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Project: SR-8-s1

Subject:

Designer:

Date:

Eurocode 1

Wind Load on Circular Cylinders (force coefficient)

Description:
Calculation of wind load action effects on circular cylinder elements. The total horizontal wind force is calculated from the force coefficient corresponding to the overall effect of the wind action on the cylindrical structure or cylindrical isolated element

According to:
EN 1991-1-4:2005+A1:2010 Section 7.9.2

Applicable for:
Cylindrical structures, isolated cylindrical elements

Input

Basic wind velocity $v_b =$ 41 m/s

Terrain category = II ▼

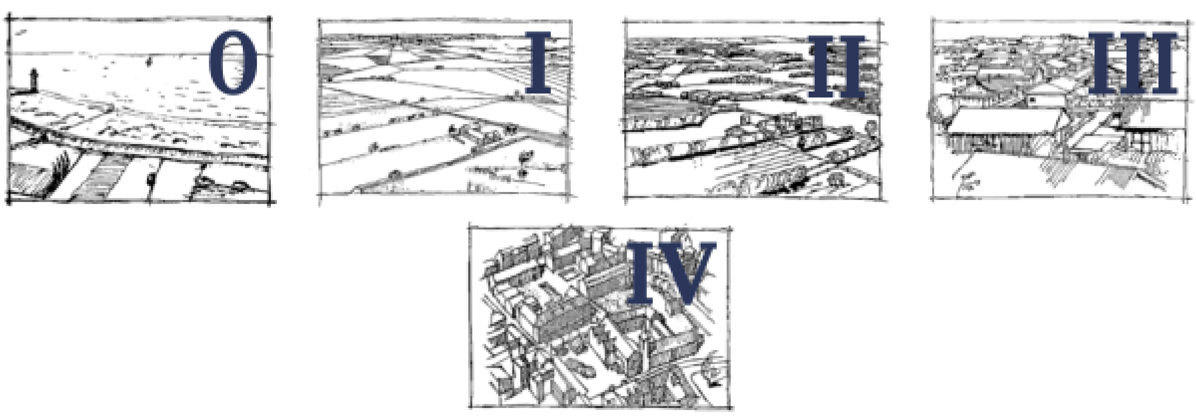

Illustration of Terrain categories reproduced from EN1991-1-4 Annex A

Diameter of the cylindrical element $b =$ 0.121 m

Length of the cylindrical element $l =$ 8 m

Maximum height above ground of the cylindrical element $z =$ 8.36 m

Surface type = spray paint ▼

Orography factor at reference height z_e $c_0(z_e) =$ 1

Structural factor $c_s c_d =$ 1

Results

Effective wind pressure $w_{eff} = 1.339\ kN/m^2$

Total wind horizontal force $F_w = 1.296\ kN$

Notes

1. The calculated effective wind pressure w_{eff} and total wind force F_W correspond to the total wind action effects and they are appropriate for global verifications of the structure according to the force coefficient method. For local verifications, such as verification of the cylinder's shell, appropriate wind pressure on local surfaces must be estimated according to the relevant external pressure coefficients, as specified in EN1991-1-4 §7.9.1.
2. For cylinders near a plane surface with a distance ratio $z_g/b < 1.5$ special advice is necessary. See EN1991-1-4 §7.9.2(6) for more details.
3. For a set of cylinders arranged in a row with normalized center-to-center distance $z_g/b < 30$ the wind force of each cylinder in the arrangement is larger than the force of the cylinder considered as isolated. See EN1991-1-4 §7.9.3 for more details.
4. The calculated wind action effects are characteristic values (unfactored). Appropriate load factors should be applied for the relevant design situation. For ULS verifications the partial load factor $\gamma_Q = 1.50$ is applicable for variable actions.

Details

Input Data

- Basic wind velocity: v_b = 41 m/s
- Terrain category: = II
- Diameter of the cylindrical element: b = 0.121 m
- Length of the cylindrical element: l = 8 m
- Maximum height above ground of the cylindrical element: z = 8.36 m
- Surface type: = spray paint
- Orography factor at reference height z_e: $c_0(z_e) = 1$
- Structural factor: $c_s c_d = 1$

Calculation of peak velocity pressure

Reference area and height

The reference height for the wind action z_e is equal to the maximum height above ground of the section being considered, as specified in *EN1991-1-4 §7.9.2(5)*. The reference area for the wind action A_{ref} is the projected area of the cylinder, as specified in *EN1991-1-4 §7.9.2(4)*. Therefore:

$$z_e = z = 8.360\ m$$

$$A_{ref} = b \cdot l = 0.121\ m \cdot 8.000\ m = 0.97\ m^2$$

Basic wind velocity

The basic wind velocity v_b is defined in *EN1991-1-4 §4.2(2)P* as a function of the wind direction and time of year at 10 m above ground of terrain category II. It is calculated as:

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

where $v_{b,0}$ is the fundamental value of the basic wind velocity which is defined in *EN1991-1-4 §4.2(1)P* as the characteristic 10 minutes mean wind velocity at 10m above ground level for terrain category II. The value of $v_{b,0}$ is provided in the National Annex based on the climatic conditions of the region where the structure is located. The influence of altitude on the basic wind velocity v_b may also be specified in the National Annex.

The directional factor c_{dir} and the seasonal factor c_{season} are defined in *EN1991-1-4 §4.2(2)P* and they take into account the effects of wind direction and time of the year. Their values are generally equal to c_{dir} = 1.0 and c_{season} = 1.0. The National Annex may specify values of c_{dir} and c_{season} different than 1.0.

In the following calculations the basic wind velocity is considered as v_b = 41.00 m/s.

Terrain roughness

The roughness length z_0 and the minimum height z_{min} are specified in *EN1991-1-4 Table 4.1* as a function of the terrain category. For terrain category II the corresponding values are z_0 = 0.050 m and z_{min} = 2.0 m.

The terrain factor k_r depending on the roughness length z_0 = 0.050 m is calculated in accordance with *EN1991-1-4 equation (4.5)*:

$$k_r = 0.19 \cdot (z_0 / z_{0,II})^{0.07} = 0.19 \cdot (0.050 \text{ m} / 0.050 \text{ m})^{0.07} = 0.1900 \text{ m}$$

The roughness factor $c_r(z_e)$ at the reference height z_e accounts for the variability of the mean wind velocity at the site of the structure due to the height above ground level and the ground roughness of the terrain upwind of the structure. It is calculated in accordance with *EN1991-1-4 equation 4.4*.

For the case where $z_e \geq z_{min}$:

$$c_r(z_e) = k_r \cdot \ln(z_e / z_0) = 0.1900 \text{ m} \cdot \ln(8.360 \text{ m} / 0.050 \text{ m}) = 0.9726$$

Orography factor

Where orography (e.g. hills, cliffs etc.) increases wind velocities by more than 5% the effects should be taken into account using an orography factor $c_0(z_e)$ different than 1.0, as specified in *EN1994-1-1 §4.3.3*. In general the effects of orography may be neglected when the average slope of the upwind terrain is less than 3° up to a distance of 10 times the height of the isolated orographic feature.

In the following calculations the orography factor is considered as $c_0(z_e)$ = 1.000.

Mean wind velocity

The mean wind velocity $v_m(z_e)$ at reference height z_e depends on the terrain roughness, terrain orography and the basic wind velocity v_b. It is determined using *EN1991-1-4 equation (4.3)*:

$$v_m(z_e) = c_r(z_e) \cdot c_0(z_e) \cdot v_b = 0.9726 \cdot 1.000 \cdot 41.00 \text{ m/s} = 39.88 \text{ m/s}$$

Wind turbulence

The turbulence intensity $I_v(z_e)$ at reference height z_e is defined as the standard deviation of the turbulence divided by the mean wind velocity. It is calculated in accordance with *EN1991-1-4 equation 4.7*.

For the case where $z_e \geq z_{min}$:

$I_v(z_e) = k_I$ / [$c_0(z_e) \cdot \ln(z_e / z_0)$] = 1.000 / [1.000 · ln(8.360 m / 0.050 m)] = 0.1953

where the turbulence factor is considered as k_I = 1.000 in accordance with *EN1991-1-4 §4.4(1)*.

Basic velocity pressure

The basic velocity pressure q_b is the pressure corresponding to the wind momentum determined at the basic wind velocity v_b. The basic velocity pressure is calculated according to the following fundamental relation, as specified in *EN1991-14 §4.5(1)*:

$q_b = (1/2) \cdot \rho \cdot v_b^2$ = (1/2) · 1.25 kg/m^3 · (41.00 m/s)^2 = 1.051 kN/m^2

where the density of the air is considered as ρ = 1.25 kg/m^3 in accordance with *EN1991-1-4 §4.5(1)*.

Peak velocity pressure

The peak velocity pressure $q_p(z_e)$ at reference height z_e includes mean and short-term velocity fluctuations. It is determined according to *EN1991-1-4 equation 4.8* as:

$q_p(z_e) = (1 + 7 \cdot I_v(z_e)) \cdot (1/2) \cdot \rho \cdot v_m(z_e)^2$ = (1 + 7·0.1953) · (1/2) · 1.25 kg/m^3 · (39.88 m/s)^2 = 2.353 kN/m^2

where the density of the air is considered as ρ = 1.25 kg/m^3 in accordance with *EN1991-1-4 §4.5(1)*.

The exposure factor $c_e(z_e)$ = 2.2397 is defined as the ratio of peak velocity pressure to basic velocity pressure:

$c_e(z_e) = q_p(z_e) / q_b$ = 2.353 kN/m^2 / 1.051 kN/m^2 = 2.2397

Therefore the peak velocity pressure is calculated as $q_p(z_e)$ = 2.353 kN/m^2.

Wind velocity corresponding to peak velocity pressure

The peak wind velocity $v(z_e)$ at reference height z_e is the wind velocity corresponding to the peak velocity pressure $q_p(z_e)$. It is calculated according to the following fundamental relation, as specified in *EN1991-14 §4.5(1)*:

$v(z_e) = [2 \cdot q_p(z_e) / \rho]^{0.5}$ = [2 · 2.353 kN/m^2 / 1.25 kg/m^3]$^{0.5}$ = 61.36 m/s

where ρ = 1.25 kg/m^3 is the density of the air as mentioned above.

Calculation of wind forces on the structure

The wind force on the structure F_w for the overall wind effect is estimated according to the force coefficient method as specified in *EN1991-1-4 §5.3*.

$F_w = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref}$

Structural factor

The structural factor $c_s c_d$ takes into account the structure size effects from the non-simultaneous occurrence of peak wind pressures on the surface and the dynamic effects of structural vibrations due to turbulence. The structural factor $c_s c_d$ is determined in accordance with *EN1991-1-4 Section 6*. A value of $c_s c_d$ = 1.0 is generally conservative for small structures not-susceptible to wind turbulence effects such as buildings with height less than 15 m or chimneys with circular cross-sections whose height is less than 60 m and 6.5 times the diameter.

In the following calculations the structural factor is considered as $c_s c_d$ = 1.000.

Reynolds number

Reynolds number characterizes the air flow around the object. For air flow around cylindrical objects Reynolds number is calculated according to *EN1991-1-4 §7.9.1(1)*:

$$Re = b \cdot v(z_e) / \nu = 0.121\ \text{m} \cdot 61.36\ \text{m/s} / 15.0 \times 10^{-6}\ \text{m}^2\text{/s} = 0.4950 \times 10^{6}$$

where the kinematic viscosity of the air is considered as $\nu = 15.0 \times 10^{-6}$ m^2/s in accordance with *EN1991-1-4 §7.9.1(1)*.

Effective slenderness

The effective slenderness λ depends on the aspect ratio and the position of the structure and it is given in *EN1991-1-4 §7.13(2)*.

For circular cylinders with length $l \leq 15$ m the effective slenderness λ is equal to:

$$\lambda_{15} = \min(l / b, 70) = \min(8.000\ \text{m} / 0.121\ \text{m}, 70) = 66.116$$

Therefore $\lambda = \lambda_{15} = 66.116$

End effect factor

The end effect factor ψ_λ takes into account the reduced resistance of the structure due to the wind flow around the end (end-effect). The value of ψ_λ is calculated in accordance with *EN1991-1-4 §7.13* . For solid structures (i.e. solidity ratio $\varphi = 1.000$) the value of the end effect factor ψ_λ is determined from *EN1991-1-4 Figure 7.36* as a function of the slenderness λ.

The estimated value for the end effect factor is $\psi_\lambda = 0.904$

Equivalent surface roughness

The equivalent surface roughness k depends on the surface type and it is given in *EN1991-1-4 §7.9.2(2)*. According to *EN1991-1-4 Table 7.13* for surface type "spray paint" the corresponding equivalent surface roughness is $k = 0.0200$ mm.

Force coefficient without free-end flow

For circular cylinders the force coefficient without free-end flow $c_{f,0}$ depends on the Reynolds number Re and the normalized equivalent surface roughness k/b. The force coefficient without free-end flow $c_{f,0}$ is specified in *EN1991-1-4 §7.9.2*. The value $c_{f,0}$ is determined according to *EN1991-1-4 Figure 7.28* for the values of $Re = 0.4950 \times 10^{6}$, $k = 0.0200$ mm, $b = 0.121$ m, $k/b = 0.000165$.

The estimated value for the force coefficient without free-end flow is $c_{f,0} = 0.630$

Force coefficient

The force coefficient c_f for finite cylinders is given in *EN1991-1-4 §7.9.2(1)* as:

$$c_f = c_{f,0} \cdot \psi_\lambda$$

where $c_{f,0}$ is the force coefficient without free-end flow, and ψ_λ the end effect factor, as calculated above. Therefore:

$$c_f = c_{f,0} \cdot \psi_\lambda = 0.630 \cdot 0.904 = 0.569$$

Total wind force

The total wind force on the structure F_w is estimated as:.

$$F_w = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref} = 1.000 \cdot 0.569 \cdot 2.353\ \text{kN/m}^2 \cdot 0.97\ \text{m}^2 = 1.296\ \text{kN}$$

The total wind force F_w takes into account the overall wind effect. The corresponding effective wind pressure w_{eff} on the reference wind area A_{ref} is equal to:

$w_{eff} = F_w / A_{ref} = 1.296$ kN / 0.97 m^2 = 1.339 kN/m^2

Additional notes

- The effective pressure w_{eff} = 1.339 kN/m^2 is appropriate for global verifications of the structure according to the force coefficient method. It is not appropriate for local verifications of structural elements, such as the shell of the cylinder. For the latter case appropriate wind pressure on local surfaces must be estimated according to the relevant external pressure coefficients, as specified in *EN1991-1-4 §7.9.1*.
- The calculated wind action effects are characteristic values (unfactored). Appropriate load factors should be applied for the relevant design situation. For ULS verifications the partial load factor γ_Q = 1.50 is applicable for variable actions according to EN1990.

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