BS EN 13001-2:2014

BSI Standards Publication

Crane safety — General design

Part 2: Load actions

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National foreword

This British Standard is the UK implementation of EN 13001-2:2014. It supersedes BS EN 13001-2:2011, which is withdrawn.

This standard, together with BS EN 13001-1:2004+A1:2009, BS EN 13001-3-1:2012+A1:2013, BS EN 13001-3-2:2014, BS EN 13001-3-3, BS EN 13001-3-4 and DD CEN/TS 13001-3-5:2010, supersedes BS 2573-1:1983 and BS 2573-2:1980, which will be withdrawn on publication of all parts of the BS EN 13001 series.

Users' attention is drawn to the fact that neither BS 2573-1:1983 nor BS 2573-2:1980 should be used in conjunction with the EN 13001 series as they are not complementary. The BS 2573 series will remain current until all parts of the BS EN 13001 series cited above have been published to ensure that a coherent package of standards remains available in the UK during the transition to European standards.

The UK participation in its preparation was entrusted to Technical Committee MHE/3/1, Crane design.

A list of organizations represented on this committee can be obtained on request to its secretary.

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This European Standard was approved by CEN on 14 June 2014.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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Foreword

This document (EN 13001-2:2014) has been prepared by Technical Committee CEN/TC 147 “Crane — Safety”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2015 and conflicting national standards shall be withdrawn at the latest by February 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 13001-2:2011.

The major changes in this revision are in 4.2.2.2, 4.2.3.4, 4.2.4.10, 4.3.2, 4.3.4 and 4.3.7. There are new issues in 4.2.4.7, 4.2.4.8, Annex B, Annex C and Annex D.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

This European Standard is one Part of EN 13001. The other parts are as follows:

- *Part 1: General principles and requirements*
- *Part 2: Load actions*
- *Part 3-1: Limit states and proof of competence of steel structures*
- *Part 3-2: Limit states and proof of competence of wire ropes in reeving systems*
- *Part 3-3: Limit states and proof of competence of wheel/rail contacts*
- *Part 3-4: Limit states and proof of competence of machinery*
- *Part 3-5: Limit states and proof of competence of forged hooks*

For the relationship with other European Standards for cranes, see Annex E.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This European Standard has been prepared to be a harmonized standard to provide one means for the mechanical design and theoretical verification of cranes to conform to the essential health and safety requirements of the Machinery Directive, as amended. This standard also establishes interfaces between the user (purchaser) of the crane and the designer, as well as between the designer and the component manufacturer, in order to form a basis for selecting cranes and components.

This European Standard is a type C standard as stated in the EN ISO 12100.

The machinery concerned and the extent to which hazards are covered are indicated in the scope of this standard.

When provisions of this type C standard are different from those, which are stated in type A or B standards, the provisions of this type C standard take precedence over the provisions of the other standards, for machines that have been designed and built according to the provisions of this type C standard.

1 Scope

This European Standard specifies load actions to be used together with the standard EN 13001-1 and EN 13001-3, and as such they specify conditions and requirements on design to prevent mechanical hazards of cranes, and provides a method of verification of those requirements.

NOTE Specific requirements for particular types of crane are given in the appropriate European Standard for the particular crane type.

The following is a list of significant hazardous situations and hazardous events that could result in risks to persons during normal use and foreseeable misuse. Clause 4 of this standard is necessary to reduce or eliminate the risks associated with the following hazards:

a) Instability of the crane or its parts (tilting).

b) Exceeding the limits of strength (yield, ultimate, fatigue).

c) Elastic instability of the crane or its parts (buckling, bulging).

d) Exceeding temperature limits of material or components.

e) Exceeding the deformation limits.

This document is not applicable to cranes that are manufactured before the date of its publication as EN.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1990, *Eurocode - Basis of structural design*

EN 13001-1, *Cranes — General Design — Part 1: General principles and requirements*

ISO 4306-1:2007, *Cranes — Vocabulary — Part 1: General*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1990, Clause 6 of ISO 4306-1:2007 and the following apply.

3.1.1

hoist load
sum of the masses lifted by the crane, taken as the maximum that the crane is designed to lift in the configuration and operational conditions being considered

3.1.2

single failure proof system
force carrying arrangement of several components, arranged so that in case of a failure of any single component in the arrangement, the capability to carry the force is not lost

3.2 Symbols and abbreviations

For the purposes of this document, the symbols and abbreviations given in Table 1 apply.

Table 1 — Symbols and abbreviations

Symbols, abbreviations	Description
A1 to A4	Load combinations including regular loads
A	Characteristic area of a crane member
A_{g}	Projection of the hoist load on a plane normal to the direction of the wind velocity
A_{c}	Area enclosed by the boundary of a lattice work member in the plane of its characteristic height d
A_{j}	Area of an individual crane member projected to the plane of the characteristic height d
b_{h}	Width of the rail head
b	Characteristic width of a crane member
B1 to B5	Load combinations including regular and occasional loads
c	Spring constant
c_{o}, c_{a}, c_{oy}, c_{oz}	Aerodynamic coefficients
C1 to C11	Load combinations including regular, occasional and exceptional loads
CFF, CFM	Coupled wheel pairs of system F/F or F/M
d	Characteristic dimension of a crane member
d_{i}, d_{n}	Distance between wheel pair i or n and the guide means
e_{G}	Width of the gap of a rail
f	Friction coefficient
f_{i}	Loads
f_{q}	natural frequency
f_{rec}	Term used in calculating $v(z)$
F	Force in general
F, F_{y}, F_{z}	Wind loads
$\hat{F}$	Maximum buffer force
F_{i}, F_{f}	Initial and final drive force
ΔF	Change of drive force
F_{x1i}, F_{x2i}, F_{y1i}, F_{y2i}	Tangential wheel forces
F_{y}	Guide force
F_{z1i}, F_{z2i}	Vertical wheel forces

Symbols, abbreviations	Description
F/F, F/M	Abbreviations for Fixed/Fixed and Fixed/Moveable, characterizing the possibility of lateral movements of the crane wheels
g	Acceleration due to gravity
h	Distance between instantaneous slide pole and guide means of a skewing crane
$h(t)$	Time dependent unevenness function
h_s	Height of the step of a rail
H_1, H_2	Lateral wheel forces induced by drive forces acting on a crane or trolley with asymmetrical mass distribution
HC1 to HC4	Stiffness classes
HD1 to HD5	Classes of the type of hoist drive and its operation method
i	Serial number
IFF, IFM	Independent wheel pairs of system F/F or F/M
j	Serial number
k	Serial number
K	Drag coefficient of terrain
K_1, K_2	Roughness factors
l	Span of a crane
l_a	Aerodynamic length of a crane member
l_o	Geometric length of a crane member
m_H	Mass of the hoist load
m	Mass of the crane and the hoist load
Δm_H	Released or dropped part of the hoist load
n	Number of wheels at each side of the crane runway
n_m	Exponent used in calculating the shielding factor η
p	Number of pairs of coupled wheels
q	Equivalent static wind pressure
$\overline{q}$	Mean wind pressure
$q(\mathrm{z})$	Equivalent static storm wind pressure
$q(3)$	Wind pressure at $v(3)$
r	Wheel radius
R	Out-of-service wind recurrence interval
Re	Reynold number
s_g	Slack of the guide
s_y	Lateral slip at the guide means

Symbols, abbreviations	**Description**
s_{yi}	Lateral slip at wheel pair i
S	Load effect
$\hat{S}$	Maximum load effect
S_{i}, S_{f}	Initial and final load effects
ΔS	Change of load effect
t	Time
u	Buffer stroke
$\hat{u}$	Maximum buffer stroke
v	Travelling speed of the crane
$\bar{v}$	Constant mean wind velocity
$\bar{v}$ *	Constant mean wind velocity if the wind direction is not normal to the longitudinal axis of the crane member under consideration
$v(\mathrm{z})$	Equivalent static storm wind velocity
$v(\mathrm{z})$*	Equivalent static storm wind velocity if the wind direction is not normal to the longitudinal axis of the crane member under consideration
$v(3)$	Gust wind velocity averaged of a period of 3 seconds
v_{g}	Three seconds gust amplitude
v_{h}	Hoisting speed
$v_{\mathrm{h,max}}$	Maximum steady hoisting speed
$v_{\mathrm{h,CS}}$	Steady hoisting creep speed
$v_{\mathrm{m}}(z)$	Ten minutes mean storm wind velocity in the height z
v_{ref}	Reference storm wind velocity
w_{b}	Distance between the guide means
z	Height above ground level
$z(t)$	Time-dependent coordinate of the mass centre
α_{r}	Relative aerodynamic length
α_{w}	Angle between the direction of the wind velocity $\bar{v}$ or $v(z)$ and the longitudinal axis of the crane member under consideration
α	Skewing angle
α_{g}	Part of the skewing angle α due to the slack of the guide
α_{G}, α_{s}	Terms used in calculating ϕ_4
α_{t}	Part of the skewing angle α due to tolerances
α_{w}	Part of the skewing angle α due to wear
β	Angle between horizontal plane and non-horizontal wind direction

Symbols, abbreviations	**Description**
β_2	Term used in calculating ϕ_2
β_3	Term used in calculating ϕ_3
γ_f	Overall safety factor
γ_m	Resistance coefficient
γ_n	Risk coefficient
γ_p	Partial safety factor
γ_s	Additional safety factor for stability
δ	Term used in calculating ϕ_1
ε_S	Conventional start force factor
ε_M	Conventional mean drive force factor
η	Shielding factor
η_W	Factor for remaining hoist load in out of service condition
λ	Aerodynamic slenderness ratio
μ, μ'	Parts of the span l
F	Term used in calculating the guide force F_y
F_1i, F_2i	Terms used in calculating F_y1i and F_y2i
ξ	Term used in calculating ϕ_7
ξ_1i, ξ_2i	Term used in calculating F_x1i and F_x2i
$\xi_\mathrm{G}(\alpha_\mathrm{G})$, $\xi_\mathrm{s}(\alpha_\mathrm{s})$	Curve factors
ρ	Density of the air
φ	Solidity ratio
ϕ_i	Dynamic factors
ϕ_1	Dynamic factor acting on the mass of the crane
ϕ_2	Dynamic factor on hoist load when hoisting an unrestrained grounded load in regular operation
ϕ_2C	Dynamic factor on hoist load when hoisting an unrestrained grounded load under exceptional conditions
$\phi_\mathrm{2,min}$	Term used in calculating ϕ_2
ϕ_3	Dynamic factor for inertial and gravity effects by sudden release of a part of the hoist load
ϕ_4	Dynamic factor for loads caused by travelling on uneven surface
ϕ_5	Dynamic factor for loads caused by acceleration of all crane drives
ϕ_6	Dynamic factor for test loads

Symbols, abbreviations	Description
ϕ_7	Dynamic factor for loads due to buffer forces
ϕ_8	Gust response factor
ϕ_L, ϕ_{ML}	Factors for calculation of force in case the load or moment limiter is activated
ψ	Reduction factor used in calculating aerodynamic coefficients

4 Safety requirements and/or measures

4.1 General

Loads and load combinations, as given in 4.2 and 4.3, shall only be applied as relevant for specified configurations and operational conditions of the crane.

The load actions shall be taken into account in proofs against failure by uncontrolled movement, yielding, elastic instability and, where applicable, against fatigue.

4.2 Loads

4.2.1 General

4.2.1.1 Introduction

The loads acting on a crane are divided into the categories of regular, occasional and exceptional as given in 4.2.1.2, 4.2.1.3 and 4.2.1.4. For the proof calculation of means of access, loads only acting locally are given in 4.2.4.13. Combinations of regular, occasional and exceptional loads into load combinations A, B and C are given in 4.3.

4.2.1.2 Regular loads

Regular loads are those loads that occur frequently under normal operation.

a) Hoisting and gravity effects acting on the mass of the crane;

b) inertial and gravity effects acting vertically on the hoist load;

c) loads caused by travelling on uneven surface;

d) loads caused by acceleration of all crane drives;

e) loads induced by displacements.

4.2.1.3 Occasional loads

a) Loads due to in-service wind;

b) snow and ice loads;

c) loads due to temperature variation;

d) loads caused by skewing.

Occasional loads occur infrequently. They are usually neglected in fatigue assessment.

4.2.1.4 Exceptional loads

a) Loads caused by hoisting a grounded load under exceptional circumstances;

b) loads due to out-of-service wind;

c) test loads;

d) loads due to buffer forces;

e) loads due to tilting forces;

f) loads caused by emergency cut-out;

g) loads due to dynamic cut-off by lifting force limiting device;

h) loads due to dynamic cut-off by lifting moment limiting device;

i) loads due to unintentional loss of hoist load;

j) loads caused by failure of mechanism or components;

k) loads due to external excitation of crane support;

l) loads caused by erection and dismantling.

Exceptional loads are also infrequent and are likewise usually excluded from fatigue assessment.

4.2.2 Regular loads

4.2.2.1 Hoisting and gravity effects acting on the mass of the crane

When lifting the load off the ground or when releasing the load or parts of the load, the crane structure is under effect of vibration excitation, which shall be taken into account as a load effect. The gravitational force induced by the mass of the crane or crane part shall be multiplied by the factor ϕ_1. Dependent upon the gravitational load effect of the mass and load combination in question, the factor ϕ_1 is calculated in accordance with either Formula (1) or (2). For definitions of unfavourable and favourable load effects see 4.3.3.

The gravitational load effect of the mass is unfavourable, Formula (1) applies:

$$\phi_1 = 1 + \delta \qquad \text{with } 0 \leq \delta \leq 0{,}1 \qquad (1)$$

The gravitational load effect of the mass is favourable, Formula (2) applies:

$$\phi_1 = 1 - \delta \qquad \text{with } 0 \leq \delta \leq 0{,}05 \qquad (2)$$

The maximum values of δ from the Formulae (1) and (2) shall be used unless other values are justified by measurements, calculations or obtained from the appropriate European Standard for the particular type of crane.

The mass of the crane includes those components which are always in place during operation except for the net load itself. For some cranes or applications, it may be necessary to add mass to account for accumulation of debris.

4.2.2.2 Hoisting an unrestrained grounded load

When hoisting an unrestrained grounded load, the crane is subject to dynamic effects of transferring the load off the ground onto the crane. These dynamic effects shall be taken into account by multiplying the gravitational force due to the mass of the hoist load m_H by a factor ϕ_2, see Figure 1.

The mass of the hoist load includes the masses of the payload, lifting attachments and a portion of the suspended hoist ropes or chains.

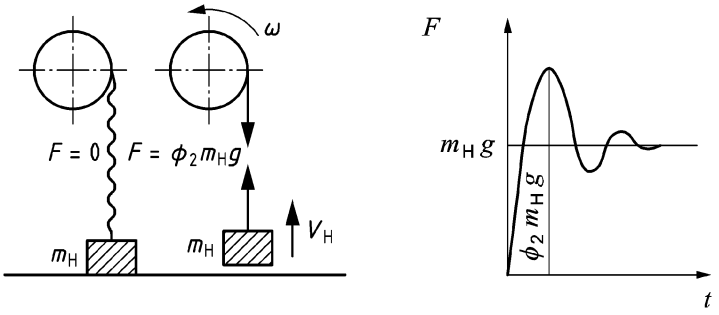


Figure 1 — Dynamic effects when hoisting a grounded load

The values of ϕ_2 and ϕ_{2C} shall be either calculated from the Formula (3) or be determined experimentally or by dynamic analysis. Where the Formula (3) is not used, the true characteristics of the drive system and the elastic properties of the overall load supporting system shall be taken into account.
The dynamic factor ϕ_2 (and respectively ϕ_{2C} for Load combination C1, see 4.2.4.1) is calculated with the Formula (3):

$$\phi_2 = \phi_{2,\text{min}} + \beta_2 \times v_h \tag{3}$$

where

β_2 is the factor dependent upon the stiffness class of the crane in accordance with the Table 2,

v_h is the characteristic hoisting speed of the load in [m/s] in accordance with the Table 3, different for calculations of ϕ_2 and ϕ_{2C},

$\phi_{2,\text{min}}$ is the minimum value of ϕ_2 and ϕ_{2C} in accordance with Table 4.

For the purposes of this standard, cranes may be assigned to stiffness classes ranging from HC1 to HC4 in accordance with the elastic properties of the crane and its support. The stiffness classes given in the Table 2 shall be selected on the basis of the characteristic vertical load displacement δ.

Table 2 — Stiffness classes

Stiffness class	Characteristic vertical load displacement δ	Factor β_2 [s/m]
HC1	0,8 m ≤ δ	0,17
HC2	0,3 m ≤ δ < 0,8 m	0,34
HC3	0,15 m ≤ δ < 0,3 m	0,51
HC4	δ < 0,15 m	0,68
The stiffness classes were called hoisting classes in the earlier versions of this standard.		

The characteristic vertical load displacement δ shall be obtained by measurement or calculated from the elasticity of the crane structure, the rope system and the crane support, using the maximum hoist load value and setting the partial safety factors and dynamic factors to 1,0. Product type crane standards may give specific guidance on selection of stiffness classes.

Where the characteristic vertical load displacement δ varies for differing crane configurations, the maximum value of *δ* may be used for the selection of the stiffness class.

For the purposes of this standard, hoist drives shall be assigned to classes HD1 to HD5 depending on the control characteristics as the weight of the load is transferred from the ground onto the crane. The hoist drive classes are specified as follows:

HD1: Creep speed is not available or the start of the drive without creep speed is possible;

HD2: Hoist drive can only start at creep speed of at least a preset duration;

HD3: Hoist drive control maintains creep speed until the load is lifted off the ground;

HD4: Step-less hoist drive control, which performs with continuously increasing speed;

HD5: Step-less hoist drive control automatically ensures that the dynamic factor ϕ_2 does not exceed $\phi_{2,\text{min}}$.

See Annex B for illustration of the types of hoist drives.

The characteristic hoisting speed v_h to be used in load combinations A, B and C is given in the Table 3.

Table 3 — Characteristic hoisting speeds v_h for calculation of ϕ_2 and ϕ_{2C}

Load combination (see 4.3.6)	Hoist drive class					Factor calculated by Formula (3)
	HD1	HD2	HD3	HD4	HD5	
A1, B1	$v_{\text{h,max}}$	$v_{\text{h,CS}}$	$v_{\text{h,CS}}$	$0,5 \cdot v_{\text{h,max}}$	$v_\text{h} = 0$	ϕ_2
C1	–	$v_{\text{h,max}}$	–	$v_{\text{h,max}}$	$0,5 \cdot v_{\text{h,max}}$	ϕ_{2C}

Key

$v_{\text{h,max}}$ for load combinations A1 and B1: the maximum steady hoisting speed of the load;

$v_{\text{h,max}}$ for load combination C1 (see 4.2.4.1): the maximum hoisting speed resulting from all drives (e.g. luffing and hoisting motion) contributing to the hoisting speed of the load;

$v_{\text{h,CS}}$ is the steady hoisting creep speed.

The minimum value $\phi_{2,\text{min}}$ depends upon the combination of the classes HC and HD and shall be selected in accordance with the Table 4.

Table 4 — Selection of $\phi_{2,\text{min}}$

Stiffness class	Hoist drive class				
	HD1	HD2	HD3	HD4	HD5
HC1	1.05	1.05	1.05	1.05	1.05
HC2	1.1	1.1	1.05	1.1	1.05
HC3	1.15	1.15	1.05	1.15	1.05
HC4	1.2	1.2	1.05	1.2	1.05

4.2.2.3 Sudden release of a part of the hoist load

For cranes that release a part of the hoist load as a normal working procedure, the peak dynamic action on the crane can be taken into account by multiplying the hoist load by the factor ϕ_3 (see Figure 2). Negative value of ϕ_3 means an uplifting force on the crane.

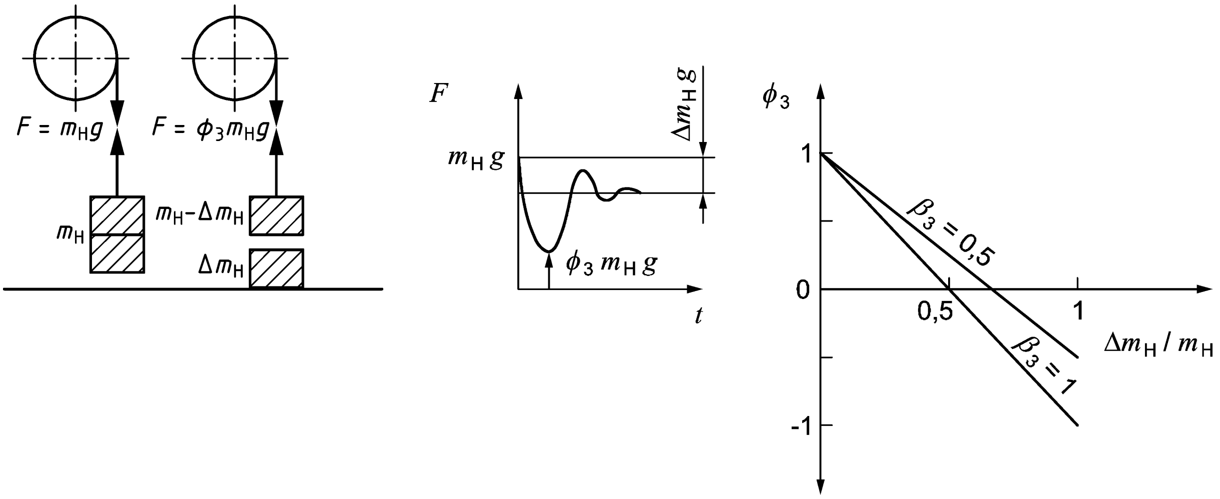


Figure 2 — Factor ϕ_3

The factor ϕ_3 shall be taken as follows:

$$\phi_3 = 1 - \frac{\Delta m_H}{m_H}\left(1 + \beta_3\right) \tag{4}$$

where

Δm_H	is the released part of the hoist load;
m_H	is the mass of the hoist load;
$\beta_3 = 0,5$	for cranes equipped with grabs or similar slow-release devices;
$\beta_3 = 1,0$	for cranes equipped with magnets or similar rapid-release devices.

4.2.2.4 Loads caused by travelling on uneven surface

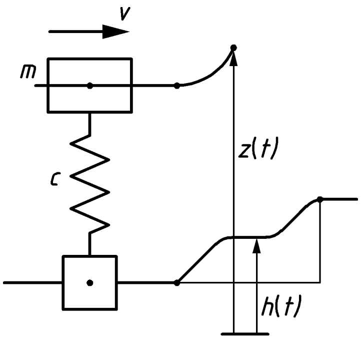
When calculating the dynamic actions on the crane by travelling, with or without load, on or off roadways or on rail tracks, the induced accelerations shall be taken into account by multiplying the gravitational forces due to the masses of the crane and hoist load by a factor ϕ_4.

The dynamic actions shall be determined in one of the following methods:

- the factor ϕ_4 is calculated using a simple single mass — spring — model for the crane as shown below. The use of this simplified model is restricted to cranes whose actual dynamic behaviour corresponds to that of the model. Where more than one natural mode contributes a significant response and/or rotation occurs, the designer may estimate the dynamic loads using an appropriate model for the circumstances.

— dynamic actions are determined by experiments or by calculation using an appropriate model for the crane or the trolley and the travel surface or the track. Conditions for the travel surface (gaps, steps) shall be specified.

— a conventional value for the factor ϕ_4 may be taken from a European Standard for the specific crane type, with specified conditions for the travel surface.



Key

m	mass of the crane and the hoist load
v	constant horizontal travelling speed of the crane
c	spring constant representing the stiffness of the crane in the vertical direction
$z(t)$	coordinate of the mass centre
$h(t)$	unevenness function describing the step or gap of the rail

Figure 3 — Single mass model of a crane for determining the factor ϕ_4

The factor ϕ_4 may be calculated as follows:

$$\phi_4 = 1 + \left(\frac{\pi}{2}\right)^2 \frac{v^2}{g\,r}\xi_s$$ for travelling over a step (see Figure 4a) (5)

$$\phi_4 = 1 + \left(\frac{\pi}{2}\right)^2 \frac{v^2}{g\,r}\xi_G$$ for travelling over a gap (see Figure 4b) (6)

where

v	is the constant horizontal travelling speed of the crane;
r	is the wheel radius;
g =	9,81 m/s^2 is the acceleration due to gravity.
$\xi_s(\alpha_s)$, $\xi_G(\alpha_G)$	are curve factors that become maximum for the time period after the wheel has passed the unevenness; they can be determined for α_s < 1,3 and α_G < 1,3 by the diagrams given in Figure 5.

where

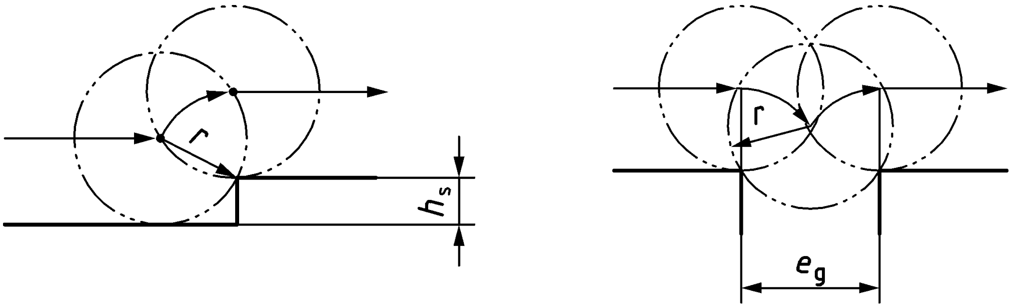
$$\alpha_s = \frac{2 f_q h_s}{v}\sqrt{\frac{2r}{h_s}}$$ (see Figure 5a);

$\alpha_G = \frac{f_q \, e_G}{v}$ (see Figure 5b);

h_s is the height of the step (see Figure 4);

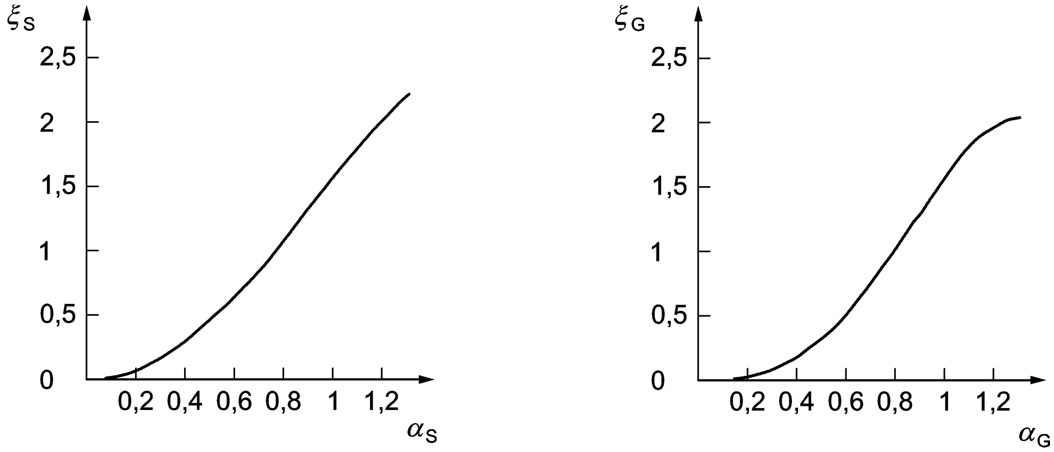
e_G is the width of the gap (see Figure 4), gaps at a plan (top view) angle of 60° or smaller in respect to the travel direction (e.g. rail joint cuts), may be neglected;

$f_q = \frac{\sqrt{c / m}}{2\pi}$ is the natural frequency of a single mass model of the crane (see Figure 3), if unknown, to be taken as 10 Hz.



a) Travelling over a step **b)Travelling over a gap**

Figure 4 — Step and gap



a) Travelling over a step **b) Travelling over a gap**

Figure 5 — Curve factors $\xi_s(\alpha_s)$ and $\xi_G(\alpha_G)$

4.2.2.5 Loads caused by acceleration of drives

Loads induced in a crane by accelerations or decelerations caused by drive forces shall be calculated. A rigid body kinetic model may be used. For this purpose, the hoist load is taken to be fixed at the top of the jib or immediately below the crab.

The load effect $\hat{S}$ shall be applied to the components exposed to the drive forces and where applicable to the crane and the hoist load as well. As a rigid body analysis does not directly reflect elastic effects, the load effect $\hat{S}$ shall be calculated by using a factor ϕ_5 as follows (see Figure 6):

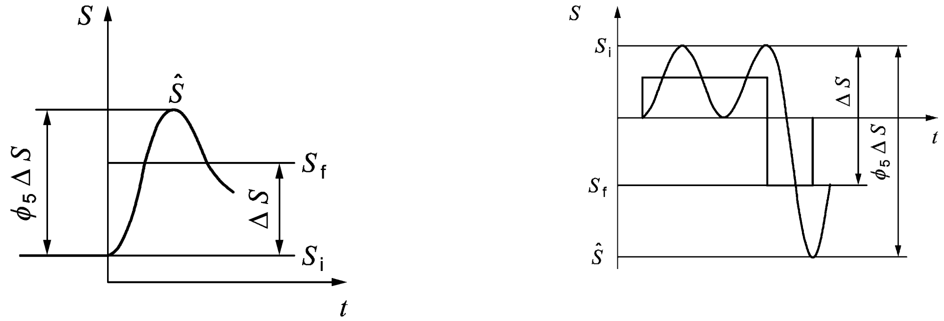
$$\hat{S} = S_\mathrm{i} + \phi_5 \Delta S \tag{7}$$

where

$\Delta S = S_\mathrm{f} - S_\mathrm{i}$ is the change of the load effect due to the change of the drive force $\Delta F = F_\mathrm{f} - F_\mathrm{i}$;

S_i, S_f are the initial (i) and final (f) load effects caused by F_i and F_f;

F_i, F_f are the initial (i) and final (f) drive forces.



a) for the change of drive forces from steady-state

b) for the positioning case

Figure 6 — Factor ϕ_5

Following values of ϕ_5 shall be applied:

$\phi_5 = 1$	for centrifugal forces;
$1 \leq \phi_5 \leq 1{,}5$	for drives with no backlash or in cases where existing backlash does not affect the dynamic forces (e.g. typical for gear boxes) and with smooth change of forces;
$1{,}5 \leq \phi_5 \leq 2$	for drives with no backlash or in cases where existing backlash does not affect the dynamic forces (e.g. typical for gear boxes) and with sudden change of forces;
$\phi_5 = 3$	for drives with considerable backlash (e.g. open gears) and when not calculated more accurately from dynamic analysis using a spring-mass model.

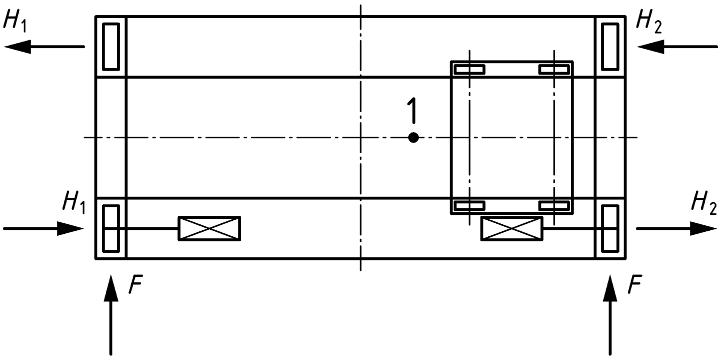
Where a force that can be transmitted is limited by friction or by the nature of the drive mechanism, the limited force and a factor ϕ_5 appropriate to that system shall be used.

Drive forces F acting on a crane or a trolley with asymmetrical mass distribution induce horizontal forces H_1 and H_2, as shown in Figure 11. Those shall be taken into account as regular loads acting on guiding means in the corners of the crane. Where a guide roller is provided, the whole horizontal force in the corner shall be applied on that. Where the guiding is by flanges of travel wheels, the horizontal forces may be distributed between the wheels in a corner as follows:

— 1 or 2 wheels per corner: force applied on the outermost wheel

— 3 or 4 wheels per corner: force distributed equally on the two outermost wheels

— More than 4 wheels per corner: force distributed equally on the three outermost wheels



Key

1 gravity centre

Figure 7 — Forces acting on rail mounted cranes or trolleys with asymmetrical mass distribution, forces due to acceleration by travel drives

4.2.2.6 Loads determined by displacements

Account shall be taken of loads arising from deformations caused by intended displacements within set limits and included in the design such as

- elastic displacements determined by skew control of the travelling movement,
- to close gaps in connections.

Other loads to be considered include those that can arise from deformations caused by unintended displacements that are within specified limits and include allowance for

- the variations in the height between rails, or the gauge,
- uneven settlement of supports.

4.2.3 Occasional loads

4.2.3.1 Loads due to in-service wind

The wind loads in respect to different design criteria are calculated as follows:

$F = q(3) \times c_{\text{a}} \times A$ Wind effect level W1, for the calculation of the structure of the crane; (8)

$F = \varepsilon_{\text{S}} \times q(3) \times c_{\text{a}} \times A$ Wind effect level W2, for the calculation of the required starting drive forces; (9)

$F = \varepsilon_{\text{M}} \times q(3) \times c_{\text{a}} \times A$ Wind effect level W3, for the calculation of power requirements of drive systems during steady movements; (10)

where

F is the wind load acting perpendicularly to the longitudinal axis of the member under consideration;

c_{a} is the aerodynamic coefficient of the member under consideration; it shall be used in combination with the characteristic area A. Values of c_{a} shall be those from Annex A or shall be those derived by recognized theoretical or experimental methods.

A is the characteristic area of the member under consideration (see Annex A);

with

$q(3) = 0{,}5 \times \rho \times v(3)^2$ is the wind pressure at $v(3)$;

$\rho = 1{,}25$ kg/m^3 is the density of the air;

$\varepsilon_S = 0{,}7$ is the factor for the Wind effect level W2;

$\varepsilon_M = 0{,}37$ is the factor for the Wind effect level W3;

$v(3) = 1{,}5 \times \bar{v}$ is the gust wind velocity averaged over a period of 3 seconds;

$\bar{v}$ is the mean wind velocity, averaged over 10 min in 10 m height above flat ground or sea level.

For the calculation of loads due to in-service wind it is assumed that the wind blows horizontally at a constant mean velocity $\bar{v}$ at all heights.

Considering a crane member, the component $\bar{v}^*$ of the wind velocity acting perpendicularly to the longitudinal axis of the crane member shall be applied; it is calculated by $\bar{v}^* = \bar{v} \times \sin \alpha_w$, where α_w is the angle between the direction of the wind velocity $\bar{v}$ and the longitudinal axis of the member under consideration.

The wind load assumed to act on the hoist load in direction of the wind velocity is determined by analogy to the wind loads assumed to act on a crane member, whereas a substitution of $\bar{v}$ by $\bar{v}^*$ shall not be applied. The factors in the given formulae for F (see above) are as follows:

F is the wind load acting on the hoist load in direction of the wind velocity;

c_a is the aerodynamic coefficient of the hoist load in direction of the wind velocity;

A_g is the projection of the hoist load on a plane normal to the direction of the wind velocity, in square metres.

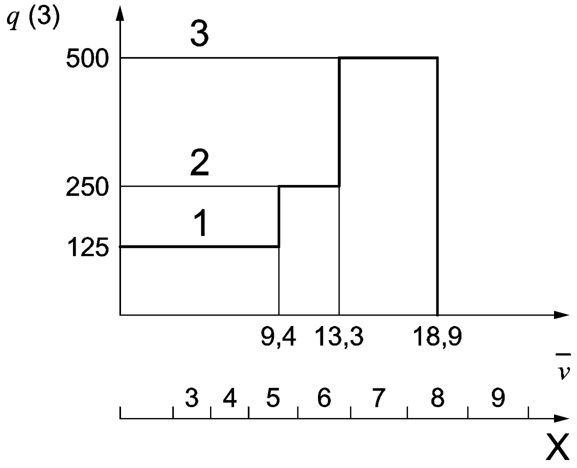
In absence of detailed information of the load it should be assumed $c_a = 2{,}4$ and $A_g = 0{,}000\,5 \times m_H$, where m_H is the mass of the hoist load in kilograms. A_g shall not be taken less than 0,8 m^2.

Depending upon the type of crane, its configuration, operation and service conditions and the specified number of out-of-service days per year, a mean wind velocity $\bar{v}$ shall be specified. Table 5 gives values of the mean velocity $\bar{v}$ for standardized wind states.

Table 5 — In-service wind states and design wind pressures

Wind State			**Design wind pressures at different Wind effect levels** [N/m^2]		
Designation	Characteristic wind speeds		W1	W2	W3
	$\bar{v}$ [m/s]	$v(3)$ [m/s]	$q(3)$	$\varepsilon_S \cdot q(3)$	$\varepsilon_M \cdot q(3)$
Light	9,4	14	125	88	46
Normal	13,3	20	250	175	92
Heavy	18,9	28	500	350	185
Other wind states may be specified for a crane. The specification shall be based on either of the characteristic wind speeds $\bar{v}$ or $v(3)$.					

The correlation of the mean wind velocity, the Beaufort scale and the in-service wind states is shown in Figure 8.



Key

X	Beaufort
1	Wind state: Light
2	Wind state: Normal
3	Wind state: Heavy

Figure 8 — Correlation of the mean wind velocity $\bar{v}$, the Beaufort scale and the in-service wind states

The design is based on the following requirement for the operation of the crane: If the wind velocity, measured at the highest point of the crane, increases and tends to reach $v(3)$, the crane shall be secured or its configuration shall be transformed into a safe configuration. As the methods and/or means for this securing are different and need different time (locking devices at special locations of the crane runway, hand-operated or automatic rail clamps) a lower level of mean wind velocity shall be chosen to start the securing. Wind velocities for the use of different crane configurations and for the starting of securing shall be specified.

Any slender structural member, when placed in a wind stream with its longitudinal axis perpendicular to this stream, may become aero-elastically unstable. Means to prevent these effects (e.g. galloping or formation of eddies) by design shall be considered both for in-service and out-of-service wind conditions.

4.2.3.2 Snow and ice loads

Where relevant, snow and ice loads shall be specified and taken into account. The increased wind exposure surfaces shall be considered.

4.2.3.3 Loads due to temperature variation

Where relevant, local temperature variation shall be specified and taken into account.

4.2.3.4 Loads caused by skewing

Skewing loads occur at the guidance means of guided wheel-mounted cranes or trolleys while they are travelling or traversing at constant speed. These loads are induced by guidance reactions which force the wheels to deviate from their free-rolling, natural travelling or traversing direction.

Skewing loads as described above are usually taken as occasional loads but their frequency of occurrence varies with the type, configuration, and accuracies of wheel axle parallelism and service of the crane or trolley. In individual cases, the frequency of occurrence will determine whether they are taken as occasional or regular loads. Guidance for estimating the magnitude of skewing loads and the category into which they are placed is given in the European Standards for specific crane types.

The lateral and tangential forces between wheels and rails as well as between guide means and guidance caused by skewing of the crane shall be calculated. A simplified mechanical model may be used, where the crane is considered to be travelling at a constant speed without anti-skewing control.

The model consists of n pairs of wheels transversally in line, of which p pairs are coupled. A coupled pair of wheels (C) is coupled mechanically or electrically. Independently supported non-driven or also — in approximation — single-driven wheels are considered as independent wheel pair (I). The latter condition is also valid in the case of independent single drives.

The wheels are arranged in ideal geometric positions in a rigid crane structure which is travelling on a rigid track. Differences in wheel diameters are neglected in this model. They are either fixed (F) or movable (M) in respect of lateral movement.

The different combinations of transversally in-line wheel pairs that are possible are shown in Figure 9.

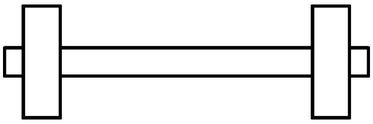
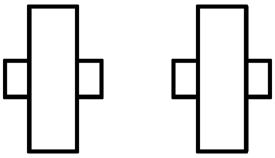
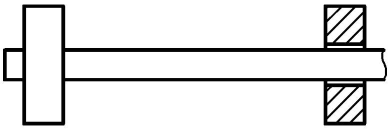
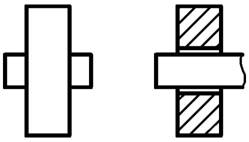
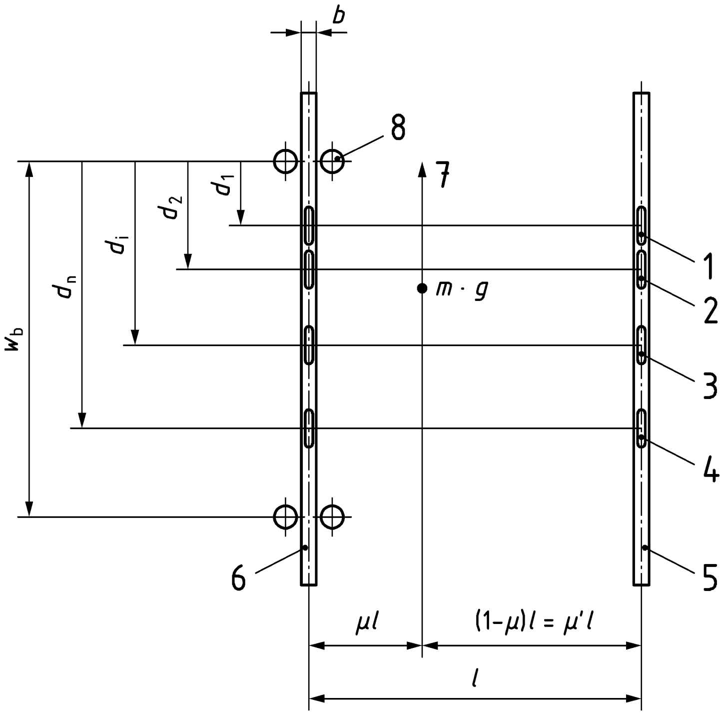
	Coupled (C)	**Independent (I)**
Fixed/Fixed (F/F)	 **CFF**	 **IFF**
Fixed/Movable (F/M)	 **CFM**	 **IFM**

Figure 9 — Different combinations of wheel pairs

The positions of the wheel pairs relative to the position of the guide means in front of the travelling crane are given by the distance d_i as shown in Figure 10. Where flanged wheels are used instead of an external guide means, it shall be set $d_1 = 0$.

It is assumed that the gravitational forces due to the masses of the loaded appliance are acting at a distance μl from rail 1 and may be distributed equally to the n wheels at each side of the crane runway.

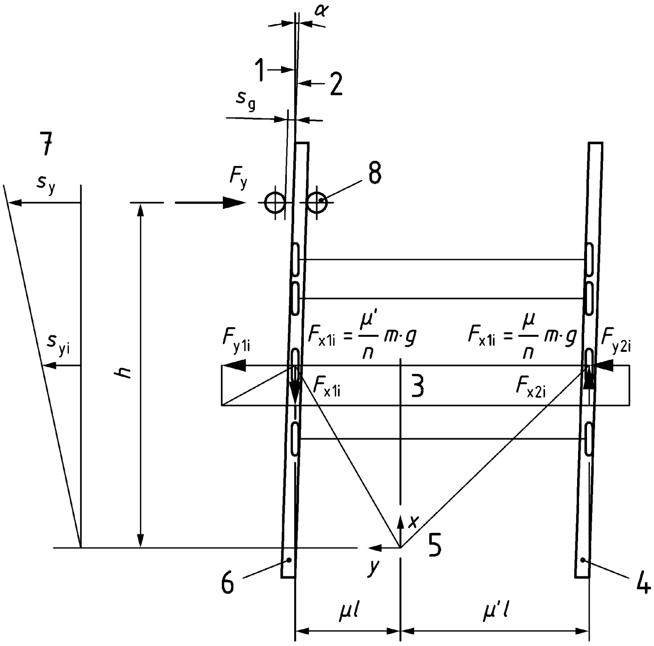


Key

1	wheel pair 1	5	rail 2
2	wheel pair 2	6	rail 1
3	wheel pair I	7	travelling direction
4	wheel pair n	8	guide means

Figure 10 — Positions of wheel pairs

The crane model is assumed to be travelling at constant speed and to have skewed to an angle α, as shown in Figure 10. The crane may be guided horizontally by external means or by wheel flanges.



Key

1	direction of motion	5	instantaneous slide pole
2	direction of rail	6	rail 1
3	wheel pair *i*	7	slip
4	rail 2	8	guide means

Figure 11 — Loads acting on crane in skewed position

A guide force F_y may be applied on the guiding means as given in 4.2.2.5.

The guide force F_y is in balance with the wheel forces F_{x1i}, F_{y1i}, F_{x2i}, F_{y2i}, which are caused by rotation of the crane about the instantaneous slide pole. With the maximum lateral slip $s_y = \alpha$ at the guide means and a linear distribution of the lateral slip s_{yi} between guide means and instantaneous slide pole, the corresponding skewing forces may be calculated as follows:

The guide force F_y is calculated by

$$F_y = \nu \times f \times m \times g \qquad (11)$$

where

$m \times g$	is the gravitational force due to the mass of the loaded crane;
$f = \mu_0 \times \left[1 - e^{(-250\alpha)}\right]$	is the friction coefficient of the rolling wheel;
μ_0 is the friction factor;	μ_0 = 0,3 for cleaned rails;
	μ_0 = 0,2 for non-cleaned rails in usual environment;
α	is the skew angle (see Figure 10), in radians;

$v = 1 - \sum d_i/nh$ for systems F/F (see Figure 9);

$v = \mu'(1 - \sum d_i/nh)$ for systems F/M (see Figure 9);

h is the distance between the instantaneous slide pole and the guide means;

$h = (p\mu\mu' l^2 + \sum d_i^2)/\sum d_i$ (for systems F/F);

$h = (p\mu l^2 + \sum d_i^2)/\sum d_i$ (for systems F/M);

n is the number of wheels at each side of the crane runway;

p is the number of pairs of coupled wheels;

l is the span of the crane (see Figure 10);

μ, μ' are parts of the span l (see Figure 10);

d_i is the distance of wheel pair i from the guide means (see Figure 10).

The skew angle α, which should not exceed 0,015 radians, shall be chosen taking into account the space between the guide means and the rail as well as reasonable dimensional variation and wear of the appliance wheels and the rails as follows:

$$\alpha = \alpha_g + \alpha_w + \alpha_t$$

where the components of the skew angle α_g, α_w and α_t are taken from Table 6.

Table 6 — Skew angle α

Skew angle resulting from		Flanged wheels	Guide rollers
α_g	Track clearance	$\alpha_g = s_{g\,min} / w_b$ when $s_g \leq \frac{4}{3} s_{g\,min}$ $\alpha_g = 0{,}75 \cdot s_g / w_b$ when $s_g > \frac{4}{3} s_{g\,min}$	
		Crane travelling	
		$s_{g\,min} = 10$ mm	$s_{g\,min} = 5$ mm
		Trolley traversing	
		$s_{g\,min} = 4$ mm	$s_{g\,min} = 2$ mm
α_t	Tolerances (wheel alignment and straightness of rail)	$\alpha_t = 0{,}001$ rad	
α_w	Wear	$\alpha_w = 0{,}1 \cdot b_h / w_b$	$\alpha_w = 0{,}03 \cdot b_h / w_b$

where

w_b is the wheel base (i.e. distance between guide rollers or between first and last wheel)

s_g is the actual track clearance of the guide means

$s_{g\,min}$ is the minimum track clearance of the guide means for the purpose of calculations

b_h is the width of rail head

The forces F_{x1i}, F_{x2i}, F_{y1i} and F_{y2i} are calculated by

$$\begin{aligned} F_{x1i} &= \xi_{1i} \times f \times m \times g \\ F_{x2i} &= \xi_{2i} \times f \times m \times g \\ F_{y1i} &= \nu_{1i} \times f \times m \times g \\ F_{y2i} &= \nu_{2i} \times f \times m \times g \end{aligned} \tag{12}$$

where ξ_{1i}, ξ_{2i}, ν_{1i} and ν_{2i} are as given in Table 7.

Table 7 — Values of ξ_{1i}, ξ_{2i}, ν_{1i} and ν_{2i}

Combinations of wheel pairs (see Figure 9)	$\xi_{1i} = \xi_{2i}$	ν_{1i}	ν_{2i}
CFF	$\mu\mu' l/nh$	$\frac{\mu'}{n}\left(1-\frac{d_i}{h}\right)$	$\frac{\mu}{n}\left(1-\frac{d_i}{h}\right)$
IFF	0		
CFM	$\mu\mu' l/nh$		0
IFM	0		

4.2.4 Exceptional loads

4.2.4.1 Loads caused by hoisting a grounded load at maximum hoisting speed

Load combination C1 is to reflect the exceptional situations when the lift is started at a speed higher than that presumed for the load combinations A1 and B1. For this case the dynamic factor ϕ_{2C} shall be calculated in accordance with 4.2.2.2.

4.2.4.2 Loads due to out-of-service wind

The out-of-service wind loads assumed to act on a member of a crane or on the hoist load remaining suspended from the crane are calculated by

$$F = q(z) \times c_a \times A \tag{13}$$

where

in case of considering a member of the crane:

F is the wind load acting perpendicularly to the longitudinal axis of the crane member;

c_a is the aerodynamic coefficient of the member under consideration; it shall be used in combination with the characteristic area A. Values of c_a shall be either those from Annex A or those derived by recognised theoretical or experimental methods;

A is the characteristic area of the member under consideration (see Annex A);

in case of considering the hoist load remaining suspended from the crane:

F is the wind load, acting on the remaining hoist load in direction of the wind velocity;

c_a is the aerodynamic coefficient of the remaining hoist load in direction of the wind velocity;

A is the projection of the remaining hoist load on a plane normal to the direction of the wind velocity.

In absence of detailed information of the load it shall be assumed

$$c_\mathrm{a} = 2{,}4$$
$$A = 0{,}000\,5 \times \eta_\mathrm{w} \times m_\mathrm{H}$$

where

A is the assumed area of the load and shall not be less than 0,8 m^2;

η_w is the factor for the remaining hoist load in out of service condition;

m_H is the mass of the hoist load in kilograms.

For the calculation of loads, it is assumed that the wind blows horizontally at a velocity increasing with the height above the surrounding ground level.

Considering a crane member, the component $v(z)^*$ of the wind velocity acting perpendicularly to the longitudinal axis of the crane member shall be applied; it is calculated by $v(z)^* = v(z) \times \sin \alpha_\mathrm{w}$, where α_w is the angle between the direction of the wind velocity $v(z)$ and the longitudinal axis of the member under consideration. Considering the hoist load remaining suspended from the crane the substitution of $v(z)$ by $v(z)^*$ shall not be applied.

The equivalent static out-of-service wind pressure $q(z)$ is calculated by

$$q(z) = 0{,}5 \times \rho \times v(z)^2 \tag{14}$$

where

ρ is the density of the air, ρ = 1,25 $\mathrm{kg/m}^3$.

The equivalent static out-of-service wind velocity $v(z)$ is calculated by

$$v(z) = f_\mathrm{rec}\left[\frac{v_\mathrm{m}(z)}{v_\mathrm{ref}} + \phi_8 \frac{v_\mathrm{g}}{v_\mathrm{ref}}\right] v_\mathrm{ref} \text{ , or the simplified form} \tag{15}$$

$$v(z) = f_\mathrm{rec}\left[(z/10)^{0{,}14} + 0{,}4\right] v_\mathrm{ref}$$

where

z	is the height above the surrounding ground level, in metres;
f_rec	is a factor depending on the recurrence interval R; for crane design in general an out-of-service wind, which may recur once in intervals of 5 years to 50 years (R = 5 to R = 50) may be selected:
f_rec = 0,815 5	for R = 5;
f_rec = 0,873 3	for R = 10;
f_rec = 0,946 3	for R = 25;
f_rec = 1,0	for R = 50;

$v_{\mathrm{m}}(z)$	is the 10 minutes mean storm wind velocity in the height z, in metres per second;
v_{ref}	is the reference storm wind velocity, in metres per second, in dependence on the different geographical regions in Europe. It is defined as the mean storm wind velocity with a recurrence interval of once in 50 years, measured at 10 m above flat open country, averaged over a period of 10 minutes;
$v_{\mathrm{m}}(z)/v_{\mathrm{ref}} = (z/10)^{0,14}$	is a simplified roughness coefficient;
$\phi_8 = 1{,}1$	is the gust response factor;
$v_{\mathrm{g}} = v_{\mathrm{ref}} \times 2 \times \sqrt{6 \times K}$	is a 3 seconds gust amplitude beyond the 10 minutes mean storm wind;
$K = 0{,}005\,5$	is the drag coefficient of the terrain.

Detailed (national) wind maps or local meteorological data should be used as sources for the reference storm wind velocities v_{ref}, e.g. EN 1991-1-4. In the absence of more precise data, a storm wind map of Europe as given in Figure 12 shall be used. This indicates the regions, where the same reference storm wind velocities are applicable. The reference storm wind velocities for these regions are given in Table 8.

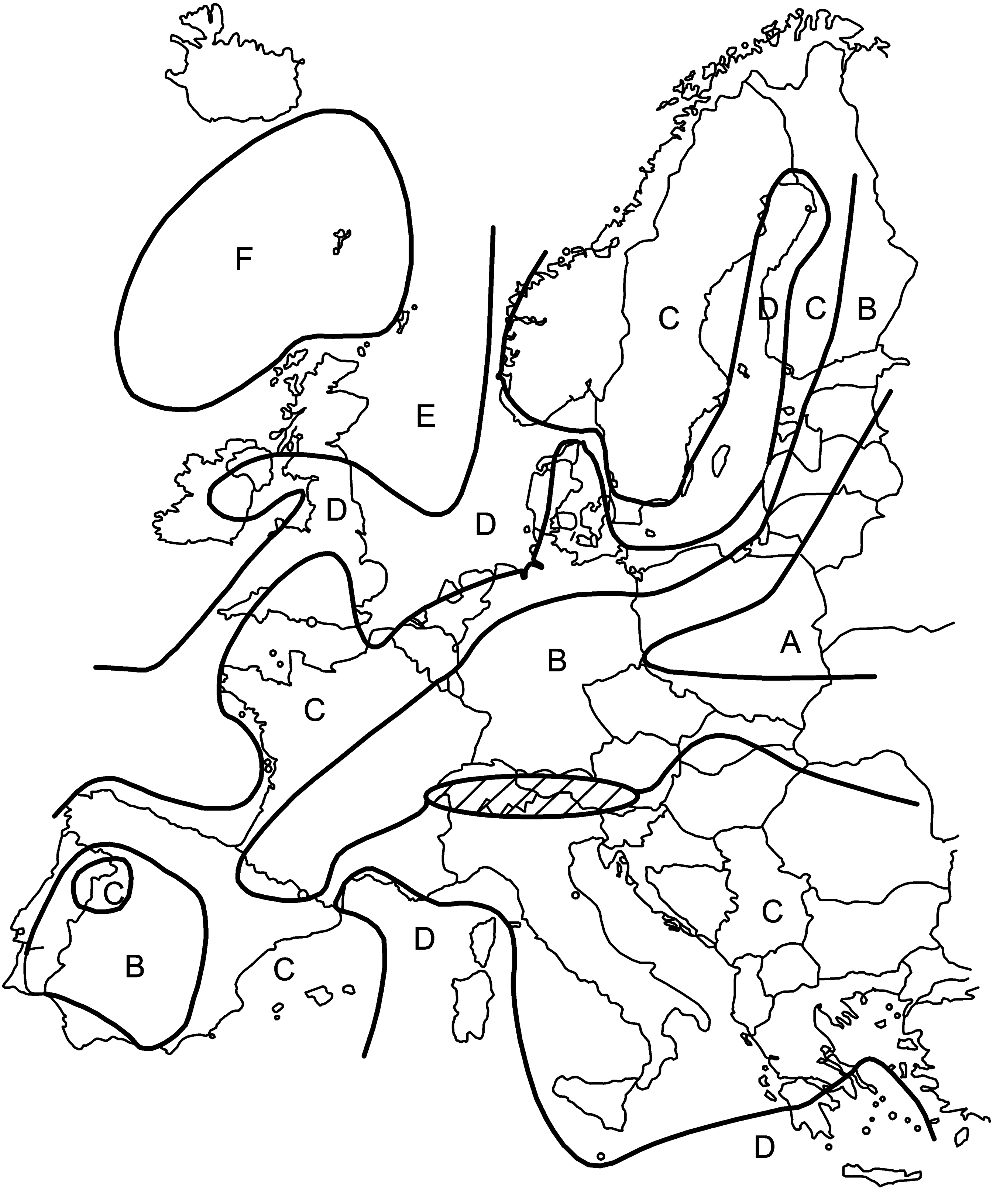


Figure 12 — Map of Europe indicating regions where the same reference storm wind velocities are applicable

Table 8 — Reference storm wind velocities in dependence on regions in Europe as shown in Figure 12

Region	A/B	C	D	E
v_{ref} [m/s]	24	28	32	36

Reference storm wind velocity shall be separately specified and applied in the design for cranes used in region F, where v_{ref} ≥ 36 m/s. Cranes likely to be used in different regions shall be designed for the conditions applicable in all of those regions.

Where cranes are installed or used for extended periods in areas, where due to the local topographical conditions the reference storm wind velocity is expected to be more severe than that given by the relevant region, the locally determined reference storm wind velocity shall be applied in the formulae given above.

4.2.4.3 Test loads

The test loads shall be applied to the crane in its service configuration. The crane system shall not be altered, e.g. by applying enlarged counterweights.

The sum of the lifted masses suspended from the crane in test load condition shall be multiplied by a factor ϕ_6. The factor ϕ_6 shall be taken as follows:

a) Dynamic test load:

The test load shall be at least 110 % of the rated capacity. The test load is moved by the drives in the way the crane will be used.

$$\phi_6 = 0,5 \times (1 + \phi_2) \tag{16}$$

where

ϕ_2 is calculated in accordance with 4.2.2.2 for the load combination A1.

b) Static test load:

The test load shall be at least 125 % of the rated capacity. The load may be increased for testing by loading the crane without the use of the drives.

ϕ_6 = 1

Where the weight of the fixed load lifting attachment is greater than 25 % of the rated capacity and not included in the rated capacity, the test load should be proportioned to the hoist load.

Other values of test loads may be given in the European Standards for specific crane types and shall be used where relevant.

In the proof calculation for test load situations a characteristic wind speed of $0,4 \times \bar{v}$ shall be taken into account, where $\bar{v}$ is the characteristic wind speed for the relevant Wind State, see Table 5.

4.2.4.4 Loads due to buffer forces

Where buffers are used, the forces arising from collision calculated by rigid body analysis shall be multiplied by a factor ϕ_7 to account for dynamic effects.

For the calculation of the factor ϕ_7, a factor ξ shall be taken as follows:

$\xi = 0{,}5$ using buffers with linear characteristics, e.g. spring buffers;

$\xi = 1{,}0$ using buffers with rectangular characteristics, e.g. hydraulic buffers.

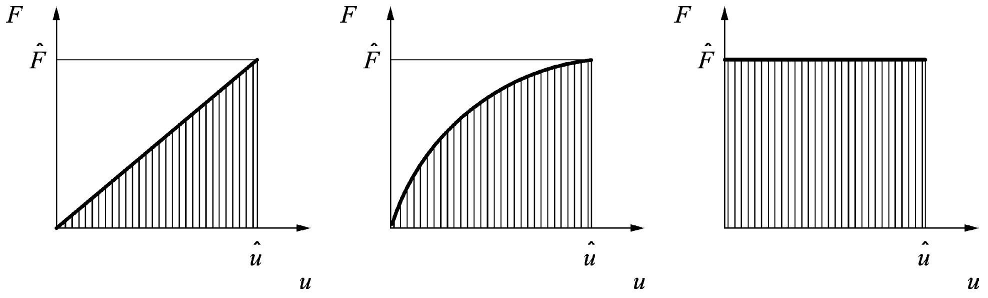
For buffers with nonlinear characteristics other values justified by calculation or by test shall be used.

Values of the factor ϕ_7 shall be calculated as follows:

$$\phi_7 = 1{,}25 \qquad \text{for } 0 \le \xi \le 0{,}5;$$

$$\phi_7 = 1{,}25 + 0{,}7(\xi - 0{,}5) \qquad \text{for } 0{,}5 \le \xi \le 1; \qquad (17)$$

with typical buffer characteristics and the corresponding values of factor ξ as illustrated in Figure 13.



a) $\xi = 0{,}5$ b) $0{,}5 < \xi < 1$ c) $\xi = 1$

Key

$\xi = \frac{1}{\hat{F} \times \hat{u}} \int_{o}^{\hat{u}} F \times \, du$	relative buffer energy;
F	buffer force;
u	buffer stroke;
$\hat{F}, \hat{u}$	maximum values.

Figure 13 — Factor ξ for different buffers characteristics

The buffer forces shall be calculated from the kinetic energy of all relevant parts of the crane. Generally speeds from 0,7 to 1 times the nominal speed should be used. Lower values than 0,7 may be used where they are justified by special measures such as the existence of a redundant control system for retarding the motion.

The buffer forces shall be calculated taking into account the distribution of relevant masses and the buffer characteristics. Where the crane or the trolley is restrained against rotation about the vertical axis (e.g. bridge crane with guide rollers on one rail) and its structure is stiff, the buffer deformations may be assumed to be equal; in that case, if the buffer characteristics are similar, the buffer forces will be equal.

In calculating buffer forces, the effects of suspended loads that are unrestrained horizontally (free to swing) need not be taken into account. However when the travel speed is reduced before collision with the buffers, it is possible that the load sway forward is near its maximum amplitude simultaneously with compression of the buffers. In this case the hoisted mass multiplied by the deceleration used before reaching the buffers should be added as a horizontal load.

4.2.4.5 Loads due to tilting forces

If a crane with horizontally restrained load (e.g. stiff masted crane or limited swing crane) or its trolley can tilt when it, its load or lifting attachment collides with an obstacle, the resulting forces shall be determined.

If a tilted crane or trolley can fall back into their normal positions uncontrolled, the resulting impact on the supporting structure shall be taken into account.

4.2.4.6 Loads caused by emergency cut-out

Loads caused by emergency cut-out shall be calculated in accordance with 4.2.2.5 taking into account the most unfavourable state of drive (i.e. the most unfavourable combination of acceleration and loading) at the time of cut-out.

4.2.4.7 Loads due to dynamic cut-off of hoisting movement by lifting force limiters

When hoisting a load, a lifting force limiting device limits the force on the crane to a level depending on type of the limiter, the drive control system and the mechanical properties of the crane. The resulting force on the crane shall be taken into account in the proof of competence calculations.

There are two different types of limiters:

1) *Directly acting lifting force (DLF) limiter*, which limits the force in the hoisting system to a specified level, e.g. a slipping clutch based on friction or a pressure limitation in a hydraulic hoisting system,

2) *Indirectly acting lifting force (ILF) limiter*, where the force on the system is measured and a second device is activated to stop the motion.

The force F_L applied to the crane, when a lifting force limiting device operates, is calculated as follows:

$$F_\mathrm{L} = \phi_\mathrm{L} \times m_\mathrm{H} \times g \tag{18}$$

where

ϕ_L is the factor for the resulting force;

m_H is the mass of the hoist load;

g is the acceleration due to gravity.

For indirectly acting lifting force limiters the F_L represents the maximum load in the hoist system after the triggering has operated and the hoist motion is brought to rest. Annex C indicates a method of calculation for the factor ϕ_L for indirectly acting lifting force limiters.

For any crane and application with an indirectly acting lifting force limiter, the value of the factor ϕ_L shall not be less than ϕ_L = 1,25. For any crane and application with a directly acting lifting force limiter, the value of the factor ϕ_L shall not be less than ϕ_L = 1,4.

Where due to nature of the application or the construction of the load lifting attachment it is foreseeable, that jamming of the load can occur, this shall be taken into account in the calculation of the force F_L. Such applications can be e.g.

- unloading of containers from ships,
- all load handling operations, where the load lifting attachment is capable of taking loads greater than the rated load of the crane, e.g. scrap metal handling or load lifting attachments relying on magnets.

4.2.4.8 Loads due to dynamic cut-off of radial movement by lifting moment limiter

The lifting moment limiter stops the radial movement of the load, when this passes beyond the lifting radius that corresponds to the rated moment. The radial over travel, by which the load exceeds the limit radius, depends upon the characteristics of the radius control of the luffing movement, the braking arrangement and the delays in the braking system.

The load actions due to exceeding the limit radius shall be taken into account in the proof of competence calculations. The loadings caused both by the handled load and by the dead weight of radially moving parts of the crane, shall be taken into account.

The over travel of the load shall either be taken from a specified tolerance of the lifting moment limiter or be calculated as follows:

$$\Delta R = v_{\mathrm{R}} \times (t_{\mathrm{ML}} + t_{\mathrm{br}} + \frac{t_{\mathrm{st}}}{2}) \qquad (19)$$

where

ΔR is the radial over travel of the load;

v_{R} is the radial speed of the load;

t_{ML} is the response time of the lifting moment limiter;

t_{br} is the reaction time of the break system;

t_{st} is the stopping time of the break system.

In the calculation the load may be assumed be located at the triggering point and the load and dead weight moment may be calculated at that position, multiplied by a factor ϕ_{ML} that covers the effect of the over travel:

$$\phi_{\mathrm{ML}} = 1 + \frac{\Delta M}{M_0} + \frac{\Delta R}{R_0} \qquad (20)$$

where

ΔM is the tolerance of the triggering moment;

M_0 is the rated moment at the triggering point;

R_0 is the load radius at the triggering point.

4.2.4.9 Unintentional loss of hoist load

The effects of unintentional loss of the hoist load shall be taken into account, especially on subsequent crane stability issues and strength issues such as jib or whole crane structure springing back, jib whipping backwards and colliding with crane structure, jib falling back into normal position or reversal of loads in components designed as unidirectional (e.g. hydraulic cylinders, tension ties).

In cases where dynamic analysis is not done, the effect of unintentional loss of hoist load may be calculated by applying a dynamic factor $\phi_9 = -0{,}3$ on the hoist load.

4.2.4.10 Loads caused by apprehended failure of mechanism or components

This load action shall be applied, where mechanisms or components are duplicated or secured by other means for safety reasons.

A failure shall be assumed to occur in any part of either system. Where protection is provided by back-up brake in addition to service brakes, failure in service brake system and back-up brake activation shall be assumed to occur under the most unfavourable condition.

Resulting loads due to failures mentioned above shall be calculated in accordance with 4.2.2.5, taking into account any resulting impacts.

Duplicated components of hoisting mechanism shall be calculated for two conditions as follows:

- Regular loading condition, where all the components of the mechanism operate as a whole sharing the hoisted load. This shall be assigned to Load Combination A and used in the proof of fatigue and static strength.
- Exceptional loading, taking into account a failure of any single component of the mechanism. The loading on the remaining part of the mechanism during the failure incident shall be assigned to Load Combination C and used in the proof of static strength of the remaining part. Dynamic impact factor ϕ_5 due to a failure may be determined by dynamic analysis or otherwise ϕ_5 shall be taken equal to 1,5. The factor shall be applied on the total load carried by the effective system remaining after the failure.

4.2.4.11 Loads due to external excitation of the crane support

Where relevant, loads caused by external excitation of the crane support, e.g. seismic or wave induced movements, shall be specified and taken into account in load combination C10.

4.2.4.12 Loads caused by erection, dismantling and transport

Depending on the crane type it may be necessary to take into account the loads caused by erection, dismantling and transport, including specified wind loads during these processes.

In some cases these loads could be occasional.

4.2.4.13 Loads on means provided for access

Loads acting on means provided for access are considered to be local, acting only on the facilities themselves and on their immediate supporting members. The partial safety γ_p shall be set to 1,22. The following perpendicular loads shall be taken into account:

- 3 000 N where materials can be deposited;
- 1 500 N on means provided for access only;
- 300 N horizontally on handrails at least, depending on location and use.

For more detailed information see ISO 11660-1.

4.3 Load combinations

4.3.1 General

In accordance with the Limit State Method (see EN 13001-1) the individual load actions shall be multiplied with partial safety factors and superimposed in accordance with specified load combinations and only thereafter applied into the proof calculations. The partial safety factors and the sets of load combinations (A, B and C) are given in Tables 9 to 12.

Load combinations A cover regular loads under normal operations, load combinations B cover regular loads combined with occasional loads and load combinations C cover a selection of regular loads combined with occasional and exceptional loads.

Safety factors given in this standard have been determined by experience and by taking into account the variations of the particular loads or the loading in general. They are only valid in connection with the limit state method in accordance with EN 13001-1. For specific crane systems, the Allowable Stress Method with global safety factors may be used (see EN 13001-1).

4.3.2 High risk situations

In some applications or crane configurations, where the human or economic consequences of failure are exceptionally severe (for example handling of hot molten metal, cranes in nuclear applications or lifting of the boom of a ship unloader), increased safety is necessary. Application of an additional risk coefficient to the design loads is one of the methods to achieve it.

In cases where a risk coefficient is used, it shall be applied to load actions f_i in accordance with Formula (21), together with the partial safety factors relevant to the load action and load combination in question, see the flow chart for the limit state method in EN 13001-1.

$$f_{\mathrm{d,i}} = \gamma_{\mathrm{n}} \times \gamma_{\mathrm{p,i}} \times f_{\mathrm{i}} \tag{21}$$

where

$f_{\mathrm{d,i}}$ is the design value of a load action i, with the risk coefficient included;

f_{i} is the characteristic value of a load action i, with ϕ-factors applied in accordance with this standard;

γ_{n} is the risk coefficient, with a value within the range from 1,0 to 2,0. Guidance is given in Annex D. European product type or application specific standards may give values of risk coefficients;

$\gamma_{\mathrm{p,i}}$ is the partial safety factor relevant for load action i and the load combination in question.

For the application of the risk coefficient with the allowable stress method, see the relevant flow chart in EN 13001-1.

The same value of risk coefficient shall be used for the proof of competence in all relevant load combinations A, B and C.

A risk coefficient may be specified for a part of the crane only, e.g. individually for a structural member or a mechanism of the crane.

Risk coefficients need not to be applied for components in a single failure proof system, see 3.1.2. Similarly, risk coefficients need not to be applied to components, which are safeguarded against risk of failure by another component.

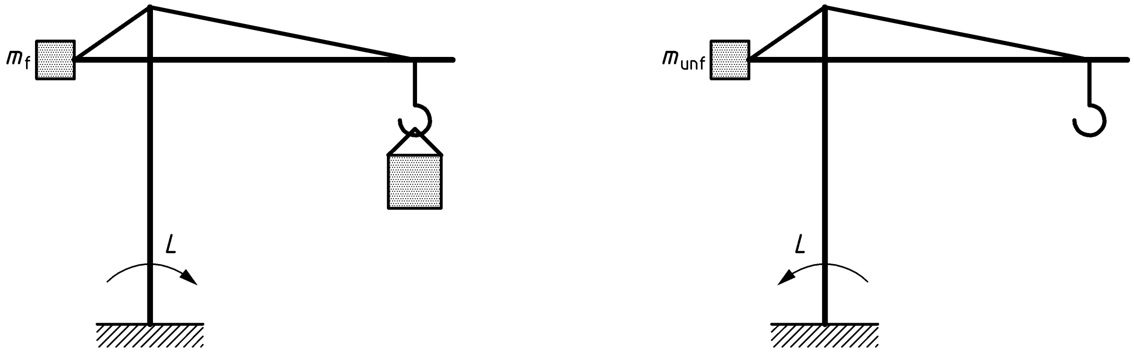
Application of risk coefficients for the proof of crane stability is given in 4.3.7.

4.3.3 Favourable and unfavourable masses

When calculating the loads from gravitation for a given load combination and crane configuration, the masses of the different parts of the crane either increase (“unfavourable”) or decrease the resulting load effect (“favourable”) in the critical point under consideration.

The same mass may be favourable in some configurations and unfavourable in other configurations or favourable for one resulting load effect and unfavourable for another load effect. Figure 14 illustrates such an example for a tower crane: with respect to the bending moment L in the tower, the mass of the counter weight acts favourably when a hoist load is applied, and the mass acts unfavourably when a hoist load is not applied.

With respect to the compression force in the tower the mass of the counter weight acts unfavourably in both cases. The decision, whether the mass is favourable or unfavourable shall, however, be based upon, which of the load effects (bending moment or compression force) is governing in respect of design stresses or forces.



a) mass of counterweight is favourable **b) mass of counterweight is unfavourable**

Figure 14 — Illustration of favourable and unfavourable masses

4.3.4 Partial safety factors for the mass of the crane

The partial safety factors γ_p shall be chosen from Table 9 depending on the method of determining the masses of the crane parts and depending on the type of the load effect.

A part of a crane, (e.g. total length of girder of an unloader, slewing upper structure of a tower crane) having both favourable and unfavourable masses, may be assigned only one partial safety factor in each load combination, related to the centre of gravity of this part.

Table 9 — Values of factor γ_p for the mass of the crane

Masses of crane parts and their centres of gravity	**Load combinations in accordance with 4.3.6**					
	A		**B**		**C**	
	unfavourable	**favourable**	**unfavourable**	**favourable**	**unfavourable**	**favourable**
obtained by calculation	1,22	0,95	1,16	0,97	1,10	1,00
obtained by weighing	1,16	1,00	1,10	1,00	1,05	1,00
in Special Condition	1,16	1,10	1,10	1,05	1,05	1,00

The factors for the Special Condition may be applied under the following two conditions:

a) masses of crane parts and their centres of gravity are determined by weighing with an accuracy of ± 2,5 %;

b) ratio between the sum load effect due to favourable masses of crane parts to the sum effect of unfavourable masses of crane parts plus hoist load shall be less than 0,6 (see the formula below). Un-factored values of loads and masses shall be used.

$$\left| \frac{L_\mathrm{f}}{L_\mathrm{unf} + L_\mathrm{h}} \right| < 0{,}6 \qquad (22)$$

where

L_f	is the load effect of favourable masses of crane parts;
L_unf	is the load effect of unfavourable masses of crane parts;
L_h	is the load effect of the hoist load.

In general, partial safety factors for favourable masses should not be greater than 1. An exception is provided in the Special Condition where the calculated resulting load effect would be excessive e.g. such as moment calculations for cranes with large counter balance weights. Since the value of the partial safety factor for the unfavourable masses should not be reduced, the partial safety factors for the favourable masses have been allowed an artificial increase above 1,0.

4.3.5 Partial safety factors to be applied to loads determined by displacements

For those parts of a crane, where intended displacements are induced to affect resulting load effects (see 4.2.2.6), upper and lower values of partial safety factors as given in Table 10 shall be taken into account to reflect deviations of the displacements.

Table 10 — Values of the partial safety factors to be applied to loads due to intended displacements

Values of partial safety factor γ_p	Load combinations in accordance with 4.3.6		
	A	B	C
unfavourable load effects	1,10	1,05	1,00
favourable load effects	0,90	0,95	1,00

Any unintended, but reasonably foreseeable elastic or rigid body displacement acting in any direction, which affect significantly the resulting load effects in a crane shall be considered as a load action and shall be amplified with the partial safety factors given in Table 11.

In general the direction of an unintended displacement can vary and therefore all directions should be considered.

Table 11 — Values of the partial safety factors to be applied to loads due to unintended displacements

	Load combinations in accordance with 4.3.6		
	A	B	C
γ_p	1,10	1,05	1,00

4.3.6 Load combinations for the proof of competence

Table 12 gives load combinations A, B and C and the partial safety factors that shall be used, where applicable, for the proof of competence of the crane.

There may exist in special applications or crane configurations other relevant load combinations additional to those given in Table 12. Such load combinations shall be assigned to one of the Load Combinations A, B or C based on their frequency of occurrence and shall be applied further in line with this standard.

The proof of competence for fatigue strength shall be done by applying the Load Combinations A, with all partial safety factors γ_{p} set to 1,0 but applying the ϕ-factors in accordance with this standard.

In some cases where a load usually being occasional or exceptional occurs frequently enough, this load shall be included into the fatigue assessment. Such a load combination shall be handled in the same way as the Load Combinations A for the regular loads.

Table 12a — Loads, load combinations and partial safety factors

Categories of loads	Loads f_i		Ref.	Load combinations A					Load combinations B						Load combinations C											
				Factor γ_p	A1	A2	A3	A4	Factor γ_p	B1	B2	B3	B4	B5	Factor γ_p	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Regular	Gravitation acceleration and impact actions	Mass of the crane	4.2.2.1	*)	ϕ_1	ϕ_1	1	–	*)	ϕ_1	ϕ_1	1	–	–	*)	ϕ_1	1	ϕ_1	1	1	1	1	1	1	1	1
		Mass of the hoist load	4.2.2.2	1,34	ϕ_2	ϕ_3	1	–	1,22	ϕ_2	ϕ_3	1	–	–	1,1	ϕ_{2C}	η_W	–	1	1	1	ϕ_L	ϕ_9	1	1	–
		Travelling on uneven surface	4.2.2.4	1,22	–	–	–	ϕ_4	1,16	–	–	–	ϕ_4	ϕ_4	–	–	–	–	–	–	–	–	–	–	–	–
	Acceleration actions from drives	Hoisting movements excluded	4.2.2.5	1,34	ϕ_5	ϕ_5	–	ϕ_5	1,22	ϕ_5	ϕ_5	–	ϕ_5	–	1,1	–	–	ϕ_5	–	–	–	–	–	–	–	–
		All movements			–	–	ϕ_5	–		–	–	ϕ_5	–	–		–	–	–	–	–	–	–	–	–	–	–
	Displacements		4.2.2.6	**)	1	1	1	1	**)	1	1	1	1	1	**)	1	1	1	1	1	1	1	1	1	1	1
Occasional	Environmental effects	In-service wind loads	4.2.3.1	–	–	–	–	–	1,22	1	1	1	1	1	1,16	–	–	1	–	–	–	–	–	–	–	1
		Snow and ice loads	4.2.3.2	–	–	–	–	–	1,22	1	1	1	1	1	1,1	–	1	–	–	–	–	–	–	–	–	–
		Temperature variations	4.2.3.3	–	–	–	–	–	1,16	1	1	1	1	1	1,05	–	1	–	–	–	–	–	–	–	–	–
	Skewing		4.2.3.4	–	–	–	–	–	1,16	–	–	–	–	1	–	–	–	–	–	–	–		–	–	–	–
Exceptional	Out-of-service wind loads		4.2.4.2	–	–	–	–	–	–	–	–	–	–	–	1,1	–	1	–	–	–	–	–	–	–	–	–
	Test loads		4.2.4.3	–	–	–	–	–	–	–	–	–	–	–	1,1	–	–	ϕ_6	–	–	–	–	–	–	–	–
	Buffer forces		4.2.4.4	–	–	–	–	–	–	–	–	–	–	–	1,1	–	–	–	ϕ_7	–	–	–	–	–	–	–
	Tilting forces		4.2.4.5	–	–	–	–	–	–	–	–	–	–	–	1,1	–	–	–	–	1	–	–	–	–	–	–
	Drive forces due to E-stop		4.2.4.6	–	–	–	–	–	–	–	–	–	–	–	1,1	–	–	–	–	–	ϕ_5	–	–	–	–	–
	Drive forces due to failure of mechanism		4.2.4.10	–	–	–	–	–	–	–	–	–	–	–	1,1	–	–	–	–	–	–	–	–	ϕ_5	–	–
	Excitation of the crane support		4.2.4.11	–	–	–	–	–	–	–	–	–	–	–	1,1	–	–	–	–	–	–	–	–	–	1	–
Overall safety factor γ_f, only for "Allowable stress method"				–	1,48				–	1,34					–	1,22										
Resistance coefficient γ_m				1,1	–				1,1	–					1,1	–										
*)	The partial safety factors shall be taken in accordance with Table 9, with due consideration to variable factors shown in the table																									
**)	The partial safety factors to be applied to loads due to displacements shall be taken in accordance with 4.3.5.																									

Table 12b — Loads, load combinations and partial safety factors

Load Combination	Clause reference	Description
A1	4.2.2.2	Hoisting and moving loads; Accelerations of those movements only, which occur regularly with hoisting movement, are to be taken into account
A2	4.2.2.3	Sudden release of part of the hoist load; Effects from other movements than hoisting are combined as in A1.
A3	4.2.2.5	Load or lifting attachment suspended; With a suspended load or lifting attachment, any combination of accelerating or decelerating forces caused by any of the drives, including the hoist drive, or of their sequence during positioning movements, shall be taken into account in accordance with the intended normal operation as well as the control of the drives.
A4	4.2.2.4	Travelling with load on an uneven surface or track, without the effects from hoisting movement;
B1 to B4	4.2.3.1	Equivalent to A1 to A4 but with the addition of in-service wind and loads from other environmental actions taken into account;
B5	4.2.3.4	Crane under normal operation, travelling on an uneven surface at constant speed and skewing, with in-service wind and loads from other environmental actions.
C1	4.2.4.1	Crane under in-service conditions, hoisting a grounded load at exceptional hoisting speed, applying ϕ_{2C},see Table 3
C2	4.2.4.2	Crane under out-of-service conditions, including out-of-service wind and loads from other environmental actions.
C3	4.2.4.3	Crane under test conditions; Effects from different movements are combined as relevant for the testing procedure; wind load as specified in 4.2.4.3 for test conditions.
C4	4.2.4.4	Crane with hoist load in combination with buffer forces.
C5	4.2.4.5	Crane with hoist load in combination with tilting forces.
C6	4.2.4.6	Crane with hoist load in combination with loads caused by emergency cut-out. Value of factor ϕ_5 shall be that relevant for the emergency cut-out situation.
C7	4.2.4.7 4.2.4.8	Loads due to operation of the overload protection; Loads in accordance with 4.2.4.7 and 4.2.4.8 shall be taken into account separately and where relevant. In case of crane stability only loads in accordance with 4.2.4.8 shall be taken into account.
C8	4.2.4.9	Crane with unintentional loss of hoist load.
C9	4.2.4.10	Crane with hoist load in combination with loads caused by failure of mechanism.
C10	4.2.4.11	Crane with hoist load in combination with loads due to external excitation of the crane support.
C11	4.2.4.12	Crane during erection, dismantling and transport.

4.3.7 The proof of crane stability

A crane standing on three or more supports is considered to be stable when, due to the specified loads and factors, the stabilising moment is greater than the overturning moment about any tipping line. Supports may lift up, as long as the remaining supported structure does not become statically indeterminate. Tipping line is a line passing through two adjacent, effective support points of the crane.

The proof of crane stability refers to the risk of overturning and shall be proven by design calculations as specified in this standard or by testing, where such method is specified in a relevant European product type crane standard. Testing method used shall be such that the result has at least the same safety level as the calculation method specified herein. The proof shall take into account deflections of the crane structure under the specified loads as well as the displacements of the load.

The ground supports are presumed to be capable of withstanding the supporting forces without exceeding the specified limits of displacements. This shall also include the case, when supports become unloaded and an increased load occurs at the remaining supports.

The partial safety factors and load combinations for the proof of crane stability shall be taken from Table 13. For a crane part extending across the tipping line it is not acceptable to treat its mass as a single mass; the two portions of the mass on either side of the tipping line shall be considered separately, with each portion treated as unfavourable or favourable, depending on whether it increases or reduces the overturning moment, respectively (in line with 4.3.3).

In all load combinations the dynamic factors ϕ_i not shown in Table 13 are set to 1,0. The factor ϕ_3 shall be calculated in accordance with 4.2.2.3. The factor shall be set to −0,1, when the calculated value of ϕ_3 is mathematically greater than −0,1.

The risk coefficient specified for the whole crane shall be applied also to the proof of crane stability unless a separate risk coefficient has been specified for such proof. The risk coefficient shall not be applied to the load actions f_i due to favourable masses.

A basic configuration for cranes with legs assumes a fixed legged crane standing on four or more legs. For other crane configurations with legs solely, partial safety factors γ_p given in Table 13 shall be multiplied by a factor γ_s:

- cranes supported on three corners, $\gamma_s = 1,10$;
- cranes supported by a hinged leg in one or more of the corners and with a risk of a hinged leg corner lifting up, $\gamma_s = 1,10$;
- cranes supported by a hinged leg in one or more of the corners and with a risk of a fixed leg corner lifting up, $\gamma_s = 1,22$.

Table 13 — Load combinations and partial safety factors for the proof of crane stability

Categories of loads	Loads f_i		Load comb. A			Load comb. B		Load combinations C									
			Factor γ_p	A1	A2	Factor γ_p	B1	Factor γ_p	C2	C3	C4	C6	C7	C8	C9	C10	C11
Regular	Unfavourable dead weight effects	Weight determined by calculation	1,16	1	1	1,1	1	1,05	1	1	1	1	1	1	1	1	1
		Weight determined by weighing (**)	1,1	1	1	1,05	1	1,0									
	Favourable dead weight effects		1,0	1	1	1,0	1	1,0	1	1	1	1	1	1	1	1	1
	Mass of the hoist load		1,22	1	ϕ_3	1,16	1	1,1	–	–	1 (*)	1	ϕ_{ML}	ϕ_9	1	1	–
	Acceleration actions from drives, all movements taken into account		1,22	1	1	1,16	1	1,1	–	1	–	–	–	–	–	–	–
	Displacements		1,1	1	1	1,05	1	1,0	1	1	1	1	1	1	1	1	1
Occasional	Environmental actions	In-service wind loads	–	–	–	1,16	1	1,1	–	1	–	–	–	–	–	–	1
		Snow and ice loads	–	–	–	1,16	1	–	–	–	–	–	–	–	–	–	–
Exceptional	Out-of-service wind loads		–	–	–	–	–	1,1	1	–	–	–	–	–	–	–	–
	Test loads		–	–	–	–	–	1,1	–	1	–	–	–	–	–	–	–
	Buffer forces		–	–	–	–	–	1,1	–	–	1	–	–	–	–	–	–
	Drive forces due to E-stop		–	–	–	–	–	1,1	–	–	–	1	–	–	–	–	–
	Forces due to failure of mechanism		–	–	–	–	–	1,1	–	–	–	–	–	–	1	–	–
	Excitation of the crane support		–	–	–	–	–	1,1	–	–	–	–	–	–	–	1	–

Descriptions of load combinations (A1, A2, B1, C2 to C11) are in accordance with Table 12.

(*) Only to be applied if unfavourable.

(**) Relevant masses and their centres of gravity shall be evaluated by weighing with an accuracy of ± 2,5 %.

Annex A

(informative)

Aerodynamic coefficients

A.1 General

The aerodynamic coefficient c_a of a member is given by

$$c_a = c_o \times \psi \tag{A.1}$$

where

c_o is the aerodynamic coefficient of a member of infinite length, where the member is a straight and prismatic element; such a member with one or more solid sections or one hollow section is called an individual member; plane or spatial lattice structure members may be assembled by those individual members;

ψ is a reduction factor, which reduces c_o for members with a finite length; it depends on the aerodynamic slenderness ratio λ of an individual member and if the member is a lattice structure it also depends on the solidity ratio φ. The factor ψ is taken from Figure A.1. For values λ > 200, the factor is set to ψ = 1.

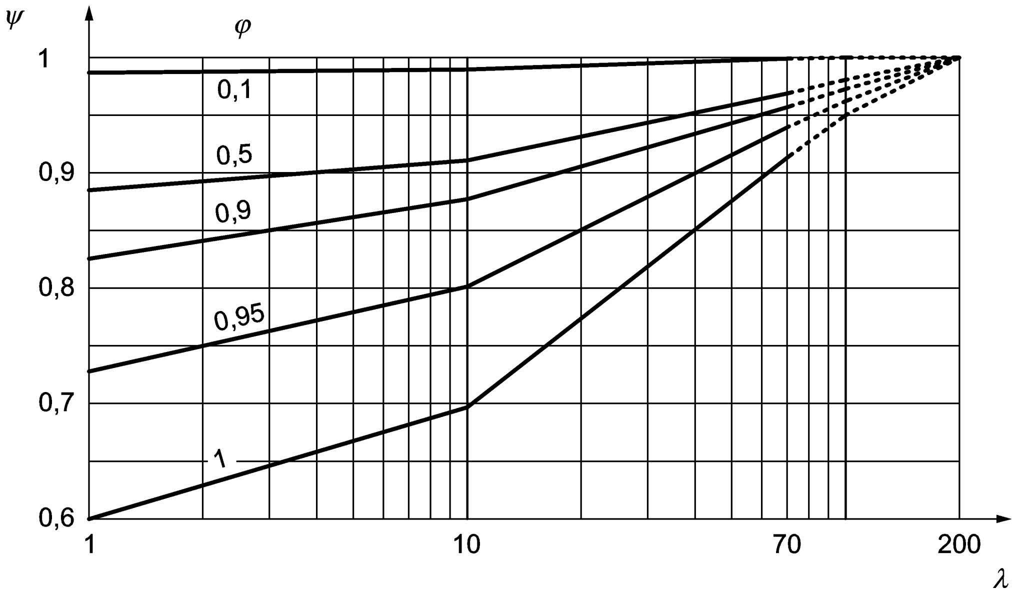


Figure A.1 — Reduction factor ψ related to the aerodynamic slenderness ratio λ and the solidity ratio φ

The aerodynamic slenderness ratio λ is defined as follows

$$\lambda = l_a / d \tag{A.2}$$

where

d is the characteristic dimension of a member as shown in the respective tables of members in this annex;

$l_a = \alpha_r \times l_o$ is the aerodynamic length of a member;

where

l_o is the length of the member;

i.e. the distance between the free ends of the member or, in case the member is connected to other members, the distance between the centers of their joints;

α_r is the relative aerodynamic length, which in relation to the position of the member and a possibly adjacent obstacle is given in Table A.1.

The solidity ratio φ of a plane lattice structure member is established as follows

$$\varphi = \sum_j A_j / A_c \tag{A.3}$$

where

$\sum_j A_j$ is the sum of the areas of the individual members with gusset plates projected to the plane of the characteristic height d of the lattice structure member (see Figure A.2);

A_c is the area enclosed by the boundary of the lattice structure member in the plane of its characteristic height d (see Figure A.2).

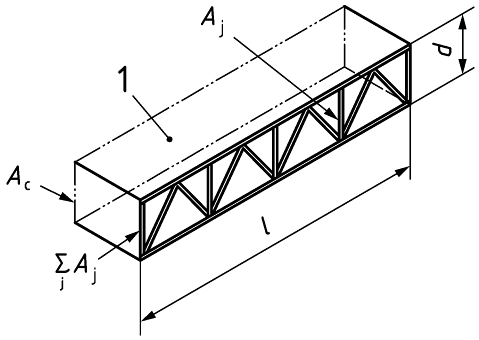
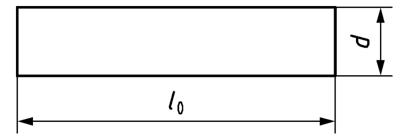
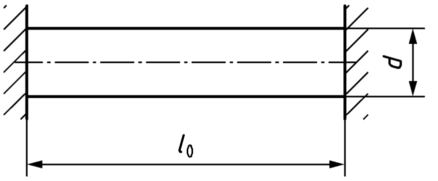
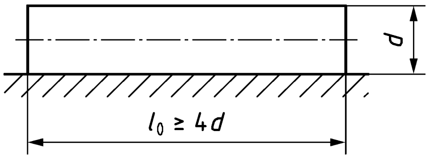
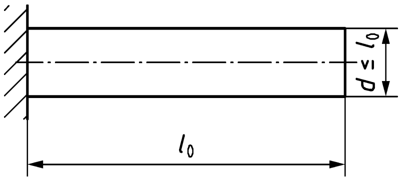
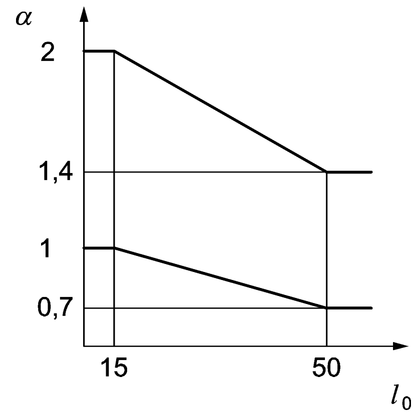
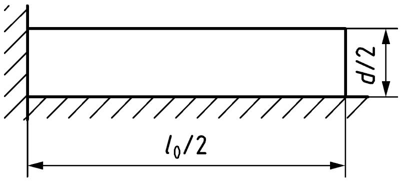
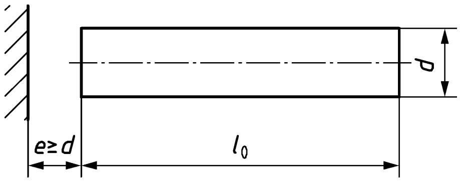
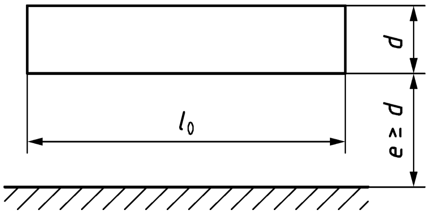


Figure A.2 — Example of a lattice structure member

Table A.1 — Relative aerodynamic length α_r

Position of member and obstacle in wind direction		α_r
1		1
2		∞ ($\psi = 1$)
3		1
4		a) Non-circular members $\alpha_r = 2{,}0$, $l_o \leq 15$ m } $\lambda \leq 70$ $\alpha_r = 1{,}4$, $l_o \geq 50$ m b) Circular members $\alpha_r = 1{,}0$, $l_o \leq 15$ m } $\lambda \leq 70$ $\alpha_r = 0{,}7$, $l_o \geq 50$ m (α_r for 15 m $\leq l_o \leq$ 50 m by linear interpolation) 
5		
6		
7		

Some aerodynamic coefficients of individual members and of lattice structure members are given in dependence on the Reynolds number Re which is established as follows

$$\mathrm{Re} = 0{,}667 \times 10^5 \times v \times d \qquad \text{(A.4)}$$

where

d is the characteristic dimension of a member in meter;

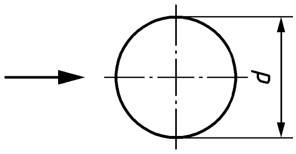
v is the wind velocity in meter per second; considering loads due to in-service wind v shall be substituted by $\bar{v}$ or $v(3)$ (see 4.2.3.1); considering loads due to out-of-service wind v shall be substituted by $v(z)$, see 4.2.4.2.

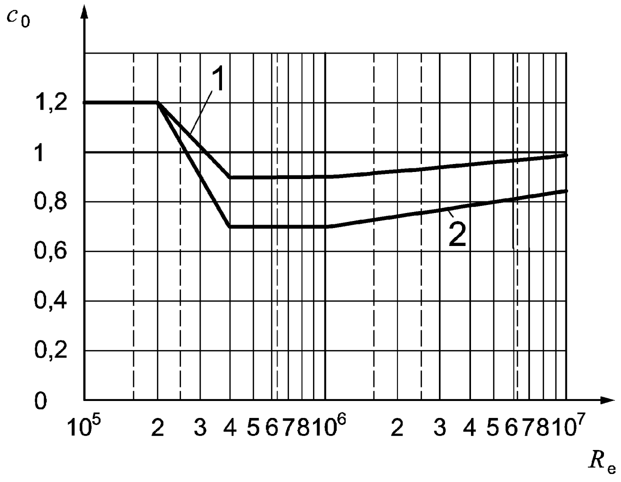
A.2 Individual members

In this clause the following Tables and Figures are given

- Table A.2: Aerodynamic coefficients c_o for individual members of circular sections;
- Figure A.3: More detailed aerodynamic coefficients c_o for individual members of circular sections related to Re;
- Figure A.4: Definition of the angle β of the wind direction and corresponding wind forces;
- Table A.3: Aerodynamic coefficients c_oy, c_oz for individual flat sided structural member;
- Table A.4: Aerodynamic coefficients c_o for individual structural members of triangular and rectangular hollow sections.

Table A.2 — Aerodynamic coefficients c_o for individual members of circular sections

No.	Shape and position of the member			Characteristic area A	c_o
	Member	Aerodynamic slenderness ratio	Wind direction β		
1		$l / d \leq \infty$	Perpendicular to axis of member	$d \cdot l$	$c_o = 1{,}20$ more accurately c_o is according to Figure A.3
2	Pipes, rods	$l / d > 100$	Perpendicular to axis of member	$d \cdot l$	$\text{Re} \leq 2 \times 10^5$ $c_o = 1{,}20$
					$4 \times 10^5 \leq \text{Re} \leq 10^6$ $c_o = 0{,}70$
					$\text{Re} > 10^6$ $2 \times 10^5 \leq \text{Re} \leq 4 \times 10^5$ c_o is according to Figure A.3
3	Ropes	$l / d > 100$	Perpendicular to axis of member	$d \cdot l$	$\text{Re} \leq 2 \times 10^5$ $c_o = 1{,}20$
					$4 \times 10^5 \leq \text{Re} \leq 10^6$ $c_o = 0{,}90$
					$\text{Re} > 10^6$ $2 \times 10^5 \leq \text{Re} \leq 4 \times 10^5$ c_o is according to Figure A.3



Key

1 ropes

2 pipes, rods

for $2 \times 10^5 \leq \mathrm{Re} \leq 4 \times 10^5$

$c_o = 1{,}2 - K_1 \log[\mathrm{Re}/(2 \times 10^5)]$

where the roughness is given by

K_1 = 0,996 6 for ropes;

K_1 = 1,660 9 for pipes and rods;

for $\mathrm{Re} \geq 10^6$

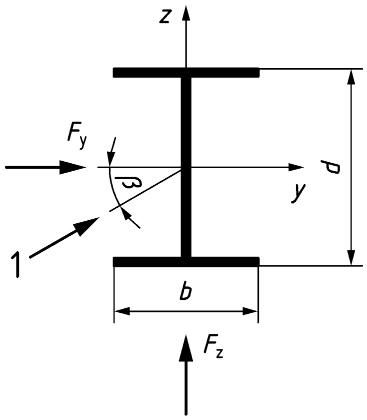
$$c_o = 1{,}2 - \frac{K_2}{1 + 0{,}4\ \log(\mathrm{Re}/10^6)}$$

where the roughness is given by

K_2 = 0,3 for ropes;

K_2 = 0,5 for pipes and rods

Figure A.3 — More detailed aerodynamic coefficients c_o for individual members of circular sections related to Re



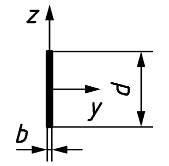
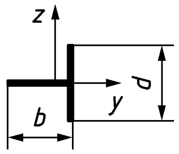
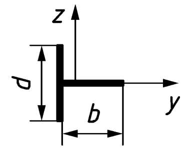
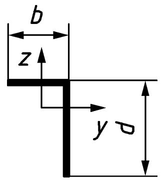
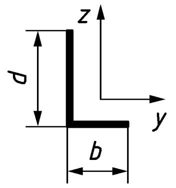
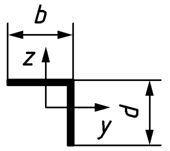
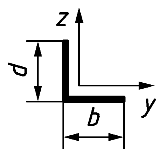
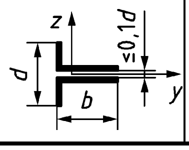
Key

1 wind direction

Figure A.4 — Definition of the angle β of the wind direction and corresponding wind forces

NOTE The force coefficients c_{oy} and c_{oz} given in Table A.3 are related to the y and z axis of the section of the structural member and depend on the wind direction given by the angle β. The wind loads F_y and F_z are calculated separately for the y and z direction according to the formulae given for F in 4.2.3.1 and 4.2.4.2.

Table A.3 — Aerodynamic coefficients c_{oy}, c_{oz} for individual flat sided structural members

No.	**Shape and position of the member**			**Characteristic area A**	c_{oy}	c_{oz}
	Member	**Section ratio**	**Wind direction** β			
1		$b/d \leq 0{,}1$	0°	$d \cdot l$	2,0	0
			±45°		1,3	±0,13
			90°		0	0,1
2		$b/d = 1$	0°	$d \cdot l$	1,65	0
			±45°		2,2	±1,0
			±90°		1,3	2,1
3		$b/d = 1$	0°	$d \cdot l$	2,0	0
			±45°		1,15	±0,8
			±90°		−1,3	2,1
4		$b/d = 0{,}5$	0°	$d \cdot l$	2,0	1,0
			+45°		1,8	0,8
			−45°		1,3	−0,2
			90°		1,75	1,25
5		$b/d = 0{,}5$	0°	$d \cdot l$	2,0	−0,1
			+45°		1,55	0,7
			−45°		1,55	−0,8
			90°		−0,25	0,8
6		$b/d = 1$	0°	$d \cdot l$	1,8	2,0
			+45°		1,8	1,8
			90°		2,0	1,8
7		$b/d = 1$	0°	$d \cdot l$	1,9	−0,2
			+45°		1,4	1,4
			−45°		0,7	−1,8
			90°		−0,2	1,9
8		$b/d = 0{,}9$	0°	$d \cdot l$	1,6	0
			±45°		1,4	0
			±90°		−0,9	0,7

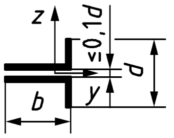
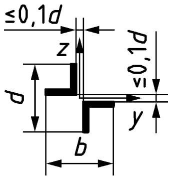
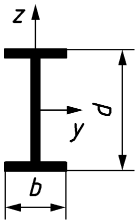
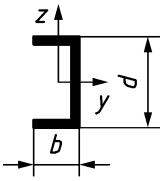
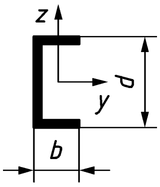
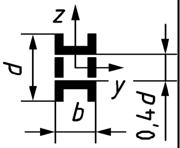
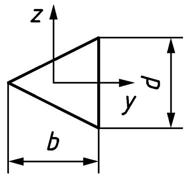
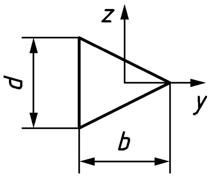
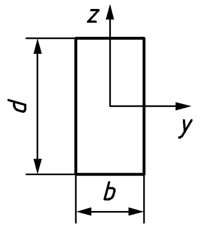
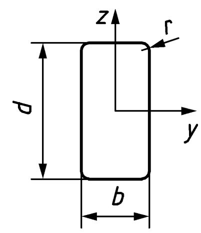
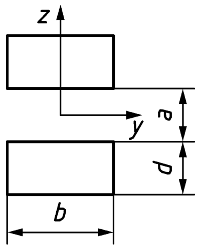
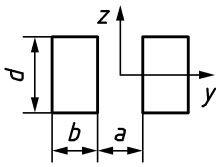
9		$b/d = 0{,}9$	0°	$d \cdot l$	1,4	0
			±45°		0,4	±1,0
			±90°		0,9	0,7
10		$b/d = 1$	0°	$d \cdot l$	1,7	0
			±45°		0,85	±0,85
			90°		0	1,7
11		$b/d = 0{,}5$	0°	$d \cdot l$	2,0	0
			±45°		1,8	±0,6
			±90°		0	0,8
		$b/d = 0{,}66$	0°		1,85	0
			±45°		1,7	±1,0
			±90°		0	1,2
		$b/d = 1$	0°		1,7	0
			±45°		1,5	±1,5
			±90°		0	1,7
12		$b/d = 0{,}5$	0°	$d \cdot l$	2,1	0
			±45°		1,8	±0,6
			±90°		0	0,7
13		$b/d = 0{,}5$	0°	$d \cdot l$	1,8	0
			±45°		1,8	±0,5
			±90°		0	0,7
14		$b/d = 0{,}6$	0°	$d \cdot l$	2,1	0
			±45°		1,6	±1,2
			±90°		0	1,2

Table A.4 — Aerodynamic coefficients c_o for individual structural members of triangular and rectangular hollow sections

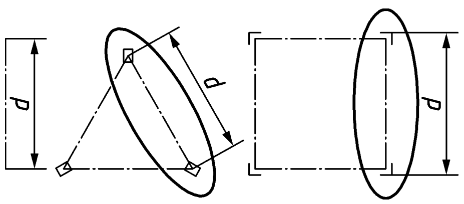
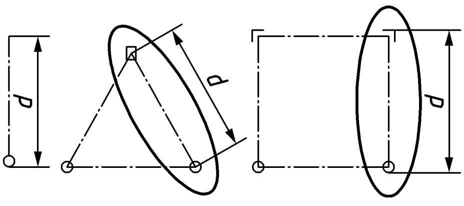
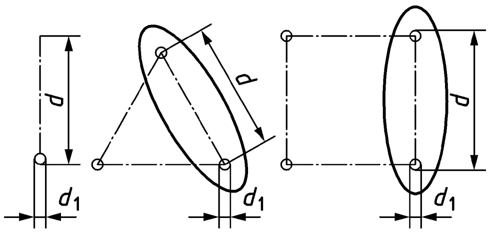
No.	**Shape and position of the member**			**Characteristic area A**	c_o
	Member	**Section ratio**	**Wind direction** β		
1		$1 \le b/d \le 1{,}4$	0°	$d \cdot l$	1,2
2		$1 \le b/d \le 1{,}4$	0°	$d \cdot l$	2
3		$b/d = 0{,}5$	0°	$d \cdot l$	2,2
		$b/d = 1$	0°	$d \cdot l$	2,0
		$b/d = 2$	0°	$d \cdot l$	1,5
		$b/d = 3$	0°	$d \cdot l$	1,3
		$b/d = 4$	0°	$d \cdot l$	1,0
4	 Rounded corners with $r/d = 1/24$	$b/d = 0{,}5$	0°	$d \cdot l$	2,1
		$b/d = 1{,}0$	0°	$d \cdot l$	1,5
		$b/d = 2{,}0$	0°	$d \cdot l$	1,1
5		$a/d = 0{,}5$; $b/d = 2$	0°	$2\, d \cdot l$	1,6
		$a/d = 1$; $b/d = 2$	0°	$2\, d \cdot l$	1,5
		$a/d = 2$; $b/d = 2$	0°	$2\, d \cdot l$	1,4
6		$a/d = 0{,}5$; $b/d = 0{,}5$	0°	$d \cdot l$	1,25
		$a/d = 1$; $b/d = 0{,}5$	0°	$d \cdot l$	1,30
		$a/d = 2$; $b/d = 0{,}5$	0°	$d \cdot l$	1,40

A.3 Plane and spatial lattice structure members

In this clause the following Tables and Figures are given

- Table A.5: Characteristic areas A and aerodynamic coefficients c_o for plane and spatial lattice structure members;
- Figure A.5: Aerodynamic coefficients c_o of plane lattice structure members in dependence on φ, circular and non-circular individual members;
- Figure A.6: Aerodynamic coefficients c_o of spatial lattice structure members in dependence on φ, circular and non-circular individual members;
- Figure A.7: Aerodynamic coefficients c_o of plane lattice structure members in dependence on Re and φ, circular individual members;
- Figure A.8: Aerodynamic coefficients c_o of spatial lattice structure members with triangular and square cross section in dependence on Re and φ, circular individual members.

Table A.5 — Characteristic areas A and aerodynamic coefficients c_o for plane and spatial lattice structure members

No.	Shape and position of the member	Characteristic area A		c_o
1	Individual members non-circular 	$A = \sum_j A_j$, $\varphi = \frac{A}{d \cdot \ell}$		For plane member see Figure A.5 For spatial member see Figure A.6
		$\sum_j A_j$	is the sum of the projected areas of all individual members and gusset plates of one wall (d) onto its plane	
2	Individual members circular and non-circular 	$A = \sum_j A_{1j} + 0{,}75 \sum_k A_{2k}$ $\varphi = \frac{A}{d \cdot \ell}$		For plane member see Figure A.5 For spatial member see Figure A.6
		$\sum_j A_{1j}$	is the sum of areas as in No. 1	
		$\sum_k A_{2k}$	is the sum of areas as in No. 3	
3	Individual members circular (without gusset plate) 	$A = \sum_j A_j$; $\varphi = \frac{A}{d \cdot \ell}$		For plane member see Figure A.7 For spatial ∇-member see Figure A.8a For spatial □-member see Figure A.8b
		$\sum_j A_j$	is the sum of the projected areas of all individual members of one wall (d) onto its plane $\mathrm{Re} = 0{,}667 \cdot 10^5 \cdot v \cdot d_1$ (see A.1)	

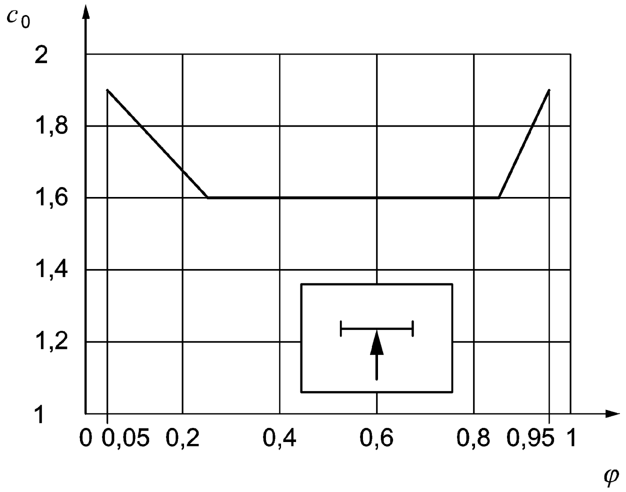


Figure A.5 — Aerodynamic coefficients c_o of plane lattice structure members in dependence on φ, having circular and non-circular individual members

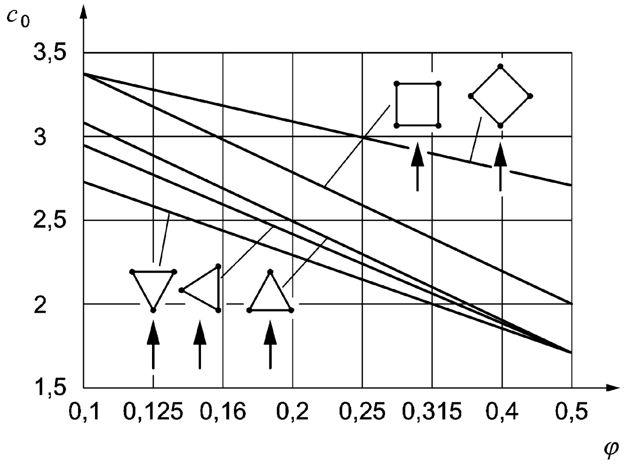


Figure A.6 — Aerodynamic coefficients c_o of spatial lattice structure members in dependence on φ, having circular and non-circular individual members

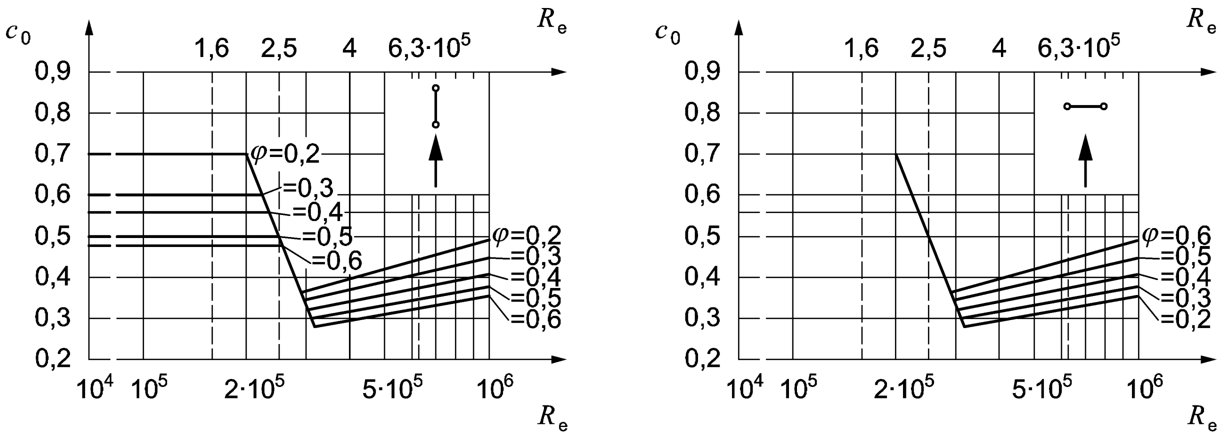


Figure A.7 — Aerodynamic coefficients c_o of plane lattice structure members in dependence on Re and φ, having circular individual members

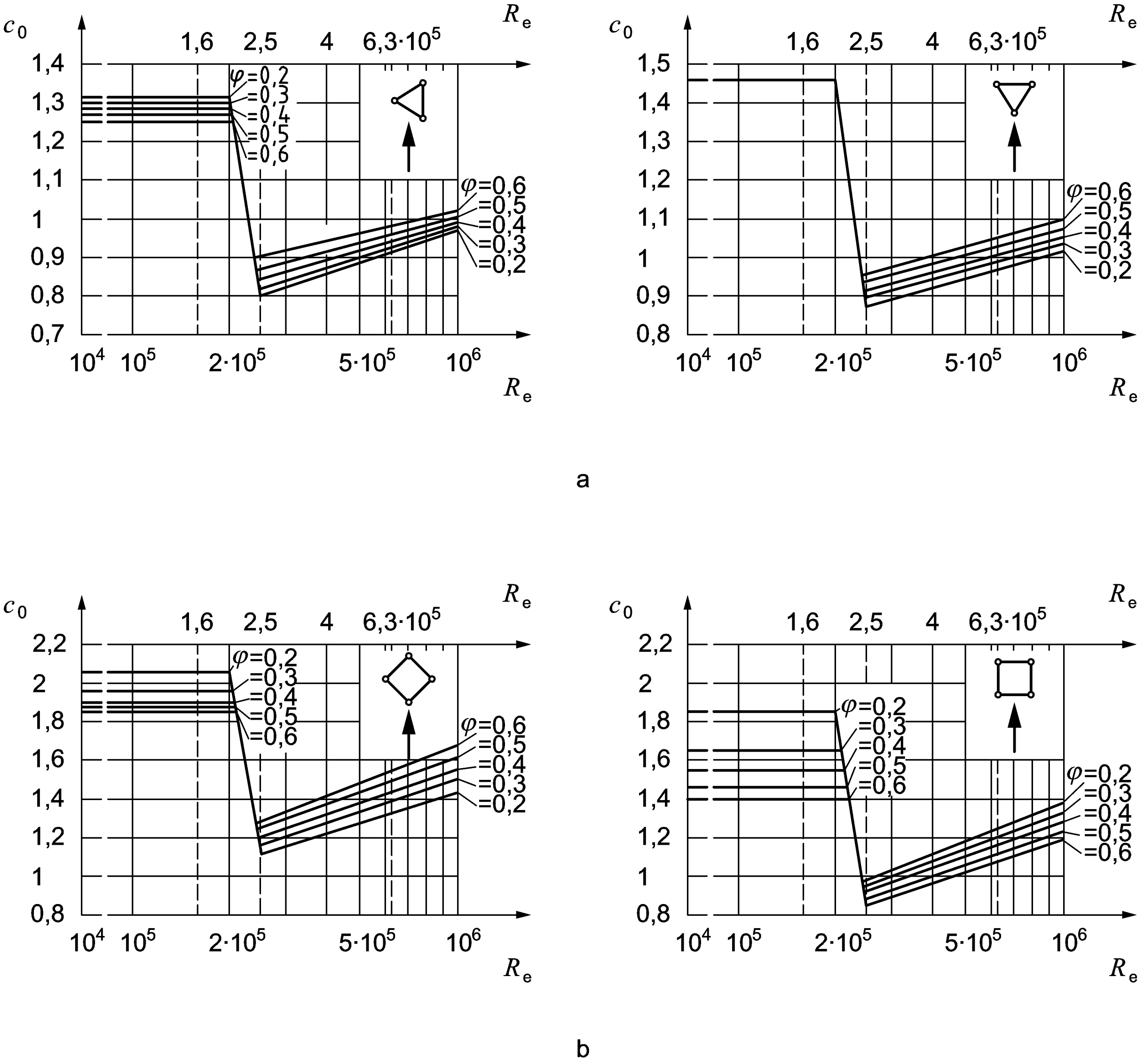


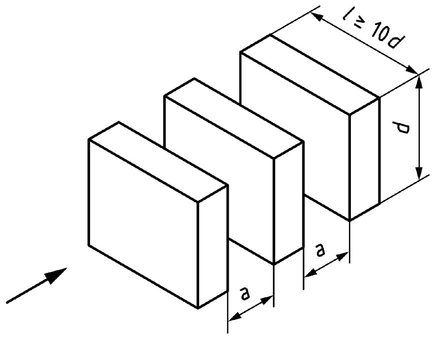
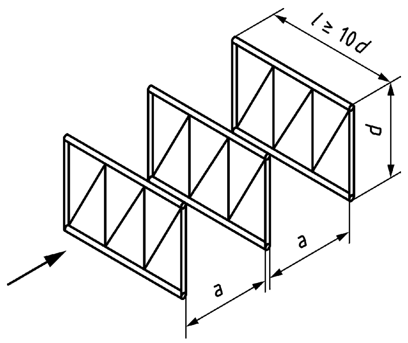
Figure A.8 — Aerodynamic coefficients c_o of spatial lattice structure members with triangular (a) and square cross section (b) in dependence on Re and φ, having circular individual members

A.4 Structural members in multiple arrangement

In this clause the following is given

- Table A.6: Characteristic areas A and aerodynamic coefficients c_o of structural members in multiple arrangement;
- Figure A.9: Shielding factor η for structural members in multiple arrangement.

Table A.6 — Characteristic areas A and aerodynamic coefficients c_o of structural members in multiple arrangement

Shape and positions of the members	Characteristic area A	c_o
 	n_m parallel and identical members if $1 \leq n_m \leq 9$ $A = \frac{1-\eta^{n_m}}{1-\eta} \times A_1$ if $n > 9$ $A = \left[\frac{1-\eta^9}{1-\eta} + (n_m - 9)\, \eta^8 \right] A_1$ with $\eta \geq 0{,}10$ where A_1 is the characteristic area of one member η is the shielding factor dependent on the solidity ratio φ and the relation a/d between space and height of the members, according to Figure A.9	Aerodynamic coefficient of one member
 		
This formula may also be used where a) the direction of the wind velocity deviates up to $\beta = 5°$ from the direction perpendicular to the surface of the members; b) the members are not identical and the greatest characteristic area $A_{1,\max}$ is taken into account and c) the distance of the members is not equal and the greatest distance $a_{\max}$ is taken into account.		

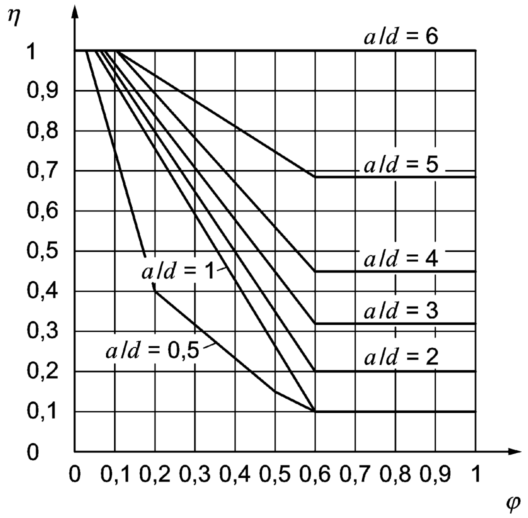


Figure A.9 — Shielding factor η for structural members in multiple arrangement

Annex B
(informative)

Illustration of the types of hoist drives

Table B.1 illustrates the five hoist drive types used in Table 3 of 4.2.2.2 by means of their time histories of actual rotational or linear hoist drive speed ω and resulting hoist force F.

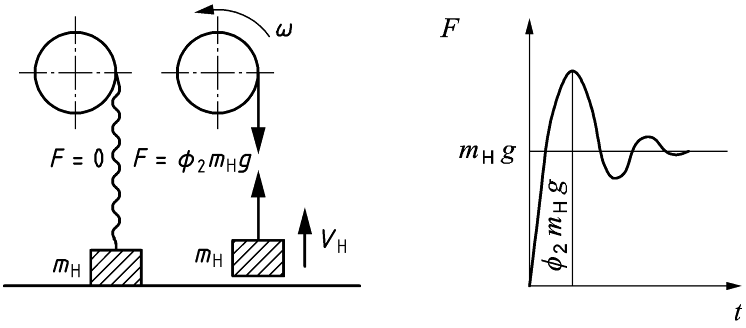
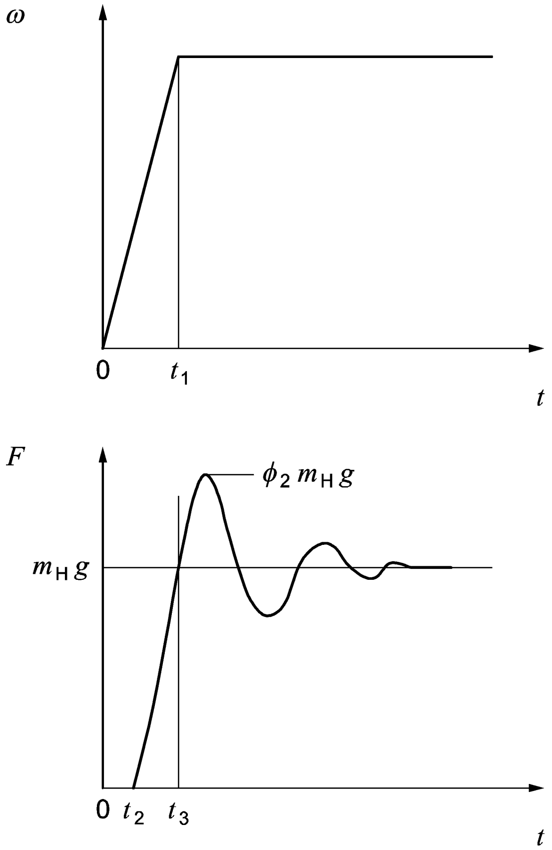
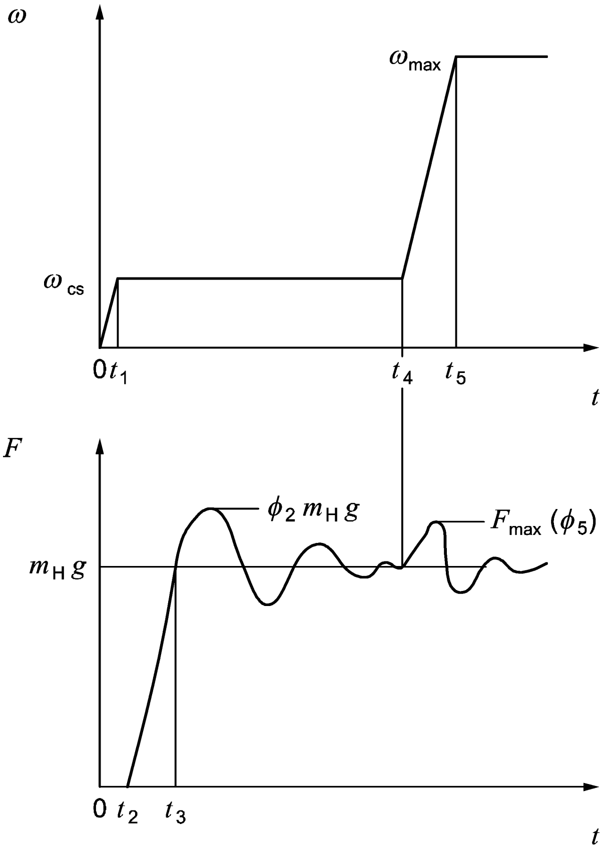


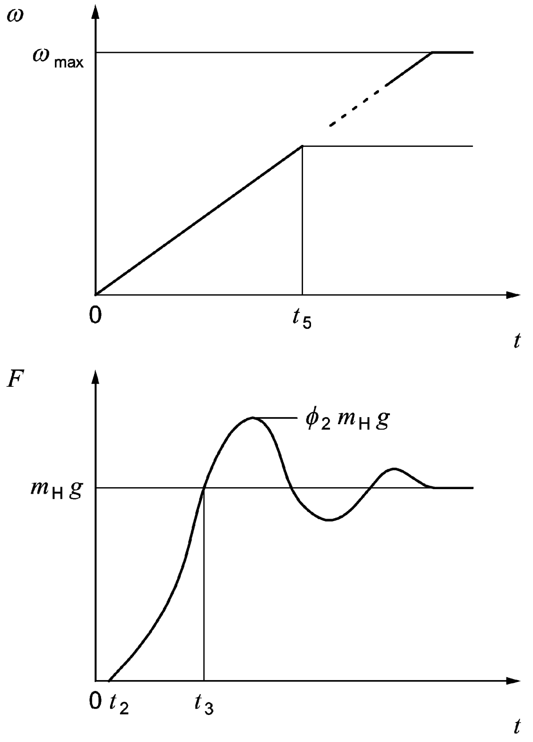
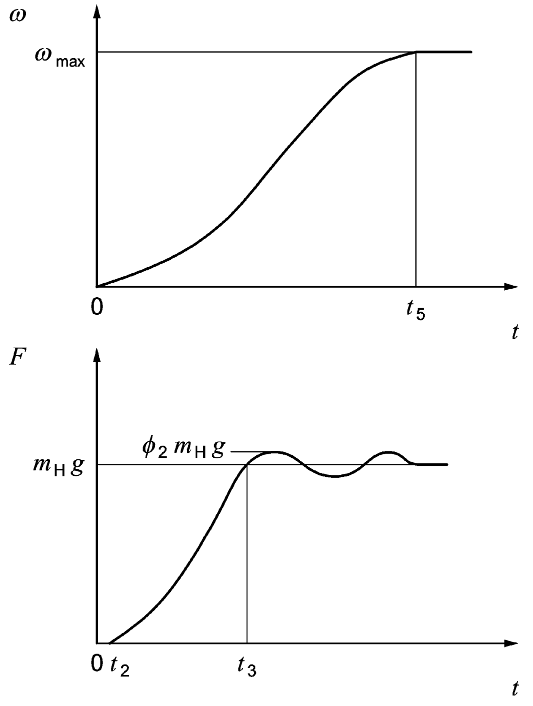
Figure B.1 — ω and F

Table B.1 — Hoist drive types

HD1	**Creep speed is not available or the start of the drive without creep speed is possible**	
		Time history $t = 0$ Start of drive $t = t_1$ $\omega = \omega_{max}$ $t = t_2$ Start of rope tightening ($t_2 \approx 0$) $t = t_3$ Start of load lifting Regular load (Combinations A, B) $\phi_2 = \phi_{2,min} + \beta_2 v_{h,max}$ Example Squirrel cage motor with or without creep speed

<table>
<tr><td rowspan="2">HD2</td><td colspan="2">Hoist drive can only start at creep speed of at least a preset duration</td></tr>
<tr><td>


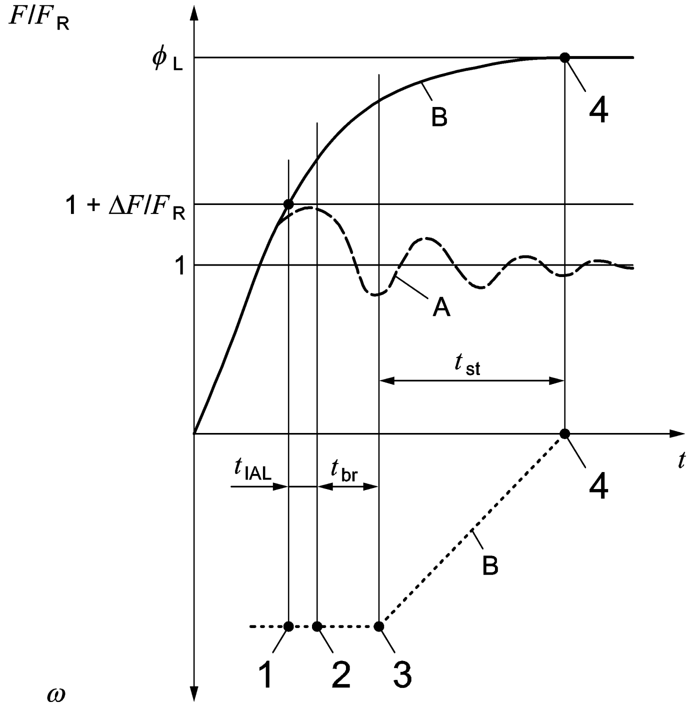
</td><td>Time history
$t = 0$ Start of drive
$t = t_1$ $\omega = \omega_{cs}$
$t = t_4$ Start of acceleration to ω_{max} ($t_4 > t_{4min}$)
$t = t_5$ $\omega = \omega_{max}$
$t = t_2$ Start of rope tightening ($t_2 \approx 0$)
$t = t_3$ Start of load lifting
Regular loads (Combinations A, B)
$\phi_2 = \phi_{2,min} + \beta_2\, v_{h,CS}$
$F_{max}(\phi_5) = m_H g + \phi_5 \cdot (F_f - m_H\, g)$
where F_f is the final drive force, see 4.2.2.5.
Exceptional load (Combination C1)
$\phi_2 = \phi_{2,min} + \beta_2\, v_{h,max}$
Example Pole changeable squirrel cage motor with creep speed. Time delay t_{4min} ensured by any means like time relay or special push button.</td></tr>
<tr><td rowspan="2">HD3</td><td colspan="2">Hoist drive control maintains creep speed until the load is lifted off the ground</td></tr>
<tr><td colspan="2">The time histories of F and ω in HD3 are the same as those shown for hoist drive types HD2. However, whilst HD3 type hoist drives ensure that $t_3 < t_4$. HD2 type drives do not prevent the application of full speed whilst the load is still grounded (i.e. foreseeable misuse of slack rope).
Therefore in HD3 only regular loads with $\phi_2 = \phi_{2,min} + \beta_2\, v_{h,CS}$ shall be considered in load combinations A and B.
Example Any drive with creep speed and load measuring devices. The maximum speed can only be activated (either automatically or manually) when F stays constant and > 0 for a certain time, thus ensuring that the load is lifted from the ground.</td></tr>
</table>

HD4	**Step-less hoist drive control, which performs with continuously increasing speed**	
		Time history $t = 0$ Start of drive $t = t_5$ $\omega = \omega_{\text{max}}$ $t = t_2$ Start of rope tightening $t = t_3$ Start of load lifting Regular load (Combinations A, B) $\phi_2 = \phi_{2,\text{min}} + \beta_2 \frac{v_{\text{h,max}}}{2}$ Exceptional load (Combination C1) $\phi_2 = \phi_{2,\text{min}} + \beta_2 \, v_{\text{h,max}}$ Example: Any drive that accelerates smoothly (e.g. ramp), e.g. by means of frequency control or DC-motor or hydraulic spool valve. As foreseeable misuse (start of lifting with slack ropes) is not prevented, load combination C1 shall be considered.
HD5	**Step-less hoist drive control automatically ensures that the dynamic factor ϕ_2 does not exceed $\phi_{2,\text{min}}$**	
		Time history $t = 0$ Start of drive $t = t_5$ $\omega = \omega_{\text{max}}$ $t = t_2$ Start of rope tightening $t = t_3$ Start of load lifting Regular load (Combinations A, B) $\phi_2 = \phi_{2,\text{min}}$ Exceptional load (Combination C1) $\phi_2 = \phi_{2,\text{min}} + \beta_2 \frac{v_{\text{h,max}}}{2}$ Example: Frequency control, DC-motor or hydraulic LS-valve plus load measuring devices. Automatic control for smooth rope tightening and e.g. cosine-type shaped acceleration or direct load control. For additional safety load combination C1 shall be considered.

Annex C
(informative)

Calculation of load factor for indirect lifting force limiter

Indirect lifting force limiters measure the load and override the controls to prevent excessive loading by bringing the motion to rest. Evaluation of the measured values and filtering of interference signals require time and act as a triggering delay. An additional time delay takes place before the braking torque is applied. Figure C.1 illustrates development of force by time in a typical hoist system with indirect lifting force limiter.



Key

F	force in the hoist system
F_R	force in the hoist system corresponding to the rated load
ω	motor speed
1	triggering happens
2	braking receive the stopping instruction
3	braking torque is applied
4	the hoist mechanism has stopped
A	hoisting a free grounded load having a weight of the rated load
B	stall load case or large overload, where the load remains grounded

Figure C.1 — Hoist system with indirect lifting force limiter, force in the hoist system and motor speed by time in stall load condition

The load factor ϕ_L for indirect lifting force limiter system functioning in accordance with the Figure C.1 is calculated as follows

$$\phi_L = 1 + \frac{\Delta F}{F_R} + \left\{ C_H \times v \times (t_{IAL} + t_{br} + \frac{t_{st}}{2}) \right\} / \left(m_H \times g \right)$$

where

ΔF	is the tolerance of the triggering force in the hoist system, to allow for dynamic impacts occurring in regular use;
F_R	is the force in the hoist system corresponding to the rated load;
v	is the maximum hoisting speed of the load at which the indirect lifting force limiter is triggered;
m_H	is the mass of the hoist load;
t_{IAL}	is the response time of the indirect lifting force limiter;
t_{br}	is the reaction time of the braking system;
t_{st}	is the time required to stop the hoist mechanism in a stall condition by the combined effects of the braking and increasing force in the ropes;
C_H	is stiffness factor of crane structure and rope system at the load suspension point.

Annex D
(informative)

Guidance on selection of the risk coefficient

Cranes with enhanced risk shall be assigned and designed to risk classes based on potential severity of consequences of a failure in a member or component of a crane. Other cranes may be designed with a risk coefficient set to 1,0.

Risk classes and the related, typical applications are given in Table D.1.

Table D.1 — Classes for enhanced risks

Risk Class	Description	Examples
Risk Class I	Consequences of failure are limited to the vicinity of the crane with medium consequences in terms of loss of human lives or with considerable economic, social and environmental consequences.	— handling of hot molten metal; — handling of radioactive material, where a failure would lead to a radiation hazard limited within the work space; — handling of dangerous materials or working above those, e.g. explosives, flammables and dangerous chemicals, where a failure would cause a hazard limited within the work space.
Risk Class II	Consequences of failure extending beyond the vicinity of the crane with high consequences in terms of loss of human lives or with very serious economic, social and environmental consequences.	— nuclear power plant cranes, where a failure would cause a hazard to functionality of the reactor; — handling of dangerous materials or working above those, e.g. explosives, flammables and dangerous chemicals, where a failure would cause a hazard to the whole site.

Risk coefficient for a whole crane or its component is selected in accordance with Table D.2, based on Risk Class of the application.

Table D.2 —Selection of risk coefficients

Member or component, to which the risk coefficient is applied	Examples	Risk coefficients			
		Risk class I		Risk class II	
		Static	Fatigue	Static	Fatigue
Rope and chain systems in hoisting mechanisms		1,25	1,25	1,6	1,6
Rope and chain systems in mechanisms suspending and moving large parts of the crane	Boom hoisting mechanism of a ship unloader	1,25	1,25	1,6	1,6
Structural members where defects are not detectable by visual inspection and whose failure would lead to loss of the hoist load	Bolted connections	1,1	1,1	1,25	1,25
Structural members where defects are not detectable by visual inspection and whose failure would lead to collapse of the whole crane or a major part of this	Supporting structure and bearing of a guide roller; End stop for a trolley	1,1	1,1	1,4	1,4
NOTE Higher values might be specified in European product type standards.					

Annex E
(informative)

Selection of a suitable set of crane standards for a given application

Is there a product standard in the following list that suits the application?	
EN 13000	Cranes — Mobile cranes
EN 14439	Cranes — Safety — Tower cranes
EN 14985	Cranes — Slewing jib cranes
EN 15011	Cranes — Bridge and gantry cranes
EN 13852–1	Cranes — Offshore cranes — Part 1 General purpose offshore cranes
EN 13852–2	Cranes — Offshore cranes — Part 2 Floating cranes
EN 14492–1	Cranes — Power driven winches and hoists — Part 1 Power driven winches
EN 14492–2	Cranes — Power driven winches and hoists — Part 2 Power driven hoists
EN 12999	Cranes — Loader cranes
EN 13157	Cranes — Safety —Hand powered cranes
EN 13155	Cranes — Safety — Non-fixed load lifting attachments
EN 14238	Cranes — Manually controlled load manipulating devices

YES

Use it directly, plus the standards that are referred to

NO

Use the following	
EN 13001–1	Cranes — General design — Part 1 General principles and requirements
EN 13001–2	Cranes — General design — Part 2 Load actions
EN 13001–3-1	Cranes — General design — Part 3–1 Limit states and proof of competence of steel structures
EN 13001–3-2	Cranes — General design — Part 3–2 Limit states and proof of competence of wire ropes in reeving systems
CEN/TS 13001–3-5	Cranes — General design — Part 3–5 Limit states and proof of competence of forged hooks
EN 13135	Cranes — Safety —Design—Requirements for equipment
EN 13557	Cranes — Controls and control stations
EN 12077–2	Cranes safety — Requirements for health and safety — Part 2 Limiting and indicating devices
EN 13586	Cranes — Access
EN 14205–1	Cranes — Equipment for the lifting of persons — Part 1 Suspended baskets
EN 14502–2	Cranes — Equipment for the lifting of persons — Part 2 Elevating control stations
EN 12644–1	Cranes — Information for use and testing — Part 1 Instructions
EN 12644–2	Cranes — Information for use and testing — Part 2 Marking

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of EU Directive 2006/42/EC

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Directive 2006/42/EC.

Once this standard is cited in the Official Journal of the European Union under that Directive and has been implemented as a national standard in at least one Member State, compliance with the normative clauses of this standard confers, within the limits of the scope of this standard, a presumption of conformity with the relevant Essential Requirements of that Directive and associated EFTA regulations.

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

Bibliography

[1] EN 1991-1-4:2005, *Eurocode 1: Actions on structures — Part 1-4: General actions — Wind actions*

[2] EN ISO 12100, *Safety of machinery - General principles for design - Risk assessment and risk reduction (ISO 12100)*

[3] ISO 11660-1, *Cranes — Access, guards and restraints — Part 1: General*

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