EN 1991-1-4:2005

Wind actions
1. General

2. Design situations

3. Modelling of wind actions

4. Wind velocity and velocity pressure

5. Wind actions

6. Structural factor

7. Pressure and force coefficients

8. Wind actions on bridges
EN 1991-1-4:2005 Contents

Annex

A. Terrain effects

B. Procedure 1 for determining the structural factor

C. Procedure 2 for determining the structural factor

D. Structural factors for different types of structures

E. Vortex shedding and aeroelastic instabilities

F. Dynamic characteristics of structures
Section 1 General – 1.1 Scope

(2) This Part is applicable to:

- Buildings and civil engineering works with heights up to 200 m
- Bridges having no span greater than 200 m, provided that they satisfy the criteria for dynamic response

(3) This part is intended to predict characteristic wind actions on land-based structures, their components and appendages
Draft corrigendum to EN 1991-1-4:2005
22 January 2008

(11) Guyed masts and lattice towers are treated in EN 1993-3-1 and lighting columns in EN 40

(12) This part does not give guidance on the following aspects:
- torsional vibrations, e.g. tall buildings with a central core
- bridge deck vibrations from transverse wind turbulence
- wind actions on cable supported bridges
- vibrations where more than the fundamental mode needs to be considered
Section 2 Design situations

(1) The relevant wind actions shall be determined for each design situation identified in accordance with EN 1990, 3.2.

(2) Traffic, snow and ice

(3) Execution

(4) Where in design windows and doors are assumed to be shut under storm conditions, the effect of these being open should be treated as an accidental design situation.
3.1 Nature

3.2 Representations of wind actions

3.3 Classification of wind actions

(1) Unless otherwise specified, wind actions should be classified as variable fixed actions

3.4 Characteristic values

(1)

Note: All coefficients or models, to derive wind actions from basic values, are chosen so that the probability of the calculated wind actions does not exceed the probability of these basic values

3.5 Models
\[ V_b = C_{\text{dir}} \cdot C_{\text{season}} \cdot V_{b,0} \]
Section 4 Wind vel. and vel. pres. - 4.2 Basic values

Norway: Basic wind velocity. NS 3491-4:2002
UK: Basic wind velocity. BS 6399-2:1997
Faroe Islands – extreme winds

EKSTREMVINDE PÅ FÆRØERNE
En analyse af ekstreme vindhastigheder

Hovedrapport

Jan Poulsen og Einar Brimnes
Faroe Islands – extreme winds
Faroe Islands – measuring stations
Faroe Islands - Glyvursnes
### Faroe Islands – basic wind velocities

<table>
<thead>
<tr>
<th>Station</th>
<th>$V_g(10)$ m/s</th>
<th>$V_g(50)$ m/s</th>
<th>$V_g(100)$ m/s</th>
<th>Ekstrapolation formel</th>
</tr>
</thead>
<tbody>
<tr>
<td>f-1 Norðradalur</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>f-2 Norðradalsskarð</td>
<td>52</td>
<td>58</td>
<td>61</td>
<td>$41.8 + 4.24 \ln T$</td>
</tr>
<tr>
<td>f-3 Sund</td>
<td>20</td>
<td>23</td>
<td>24</td>
<td>$16.1 + 1.75 \ln T$</td>
</tr>
<tr>
<td>f-4 Oyrareingir</td>
<td>31</td>
<td>35</td>
<td>37</td>
<td>$24.2 + 2.86 \ln T$</td>
</tr>
<tr>
<td>f-5 Skála</td>
<td>27</td>
<td>31</td>
<td>32</td>
<td>$21.7 + 2.31 \ln T$</td>
</tr>
<tr>
<td>f-6 Leirvík</td>
<td>25</td>
<td>29</td>
<td>30</td>
<td>$20.8 + 2.02 \ln T$</td>
</tr>
<tr>
<td>f-7 Klaksvík</td>
<td>25</td>
<td>28</td>
<td>29</td>
<td>$20.5 + 1.84 \ln T$</td>
</tr>
<tr>
<td>f-8 Glyvursnes</td>
<td>31</td>
<td>35</td>
<td>36</td>
<td>$25.1 + 2.41 \ln T$</td>
</tr>
</tbody>
</table>
IL PROGETTO DI MASSIMA DEFINITIVO

SEZIONE TRASVERSALE DELL'IMPALCATO

11.50  8.25  10.60  8.25  11.50

4.20

60.40
Southerly winds at Messina – bridge deck height
Basis for updated European wind map?

Climatological changes?
Influence of terrain - measured wind velocities

- Height 43.1m
- Height 25.5m
- Height 14.7m

Wind velocity m/s

Minutes
Section 4.3 Mean wind

\[ v_m(z) = c_r(z) \cdot c_o(z) \cdot v_b \]
Section 4.3.2 Terrain roughness

\[ c_r(z) = k_r \cdot \ln(z / z_0) \]

\[ k_r = 0,19 \cdot \left( \frac{z_0}{z_{0,II}} \right)^{0,07} \]

\[ z_{0,II} = 0,05 \, m \]
## Terrain categories and terrain parameters

<table>
<thead>
<tr>
<th>Terrain category</th>
<th>$Z_0$ m</th>
<th>$Z_{\text{min}}$ m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Sea or coastal area exposed to the open sea</td>
<td>0,003</td>
<td>1</td>
</tr>
<tr>
<td>I Lakes or flat and horizontal area with negligible vegetation and without obstacles</td>
<td>0,01</td>
<td>1</td>
</tr>
<tr>
<td>II Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights</td>
<td>0,05</td>
<td>2</td>
</tr>
<tr>
<td>III Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)</td>
<td>0,3</td>
<td>5</td>
</tr>
<tr>
<td>IV Area in which at least 15% of the surface is covered with buildings and their average height exceeds 15 m</td>
<td>1,0</td>
<td>10</td>
</tr>
</tbody>
</table>

**NOTE:** The terrain categories are illustrated in A.1.
Annex A: Terrain category I and II
Annex A: Terrain category III and IV
Annex A: Terrain category 0 – coastal area
Coastal area exposed to the open sea
Figure 4.1 - Assessment of terrain roughness
A.2 Transition between roughness categories
A.2 Transition between roughness categories

Procedure 1

If the structure is situated near a change of terrain roughness at a distance:

- less than 2 km from the smoother category 0
- less than 1 km from the smoother categories I to III

the smoother terrain category in the upwind direction should be used.

Small areas (less than 10% of the area under consideration) with deviating roughness may be ignored.
A.3 Terrain orography. Figure A.1

\[ v_m : \text{mean wind velocity at height } z \text{ above terrain} \]
\[ v_{mf} : \text{mean wind velocity above flat terrain} \]
\[ c_0 = \frac{v_m}{v_{mf}} \]
Section 4.4 Wind turbulence. Turbulence intensity

\[ I_v(z) = \frac{1}{c_o} \frac{k_I}{\ln(z/z_0)} \]
Section 4.5 Peak velocity pressure, peak velocity

\[
q_p(z) = (1 + 7 \cdot I_v(z)) \cdot \frac{1}{2} \cdot \rho \cdot v_m^2(z)
\]

\[
v_p(z) = \sqrt{1 + 7 \cdot I_v(z) \cdot v_m(z)}
\]
Measured wind velocities

- Height 43.1m
- Height 25.5m
- Height 14.7m
## Section 5 Wind actions – 5.1 General

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Subject Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>peak velocity pressure $q_p$</td>
<td>4.2 (2)P</td>
</tr>
<tr>
<td>basic wind velocity $v_b$</td>
<td>Section 7</td>
</tr>
<tr>
<td>reference height $z_r$</td>
<td>Table 4.1</td>
</tr>
<tr>
<td>terrain category</td>
<td></td>
</tr>
<tr>
<td>characteristic peak velocity pressure $q_p$</td>
<td>4.5 (1)</td>
</tr>
<tr>
<td>turbulence intensity $l_v$</td>
<td>4.4</td>
</tr>
<tr>
<td>mean wind velocity $v_m$</td>
<td>4.3.1</td>
</tr>
<tr>
<td>orography coefficient $c_0(z)$</td>
<td>4.3.3</td>
</tr>
<tr>
<td>roughness coefficient $c_t(z)$</td>
<td>4.3.2</td>
</tr>
</tbody>
</table>

**Wind pressures, e.g. for cladding, fixings and structural parts**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Subject Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>external pressure coefficient $c_{pe}$</td>
<td>Section 7</td>
</tr>
<tr>
<td>internal pressure coefficient $c_{pl}$</td>
<td>Section 7</td>
</tr>
<tr>
<td>net pressure coefficient $c_{p.net}$</td>
<td>Section 7</td>
</tr>
<tr>
<td>external wind pressure: $w_e=q_p c_{pe}$</td>
<td>5.2 (1)</td>
</tr>
<tr>
<td>internal wind pressure: $w=q_p c_{pl}$</td>
<td>5.2 (2)</td>
</tr>
</tbody>
</table>

**Wind forces on structures, e.g. for overall wind effects**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Subject Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>structural factor: $c_0 c_d$</td>
<td>6</td>
</tr>
<tr>
<td>wind force $F_W$ calculated from force coefficients</td>
<td>5.3 (2)</td>
</tr>
<tr>
<td>wind force $F_W$ calculated from pressure coefficients</td>
<td>5.3 (3)</td>
</tr>
</tbody>
</table>
Section 5.2 Wind pressure on surfaces

\[ w_e = q_p(z_e) \cdot c_{pe} \]

\[ w_i = q_p(z_i) \cdot c_{pi} \]
Figure 5.1 – Pressure on surfaces

(a) Positive internal pressure

(b) Negative internal pressure

(c) $w_{e1}$ and $w_{e2}$

(d) $w_{i1}$ and $w_{i2}$
The figure is based on the following:

for $1 \text{ m}^2 < A < 10 \text{ m}^2$ \quad $c_{pe} = c_{pe,1} - (c_{pe,1} - c_{pe,10}) \log_{10} A$
Section 7.2.2 Vertical walls. Figure 7.5

- Plan

\[ d \]

- Elevation

\[ \text{Elevation for } e < d \]

\[ e = b \text{ or } 2h, \text{ whichever is smaller} \]

\[ b: \text{ crosswind dimension} \]

- Diagram showing wind directions and dimensions.
### Section 7.2.2 Vertical walls. Table 7.1

<table>
<thead>
<tr>
<th>Zone</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$c_{pe,10}$</td>
<td>$c_{pe,1}$</td>
<td>$c_{pe,10}$</td>
<td>$c_{pe,1}$</td>
<td>$c_{pe,10}$</td>
</tr>
<tr>
<td>$h/d$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-1,2</td>
<td>-1,4</td>
<td>-0,8</td>
<td>-1,1</td>
<td>-0,5</td>
</tr>
<tr>
<td>1</td>
<td>-1,2</td>
<td>-1,4</td>
<td>-0,8</td>
<td>-1,1</td>
<td>-0,5</td>
</tr>
<tr>
<td>≤ 0,25</td>
<td>-1,2</td>
<td>-1,4</td>
<td>-0,8</td>
<td>-1,1</td>
<td>-0,5</td>
</tr>
</tbody>
</table>
Section 7.2.5 Duopitch roofs. Figure 7.8

(b) wind direction $\theta = 0^\circ$

(c) wind direction $\theta = 90^\circ$
### Section 7.2.5 Duopitch roofs. Table 7.4a

#### Zone for wind direction $\theta = 0^\circ$

<table>
<thead>
<tr>
<th>Pitch Angle $\alpha$</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_{p_{e,10}}$</td>
<td>$C_{p_{e,1}}$</td>
<td>$C_{p_{e,10}}$</td>
<td>$C_{p_{e,1}}$</td>
<td>$C_{p_{e,10}}$</td>
</tr>
<tr>
<td>-45°</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.8</td>
<td>-0.7</td>
<td>-1.0</td>
</tr>
<tr>
<td>-30°</td>
<td>-1.1</td>
<td>-2.0</td>
<td>-0.8</td>
<td>-1.5</td>
<td>-0.8</td>
</tr>
<tr>
<td>-15°</td>
<td>-2.5</td>
<td>-2.8</td>
<td>-1.3</td>
<td>-2.0</td>
<td>-0.9</td>
</tr>
<tr>
<td>-5°</td>
<td>-2.3</td>
<td>-2.5</td>
<td>1.2</td>
<td>2.0</td>
<td>-0.8</td>
</tr>
<tr>
<td>5°</td>
<td>-1.7</td>
<td>-2.5</td>
<td>-1.2</td>
<td>-2.0</td>
<td>-0.6</td>
</tr>
<tr>
<td>15°</td>
<td>-0.9</td>
<td>-2.0</td>
<td>-0.8</td>
<td>-1.5</td>
<td>-0.3</td>
</tr>
<tr>
<td>30°</td>
<td>-0.5</td>
<td>-1.5</td>
<td>-0.5</td>
<td>-1.5</td>
<td>-0.2</td>
</tr>
<tr>
<td>45°</td>
<td>-0.0</td>
<td>-0.0</td>
<td>-0.0</td>
<td>-0.0</td>
<td>-0.2</td>
</tr>
<tr>
<td>60°</td>
<td>+0.7</td>
<td>+0.7</td>
<td>+0.7</td>
<td>+0.7</td>
<td>-0.2</td>
</tr>
<tr>
<td>75°</td>
<td>+0.8</td>
<td>+0.8</td>
<td>+0.8</td>
<td>+0.8</td>
<td>-0.2</td>
</tr>
</tbody>
</table>
Section 5.3 Wind forces

\[ F_w = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref} \]
Section 6 Structural factor

6.2 Determination of structural factor

The structural factor may be taken as 1 for

a) buildings with a height less than 15 m

b) facade and roof elements having a natural frequency greater than 5 Hz

c) framed buildings which have structural walls and which are less than 100 m high and whose height is less than 4 times the in-wind depth

d) chimneys with circular cross-sections whose height is less than 60 m and 6.5 times the diameter
Annex D Structural factor

c_s c_d for multistorey steel buildings

based on:
- \( \delta \approx 0.05 \)
- Roughness category I (solid lines)
- Roughness category II (dotted lines)
- \( v_c = 28 \text{ m/sec} \)
- \( \delta = 0 \)
Annex D Structural factor

$c_s c_d$ for multistorey concrete buildings

based on:
- $\frac{\delta}{L}=0.1$
- Roughness category II (solid lines)
- Roughness category III (dotted lines)
- $v_e=28$ m/sec
- $\delta=0$

Graph showing $c_s c_d$ values for different heights and widths.
Annex D Structural factor

$c_s c_d$ for steel chimneys without liners

Based on:

- $\delta_s = 0.012$
- $W/W_1 = 1$
- Roughness category II (solid lines)
- Roughness category III (dotted lines)
- $v_s = 28$ m/sec
- $\delta_s = 0$

Height [m] vs Diameter [m] graph
Annex D Structural factor

$c_sc_d$ for concrete chimneys without liners

based on:

- $\delta_s = 0.03$
- Roughness category I (solid lines)
- Roughness category II (dotted lines)
- $v = 28$ m/sec
- $\delta_s = 0$

Graph showing the relationship between height and diameter for concrete chimneys without liners.
Annex D Structural factor

$c_s c_d$ for steel chimneys with liners

Based on:

- $\delta_s = \text{depending on } h/b =$ ratio
  - $h/b < 18 \quad \delta_s = 0.02$
  - $20 \leq h/b \leq 24 \quad \delta_s = 0.04$
  - $h/b > 26 \quad \delta_s = 0.025$

- Roughness category I (solid lines)
- Roughness category II (dotted lines)

- $v_s = 28 \text{ m/sec}$
- $\delta_s = 0$
NOTE  Limitations are also given in 1.1 (2)
Section 6.3 Detailed procedure

\[ C_s C_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_s)} \]

\[ C_s = \frac{1 + 7 \cdot I_v(z_s) \cdot \sqrt{B^2}}{1 + 7 \cdot I_v(z_s)} \]

\[ C_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_s) \cdot \sqrt{B^2}} \]
Background turbulence and resonance turbulence

\[ S_u(f)/\sigma_u^2 \]

\[ k^2|H_\xi(f)|^2 S_u(f_1)/\sigma_u^2 \]

Areal = \( k_b \), formel (5.2 - 16)

Areal = \( k_r \), formel (5.2 - 17)
Wind vortices versus structural size
Procedure 1 (dotted line) versus theory (solid line)
Procedure 2 (dotted line) versus theory (solid line)
Procedure 2 has a more accurate representation of the theoretical background compared to procedure 1
Annex E Vortex shedding

Chimneys

Bridges
Annex E Vortex shedding. Bending vibrations
Annex E Vortex shedding. Ovaling vibrations
Annex E Vortex shedding. Critical wind velocity

\[ V_{\text{crit},i} = \frac{b \cdot n_{i,y}}{St} \]

\[ V_{\text{crit},i} = \frac{b \cdot n_{i,o}}{2 \cdot St} \]
Vortex shedding. Chimneys
Vortex shedding. Chimneys

[Images of a snowy landscape and a chimney]

EUROCODES
Background and Applications
Approach 1 versus approach 2

Approach 1: Vortex-resonance model

Approach 2: Spectral model

Turbulence is an active parameter only in approach 2

E1.5.1 General
(3)

Approach 2 allows for the consideration of different turbulence intensities, which may differ due to meteorological conditions.

For regions where it is likely that it may become very cold and stratified flow condition may occur (e.g. in coastal areas in Northern Europe), approach 2 may be used.
Vortex shedding. Bridge cross section
Vortex shedding. Bridge cross section. Approach 1

![Graph showing vortex shedding data for Eurocode 1, Approach 1, with data points for wind tunnel tests under smooth and turbulent wind conditions.](image)
Vortex shedding. Approach 1 or 2?

Approach 2 has a more accurate representation of the physical phenomenon compared to approach 1