WIND PROJECT

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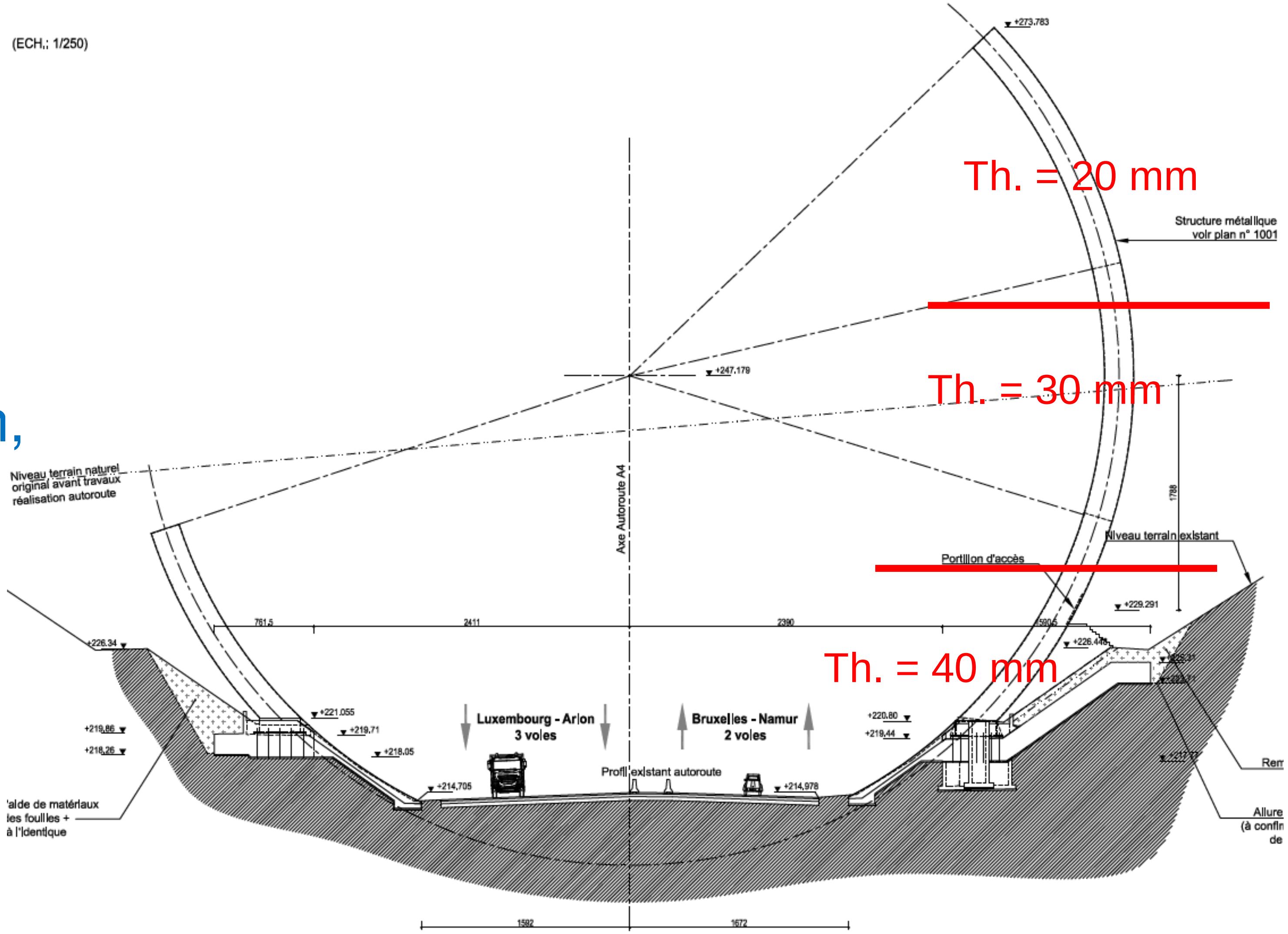
Wind verification of a work of art: the Arc Majeur according Eurocode 1991-1-4

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

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



Wind characteristics

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

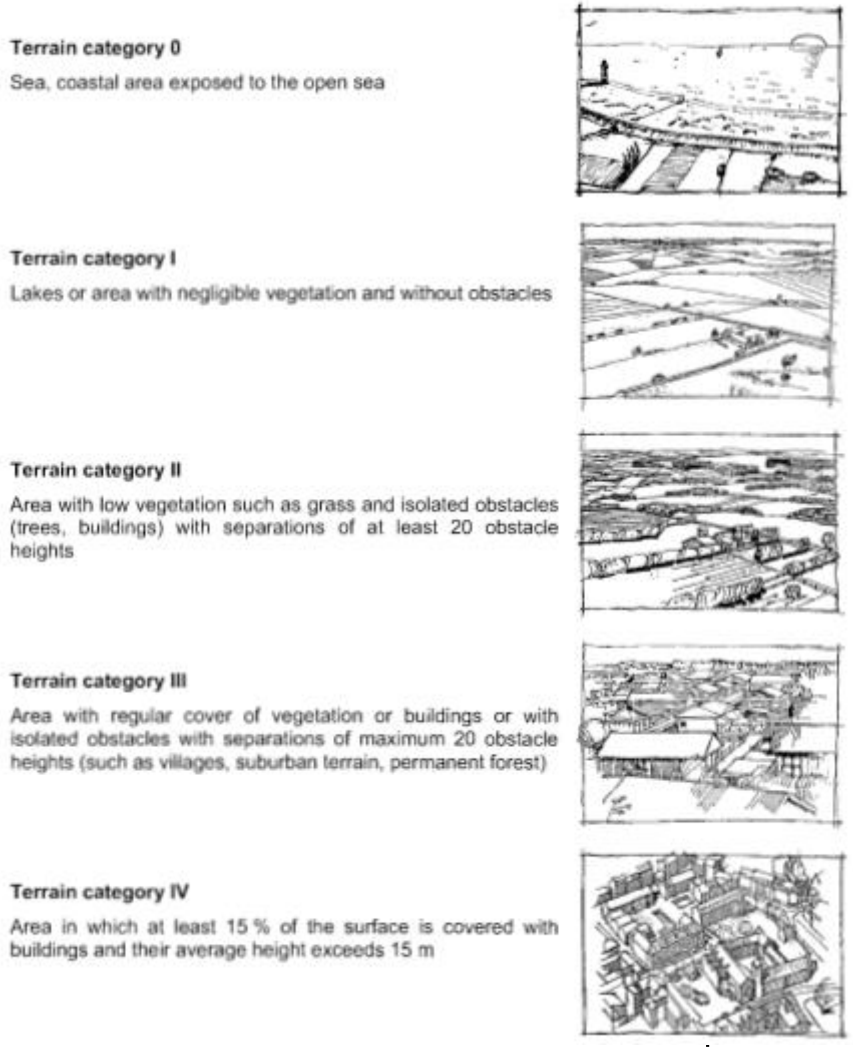
Reference wind speed = Vb,0 = 23m/s

Return period = 50 years

Cdir = Cseasonal = C_0 = 1,0

Terrain Category II ➔ z0 = 0.05m 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).

$$v_b = c_{dir} \cdot c_{season} \cdot v_{b,0} \tag{4.1}$$

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)

$$v_m(z) = c_r(z) \cdot c_o(z) \cdot v_b \tag{4.3}$$

$V_{mean,top}$ = 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

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4.5 Peak velocity pressure

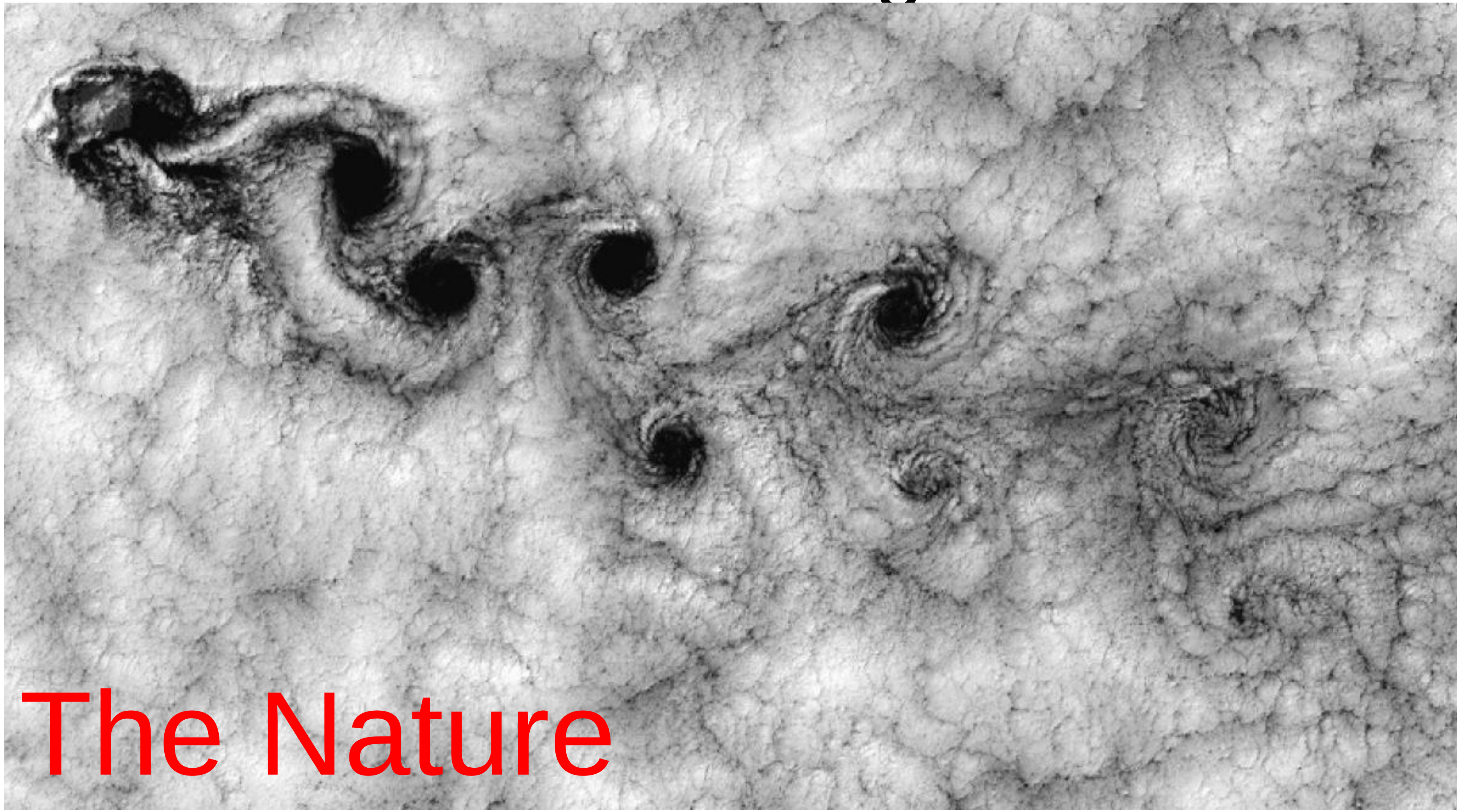
(1) The peak velocity pressure $q_p(z)$ at height z, which includes mean and short-term velocity fluctuations, should be determined.

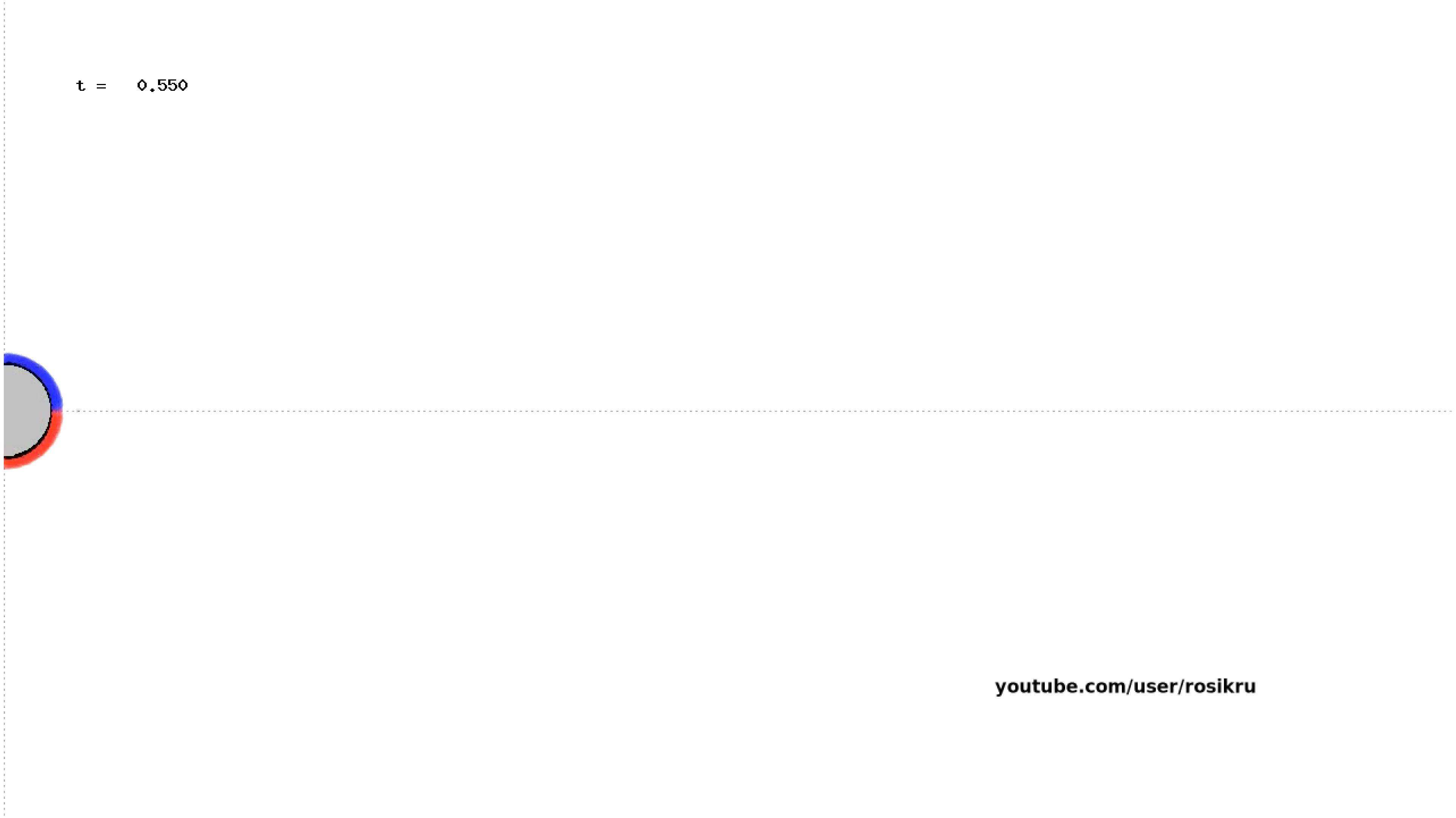
NOTE 1 The National Annex may give rules for the determination of $q_p(z)$. The recommended rule is given in Expression (4.8).

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

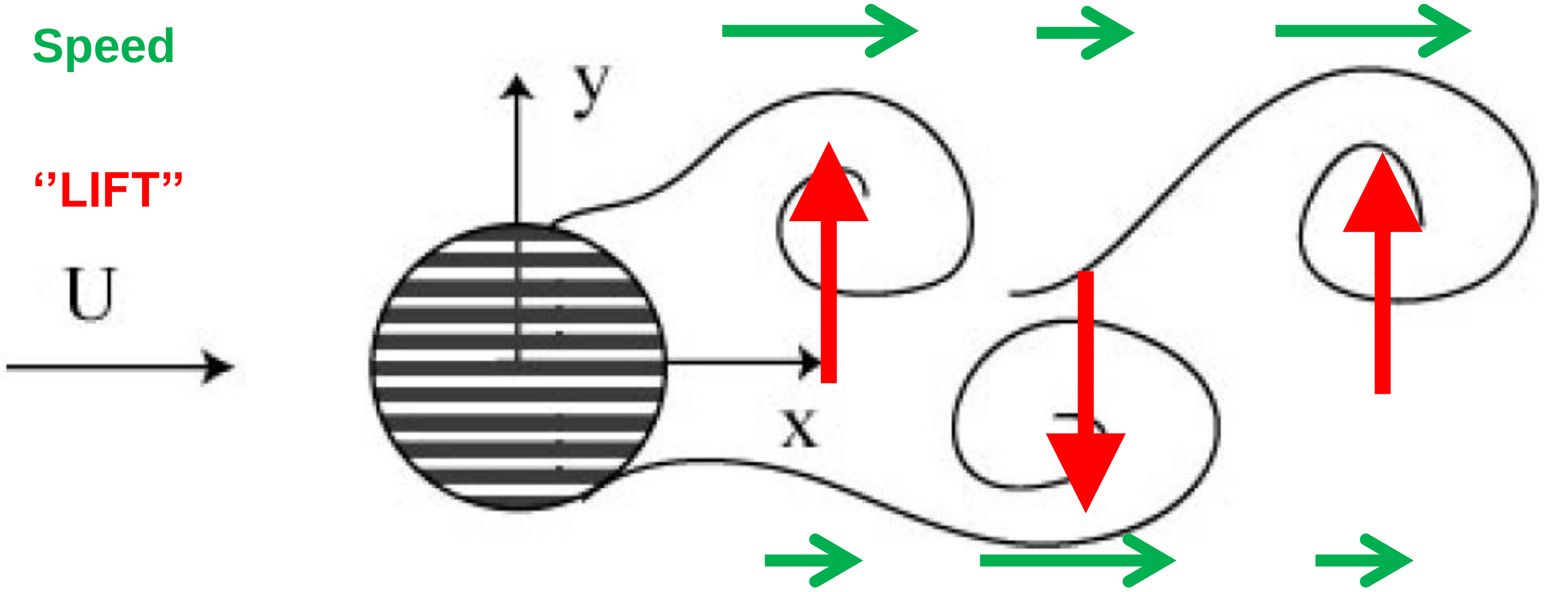
$V_{peak,top}$ = 43.7 m/s
$Q_{p,top}$ = 1200 N/m²

Vortex Shedding verification





Animation - VIV


Speed
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y
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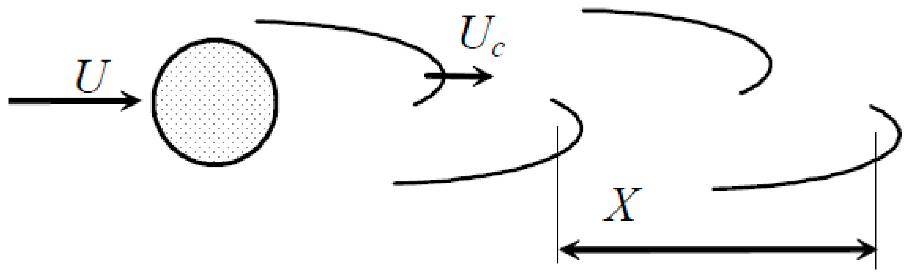
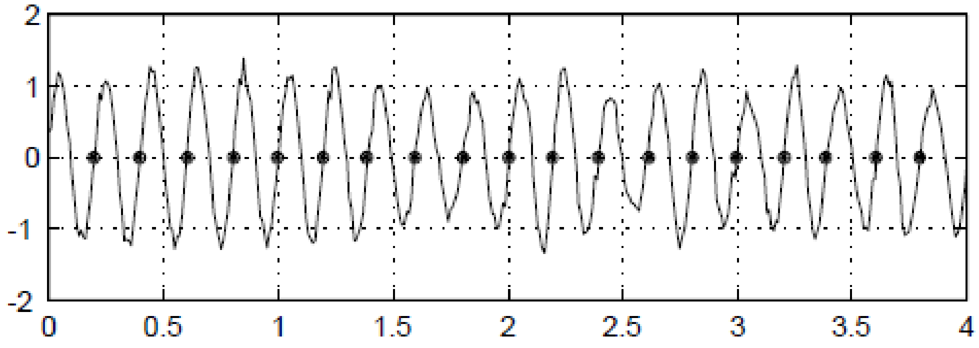


Vortices generates sinusoidal lateral lift forces

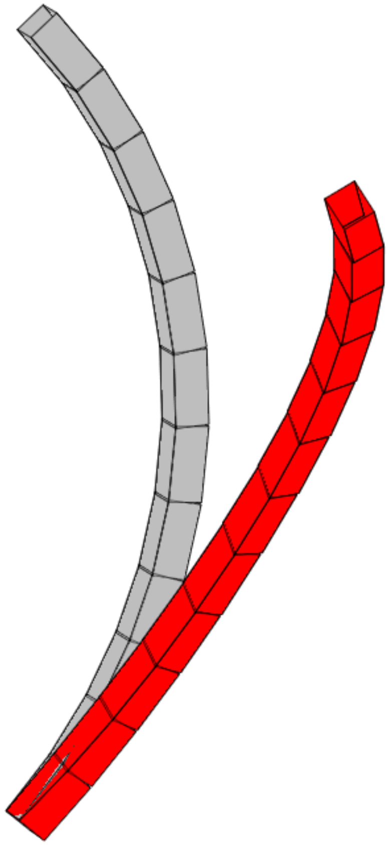
These alternated vortices

- **Will create lift forces**
- **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

$$v_{\mathrm{crit,i}} = \frac{b \cdot n_{\mathrm{i,y}}}{St} \qquad \text{(E.2)}$$

V_{critic} = 16.5 m/s < 1.25 * 31 m/s

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 $n_{1,y}$ are given in F.2

St Strouhal number as defined in E.1.3.2.

Vortex Shedding Verification

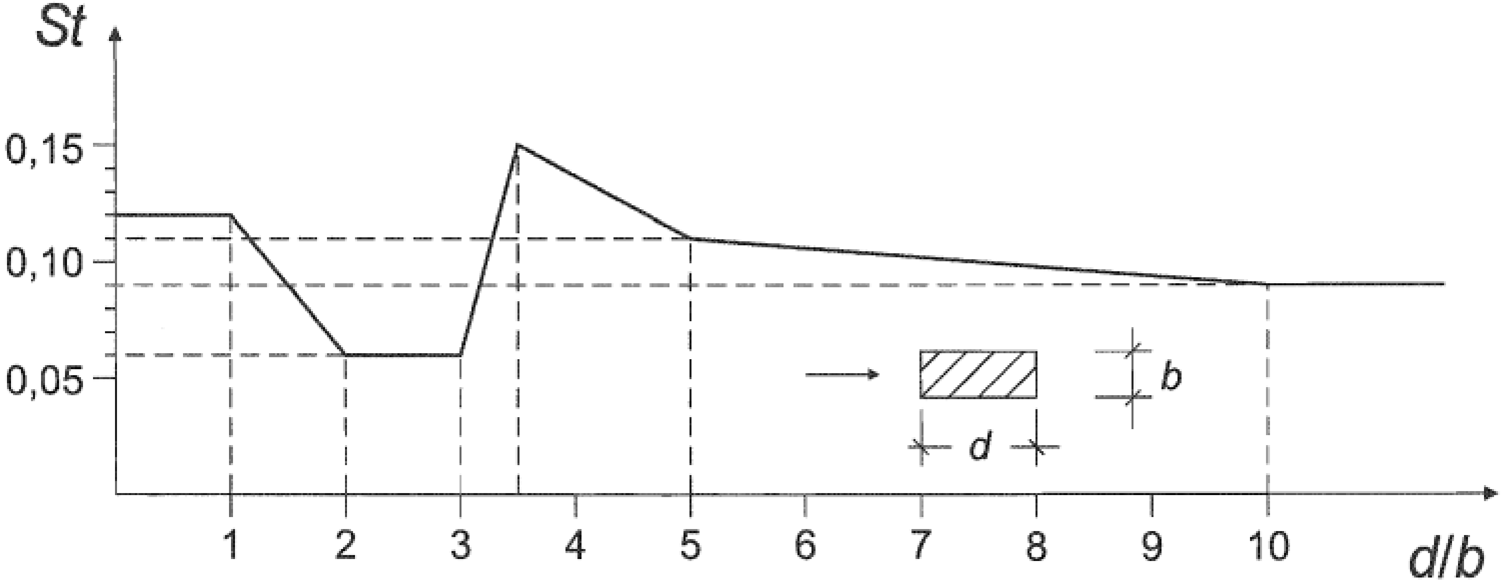


Figure E.1 — Strouhal number (*St*) for rectangular cross-sections with sharp corners

Vortex Shedding Verification – amplitude approach 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).

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

y_{max} = 1.37 m

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).

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

Structural damping

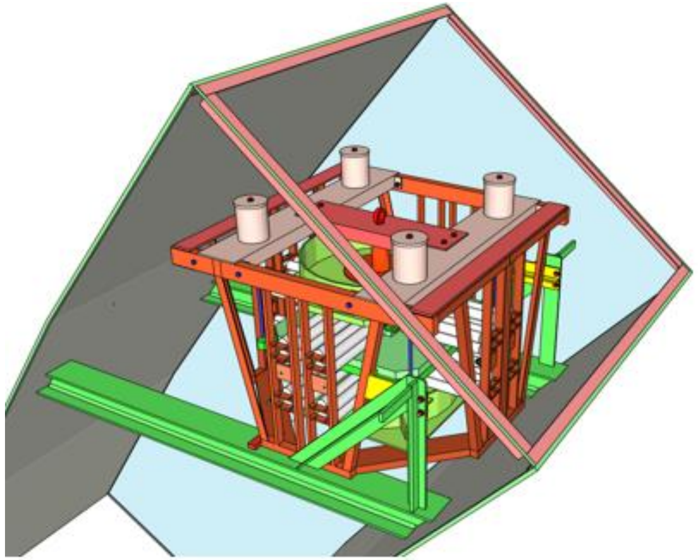
BS EN 1991-1-4:2005+A1:2010
EN 1991-1-4:2005+A1:2010 (E)

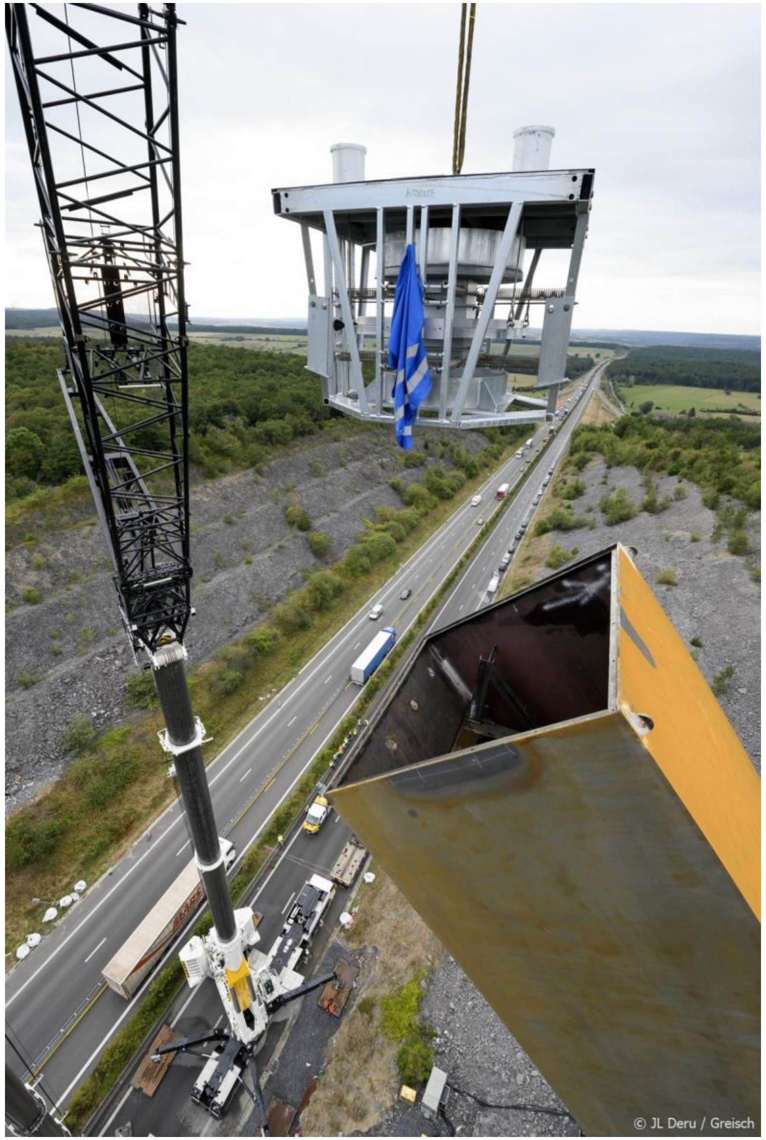
Table F.2 —Approximate values of logarithmic decrement of structural damping in the fundamental mode, δ_s

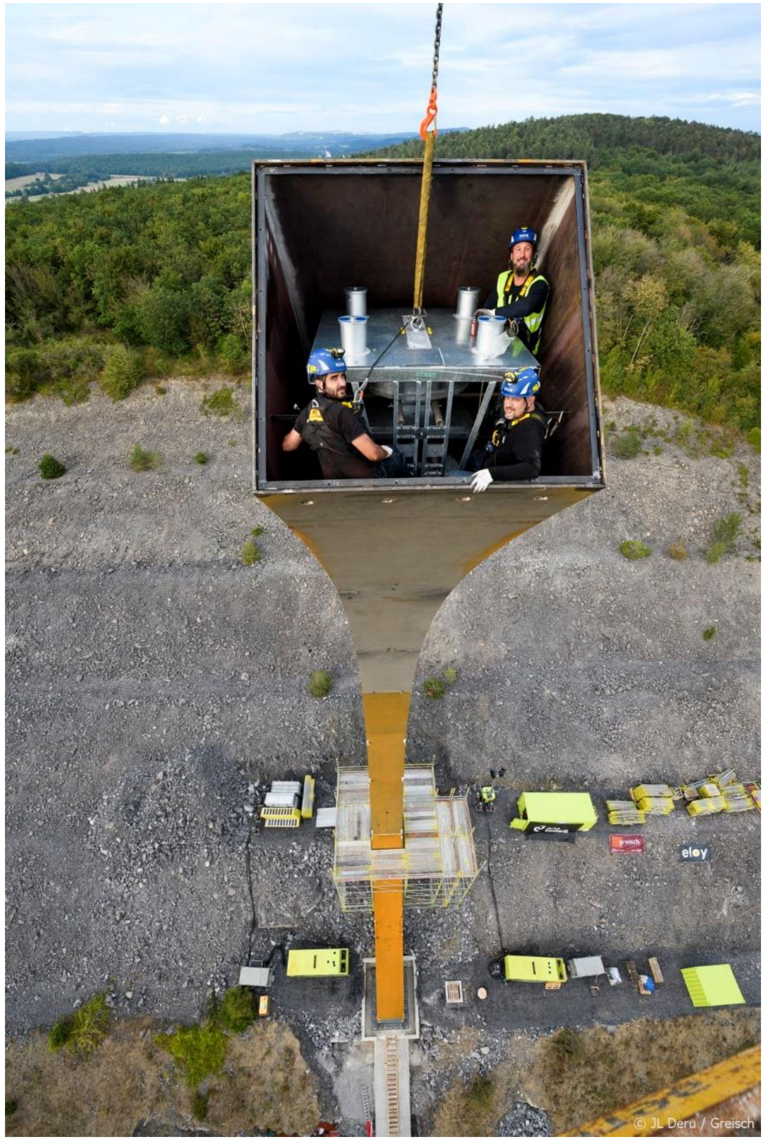
Structural type		structural damping, δ_s
reinforced concrete buildings		0,10
steel buildings		0,05
mixed structures concrete + steel		0,08
reinforced concrete towers and chimneys		0,03
unlined welded steel stacks without external thermal insulation		0,012
unlined welded steel stack with external thermal insulation		0,020
steel stack with one liner with external thermal insulation[a]	$h/b < 18$	0,020
	$20 \leq h/b < 24$	0,040
	$h/b \geq 26$	0,014
steel stack with two or more liners with external thermal insulation [a]	$h/b < 18$	0,020
	$20 \leq h/b < 24$	0,040
	$h/b \geq 26$	0,025
steel stack with internal brick liner		0,070
steel stack with internal gunite		0,030
coupled stacks without liner		0,015
guyed steel stack without liner		0,04
steel bridges + lattice steel towers	welded	0,02
	high resistance bolts	0,03
	ordinary bolts	0,05
composite bridges		0,04
concrete bridges	prestressed without cracks	0,04

$\delta = 0.012$
$\xi = \delta/(2.\pi) = 0.002$

Vortex Shedding Verification – TMD design







Vortex Shedding Verification – TMD design

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