WIND PROJECT

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Wind verification of a work of art: the Arc Majeur according Eurocode 1991-1-4

Make the wind verification of the work of art Arc Majeur located on the motorway E411 according to the Eurocode EN 1991-1-4

Main dimensions

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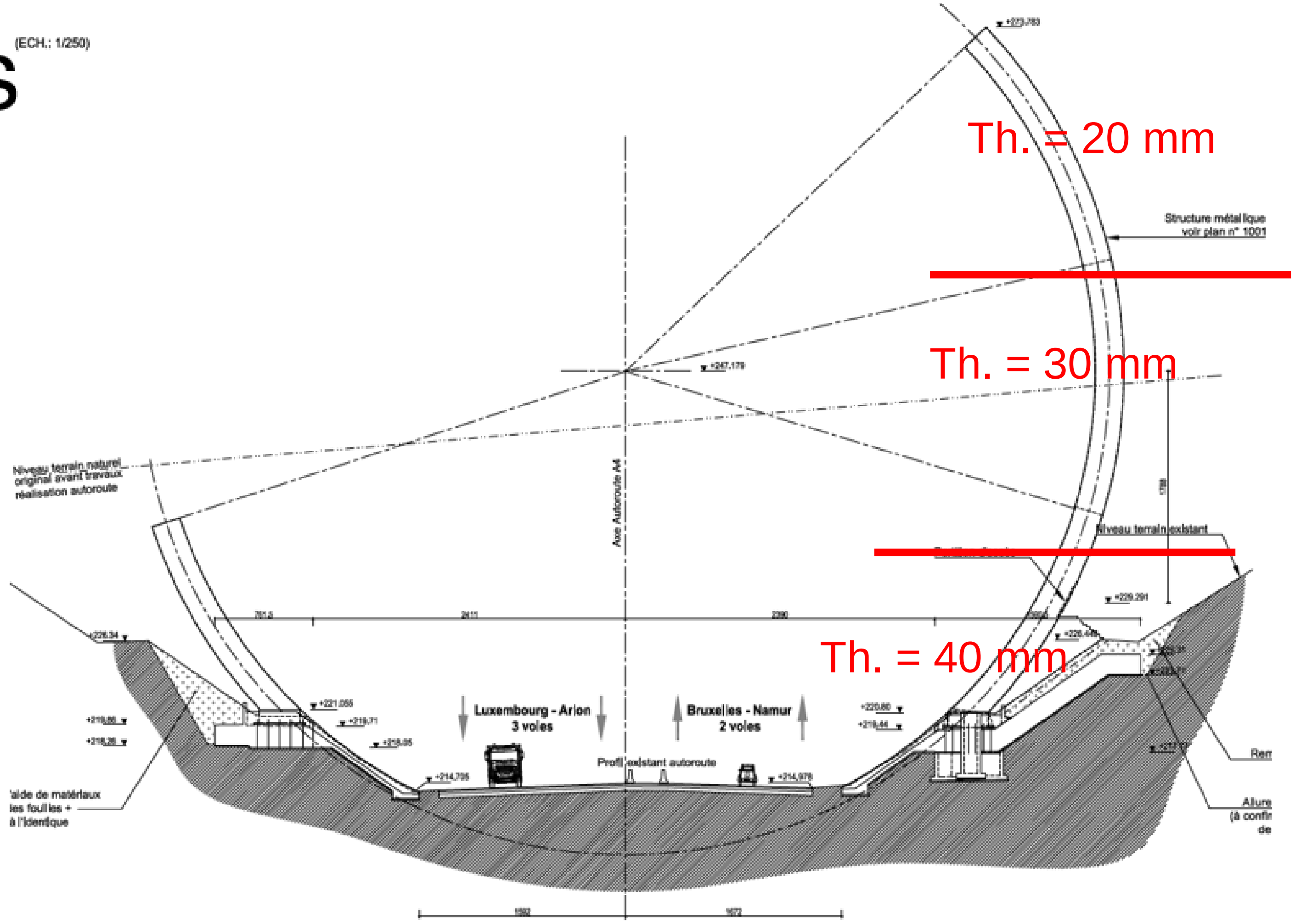
(ECH.: 1/250)

- Angle of 205°
- Radius of 38,5m
- Height : 60m
- Square section 2,25m
- Corten Steel: thk of 20 mm, 30mm and 40mm

- Total mass 147 To + 37 To
- Foundations: 1200 To



Wind characteristics

- Mean wind speed
- Turbulence intensity
- The peak wind speed
- The peak wind pressure
- Wind distributed loads on the arc

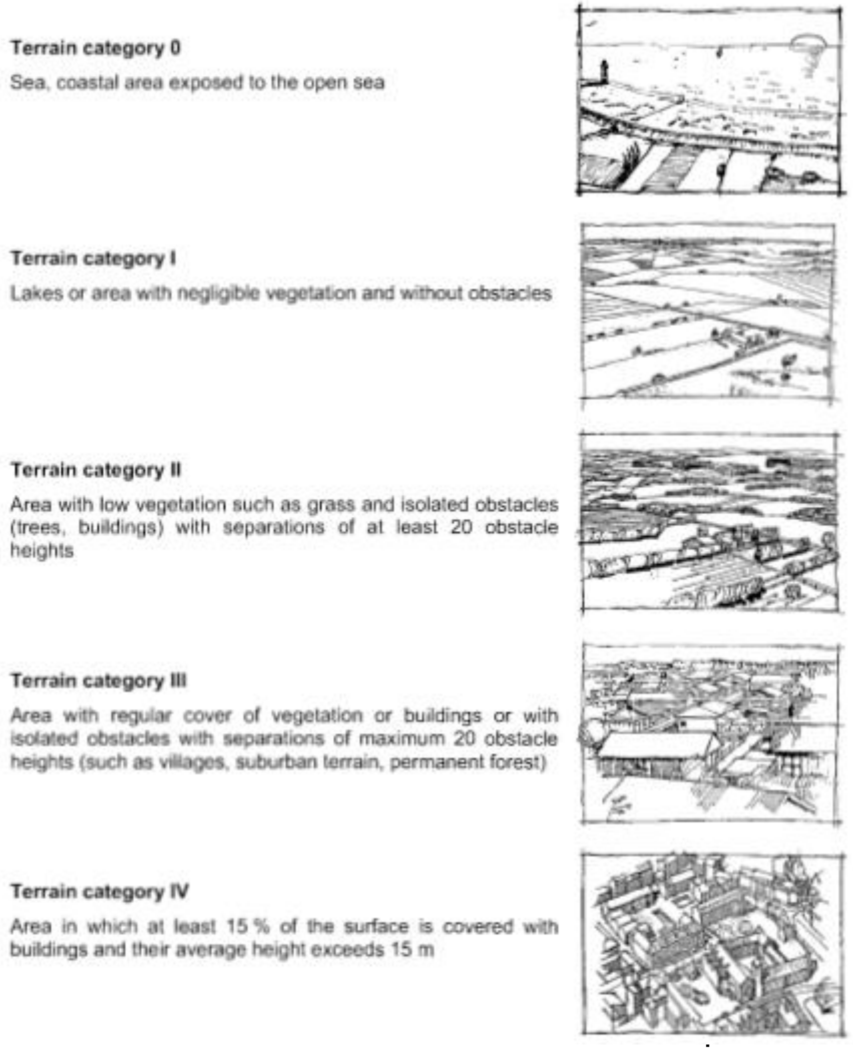
Reference wind speed = $V_{b,0}$ = 23m/s

Return period = 50 years

Cdir = Cseasonal = C_0 = 1,0

Terrain Category II ➔ z0 = 0.05 and zmin = 2m

The force coefficient for a square section is taken equal to: Cf = 2,0



Wind characteristics

(2)P The basic wind velocity shall be calculated from Expression (4.1).

$$v_b = c_{dir} \cdot c_{season} \cdot v_{b,0} \qquad (4.1)$$

where:

v_b is the basic wind velocity, defined as a function of wind direction and time of year at 10 m above ground of terrain category II

$v_{b,0}$ is the fundamental value of the basic wind velocity, see (1)P

c_{dir} is the directional factor, see Note 2.

c_{season} is the season factor, see Note 3.

4.3 Mean wind

4.3.1 Variation with height

(1) The mean wind velocity $v_m(z)$ at a height z above the terrain depends on the terrain roughness and orography and on the basic wind velocity, v_b, and should be determined using Expression (4.3)

$$v_m(z) = c_r(z) \cdot c_o(z) \cdot v_b \qquad (4.3)$$

$V_{m,top}$ = 31 m/s

Wind characteristics

4.4 Wind turbulence

(1) The turbulence intensity $I_v(z)$ at height z is defined as the standard deviation of the turbulence divided by the mean wind velocity.

NOTE 1 The turbulent component of wind velocity has a mean value of 0 and a standard deviation σ_v. The standard deviation of the turbulence σ_v may be determined using Expression (4.6).

$$\sigma_v = k_r \cdot v_b \cdot k_I \tag{4.6}$$

For the terrain factor k_r see Expression (4.5), for the basic wind velocity v_b see Expression (4.1) and for turbulence factor k_I see Note 2.

NOTE 2 The recommended rules for the determination of $I_v(z)$ are given in Expression (4.7)

$$\begin{aligned} I_v(z) &= \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z) \cdot \ln(z/z_0)} && \text{for} \quad z_{min} \le z \le z_{max} \\ I_v(z) &= I_v(z_{min}) && \text{for} \quad z < z_{min} \end{aligned} \tag{4.7}$$

$I_{v,top}$ = 0.141

Wind characteristics

4.4 Wind turbulence

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$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min} \qquad (4.7)$$

4.5 Peak velocity pressure

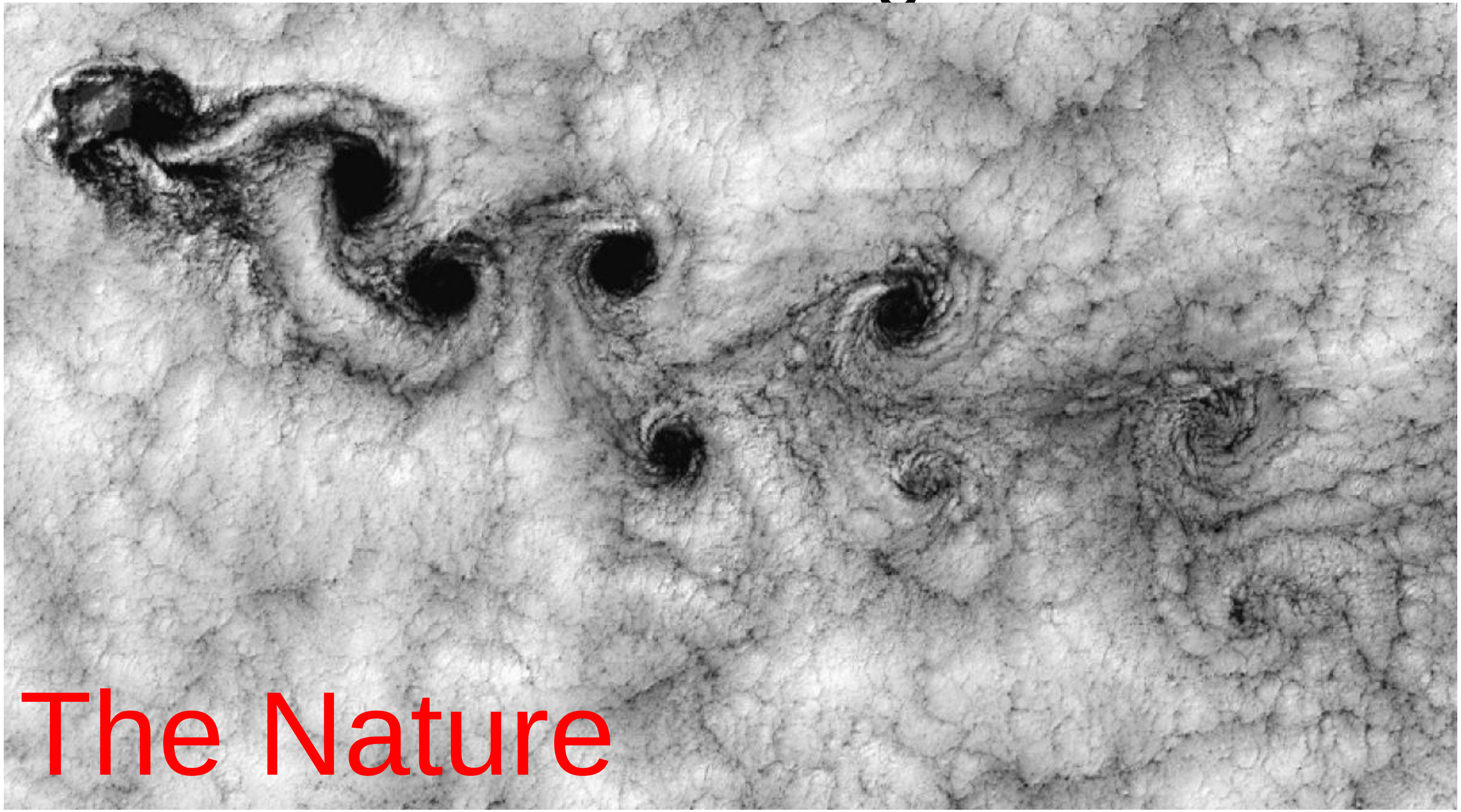
(1) The peak velocity pressure $q_p(z)$ at height z, which includes mean and short-term velocity fluctuations, should be determined.

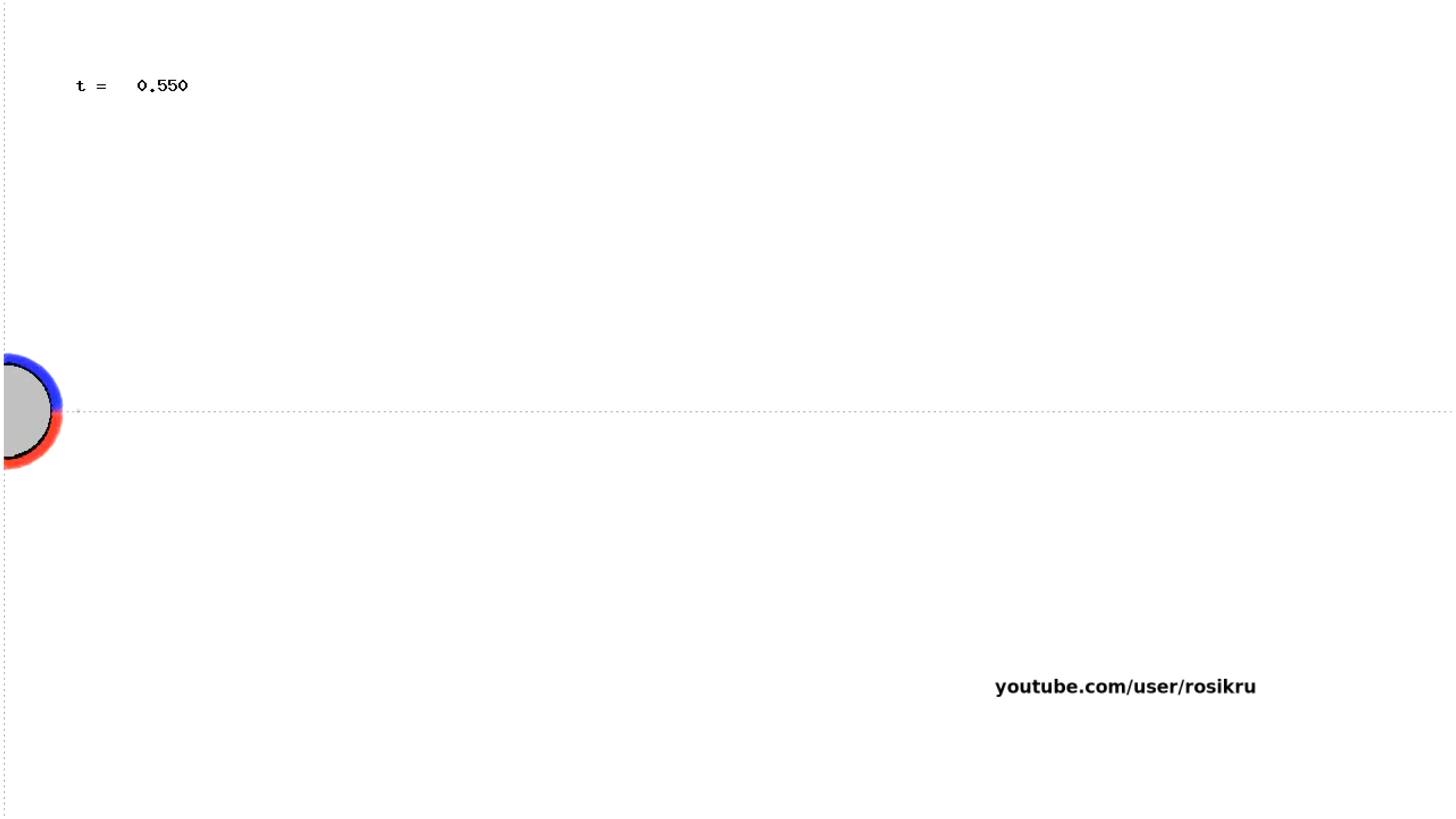
NOTE 1 The National Annex may give rules for the determination of $q_p(z)$. The recommended rule is given in Expression (4.8).

$$q_p(z) = [1 + 7 \cdot I_v(z)] \cdot \tfrac{1}{2} \cdot \rho \cdot v_m^2(z) = c_e(z) \cdot q_b \qquad (4.8)$$

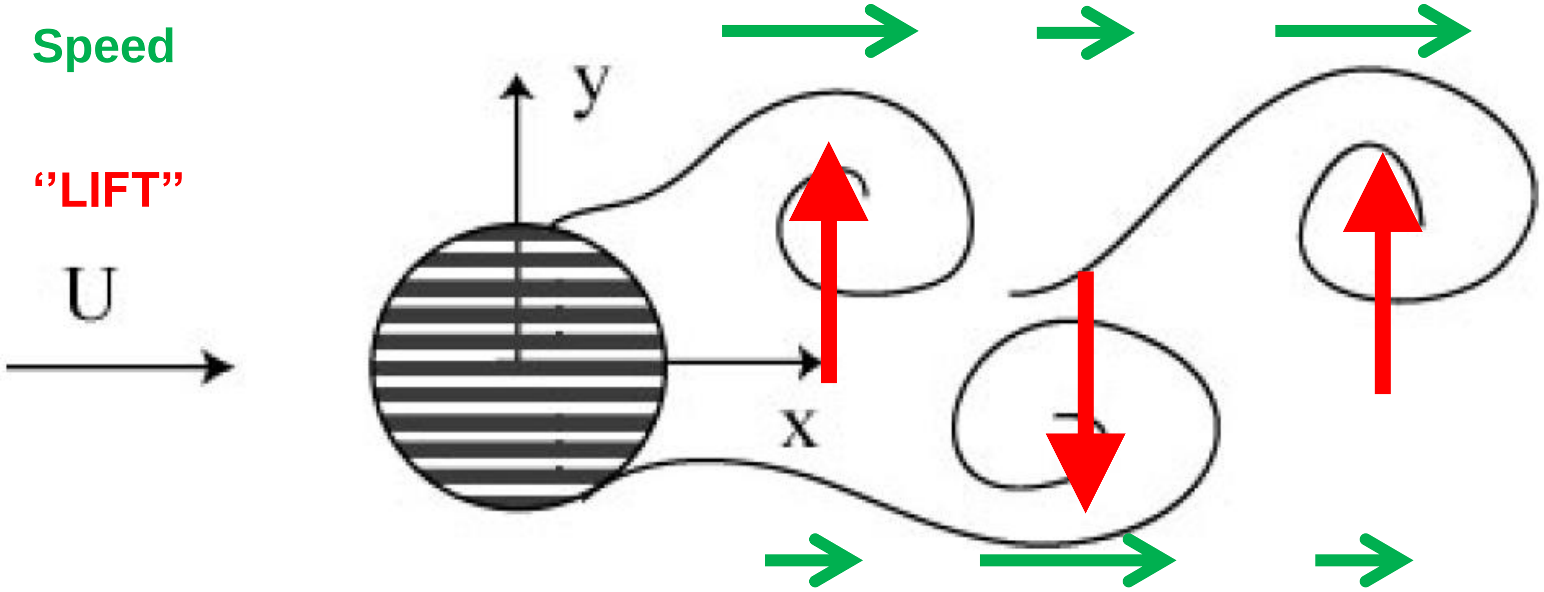
$V_{p,top}$ = 43.7 m/s
$Q_{p,top}$ = 1200 N/m²

Vortex Shedding verification





Animation - VIV


Speed
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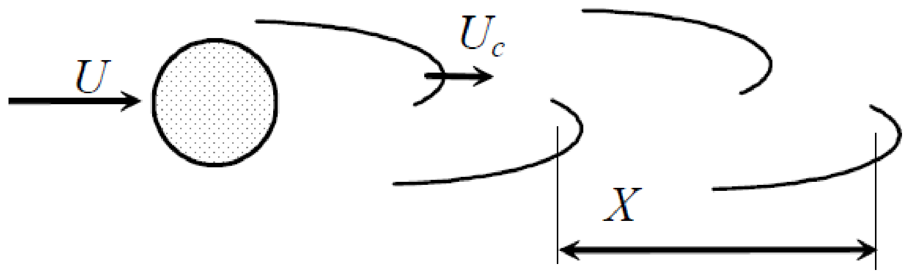
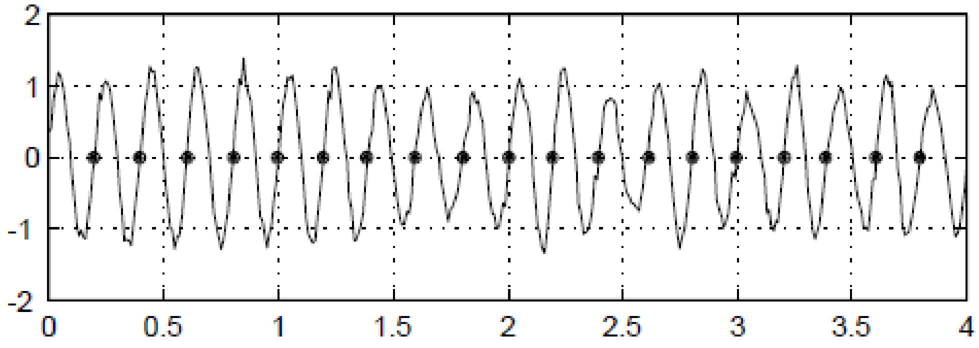


Vortices generates sinusoidal lateral lift forces

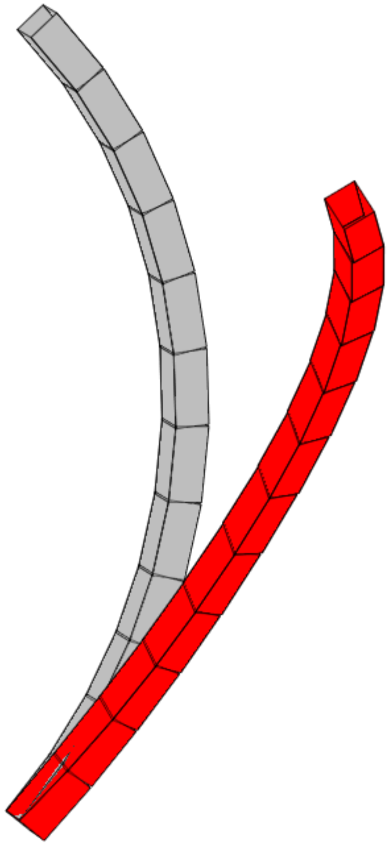
These altenated vortices

- **Will create lift forces**
  (Iu, Iv)
- **Will be more regular if the wind turbulence (Iu, Iv) is low**



Eigen Modes

Beam models



- Compute first eigen modes
- Calculate modal masses

Eigen Modes (Ψ) normalized with maximum displacement = 1

With Matlab : $\Psi^T.M.\Psi = 1$

Matlab value should be corrected:

$\Psi \rightarrow \Psi/max(\Psi)$

Modal mass $\rightarrow \Psi^T.M.\Psi \ / \ max(\Psi)^2$

Vortex Shedding Verification

BS EN 1991-1-4:2005+A1:2010
EN 1991-1-4:2005+A1:2010 (E)

Annex E
(informative)

Vortex shedding and aeroelastic instabilities

E.1 Vortex shedding

Vortex Shedding Verification

BS EN 1991-1-4:2005+A1:2010
EN 1991-1-4:2005+A1:2010 (E)

Annex E
(informative)

Vortex shedding and aeroelastic instabilities

$$v_{\mathrm{crit,i}} = \frac{b \cdot n_{\mathrm{i,y}}}{St} \tag{E.2}$$

where:

b is the reference width of the cross-section at which resonant vortex shedding occurs and where the modal deflection is maximum for the structure or structural part considered; for circular cylinders the reference width is the outer diameter

$n_{\mathrm{i,y}}$ is the natural frequency of the considered flexural mode i of cross-wind vibration; approximations for $n_{1,\mathrm{y}}$ are given in F.2

St Strouhal number as defined in E.1.3.2.

Vortex Shedding Verification

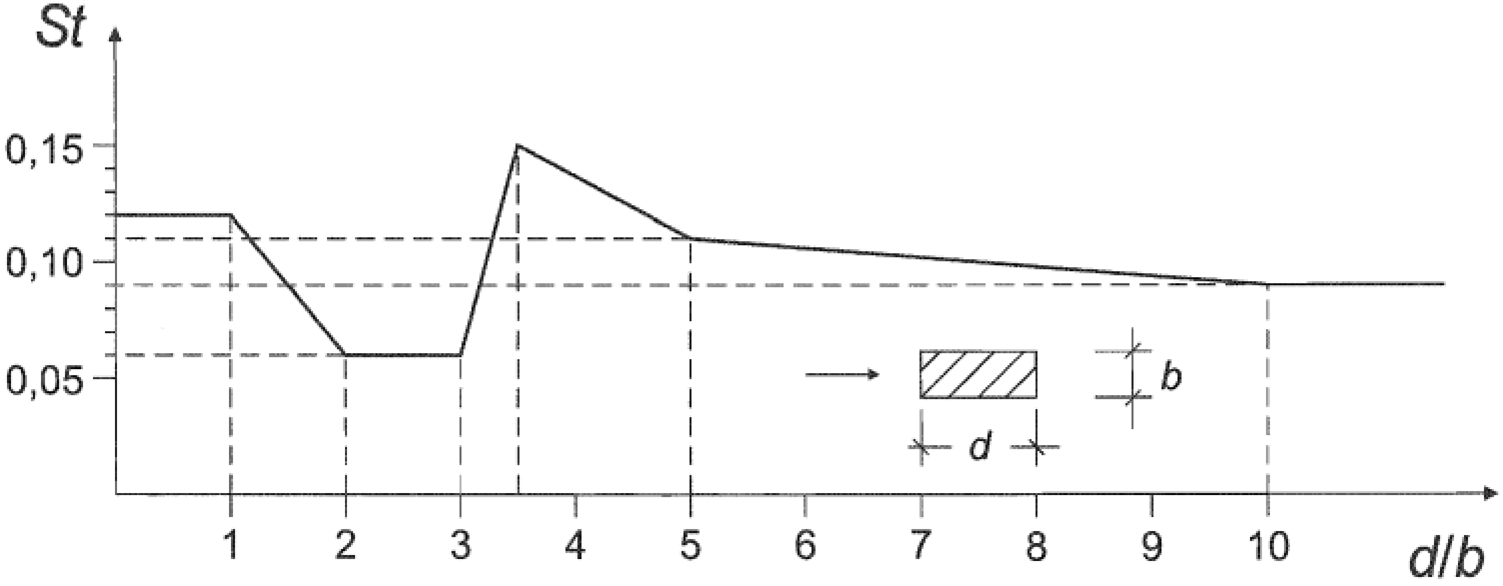


Figure E.1 — Strouhal number (*St*) for rectangular cross-sections with sharp corners

Vortex Shedding Verification – amplitude approach 1

E.1.5.2 Approach 1 for the calculation of the cross wind amplitudes

E.1.5.2.1 Calculation of displacements

The largest displacement $y_{F,max}$ can be calculated using Expression (E.7).

$$\frac{y_{F,max}}{b} = \frac{1}{St^2} \cdot \frac{1}{Sc} \cdot K \cdot K_W \cdot c_{lat} \tag{E.7}$$

where:

St is the Strouhal number given in Table E.1

Sc is the Scruton number given in E.1.3.3

K_W is the effective correlation length factor given in E.1.5.2.4

K is the mode shape factor given in E.1.5.2.5

c_{lat} is the lateral force coefficient given in Table E.2

NOTE The aeroelastic forces are taken into account by the effective correlation length factor K_W.

Vortex Shedding Verification – amplitude approach 2

E.1.5.3 Approach 2, for the calculation of the cross wind amplitudes

(1) The characteristic maximum displacement at the point with the largest movement is given in Expression (E.13).

$$y_{\max} = \sigma_y \cdot k_p \tag{E.13}$$

where:

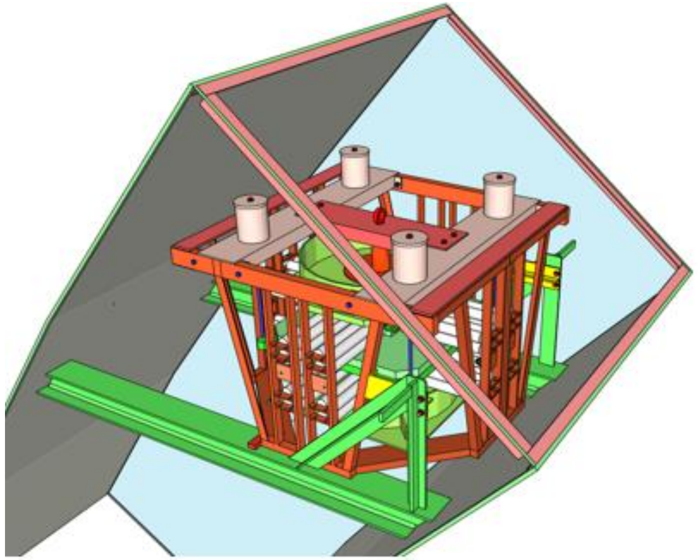
σ_y is the standard deviation of the displacement, see (2)

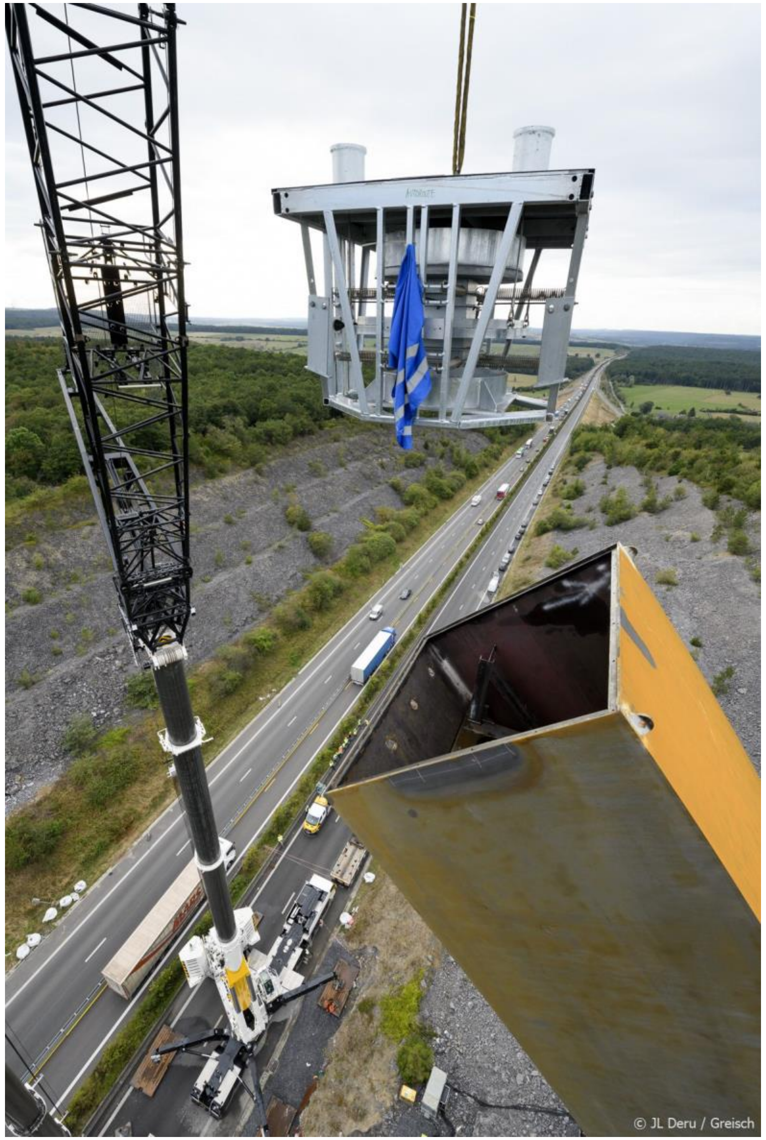
k_p is the peak factor, see (6)

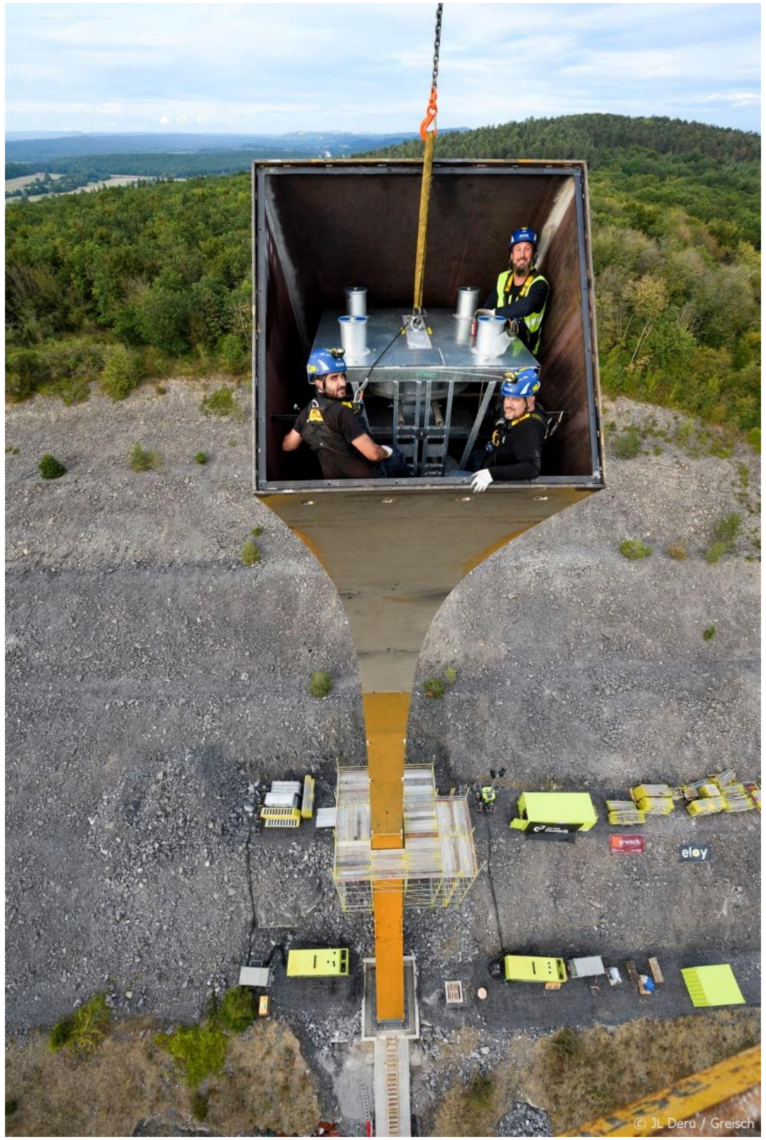
(2) The standard deviation σ_y of the displacement related to the width b at the point with the largest deflection (Φ = 1) can be calculated by using Expression (E.14).

$$\frac{\sigma_y}{b} = \frac{1}{St^2} \cdot \frac{C_c}{\sqrt{\frac{Sc}{4 \cdot \pi} - K_a \cdot \left(1 - \left(\frac{\sigma_y}{b \cdot a_L}\right)^2\right)}} \cdot \sqrt{\frac{\rho \cdot b^2}{m_e}} \cdot \sqrt{\frac{b}{h}} \tag{E.14}$$

Vortex Shedding Verification – TMD design







Vortex Shedding Verification – TMD design

- Use Den Hartog formulation to optimise the TMD
  - Frequency f_{TMD} = ? $\nu = \frac{1}{1+\mu}$ $\mu = m_{TMD}$/modal mass
  - Damping ratio ξ = ? $\xi = \sqrt{\frac{3\mu}{8(1+\mu)}} = \frac{b}{2\sqrt{km}}$
  - m_{TMD} = ?
- Top displacements reduced by 10
- Plot Bode diagram of the 1 dof system
- Compare with the 2 dof's (+TMD)