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Cranes and hoists — Selection of wire ropes, drums and sheaves

Appareils de levage à charge suspendue et treuils — Choix des câbles, tambours et poulies

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 96, *Cranes*, Subcommittee SC 3, *Selection of ropes.*

This second edition cancels and replaces the first edition (ISO 16625:2013), which has been technically revised.

The main changes are as follows:

— rope selection has been based on working cycles as opposed to the previous time-based concept;

— different proofs of competence for running ropes (static, fatigue, multilayer spooling) and stationary ropes (static, fatigue) have been incorporated;

— the substantial innovation of this document lies in a new mathematical approach for the proof of fatigue strength of running steel wire ropes. A new reference point has been introduced as a characteristic value for the fatigue strength, from which the S-N curves of the fatigue strength of steel wire ropes at different D/d-ratios are described;

— additional annexes have been introduced:

  — Annex A (normative) Number of relevant bending cycles;

  — Annex B (informative) Determination of the maximum tensile force in the ropes of multi-rope grabs (holding and closing);

  — Annex C (informative) Comparison of the minimum design factor according to ISO 16625:2013 and safety level according current version;

  — Annex D (informative) Selection of a rope by minimum design factor Z_p ;

  — Annex E (informative) Assumed number of hoist ropes $\boldsymbol{l}_{\mathbf{r}}$ during life of a crane.

This document is intended to be used together with the ISO 4301-1 or other applicable part of the ISO 4301 series, ISO 4309, ISO 8686-1 or applicable part of the ISO 8686 series.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Cranes and hoists — Selection of wire ropes, drums and sheaves

1 Scope

This document provides a proof of competence and criteria for the selection of steel wire ropes used in cranes as defined in ISO 4306-1.

The influence of the geometry of the rope drive, as well as drum and sheave geometry, are incorporated in the proof of competence.

This document does not apply to fibre ropes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2408, *Steel wire ropes — Requirements*

ISO 4301-1, *Cranes — Classification — Part 1: General*

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

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

ISO 8686-1:2012, *Cranes — Design principles for loads and load combinations — Part 1: General*

ISO 8686-2, *Cranes — Design principles for loads and load combinations — Part 2: Mobile cranes*

ISO 8686-3, *Cranes — Design principles for loads and load combinations — Part 3: Tower cranes*

ISO 8686-4, *Cranes — Design principles for loads and load combinations — Part 4: Jib cranes*

ISO 8686-5, *Cranes — Design principles for loads and load combinations — Part 5: Overhead travelling and portal bridge cranes*

ISO 8793, *Steel wire ropes — Ferrule-secured eye terminations*

ISO 17558, *Steel wire ropes — Socketing procedures — Molten metal and resin socketing*

ISO 17893, *Steel wire ropes — Vocabulary, designation and classification*

ISO 20332, *Cranes — Proof of competence of steel structures*

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 sockets*

EN 13411-8, *Terminations for steel wire ropes — Safety — Part 8: Swage Terminals and Swaging*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4301-1, ISO 4306-1, ISO 17893 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
running rope
rope which is wound on and off a drum and bent over sheaves and/or drums, therefore stressed mainly by bending and secondly by tension

3.1.2
stationary rope
rope fixed at both ends, primarily under tensile load, and which is not subject on coiling (winding) on a drum or over a sheave

3.1.3
design life
estimation of the intended period of use for a crane, or component based on its original design specification and taking into consideration the load cycles and load spectrum expected during its intended usage

Note 1 to entry: According to ISO 4301-1, a rope is considered to be a component in this document.

[SOURCE: ISO 12482:2014, 3.2, modified]

3.1.4
work cycle
operating sequence starting from hoisting a load, transferring the load, lowering and grounding the load, detaching the load and moving the unloaded load lifting attachment back to a starting position ready to hoist another load

[SOURCE: ISO 12482:2014, 3.6]

3.1.5
rope bending diameter
diameter of the axis of the rope in the state when bent over a sheave or a drum

3.2 Symbols

The main symbols used in this document are given in ISO 4301-1, ISO 8686-1, ISO 20332 and Table 1.

Table 1 — Symbols

Symbols	Description
A	Classes for group classification of a crane or hoist (see ISO 4301-1)
A_C	Classes for group classification of a component (see ISO 4301-1)
a	Acceleration or deceleration
C	Total number of working cycles during design life of a crane (see ISO 4301-1)
C_r	Total number of working cycles during the design life of a rope
D	Rope bending diameter
D_1	Rope bending diameter of drum

Table 1 *(continued)*

Symbols	Description
D_2	Rope bending diameter of sheave
d	Nominal rope diameter
F, S	Rope tension force
F_h	Horizontal force acting on the hoist load
F_{min}	Minimum breaking force of the rope (see ISO 17893)
$F_{Rd,f}$	Limit design rope force for the proof of fatigue strength
$F_{Rd,m}$	Limit design rope force for multilayer spooling
$F_{Rd,s}$	Limit design rope force for the proof of static strength
F_{ref}	Reference value of rope tensile force to describe the reference point of the S-N curve (Wöhler-curve) at the proof of fatigue strength
F_{Sd}	Design rope force
$F_{Sd,f}$	Design rope force for the proof of fatigue strength
$F_{Sd,m}$	Design rope force for multilayer spooling
$F_{Sd,s}$	Design rope force for the proof of static strength
f_F	Factor of further influences to the rope tension force F_{ref}
f_{F1}	Factor of influence of wire tensile strength
f_{F2}	Factor of fleet angle influence
f_{F3}	Factor of lubrication influence
f_{F4}	Factor of groove radius influence
f_{S1}	Rope force increasing factor from rope reeving efficiency to be used at the proof of static strength
f_{S2}	Rope force increasing factor from non-parallel falls to be used at the proof of static strength
f_{S3}	Rope force increasing factor from horizontal forces to be used at the proof of static strength
f_{S4}	Rope force reduction factor due to the type of rope termination to be used at the proof of static strength
f_{S2}^*	Rope force increasing factor from non-parallel falls to be used at the proof of fatigue strength
f_{S3}^*	Rope force increasing factor from horizontal forces to be used at the proof of fatigue strength
f_w	Factor of further influences to the reference number of bending cycles w_{ref}
f_{w1}	Factor of rope type influence
f_{w2}	Factor of rope diameter influence
g	Acceleration due to gravity
K_p	Load spectrum factor (see ISO 4301-1)
k_r	Rope force spectrum factor
l_r	Number of ropes assumed to be used during the design life of the crane
m	Exponent, slope of the S-N curve (Wöhler-curve)
m_H	Mass of the hoist (gross) load (see ISO 8686-1)
m_{Hr}	Mass of the hoist load or that part of the mass of the hoist load that is acting on the rope falls
$m_{Hr,1}$	Portion of the total mass of the hoist load m_H that is acting on the closing ropes
$m_{Hr,2}$	Portion of the total mass of the hoist load m_H that is acting on the holding ropes
m_R	Mass of the portion of the suspended ropes of the hoist drive
N_{ref}	Number of tensile force cycles at reference point (see also ISO 20332)
N_t	Total number of tensile force cycles during the design life of a crane (see ISO 20332)
n	Number of contact points passed by a part of the rope that initiates a change of curvature in the rope
n	Number of tensile force cycles

Table 1 *(continued)*

Symbols	Description
n_m	Mechanical advantage
n_s	Number of fixed sheaves between drum and moving part
$p_{f,r}$	Proof of fatigue strength for running ropes
$p_{f,s}$	Proof of fatigue strength for stationary ropes
$p_{m,r}$	Proof of competence for multilayer spooling for running ropes
$p_{s,r}$	Proof of static strength for running ropes
$p_{s,s}$	Proof of static strength for stationary ropes
$q(z)$	Normalized position density
R_r	Rope grade (see ISO 2232)
r_g	Groove radius
S_k	Design load effect in rope drive *k* of ropes or rope falls, as an inner force, resulting from load combination F_j
S_r	Resulting design force in particular rope
S_{r1}	Design load effect in particular rope
S_{r2}	Design load effect in particular rope arising from local effects
s_r	Rope force history parameter
w	Number of bending cycles
w_c	Bending count of a particular type of bending
w_{Crane}	Assumed total number of bending cycles during the design life of a crane
w_{max}	Maximum number of bending cycles in the most unfavourable part of the reeving system
w_{ref}	Reference number of bending cycles of the S-N curve (Wöhler-curve) for the proof of fatigue strength
w_{tot}	Total number of bending cycles during the design life of a rope in the rope section
w^*	Assumed total number of bending cycles during the design life of a rope
Z_p	Minimum design factor
z, z_i, z_{min}, z_{max}, z_{ref}	Position coordinates
α	Deflection angle
β_{max}	Maximum angle between falls and line of action of force
$\beta(z)$	Angle between falls and line of action of force depending on coordinate z
γ	Angle between direction of gravity and rope projected in plane of F_h and g
γ_n	Risk coefficient (see ISO 8686-1)
γ_p	Partial safety factor (see ISO 8686-1)
γ_{rb}	Rope resistance factor to be used at the proof of static strength and multilayer spooling
γ_{ref}	Factor to adapt the minimum breaking force of the rope F_{min} to the reference rope tension force F_{ref} at the proof of fatigue strength
γ_{rf}	Rope resistance factor to be used at the proof of fatigue strength
γ_{rfD}	Minimum rope resistance factor to prevent from exceeding the Donandt-force
δ	Fleet angle
ε	Angle between sheave planes
η_s	Efficiency of applied rope, sheave and bearing
η_{tot}	Total rope reeving efficiency of the rope drive
ν_r	Relative total number of cycles
ϕ	Dynamic factor for inertial and gravity effects
ϕ^*	Dynamic factor for inertial effects at the proof of fatigue strength and multilayer spooling

Table 1 *(continued)*

Symbols	Description
ϕ_2	Dynamic factor for inertial and gravity effects when hoisting an unrestrained grounded load (see ISO 8686-1)
ϕ_5	Dynamic factor for inertial effect (see ISO 8686-1)
ϕ_6	Dynamic factor for inertial and gravity effects when hoisting an unrestrained grounded load under dynamic test load conditions (see ISO 8686-1)
ω	Groove opening angle

4 Running ropes and stationary ropes

4.1 General

Running ropes on cranes are stressed by tensile loads and by bending over sheaves and/or on drum. These cyclic load effects constitute a cumulative fatigue effect to the rope. Within this document this effect is expressed with the rope force history parameter s_r, which is independent of time. For the fatigue proof of competence, it is essential to select a proper number of ropes l_r, which are assumed to be used during the design life of the crane or hoist. Guidance for the choice of l_r is given in Annex E.

Stationary ropes are considered to be part of the cranes load bearing structure and are stressed primarily by tensile loads.

For both categories of wire ropes, running ropes and stationary ropes, several proofs of competence shall be performed.

For running ropes:

— static proof of competence, see 5.1;

— fatigue proof of competence, see 5.2;

— proof of competence for ropes in multilayer spooling, see 5.3, if applicable.

For stationary ropes:

— static proof of competence, see 6.1;

— fatigue proof of competence, see 6.2.

NOTE 1 Only in exceptional cases where some essential information regarding the crane or hoist is missing or some essential parameter values are unknown and cannot be obtained from the documentation of the crane or hoist, a selection of the wire rope according Annex D can be done in order to provide a minimum safety level.

NOTE 2 For the purposes of this document, 'single-layer ropes' and 'parallel-closed ropes', as defined in ISO 17893, are referred to as 'standard ropes' to distinguish themselves from 'rotation-resistant ropes'.

NOTE 3 Single-layer ropes and parallel-closed ropes are sometimes referred to as 'non-rotation-resistant ropes'.

4.2 Discard criteria

To ensure the safe use of the wire rope, the discard criteria of ISO 4309 shall apply.

If the intended number of ropes l_r to be used during the design life of the crane is greater than 1, then the design life of the specified rope shall be chosen to exceed the periodic inspection interval of the rope always.

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.

Further information is given in Annex F, F.3.

4.3 Rope and rope terminations

The wire rope shall meet the requirements specified in ISO 2408.

Ropes selected shall be fit for the application and be made of suitable materials so that they withstand the design forces during the design life of the rope.

The operating environment shall be taken into account and, if necessary, greasing, galvanising or special rope materials shall be considered.

Rope terminations shall meet the requirements of one or more of the following standards: ISO 8793, ISO 17558, EN 13411-3, EN 13411-4, EN 13411-6, EN 13411-8.

Rope terminations shall be such that bending of the rope adjacent to the termination and other additional stresses on the rope are eliminated.

For non-rotation resistant ropes, the end termination shall be made in such a way that it is not possible for the rope to twist around the longitudinal axis. For rotation resistant ropes, a swivel can be integrated in the end termination to relieve any twist induced into the rope reeving system.

Further information is given in Annex F, F.10.2 and F.11.

5 Proof of competence of running ropes

5.1 Proof of static strength

5.1.1 General

The proof of static strength according to Formula (1) shall be provided for all relevant load combinations according to ISO 8686-1, or ISO 8686-2, ISO 8686-3, ISO 8686-4 or ISO 8686-5, as applicable, considering the rope specific effects described in this document.

$$p_{s,r} : F_{Sd,s} \leq F_{Rd,s} \tag{1}$$

where

$p_{s,r}$ is the proof of static strength for running ropes;

$F_{Sd,s}$ is the design rope force for the proof of static strength;

$F_{Rd,s}$ is the limit design rope force for the proof of static strength.

5.1.2 Vertical hoisting of loads

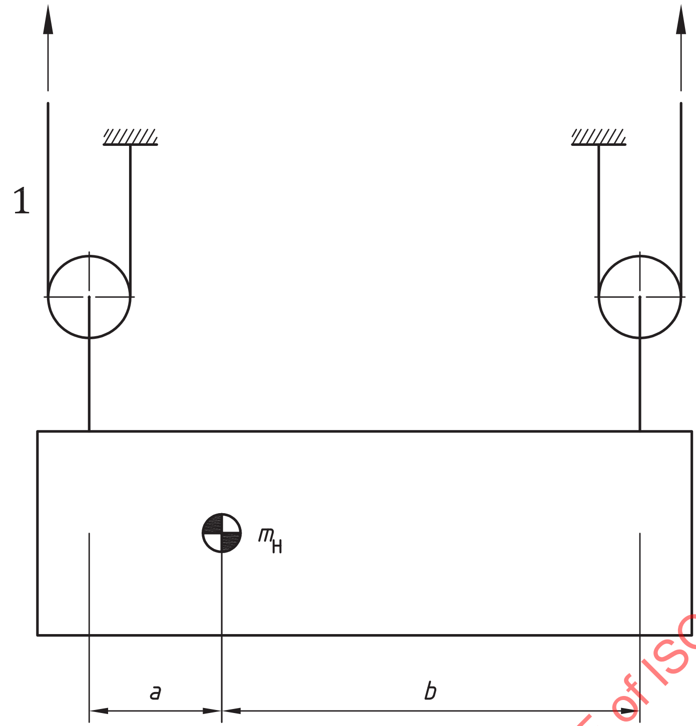
5.1.2.1 Design rope force

The design rope force $F_{Sd,s}$ in vertical hoisting of loads shall be calculated according to Formula (2):

$$F_{Sd,s} = \frac{m_{Hr} \times g}{n_m} \times \phi \times f_{S1} \times f_{S2} \times f_{S3} \times \gamma_p \times \gamma_n \tag{2}$$

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, load-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 reeving;
ϕ	is the dynamic factor for inertial and gravity effects, see 5.1.2.2;
f_{S1} to f_{S3}	are the rope force increasing factors, see 5.1.2.3;
γ_p	is the partial safety factor (see ISO 8686-1):
$\gamma_p = 1{,}34$	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, where applicable (see ISO 8686-1, additionally ISO 12100 may be used for risk assessment).



Key

1 rope number 1

2 rope number 2

m_H mass of the hoist load

a distance between line of action of rope drive 1 to the centre of gravity of the hoist load

b distance between line of action of rope drive 2 to the centre of gravity of the hoist load

Figure 1 — Example for acting ropes on eccentric mass of hoist load

Further information regarding the determination of the maximum tensile force in the ropes of multi-rope grabs is given in Annex B.

5.1.2.2 Inertial and gravitational effects acting vertically on the load

5.1.2.2.1 General

For vertical hoisting of loads the maximum inertial effects from either hoisting an unrestrained grounded load or from acceleration or deceleration of same shall be taken into account by the dynamic factor ϕ, given in 5.1.2.2.2 to 5.1.2.2.4 according to ISO 8686-1.

5.1.2.2.2 Hoisting an unrestrained grounded load

The dynamic factor ϕ to consider hoisting of an unrestrained grounded load shall be calculated according to Formula (3):

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

where ϕ_2 is the dynamic factor for inertial and gravity effects when hoisting an unrestrained grounded load (see ISO 8686-1).

5.1.2.2.3 Accelerating a suspended load

The dynamic factor ϕ to consider accelerating a suspended load shall be calculated according to Formula (4):

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

where

ϕ_5 is the dynamic factor for inertial effects when accelerating or decelerating a suspended load (see ISO 8686-1);

a is the vertical acceleration of the suspended load;

g is the acceleration due to gravity.

5.1.2.2.4 Hoisting of dynamic test load

The dynamic factor ϕ to consider hoisting of a dynamic test load shall be calculated according to Formula (5):

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

where ϕ_6 is the dynamic factor for inertial and gravity effects when hoisting an unrestrained grounded load under dynamic test load conditions (see ISO 8686-1).

NOTE When testing a crane typically dynamic and static tests are performed (see ISO 4310).

5.1.2.2.5 Loads caused by emergency cut-out

The dynamic factor ϕ to consider loads caused by emergency cut-out shall be calculated according to Formula (6):

$$\phi = 1 + \phi_5 \times \frac{a}{g} \tag{6}$$

where

ϕ_5 is the dynamic factor for inertial effects when accelerating a suspended load in an emergency cut-out situation (see ISO 8686-1);

a is the vertical acceleration or deceleration of the suspended load;

g is the acceleration due to gravity.

5.1.2.3 Rope force increasing factors

5.1.2.3.1 Rope reeving efficiency

The rope force increasing factor from rope reeving efficiency f_{S1} shall be calculated according to Formula (7):

$$f_{S1} = \frac{1}{\eta_{tot}} \tag{7}$$

with

$$\eta_{tot} = \frac{(\eta_S)^{n_s}}{n_m} \times \frac{1-(\eta_S)^{n_m}}{1-\eta_S} \tag{8}$$

where

η_{tot} is the total rope reeving efficiency of the rope drive;

η_S is the efficiency of applied rope, sheave and bearing:

for sheave with roller bearing, commonly used $\eta_S = 0{,}985$

for sheave with plain bearing, commonly used $\eta_S = 0{,}965$

NOTE The values for η_S vary due to the rope design, *D/d*-ratio and bearing type;

n_m is the mechanical advantage of reeving (see example in Figure 2);

n_s is the number of fixed sheaves between drum and moving part.

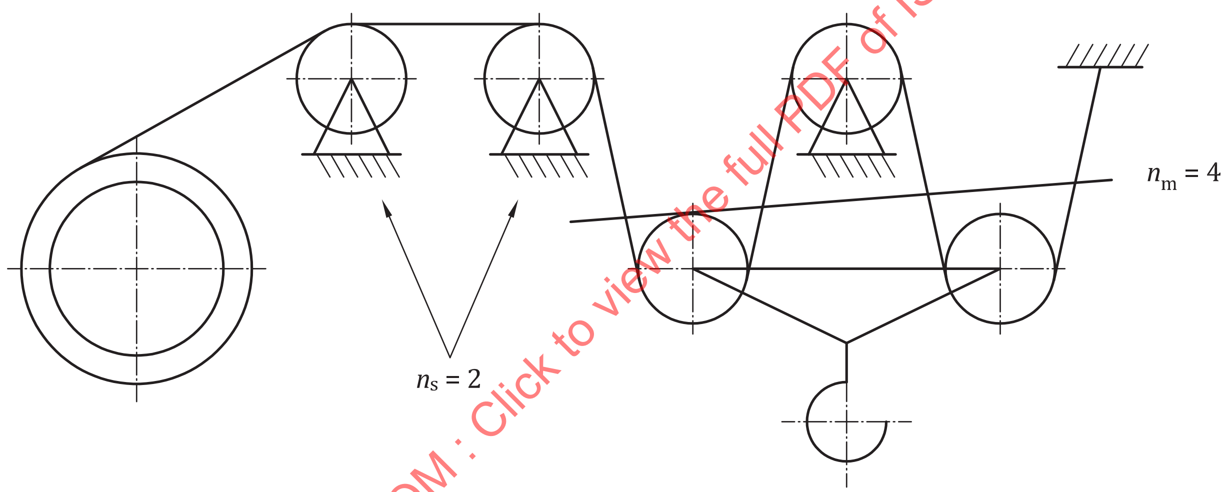


Figure 2 — Example of a rope reeving

5.1.2.3.2 Non-parallel falls

When the rope falls are not parallel, the rope force is increased. The rope force increasing factor from non-parallel falls f_{S2} shall be determined for the most unfavourable position.

The rope force increasing factor from non-parallel falls f_{S2} shall be calculated according to Formula (9):

$$f_{S2} = \frac{1}{\cos \beta_{max}} \tag{9}$$

where β_{max} is the maximum angle between falls and line of action of force, see Figure 3.

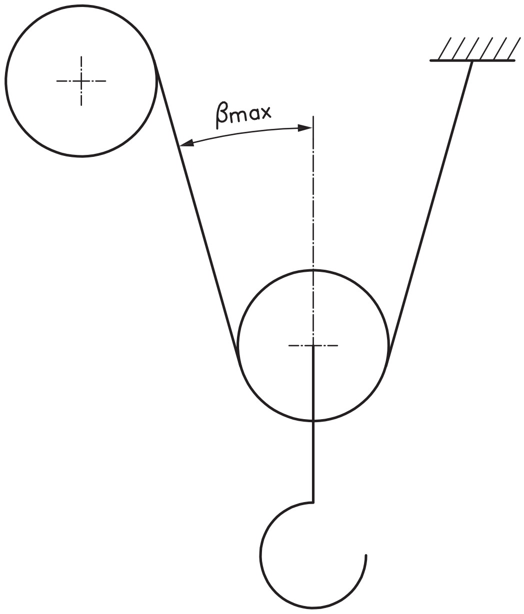


Figure 3 — Angle β_{max} at inclined rope falls

5.1.2.3.3 Horizontal forces acting on the hoist load

The rope force increasing effect due to 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 and independent ropes (e.g. anti-oscillatory reeving, see Figure 4) horizontal forces increase the rope force considerably. This effect shall be taken into account.

Simplified, the rope force increasing factor from horizontal forces f_{S3} may be calculated according to Formula (10):

$$f_{S3} = 1 + \frac{F_h}{m_{Hr} \times g \times \tan\gamma} \leq 2 \quad (10)$$

where

F_h is the horizontal force acting on the hoist load;

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, load-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;

γ is the angle between direction of gravity and the rope projected in the plane determined by F_h and direction of gravity g .

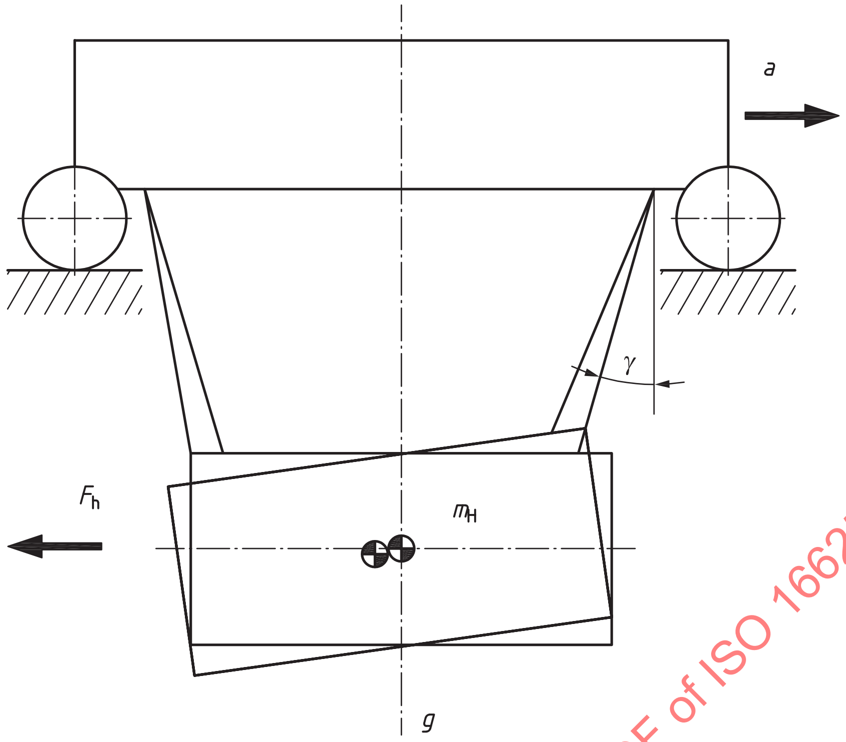


Figure 4 — Load suspension with inclined and independent ropes

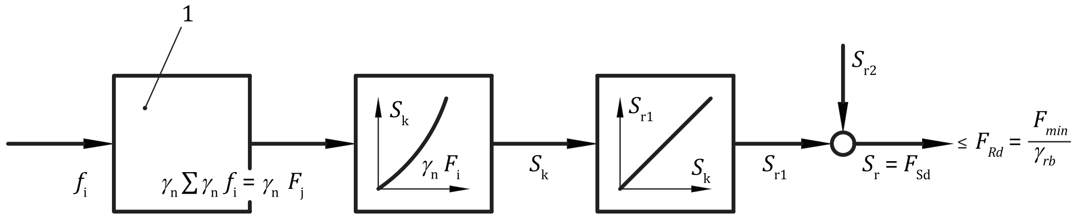
Increase of load effects due to ϕ and f_{S3} in Formula (2) may be handled separately, only in cases where simultaneous action of horizontal and vertical accelerations is prevented by technical means (e.g. by the control system).

In case conditions of this subclause apply, f_{S2} is usually already incorporated in f_{S3} in the plane of the horizontal force acting. In the plane perpendicular to this force, the effect of inclined rope falls shall be considered.

5.1.3 General rope drives

5.1.3.1 Design rope force

Figure 5 illustrates the general determination of the design rope force using the limit state method for the proof of competence.



Key

1	load and load combinations, see Table 2 and ISO 8686-1:2012, Table 3
f_i	characteristic load action *i* acting on the component including dynamic factors ϕ_i
F_j	combined load actions from load combination j
S_k	design load effects in rope drive *k* of ropes or rope falls, such as inner forces, resulting from load combination F_j
S_{r1}	design load effect in the particular rope as a result of load effects S_k including rope force increasing factors f_{S1} and f_{S2}
S_{r2}	additional design load effect in the particular rope arising from local effects, e.g. rope pre-tensioning force (in case this load effect has not been applied as load action)
$F_{Sd} = S_r$	resulting design force in particular rope
F_{Rd}	limit design rope force
F_{min}	minimum breaking force of the rope
γ_p	partial safety factors applied to individual load actions according to the load combination under consideration
γ_n	risk coefficient, where applicable (see ISO 8686-1, additionally ISO 12100 may be used for risk assessment)
γ_{rb}	rope resistance factor

Figure 5 — Flow chart of limit state method for the proof of competence of wire ropes

NOTE A flow chart similar to Figure 5 can be found in ISO 8686-1:2012, Annex A, where it is used to explain the proof of competence of structural parts using the limit state method.

Step '1' in Figure 5 illustrates the creation of the relevant load combinations, which shall be applied on the mechanical model. It is important that for general rope drives additional load actions shall be considered, which are not given in ISO 8686-1:2012, Table 3. These additional load actions shall be taken from Table 2. These load actions shall be multiplied with their partial safety factor γ_p and added to each relevant load combination. Hence, Table 2 shall always be used in conjunction with ISO 8686-1:2012, Table 3, where all further information regarding load actions and load combinations are given.

Table 2 — Additional loads and their partial safety factors γ_p

Categories of loads	Loads, f_i	Load combinations A	Load combinations B	Load combinations C
		Partial safety factors γ_p	Partial safety factors γ_p	Partial safety factors γ_p
Regular	Travel resistance force	1,34	1,22	1,1
	Rope pre-tensioning force without controlled application [a]	1,22	1,16	1,1
	Rope pre-tensioning force with controlled application [a]	1,16	1,1	1,05
[a] Controlled application means that the rope pre-tensioning force is quantified, and its application is measurable, e.g. by a torque wrench.				

The design rope force $F_{Sd,s}$ in general rope drives shall be calculated according to Formula (11):

$$F_{Sd,s} = S_r = S_{r1} + S_{r2} = \frac{S_k}{n_m} \times f_{S1} \times f_{S2} + S_{r2} \tag{11}$$

where

S_r is the resulting design force in particular rope;

S_{r1} is the design load effect in particular rope;

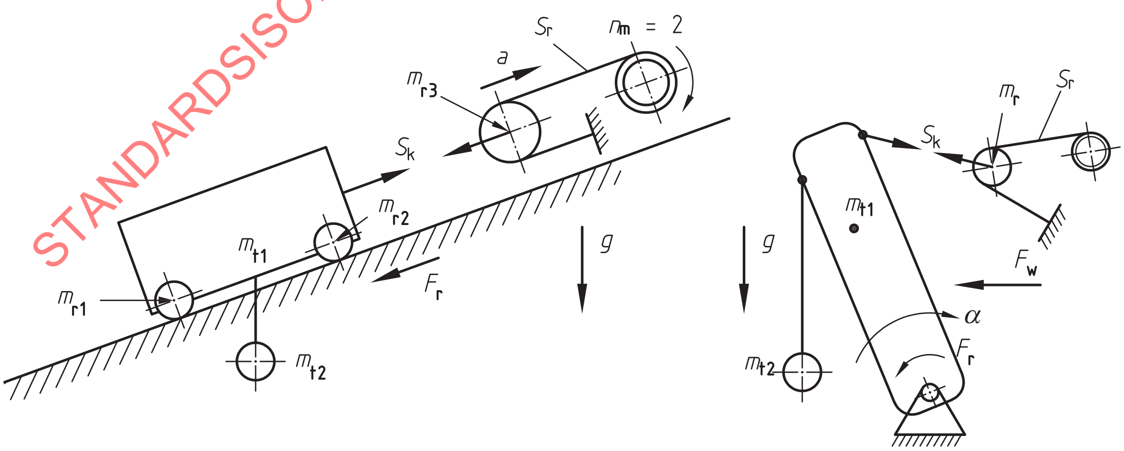
S_{r2} is the design load effect in particular rope arising from local effects;

S_k is the design load effects in rope drive k of ropes or rope falls, as an inner force, resulting from load combination F_j;

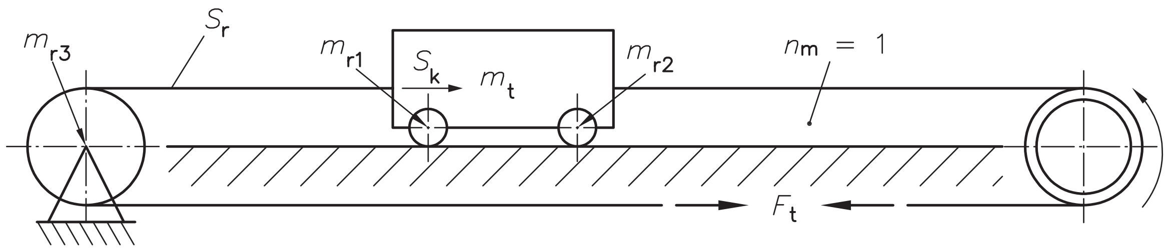
n_m is the mechanical advantage of reeving;

f_{S1}, f_{S2} are the rope force increasing factors, see 5.1.2.3.

Figure 6 illustrates general rope drives with different load actions and dynamic effects leading to a complex state of loading.



a) Examples for general rope drive with translatory and rotatory masses



b) Example for general rope drive including rope pre-tension

Key

m_r, m_{r1}, m_{r2}, m_{r3}	rotatory rope driven masses
m_t, m_{t1}, m_{t2}	translational rope driven masses
S_r , S_k	design load effects, see 5.1.3.1
F_w, F_r , F_t	forces induced by wind forces, or by resistances, or by rope tightening forces
a, g, $\propto$	accelerations
n_m	mechanical advantage

Figure 6 — Examples for general rope drives

5.1.4 Limit design rope force

The limit design rope force $F_{Rd,s}$ shall be calculated according to Formula (12):

$$F_{Rd,s} = \frac{F_{min}}{\gamma_{rb}} \times \min\{f_{S4}; f_{S5}\} \quad (12)$$

$$\text{with } \gamma_{rb} = \gamma_m \times \gamma_s \quad (13)$$

where

F_{min} is the specified minimum breaking force of the rope, see ISO 17893;

γ_{rb} is the rope resistance factor and results to 2,0;

f_{S4} is the rope force reduction factor due to the type of rope termination, see Table 3;

f_{S5} is the rope force reduction factor due to D/d-ratio of drum or sheave and rope, see Formula (14);

γ_m is the general resistance factor γ_m = 1,1, see ISO 8686-1;

γ_s is the specific resistance factor γ_s = 1,82 for a proof of competence against breaking strength of a wire rope taking into account the decrease of the minimum breaking load over the operating time as well as the exceeding of the yield point of individual wires in the rope.

Table 3 — Reduction factors f_{S4}

Rope termination	Reduction factors f_{S4}
Metal sockets	1,0
Resin sockets	1,0
Swage sockets	0,9
Ferrule-secured sockets	0,9
Wedge socketing	0,8
Wire rope grips[a]	0,8
[a] not allowed for lifting loads	

The rope force reduction factor f_{S5} due to D/d-ratio of drum or sheave and rope shall be calculated as follows:

$$f_{S5} = 1 - \left(\frac{1}{\left(D/d \right)^{0,9}} \right) \tag{14}$$

where

D is the minimum rope bending diameter of drum or sheave in the rope drive;

d is the nominal rope diameter.

The D/d-ratio shall not be chosen less than 11,2 in order not to fall below the validity range of the Formula (14).

If the proof of static strength becomes the decisive proof of competence, a change of the type of the rope termination can have an influence on the limit design rope force. This information shall be included in the operating manual of the crane.

NOTE 1 Rope terminations at the drum side using safety windings (refer to F.11.2) do not need to be considered as they do not reduce the breaking force of the rope.

NOTE 2 The values of the "design factor" Z_p quoted in ISO 16625:2013, are in all cases greater than the rope resistance factor γ_{rb}, as partial safety factors and other load increasing factors are included in the design rope force, see Annex C.

5.2 Proof of fatigue strength

5.2.1 General

According to test results, the endurable number of bending cycles w for ropes until breakage corresponds to the ratio of the reference rope tension force F_{ref} and the rope tension force F to the power of m, multiplied with the reference number of bending cycles w_{ref} and thus corresponds to the original Miner-Rule. The endurable number of bending cycles w shall be calculated according to Formula (15):

$$w = \left(\frac{F_{ref}}{F} \right)^m \times w_{ref} \tag{15}$$

where

w is the endurable number of bending cycles;

F_{ref} is the reference rope tension force;

F is the rope tension force;

m is the exponent, slope of the S-N curve (Wöhler-curve);

w_{ref} is the reference number of bending cycles.

The exponent m in Formula (15), which is the slope of the S-N curve (Wöhler-curve) in a double logarithmic representation, depends on the quotient of the decisive rope bending diameter D in the rope drive and the nominal rope diameter d. The exponent m shall be calculated according to Formula (16):

$$m = 2{,}6 \times log_{10}\left(\frac{D}{d}\right) - 1{,}6 \qquad (16)$$

where

m is the exponent, slope of the S-N curve (Wöhler-curve);

D is the rope bending diameter;

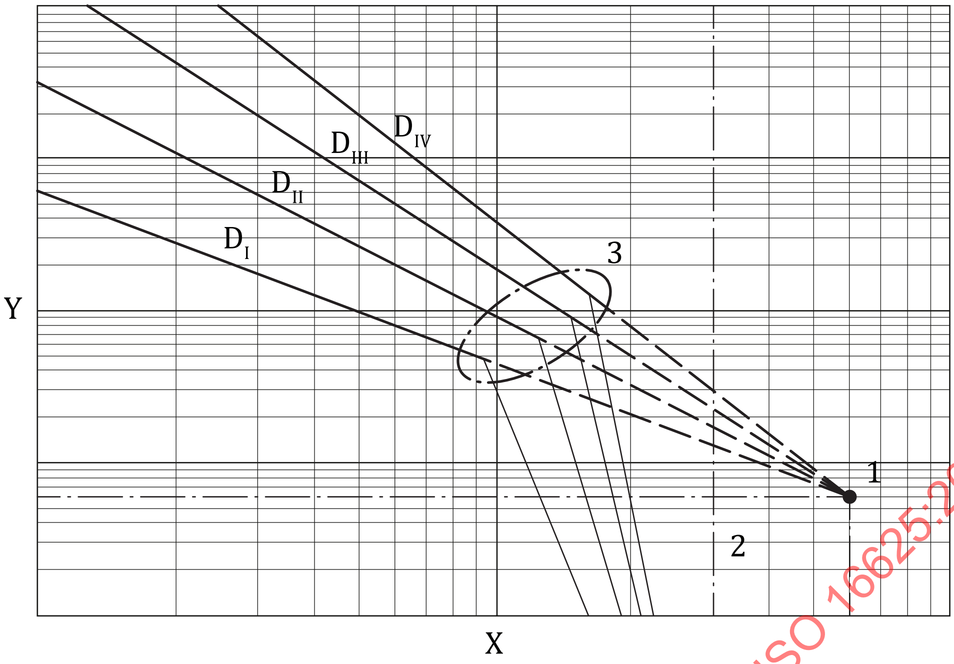
d is the nominal rope diameter.

NOTE The values for the reference number of bending cycles w_{ref} and the reference rope tension force F_{ref} can be derived from testing.

The reference rope tension force as well as the number of bending cycles at the reference point allow a uniform description of the different fatigue strength lines of the fatigue bending strength of steel wire ropes at different ratios of the rope bending diameter to the rope diameter. Contrary to the usual fatigue strength calculation of components, the reference point for marking the S-N curve (Wöhler-curve) is not located near the endurance limit any longer, but at the other end of the life time curve. This change makes sense as tests have shown that all fatigue strength lines intersect at this single point approximately.

The reference point of the S-N curves (Wöhler curves) of a rope represents the characteristic value of fatigue strength against breakage at reference bending cycles under constant force range loading and with a probability of survival of 97,7 % (mean value minus two standard deviations obtained at normal distribution and single sided test) valid for all diameter ratios D/d of sheave and rope.

The typical fatigue behaviour of a rope for different bending diameters (rope bending diameter D) is shown in Figure 7.



Key

X rope tensile force (logarithmic representation)

Y rope bending cycles (logarithmic representation)

1 reference point of fatigue life time curves defined by F_{ref} and w_{ref}

2 level of minimum rope breaking force F_{min}

3 Donandt-force, limit value of the fatigue life time curve associated with a significant drop of the endurable number of bending cycles

D_I, D_{II}, D_{III}, D_{IV} fatigue life time curves with increasing rope bending diameters from D_I to D_{IV} and hence an increasing exponent

Figure 7 — Example of rope fatigue life time curves and definition of the reference point

The fact that the *D*/*d*-ratio increases the number of bending cycles w, is incorporated in Formula (15) by the exponent m.

The decisive rope bending diameter D, used in Formula (16), shall be calculated according to Formula (17):

$$D = min\{D_1 ; D_2\} \tag{17}$$

where

D_1 is the rope bending diameter of the drum (see Figure F.2);

D_2 is the rope bending diameter of the sheave (see Figure F.3).

The *D*/*d*-ratio shall not be chosen less than 11,2 in order not to fall below the validity range of the Formula (16) for the exponent m.

The commonly used minimum values of *D*/*d*-ratio depending on A_C-classes (see ISO 4301-1) are given in Table 4.

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

	A_C1	A_C2	A_C3	A_C4	A_C5	A_C6	A_C7	A_C8	A_C9	A_C10
D/*d*	11,2	12,5	14,0	16,0	18,0	20,0	22,4	25,0	28,0	31,5

NOTE Above conversion of the former time-based M-classes into cycle-based A_C-classes and thus the assignment of the *D/d*-values was carried out with a fixed cycle time of 36 s. As the cycle time is considerably longer for some types of crane, e.g. mobile cranes, tower cranes, the M-classes and thus the *D/d*-ratios for these crane types have been empirically adjusted in the past.

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 (see 5.2.3).

The proof of fatigue strength shall be proven according to Formula (18):

$$p_{f,r} : F_{Sd,f} \leq F_{Rd,f} \tag{18}$$

where

$p_{f,r}$	is the proof of fatigue strength for running ropes;
$F_{Sd,f}$	is the design rope force for the proof of fatigue strength;
$F_{Rd,f}$	is the limit design rope force for the proof of fatigue strength.

5.2.2 Design rope force

5.2.2.1 General

The design rope force $F_{Sd,f}$ shall be calculated for regular loads (load combinations A, see ISO 8686-1), with partial safety factors γ_p and rope reeving efficiency η_{tot}, respectively f_{S1} set to 1,0.

5.2.2.2 Vertical hoisting of loads

The design rope force $F_{Sd,f}$ in vertical hoisting of loads shall be calculated according to Formula (19):

$$F_{Sd,f} = \frac{m_{Hr} \times g}{n_m} \times \phi^* \times f_{S2}^* \times f_{S3}^* \times \gamma_n \tag{19}$$

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, load-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 reeving;
ϕ^*	is the dynamic factor for inertial effects, see 5.2.2.4;
f_{S2}^*, f_{S3}^*	are the rope force increasing factors, see 5.2.2.5 and 5.2.2.6;
γ_n	is the risk coefficient, where applicable (see ISO 8686-1; additionally, ISO 12100 may be used for risk assessment).

5.2.2.3 General rope drives

The design rope force $F_{Sd,f}$ in general rope drives shall be calculated according to Formula (20):

$$F_{Sd,f} = S_r = S_{r1} + S_{r2} = \frac{S_k}{n_m} \times f_{S2}^* + S_{r2} \qquad (20)$$

where

- S_r is the resulting design force in particular rope;
- S_{r1} is the design load effect in particular rope;
- S_{r2} is the design load effect in particular rope arising from local effects;
- S_k is the design load effects in rope drive k of ropes or rope falls, as an inner force, resulting from load combination F_j;
- n_m is the mechanical advantage of reeving;
- f_{S2}^* is the rope force increasing factor, see 5.2.2.5.

The determination of the fatigue design rope force for general rope drives shall be carried out according to Figure 5 in 5.1.3.1 together with the rules given in the beginning of this subclause. The possibility of reducing the dynamic factors according to 5.2.2.2 is also permissible but shall be carried out in step '1' of Figure 5 for each load action separately.

5.2.2.4 Inertial and gravitational effects

As dynamic effects reduce the mean value of the acceleration and act for a short time only, they are not effective for all bending cycles. Therefore, the dynamic factors ϕ^* may be calculated according to Formula (21):

$$\phi^* = \sqrt[3]{\frac{(w_{max} - 1) + \phi^3}{w_{max}}} \quad \text{for } w_{max} \geq 1 \qquad (21)$$

$$\phi^* = \phi \quad \text{for } w_{max} = 0$$

where

- w_{max} is the maximum number of bending cycles in the most unfavourable part of the reeving system, see Annex A;
- ϕ is the dynamic factor, see 5.1.2.2 or 5.1.3.1.

For general rope drives, the Formula (21) may be applied to all different dynamic factors of a load combination when calculating the design rope force.

5.2.2.5 Non-parallel falls

Non-parallel falls shall be taken into account in the proof of fatigue strength. The distribution of height and angle β within the working range may be taken into account by the rope force increasing factor f_{S2}^*. A crane can be operated in a working range from z_{min} to z_{max} (refer to Figure 8).

When the crane operates approximately equal on all positions of the most typical working range from z_1 to z_2 the density function according to Formula (22) is constant:

$$q(z)=\frac{1}{z_2-z_1} \tag{22}$$

and f_{S2}^* may be calculated as according to Formula (23):

$$f_{S2}^*=1+\left[\frac{1}{\cos\beta(z_2)}-1\right]\times\left(\frac{z_{ref}-z_2}{z_{ref}-z_1}\right)^{0,9} \tag{23}$$

where

z, z_i	are position coordinates as shown in Figure 8;
z_{ref}	is the reference position;
$\beta(z)$	is the angle between falls and line of action of force depending on coordinate z;
$q(z)$	is the normalized position density of the crane, when used in the working range.

whereby Formula (24) applies:

$$\int_{z_{min}}^{z_{max}} q(z)\,dz=1 \tag{24}$$

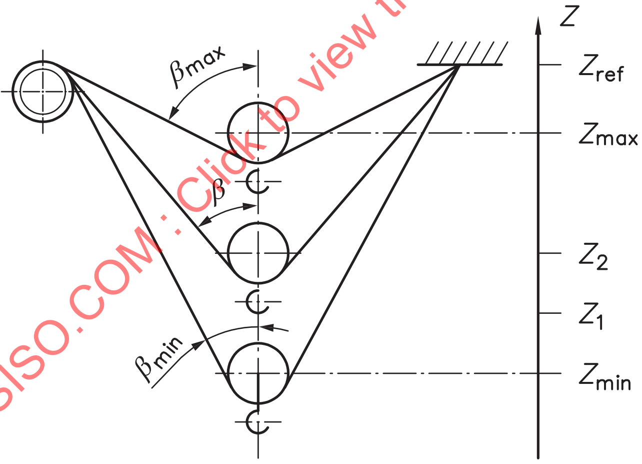


Figure 8 — Lifting positions

5.2.2.6 Horizontal forces acting on the hoist load (in vertical hoisting)

In applications with several non-parallel ropes (e.g. rope pyramid, see Figure 4), the rope force increasing factor f_{S3}^* shall be calculated according to Formula (25):

$$f_{S3}^*=f_{S3} \tag{25}$$

where f_{S3} is the rope force increasing factor calculated from an average angle γ, see 5.1.2.3.3.

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 1,0. However, under these conditions it is of particular importance to take the rope force increasing factor f_{S2}^{*} fully into account.

5.2.3 Limit design rope force

5.2.3.1 Basic formula

The limit design rope force $F_{Rd,f}$ shall be calculated according to Formula (26):

$$F_{Rd,f} = \min\left\{\frac{F_{ref}}{\gamma_{rf} \times \sqrt[m]{s_r}}; \frac{F_{min}}{\gamma_{rfD}}\right\} \tag{26}$$

with

$$F_{ref} = \frac{F_{min}}{\gamma_{ref}} \times f_F \tag{27}$$

where

F_{ref} is the reference rope tension force representing the characteristic value of fatigue strength against breakage at reference bending cycles valid for all diameter ratios D/d of sheave and rope;

F_{min} is the specified minimum breaking force of the rope;

γ_{ref} $\gamma_{ref} = 0,5$, increases F_{min} to the reference rope tension force F_{ref} achieving a probability of survival of at least 97,7 %, see Figure 7;

s_r is the rope force history parameter;

m is the exponent, slope of the S-N curve (Wöhler-curve), see Formula (16);

γ_{rf} is the rope resistance factor: $\gamma_{rf} = 1,25$; γ_{rf} is a combined safety factor taking into account the accessibility of the rope and the possible consequences of fatigue damage. The value is chosen to allow a detection prior to failure of the rope;

γ_{rfD} is the minimum rope resistance factor to prevent from exceeding the Donandt-force; γ_{rfD} is a combination of a correlation factor to describe the Donandt-force depending on F_{min} and the D/d-ratio and a safety factor, see Figure 7;

f_F is the factor of further influences to F_{ref}, see 5.2.3.3 and Formula (35).

The minimum rope resistance factor γ_{rfD} to prevent from exceeding the Donandt-force is dependent on the geometry of the reeving system and shall be calculated as according to Formula (28):

$$\gamma_{rfD} = 1,1 \times \left(\frac{1}{0,65 - 3,80 \times \dfrac{d}{D}}\right) \tag{28}$$

where

D is the minimum relevant diameter, see Formula (17);

d is the nominal rope diameter.

The D/d-ratio shall not be chosen less than 11,2. Only drum, sheave or general components where the wrap angle α (see Table A.1) is greater than 5° need to be taken into account.

Table 5 gives minimum rope resistance factors in accordance with Formula (28) for selected *D/d*-ratios.

Table 5 — Minimum rope resistance factor γ_{rfD}

D/d	11,2	12,5	14	16	18	20	25	28	63
γ_{rfD}	3,54	3,18	2,91	2,67	2,51	2,39	2,21	2,14	1,87

5.2.3.2 Rope force history parameter

5.2.3.2.1 General

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. When counting bending cycles on a rope, all movements, with or without load, included in any work cycle of the crane, shall be taken into account. Counting bending cycles shall be in accordance with Annex A.

Analogous to the stress history parameter in accordance with ISO 20332, the rope force history parameter s_r shall be calculated according to Formula (29):

$$s_r = k_r \times \nu_r \tag{29}$$

where

k_r is the rope force bending spectrum factor;

ν_r is the relative total number of bending cycles.

It shall be emphasized that for the practical and general implementation of determining the most unfavourable rope force history parameter, the rope shall be divided into several rope sections, for which it can be assumed that an equal number of bending cycles take place. The proof of competence is then to be provided for the rope section in which the largest rope force history parameter is achieved. Simplified, it is assumed that the rope tensile force is the same in all rope sections.

5.2.3.2.2 Rope force bending spectrum factor

The rope force bending spectrum factor k_r for the rope section under investigation shall be calculated according to Formulae (30) and (31):

$$k_r = \sum_i \left(\frac{F_{Sd,f,i}}{F_{Sd,f}} \right)^m \times \frac{w_i}{w_{tot}} \tag{30}$$

with

$$w_{tot} = \sum_i w_i \tag{31}$$

where

$F_{Sd,f,i}$ is the design rope force of range i;

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

m is the exponent, slope of the S-N curve (Wöhler-curve), see Formula (16);

w_i is the relevant number of bending cycles of range i in the rope section under investigation, see Annex A;

w_{tot} is the total number of bending cycles during the design life of a rope in the rope section under investigation when the total number of working cycles per rope C_r is reached.

The total number of working cycles per rope C_r shall be calculated according to Formula (32):

$$C_r = \frac{C}{l_r} \tag{32}$$

where

C is the total number of working cycles during the design life of the crane (see ISO 4301-1);

l_r is the number of ropes assumed to be used during the design life of the crane, see 4.2 and Annex E.

5.2.3.2.3 Relative total number of bending cycles

The relative total number of bending cycles v_r shall be calculated according to Formula (33):

$$v_r = \frac{w_{tot}}{w_{ref}} \tag{33}$$

with

$$w_{ref} = 600 \times f_w \tag{34}$$

where

w_{tot} is the total number of bending cycles during the design life of a rope in the rope section under investigation when the total number of working cycles per rope C_r is reached;

w_{ref} is the number of bending cycles at reference point representing the characteristic number of bending cycles valid for all diameter ratios *D/d* of sheave and rope, see Figure 7;

f_w is the factor of further influences to w_{ref}, see 5.2.3.4 and Formula (38).

5.2.3.3 Further influences on the limit design rope force, respectively to F_{ref}

5.2.3.3.1 Basic formula

The factor f_F takes into account further influences on F_{ref} and shall be calculated according to Formula (35):

$$f_F = f_{F1} \times f_{F2} \times f_{F3} \times f_{F4} \tag{35}$$

where f_{F1} to f_{F4} are the factors of influences as given in 5.2.3.3.2 to 5.2.3.3.5.

5.2.3.3.2 Tensile strength of wire

A nonlinear relationship between the rope grade R_r and the limit design rope force shall be taken into account by factor f_{F1} according to Formula (36):

$$f_{F1} = \left(\frac{1770}{R_r}\right)^{0,6} \quad \text{for } R_r > 1770 \tag{36}$$

$$f_{F1} = 1 \quad \text{for } R_r \leq 1770$$

where R_r is the rope grade, which is designated by a number (e.g. 1770, 1960), (see ISO 2408).

5.2.3.3.3 Fleet angle

Fleet angles at sheaves or drums are illustrated in Figure 9. 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_{F2} as given in Table 6. The design fleet angle shall be calculated according to Formula (37):

$$\delta = \sqrt[3]{\frac{\sum_{j=1}^{n} \delta_j^3}{n}} \tag{37}$$

where

δ_j is the fleet angle at the tangential contact point j of rope at drum or sheave (see Figure 9);

n is the number of contact points passed by a part of the rope that initiates a change of curvature in the rope (see Figure 9 for an example with $n = 6$).

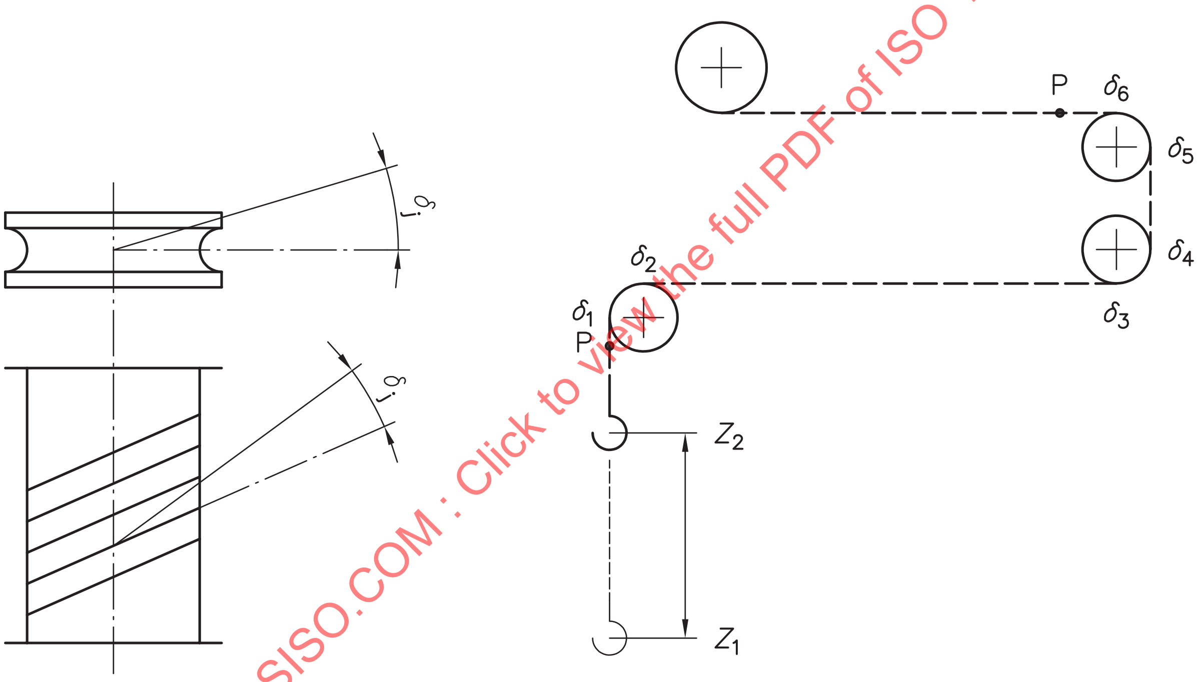


Figure 9 — Fleet angles

Table 6 — Factor of fleet angle influence f_{F2}

Design fleet angle δ	f_{F2} for non-rotation resistant rope	f_{F2} 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.		

5.2.3.3.4 Rope lubrication

For ropes manufactured with internal lubrication the factor f_{F3} is set to 1,0. For ropes without internal lubrication (e.g. clean room) the factor f_{F3} shall be set to 0,5. Relubrication is not taken into account in this document. Guidance concerning lubrication is given in F.12.

5.2.3.3.5 Groove

The ratio of groove radius r_g to nominal rope diameter d and the requirements for the groove opening angle ω (see Figure 10) shall be taken into account by factor f_{F4} according to Table 7.

NOTE Values of Table 7 consider a maximum rope diameter tolerance ≤ +5 %, see ISO 2408:2017, Table 2. For rope diameters < 8 mm, this tolerance of +5 % can be exceeded.

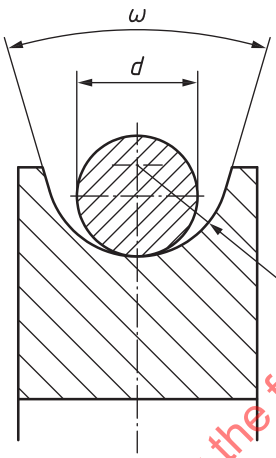


Figure 10 — Groove

Table 7 — Factor of groove radius influence f_{F4}

$\frac{r_g}{d}$	ω	f_{F4}
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.		

5.2.3.4 Further influences on the limit design rope force, respectively to w_{ref}

5.2.3.4.1 Basic formula

The factor f_w takes into account further influences on w_{ref} and shall be calculated according to Formula (38):

$$f_w = f_{w1} \times f_{w2} \tag{38}$$

where f_{w1} to f_{w2} are the factors of influence, as given in 5.2.3.4.2 to 5.2.3.4.3.

5.2.3.4.2 Rope type factor f_{w1}

Differing bending fatigue performance of the various rope types shall be taken into account by the rope type factor f_{w1}.

The rope type factor f_{w1} is dependent upon the type of rope and the number of outer strands as given in Table 8.

Table 8 — Rope type factors f_{w1}

Type of rope	Number of outer strands	f_{w1}
Single layer or parallel-closed	<6	0,4
	6	0,8
	8	1,0
	10	1,1
Rotation-resistant	<6	0,4
	other	0,7

NOTE 1 The values of the rope type factor f_{w1} shown in Table 8 were determined by a correlation calculation based on fatigue test results from the University of Stuttgart, Germany, partly published in Reference [2], and compared with information from the Technical University of Dresden, Germany, partly published in Reference [16].

NOTE 2 The influence of rope compaction on bending fatigue performance is highly complex. As no test results were available for compacted ropes, it was not possible to determine a specific rope type factor to consider the influence of rope compaction on the bending fatigue strength. In case no information is available for compacted rope, the value of a non-compacted rope with the same number of outer strands can be used.

NOTE 3 According to ISO 17893:2004, 2.6.1.3, three- or four-strand ropes can be designed to exhibit a rotation-resistant behaviour. As no test results were available, the rope type factor was equated with that of single layer or parallel-closed ropes.

5.2.3.4.3 Rope diameter factor f_{w2}

Differing bending fatigue performance of the various rope diameters shall be taken into account by the rope diameter factor f_{w2} according to Formula (39):

$$f_{w2} = \frac{0{,}52}{-0{,}48 + \left(\frac{d}{16}\right)^{0{,}3}} \quad (39)$$

where d is the nominal rope diameter in unit of measure mm.

NOTE The Formula (39) and further explanation can be found in Reference [2].

5.3 Proof of competence for multilayer spooling

5.3.1 General

When using a multilayer spooling design, an additional proof is required due to:

— increased wear due to sliding contact at cross-over areas;

— plastic deformation at cross-over areas;

— rope crushing.

The proof of wear at multilayer spooling according to Formula (40) shall be proven for all relevant load combinations of ISO 8686-1 or ISO 8686-2, ISO 8686-3, ISO 8686-4 or ISO 8686-5, as applicable.

$$p_{m,r} : F_{Sd,m} \le F_{Rd,m} \quad (40)$$

where

$p_{m,r}$ is the proof of competence for multilayer spooling for running ropes;

$F_{Sd,m}$ is the design rope force for multilayer spooling;

$F_{Rd,m}$ is the limit design rope force for multilayer spooling.

5.3.2 Vertical hoisting of loads

The design rope force for multilayer spooling $F_{Sd,m}$ for vertical hoisting shall be calculated according to Formula (41):

$$F_{Sd,m} = F_{Sd,s} = \frac{m_{Hr} \cdot g}{n_m} \times \phi \times f_{S1} \times f_{S2} \times f_{S3} \times \gamma_p \times \gamma_n \quad (41)$$

where

$F_{Sd,s}$ is the design rope force for the proof of static strength, see 5.1.2.1;

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, load-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 reeving;

ϕ is the dynamic factor for inertial and gravity effects, see 5.1.2.2;
As a less conservative assumption, the value of ϕ^* as defined in 5.2.2.2 may be used instead;

f_{S1} *to* f_{S3} are the rope force increasing factors, see 5.1.2.3;

γ_p is the partial safety factor (see ISO 8686-1);

γ_n is the risk coefficient, where applicable (see ISO 8686-1, additionally ISO 12100 may be used for risk assessment).

5.3.3 General rope drive

The design rope force for multilayer spooling $F_{Sd,m}$ of general rope drives shall be calculated according to Formula (42):

$$F_{Sd,m} = F_{Sd,s} = S_r = S_{r1} + S_{r2} = \frac{S_k}{n_m} \times f_{S1} \times f_{S2} + S_{r2} \quad (42)$$

where

$F_{Sd,s}$ is the design rope force for the proof of static strength, see 5.1.2.1;

S_r is the resulting design force in particular rope;

S_{r1} is the design load effect in particular rope;

S_{r2} is the design load effect in particular rope arising from local effects;

S_k is the design load effects in rope drive k of ropes or rope falls, as an inner force, resulting from load combination F_j;

n_m is the mechanical advantage of reeving;

f_{S1}, f_{S2} are the rope force increasing factors as shown in 5.1.2.3.

As with the design rope force for multilayer spooling for vertical hoisting it is allowed here also to use the reduced dynamic factors as defined in 5.2.2.2. The application takes place at step '1' of Figure 5 described in 5.1.3.1.

5.3.4 Limit design rope force

The limit design rope force for multilayer spooling $F_{Rd,m}$ shall be calculated according to Formula (43):

$$F_{Rd,m} = \frac{F_{min}}{\gamma_{rb}} \times \sqrt[4]{\left(\frac{\frac{D}{d}}{\left(\frac{D}{d}\right)_{ref}} \right)} \quad (43)$$

where

F_{min} is the specified minimum breaking force of the rope;

γ_{rb} is the rope resistance factor for multilayer spooling, see Table 9;

$\frac{D}{d}$ is the actual *D*/*d*-ratio of the rope drum and rope diameter, which is not allowed to be lower than the minimum admissible *D*/*d*-ratio, see Table 9;

$\left(\frac{D}{d}\right)_{ref}$ is the reference *D*/*d*-ratio of rope drum and rope diameter defined by experience, see Table 9.

Table 9 gives the empirically defined, rope resistance factors γ_{rb} together with the minimum *D*/*d*-ratio of the rope drum for multilayer spooling depending on the type of crane, type of rope and mechanism. The term of the root expression of the quotient of the actual and reference *D*/*d*-ratio is a factor for correction of the resistance factor.

Table 9 — Rope resistance factor γ_{rb} for multilayer spooling

Type of crane	Type of rope	Mechanism	Resistance factor γ_{rb}	Reference D/d-ratio	Minimum D/d-ratio
Tower cranes	SR	all	2,71	20	20
	SR	erecting	2,41	20	16
	RR	all	2,71	25	22,4
Mobile cranes	SR	hoisting	2,71	20	16
	RR	hoisting	3,05	20	16
	SR	boom hoisting working	2,30	20	16
	SR	boom hoisting erecting	2,60	20	16
	RR	boom hoisting working	3,10	20	16
	RR	boom hoisting erecting	3,90	20	16
All other cranes	SR	all	2,71	20	20
	RR	all	2,71	25	22,4
SR: Standard rope RR: Rotation-resistant rope					

6 Proof of competence of stationary ropes

6.1 Proof of static strength

6.1.1 General

The proof of static strength shall be provided according to Formula (44) for all relevant load combinations according to ISO 8686-1 or ISO 8686-2, ISO 8686-3, ISO 8686-4 or ISO 8686-5, as applicable.

$$p_{s,s} : F_{Sd,s} \leq F_{Rd,s} \quad (44)$$

where

$p_{s,s}$ is the proof of static strength for stationary ropes;

$F_{Sd,s}$ is the design rope force for the proof of static strength;

$F_{Rd,s}$ is the limit design rope force for the proof of static strength.

Stationary ropes can be subject to non-linear effects due to the elasticity of surrounding structure. Therefore, an explicit formula for the design rope force $F_{Sd,s}$ cannot be given. When modelling the crane structure, stationary ropes should be modelled as beam elements with one degree of freedom. The design rope force $F_{Sd,s}$ for stationary ropes shall be calculated according to ISO 8686-1 or ISO 8686-2, ISO 8686-3, ISO 8686-4 or ISO 8686-5, as applicable.

6.1.2 Limit design rope force

The limit design rope force $F_{Rd,s}$ shall be calculated according to Formula (45):

$$F_{Rd,s} = \frac{F_{min}}{\gamma_{rb}} \times f_{S4} \quad (45)$$

$$\text{with } \gamma_{rb} = \gamma_m \times \gamma_s \tag{46}$$

where

F_{min}	is the specified minimum breaking force of the rope, see ISO 17893;
γ_{rb}	is the rope resistance factor and results to 2,0;
f_{S4}	is the reduction factor due to the type of rope termination, see Table 3;
γ_m	is the general resistance factor $\gamma_m = 1{,}1$, see ISO 8686-1;
γ_s	is the specific resistance factor γ_s = 1,82 for a proof of competence against breaking strength of a wire rope taking into account the decrease of the minimum breaking load over the operating time as well as the exceeding of the yield point of individual wires in the rope.

6.2 Proof of fatigue strength

6.2.1 General

The proof of fatigue strength shall be provided according to Formula (47) for all relevant load combinations according to ISO 8686-1 or ISO 8686-2, ISO 8686-3, ISO 8686-4 or ISO 8686-5, as applicable.

$$p_{f,s} : F_{Sd,f} \leq F_{Rd,f} \tag{47}$$

where

$p_{f,s}$	is the proof of fatigue strength for stationary ropes;
$F_{Sd,f}$	is the design rope force for the proof of fatigue strength;
$F_{Rd,f}$	is the limit design rope force for the proof of fatigue strength.

The design rope force $F_{Sd,f}$ for stationary ropes shall be calculated according to ISO 8686-1 or ISO 8686-2, ISO 8686-3, ISO 8686-4 or ISO 8686-5, as applicable, considering regular loads (load combinations A) only, with partial safety factors γ_p set to 1,0. When modelling the crane structure, stationary ropes should be modelled as beam elements with one degree of freedom.

6.2.2 Limit design rope force

The limit design rope force $F_{Rd,f}$ shall be calculated according to Formula (48):

$$F_{Rd,f} = \frac{F_{ref}}{\gamma_{rf} \times \sqrt[m]{s_r}} \tag{48}$$

with

$$F_{ref} = \frac{F_{min}}{\gamma_{ref}} \times f_{S4} \tag{49}$$

where

F_{ref}	is the reference rope tension force representing the characteristic value of fatigue strength against breakage at reference bending cycles valid for all diameter ratios D/d of sheave and rope;
F_{min}	is the specified minimum breaking force of the rope;

γ_{ref} $\gamma_{ref} = 6{,}0$ reduces F_{min} to the reference rope tension force F_{ref} achieving a probability of survival of at least 97,7 %;

γ_{rf} is the rope resistance factor and is set to $\gamma_{rf} = 1{,}25$; γ_{rf} is a combined safety factor taking into account the accessibility of the rope and the possible consequences of fatigue damage. The value is chosen to allow a detection prior to failure of the rope;

s_r is the rope force history parameter;

m Is the negative inverse slope constant of the S-N curve (Wöhler-curve) and is set to 5,0;

f_{S4} is the reduction factor due to the type of rope termination, see Table 3.

Analogous to the stress history parameter in accordance with ISO 20332, the rope force history parameter s_r shall be calculated according to Formula (50):

$$s_r = k_r \times v_r \tag{50}$$

where

k_r is the rope force tensile spectrum factor;

v_r is the relative total number of tensile force cycles.

The rope force tensile spectrum factor k_r shall be calculated according to Formula (51):

$$k_r = \sum_i \left(\frac{F_{Sd,f,i}}{F_{Sd,f}} \right)^m \times \frac{n_i}{N_t} \tag{51}$$

where

$F_{Sd,f,i}$ is the design rope force of range i;

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

m Is the negative inverse slope constant of the S-N curve (Wöhler-curve) and is set to 5,0;

n_i is the relevant number of tensile force cycles of range i;

N_t is the total number of cycles during the design life of the crane.

The number of cycles N_t shall be derived from the number of working cycles C (see ISO 4301-1) occurring during the design life of the crane.

The relative total number of tensile force cycles v_r shall be calculated according to Formula (52):

$$v_r = \frac{N_t}{N_{ref}} \tag{52}$$

where

N_{ref} is the number of cycles at reference point: $N_{ref} = 2 \times 10^6$;

N_t is the total number of cycles during the design life of the crane.

Annex A
(normative)

Number of relevant bending cycles

A.1 General

The maximum number of relevant bending cycles of a rope w_{max} within a work cycle shall be established for the most unfavourable part of the rope by summing the bending counts w_c of each relevant element in a reeving system and shall be calculated according to Formula (A.1):

$$w_{max} = \sum_{i=1}^{i_{max}} w_{c,i} \tag{A.1}$$

where

i_{max}	is the total number of types of bending occurring in the most unfavourable part of the reeving system;
w_{max}	is the maximum number of bending cycles in the most unfavourable part of the reeving system for one work cycle;
$w_{c,i}$	is the bending count of a particular type of bending of element i in the rope drive creating a relevant deflection angle α in a reeving system for a full work cycle (see Table A.1).

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

The count of bending cycles in Table A.1 and Table A.2 assume a full work cycle including forward and backward movement of the rope over a sheave or on and off a drum. Table A.2 shows examples of hoisting rope drives assuming movements where the most bent part of the rope runs from the drum over all sheaves and where the count of bending cycles comprises both of a lifting and lowering movement.

Where other crane movements cause bending cycles in the ropes under review, any additional bending cycle induced shall be taken into account. Typical situations are the trolley travelling movement of a tower crane or the luffing movement of a jib crane with a reeving system providing a horizontal load path inducing bending cycles in the hoist rope.

For crane types with complex reeving systems or different lifting tasks, compared to above stipulations, a division of the work cycle into differently loaded partial movements shall be made analogous to the hoist rope drives shown.

Table A.1 — Bending counts w_c of reeving system elements

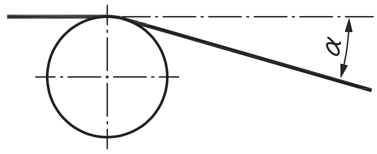
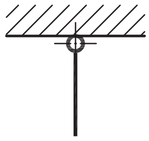
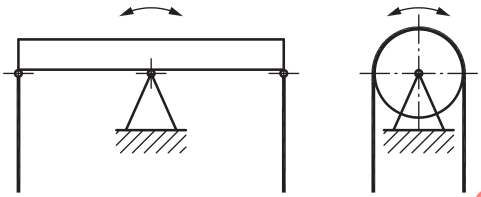
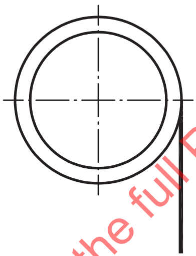
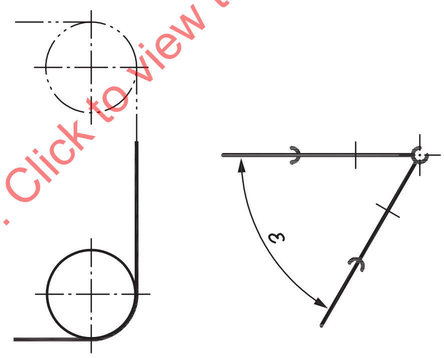
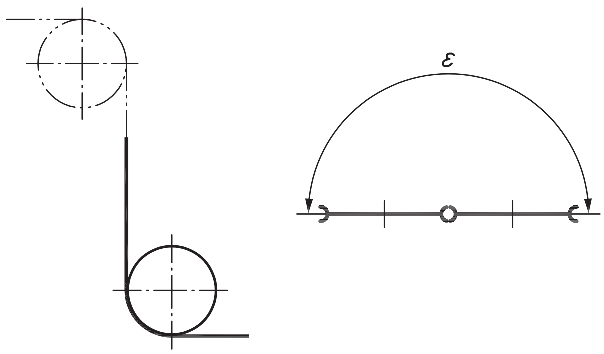
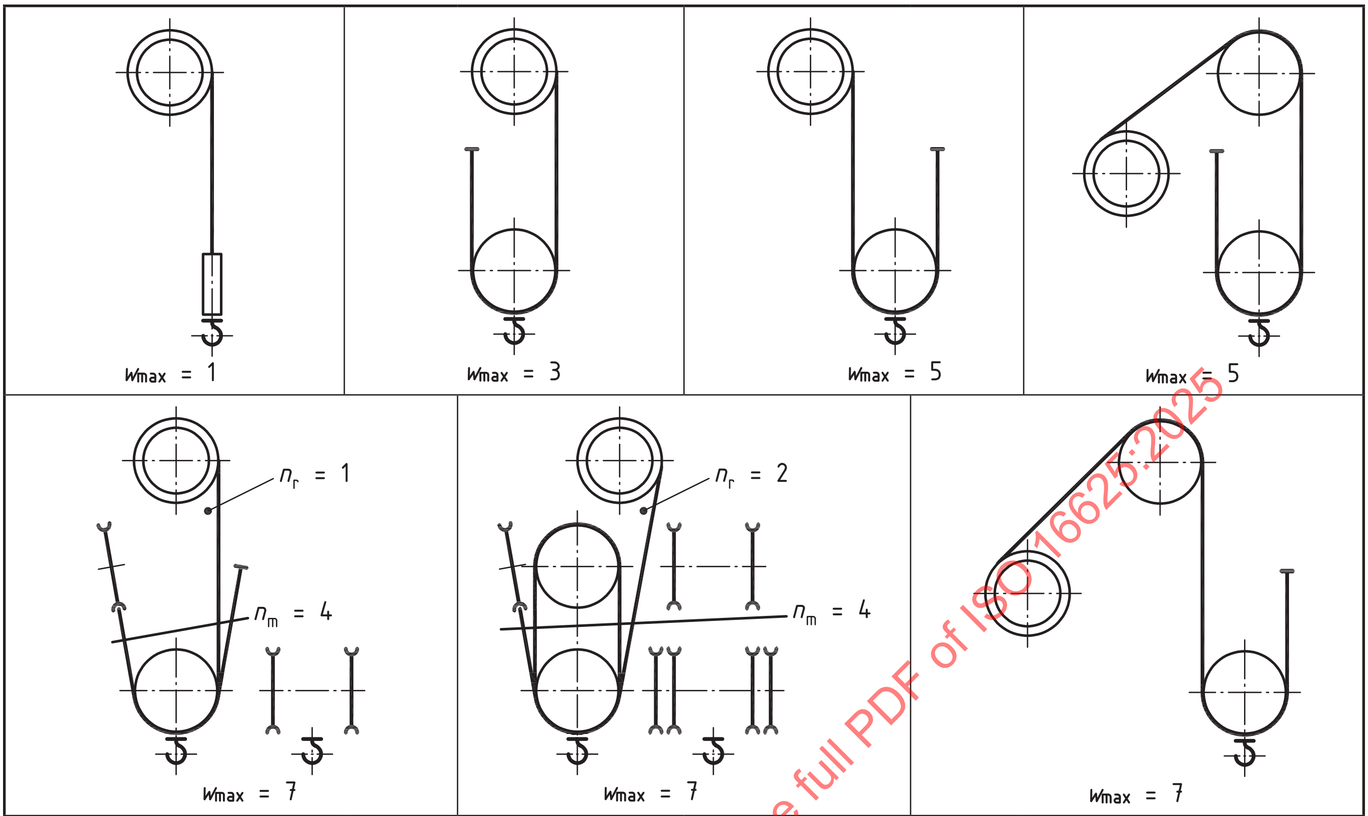
Element of reeving system	Illustration	Bending count
Any bending with a deflection α less than 5° (wrap angle).		$w_c = 0$
Rope termination		$w_c = 0$
Compensating sheave/whip		$w_c = 0$
Drum		$w_c = 1$
Sheave with same sense bending (angle ε between planes less than 120°)		$w_c = 2$
Sheave with reverse sense bending (angle $\varepsilon \geq 120°$)		$w_c = 4$

Table A.2 — Examples for the maximum number of relevant bending cycles w_{max}

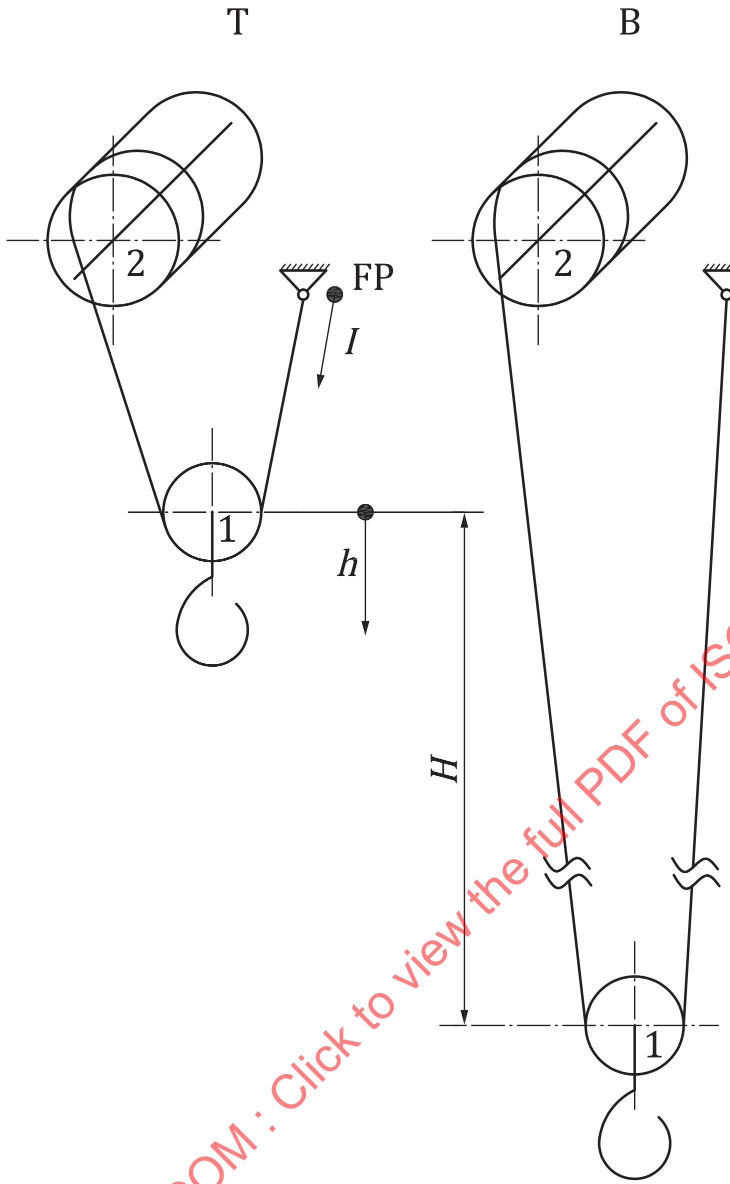


The bending count assumes one movement which comprises of both a lifting and lowering action.

A.2 One method to determine the distribution of relevant number of bending cycles in reeving systems

A.2.1 General

To estimate the number of relevant bending cycles, the following graphical method based on References [9] and [10] can be used to determine the bending cycle distribution along the rope length during different hoisting movements. The method can be used for any complex rope drive with defined dimensions regarding the distances of the rope drive elements (sheaves, drums, etc.). Using the hoist with a 2/1 reeving system in Figure A.1 the graphical determination of bending cycle distributions in Figure A.2 can be comprehended and applied to other rope drives. This and the following additional examples in Figure A.4 to Figure A.8 consider the bending cycle distribution during one working cycle, including both lifting and one lowering action.



Key

1	sheave with $w_c = 2$
2	drum with $w_c = 1$
B	bottom position of the hoist
FP	fixed point of rope
l	rope length – origin at FP with $l = 0$
h	hoisting ordinate – origin at top position
H	maximum hoisting height
T	top position of the hoist

Figure A.1 — Hoist with 2/1 reeving system

A.2.2 Procedure

Step 1: With reference to the defined values in Figure A.1, a chart shall be created with the following parameters:

— y-axis with the complete relevant “winded up” rope length *l* of the rope drive

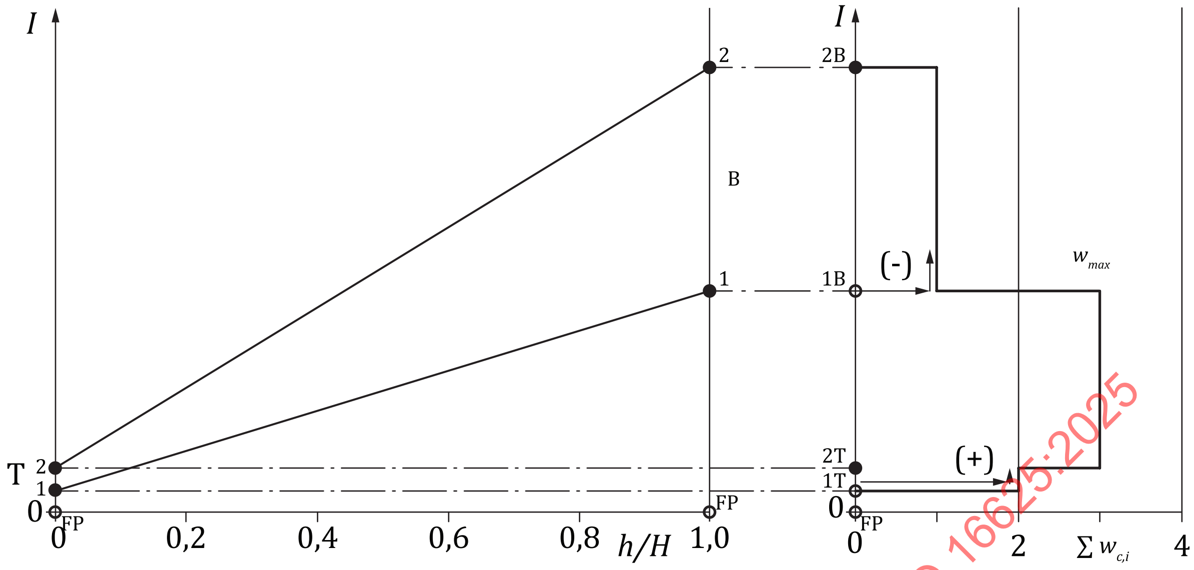
— x-axis with the lifting ratio h/H
(defines the position of the rope drive – in the example: the height of the hook block)

— secondary x-axis with the number of bending cycles or use an additional chart like it is shown in Figure A.2 on the right

Step 2: Depending on the hoisting cycle which is to be considered, the starting and the end position of the lifting/lowering action shall be defined, using the lifting ratio h/H (in Figure A.2: full hoisting cycle between h/H = 0 and 1,0 defined as top position T and bottom position B).

Step 3: At both positions the distances of the rope drive elements shall be marked in terms of the rope length (y-axis).

Step 4: As shown in Figure A.2 at every entrance of one rope drive element, the bending count w_c according to Table A.1 shall be counted (+) while going upwards the rope length *l*. If one rope drive element exits while going upwards the rope length *l*, the bending count w_c shall be subtracted (-). The entrance and exit points are additional marked in the rope drive in Figure A.3 and Figure A.4. As a simplification, the diameters of the rope drive elements are neglected.



Key

(+)	count up $w_{c,i}$, refer to Formula (A.1)
(-)	count down $w_{c,i}$, refer to Formula (A.1)
1, 2	elements of the reeving system, refer to Figure A.1
1B, 2B, 1T, 2T	positions of the rope sections, refer to Figure A.3
B	bottom position of the hoist
FP	fixed point of rope
l	rope length
h/*H*	lifting ratio
h	hoisting ordinate – origin at top position
H	maximum hoisting height
T	top position of the hoist
w_{max}	maximum number of bending cycles in the most unfavourable part of the reeving system for one work cycle, refer to Formula (A.1)

Figure A.2 — Bending cycle distribution at one full hoisting cycle between *h*/*H* = 0 and 1,0

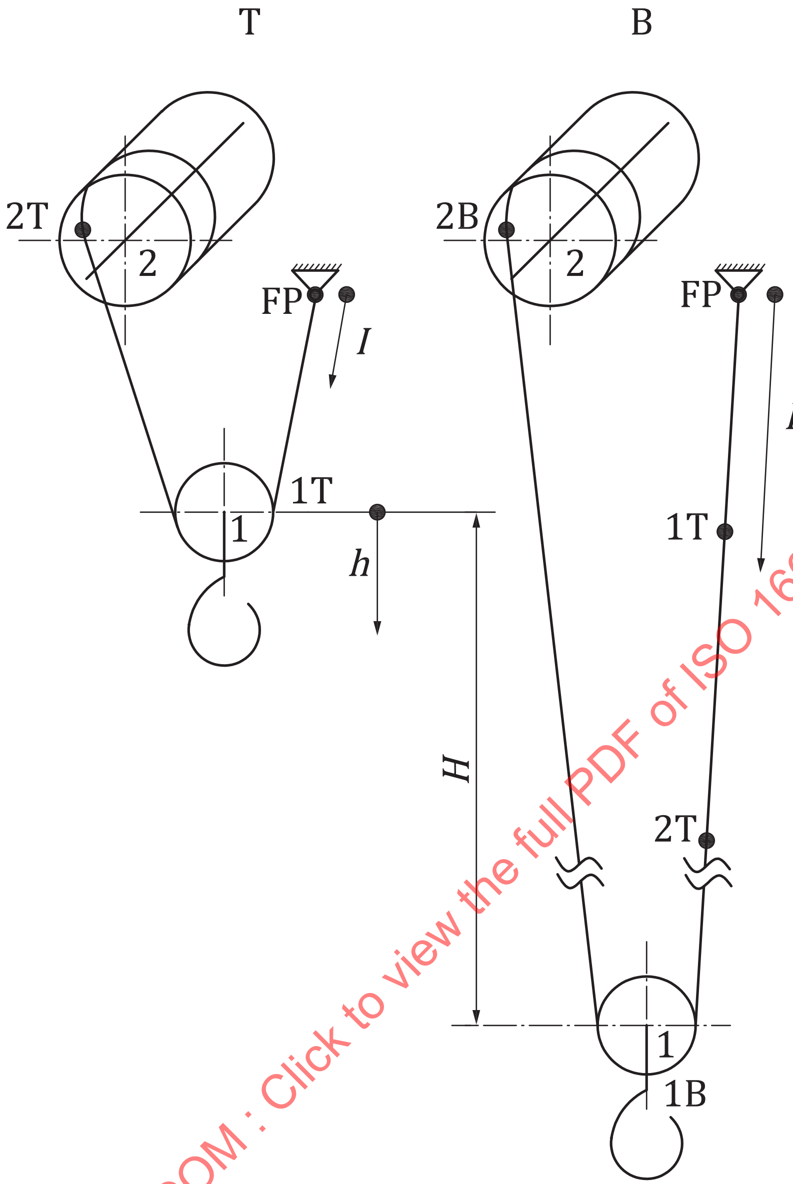
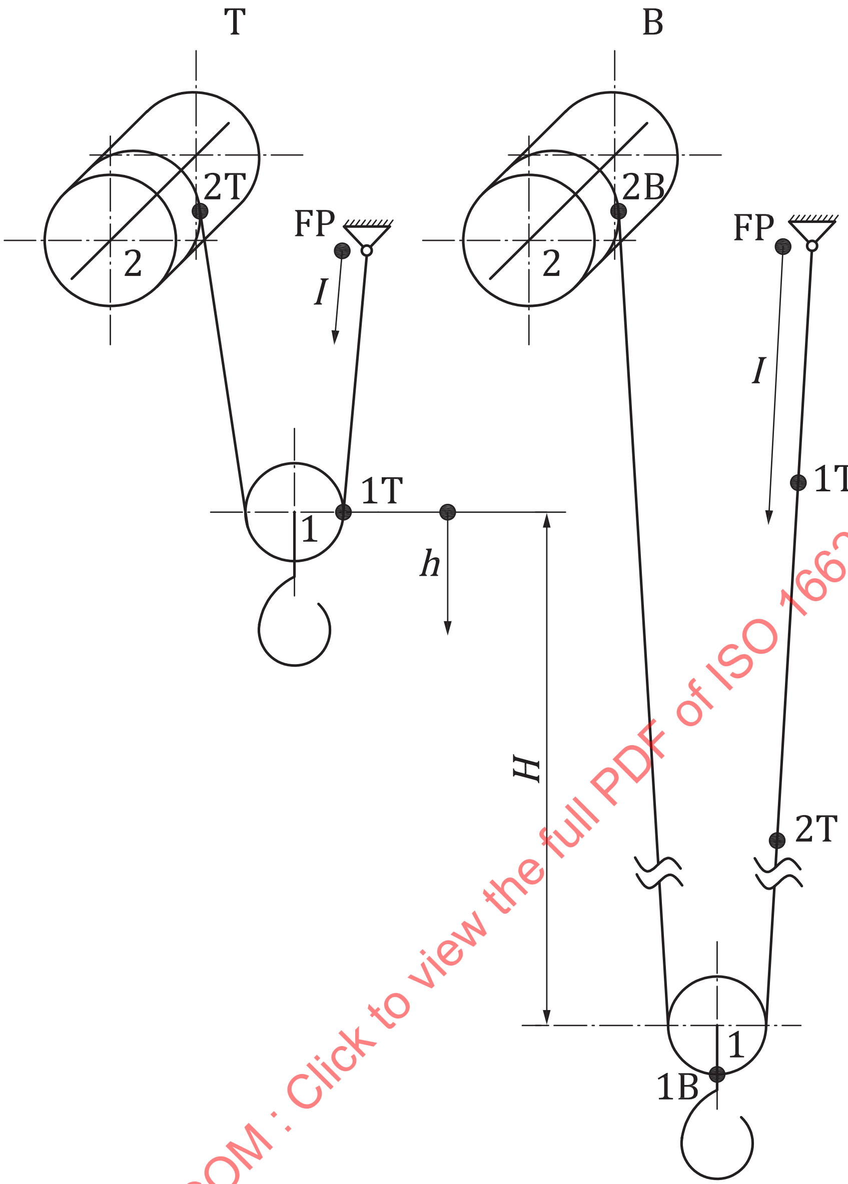


Figure A.3 — Rope sections in correspondence to Figure A.2

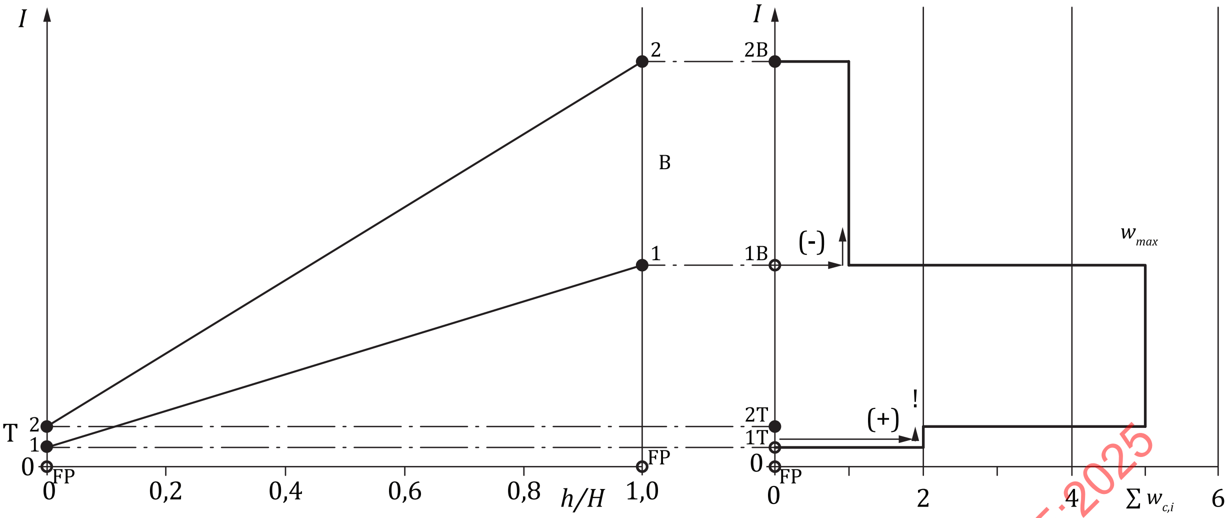
The example in Figure A.4 shows a 2/1 reeving system with reverse bending. The bending counts w_c in Figure A.5 depend on the rope sections that actually endure the same/reverse sense bending. In this example:



Key

1	sheave with $w_c = 2$ or $w_c = 4$ when reverse sense bending is present rope section between 1T and 2T – sheave with same sense bending $w_c = 2$ rope section between 2T and 1B – sheave with reverse sense bending $w_c = 4$
2	drum with $w_c = 1$
1B, 2B, 1T, 2T	positions of the rope sections
B	bottom position of the hoist
FP	fixed point of rope
l	rope length
h	hoisting ordinate – origin at top position
H	maximum hoisting height
T	top position of the hoist

Figure A.4 — Hoist with 2/1 reeving system and reverse bending

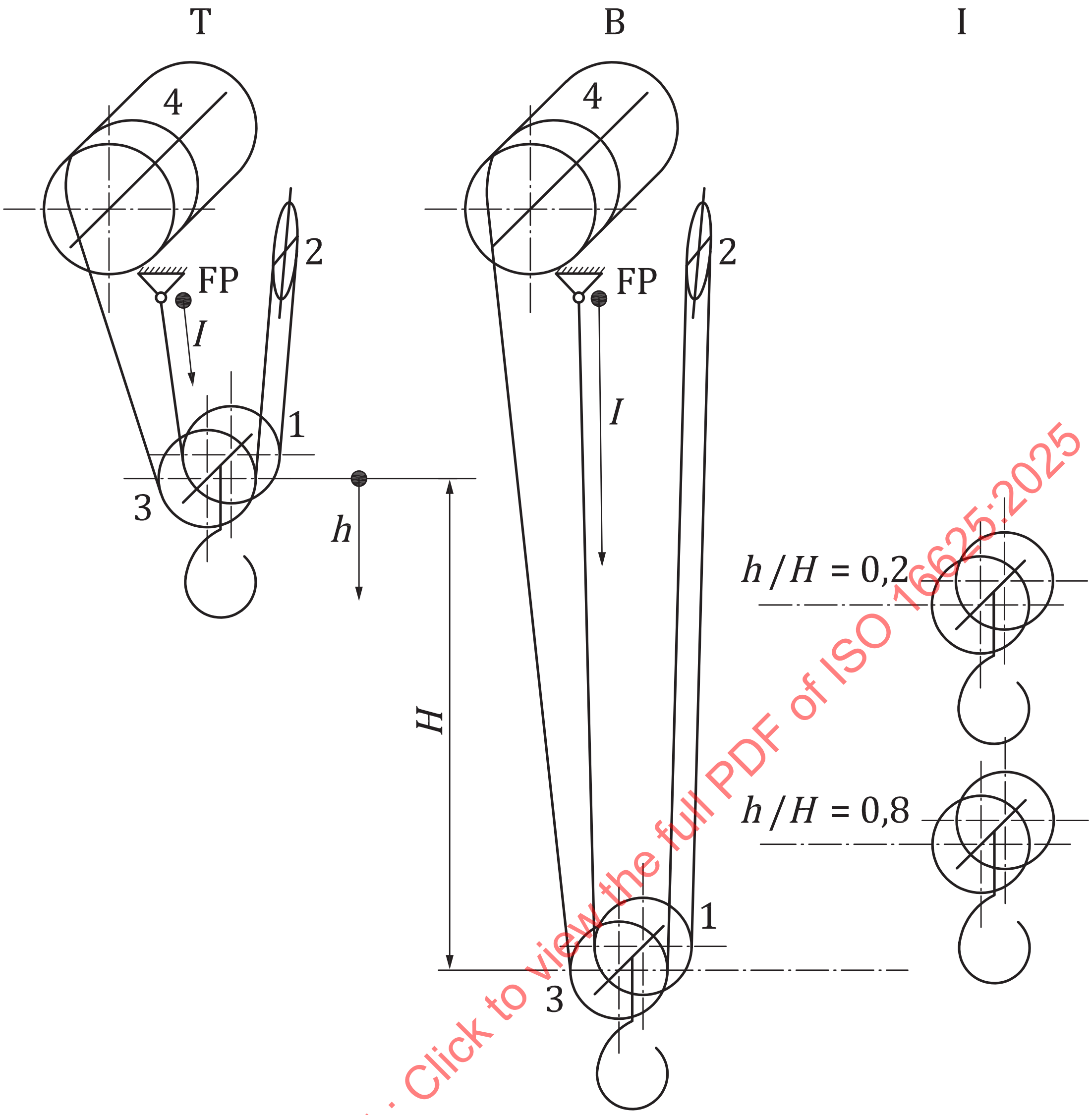


Key

(+)	count up $w_{c,i}$, refer to Formula (A.1)
(-)	count down $w_{c,i}$, refer to Formula (A.1)
1, 2	elements of the reeving system, refer to Figure A.4
1B, 2B, 1T, 2T	positions of the rope sections, refer to Figure A.4
B	bottom position of the hoist
FP	fixed point of rope
l	rope length
h/*H*	lifting ratio
h	hoisting ordinate – origin at top position
H	maximum hoisting height
T	top position of the hoist
w_{max}	maximum number of bending cycles in the most unfavourable part of the reeving system for one work cycle, refer to Formula (A.1)

Figure A.5 — Bending cycle distribution at one full hoisting cycle between *h*/*H* = 0 and 1,0

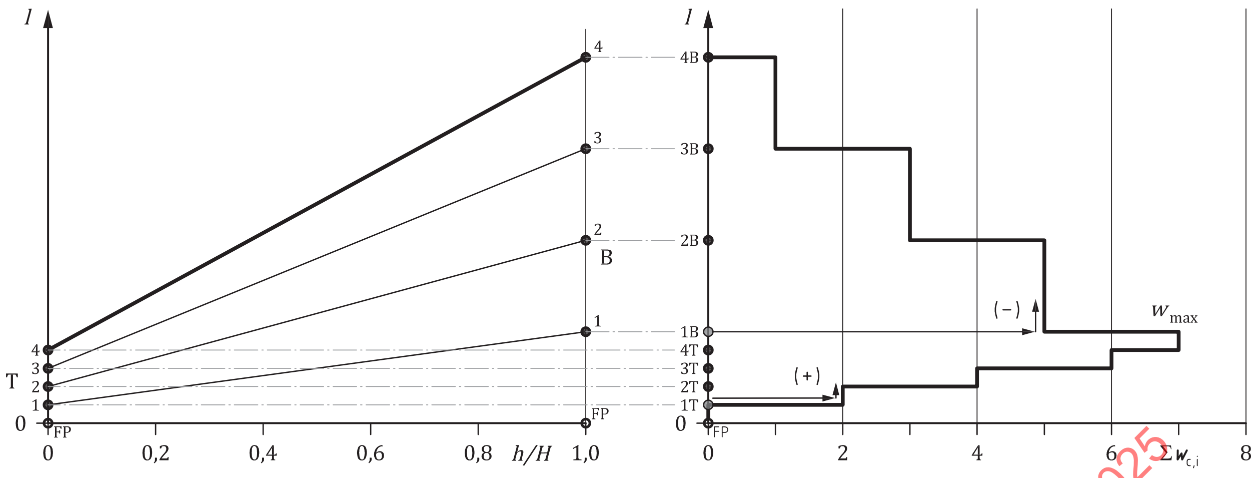
The example in Figure A.6 shows a 4/1 reeving system. Figure A.7 shows the hoisting cycle from *h*/*H* = 0 to 1,0. For comparison a different hoisting cycle from *h*/*H* = 0,2 to 0,8 is shown in Figure A.8. The distribution as well as the most bent rope section changes in dependence of the given hoisting cycle.



Key

1, 2, 3, 4	elements of the reeving system
B	bottom position of the hoist
FP	fixed point of rope
l	rope length
h/*H*	lifting ratio
h	hoisting ordinate – origin at top position
H	maximum hoisting height
I	intermediate positions
T	top position of the hoist

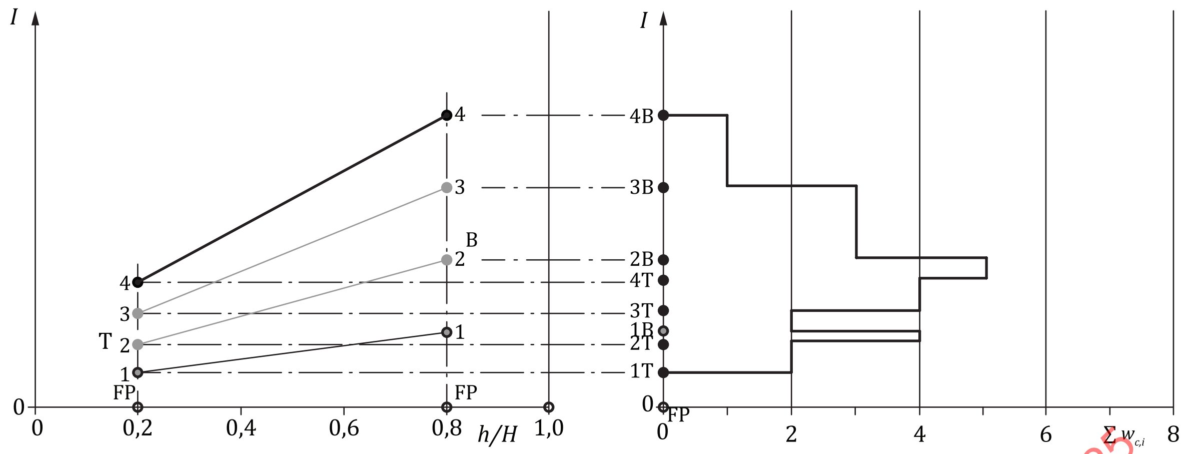
Figure A.6 — Hoist with a 4/1 reeving system



Key

(+)	count up $w_{c,i}$, refer to Formula (A.1)
(-)	count down $w_{c,i}$, refer to Formula (A.1)
1, 2, 3, 4	elements of the reeving system, refer to Figure A.6
1B, 2B, 3B, 4B, 1T, 2T, 3T, 4T	positions of the rope sections, refer to Figure A.6
B	bottom position of the hoist
FP	fixed point of rope
l	rope length
h/H	lifting ratio
h	hoisting ordinate – origin at top position
H	maximum hoisting height
I	intermediate positions
T	top position of the hoist
w_{max}	maximum number of bending cycles in the most unfavourable part of the reeving system for one work cycle, refer to Formula (A.1)

Figure A.7 — Bending cycle distribution at one full hoisting cycle between *h/H* = 0 and 1,0



Key

1, 2, 3, 4	elements of the reeving system, refer to Figure A.6
1B, 2B, 3B, 4B, 1T, 2T, 3T, 4T	positions of the rope sections, refer to Figure A.6
B	bottom position of the hoist
FP	fixed point of rope
l	rope length
h/*H*	lifting ratio
h	hoisting ordinate – origin at top position
H	maximum hoisting height
T	top position of the hoist
$w_{c,i}$	bending count of a particular type of bending *i* of an element, refer to Formula (A.1)

Figure A.8 — Bending cycle distribution at a hoisting cycle between *h*/*H* = 0,2 and 0,8

Annex B
(informative)

Determination of the maximum tensile force in the ropes of multi-rope grabs (holding and closing)

In the case of appliances with grabs, where the mass of the load is not always equally distributed between the closing ropes and the holding ropes during the whole work cycle, the value of the design rope force F_{Sd} for each rope shall be determined by a distribution of the mass of the hoist load including the grab m_H as follows.

a) If the hoist mechanism automatically ensures an equal division of the hoisted load between the closing and holding ropes, and any difference between the loads carried by the ropes is limited to a short period at the end of the closing or the beginning of the opening:

1) the mass of the hoist load to be considered for closing ropes: $m_{Hr,1} = 66\ \% \times m_H + m_R$;

2) the mass of the hoist load to be considered for holding ropes: $m_{Hr,2} = 66\ \% \times m_H + m_R$.

b) If the hoist mechanism does not automatically ensure an equal division of load between the closing ropes and the holding ropes and, in practice, almost all the load is applied to the closing ropes:

1) the mass of the hoist load to be considered for closing ropes: $m_{Hr,1} = 100\ \% \times m_H + m_R$;

2) the mass of the hoist load to be considered for holding ropes: $m_{Hr,2} = 66\ \% \times m_H + m_R$.

where

m_H	is the mass of the hoist load including the masses of the payload and the grab without the mass of the suspended holding and closing ropes;
m_R	is the mass of the portion of the suspended ropes of the rope drive under consideration (holding or closing);
$m_{Hr,1}$	is the portion of the total mass of the hoist load (m_H) that is acting on the closing ropes (see 5.1.2, Figure 1);
$m_{Hr,2}$	is the portion of the total mass of the hoist load (m_H) that is acting on the holding ropes (see 5.1.2, Figure 1).

The determination of the design rope force F_{Sd} for each rope shall be performed according to 5.1.2 for the proof of static strength, 5.2.2 for the proof of fatigue strength and if applicable according to 5.3 for the proof of multilayer spooling separately. Thus, the parameter m_{Hr} given in 5.1.2, 5.2.2 and 5.3 shall be replaced by $m_{Hr,1}$ and $m_{Hr,2}$ for the closing and holding ropes, respectively.

Annex C
(informative)

Comparison of minimum design factor according to ISO 16625:2013 and safety level according current version

Purpose of this annex is to compare minimum design factor Z_p from former edition of ISO 16625:2013 with a safety level laid down in current edition of this document.

The safety level for each proof of competence given by Formula (1), Formula (18), Formula (40), Formula (44) and Formula (47) can be compared with the minimum design factors Z_p. Applying this comparison, the results of the proofs of competence can be evaluated or compared with the values given in Table D.1, Table D.2 and Table D.3, respectively.

The former edition of the ISO 16625 did not provide different proofs of competence (static, fatigue, multilayer spooling). A minimum breaking force of the rope, F_{min} was calculated by using Formula (C.1):

$$F_{min} \geq S \times Z_p \rightarrow S \leq \frac{F_{min}}{Z_p} \tag{C.1}$$

"where, for hoisting ropes, S is the maximum [characteristic] *rope tension, in kN, obtained by taking into account*

- *rated working load of the appliance,*
- *mass of the sheave block and/or other lifting attachments,*
- *mechanical advantage of reeving,*
- *efficiency of reeving (e.g. bearing efficiency), and*
- *the increase in force in the rope caused by the rope inclination at the upper extreme position of the hook, if the inclination with respect to the drum axis exceeds 22,5°;*

or, for stationary ropes, S is the maximum [characteristic] rope tension, in kN, obtained by taking account of both the static forces and dynamic forces;

and where Z_p is the minimum design factor."

ISO 16625:2013, 5.3.

Simplified calculations can be conducted to evaluate or compare the safety levels of this document with the former Z_p design factor, respectively. See the following example.

The proof of static strength according to Formula (1) for running ropes of 5.1 can be executed as shown in Formula (C.2):

$$F_{Sd,s} = \frac{m_{Hr} \times g}{n_m} \times \phi \times f_{S1} \times f_{S2} \times f_{S3} \times \gamma_p \times \gamma_n \leq \frac{F_{min}}{\gamma_{rb}} \times \min\{f_{S4}; f_{S5}\} = F_{Rd,s} \tag{C.2}$$

where

$F_{Sd,s}$	is the design rope force for the proof of static strength;
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, load-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 reeving;
ϕ	is the dynamic factor for inertial and gravity effects, see 5.1.2.2;
f_{S1} to f_{S3}	are the rope force increasing factors, see 5.1.2.3;
f_{S4}	is the reduction factor due to the type of rope termination, see 5.1.4;
f_{S5}	is the rope force reduction factor due to *D*/*d*-ratio of drum or sheave and rope, see 5.1.4;
γ_p	is the partial safety factor (see ISO 8686-1);
γ_n	is the risk coefficient, where applicable (see ISO 8686-1; additionally ISO 12100 may be used for risk assessment);
F_{min}	is the specified minimum breaking force of the rope;
γ_{rb}	is the rope resistance factor;
$F_{Rd,s}$	is the limit design rope force for the proof of static strength.

Out of C.1, Formula (C.3) can be expressed:

$$S \approx \frac{m_{Hr} \cdot g}{n_m} \times f_{S1} \times f_{S2} \times f_{S3} \leq \frac{F_{min}}{\gamma_{rb} \times \min\{f_{S4}; f_{S5}\}^{-1} \times \gamma_p \times \gamma_n \times \phi} \approx \frac{F_{min}}{Z_p} \quad \text{(C.3)}$$

where

S	is the maximum rope tension (see ISO 16625:2013);
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, load-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 reeving;
ϕ	is the dynamic factor for inertial and gravity effects, see 5.1.2.2;
f_{S1} to f_{S3}	are the rope force increasing factors, see 5.1.2.3;
f_{S4}	is the reduction factor due to the type of rope termination, see 5.1.4;
f_{S5}	is the rope force reduction factor due to *D*/*d*-ratio of drum or sheave and rope, see 5.1.4;

γ_p is the partial safety factor (see ISO 8686-1);

γ_n is the risk coefficient, where applicable (see ISO 8686-1; additionally ISO 12100 may be used for risk assessment);

F_{min} is the specified minimum breaking force of the rope;

γ_{rb} is the rope resistance factor;

Z_p is the minimum design factor (see ISO 16625:2013).

Out of C.3, Formula (C.4) can be derived:

$$Z_p \approx \gamma_{rb} \times \min\{f_{S4}; f_{S5}\}^{-1} \times \gamma_p \times \gamma_n \times \phi \rightarrow \gamma_{rb} \approx \frac{Z_p}{\min\{f_{S4}; f_{S5}\}^{-1} \times \gamma_p \times \gamma_n \times \phi} \quad \text{(C.4)}$$

where

Z_p is the minimum design factor (see ISO 16625:2013);

γ_{rb} is the rope resistance factor;

f_{S4} is the reduction factor due to the type of rope termination, see 5.1.4;

f_{S5} is the rope force reduction factor due to *D*/*d*-ratio of drum or sheave and rope, see 5.1.4;

γ_p is the partial safety factor (see ISO 8686-1);

γ_n is the risk coefficient, where applicable (see ISO 8686-1; additionally ISO 12100 may be used for risk assessment);

ϕ is the dynamic factor for inertial and gravity effects, see 5.1.2.2.

It is now possible either to calculate a design factor Z_p out of the safety values γ_p, γ_n and the dynamic factor ϕ of this document or to calculate a rope resistance factor γ_{rb} which should be not smaller than 2,0.

Similar procedure can be done for all other proofs of competence of this document, see below.

From Formula (18), running ropes - proof of fatigue strength (prevention from exceeding the Donandt-force not taken into account), Formula (C.5) can be derived:

$$Z_p \approx \gamma_{rf} \times \gamma_{ref} \times \sqrt[m]{s_r} \times \gamma_n \times \phi^* \times f_F^{-1} \rightarrow \gamma_{rf} \approx \frac{Z_p}{\gamma_{ref} \times \sqrt[m]{s_r} \times \gamma_n \times \phi^* \times f_F^{-1}} \quad \text{(C.5)}$$

whereby γ_{rf} should be not smaller than 1,25;

From Formula (40), running ropes - requirements for multilayer spooling, Formula (C.6) can be derived:

$$Z_p \approx \gamma_{rb} \times \sqrt[4]{\left(\frac{\frac{D}{d}}{\left(\frac{D}{d}\right)_{ref}}\right)^{-1}} \times \gamma_p \times \gamma_n \times \phi \rightarrow \gamma_{rb} \approx \frac{Z_p}{\sqrt[4]{\left(\frac{\frac{D}{d}}{\left(\frac{D}{d}\right)_{ref}}\right)^{-1}} \times \gamma_p \times \gamma_n \times \phi} \quad \text{(C.6)}$$

whereby γ_{rb} should be not smaller than 2,41;

From Formula (44), stationary ropes – proof of static strength, Formula (C.7) can be derived:

$$Z_p \approx \gamma_{rb} \times f_{S4}{}^{-1} \rightarrow \gamma_{rb} \approx \frac{Z_p}{f_{S4}{}^{-1}} \quad \text{(C.7)}$$

whereby γ_{rb} should be not smaller than 2,0;

From Formula (47), stationary ropes – proof of fatigue strength, Formula (C.8) can be derived:

$$Z_p \approx \gamma_{rf} \times f_{S4}{}^{-1} \times \gamma_{ref} \times \sqrt[7]{s_r} \rightarrow \gamma_{rf} \approx \frac{Z_p}{\gamma_{ref} \times f_{S4}{}^{-1} \times \sqrt[7]{s_r}} \quad \text{(C.8)}$$

whereby γ_{rf} should be not smaller than 1,25;

where

Z_p	is the minimum design factor (see ISO 16625:2013);
γ_{rb}	is the rope resistance factor;
f_{S4}	is the reduction factor due to the type of rope termination, see 5.1.4;
D	is the relevant bending diameter;
d	is the nominal rope diameter;
$\left(\frac{D}{d}\right)_{ref}$	is the reference D/d-ratio of rope drum and rope diameter, defined by experience;
γ_p	is the partial safety factor (see ISO 8686-1);
γ_n	is the risk coefficient, where applicable (see ISO 8686-1; additionally ISO 12100 may be used for risk assessment);
ϕ	is the dynamic factor for inertial and gravity effects, see 5.1.2.2;
γ_{rf}	is the rope resistance factor; γ_{rf} is a combined safety factor taking into account the uncertainty of fatigue strength values and the possible consequences of fatigue damage;
γ_{ref}	$\gamma_{ref} = 0,5$ increases F_{min} to the reference rope tension force F_{ref} (running ropes);
	$\gamma_{ref} = 6,0$ reduces F_{min} to fatigue strength at reference point (stationary ropes);
m	is the exponent, slope of the S-N curve (Wöhler-curve), see Formula (16);
s_r	is the rope force history parameter, see 5.2.3.2;
ϕ^*	is the dynamic factor for inertial and gravity effects, see 5.2.2.4;
f_F	is the factor of further influences [see 5.2.3.3 and Formula (33)].

If an evaluation respectively a comparison is done, it is recommended to set $\gamma_p = 1,34$ and ϕ, ϕ^* to a minimum of 1,1.

Annex D
(informative)

Selection of a rope by minimum design factor Z_p

Referring to 4.1, only in cases where some essential information regarding the crane/hoist is missing and/or essential parameter value are unknown, a selection of a rope – respectively the minimum safety level given by the minimum design factor – should be specified in accordance with Table D.1, Table D.2, or Table D.3. The content of the tables is similar to Table 1, Table 2 and ISO 16625:2013, Table 3. A_C-classes have been determined according to the calculation given in ISO 4301-1:2016, Annex B where the average displacement time t_{av} has been chosen to be 36 s.

NOTE A$_C$-classes in below Tables D.1, D.2 and D.3 are derived from Reference [5].

Table D.1 — Minimum design factors Z_p for all cranes and hoists except mobile cranes

Ac Class	Hoisting				Boom hoisting or luffing	
	Single-layer spooling		Multi-layer spooling			
	Standard rope	Rotation-resistant rope	Standard rope	Rotation-resistant rope	Standard rope	Rotation-resistant rope
Ac2	3,15	3,15	3,55	3,55	3,55	4,5
Ac3	3,35	3,35	3,55	3,55	3,55	4,5
Ac4	3,55	3,55	3,55	3,55	3,55	4,5
Ac5	4,0	4,0	4,0	4,0	4,0	4,5
Ac6	4,5	4,5	4,5	4,5	4,5	4,5
Ac7	5,6	5,6	5,6	5,6	5,6	5,6
Ac8	7,1	7,1	—	—	7,1	—
Ac9	9,0	9,0	—	—	9,0	—

Table D.2 — Minimum design factors Z_p for mobile cranes

Ac Class	Running rope						
	Hoisting		Boom hoisting				Telescoping
			Working		Erecting		
	Standard rope	Rotation-resistant rope	Standard rope	Rotation-resistant rope	Standard rope	Rotation-resistant rope	
Ac2	3,55	4,5	3,35	4,5	3,05	4,5	3,15
Ac3	3,55	4,5	3,35	4,5	3,05	4,5	3,35
Ac4	3,55	4,5	3,35	4,5	3,05	4,5	3,35
Ac5	4,0	4,5	3,35	4,5	3,05	4,5	3,35
Ac6	4,5	4,5	3,35	4,5	—	—	—
Ac7	5,6	5,6	3,35	4,5	—	—	—

Table D.3 — Minimum design factors Z_p for stationary rope and erecting rope

Ac Class	All cranes	
	Stationary ropes	Erection ropes
Ac1	3,0	2,73
Ac2	3,0	2,73
Ac3	3,0	2,73
Ac4	3,5	2,73
Ac5	4,0	2,73
Ac6	4,5	—
Ac7	5,0	—
Ac8	5,0	—

Annex E
(informative)

Assumed number of hoist ropes l_r during the design life of a crane

Purpose of this annex is to show a simplified approach to calculate the assumed number of ropes l_r during the design life of a crane according to Formulae (E.1) to (E.5):

$$w_{Crane} = w_{max} \times C \quad \text{(E.1)}$$

$$w^* = \left(\frac{F_{ref}}{\frac{m_{Hr} \times g}{n_m}} \right)^m \times \frac{w_{ref}}{k_r} \quad \text{if } k_r \text{ is known} \quad \text{(E.2)}$$

$$w^* = \left(\frac{F_{ref}}{\frac{m_{Hr} \times g}{n_m}} \right)^m \times \frac{w_{ref}}{(K_p)^{\frac{m}{3}}} \quad \text{if } K_p \text{ is known} \quad \text{(E.3)}$$

$$m = 2{,}6 \times log_{10} \left(\frac{D}{d} \right) - 1{,}6 \quad \text{(E.4)}$$

$$l_r = \frac{w_{Crane}}{w^*} \quad \text{(E.5)}$$

where

w_{Crane} is the assumed total number of bending cycles during the design life of a crane;

w_{max} is the maximum number of bending cycles in the most unfavourable part of the reeving system for one cycle, see Annex A;

C is the total numbers of working cycles during the design life of the crane (ISO 4301-1);

w^* is the assumed total number of bending cycles during the design life of a rope.
The formula of w^* has been derived from Formula (15). In cases where the rope force spectrum factor k_r is not known, for simplification purposes the load spectrum factor K_p of the crane can be utilized to determine w^* if the *D/d*-ratio is less than 40. The result of w^* will be smaller and therefore more conservative;

F_{ref} is the reference rope tension force, see Formula (27) with:
$\gamma_{ref} = 0{,}5$ increases F_{min} to the reference rope tension force F_{ref} (see Figure 7) and
$f_F = 1$, the factor of further influences to F_{ref} to be neglected in this simplified approach;

m_{Hr} is the mass of the hoist load or that part of the mass of the hoist load that is acting on the rope falls under consideration;

g is the acceleration due to gravity;

n_m is the mechanical advantage of reeving;

w_{ref} is the reference number of bending cycles;

k_r is the rope force spectrum factor, see Formula (30);

K_p is the load spectrum factor (ISO 4301-1);

m is the exponent, slope of the S-N curve (Wöhler-curve), see Formula (16);

l_r is the number of ropes assumed to be used during the design life of the crane.

NOTE 1 The design life of a rope correlates to the periodic inspection interval, see 4.2.

NOTE 2 The above approach is only suitable for cranes where there is a linear relationship between the crane spectrum and the rope-bending spectrum at the critical rope section. This is the case, for example, if the load is always picked up at the same position and the positions of the rope sheaves in the rope drive do not change. At all other types of cranes, the correlation of both spectra can be determined by simulation or test.