INTERNATIONAL STANDARD

ISO 8686-1

Second edition
2012-12-15

Cranes — Design principles for loads and load combinations —

Part 1: General

Appareils de levage à charge suspendue — Principes de calcul des charges et des combinaisons de charge —

Partie 1: Généralités

Reference number
ISO 8686-1:2012(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 8686-1 was prepared by Technical Committee ISO/TC 96, *Cranes*, Subcommittee SC 10, *Design — Principles and requirements*.

This second edition cancels and replaces the first edition (ISO 8686-1:1989), which has been technically revised.

ISO 8686 consists of the following parts, under the general title *Cranes — Design principles for loads and load combinations*:

— *Part 1: General*

— *Part 2: Mobile cranes*

— *Part 3: Tower cranes*

— *Part 4: Jib cranes*

— *Part 5: Overhead travelling and portal bridge cranes*

Cranes — Design principles for loads and load combinations —

Part 1:
General

1 Scope

This part of ISO 8686 establishes general methods for the calculating loads and principles to be used in the selection of load combinations for proofs of competence in accordance with ISO 20332 for the structural and mechanical components of cranes as defined in ISO 4306-1.

It is based on rigid body kinetic analysis and elastostatic analysis but expressly permits the use of more advanced methods (calculations or tests) to evaluate the effects of loads and load combinations, and the values of dynamic load factors, where it can be demonstrated that these provide at least equivalent levels of competence.

This part of ISO 8686 provides for two distinct kinds of application:

a) the general form, content and ranges of parameter values for more specific standards to be developed for specific types of cranes;

b) a framework for agreement on loads and load combinations between a designer or manufacturer and a crane purchaser for those types of cranes where specific standards do not exist.

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.

ISO 4302, *Cranes — Wind load assessment*

ISO 4306 (all parts), *Lifting appliances — Vocabulary*

ISO 4310, *Cranes — Test code and procedures*

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

3 Terms and definitions

For the purposes of this document, the definitions given in ISO 4306 and the following apply.

3.1
load or loads
external or internal actions in the form of forces, displacements or temperature, which cause stresses in the structural or mechanical components of the crane

3.2
analysis
<rigid bodies> study of the movement and the inner forces of systems modelled by elements that are assumed to be non-elastic

3.3
analysis
<elastic bodies> study of the relative elastic displacements (distortion), movement and the inner forces of systems modelled by elements that are assumed to be elastic

4 Symbols

The main symbols used in this part of ISO 8686 are given in Table 1.

Table 1 — Main symbols

Symbol	Description	Reference
ϕ	Factors for dynamic effects	Various
ϕ_1	Factors for hoisting and gravity effects acting on the mass of the crane	6.1.1
ϕ_2	Factor for hoisting a grounded load	6.1.2.1
ϕ_3	Factor for dynamic effects of sudden release of part of load	6.1.2.2
ϕ_4	Factor for dynamic effects of travelling on an uneven surface	6.1.3.2
ϕ_5	Factor for dynamic loads arising from acceleration of crane drives	6.1.4
ϕ_6	Factor for effects of dynamic load tests	6.3.2
ϕ_7	Factor for elastic effects arising from collision with buffers	6.3.3
ϕ_9	Factor for dynamic effects from unintentional loss of payload	6.3.5
HC1 to HC4	Hoisting classes assigned to cranes	6.1.2.2 to 6.1.2.1.4
β_2	Factor assigned to hoisting class	6.1.2.1.1 to 6.1.2.1.2; 6.1.2.1.5
β_3	Term used in determining the value of ϕ_3	6.1.2.2
v_h	Steady hoisting speed, in metres per second	6.1.2.1.3 (Table 2b)
F_x, F_{x2}, F_{x4}	Buffer forces	6.3.3, Annex D
γ_f	Coefficients for calculating allowable stresses	7.3.2, Table 3, A.2 to A.3
γ_p	Partial safety factor	7.3.3, Table 3, 7.3.7.2, 7.3.8, A.2 to A.3
γ_m	Resistance coefficient	Table 3, Annex A
γ_n	Coefficient for high-risk applications	7.3.6, Annex A
m	Mass of pay load	6.1.2.2
m_H	Mass of the gross load	6.1.2.1.1, 6.1.2.3, 6.3.1, Annex D
$\eta m = m_H - \Delta m_H$	Mass of that part of the hoist load remaining suspended from the crane	6.3.1
NOTE Further symbols are used in the annexes and are defined therein.		

5 General

5.1 General principles

The objective of proof of competence calculations carried out in accordance with this part of ISO 8686 is to determine mathematically that a crane will be competent to perform in practice when operated in compliance with the manufacturer's instructions.

The basis for such proof against failure (e.g. by yielding, elastic instability or fatigue) is the comparison between calculated stresses induced by loads and the corresponding calculated strengths of the constituent structural and mechanical components of the crane.

Proof against failure may also be required in respect of overturning stability. Here, the comparison is made between the calculated overturning moments induced by loads and the calculated resistance to overturning provided by the crane. In addition, there may be limitations on forces that are necessary to ensure the stability and/or to avoid unwanted displacement of portions of the crane or of the crane itself, for example, the jib support ropes becoming unloaded or the crane sliding.

The effects of differences between actual and ideal geometry of mechanical and structural systems (e.g. the effect of tolerances, settlements, etc.) shall be taken into account. However, they shall be included specifically in proof of competence calculations only where, in conjunction with applied loads, they may cause stresses that exceed specified limits.

When applying this part of ISO 8686 to the different types of cranes, operating in the same service and environmental conditions, equivalent resistance to failure should be sought.

5.2 Methods of proof of competence calculations

There are two general approaches to structural design or proof of competence.

a) **The allowable stress method**: where the design stresses induced by combined loads are compared with allowable stresses established for the type of member or condition being examined. The assignment of allowable stress is made on the basis of service experience with consideration for protection against failure due, for example, to yielding, elastic instability or fatigue.

b) **The limit state method**: where partial safety factors are used to amplify loads before they are combined and compared with the limit states imposed, for example, by yielding or elastic instability. The partial safety factor for each load is established on the basis of probability and the degree of accuracy with which the load can be determined. Limit state values comprise the characteristic strength of the member reduced to reflect statistical variations in its strength and geometric parameters. This method is a prerequisite if this part of ISO 8686 is applied together with ISO 20332 and/or the 2nd order method.

Annex A gives a more detailed description of the application of the two methods.

5.3 Assessment of loads

To calculate stresses from applied loads, an appropriate model of the crane shall be used. Under the provisions of this part of ISO 8686, loads which cause time variant load effects are assessed as equivalent static loads from experience, experiments or by calculation. A rigid body kinetic analysis can be used with dynamic factors to estimate the forces necessary to simulate the response of the elastic system. Alternatively, either elasto-kinetic analysis or field measurements can be carried out, but to reflect the operating regime, a realistic model of the actions of the crane operator may be required.

For both the allowable stress and limit state methods, and for considerations of stability and displacements, loads, load combinations and load factors should be assigned either on the basis of experience, with consideration of other International Standards or, if applicable, on the basis of experimental or statistical data. The parameters used in this part of ISO 8686 are considered to be deterministic.

Where a specific loading cannot occur (for example, wind loading on a crane used indoors) then that loading can be ignored in the proof of competence calculations. Similarly, loadings can be modified when they result from

a) conditions prohibited in the crane instructions,

b) features not present in the design, or

c) conditions prevented or suppressed by the design of the crane.

If a probabilistic proof of competence calculation is used, the relevant conditions, particularly the acceptable probability of failure, shall be stated.

5.4 Categories of loads

Clause 6 gives loads and ranges of values for the factors used in proof of competence calculations when determining load effects.

NOTE Individual values for specific types of cranes, selected from these ranges, are to be found in the parts of ISO 8686 applicable to specific crane types (see Foreword).

The loads acting on a lifting crane are divided into the categories of regular, occasional, exceptional and miscellaneous. Individual loads are considered only when and if they are relevant to the crane under consideration or to its usage, as follows.

a) **Regular loads**, occurring during normal operation, shall be considered in proof of competence calculations against failure by yielding, elastic instability and, when applicable, against fatigue. They result from gravity and from acceleration or deceleration produced by drives and brakes acting on the masses of the crane and the hoist load, as well as from displacements.

b) **Occasional loads** and effects which occur infrequently may usually be neglected in fatigue evaluations. They include loads induced by in-service wind, snow and ice, temperature and skewing.

c) **Exceptional loads** and their effects are also infrequent and may likewise usually be excluded from fatigue consideration. They include loads caused by testing, out-of service wind, buffer forces and tilting, as well as from emergency cut-out, failure of drive components and external excitation of the crane foundation.

d) **Miscellaneous loads** include erection and dismantling loads as well as loads on platforms and means of access.

The category in which a load is placed is not necessarily an indication of the importance or criticality of that load: erection and dismantling loads, although in the last category, shall be given particular attention, as a substantial portion of accidents occur during those phases of operation.

6 Loads and applicable factors

6.1 Regular loads

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

The mass of the crane includes those components which are always in place during operation, except for the payload itself (see 6.1.2). For some cranes or applications, it may be necessary to add mass to account for encrustation of materials, such as coal or similar dust, which build up on the crane or its parts.

The gravitational force induced by the mass of the crane (dead weight) shall be multiplied by a factor, ϕ_1, where

$$\phi_1 = 1 \pm a, 0 \le a \le 0{,}1 \qquad (1)$$

In this way the vibrational excitement of the crane structure, when lifting the pay load off the ground, is taken into account. There are always two values for the factor, in order to reflect both the upper and lower reaches of the vibrational pulses.

Factor ϕ_1 shall be used in the design of the crane structure and its supports; in some cases, both values of the factor shall be applied in order to find the most critical loadings in members and components.

Annex B gives a general comment on the application of ϕ factors.

6.1.2 Inertial and gravity effects acting vertically on the gross load

6.1.2.1 Hoisting an unrestrained grounded load

6.1.2.1.1 General

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

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

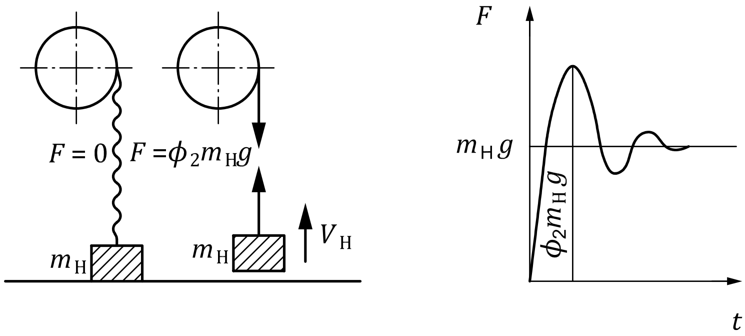


Figure 1 — Dynamic effects when hoisting grounded load

Factor ϕ_2 is calculated as follows:

$$\phi_2 = \phi_{2,\min} + \beta_2 \cdot v_h \tag{2}$$

where

β_2 is the factor dependent upon the hoisting class of the crane in accordance with Table 2a;

v_h is the characteristic hoisting speed in m/s of the drive system selected in accordance with Table 2b;

$\phi_{2,\min}$ is the minimum value of ϕ_2 in accordance with Table 2c.

6.1.2.1.2 Hoisting classes

For the purposes of specific type, cranes are assigned to hoisting classes HC1 to HC4 in accordance with the elastic properties of the crane and its support. The hoisting classes are given in Table 2a and shall be selected on the basis of the characteristic vertical load displacement, δ.

Table 2a — Hoisting classes

Hoisting class	Characteristic vertical load displacement δ	β_2 s/m
HC1	0,8 m ≤ δ	0,17
HC2	0,3 m ≤ δ < 0,8 m	0,34
HC3	0,15 m ≤ δ < 0,3 m	0,51
HC4	δ < 0,15 m	0,68

The load displacement, δ, shall be calculated statically from the elasticity of the crane and its supporting structure and the rope system using the appropriate maximum gross load value without amplifying factors.

As the load displacement varies for differing crane configurations, the maximum value of δ may be used for the selection of the hoisting class.

6.1.2.1.3 Hoist drive classes

For the purposes of ISO 8686, hoist drives are assigned to classes HD1 to HD5, depending on the control characteristics as the weight of the load is transferred from the ground onto the crane. The hoist drive classes are as follows:

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

HD2: hoist drive can only start at creep speed of at least pre-set duration;

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

HD4: stepless hoist drive control, which performs with continuously increasing speed;

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

See Annex F for further information and examples of typical hoist controls and their characteristics for each class.

The characteristic hoisting speed, v_h, to be used in load combinations A1, B1 and C1, is given in Table 2b.

Table 2b — Characteristic hoisting speeds v_h for calculation of ϕ_2

Load combination (see Clause 7)	Hoist drive class				
	HD1	**HD2**	**HD3**	**HD4**	**HD5**
A1, B1	$v_{h,max}$	$v_{h,CS}$	$v_{h,CS}$	$0{,}5v_{h,max}$	$v_h = 0$
C1	$v_{h,max}$	$v_{h,max}$	$0{,}5v_{h,max}$	$v_{h,max}$	$0{,}5v_{h,max}$

$v_{h,max}$ is the maximum steady hoisting speed of the main hoist for load combinations A1 and B1;

$v_{h,max}$ is the maximum hoisting speed resulting from all drives (e.g. luffing and hoisting motion) contributing to the hoist speed in load combination C1;

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

Load combination C1 is used to reflect exceptional situations when the lift is started at a speed higher than that intended for load combinations A1 and B1.

6.1.2.1.4 Minimum values for factor ϕ_2

The minimum value of ϕ_2 depends upon classes HC and HD and is given in Table 2c.

Table 2c — Values of $\phi_{2,\min}$

Hoisting class	Hoist drive class				
	HD1	**HD2**	**HD3**	**HD4**	**HD5**
HC1	1,05	1,05	1,05	1,05	1,05
HC2	1,1	1,1	1,05	1,1	1,05
HC3	1,15	1,15	1,05	1,15	1,05
HC4	1,2	1,2	1,05	1,2	1,05

6.1.2.1.5 Alternative methods

Alternatively, the value of ϕ_2 may be determined through experiments or dynamic analysis. When applying alternative methods, the true characteristics of the drive system and the elastic properties of the overall load supporting system shall be simulated. Based upon these results, cranes may be assigned to a hoisting class with equivalent $\phi_{2,\mathrm{min}}$ and β_2.

6.1.2.2 Effects of sudden release of part of payload

For cranes that release or drop part of the payload as a normal working procedure, such as when grabs or magnets are used, the peak dynamic effect on the crane can be simulated by multiplying the payload by the factor ϕ_3 (see Figure 2).

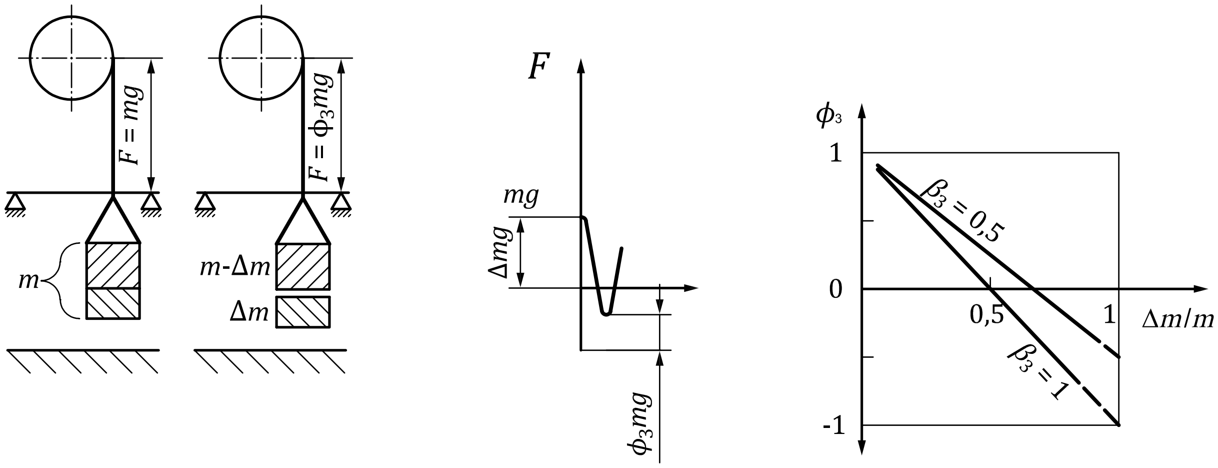


Figure 2 — Factor ϕ_3

The value of ϕ_3 is given by

$$\phi_3 = 1 - \frac{\Delta m}{m}(1 + \beta_3) \tag{3}$$

where

Δm	is the released or dropped part of the payload;
m	is the mass of the payload;
$\beta_3 = 0{,}5$	for cranes equipped with grabs or similar slow release devices,
$\beta_3 = 1{,}0$	for cranes equipped with magnets or similar rapid-release devices.

Annex B gives a general comment on the application of the ϕ factors.

6.1.3 Loads caused by travelling on an uneven surface

6.1.3.1 Cranes travelling on or off roadways

The effects of travelling, with or without load, on or off roadways, depend on the crane configuration (mass distribution), the elasticity of the crane and/or its suspension, the travel speed and on the nature and condition of the travel surface. The dynamic effects shall be estimated from experience or experiment, or by calculation using an appropriate model for the crane and the travel surface.

6.1.3.2 Cranes travelling on rails

The effects of travelling with or without load on rail tracks having geometric or elastic characteristics that induce accelerations at the wheels of the cranes depend on the crane configuration (mass distribution, elasticity of the crane and/or its suspension), travel speed and wheel diameter. They shall be estimated from experience or experiment, or by calculation using an appropriate model for the crane and the track.

The induced accelerations may be taken into account by multiplying the gravitational forces due to the masses of the crane and gross load by a factor, ϕ_4. International Standards for specific types of cranes may specify tolerances for rail tracks and indicate conditions within which the value of ϕ_4 may be taken as 1.

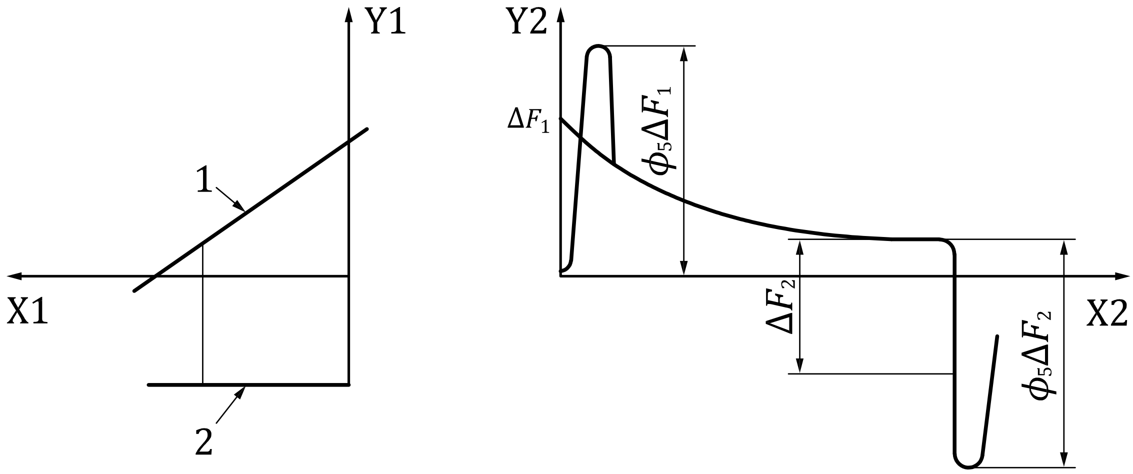
Annex B gives a general comment on the application of the ϕ factors.

Annex C gives an example of a model for estimating the value of ϕ_4 to take into account the vertical accelerations induced at the wheels of a crane travelling on rail tracks with non-welded steps or gaps.

6.1.4 Loads caused by acceleration of all crane drives including hoist drives

Loads induced in a crane by accelerations or decelerations caused by drive forces may be calculated using rigid body kinetic models that take into account the geometric properties and mass distribution of the crane drive and, where applicable, resulting inner frictional losses. For this purpose, the gross load is taken to be fixed at the top of the jib or immediately below the crab.

A rigid body analysis does not directly reflect elastic effects. To allow for these, the change in the drive force, ΔF, inducing either the acceleration or deceleration, may be multiplied by a factor, ϕ_5, and algebraically added to the force present before the acceleration or deceleration takes place. This amplified force is then applied to the components exposed to the drive force and, where applicable, to the crane and the gross load as well (see Figure 3).



Key

1 motor force
2 brake force
X1 speed
X2 time
Y1 drive force
Y2 load effects on lifting appliances caused by drive force

Figure 3 — Factor ϕ_5

The range of values for ϕ_5 is $1 \le \phi_5 \le 2$. The value used depends on the rate of change of the drive or braking force and on the mass distribution and elastic properties of the system. In general, lower values correspond to systems in which forces change smoothly and higher values to those in which sudden changes occur.

For centrifugal forces, ϕ_5 may be taken as 1.

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

Annex B gives a general comment on the application of the ϕ factors.

Annex D gives an example of a determination of the loads caused by acceleration of a bridge crane having unsynchronized travel gear and non-symmetrical load distribution.

6.1.5 Loads induced by displacements

Account shall be taken of loads arising from displacements included in the design, such as those resulting from pre-stressing and those within the limits necessary to initiate response of skewing and other compensating control systems.

Other loads to be considered include those that can arise from displacements that are within defined limits, such as those set for the variation in the gauge between rails or uneven settlement of supports.

6.2 Occasional loads

6.2.1 Climatic effects

6.2.1.1 In-service wind

Loads due to in-service wind shall be calculated in accordance with ISO 4302.

6.2.1.2 Snow and ice loads

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

6.2.1.3 Loads due to temperature variation

Loads caused by the restraint of expansion or contraction of a component due to local temperature variation shall be taken into account.

6.2.2 Loads caused by skewing

This subclause covers skewing loads that occur at the guidance means (such as guide rollers or wheel flanges) of a guided, wheel-mounted crane while it is travelling or traversing in steady-state motion. These loads are induced by guidance reactions which force the wheels to deviate from their free-rolling, natural travelling direction. Similar loads, induced by acceleration acting on asymmetrical mass distribution and that can also cause the crane to skew, are taken into account under 6.1.4.

Skewing loads as defined above are usually taken as occasional loads but their frequency of occurrence varies with the type, configuration, accuracies of wheel axle parallelism and service of the crane. In individual cases, the frequency of occurrence will determine whether they are taken as occasional or regular loads.

NOTE Guidance for establishing the magnitude of skewing loads and the category into which they are placed for a specific crane type is given in those parts of ISO 8686 covering specific types of cranes.

Annex E gives an example of a method for analysing skewing loads on a rigid crane structure travelling at a constant speed. For cranes with structures that are not rigid in respect of applied skewing forces or that have specially controlled travel guidance, appropriate models shall be used which take the system properties into account.

6.3 Exceptional loads

6.3.1 Out-of-service wind conditions

When considering out-of-service wind conditions, the gravitational force on that part of the mass of the hoist load remaining suspended from the crane, ηm, shall be taken into account:

$$\eta m = m_H - \Delta m_H \tag{4}$$

where

$m_H - \Delta m_H$ is that part of the gross load remaining suspended from the crane;

m_H is the mass of the gross load.

Wind loads shall be calculated in accordance with ISO 4302.

6.3.2 Test loads

The values of test loads shall be in accordance with ISO 4310.

Where values for dynamic or static test loads are required that are above the minimum given in ISO 4310, proof of competence calculations for these test conditions may be necessary. In this case, the dynamic test load shall be multiplied by a factor, ϕ_6, given by

$$\phi_6 = 0,5\left(1 + \phi_2\right) \tag{5}$$

where ϕ_2 is calculated according to 6.1.2.

Annex B gives a general comment on the application of the ϕ factors.

In the proof calculation for test load situations, a minimum level of wind of $\bar{v} = 5,42\ \text{m/s}$ shall be taken into account.

6.3.3 Buffer forces

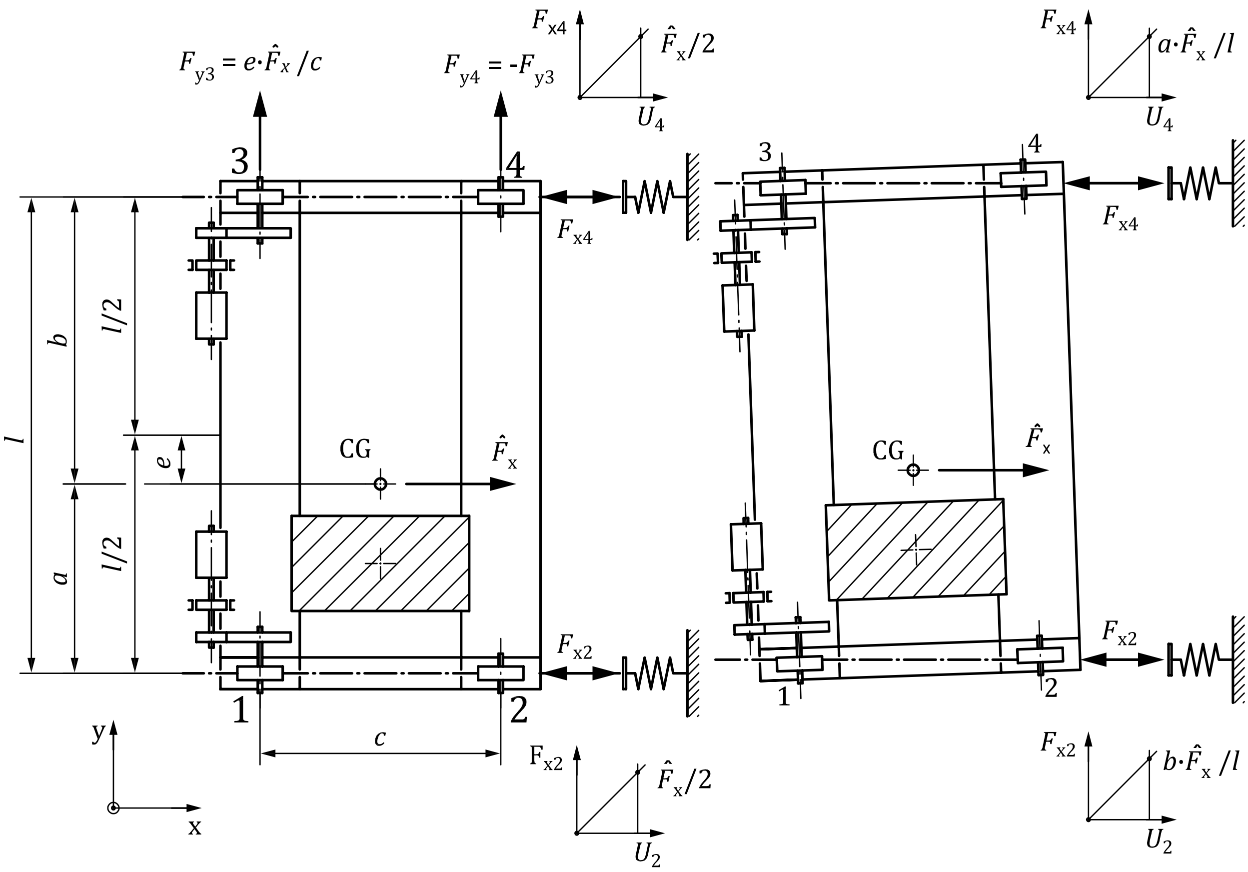
Where buffers are used, the forces on the crane structure arising from collision with them shall be calculated from the kinetic energy of all relevant parts of the crane moving in general at 0,7 to 1 times the nominal speed. Lower values may be used where they are justified by special considerations such as the existence of an automatic control system of demonstrable reliability for retarding the motion or where there would be limited consequences in the event of a buffer impact.

The calculation may be based on a rigid body model. The actual behaviour of the crane and buffer system shall be taken into account.

Where the crane or component is restrained against rotation — for example, by guide rails — the buffer deformations may be assumed to be equal, in which case, if the buffer characteristics are similar, the buffer forces will be equal. This case is illustrated in Figure 4 a) in which

$$F_{x2} = F_{x4} = \hat{F}_x / 2 \tag{6}$$

Where the crane or component is not restrained against rotation, the buffer forces shall be calculated taking into account the distribution of the relevant masses and the buffer characteristics. This case is illustrated in Figure 4 b).



a) Crane horizontally guided by rails ($\mu_2 = \mu_4$)   **b) Crane not restrained against rotation ($F_{y3} = F_{y4} = 0$)**

Figure 4 — Examples of buffer forces and buffer deformation (four-wheel bridge crane shown)

The resulting forces as well as the horizontal inertia forces in balance with the buffer forces shall be multiplied by a factor, ϕ_7, to account for elastic effects which cannot be evaluated using a rigid body analysis. Factor ϕ_7 shall be taken as 1,25 in the case of buffers with linear characteristics (for example, springs) and as 1,6 in the case of buffers with rectangular characteristics (for example, hydraulic constant force buffers). For buffers with other characteristics, other values justified by calculation or by testing shall be used (see the following Note and Figure 5).

NOTE Intermediate values of ϕ_7 can be estimated as

$$\phi_7 = 1{,}25 \text{ if } 0 \le \xi \le 0{,}5$$

$$\phi_7 = 1{,}25 + 0{,}7(\xi - 0{,}5) \text{ if } 0{,}5 < \xi \le 1$$

In calculating buffer forces, the effects of suspended loads that are unrestrained horizontally (free to swing) should not be taken into account.

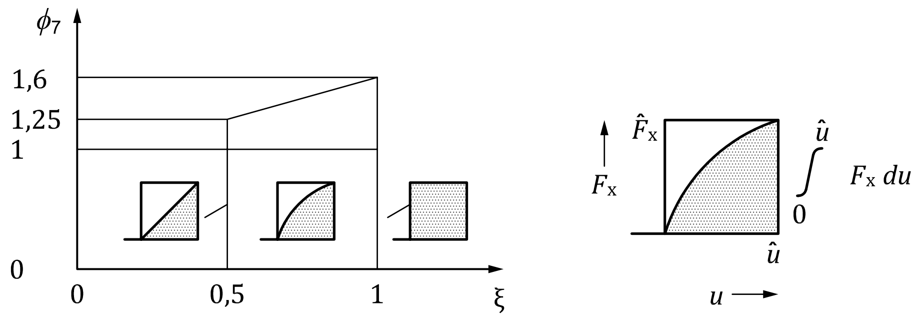


Figure 5 — Factor ϕ_7

$$\xi = \frac{1}{\hat{F}\hat{u}} \int_{0}^{\hat{u}} F_x \, du \tag{7}$$

where

ξ is the relative buffer energy:

for a buffer with linear characteristics: $\xi = 0{,}5$;

for a buffer with rectangular characteristics: $\xi = 1$.

6.3.4 Tilting forces

If a crane with horizontally restrained load can tilt when it, its load or its lifting attachment collides with an obstacle, the resulting static forces shall be determined.

If a tilted crane can fall back into its normal position in an uncontrolled manner, the resulting impact on the supporting structure shall be taken into account.

6.3.5 Unintentional loss of payload

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

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

6.3.6 Loads caused by emergency cut-out

Loads caused by emergency cut-out shall be evaluated in accordance with 6.1.4, taking into account the most unfavourable state of drive (i.e. the most unfavourable combination of acceleration and loading) at the time of the cut-out. The value of the factor ϕ_5 hall be chosen from the range $1{,}5 \leq \phi_5 \leq 2$.

6.3.7 Loads caused by failure of mechanism or components

Where protection is provided by emergency brakes in addition to service brakes, failure and emergency brake activation shall be assumed to occur under the most unfavourable condition. Where mechanisms are duplicated for safety reasons, failure shall be assumed to occur in any part of either system.

In both these cases, the resulting loads shall be evaluated in accordance with 6.1.4, taking into account any impacts resulting from the transfer of forces.

6.3.8 External excitation of the crane support

Examples of crane support excitation are earthquakes (seismic loads) or wave-induced movements.

Loads caused by such excitations shall be considered only when they constitute a significant risk.

Seismic loads need to be calculated according to the appropriate methods[2].

6.4 Miscellaneous loads

6.4.1 Loads due to erection, dismantling and transport

The loads acting at each stage of the erection and dismantling process shall be taken into account, including those arising from a wind speed of 8,3 m/s or greater. Higher values may be specified for the specific types of cranes covered by the other parts of ISO 8686. They shall be combined in accordance with 7.2.

In some cases it may also be necessary to take account of loads occurring during transport.

6.4.2 Loads on platforms and other means provided for access

The loads are considered to be local, acting only on the facilities themselves and on their immediate supporting members.

The following loads shall be taken into account:

— 3 000 N, where materials can be deposited;

— 1 500 N, on means provided for access only;

— not less than 300 N, horizontally on railings, depending on location and use.

7 Principles of choice of load combinations

7.1 Basic considerations

Loads shall be combined to determine the stresses a crane will experience during normal operation as simulated by an elastostatic calculation. To achieve this,

a) the crane is taken in its most unfavourable attitude and configuration while the loads are assumed to act in magnitude, position and direction causing unfavourable stresses at the critical points selected for evaluation at the basis of engineering considerations, and

b) conservatively, loads can be combined at the values defined in this part of ISO 8686 or, when appropriate, they can be combined with some loads factored to more closely reflect loading conditions actually found in practice.

Basic load combinations are given in Table 3. In general, load combinations A cover regular loads, load combinations B cover regular loads combined with occasional loads and load combinations C cover regular loads combined with occasional and exceptional loads.

The load combinations appropriate to specific types of cranes shall be in accordance with the principles set out in Table 3 and 7.2.

Table 3 — Loads and load combinations

1	2		3					4						5												6
Cat. of load	Loads, f_i		Load combinations A					Load combinations B						Load combinations C												Line no.
			Partial safety factors γ_p	A1	A2	A3	A4	Partial safety factors γ_p	B1	B2	B3	B4	B5	Partial safety factors γ_p	C1	C2	C3	C4	C5	C6	C7	C8	C9	C 10	C 11	
Regular (see 6.1)	Gravitation, acceleration impacts	1) Mass of the crane	*)	ϕ_1	ϕ_1	1	—	*)	ϕ_1	ϕ_1	1	—	—	*)	ϕ_1	1	ϕ_1	1	1	1	1	1	—	—	—	1
		2) Mass of gross load	1,34	ϕ_2	ϕ_3	1	—	1,22	ϕ_2	ϕ_3	1	—	—	1,1	—	η	—	1	1	1	1	1	—	—	—	2
		3) Masses of crane and hoist load, travelling on an uneven surface	1,22	—	—	—	ϕ_4	1,16	—	—	—	ϕ_4	ϕ_4	—	—	—	—	—	—	—	—	—	—	—	—	3
	Acceleration from drives	4) Masses of crane and gross load: a) Hoist drives excluded	1,34	ϕ_5	ϕ_5	—	ϕ_5	1,22	ϕ_5	ϕ_5	—	ϕ_5	—	1,1	—	—	ϕ_5	—	—	—	—	—	—	—	—	4
		4) Masses of crane and gross load: b) Hoist drives included		—	—	ϕ_5	—		—	—	ϕ_5	—	—		—	—	—	—	—	—	—	—	—	—	—	5
	Displacements	5) See 6.1.5	**)	1	1	1	1	**)	1	1	1	1	1	**)	1	1	1	1	1	1	1	1	—	—	—	—
Occasional (see 6.2)	Effects of climate	1) In-service wind loads		—	—	—	—	1,22	1	1	1	1	1	1,16	—	—	1	—	—	—	—	—	—	—	—	7
		2) Snow and ice loads		—	—	—	—	1,22	1	1	1	1	1	1,16	—	1	—	—	—	—	—	—	—	—	—	8
		3) Temperature variations		—	—	—	—	1,16	1	1	1	1	1	1,05	—	1	—	—	—	—	—	—	—	—	—	9
	Skewing	4) See 6.2.2		—	—	—	—	1,16	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—		10

*) For values of the partial safety factor to be applied see Table 4.

**) For values of the partial safety factor to be applied to loads due to displacements see 7.3.8.

Table 3 *(continued)*

1	2	3					4						5												6
Cat. of load	Loads, f_i	Load combinations A					Load combinations B						Load combinations C												Line no.
		Partial safety factors γ_p	A1	A2	A3	A4	Partial safety factors γ_p	B1	B2	B3	B4	B5	Partial safety factors γ_p	C1	C2	C3	C4	C5	C6	C7	C8	C9	C 10	C 11	
Excep-tional (see 6.3)	1) Hoisting a grounded load		—	—	—	—		—	—	—	—	—	1,1	ϕ_2	—	—	—	—	—	—	—	—	—	—	**11**
	2) Out-of-service wind loads		—	—	—	—		—	—	—	—	—	1,16	—	1	—	—	—	—	—	—	—	—	—	**12**
	3) Test loads		—	—	—	—		—	—	—	—	—	1,1	—	—	ϕ_6	—	—	—	—	—	—	—	—	**13**
	4) Buffer forces		—	—	—	—		—	—	—	—	—	1,1	—	—	—	ϕ_2	—	—	—	—	—	—	—	**14**
	5) Tilting forces		—	—	—	—		—	—	—	—	—	1,1	—	—	—	—	1	—	—	—	—	—	—	**15**
	6) Emergency cut-out		—	—	—	—		—	—	—	—	—	1,1	—	—	—	—	—	ϕ_5	—	—	—	—	—	**16**
	7) Failure of mechanism		—	—	—	—		—	—	—	—	—	1,1	—	—	—	—	—	—	ϕ_5	—	—	—	—	**17**
	8) Excitation of the crane support		—	—	—	—		—	—	—	—	—	1,1	—	—	—	—	—	—	—	1	—	—	—	**18**
	9) Activating the overload protection		—	—	—	—		—	—	—	—	—	1,1	—	—	—	—	—	—	—	—	1	—	—	**19**
	10) Unintentional loss of payload		—	—	—	—		—	—	—	—	—	1,1	—	—	—	—	—	—	—	—	—	ϕ_9	—	**20**
	11) Erection, dismantling and transport		—	—	—	—		—	—	—	—	—	1,1	—	—	—	—	—	—	—	—	—	—	1	**21**
Resistance coefficient γ_m (limit state method)		1,1					1,1						1,1												**22**
Strength coefficient γ_f (allowable stress method)		1,48					1,34						1,22												

Table 3 *(continued)*

1	2	3					4						5												6
Cat. of load	**Loads, f_i**	**Load combinations A**					**Load combinations B**						**Load combinations C**												**Line no.**
		Partial safety factors γ_p	**A1**	**A2**	**A3**	**A4**	**Partial safety factors** γ_p	**B1**	**B2**	**B3**	**B4**	**B5**	**Partial safety factors** γ_p	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C 10**	**C 11**	

Load combinations

A1 and B1: Cranes under normal service conditions, hoisting and depositing loads, without in-service wind and loads from other climatic effects (A1), and with in-service wind and loads from other climatic effects (B1). In general, the loads shall be combined to reflect the events during the acceleration, deceleration and positioning of the loaded or unloaded crane, moving in both directions. During the hoisting of a grounded load or a grounded lifting attachment, only a combination of accelerating drive forces caused by other drives (excluding the hoist drive) shall be taken into account in accordance with the intended normal operation as well as the control of the drives.

A2 and B2: Cranes under normal service conditions, sudden releasing of a part of the hoist load, without in-service wind and loads from other climatic effects (A2), and with in-services wind and loads from other climatic effects (B2). Drive forces shall be combined as in A1 and B1.

A3 and B3: Cranes under normal service conditions, accelerating the suspended load, without in-service wind and loads from other climatic effects (A3), and with in-service wind and loads from other climatic effects (B3). Other drive forces shall be combined as in A1 and B1.

A4 and B4: Cranes under normal service conditions, travelling on an uneven surface or track, without in-service wind and loads from other climatic effects (A4), and with in-service wind and loads from other climatic effects (B4). Drive forces shall be combined as in A1 and B1.

B5: Cranes under normal service condition, travelling on an uneven surface at constant speed and skewing, with in-service wind and loads from other climatic effects.

C1: Cranes under in-service conditions hoisting a grounded load under the exceptional circumstance applying 6.1.2.1.3., Table 2b.

C2: Cranes under out-of-service conditions, including out-of-service wind and loads from other climatic effects.

C3: Cranes under test conditions. Drive forces shall be combined as in A1 and B1.

C4 to C8: Cranes with gross load in combination with loads such as buffer forces (C4), tilting forces (C5), emergency cut-out (C6), failure of mechanism (C7), excitation of the crane support (C8).

C9: Activating the overload protection.

C10: Unintentional loss of payload.

C11: Erection, dismantling and transport loads, see 7.2.

7.2 Load combinations during erection, dismantling and transport

Each stage of the erection and dismantling process shall be considered, taking into account the appropriate loads and load combinations, which shall be as specified in those parts of ISO 8686 covering specific types of cranes. Proof of competence calculations shall be carried out for each instance of significant loading of a member or component.

In some cases it may also be necessary to take account of load occurring during transport.

7.3 Application of Table 3

7.3.1 General

The masses given in column 2, lines 1 to 3, shall be multiplied by gravitational acceleration, g, and the masses in column 2, lines 4 and 5, by the appropriate accelerations. The resulting or given loads shall be multiplied by the corresponding factors in accordance with 7.3.7.

Each combination of loads shall be applied in accordance with 7.1.

7.3.2 Allowable stress method

The allowable stresses for load combinations A, B and C shall be determined by dividing the appropriate specified strength of the material, element, component or connection (for example, the stress at yielding, buckling or limit of elastic stability) by strength coefficients, γ_f, as given in Table 3.

7.3.3 Limit state method

The various loads shall be multiplied by the partial safety factors, γ_p, depending on the type of load and load combinations A, B or C before being applied to the model.

The partial safety factors γ_p to be selected are listed in columns 3, 4 and 5 of Table 3.

7.3.4 Elastic displacements

In some instances, elastic displacements can render a crane unfit to perform its intended duties, affect stability or may interfere with the proper functioning of mechanisms. In such instances, consideration of displacements shall be part of the proof of competence calculations and, where appropriate, calculated displacements shall be compared with established limits.

7.3.5 Proofs of fatigue strength

The effects of fatigue shall be considered. Where proofs of fatigue strength are found to be necessary they shall be carried out in accordance with the principles set down in 7.1. In general, load combinations A1, A2, A3 and A4 (regular loads) shall be taken into account.

In some applications it may be necessary to consider also occasional loads such as in-service wind, skewing and exceptional loads such as test loads and excitation of the crane support (for example, wave effects).

7.3.6 High-risk applications

In special cases where the human or economic consequences of failure are exceptionally severe (for example, ladle cranes or cranes for nuclear applications), increased reliability shall be obtained by the use of a risk coefficient, $\gamma_n > 1$, the value of which shall be selected according to the requirements of the particular application.

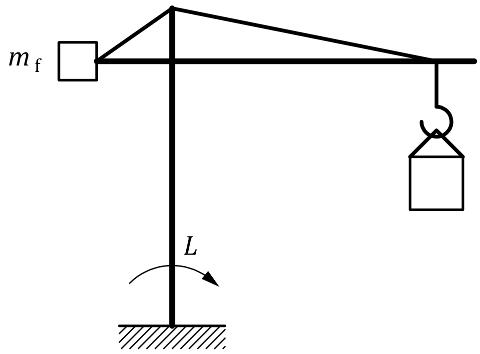
Using the allowable stress method, the allowable stresses shall be divided by the coefficient. Using the limit state method, the loads shall be multiplied by γ_n (see Annex A).

7.3.7 Masses of crane and crane parts

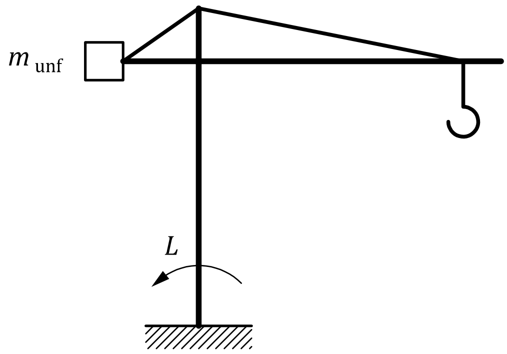
7.3.7.1 Favourable and unfavourable masses

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

The same mass may be favourable in some configurations and unfavourable in others, or favourable for one resulting load effect und unfavourable for another. Figure 6 illustrates this for a tower crane: With respect to the bending moment, *L*, in the tower the mass of the counter weight acts as favourable when a hoist load is applied and unfavourable without hoist load. With respect to the compression force in the tower, the mass of the counter weight acts as unfavourable in both cases.



a) Mass of counterweight favourable



b) Mass of counterweight unfavourable

Key

L bending moment in tower

m_f favourable acting mass

m_{unf} unfavourable acting mass

Figure 6 — Illustration of favourable and unfavourable masses

7.3.7.2 Partial safety factors for the masses of the crane (limit state method)

The partial safety factors, γ_p, shall be chosen from Table 4, depending on the method of determining the masses of the crane parts and the type of load effect.

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

Table 4 — Values of partial safety factors γ_p

Method of determining masses of crane parts and their centres of gravity	Load combinations according to Table 3					
	A		B		C	
	Unfavourable	Favourable	Unfavourable	Favourable	Unfavourable	Favourable
By calculation	1,22	0,95	1,16	0,97	1,10	1,00
By weighing	1,16	1,00	1,10	1,00	1,05	1,00
Special condition	1,16	1,10	1,10	1,05	1,05	1,00

The factors for the special condition may be applied under the following two conditions:

a) masses of crane parts and their centres of gravity are determined by weighing;

b) the ratio of *the sum load effect due to favourable masses of crane parts* and *the sum effect of unfavourable masses of crane parts plus gross load* shall be less than 0,6 — see Formula (10).

Unfactored static values of loads and masses shall be used.

$$\left| \frac{L_f}{L_{unf} + L_h} \right| < 0{,}6 \qquad (10)$$

where

L_f is the static load effect of favourable masses of crane parts;

L_{unf} is the static load effect of unfavourable masses of crane parts;

L_h is the static load effect of the gross load.

NOTE In general, partial safety factors for favourable masses should not be greater than 1. An exception is provided in the special condition where the calculated resulting load effect would be excessive. Since the value of the partial safety factor for the unfavourable masses should not be reduced, the partial safety factor for the favourable masses has been allowed an artificial increase above 1,0.

7.3.7.3 Safety factors for the masses of the crane (allowable stress method)

The coefficients, γ_f, of the allowable stress method do not take into account negative deviations of favourable masses. In order to take those effects (e.g. mass is smaller than assumed) into account when calculating the resulting load effect, favourable masses shall be multiplied be a reduction factor, γ_{red}:

γ_{red} = 0,85 in load combinations A;

γ_{red} = 0,90 in load combinations B;

γ_{red} = 0,95 in load combinations C.

7.3.8 Partial safety factors to be applied to loads caused by displacements

For those parts of a crane where intended displacements are induced to affect resulting load effects, upper and lower values of partial safety factors as given in Table 5 shall be taken into account to reflect deviations of the displacements due to the inaccuracies of the prestressing process and its parameters.

In cases where intended displacements are applied locally to create compression forces in connections to avoid gaping or to cause friction forces, such as the prestressing of high tensile bolts, the same upper and lower limits of the partial safety factor shall be applied.

Table 5 — Values of partial safety factor γ_p to be applied to loads due to intended displacements

Values of partial safety factor γ_p	Load combinations according to Table 3		
	A	B	C
upper value	1,10	1,05	1,00
lower value	0,90	0,95	1,00

Any unintended, but reasonably foreseeable elastic or rigid body displacement acting in any direction, which affect significantly the resulting load effects in a crane shall be considered as load and shall be amplified with the partial safety factors given in Table 6.

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

Table 6 — Values of partial safety factor γ_p to be applied to loads due to unintended displacements

	Load combinations according to Table 3		
	A	**B**	**C**
γ_p	1,10	1,05	1,00

7.4 Partial safety factors for the proof of rigid body stability

The partial safety factors used to prove that a crane is stable as a rigid body are given in Table 7 for the relevant load combinations A1, A2, B1, C2, C3, C4, C6, C7, C9, C10 and C11.

In all these load combinations, dynamic factors ϕ_i, except for ϕ_3 and ϕ_9, shall be set to $\phi_i = 1,0$; while ϕ_3 shall be shall be set to −0,1, when the calculated value of $\phi_3 > -0,1$.

In cases where the overturning moment is governed by the crane masses, higher partial safety factors are recommended to be applied in order to achieve an overall safety factor of 1,2.

Annex A
(normative)

Application of allowable stress method and limit state method of design

A.1 General

Most of the principles for determining the loads and load combinations to be taken into account in proof of competence calculations set out in this part of ISO 8686 (see Clause 5) are applicable to both the allowable stress method and the limit state method of design. Both methods are equivalent in cases of linear relationship between loads and stresses. In cases of nonlinear relationship between loads and stresses (i.e. where the 2nd order method is applied) the limit state method of design shall be applied.

NOTE ISO 20332 gives values for limit states but not for allowable stresses.

A.2 Allowable stress method

Individual specified loads, f_{i}, are calculated and amplified where necessary using the applicable factors ϕ. They are then combined according to the load combination under consideration from Table 3. The combined load, $\bar{F}_{\mathrm{j}}$, is used to determine the resulting load effects, $\bar{S}_{\mathrm{k}}$, i.e. the inner forces and moments in members or the forces on supports.

The stresses, $\bar{\sigma}_{1\mathrm{l}}$, due to the action of the load effects on a particular element or component are calculated and combined with any stresses, $\bar{\sigma}_{2\mathrm{l}}$, resulting from local effects. The resulting design stress $\bar{\sigma}_{\mathrm{l}}$ should be compared with an appropriate value of allowable stress, adm σ.

Admissible stresses are obtained by dividing the specified strengths, R, of the material, such as the stresses corresponding to the yield point, limit of elastic stability or fatigue strength, by a coefficient, γ_{f}, specified in Table 3, according to the basic load combination (see 7.1) and, where appropriate, by a risk coefficient, γ_{n} (see 7.3.5).

Special care is required to ensure a valid proof of competence when the allowable stress method is applied to cases where internal forces are not linearly proportional to the loads producing them or critical values of stress result from the combination of independently varying loads which give stresses of opposite signs.

A flow chart illustrating the allowable stress method of design is shown in Figure A.1.

Table 7 — Partial safety factors for the proof of rigid body stability

Categories of load	Loads f_i		i *)	Load comb. A				L. comb. B		Load combination C														
				A1		A2		B1		C2		C3		C4	C6		C8	C9		C10		C11
				S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1, S2	S1	S2	S1, S2	S1	S2	S1	S2	S1, S2
Regular	Gravitation, acceleration impacts	Mass of crane, unfavourable	1	1,1	1,05	1,1	1,05	1,1	1,05	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
		Mass of crane, favourable	1	0,95	1,0	0,95	1,0	0,95	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
		Mass of gross load	2	1,34	1,22	1,0	1,0	1,22	1,1	1,0	1,0	—	—	1,0 **)	1,1	1,05	1,0	1,0 **)	1,0 **)	—	—	—
	Acceleration from drives	Masses of crane and gross load, hoist drives included	5	1,34	1,22	1,34	1,22	1,22	1,1	—	—	1,1	1,0	—	—	—	—	—	—	—	—	—
	Displacements		6	1,1	1,1	1,1	1,1	1,05	1,05	1,0	1,0	1,0	1,0	1,0	1,0	1,0	—	1,0	1,0	1,0	1,0	1,0
Occasional	Climate effects	In-service wind	7	—	—	—	—	1,22	1,16	—	—	1,0	1,0	—	—	—	—	1,16	1,1	1,16	1,1	—
		Snow and ice	8	—	—	—	—	1,22	1,22	—	—	—	—	—	—	—	—	—	—	—	—	—

*) According to line numbering in Table 3.

**) Only to be applied if unfavourable.

Table 7 *(continued)*

Categories of load	Loads f_i	*i* *)	Load comb. A				L. comb. B		Load combination C												
			A1		A2		B1		C2		C3		C4	C6		C8	C9		C10		C11
			S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1, S2	S1	S2	S1, S2	S1	S2	S1	S2	S1, S2
Exceptional	Out-of-service wind loads	12	—	—	—	—	—	—	1,16	1,1	—	—	—	—	—	—	—	—	—	—	—
	Test loads	13	—	—	—	—	—	—	—	—	1,16	1,1	—	—	—	—	—	—	—	—	—
	Buffer forces	14	—	—	—	—	—	—	—	—	—	—	1,1	—	—	—	—	—	—	—	—
	Emergency cut-out	16	—	—	—	—	—	—	—	—	—	—	—	1,1	1,1	—	—	—	—	—	—
	Excitation of the crane support	18	—	—	—	—	—	—	—	—	—	—	—	—	—	1,0	—	—	—	—	—
	Activating overload protection	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1,0	1,0	—	—	—
	Unintentional loss of payload	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1,0	1,0	—
	Erection, dismantling, transport	21	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1,1

S1, S2 are the stability classes.

Partial safety factors given in the columns of stability class S1 are applicable to all types of cranes.

Partial safety factors given in the columns of stability class S2 may only be applied to cranes which fulfil the following conditions:

a) proof exists that the ground to support the crane can reliably withstand the supporting forces, without significant unintended displacements or taking into account their affect on stability. This shall also be shown in the case, if supports (those not causing rigid body movement) become unloaded and thus cause maximum forces at other supports;

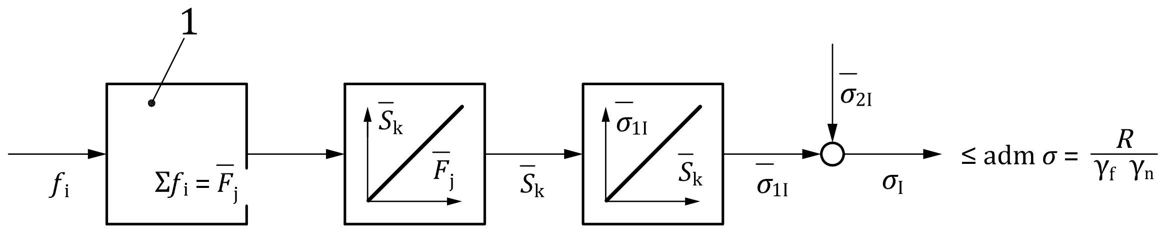
b) reliable load indicating and limiting system exists, that prewarns the crane driver and finally cuts out any movement if approaching a situation of rigid body instability in any configuration, position and state of loading;

c) relevant masses and their centres of gravity shall be evaluated by weighing with an accuracy of ± 2,5 %;

d) the crane being driven by competent crane drivers, who are familiar with the crane and its indicating and limiting devices.

*) According to line numbering in Table 3.

**) Only to be applied if unfavourable.



Key

f_i	load *i* on element or component
$\bar{F}_j$	load combination *j*
$\bar{S}_k$	load effects in section *k* of members or supporting parts (such as inner forces and moments resulting from load combination $\bar{F}_l$)
$\bar{\sigma}_{1l}$	stresses in particular element *l* as result of load effects $\bar{S}_k$
$\bar{\sigma}_{2l}$	stresses in particular element *l* arising from local effects
$\bar{\sigma}_l$	resulting design stress in particular element *l*
R	specified strength or characteristic resistance of the material, particular element or connection — such as the stress corresponding to the yield point, limit of elastic-stability or fatigue strength (limit states)
adm σ	allowable stresses
γ_f	coefficients applied to specified strength according to load combination under consideration
γ_n	risk coefficient, where applicable

Figure A.1 — Typical flow chart of allowable stress method

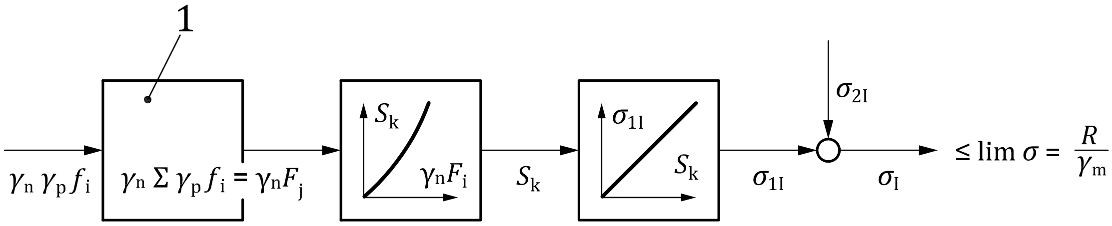
A.3 Limit state method

Individual specified or characteristic loads, f_i, are calculated and amplified where necessary using factors ϕ multiplied by the appropriate partial safety factors, γ_p. They are then combined according to the load combination under consideration to give $\bar{F}_j$. Factors ϕ and partial safety factors γ_p for individual loads are given in Tables 3 and 7.

Where appropriate, the risk coefficient γ_n is applied to $\bar{F}_j$ (see 7.3.6) to give the design load, $\gamma_n \bar{F}_j$. Design load effects, $\bar{S}_k$ are determined from the design load. The stresses, σ_{1l}, due to the action of the load effects on a particular element or component are calculated and combined with any stresses, σ_{2l}, resulting from local effects which have also been calculated using the appropriate load coefficients.

The resulting design stress, σ_l, shall be compared with an appropriate limit value, lim σ.

A flow chart illustrating the limit state method of design is shown in Figure A.2.



Key

f_i load i on element or component

$\bar{F}_j$ load combination j from loads f_i multiplied with partial safety factors and risk coefficient, when applicable

$\bar{S}_k$ load effects in section k of members or supporting parts (such as inner forces and moments) resulting from load combination $\bar{F}_j$

σ_{1l} stresses in particular element l as result of load effects $\bar{S}_k$

σ_{2l} stresses in particular element l arising from local effects

σ_l resulting design stress in the particular element l

R specified strength or characteristic resistance of material, particular element or connection — such as stress corresponding to yield point, limit of elastic stability or fatigue strength (limit states)

$\lim \sigma$ limit design stress

γ_f partial safety factors applied to individual loads according to load combination under consideration

γ_n risk coefficients, where applicable

γ_m resistance coefficient

Instead of a comparison of stresses (see above), a comparison of forces, moments, deflections, etc. may be made.

NOTE A general description of the limit state method of design is given in ISO 2394.

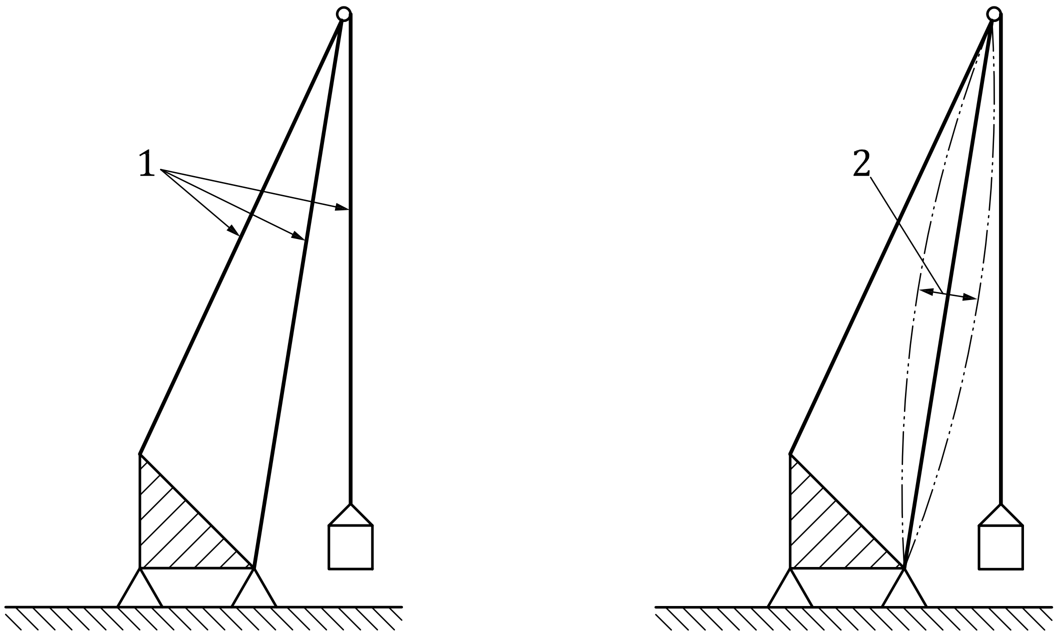
Figure A.2 — Typical flow chart of limit state method

Annex B
(informative)

General guidance on application of dynamic factors ϕ

In general, the dynamic responses induced by different loads (see Clause 6) are taken into account by the use of dynamic factors ϕ, by which gravitational forces due to the masses and inertia forces due to rigid body movements are multiplied (see Figure B.1).

In cases where the load effect and dynamic response are not covered by these factors, elasto-kinetic analyses or experiments shall be carried out, unless it is known from experience that these effects are sufficiently small to be ignored.



a) Example of load effects covered by dynamic factors ϕ

b) Example of load effects not covered by dynamic factors ϕ

Key

1 static axial forces

2 additional bending due to vibrations

Figure B.1 — Application of dynamic factors ϕ

Annex C
(informative)

Example of model for estimating value of dynamic factor ϕ_4 for cranes travelling on rails

C.1 General

The dynamic loads caused by travelling or traversing on rails (see 6.1.3.2) with steps or gaps may be estimated by using appropriate elasto-kinetic models. Unevenness functions may be used to represent the steps or gaps in the rails.

C.2 Elasto-kinetic model

In this example, the dynamic loads on the crane caused by excitation of the system are estimated using a simple model.

A single mass, m, in kilograms, moving horizontally at constant speed, v, in metres per second, is supported by a linear elastic spring with a spring constant, c, in newtons per metre, and is guided by a rail (see Figure C.1).

With the unevenness function, $h(t)$, and the coordinate, $z(t)$, both expressed in metres, describing the position of the spring supported mass, the dynamic force in the spring follows the expression $F(t) = c\,[h(t) - z(t)]$ in newtons.

The maximum force, F_{max}, is given by the maximum value of expression $F(t)$ during the period of response. This may occur during or after the period of excitation.

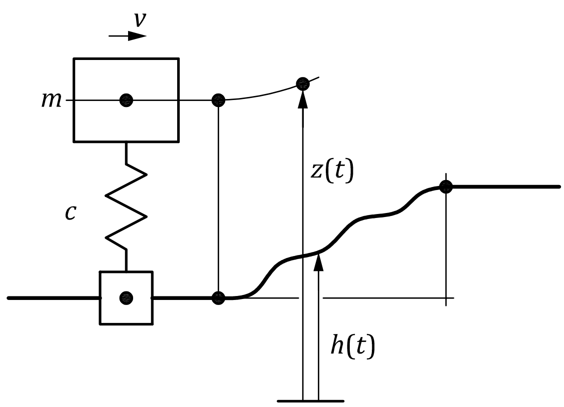


Figure C.1 — Model for determining dynamic factor ϕ_4

C.2.1 Movement of wheel centre when passing over step or gap

The movement of the wheel centre when passing over a step or gap and the corresponding formulae are shown in Figure C.2.

$e_S \approx \sqrt{2rh_S} \quad (h_S << r)$

a) Passing over step

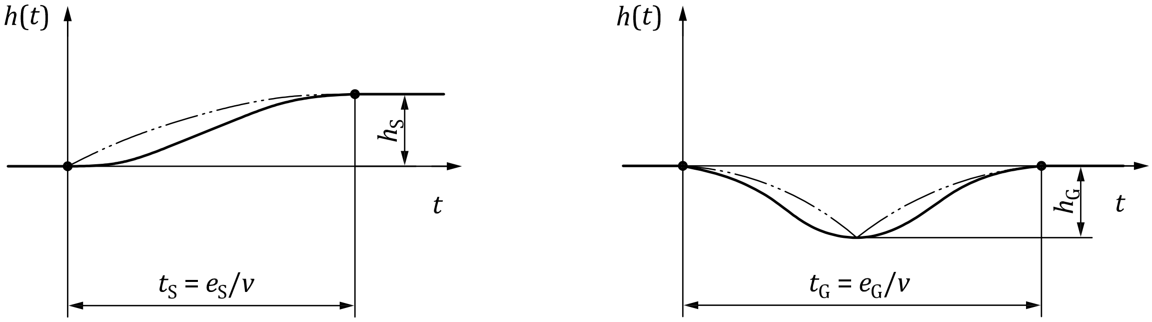
$h_G \approx \dfrac{e_G^2}{8r} \quad (e_G \approx r)$

b) Passing over gap

Figure C.2 — Movement of wheel centre

C.2.2 Approximate unevenness functions for exciting elasto-kinetic model

Approximate unevenness functions $h(t)$ for exciting the elasto-kinetic model are shown in Figure C.3 and in the corresponding formulae in C.2.3.



$$h(t) = \frac{h_S}{2}(1 - \cos \Omega \cdot t)$$

where $\Omega \cdot t_S = \pi$

a) Passing over step

$$h(t) = \frac{h_G}{2}(1 - \cos \Omega \cdot t)$$

where $\Omega \cdot t_G = 2\pi$

b) Passing over gap

Figure C.3 — Unevenness functions *h*(*t*)

C.2.3 Maximum vertical accelerations

C.2.3.1 Lower end of spring

The maximum vertical acceleration of the lower end of the spring, $\hat{\ddot{h}}$, when passing over a step or a gap at constant speed v is given by

$$\hat{\ddot{h}} = \frac{h_S}{2}\Omega^2 = \frac{h_G}{2}\Omega^2 = \left(\frac{\pi}{2}\right)^2 \frac{v^2}{r}$$

where h_S, h_G, Ω, v and r are as shown in Figures C.2 and C.3.

C.2.3.2 Mass passing a step

The maximum vertical acceleration, $\hat{\ddot{z}}$, for a mass, m, passing a step is given by

$$\hat{\ddot{z}} = \hat{\ddot{h}}\,\xi_S(\alpha_S)$$

where

$$\alpha_S = \frac{\omega h}{\pi v}\sqrt{\frac{2r}{h_S}}$$

in which

$$\omega = \sqrt{c/m}$$

is the natural circular frequency of the elasto-kinetic model.

C.2.3.3 Mass passing a gap

The maximum vertical acceleration, $\hat{\ddot{z}}$, for a mass, m, passing a gap is given by

$$\hat{\ddot{z}} = \hat{\ddot{h}}\,\xi_G(\alpha_G)$$

where

$$\alpha_G = \frac{\omega e_G}{2\pi v}$$

C.2.4 Factors ξ_S and ξ_G

In Figure C.4, the curves for factors ξ_S (α_S) and ξ_G (α_G) for a parabolic (par) unevenness function are compared with those for the approximate cosine (cos) unevenness function previously introduced. The numbers in brackets [(1) or (2)] indicate the periods for which the factors ξ are valid. Period (1) covers times t_S and t_G and period (2) is the response time thereafter.

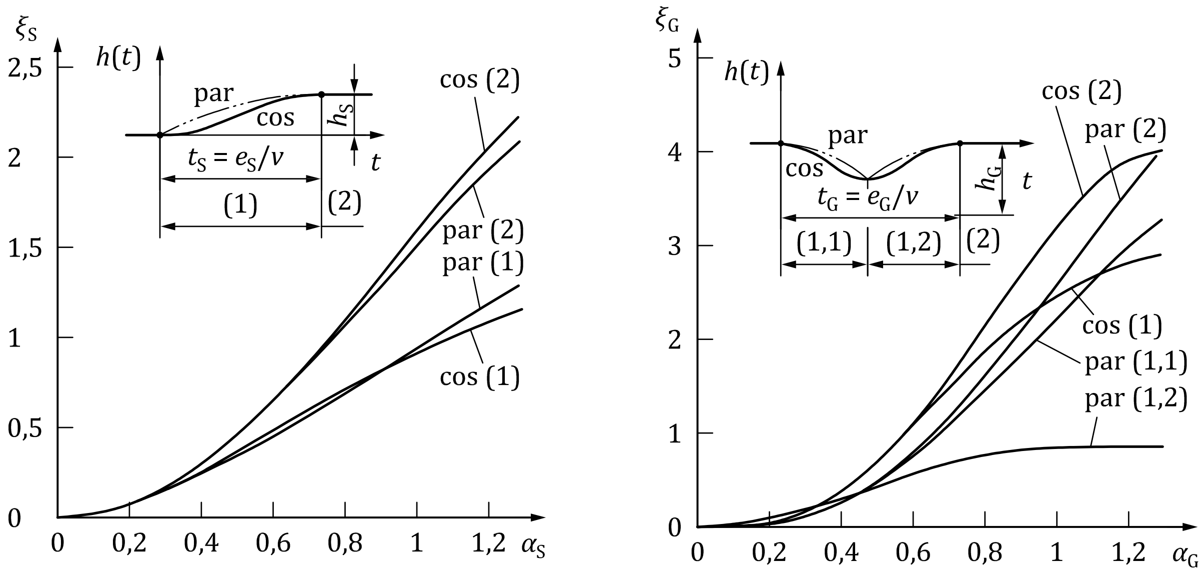
For both excitations (step or gap), the maximum values of ξ_S or ξ_G for α approximately $< 1{,}3$ have been found to occur in period (2), i.e. after the time the wheel has passed the unevenness, and with the cosine unevenness function [cos(2)].

In this case, the values of the factors may be determined analytically by

$$\xi_S = \frac{\alpha_S^2}{1-\alpha_S^2}\sqrt{2+\cos(2\pi\alpha_S)}$$

or

$$\xi_G = \frac{\alpha_G^2}{1-\alpha_G^2}\sqrt{2-2\cos(2\pi\alpha_G)}$$



a) For step **b) For gap**

Figure C.4 — Curves of unevenness function

C.2.5 Dynamic factor ϕ_4

Dynamic factor ϕ_4 is defined as

$$\phi_4 = \frac{mg + m\hat{\ddot{z}}}{mg} = 1 + \frac{\hat{\ddot{h}}}{g}\xi$$

For the two cases and the assumptions made including $\alpha \leq 1{,}3$ using the formulae for ξ_S, α_S and ξ_G, α_G, factors ϕ_4 may be calculated as follows.

For a step:

$$\phi_4 = 1 + \left(\frac{\pi}{2}\right)^2 \frac{v^2}{gr}\xi_S(\alpha_S)$$

For a gap:

$$\phi_4 = 1 + \left(\frac{\pi}{2}\right)^2 \frac{v^2}{gr}\xi_G(\alpha_G)$$

C.2.6 Comments

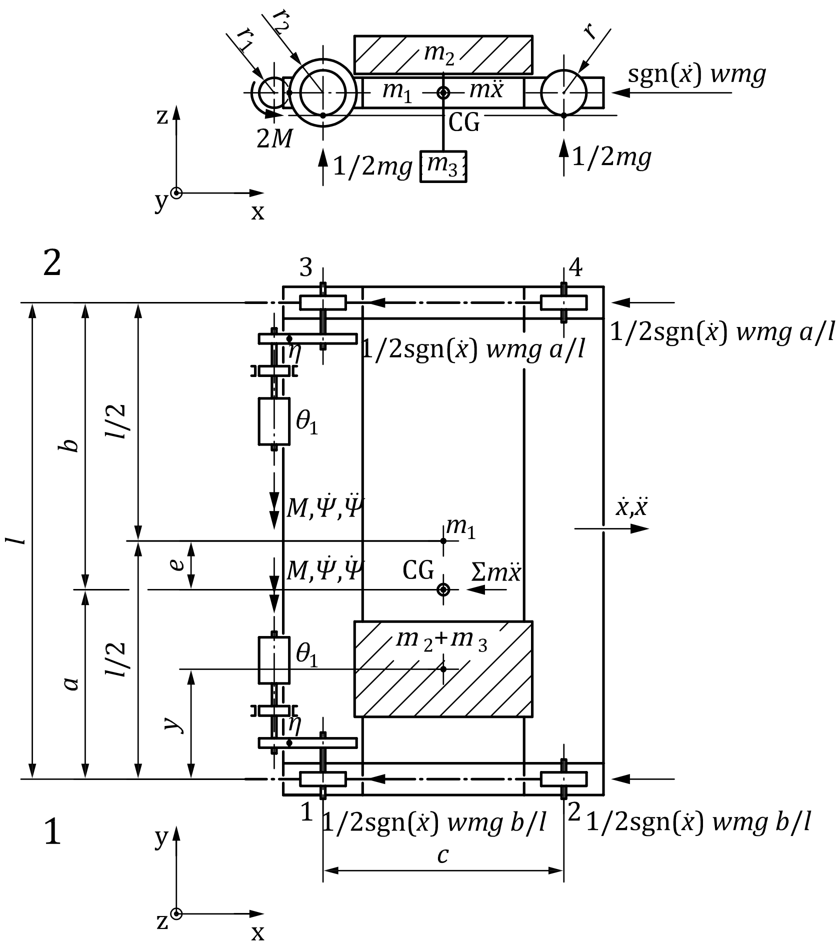
The use of this simple elasto-kinetic model is restricted to cranes whose actual dynamic behaviour corresponds to that of the model and which are excited in the manner shown by passing over steps or gaps in the rails. If more than one natural mode contributes a significant response and/or rotation occurs, the designer should estimate the dynamic loads using an appropriate model for the circumstances.

Annex D
(informative)

Example of determination of loads caused by acceleration

D.1 Rigid body kinetic model

The example considered is that of a rigid crane (i.e. an overhead travelling crane) consisting of a double-girder crane bridge, supported by four crane travel wheels, travelling at a constant speed. One wheel on each side is driven by a simplified independent drive. A traversing loaded trolley is supported by the crane bridge (see Figure D.1). See 6.1.4.



Key

1 rail 1

2 rail 2

Figure D.1 — Loads acting on overhead travelling crane (see Table D.1)

The drive forces developed by the motors and brakes are transferred through one-step gears to the crane travel wheels. The travel wheels are supported in the end carriages, those on one side being laterally fixed and those on the other being laterally movable.

D.2 Symbols

The symbols used in this annex are given in Table D.1.

Table D.1 — Symbols used in Annex D

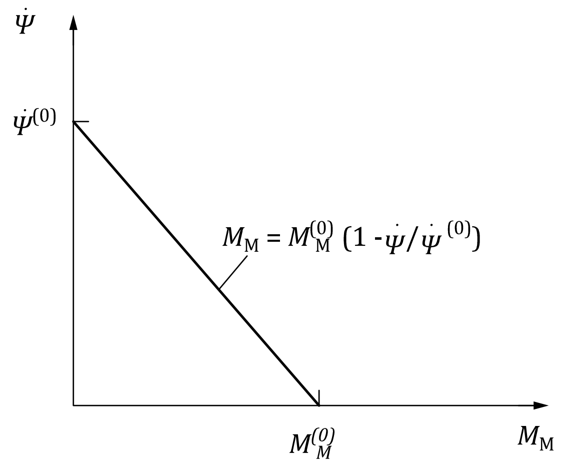
Symbol	Description
Geometric parameters (in metres)	
l	Span of the crane
y	Distance of centre of mass of loaded trolley from rail 1
a	Distance of centre of gravity (CG) from rail 1
b	Distance of centre of gravity (CG) from rail 2
c	Wheel base
r_1	Radius of gear wheel 1
r_2	Radius of gear wheel 2
r	Radius of crane travel wheels
Masses (in kilograms)	
m_1	Mass of crane bridge with travel drives
m_2	Mass of crab
m_3	Gross load, equivalent to m_H
m	Mass of the loaded crane ($m = m_1 + m_2 + m_3$)
Mass moments of inertia (in kilogram metres squared)	
θ_1	Mass moment of inertia of motor, coupling, brake drum and gear wheel 1
θ_2	Mass moment of inertia of gear wheel 2 and crane travel wheels (neglected in this example)
Internal friction losses	
η	Ratio of output power of gearing to input power of gearing
Speeds and accelerations (in radians or metres per second or second squared)	
$\psi, \ddot{\psi}$	Rotational speed and acceleration, respectively, of motor, coupling, brake drum and gear wheel 1
$x, \ddot{x}$	Travel speed and acceleration, respectively, of the crane
Torques (in newton metres)	
M	Drive torque acting on the first shaft of the crane travel gear
M_M	Torque due to the stationary characteristics of the motor
M_B	Torque of the mechanical brake

D.3 Forces

D.3.1 Drive forces and external forces

The motion of the crane, [$x(t)$], and load effects depend on drive forces which are in balance with the internal frictional forces, the inertia forces and the external forces. The external forces include the frictional forces due to mechanical resistance (losses) at the wheels, wind load and, in the case of an inclined track, gravitational forces.

The torques, $M = M_M$ or $M = M_B$, may be defined by the motor or brake characteristics. These are illustrated by the examples given in Figures D.2 and D.3.



Key

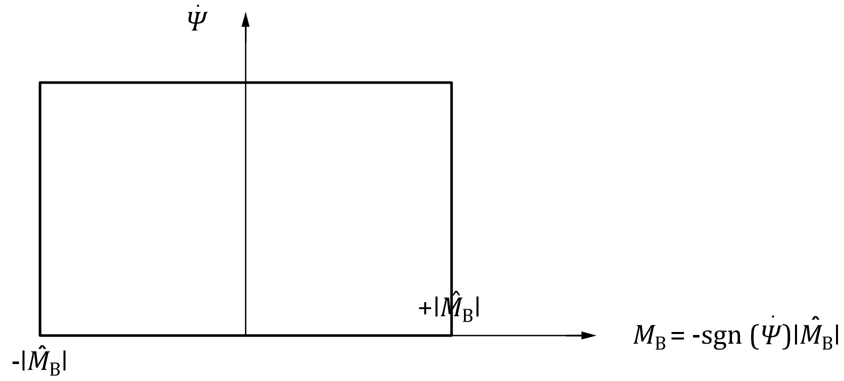
M_M steady-state output torque of motor at motor speed of $\dot{\psi}$

$M_M^{(0)}$ motor starting torque $(\dot{\psi} = 0)$

$\dot{\psi}^{(0)}$ synchronous rotational speed of motor ($M_M = 0$)

Figure D.2 — Resistor-controlled slip-ring motor — Simplified presentation of motor characteristics

For simplification purposes, in Figure D.3 the magnitude of M_B, $\left|\hat{M}_B\right|$, is taken as constant; mathematically it is expressed as $\hat{M}_B = -\text{sgn}(\dot{\psi})\left|\hat{M}_B\right|$.



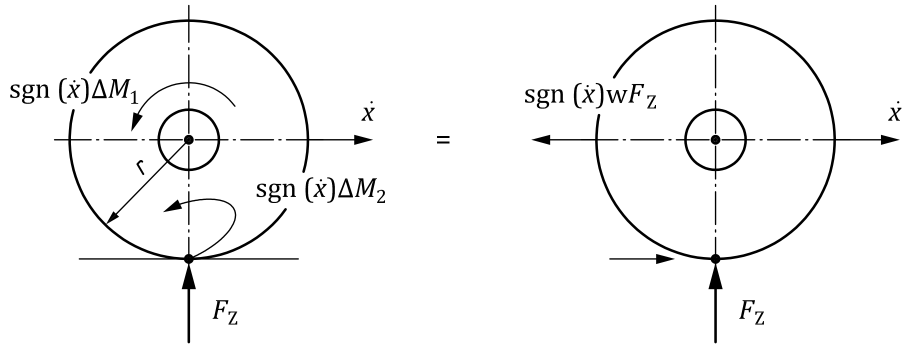
Key

M_B brake torque whose direction is opposite to that of $\dot{\psi}$

Figure D.3 — Mechanical brake — Formal presentation of brake torque

D.3.2 Frictional losses at a wheel

Figure D.4 illustrates frictional losses at a wheel.



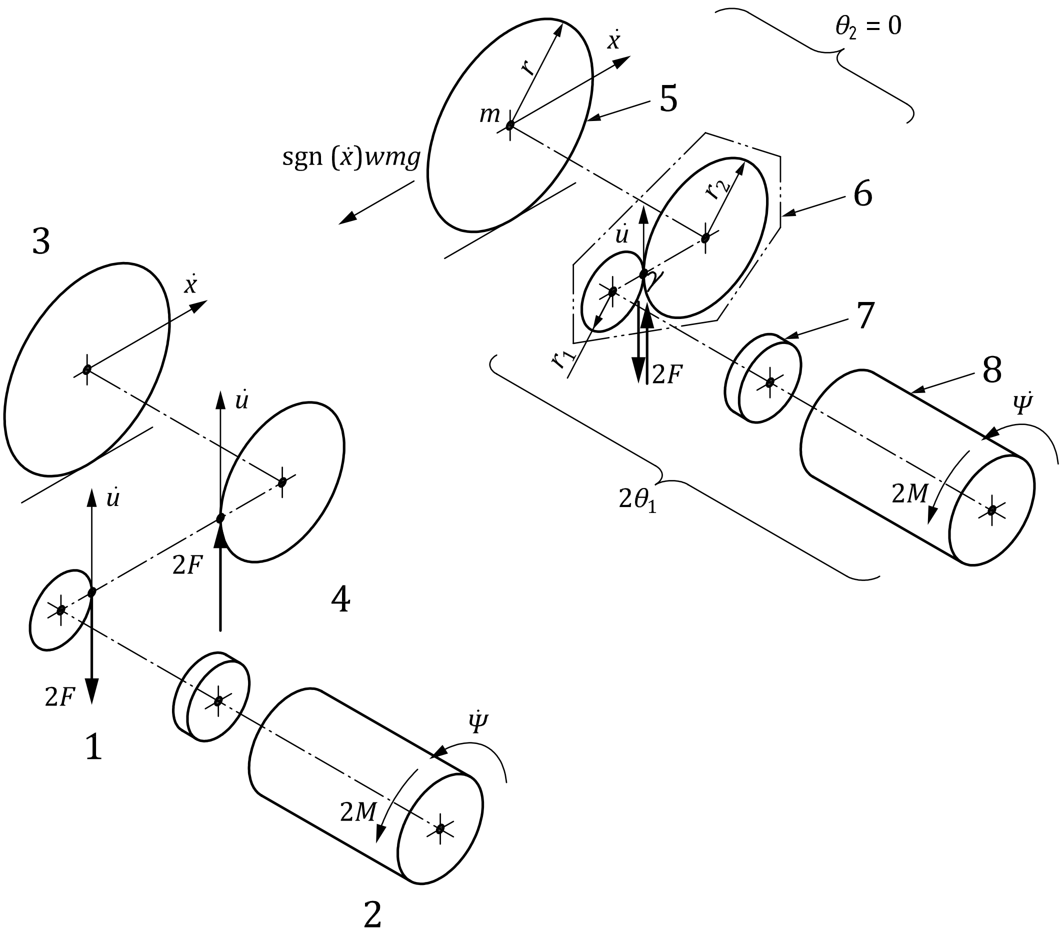
Key

ΔM_1	torque loss due to friction in wheel bearing
ΔM_2	torque representing the losses due to rolling friction in contact zone of rolling wheel
F_z	wheel load
w	equivalent friction coefficient ($\Delta M_1 + \Delta M_2 = wF_z r$)

Figure D.4 — Frictional losses at wheel

D.4 Drive accelerations

The drive model shown in Figure D.5 is used for estimating drive accelerations. This representation combines the two drives acting to balance forces and includes all significant effects.



Key

1	output side of gear element 1	5	wheels
2	input side of gear element 1	6	gears
3	output side of gear element 2	7	brakes
4	input side of gear element 2	8	motors

Figure D.5 — Crane drive model (sign convention)

From rigid body kinetic analysis, neglecting the mass moments of inertia, θ_2, the acceleration, $\ddot{x}$, of a crane not affected by wind forces can be expressed as

$$\ddot{x} = \frac{2Mr_1^{-1} r_2 r^{-1} \eta^{\lambda} - \text{sgn}\,(\dot{x}) wmg}{2\theta_1 (r_1^{-1} r_2 r^{-1})^2 \eta^{\gamma} + m}$$

where

$\lambda = \text{sgn}\,(\dot{u}F)$;

$\dot{u}$ is the tangential speed of gear wheels;

F is the tangential force to be transferred by the gear wheels.

NOTE Sign convention of speed and internal forces: internal forces of a gear element are assumed to be positive when acting at the input side in the direction of the positive speed and at the output side opposite to the direction of the positive speed. The speeds of gear elements are chosen positive if acting in the positive direction of the movements of the crane, considering the kinematic interactions of the mechanical parts.

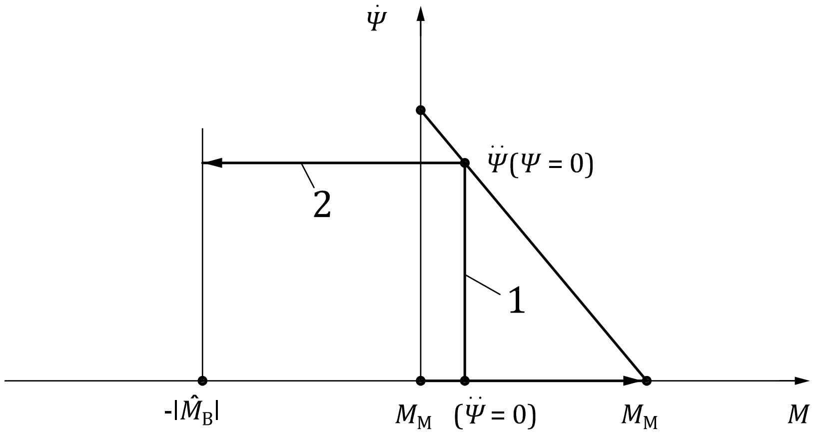
D.5 Loads and load effects

The loads and load effects caused by crane drives during regular use can be taken into account considering the relevant events, for example:

— **event I**: accelerating crane from rest, $(\dot{\psi} = 0)$ by applying starting torque, $M_{\mathrm{M}}^{(0)}$, to each travel drive;

— **event II**: decelerating crane from steady-state motion, $(\ddot{\psi} = \ddot{x} = 0)$, by mechanical braking whereby the torque on each travel drive is changed from a motor torque $M_{\mathrm{M}}(\ddot{\psi} = 0)$ to a braking torque of $-\left|\hat{M}_{\mathrm{B}}\right|$.

For the purposes of this example, events I and II are taken to be instantaneous changes in torque; they are illustrated in Figure D.6.



Key

1 event I

2 event II

Figure D.6 — Illustration of events I and II

D.6 Accelerations

Before the design load effects arising from changes in torque can be calculated, such as those of events I and II set out in Clause D.5, it is necessary to estimate the initial acceleration, $\ddot{x}_{(\mathrm{i})}$, and the final acceleration, $\ddot{x}_{(\mathrm{f})}$, bounding the event. This can be done as follows.

For event I:

$$\ddot{x}_{(\mathrm{i})} = 0$$

$$\ddot{x}_{(\mathrm{f})} = \frac{2M_{\mathrm{M}}^{(0)} r_2^{-1} r_2 r^{-1} \eta - wmg}{2\theta_1 (r_1^{-1} r_2 r^{-1})^2 \eta + m}$$

since λ = +1 as $(\dot{u} > 0)$ and $(F > 0)$.

For event II:

$$\ddot{x}_{(i)} = 0 = \frac{2M_M(\ddot{\psi}=0) r_1^{-1} r_2 r^{-1} \eta - wmg}{2\theta_1 (r_1^{-1} r_2 r^{-1})^2 \eta + m}$$

since $\lambda = +1$ as $(\dot{u} > 0)$ and $(F > 0)$;

$$\ddot{x}_{(f)} = -\frac{2\left|\hat{M}_B\right| r_1^{-1} r_2 r^{-1} \eta^{-1} + wmg}{2\theta_1 (r_1^{-1} r_2 r^{-1})^2 \eta^{-1} + m}$$

since $\lambda = -1$ as $(\dot{u} > 0)$ and $(F < 0)$.

From these results it can be seen that if $M_M^{(0)} = \left|\hat{M}_B\right|$, the acceleration, $\ddot{x}_{(f)}$, for event I is less than the deceleration, $\ddot{x}_{(f)}$, for event II.

D.7 Design load effects in mechanical components

As an example, the tangential force to be transferred by the gears and to be considered in design F is estimated as follows (see Clause D.4 and Figure D.5):

$$F = (M - \theta_1 \ddot{\psi}) r_1^{-1}$$

where

$$\ddot{\psi} = r_1^{-1} r_2 \cdot r^{-1} \ddot{x}$$

$$\hat{F} = F_{(i)} + \phi_5 \Delta F$$

where $\Delta F = F_{(f)} - F_{(i)}$.

For event I:

$$F_{(i)} = 0$$

$$F_{(f)} = [M_M^{(0)} - \theta_1 r_1^{-1} r_2 r^{-1} \ddot{x}_{(f)}] r_1^{-1}$$

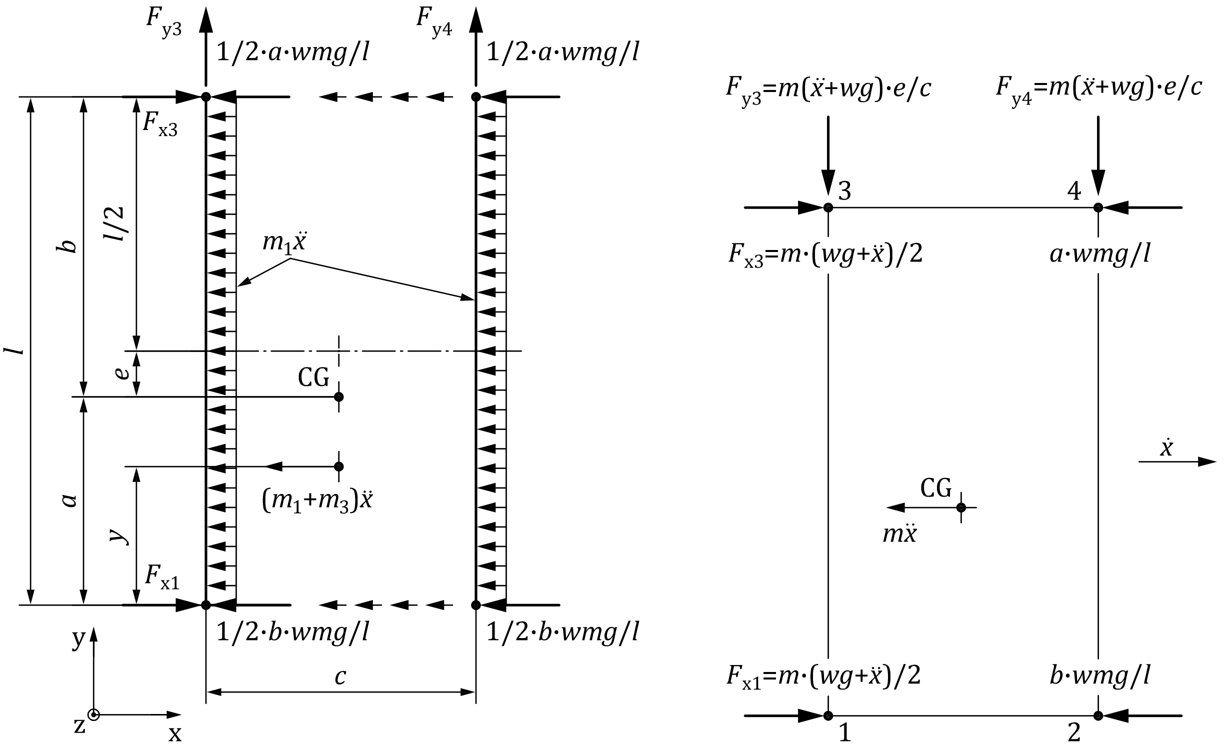
For event II:

$$F_{(i)} = M_M(\ddot{\psi} = 0) r_1^{-1}$$

$$F_{(f)} = [-\left|\hat{M}_B\right| - \theta_1 r_1^{-1} r_2 r^{-1} \ddot{x}_{(f)}] r_1^{-1}$$

D.8 Design load effects in the structural components

As an example, the horizontal loads and reactions to be transferred by the crane girder and to be considered in design, are estimated as follows (see Figure D.7).



a) Distribution of horizontal loads during acceleration of crane

b) Resultant loads — Acting drive forces, $F_{x3} = F_{x1}$**, and reacting forces,** $F_{y3} = F_{y1}$

Figure D.7 — Horizontal loads and reactions

The horizontal loads and forces are caused by drive forces accelerating the crane and do not include skewing forces.

During acceleration, the two acting drives balance the mass forces $(m\ddot{x} = m_1\ddot{x} + m_2\ddot{x} + m_3\ddot{x})$ and the forces due to the frictional losses at all wheels (*wmg*). It is assumed that the crane drive characteristics are identical as well as their control; therefore, the drive forces are equally distributed to both of the drives $\left(F_{x3} = F_{x1} = \frac{1}{2}m\ddot{x} + \frac{1}{2}wmg\right)$. The resultant drive force acts in the centreline of the span.

Forces transverse to the runway, $F_{y4} = -F_{y3}$, usually occur due to the distance, $e = \frac{l}{2} - a$, between the acting and reacting forces, and become

$$F_{y4} = F_{y3} = m(\ddot{x} + wg)\frac{e}{c}$$

The design load effects, $\hat{F}$, and the accelerations before $[\ddot{x}_{(i)}]$ and after $[\ddot{x}_{(f)}]$ changing the torques for any considered event should be evaluated.

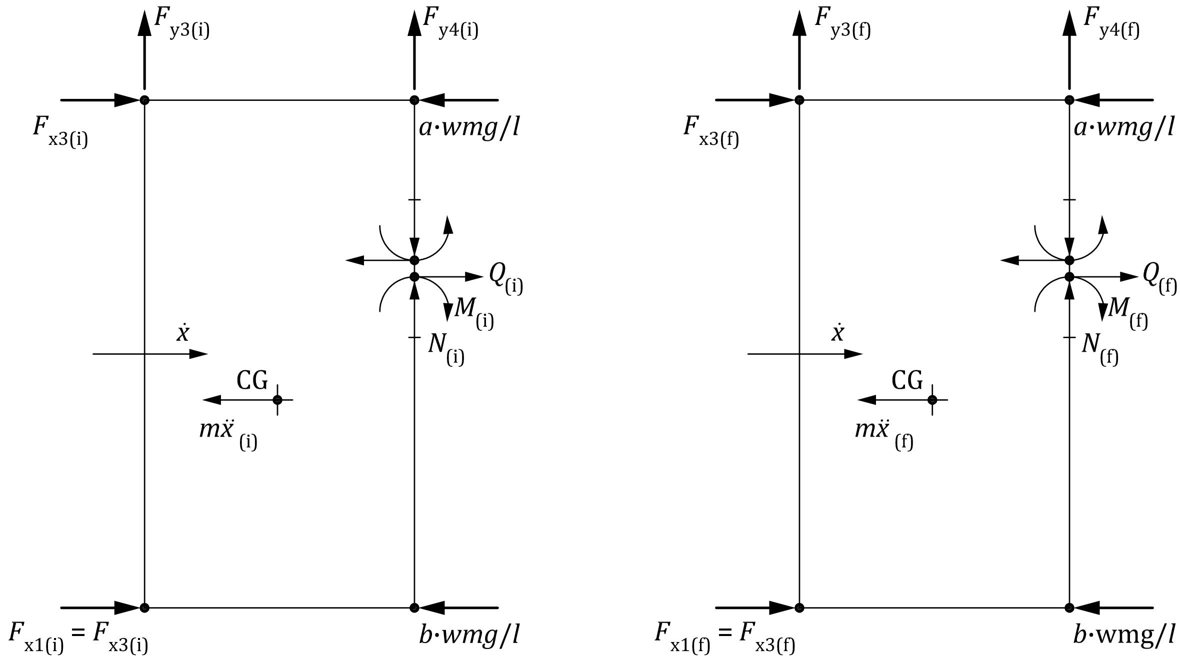
From the acting loads, the mass forces, $[m\ddot{x}_{(i)}]$ and $[m\ddot{x}_{(f)}]$, as well as the resultant friction forces, all relevant load effects, $F_{(i)}$ $[N_{(i)}, Q_{(i)}, M_{(i)}]$ and $F_{(f)}$ $[N_{(f)}, Q_{(f)}, M_{(f)}]$, respectively, should be estimated by an elastostatic calculation considering the crane girder as a plane (or space) frame (see Figure D.8).

The design load effects may be evaluated, having reference to Clauses D.4 and D.7, from

$$\hat{F} = F_{(i)} + \phi_5 \, \Delta F$$

where $\Delta F = F_{(f)} - F_{(i)}$.

In the special cases of events I and II, $\ddot{x}_{(i)} = 0$.



a) Before changing torques (i)

b) After changing torques (f)

The reacting forces, F_y, may be distributed between the wheels grouped in the corners of the crane as follows:

1 or 2 wheels per corner:	F_y	acting on the outer wheel;
3 or 4 wheels per corner:	F_y	acting on the two outermost wheels;
More than 4 wheels per corner:	F_y	acting on the three outermost wheels.

Figure D.8 — Loading state

Annex E
(informative)

Example of method for analysing loads due to skewing

E.1 Model of crane

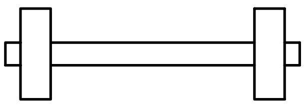
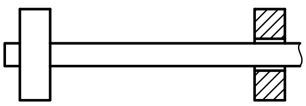
In order to enable an estimation to be made of the tangential forces between wheels and rails as well as of the forces between the acting guide means, caused by skewing of the crane (see 6.2.2), a simple travel-mechanic model is necessary. The crane is considered to be travelling at a constant speed without anti-skewing control.

The model consists of n pairs of wheels transversally in line, of which p pairs are coupled. An individual (i) pair of wheels can be defined, either as coupled (C) (i.e. same rotational speed obtained by mechanical or electrical means) or mounted independently (I) of each other. The latter condition is also valid in the case of independent single drives.

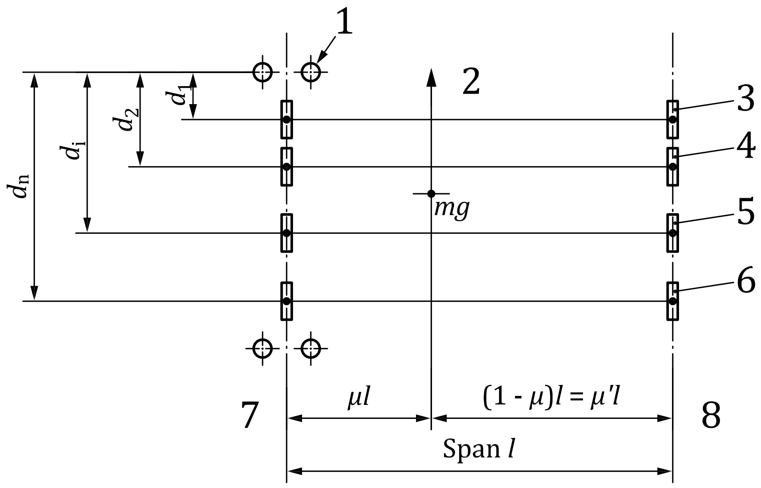
The wheels are arranged in ideal geometric positions in a rigid crane structure travelling on a rigid track. Differences in wheel diameters are neglected in this model. They are either fixed (F) or movable (M) in respect of lateral movement. The lateral degree of freedom can, for example, be provided by a hinged leg.

The different combinations of transversally in-line wheel pairs that are possible are shown in Table E.1.

Table E.1 — Different combinations of wheel pairs

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

In Figure E.1, the positions of the wheel pairs relative to the position of the guide means in front of the travelling crane are defined by the distances, d_i.



Key

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

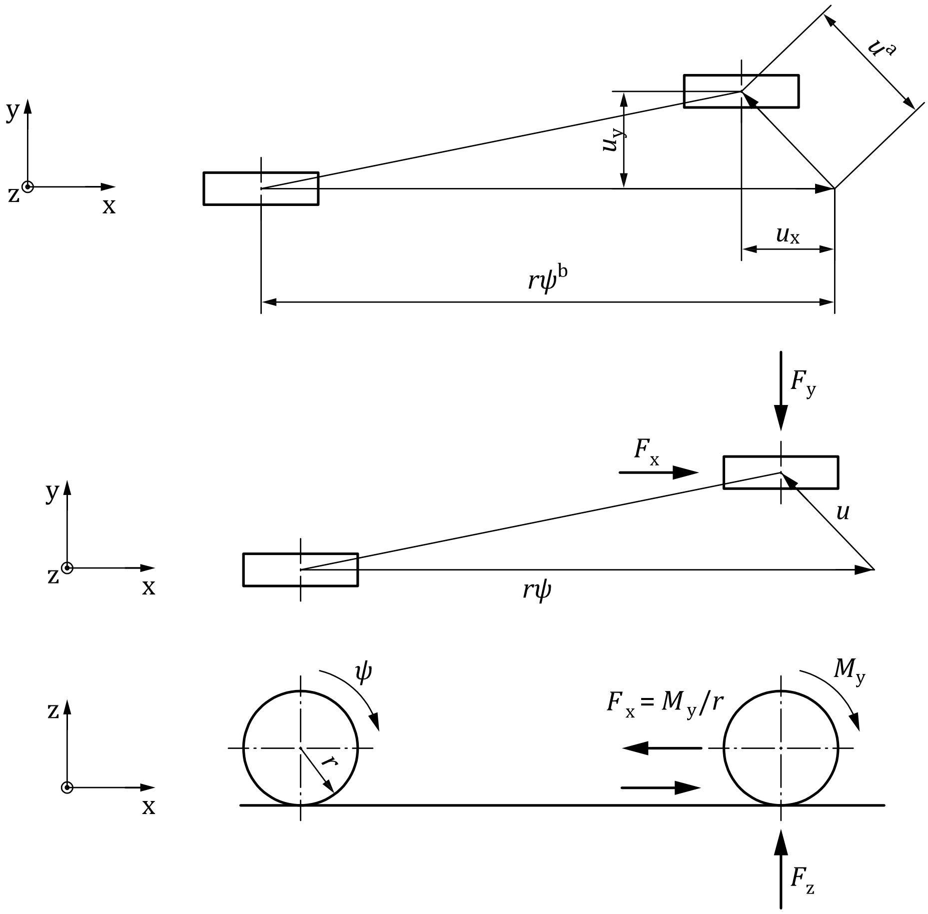
NOTE Where flanged wheels are used instead of an external guide means, $d_1 = 0$

Figure E.1 — Positions of wheel pairs

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

E.2 Relationship between tangential forces and displacements

It is first necessary to assume a relationship between the tangential forces and the corresponding displacements occurring between wheel and rail. Since the wheel has to transfer drive moments (M_y) to the rail and its movement is restricted by the system (crane and runway) it slides in longitudinal and lateral directions $u(u_x, u_y)$. Corresponding tangential forces (F_x, F_y) react on the crane (see Figure E.2).



a Sliding distance.

b Rolling distance.

Figure E.2 — Tangential forces and displacements

In general, a relationship exists between the sliding distances (u_x, u_y) the free-rolling distance $r\psi$, the wheel load F_z and the tangential forces (F_x, F_y), as follows:

$F_x = f_x$ (s_x, s_y, p_c, surface conditions) F_z;

$F_y = f_y$ (s_x, s_y, p_c, surface conditions) F_z.

The friction coefficients of the rolling wheel (f_x, f_y) depend on the slip, i.e. the relation between slide and free-rolling distances ($s_x = u_x/r\psi$) and ($s_y = u_y/r\psi$) on the contact pressure between wheel and rail (p_c) and the surface conditions of the rail. To simplify the calculation, the following empirical relationships may be used:

$f_x = \mu_0\,[1 - e^{(-250 s_x)}]$, for $s_x \leq 0{,}015$,

$f_y = \mu_0\,[1 - e^{(-250 s_y)}]$, for $s_y \leq 0{,}015$

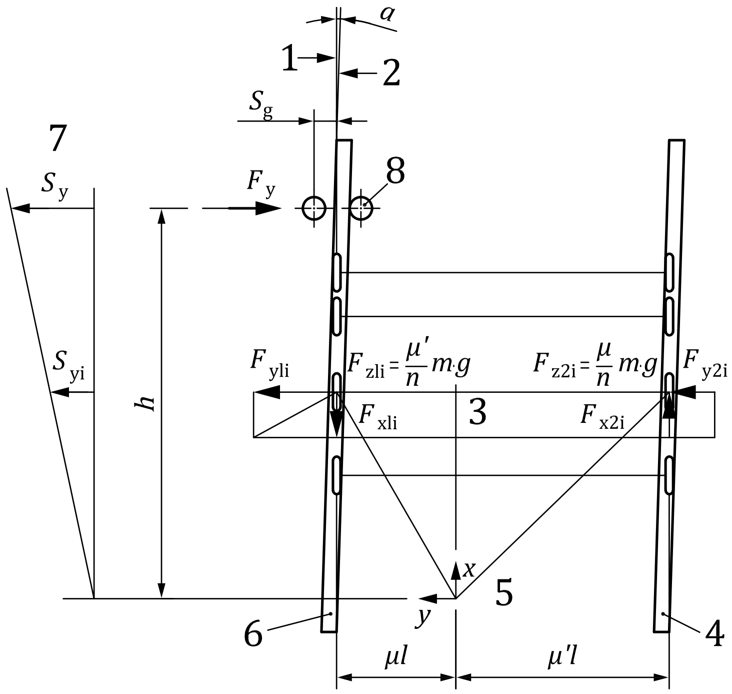
where the adhesion factor,

$\mu_0 = 0{,}3$ for cleaned rails, and

$\mu_0 = 0{,}2$ for non-cleaned rails (i.e. in a normal operation and environment)

E.3 Loads due to skewing

The crane model is assumed to be travelling in steady motion and to have skewed to an angle α, as shown in Figure E.3. The crane may be guided horizontally by external means or by wheel flanges.



Key

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

Figure E.3 — Loads acting on crane in skewed position

The skewing angle, α, which should be ≤0,015, should be chosen taking into account the space between the guide means and the rail as well as reasonable dimensional variation and wear of the crane wheels and the rails; $\alpha = \alpha_g + \alpha_t + \alpha_w$ may be chosen from Table E.2.

Table E.2 — Skewing angle α

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

where

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

b_h is the width of rail tread.

A guide force, F_y, is in balance with the tangential wheel forces, F_{x1i}, F_{y1i}, F_{x2i}, F_{x1i}, F_{y2}, which are caused by rotation of the crane about the instantaneous slide pole. With the maximum lateral slip, $s_y = \alpha$, at the guide means and a linear distribution of the lateral slip, s_{yi}, between the guide means and the instantaneous slide pole, the corresponding skewing forces can be calculated as follows.

E.3.1 Distance between instantaneous slide pole and guide means, h

$$h = (p\mu\mu' l^2 + \sum d_i^2) / \sum d_i \quad \text{for systems F/F}$$

$$h = (p\mu l^2 + \sum d_i^2) / \sum d_i \quad \text{for systems F/M}$$

where

p is the number of pairs of coupled wheels;

μ is the distance of the instantaneous slide pole from rail 1;

μ' is the distance of the instantaneous slide pole from rail 2;

l is the span of the crane;

d_i is the distance of wheel pair *i* from the guide means.

E.3.2 Guide force, F_y

$$F_y = vfmg$$

where

$v = 1 - \sum d_i / nh$ for systems F/F;

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

$f = \mu_0 \, [1 - e^{(-250\,\alpha)}]$, where $\alpha \leq 0{,}015$ rad;

mg is the gravitational force due to the mass of the loaded crane.

NOTE Guide forces acting on flanged wheels can be distributed between the wheels grouped in the corners of the crane as shown in Clause D.8.

E.4 Tangential forces, F_x and F_y

$F_{x1i} = \xi_{1i} fmg$

$F_{x2i} = \xi_{2i} fmg$

$F_{y1i} = v_{1i} fmg$

$F_{y2i} = v_{2i} fmg$

where

f and mg are as given in E.3.2, above;

ξ_{1i}, ξ_{2i}, v_{1i} and v_{2i} are as given in Table E.3, below.

Table E.3 — Values of ξ_{1i}, ξ_{2i}, v_{1i} and v_{2i}

Combinations	$\xi_{1i} = \xi_{2i}$,	v_{1i}	v_{2i}
CFF	$\mu\mu' l/nh$	$\frac{\mu'}{n}\left(1 - \frac{d_i}{h}\right)$	$\frac{\mu}{n}\left(1 - \frac{d_i}{h}\right)$
IFF	0		
CFM	$\mu\mu l/nh$		0
IFM	0		

Annex F
(informative)

Illustration of types of hoist drives

This annex illustrates the five hoist drive types, presented in Table 2b, by means of their time histories of actual rotational or linear hoist drive speed, ω, and resulting hoist force, F (see Figure F.1)

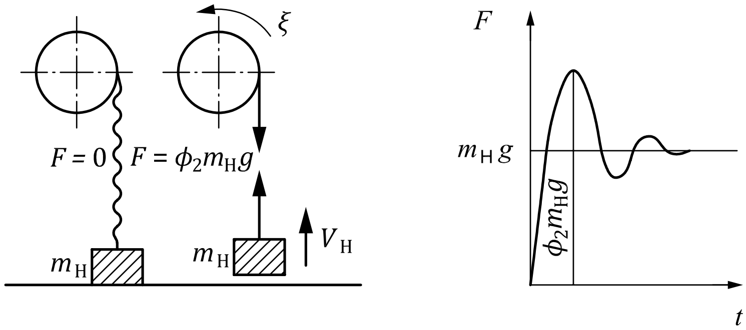
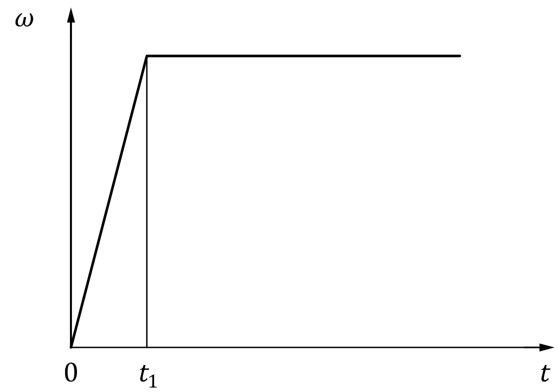
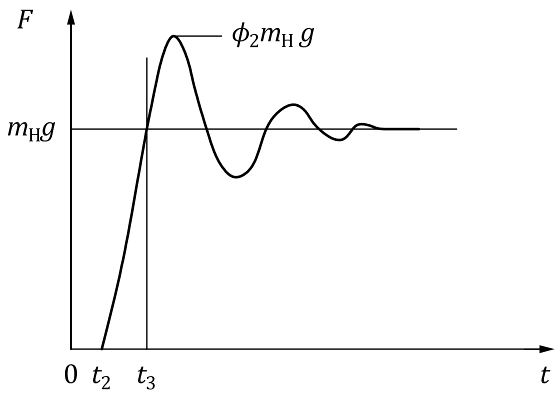
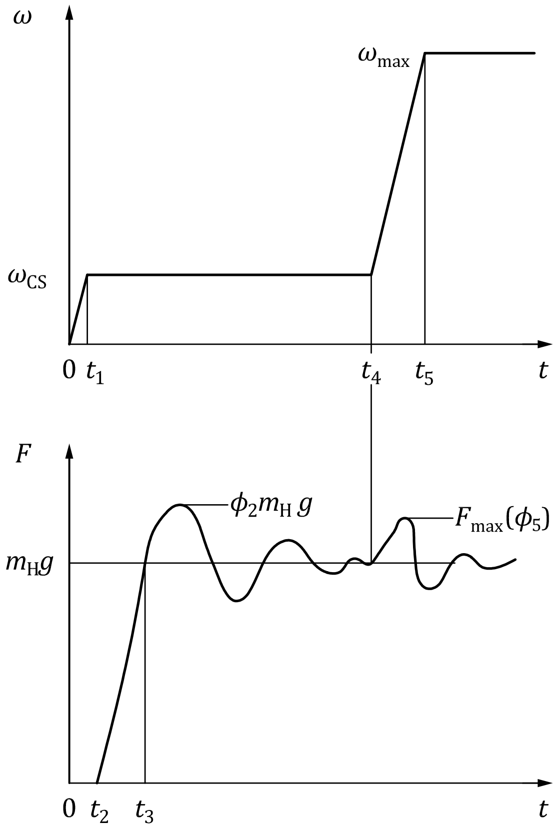


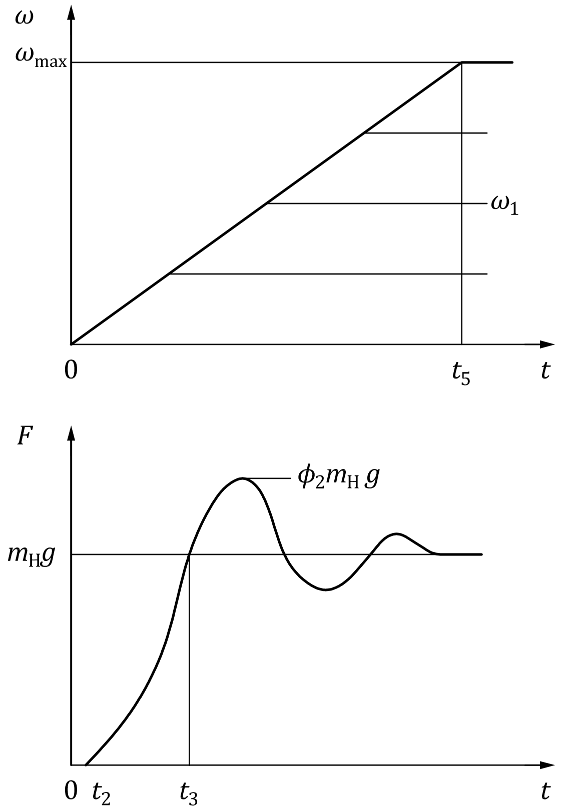
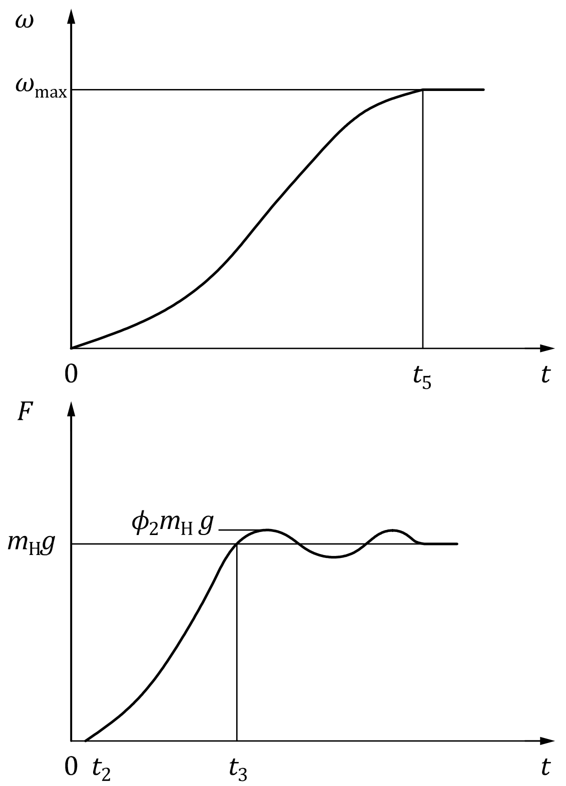
Figure F.1 — ω and F

<table>
<tr><th colspan="2">Hoist drive types</th></tr>
<tr><td colspan="2">HD1: Creep speed not available or start of drive without creep speed is possible</td></tr>
<tr><td rowspan="2">


</td>
<td>Time history:
$t = 0$: start of drive
$t = t_1$: $\omega = \omega_{max}$
$t = t_2$: start of rope tightening ($t_2 \approx 0$)
$t = t_3$: start of load lifting
Regular load (Combinations A, B):
$\phi_2 = \phi_{2,min} + \beta_2 v_{h,max}$</td></tr>
<tr><td>EXAMPLE Squirrel cage motor with or without creep speed.</td></tr>
</table>

<table>
<tr><td colspan="2">HD2: Hoist drive can only start at creep speed of at least pre-set duration</td></tr>
<tr><td>


</td><td>
Time history:
$t = t_0$: start of drive
$t = t_1$: $\omega = \omega_{CS}$
$t = t_4$: start of acceleration to ω_{max} ($t_4 > t_{4min}$)
$t = t_5$: $\omega = \omega_{max}$
$t = t_2$: start of rope tightening ($t_2 \approx 0$)
$t = t_3$: start of load lifting
Regular loads (Combinations A, B):
$\phi_2 = \phi_{2,min} + \beta_2 \, v_{h,CS}$
$F_{max} (\Phi_5) = m_H \, g + \Phi_5 \, (F_{(f)} - m_H \, g)$
Where $F_{(f)}$ is the final drive force, see Annex D.
Exceptional load (Combination C1):
$\phi_2 = \phi_{2,min} + \beta_2 \, v_{h,max}$
<hr>
EXAMPLE Pole changeable squirrel cage motor with creep speed. Time delay t_{4min} ensured by any means like time relay or special push button.
</td></tr>
<tr><td colspan="2">HD3: Hoist drive control maintains creep speed until load is lifted off ground
The time histories of F and ω in HD3 are the same as those shown for hoist drive types HD2. However, whereas HD3 type hoist drives ensure that $t_3 < t_4$, HD2 type drives do not prevent the application of full speed while the load is still grounded (i.e. foreseeable misuse of slack rope).
Therefore, in HD3, only regular loads with $\phi_2 = \phi_{2,min} + \beta_2 \, v_{h,CS}$ can be considered in load combinations A and B.
EXAMPLE Any drive with creep speed and load measuring devices. The maximum speed can only be activated (either automatically or manually) when F stays constant and > 0 for a certain time, thus ensuring that the load is lifted from the ground.
</td></tr>
</table>

<table>
<tr><td colspan="2">HD4: Stepless hoist drive control, performing with continuously increasing speed</td></tr>
<tr><td rowspan="2">
</td>
<td>Time history:
$t = t_0$: start of drive
$t = t_5$: $\omega = \omega_{max}$
$t = t_2$: start of rope tightening
$t = t_3$: start of load lifting
Regular load (Combinations A, B):
$\phi_2 = \phi_{2,min} + \beta_2 \frac{v_{h,max}}{2}$
Exceptional load (Combination C1):
$\phi_2 = \phi_{2,min} + \beta_2\, v_{h,max}$</td></tr>
<tr><td>EXAMPLE Any drive that accelerates smoothly (e.g. ramp), e.g. by means of frequency control or DC-motor or hydraulic spool valve.
As foreseeable misuse (start of lifting with slack ropes) is not prevented, load combination C1 needs to be considered.</td></tr>
<tr><td colspan="2">HD5: Stepless hoist drive control automatically ensures that dynamic factor ϕ_2 does not exceed $\phi_{2,min}$</td></tr>
<tr><td rowspan="2">
</td>
<td>Time history:
$t = t_0$: start of drive
$t = t_5$: $\omega = \omega_{max}$
$t = t_2$: start of rope tightening
$t = t_3$: start of load lifting
Regular load (Combinations A, B):
$\phi_2 = \phi_{2,min}$
Exceptional load (Combination C1):
$\phi_2 = \phi_{2,min} + \beta_2 \frac{v_{h,max}}{2}$</td></tr>
<tr><td>EXAMPLE Frequency control, DC-motor or hydraulic LS-valve plus load measuring devices. Automatic control for smooth rope tightening and cosine shaped acceleration or direct load control.
For additional safety, load combination C1 needs to be considered.</td></tr>
</table>

Bibliography

[1] ISO 2394, *General principles on reliability for structures*

[2] ISO 11031, *Cranes — Design principles for seismic loads*

ICS 53.020.20
Price based on 49 pages