BS EN 13001-3-2:2014

BSI Standards Publication

Cranes — General design

Part 3-2: Limit states and proof of competence of wire ropes in reeving systems

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National foreword

This British Standard is the UK implementation of EN 13001-3-2:2014. It supersedes DD CEN/TS 13001-3-2:2004, which is withdrawn.

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BS EN 13001-3-4 and DD CEN/TS 13001-3-5:2010, supersedes BS 2573-1:1983 and BS 2573-2:1980, which will be withdrawn on publication of all parts of the BS EN 13001 series.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

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

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Appareils de levage à charge suspendue - Conception générale - Partie 3-2 : Etats limites et vérification d'aptitude des câbles en acier mouflés

Krane - Konstruktion allgemein - Teil 3-2: Grenzzustände und Sicherheitsnachweis von Drahtseilen in Seiltrieben

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Contents

Page

Foreword

This document (EN 13001-3-2:2014) 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of an identical text or by endorsement, at the latest by February 2015 and conflicting national standards shall be withdrawn at the latest by February 2015.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 CEN/TS 13001-3-2:2008.

CEN/TC 147/WG 2 has reviewed CEN/TS 13001-3-2:2008 to adapt the standard to the technical progress.

The major changes in this document are in the following clauses:

— 6.3 and 6.5;

— there are new issues in Clause 7.

The provisions of this standard shall not be mandatory to cranes manufactured within the first 12 months following the date of availability (DAV) of the standard.

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, *Cranes — General design*. 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 3-3: 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*

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) 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 EN ISO 12100.

The machinery concerned and the extent to which hazards, hazardous situations and events 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.

1 Scope

This European Standard is to be used together with EN 13001-1 and EN 13001-2 and as such they specify general conditions, requirements and methods to prevent mechanical hazards of wire ropes of cranes by design and theoretical verification.

NOTE Specific requirements for particular types of cranes 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 intended use and reasonably foreseeable misuse. Clauses 5 to 6 of this standard are necessary to reduce or eliminate risks associated with the following hazard:

− exceeding the limits of strength (yield, ultimate, fatigue).

This European Standard is not applicable to cranes which are manufactured before the date of its publication as EN and serves as reference base for the European Standards for particular crane types (see Annex C).

EN 13001-3-2 deals only with the limit state method in accordance with EN 13001-1.

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 1990:2002, *Eurocode — Basis of structural design*

EN 12385-2, *Steel wire ropes — Safety — Part 2: Definitions, designation and classification*

EN 12385-4, *Steel wire ropes — Safety — Part 4: Stranded ropes for general lifting applications*

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

EN 13001-2, *Crane safety — General design — Part 2: Load actions*

EN 13411-1, *Terminations for steel wire ropes — Safety — Part 1: Thimbles for steel wire rope slings*

EN 13411-2, *Terminations for steel wire ropes — Safety — Part 2: Splicing of eyes for wire rope slings*

EN 13411-3, *Terminations for steel wire ropes — Safety — Part 3: Ferrules and ferrule-securing*

EN 13411-4, *Terminations for steel wire ropes — Safety — Part 4: Metal and resin socketing*

EN 13411-6, *Terminations for steel wire ropes — Safety — Part 6: Asymmetric wedge socket*

EN ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction (ISO 12100:2010)*

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

ISO 4309, *Cranes — Wire ropes — Care and maintenance, inspection and discard*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 12100:2010 and the basic list of definitions as provided in EN 1990:2002 apply. For the definitions of loads, Clause 6 of ISO 4306-1:2007 applies.

3.2 Symbols and abbreviations

The symbols and abbreviations used in this Part of the EN 13001 are given in Table 1.

Table 1— Symbols and abbreviations

Symbols, abbreviations	Description
a	Acceleration
C	Total number of working cycles (see EN 13001–1) during design life of crane
D	Relevant diameter
D_{drum}	Minimum pitch diameter of drum
D_{sheave}	Minimum pitch diameter of sheave
D_{comp}	Minimum pitch diameter of compensating sheave
d	Rope diameter
$d_{bearing}$	Diameter of bearing or shaft
F_{equ}	Equivalent force
F_{gd}	Part of F_{equ} induced by gravity, exclusive of mass of payload, amplified by γ_p
F_{gl}	Part of F_{equ} induced by gravity forces of mass of payload, amplified by γ_p
F_o	Part of F_{equ} induced by any other forces, amplified by γ_p
$F_{Rd,s}$	Limit design rope force for the proof of static strength
$F_{Rd,f}$	Limit design rope force for the proof of fatigue strength
$F_{Sd,s}$	Design rope force for the proof of static strength
F_r	Part of F_{equ} induced by resistances, amplified by γ_p
$F_{Sd,f}$	Design rope force for the proof of fatigue strength
F_t	Part of F_{equ} induced by rope tightening forces, amplified by γ_p
F_u	Minimum rope breaking force
F_w	Part of F_{equ} induced by wind forces, amplified by γ_p
f_f	Factor of further influences
f_{f1}	Factor of diameter ratio influence
f_{f2}	Factor tensile strength of wire influence

Symbols, abbreviations	Description
f_{f3}	Factor of fleet angle influence
f_{f4}	Factor of lubrication influence
f_{f5}	Factor of multilayer drum influence
f_{f6}	Factor of groove radius influence
f_{f7}	Factor of rope type influence
f_{S1}	Rope force increasing factor from rope reeving efficiency
f_{S2}	Rope force increasing factor from non parallel falls
f_{S3}	Rope force increasing factor from horizontal acceleration
f_{si}^{*}	Rope force increasing factors in fatigue
g	Acceleration due to gravity
i	Index for cycles of lifting and lowering
i_{max}	Total number of movements
k_{r}	Rope force spectrum factor
l_{r}	Number of ropes used during design life of the crane
q	Normalized height distribution
m_{H}	Mass of hoist load (see EN 13001–2)
m_{Hr}	Mass of hoist load that is acting on the rope falls under consideration
m_{r}	Rotatory rope driven mass
m_{t}	Translational rope driven mass
n_{s}	Number of fixed sheave between drum and moving part
n_{m}	Mechanical advantage
n_{r}	Number of ropes reeved from a drum
R_{0}	Minimum tensile strength of the wire used in the rope
R_{Dd}	Reference ratio of rope bending diameter to rope diameter
R_{r}	Tensile strength level of wire
r_{g}	Groove radius
s_{r}	Rope force history parameter
t	Rope type factor
w	Number of relevant bendings per movement
w_{c}	Bending count
w_{D}	Number of bendings at reference point
w_{tot}	Total number of bendings

Symbols, abbreviations	Description
z, z_i, z_{min}, z_{max}, z_{ref}	Height coordinates
α	Angle of slope
β, β_{max}	Angles between falls and line of acting force
γ	Angle between gravity and projected rope in plane of F_h and g
γ_n	Risk coefficient
γ_p	Partial safety factor
γ_{rb}	Minimum rope resistance factor (static)
γ_{rf}	Minimum rope resistance factor (fatigue)
δ	Design fleet angle
ε	Angle between sheave planes
η_s	Efficiency of single sheave
η_{tot}	Total rope reeving efficiency
ν_r	Relative total number of bendings
ϕ	Dynamic factor for inertial or gravity effects
ϕ^*	Dynamic factor for inertial or gravity effects in fatigue
ϕ_2	Dynamic factor for hoisting an unrestrained grounded load
ϕ_5	Dynamic factor for loads caused by acceleration
ϕ_6	Dynamic factor for test load
ω	Angle between the sheave groove sides

4 General

4.1 Running ropes

Running wire ropes in cranes are stressed by loads and by bendings. Together these constitute a cumulative fatigue effect on the rope, which is expressed as a rope force history parameter s_r. The rope force history parameter is independent of time.

The proof of competence for static strength and the proof of competence for fatigue strength shall be fulfilled for the selection of ropes and components.

4.2 Stationary ropes

Stationary ropes are considered as part of the crane structure.

Clause 7 gives the requirements for the proof of competence for static strength and for fatigue strength of stationary ropes.

4.3 Discard criteria

To ensure safe use of the rope, the discard criteria in accordance with ISO 4309 shall be applied.

When polymer sheaves are used exclusively in conjunction with single-layer spooling, the deterioration of the rope is likely to advance at a greater rate internally than externally and the discard criteria in accordance with ISO 4309 cannot be applied.

4.4 Rope and rope terminations

The wire rope should be in accordance with EN 12385-4. Rope terminations shall meet the requirements of EN 13411-1, EN 13411-2, EN 13411-3, EN 13411-4 and EN 13411-6.

4.5 Documentation

The documentation of the proof of competence shall include:

— design assumptions including calculation models;

— applicable loads and load combinations;

— rope specification and number of ropes specified for the design;

— relevant limit states;

— results of the proof of competence calculation and tests when applicable.

5 Proof of static strength

5.1 General

For the proof of static strength it shall be proven that for all relevant load combinations of EN 13001-2

$$F_{\mathrm{Sd,s}} \leq F_{\mathrm{Rd,s}} \tag{1}$$

where

$F_{\mathrm{Sd,s}}$ is the design rope force;

$F_{\mathrm{Rd,s}}$ is the limit design rope force.

5.2 Vertical hoisting

5.2.1 Design rope force

The design rope force $F_{\mathrm{Sd,s}}$ in vertical hoisting shall be calculated as follows:

$$F_{\mathrm{Sd,s}} = \frac{m_{\mathrm{Hr}} \cdot g}{n_{\mathrm{m}}} \cdot \phi \times f_{\mathrm{S1}} \times f_{\mathrm{S2}} \times f_{\mathrm{S3}} \times \gamma_{\mathrm{p}} \times \gamma_{\mathrm{n}} \tag{2}$$

where

m_{Hr} is the mass of the hoist load (m_H) or that part of the mass of the hoist load that is acting on the rope falls under consideration (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. In statically undetermined systems, the unequal load distribution between ropes depends on elasticities and shall be taken into account;

g is the acceleration due to gravity;

n_m is the mechanical advantage of falls carrying m_{Hr};

ϕ is the dynamic factor for inertial and gravity effects as shown in 5.2.2;

f_{S1} to f_{S3} are the rope force increasing factors as shown in 5.2.3 to 5.2.5;

γ_p is the partial safety factor (see EN 13001–2):

$\gamma_p = 1{,}34$ for regular loads (load combinations A),

$\gamma_p = 1{,}22$ for occasional loads (load combinations B),

$\gamma_p = 1{,}10$ or exceptional loads (load combinations C);

γ_n is the risk coefficient (see EN 13001–2), where applicable.

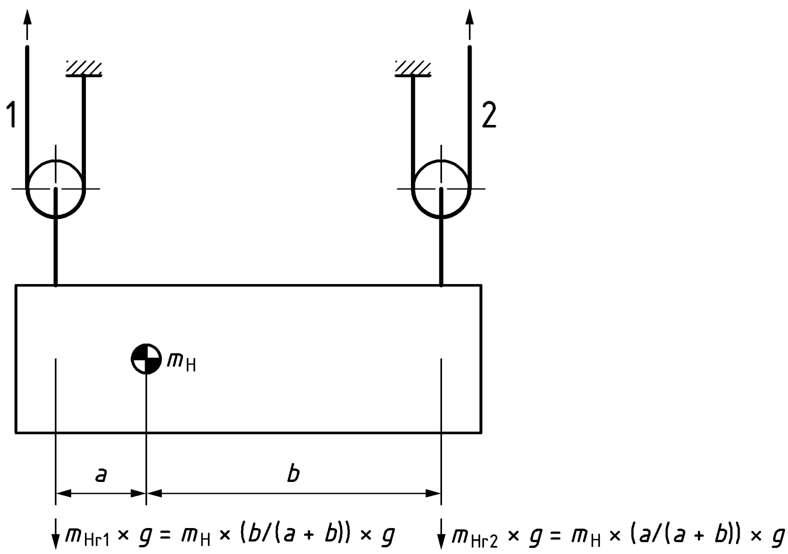


Figure 1 — Example for the acting parts of hoist mass

5.2.2 Inertial and gravitational effects

5.2.2.1 Dynamic factors

For vertical hoisting the maximum inertial effects from either hoisting an unrestrained grounded load or from acceleration or deceleration shall be taken into account by the dynamic factor ϕ, given in 5.2.2.2 to 5.2.2.4.

5.2.2.2 Hoisting an unrestrained grounded load

$$\phi = \phi_2 \quad (3)$$

where

ϕ_2 is the dynamic factor for inertial and gravity effects when hoisting an unrestrained grounded load (see EN 13001-2).

5.2.2.3 Acceleration or deceleration of the suspended load

$$\phi = 1 + \phi_5 \times \frac{a}{g} \tag{4}$$

where

ϕ_5 is the dynamic factor for loads caused by acceleration (see EN 13001–2);

a is the vertical acceleration or deceleration;

g is the acceleration due to gravity.

5.2.2.4 Test load

$$\phi = \phi_6 \tag{5}$$

where

ϕ_6 is the dynamic factor for test load (see EN 13001-2).

5.2.3 Rope reeving efficiency

The rope force increasing factor from rope reeving efficiency f_{S1} shall be calculated as follows:

$$f_{S1} = \frac{1}{\eta_{tot}} \tag{6}$$

The total rope reeving efficiency of the rope drive η_{tot} shall be calculated as follows:

$$\eta_{tot} = \frac{(\eta_S)^{n_s}}{n_m} \times \frac{1-(\eta_S)^{n_m}}{1-\eta_S} \tag{7}$$

where

η_S	is the efficiency of a single sheave:
η_S = 0,985	for sheave with roller bearing,
$\eta_S = 0{,}985 \times (1 - 0{,}15 \times d_{bearing}/D_{Sheave})$	for sheave with plain bearing. Other values for η_S may be used if verified by test results for the applied rope, sheave and bearing.
n_m	is the mechanical advantage (see example in Figure 2);
n_s	is the number of fixed sheaves between drum and moving part.

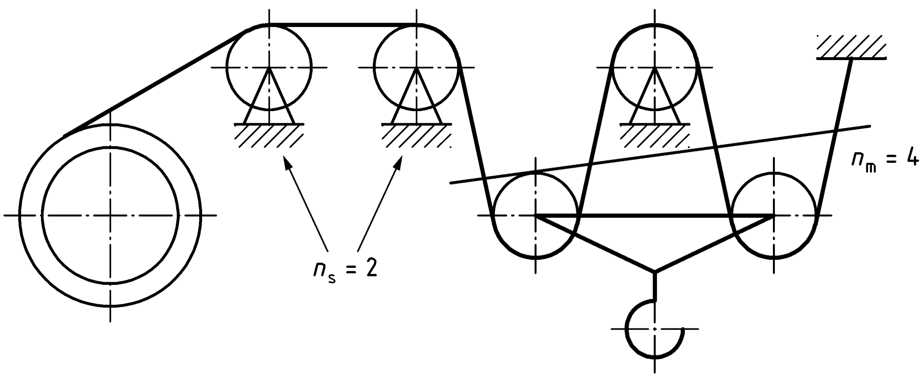


Figure 2 — Example for a rope reeving

5.2.4 Non parallel falls

When the rope falls are not parallel, the rope force is increased. The rope force increasing factor f_{S2} shall be determined for the most unfavourable position. For simplification f_{S2} may be calculated by

$$f_{S2} = \frac{1}{\cos \beta_{max}} \tag{8}$$

where

β_{max} is the maximum angle between the falls and the direction of load (see Figure 3).

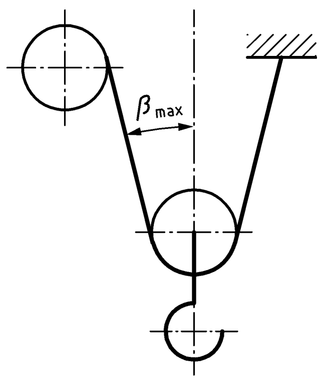


Figure 3 — Angle β_{max}

5.2.5 Horizontal forces on the hoist load

The rope force increasing effect of the horizontal forces (e.g. by trolley or crane accelerations, wind) may be neglected in applications with free swinging loads.

However in applications with several non-parallel ropes (rope pyramid, see Figure 4) the horizontal forces increase the rope force considerably. This effect shall be taken into account. For simplification the rope force increasing factor f_{S3} may be calculated by

$$f_{S3} = 1 + \frac{F_h}{m_H \times g \times \tan\gamma} \leq 2 \tag{9}$$

where

F_h	is the horizontal force on the hoist load;
m_H	is the mass of the hoist load;
g	is the acceleration due to gravity;
γ	is the angle between direction of gravity and the rope projected in the plane determined by F_h and direction of gravity.

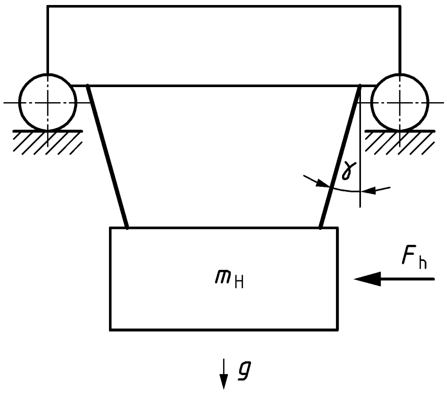


Figure 4 — Load suspension with inclined ropes

Load actions due to ϕ and f_{S3} in Formula (2) may be handled separately, only in cases where simultaneous action of horizontal and vertical accelerations is prevented by technical means (e.g. by a control system).

5.3 Non vertical drives

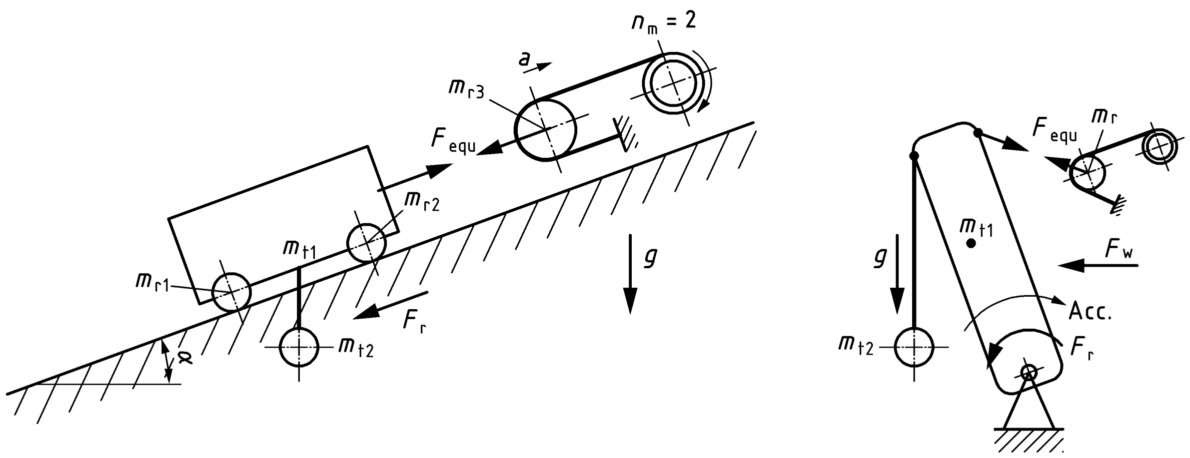
5.3.1 Design rope force

The design rope force $F_{Sd,s}$ in non-vertical drives (see examples in Figure 5 and Figure 6) shall be calculated as follows:

$$F_{Sd,s} = \frac{F_{equ}}{n_m} \times \phi \times f_{S1} \times f_{S2} \times \gamma_n \tag{10}$$

where

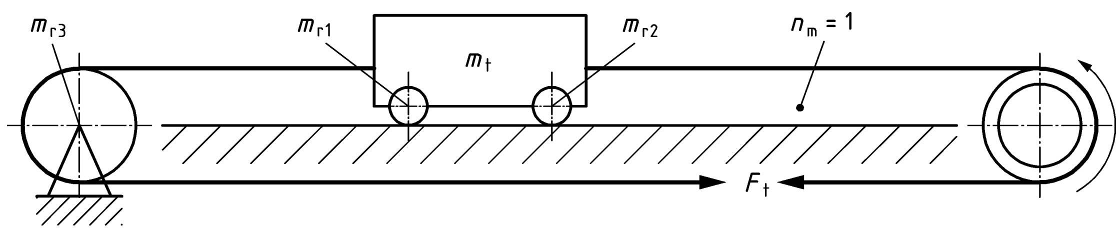
F_{equ}	is the equivalent force acting on the reeving system under consideration as shown in 5.3.2. In statically undetermined systems, the unequal load distribution between ropes depends on elasticities and shall be taken into account;
n_m	is the mechanical advantage of the reeving;
ϕ	is the dynamic factor for inertial effects as shown in 5.3.3;
f_{S1}, f_{S2}	are the rope force increasing factors as shown in 5.3.4 and 5.3.5;
γ_n	is the risk coefficient (see EN 13001–2), where applicable.



Key

m_{r1}, m_{r2}, m_{r3}	rotatory rope driven masses, referred to the coordinate of acceleration
m_{t1}, m_{t2}	translational rope driven masses, referred to the coordinate of acceleration
F_{equ}, F_w, F_r	forces, see 5.3.2
Acc., a	accelerations
n_m	mechanical advantage

Figure 5 — Examples for non-vertical drive



Key

m_{r1}, m_{r2}, m_{r3}	rotatory rope driven masses, referred to the coordinate of acceleration
m_t	translational rope driven mass, referred to the coordinate of acceleration
F_t	tightening forces, see 5.3.2
n_m	mechanical advantage

Figure 6 — Example for rope tightening

5.3.2 Equivalent force

In general the load actions of gravity forces, resistances (e.g. rolling or gliding, wheels, bearings), rope tightening forces, wind forces and any other forces (e.g. buffer forces, forces from climatic effects) contribute to the equivalent force F_{equ} as illustrated in Formula (11). The individual load actions shall be amplified by the relevant partial safety factors γ_p (see EN 13001-2) for the load combination under consideration, as given in Table 2.

$$F_{equ} = F_{gd} + F_{gl} + F_r + F_w + F_t + F_o \quad (11)$$

where

- F_{gd} is that part of F_{equ} that is induced by gravity forces of the rope driven masses, exclusive of the mass of the payload;
- F_{gl} is that part of F_{equ} that is induced by gravity forces of the rope driven mass of the payload;
- F_r is that part of F_{equ} that is induced by resistances;
- F_w is that part of F_{equ} that is induced by wind forces;
- F_t is that part of F_{equ} that is induced by rope tightening forces (see example in Figure 6);
- F_o is that part of F_{equ} that is induced by any other forces.

Table 2 — Partial safety factors γ_p

	Description	Regular loads Load combinations A	Occasional loads Load combinations B	Exceptional loads Load combinations C
F_{gd}	Gravitation on masses, exclusive of mass of payload	1,22	1,16	1,1
F_{gl}	Gravitation on payload	1,34	1,22	1,1
ϕ	Inertia	1,34	1,22	1,1
F_r	Resistances	1,34	1,22	1,1
F_t	Rope tightening	1,22	1,16	1,1
F_w	Wind forces: in service	—	1,22	1,16
	Wind forces: out of service	—	—	1,1
F_o	Snow and ice	—	1,22	1,1
	Temperature	—	1,16	1,05
	Buffer forces	—	—	1,1

5.3.3 Inertial effects

In non-vertical drives the inertial effects from accelerations shall be taken into account by the dynamic factor ϕ calculated as follows:

$$\phi = 1 + \frac{\left(\sum m_t + \sum m_r\right) \times a \times \phi_5 \times \gamma_p}{F_{equ}} \quad (12)$$

where

- Σm_t is the sum of translational rope driven masses, referred to the coordinate of acceleration;
- Σm_r is the sum of rotatory rope driven masses (see examples in Figure 5 and Figure 6), referred to the coordinate of acceleration;

a is the acceleration or deceleration;

ϕ_5 is the dynamic factor for loads caused by acceleration (see EN 13001–2);

γ_p is the partial safety factor, as given in Table 2, line inertia;

F_{equ} is the equivalent force.

5.3.4 Rope reeving efficiency

The increase of the design rope force by the rope reeving efficiency shall be taken into account by the rope force increasing factor f_{S1}, calculated as shown in 5.2.3, Formulae (6) and (7).

5.3.5 Non parallel falls

The increase of the design rope force by non-parallel falls shall be taken into account by the rope force increasing factor f_{S2}, calculated as shown in 5.2.4 and Formula (8).

5.4 Limit design rope force

The limit design rope force $F_{Rd,s}$ shall be calculated by

$$F_{Rd,s} = \frac{F_u}{\gamma_{rb}} \tag{13}$$

where

F_u is the specified minimum breaking force of the rope;

γ_{rb} is the minimum rope resistance factor.

The minimum rope resistance factor γ_{rb} is dependent on the geometry of the reeving system and is given by

$$\gamma_{rb} = 1{,}35 + \frac{5{,}0}{\left(\frac{D}{d}\right)^{0{,}8} - 4} \geq 2{,}07 \tag{14}$$

where

D is the minimum relevant diameter: D = Min (D_{sheave}; 1,125 × D_{drum}; 1,125 × D_{comp});

d is the rope diameter.

The chosen ratio D/d shall not be less than 11,2.

Table 3 gives minimum rope resistance factors for selected ratios of D/d.

Table 3 — Minimum rope resistance factor γ_{rb}

D/d	11,2	12,5	14,0	16,0	18,0	≥ 20,0
γ_{rb}	3,07	2,76	2,52	2,31	2,17	2,07

6 Proof of fatigue strength

6.1 General

According to test results the fatigue strength of ropes in terms of number of bendings (rope force to number of bendings relationship) is approximately inversely proportional to the second power of the applied rope tension force. With the additional requirement that the ratio of the rope bending diameter D to the rope diameter d increases with the number of bendings w_{tot} according to

$$\frac{D}{d} \sim 1{,}125^{\log_2 \left(w_{tot}\right)} \qquad (15)$$

(i.e. D/d increases by 1,125 for increasing w_{tot} by 2), the rope force to number of bendings relationship is closely inversely proportional to the power of 3. Therefore, this additional criteria is used in the calculation of the rope force history.

When counting bendings on a rope all movements, with or without load, included in a work cycle as specified for the crane, shall be taken into account. In the rope force spectrum calculation movements at different force levels are calculated separately. For details of bending counting, see Annex A.

For the proof of fatigue strength it shall be proven that

$$F_{Sd,f} \leq F_{Rd,f} \qquad (16)$$

where

$F_{Sd,f}$	is the design rope force for fatigue;
$F_{Rd,f}$	is the limit design rope force for fatigue;

6.2 Design rope force

6.2.1 Principle conditions

The design rope force $F_{Sd,f}$ shall be calculated for regular loads (load combinations A, see EN 13001-2) only, with partial safety factors γ_p and rope reeving efficiency η_{tot} set to 1.

For vertical hoisting:

$$F_{Sd,f} = \frac{m_{Hr} \times g}{n_m} \times \phi^* \times f_{S2}^* \times f_{S3}^* \times \gamma_n \qquad (17)$$

where

m_{Hr}	is the mass of the hoist load (m_H) or that part of the mass of the hoist load that is acting on the rope (see Figure 1);
g	is the acceleration due to gravity (gravity constant);
n_m	is the mechanical advantage of falls carrying m_{Hr};
ϕ^*	is the dynamic factor for inertial and gravity effects as shown in 6.2.2;
f_{S2}^*, f_{S3}^*	are the rope force increasing factors as shown in 6.2.3 to 6.2.4.

γ_n is the risk coefficient (see EN 13001–2), where applicable.

For non-vertical drives:

$$F_{Sd,f} = \frac{F_{equ}}{n_m} \times \phi^* \times f_{S2}^* \times \gamma_n \quad (18)$$

where

F_{equ} is the equivalent force acting on the rope according to the principles of 5.3.2;

n_m is the mechanical advantage of the reeving;

ϕ^* is the dynamic factor for inertial effects as shown in 6.2.2;

f_{S2}^* is the rope force increasing factor as shown in 6.2.3;

γ_n is the risk coefficient (see EN 13001–2), where applicable.

For vertical and non-vertical drives the following applies:

— Instead of the rope force increasing factors f_{si}^* the factors f_{si} as given in Clause 5 may be used.

— Instead of the dynamic factor ϕ^* the factor ϕ as given in Clause 5 may be used.

6.2.2 Inertial effects

As the inertial effects act for short time only, they do not affect all bendings. Therefore the dynamic factors ϕ^* may be calculated by

$$\phi^* = \sqrt[3]{\frac{(w-1)+\phi^3}{w}} \quad \text{for } w \geq 1 \quad (19)$$

$$\phi^* = \phi \quad \text{for } w = 0{,}5$$

where

w is the relevant number of bendings per movement;

ϕ is the dynamic factor (see 5.2.2 or 5.3.3).

6.2.3 Non parallel falls

Non parallel falls shall be taken into account in the proof of fatigue strength. The distribution of height and angle within the working range can be taken into account by the rope force increasing factor f_{S2}^*.

When the crane operates approximately equal on all heights of the most frequent working range, the density function is constant

$$q(z) = \frac{1}{z_2 - z_1} \quad (20)$$

and f_{S2}^* may be calculated as

$$f_{S2}^{*} = 1 + \left[\frac{1}{\cos \beta(z_2)} - 1 \right] \times \left(\frac{z_{ref} - z_2}{z_{ref} - z_1} \right)^{0,9} \tag{21}$$

In general cases f_{S2}^{*} should be calculated as

$$f_{S2}^{*} = \sqrt[3]{\int_{z_{min}}^{z_{max}} \frac{q(z)}{\cos^3 \beta(z)} dz} \tag{22}$$

where

z are height coordinates as shown in Figure 7,

z_{ref} is the reference height,

the whole working range is from z_{min} to z_{max},

the most frequent working range is from z_1 to z_2;

$\beta(z)$ is the angle between rope and line of the acting force;

$q(z)$ is the normalized height density of the crane, when used in the working range, where

$$\int_{z_{min}}^{z_{max}} q(z) dz = 1 \tag{23}$$

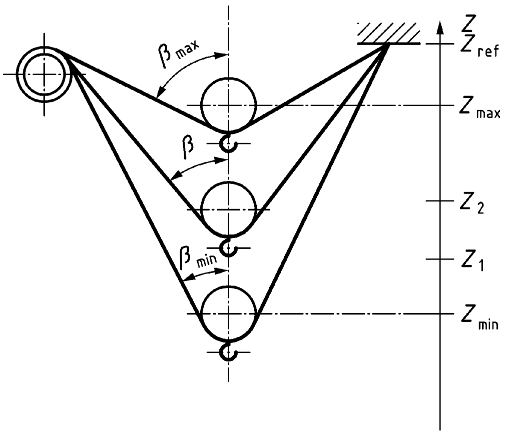


Figure 7 — Lifting positions

6.2.4 Horizontal forces in vertical hoisting

In applications with several non-parallel ropes (rope pyramid, see Figure 4), f_{S3}^{*} shall be calculated by

$$f_{S3}^{*} = f_{S3} \tag{24}$$

where

f_{S3} is the rope force increasing factor calculated from an average angle γ (see 5.2.5).

When horizontal forces and lifting acceleration do not act together regularly or where there is a considerable difference in acceleration time, f_{S3}^{*} may be set to 1.

6.3 Limit design rope force

6.3.1 Basic formula

The limit design rope force $F_{Rd,f}$ shall be calculated by

$$F_{Rd,f} = \frac{F_u}{\gamma_{rf} \times \sqrt[3]{s_r}} \times f_f \quad (25)$$

where

F_u is the specified minimum breaking force of the rope ;

s_r is the rope force history parameter;

γ_{rf} is the minimum rope resistance factor: $\gamma_{rf} = 7$;

γ_{rf} combines a safety factor (taking into account the uncertainty of fatigue strength values and the possible consequences of fatigue damage) and a factor that reduces F_u to fatigue strength at reference point (see 6.3.4);

f_f is the factor of further influences (see 6.4 and Formula (30)).

6.3.2 Rope force history parameter

In analogy to stress history parameter in accordance with EN 13001-1, the rope force history parameter is given by

$$s_r = k_r \times v_r \quad (26)$$

where

k_r is the rope force spectrum factor;

v_r is the relative total number of bendings.

6.3.3 Rope force spectrum factor

The rope force spectrum factor k_r is calculated by

$$k_r = \sum_{i=1}^{i_{max}} \left(\frac{F_{Sd,f,i}}{F_{Sd,f}} \right)^3 \times \frac{w_i}{w_{tot}} \quad (27)$$

where

i is the index of one movement with $F_{Sd,f,i}$;

i_{max} is the total number of movements per rope. All the working cycles C shall be taken into account, numbers of which per rope equals to C/l_r;

$F_{Sd,f,i}$ is the design rope force in movement i;

$F_{Sd,f}$ is the maximum design rope force;

w_i is the relevant number of bendings in one movement i (see Annex A);

w_{tot} is the total number of bendings during the design life of a rope;

C is the total number of working cycles during the design life of the crane in accordance with EN 13001–1;

l_r is the number of ropes specified for the design life of the crane (guidance for l_r is given in the Annex B).

The total number of bendings w_{tot} is calculated by

$$w_{tot} = \sum_{i=1}^{i_{max}} w_i \quad (28)$$

where

w_i is the relevant number of bendings per movement (see Annex A);

i_{max} is the total number of movements per rope.

6.3.4 Relative total number of bendings

The relative total number of bendings is calculated by

$$v_r = \frac{w_{tot}}{w_D} \quad (29)$$

where

w_{tot} is the total number of bendings during the design life of a rope;

w_D is the number of bendings at reference point: $w_D = 5 \cdot 10^5$

6.4 Further influences on the limit design rope force

6.4.1 Basic formula

The factor f_f takes into account further influences on the limit design rope force:

$$f_f = f_{f1} \times f_{f2} \times f_{f3} \times f_{f4} \times f_{f5} \times f_{f6} \times f_{f7} \quad (30)$$

where

f_{f1} to f_{f7} are the factors of influences as given in 6.4.2 to 6.4.6.

6.4.2 Diameters of drum and sheaves

The additional requirement of 6.1 that the ratio D/d of the rope bending diameter D to the rope diameter d increases with the number of bendings w_{tot} according to Formula (15), is incorporated in Formula (32).

D shall be calculated by

$$D = \text{Min}\left[D_{\text{sheave}}; 1{,}125 \times D_{\text{drum}}; 1{,}125 \times D_{\text{comp}}\right] \tag{31}$$

The reference ratio value of D/d is calculated by

$$R_{\text{Dd}} = 10 \times 1{,}125^{\log_2\left(\frac{w_{\text{tot}}}{8000}\right)} \tag{32}$$

and thus increses with increasing total number of bendings.

The factor f_{f1} is calculated by

$$f_{\text{f1}} = \frac{D/d}{R_{\text{Dd}}} \tag{33}$$

The chosen ratio D/d shall not be less than 11,2 and shall be selected such that f_{f1} becomes equal or greater than 0,75.

Table 4 gives commonly used values of ratio D/d:

Table 4 — Commonly used values of ratio *D*/*d*

D/d	11,2	12,5	14,0	16,0	18,0	20,0	22,4	25,0	28,0	31,5

6.4.3 Tensile strength of wire

A nonlinear relationship between the rope grade R_r of the wire and the limit design rope force shall be taken into account by

$$f_{\text{f2}} = \left(\frac{1770}{R_{\text{r}}}\right)^{0,6}, \quad \text{for } R_{\text{r}} > 1\,770 \tag{34}$$

$$f_{\text{f2}} = 1, \quad \text{for } R_{\text{r}} \le 1\,770$$

where

R_r is the rope grade, which is designated by a number (e.g. 1 770, 1 960), in accordance with EN 12385-4.

6.4.4 Fleet angle

Fleet angles at sheaves or drums are illustrated in Figure 8. Fleet angles shall always be counted positive. For a selected point (P) of the rope, the design fleet angle δ being associated with the most frequent working range (Z_1 to Z_2) shall be taken into account by factor f_{f3} as given in Table 5. The design fleet angle shall be calculated by

$$\delta = \sqrt[3]{\frac{\sum_{j=1}^{n} \delta_j^3}{n}} \quad (35)$$

where

δ_j is the fleet angle at the tangential contact point j of rope at drum or sheave (see Figure 8);

n is the number of contact points passed by the most bent part of the rope (see Figure 8 for an example with n = 6).

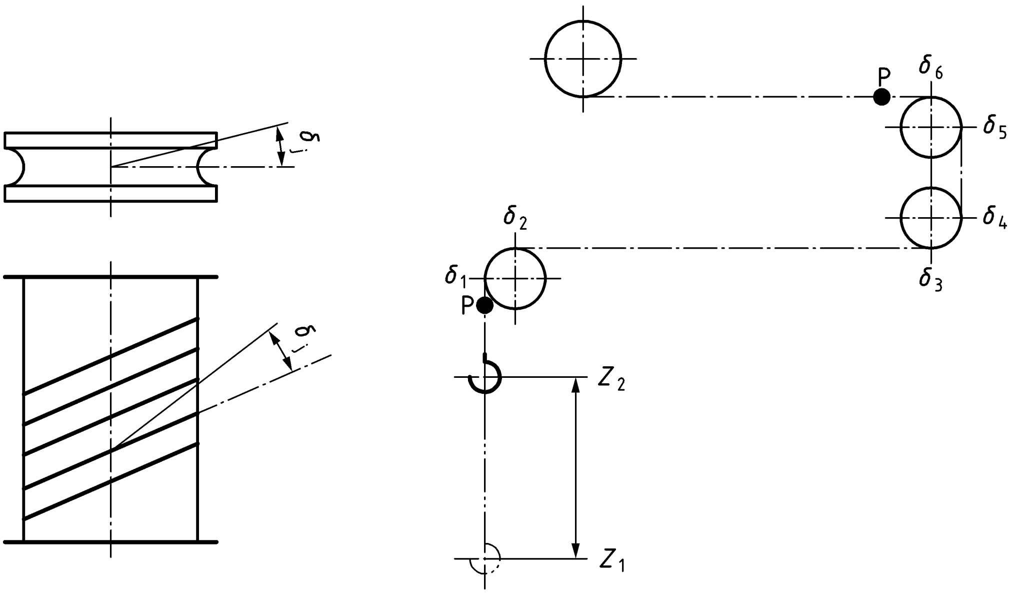


Figure 8 — Fleet angles

Table 5 — Factor f_{f3}

Design fleet angle δ	f_{f3} for non-rotation resistant rope	f_{f3} for rotation resistant rope
≤ 0,5°	1,0	1,0
1,0°	0,95	0,95
2,0°	0,86	0,84
3,0°	0,84	not covered
4,0°	0,82	
Intermediate values may be interpolated.		

6.4.5 Rope lubrication

For ropes manufactured with internal lubrication the factor f_{f4} is set to one. For ropes without internal lubrication (e.g. clean room) the factor f_{f4} shall be f_{f4} = 0,5.

6.4.6 Groove

The ratio of groove radius r_g to rope diameter d and the requirements for angle ω between the sides of a sheave (see Figure 9) shall be taken into account by f_{f6} according to Table 6.

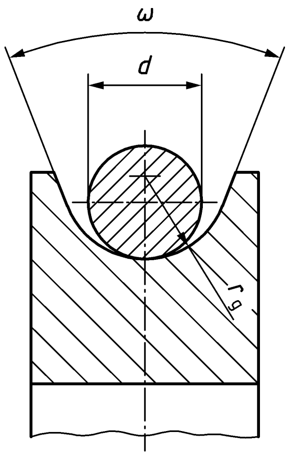


Figure 9 — Groove

Table 6 — Factor f_{f6}

r_g/d	ω	f_{f6}
0,53	≤ 60°	1
0,55		0,92
0,6	No requirement	0,86
0,7		0,79
0,8		0,76
≥ 1,0		0,73
Intermediate values may be interpolated.		

6.4.7 Rope types

Differing bending fatigue performance of the various rope types shall be taken into account by the factor f_{f7}, given by

$$f_{f7} = \frac{1}{t} \quad (36)$$

where

t is the rope type factor.

The rope type factor t is dependent upon the number of outer strands as given in Table 7.

Table 7 — Rope type factors

Rope type in accordance with EN 12385–2	Number of outer strands	*t*-factor
Single layer or parallel-closed	3	1,25
	4, 5	1,15
	6 or more	1,00
	6 to 10 with plastic impregnation	0,95
Rotation-resistant and non-compacted	all	1,00
Rotation-resistant, compacted	all	0,9

6.5 Additional requirements for multilayer drum

When using a multilayer drum design the useful life of the wire rope will be much shorter than the design life with a single layer drum due to e.g.

— Increased wear due to sliding contact at cross-over areas

— Plastic deformation at cross-over areas

— Lack of pretension in the lower layers

— Rope crushing

These effects shall be taken into account. In the absence of more definitive methods the reduction of the limit design rope force by the factor f_{f5} as given in Table 8 may be applied.

Table 8 — Factor f_{f5}

$i_{max} \cdot k_r$	f_{f5} for drum without guided spooling	f_{f5} for drum with guided spooling
$i_{max} \cdot k_r \leq 500$	1,0	1,0
$500 < i_{max} \cdot k_r \leq 1\,000$	0,9	1,0
$1\,000 < i_{max} \cdot k_r \leq 2\,000$	0,8	1,0
$2\,000 < i_{max} \cdot k_r \leq 5\,000$	0,7	0,9
$5\,000 < i_{max} \cdot k_r$	0,6	0,8
Where i_{max} is the total number of movements and k_r is the rope force spectrum factor. Means for guided spooling are rope guide connected to the rotation of drum, rope wedges, starter strips or groove (e.g. Lebus drums).		

A drum system, where two separate ropes are spooled on top of each other but both ropes only in a single layer, spooling is guided and neither of the ropes crosses over anywhere with itself or the other rope, is regarded a single layer drum.

To ensure safe use of the rope, the discard criteria in accordance with ISO 4309 shall be applied.

NOTE This clause is subject to technical development and will be amended, when more data are available.

7 Stationary ropes

7.1 Proof of static strength

The design rope forces $F_{Sd,s}$ for stationary ropes shall be calculated considering the rope as a beam with one degree of freedom.

For the proof of static strength it shall be proven that for all relevant load combinations of EN 13001-2

$$F_{Sd,s} \leq F_{Rd,s} \tag{37}$$

where

$F_{Sd,s}$ is the design rope force;

$F_{Rd,s}$ is the limit design rope force.

The limit design rope force $F_{Rd,s}$ is given by

$$F_{Rd,s} = \frac{F_u}{\gamma_{rb}} \tag{38}$$

where

F_u is the specified minimum breaking force of the rope;

γ_{rb} is the minimum rope resistance factor, $\gamma_{rb} = 2{,}5$.

7.2 Proof of fatigue strength

The design rope force $F_{Sd,f}$ shall be calculated considering the rope as a beam with one degree of freedom for regular loads (load combinations A, see EN 13001-2) only, with partial safety factors γ_p set to 1.

The number of stress cycles N shall be derived from the number of working cycles C (see EN 13001-1) of the crane.

For the proof of fatigue strength it shall be proven that

$$F_{Sd,f} \leq F_{Rd,f} \tag{39}$$

where

$F_{Sd,f}$ is the design rope force for fatigue;

$F_{Rd,f}$ is the limit design rope force for fatigue.

The limit design rope force $F_{Rd,f}$ shall be calculated by

$$F_{Rd,f} = \frac{F_u}{\gamma_{rf} \times \sqrt[3]{s_r}} \times f_{f2} \tag{40}$$

where

F_u is the specified minimum breaking force of the rope;

s_r is the rope force history parameter;

γ_{rf} is the minimum rope resistance factor: γ_{rf} = 7;

γ_{rf} combines a safety factor (taking into account the uncertainty of fatigue strength values and the possible consequences of fatigue damage) and a factor that reduces F_u to fatigue strength at reference point (see 6.3.4);

f_{f2} is the factor for the influence of the tensile strength of the wire in accordance with 6.4.3:

In analogy to stress history parameter in accordance with EN 13001-1, the rope force history parameter is given by

$$s_r = k_r \times v_r \tag{41}$$

where

k_r is the rope force spectrum factor;

v_r is the relative total number of stress cycles.

The rope force spectrum factor k_r is calculated by

$$k_r = \sum_{i=1}^{N} \left(\frac{F_{Sd,f,i}}{F_{Sd,f}} \right)^3 \times \frac{1}{N} \tag{42}$$

where

i is the index of one stress cycle ;

$F_{Sd,f,i}$ is the design rope force in stress cycle i;

$F_{Sd,f}$ is the maximum design rope force;

N is the total number of stress cycles during the design life of the crane.

The relative total number of stress cycles is calculated by

$$v_r = \frac{N}{N_D} \tag{44}$$

where

N_D is the number of stress cycles at reference point: $N_D = 5 \cdot 10^5$.

Annex A
(normative)

Number of relevant bendings

The number of relevant bendings of a rope within a work cycle shall be established for the most unfavourable part of the rope by counting the sum of bending counts w_c.

In vertical drives one movement is considered to comprise both a lifting and lowering action, with or without load. In non-vertical drives, back and forth movements are treated analogous as one horizontal movement.

Where other crane motions cause bendings in the ropes of vertical drives (e.g. trolley movement in a tower crane), any additional bendings induced shall be taken into account.

Each lifting and lowering movement included in a specified work cycle shall be taken into account. Examples of vertical movements, which may occur within a work cycle, are

a) Lifting and lowering a load and return movement (lifting and lowering) of an unloaded load lifting attachment. Separate bending counts shall be done for the loaded and unloaded movement.

b) Lifting a load and lowering an unloaded load lifting attachment (e.g. when loads are deposited at upper level). Due to different rope forces in the movements, separate bending counts are needed, but both of those with a halved number of bendings given in the tables i.e. $w_c/2$.

In non-vertical drives, division of a work cycle into differently loaded movements shall be done analogous to hoisting drives.

The bending counts in the Tables A.1 and A.2 assume a reverse movement of the rope over a sheave or to and from a drum. Table A.2 shows examples of vertical drives assuming movements where the most bent part of the rope runs from the drum over all sheaves and where the bending count comprises both of a lifting and lowering action.

Table A.1 — Bending counts

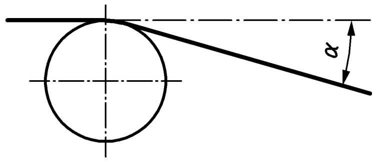
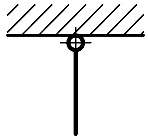
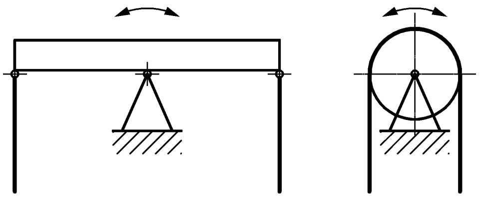
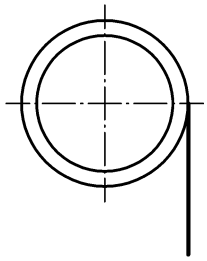
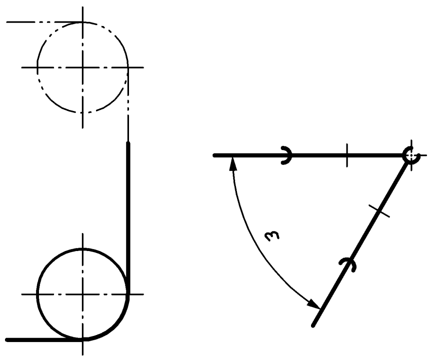
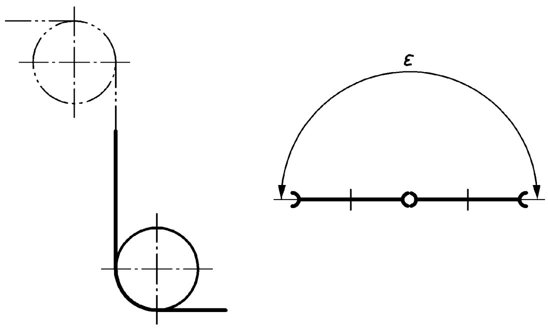
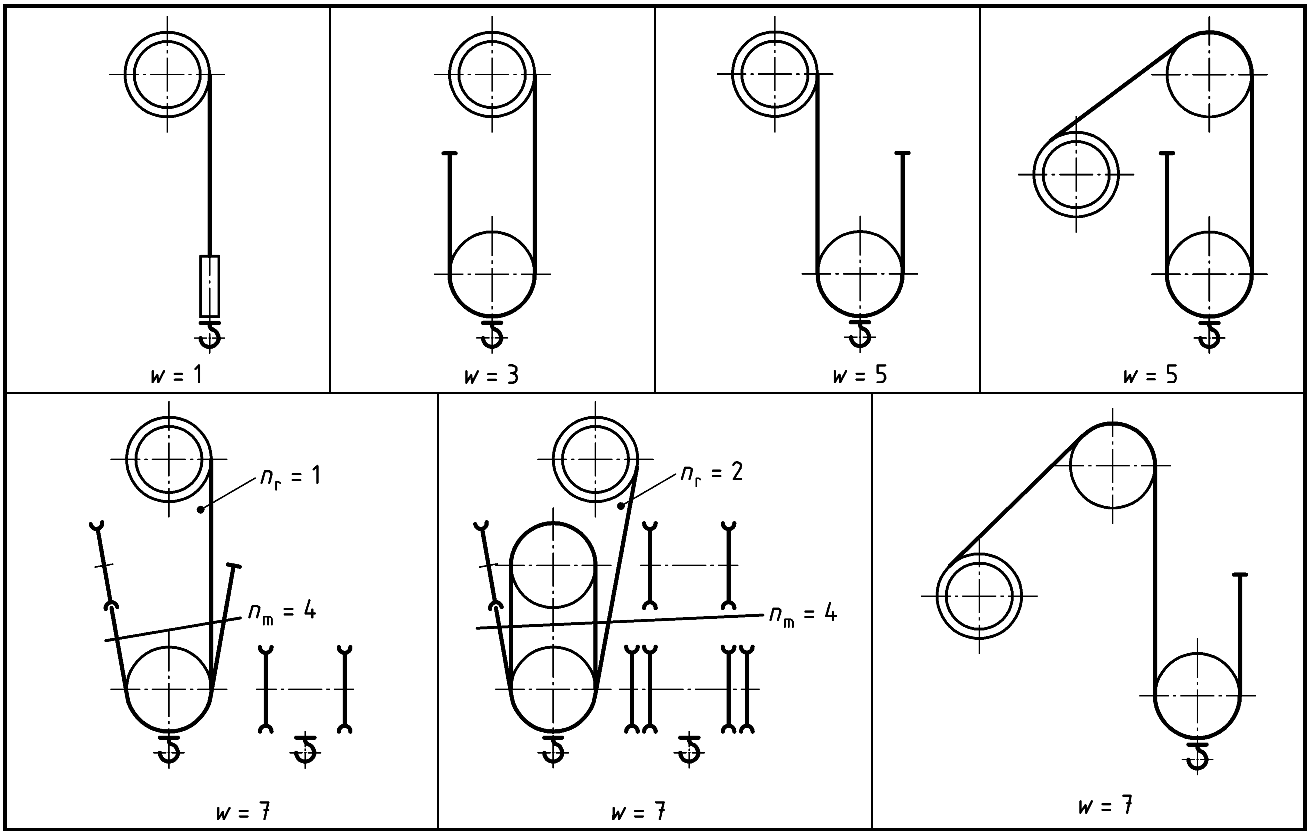
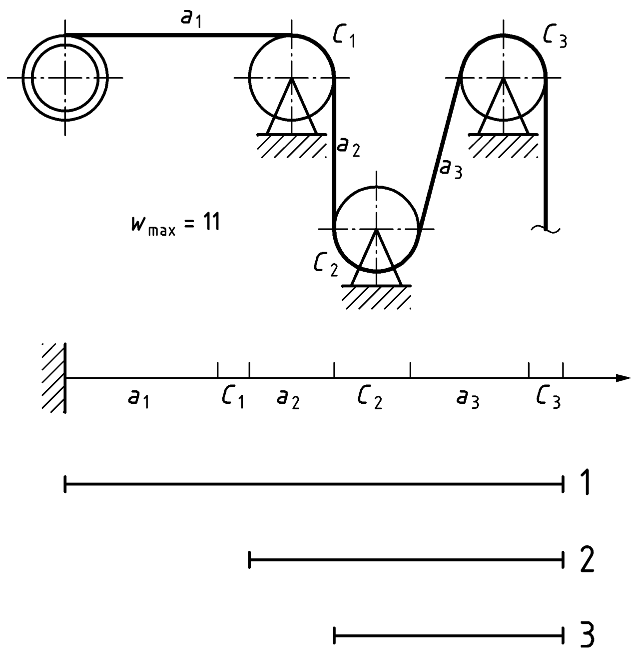
Type of bending	Illustration	Bending count
Any bending with a deflection angle *α* less than 5°.		$w_c = 0$
Rope termination		$w_c = 0$
Compensating sheave/whip		$w_c = 0$
Drum		Single layer: $w_c = 1$ Multilayer with guided spooling: $w_c = 3$ Multilayer without guided spooling: $w_c = 8$
Sheave with same sense bending (angle *ε* between planes less than 120°)		$w_c = 2$
Sheave with reverse sense bending (angle *ε* ≥ 120°)		$w_c = 4$

Table A.2 — Examples for the number of relevant bendings w



The bending count assumes one movement which comprises of both a lifting and lowering action.

If during the cycle the rope runs only over a part of the sheaves, w depends on the length of the stroke. Figure A.1 gives an example:



Key

a_1, a_2, a_3	length between sheaves
c_1, c_2, c_3	circumferential length
1	rope travel distance w = 11
2	rope travel distance w = 10
3	rope travel distance w = 6

Figure A.1 — Number of relevant bendings

Annex B
(informative)

Guidance for selection of design number of hoist ropes l_r used during the design life of crane

Item no.	Type of crane	Operation method	U-class (see EN 13001–1)	Number of ropes l_r
1	Hand-operated cranes		U0 – U2	1–2
2	Assembly cranes		U0 – U2	1–2
3	Powerhouse cranes		U1 – U3	1–3
4	Warehouse cranes	Intermittent operation	U4 – U5	3–6
5	Warehouse cranes, lifting beam cranes, scrapyard cranes	Continuous operation	U6 – U8	6–14
6	Workshop cranes		U3 – U5	2–6
7	Bridge cranes, skull cracker cranes	Grab, magnet, spreader	U6 – U8	6–14
8	Ladle cranes		U6 – U8	6–14
9	Pit cranes		U7 – U9	8–20
10	Stripper cranes, charging cranes		U8 – U9	10–20
11	Forging cranes		U6 – U8	6–14
12	Unloaders, stocking and reclaiming bridges, semi-portal cranes, portal cranes with trolley or slewing crane	Hook service	U4 – U6	3–8
13		Grab, magnet, spreader	U6 – U9	6–20
14	Travelling conveyor gantries with fixed or sliding conveyor(s)		U3 – U5	2–6
15	Shipbuilding cranes, slipway cranes, fitting-out cranes	Hook service	U3 – U5	2–6
16	Wharf cranes, slewing cranes, floating cranes, level-luffing slewing cranes	Hook service	U4 – U6	3–8
17		Grab, magnet, spreader	U6 – U8	6–14
18	High-capacity floating cranes, high capacity gantry cranes		U1 – U3	1–3
19	Shipdeck cranes	Hook service	U3 – U5	2–6
20		Grab, magnet, spreader	U4 – U6	3–8
21	Revolving tower cranes for construction service		U1 – U4	1–4
22	Erection cranes, derricks	Hook service	U1 – U3	1–3
23	Rail-mounted slewing cranes	Hook service	U3 – U5	2–6
24		Grab, magnet, spreader	U4 – U6	3–8
25	Locomotive cranes, licensed for in-train Haulage		U4 – U5	3–6
26	Loader cranes, mobile cranes	Hook service	U2 – U5	2–6
27		Grab, magnet, spreader	U4 – U6	3–8
28	High capacity loader and mobile cranes		U1 – U3	1–3

Annex C
(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 — 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 — Non-fixed load lifting attachments
EN 14238	Cranes — Manually controlled load manipulating devices
EN 15056	Cranes — Requirements for container handling spreaders

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	Crane safety — General design — Part 2: Load actions
EN 13001–3-1	Cranes — General Design — Part 3–1: Limit States and proof of competence of steel structure
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 14502–1	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 Machinery 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.

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[2] Feyrer, Klaus: *Laufende Drahtseile — Bemessung und Überwachung. Renningen-Malsheim: Expert-Verlag1998. ISBN 3-8169-14810*[1)]

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[1)] According to the website of Expert Verlag a new third edition has been published in 2005: Wehking, Karl-Heinz: Laufende Seile — Bemessung und Überwachung. ISBN 3-8169-2497-2

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