.3</td>
<td>51.1</td>
</tr>
<tr>
<td>Cable diameter [mm]</td>
<td>24</td>
<td>28</td>
<td>26</td>
<td>30</td>
<td>42</td>
</tr>
<tr>
<td>Cable Young modulus [MPa]</td>
<td>175000</td>
<td>175000</td>
<td>175000</td>
<td>175000</td>
<td>175000</td>
</tr>
<tr>
<td>Lineic mass [kg/m]</td>
<td>2.84</td>
<td>3.87</td>
<td>3.33</td>
<td>4.43</td>
<td>8.70</td>
</tr>
<tr>
<td>Sag-to-span ratio [-]</td>
<td>0.35%</td>
<td>0.40%</td>
<td>0.63%</td>
<td>0.74%</td>
<td>1.31%</td>
</tr>
<tr>
<td>Irvine parameter $\lambda^2$ [-]</td>
<td>0.45</td>
<td>0.55</td>
<td>1.27</td>
<td>1.79</td>
<td>9.01</td>
</tr>
<tr>
<td>Nominal fundamental frequency [Hz]</td>
<td>0.88</td>
<td>0.74</td>
<td>0.46</td>
<td>0.40</td>
<td>0.28</td>
</tr>
</tbody>
</table>
The Problem
Investigation tracks

- Near the sea, Cat-0 terrain, very low turbulence intensity
- Several cables, with different skew angles, show simultaneous vibrations -> not dry galloping
- Vibrations happen in various weather conditions -> not rain-wind vibration
- Vibrations occur at low to medium wind velocity, seem to disappear for higher velocities
  - More turbulence at high velocity
  - More aerodynamic damping at high velocity

Vortex-Induced Vibrations
Evaluation campaign

Phase I
Measure acceleration on the cables and pylon

Phase II
Measure accelerations cables only (long-term monitoring)
Position of the sensors on the cable
Measured acceleration on the cable

Without VIV

**Accelerations - Layer 1 [g]**

- **Time**
  - 12:20:30
  - 12:20:40
  - 12:20:50
  - 12:21:00
  - 12:21:10
  - 12:21:20

- **Frequency [Hz]**
  - 0
  - 20
  - 40
  - 60
  - 80
  - 100
  - 120

**Spectrum**

- **Left-y**
- **Left-z**
- **Right-y**
- **Right-z**

**Zoom**

Ambient vibration tests, without apparent VIV
More than 50 modes observable with a single accelerometer
Measured acceleration on the cable

Without VIV

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Measured acceleration on the cable

Example of an overnight measurement

Wind & Turbulence intensity drop

Spectrogram of acceleration at level 5
Measured accelerations on the cable
With VIV

Accelerations - Cables 3,4,5 [g]

Spectrum

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Measured accelerations on the cable

With VIV

\[ f_s = \frac{USt}{D} \]

\[ U = 7m/s \quad St = 0.2 \]

For cable 3:
\[ d = 26mm \rightarrow f_s = 53.8Hz \]

For cable 4:
\[ d = 30mm \rightarrow f_s = 46.7Hz \]

For cable 5:
\[ d = 42mm \rightarrow f_s = 33.3Hz \]
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The Spectral Model

\[ S_L(f, z) = \left( \frac{1}{2} \rho C_L D(z) U^2(z) \right)^2 \frac{1}{\sqrt{\pi B(z) f_s(z)}} \exp \left[ -\frac{1}{B^2(z)} \left( 1 - \frac{f}{f_s(z)} \right)^2 \right] \]

Spectral model by B. J. Vickery and A. W. Clark (1972)

Approx 10% of Strouhal Frequency

Cable 3

Cable 4

Cable 5

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Summary

- VIV observed on 3 cables with different diameters —> confirms scaling
- Consistent with the spectral bandwidth parameter
- Long cables are the perfect « observer »

Coming next: monitoring & installation of airflow spoilers …