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Cranes — Design principles for loads and load combinations —

Part 5:
Overhead travelling and portal bridge cranes

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

Partie 5: Ponts roulants et ponts portiques

Reference number
ISO 8686-5:2017(E)

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, 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 9, *Bridge and gantry cranes*.

This second edition cancels and replaces the first edition (ISO 8686-5:1992), which has been technically revised. It has been adapted to technical progress and new requirements and changes in the International Standards referenced by it. The main changes are

— the normative references to ISO 8686-1, ISO 20332 and ISO 12488-1 have been updated, and

— a calculation method for loads caused by skewing for bridge and gantry cranes with rigid or flexible characteristics has been added.

A list of all parts in the ISO 8686 series can be found on the ISO website.

Cranes — Design principles for loads and load combinations —

Part 5: Overhead travelling and portal bridge cranes

1 Scope

This document establishes the application of ISO 8686-1 to overhead travelling and portal bridge cranes as defined in ISO 4306-1 and gives specific values for the factors to be used.

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 4301-1:2016, *Cranes — Classification — Part 1: General*

ISO 4302:2016, *Cranes — Wind load assessment*

ISO 4306-5:2005, *Cranes — Vocabulary — Part 5: Bridge and gantry cranes*

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

ISO 12488-1:2012, *Cranes — Tolerances for wheels and travel and traversing tracks — Part 1: General*

ISO 20332:2016, *Cranes — Proof of competence of steel structures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4306-5 and ISO 8686-1 apply.

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

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

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

4 Symbols

Table 1 — Symbols and abbreviated terms

Symbol	Description
a	acceleration or deceleration value
a	term used in determining the value of ϕ_1
b_j	distance in travel direction from wheel j
C_H	elasticity factor of crane structure and rope system at the load suspension point
d_j	distance in travel direction from the front guide means to wheel j
e	base of natural logarithms, 2,718

Table 1 *(continued)*

Symbol	Description
$F_{max,L}$	maximum force
f_{uc}	ultimate strength of the chain steel
g	gravity constant
h_M	flexibility of the portal in angle per moment
l	span of crane
l_r, l_c	length of rope/chain fall
m	mass
m_T	total mass of the loaded crane
M	moment turning the floating end carriage by forces Y_j applied to the wheels of that carriage
M	moment between the portal and the unguided carriage
m_H	mass of the hoist load (gross load)
m_{RC}	mass of the rated hoist load
R_r	rope grade
$S_{(f)}$	final load effect
$S_{(i)}$	initial load effect
sgn	signum function
s_j	selection factor
t_{br}	reaction time of the braking
t_{IAL}	response-time of the indirect acting lifting force limiter
t_{st}	time to stop the mechanism in stall condition by effects of the braking and increasing rope force
v_h	maximum hoisting speed
$v_{h,max}$	maximum steady hoisting speed
W	resulting wheel force
Y_F	lateral force at the guide means (F_y in ISO 8686-1:2012)
Y_j	lateral force at the contact point of wheel j (F_{yij} in ISO 8686-1:2012)
Z_{1i}	wheel load of the 1st wheel of shaft i
Z_{2i}	wheel load of the 2nd wheel of shaft i
Z_a	actual coefficient of utilization of the rope/chain
Z_j	vertical wheel force of wheel j
Z_j	wheel load of wheel j, ($Z_j \geq 0$), (j = 1, 2…n with n = number of wheels) The trolley carries maximum load. The trolley should be positioned on the crane’s side, which has no guide means.
α	skewing angle in radian
α	triggering-factor [–]
α_g	skew component due to track clearance
α_w	component due to wear
α_t	component due to alignment tolerances of rail/wheel
$\Delta\alpha$	additional skewing angle due to flexible deformation
$(\dot{\alpha} / \dot{x})$	portal turning speed per travel speed
ϕ_{DAL}	force-limit factor for direct acting lifting force limiters
ϕ_{IAL}	force-limit factor for indirect acting lifting force limiters
ϕ_5	amplification factor for dynamic loads arising from acceleration of crane drives
ϕ_p	factor for effect of sequential positioning movements
μ_0	adhesion factor

Table 1 *(continued)*

Symbol	Description
μ_f (σ_j)	friction coefficient of wheel *j* by lateral slip σ_j
μ_f	friction slip coefficient (*f* in ISO 8686-1:2012)
σ_j	lateral slip of wheel *j*
σ	slip factor

5 Loads and applicable factors

5.1 Regular loads

5.1.1 General

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 in accordance with ISO 8686-1:2012, 6.1 and the following amendments.

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

The gravitational force induced by the mass of the crane (dead weight) shall be multiplied by a factor ϕ_1, as shown in Formula (1):

$$\phi_1 = 1 + \alpha \tag{1}$$

For masses with unfavourable gravitational load effect, the factors shall be taken as a = 0,10 and ϕ_1 = 1,10, and for masses with favourable gravitational load effect as a = −0,05 and ϕ_1 = 0,95, unless other values are obtained by measurements or calculations.

Where cranes work in atmospheres contaminated by process debris, such material accumulations deposited upon the upper surfaces of the crane shall be taken into account in the dead load computation.

5.1.3 Hoisting an unrestrained grounded load

5.1.3.1 General

The hoist load shall be multiplied by factor ϕ_2 that represents the additional dynamic force applied on the crane, when the weight of a grounded load is transferred on the hoisting medium (ropes or chains).

When assuming the most extreme conditions, the hoisting medium is slack while the hoist mechanism reaches its maximum hoisting speed. In this condition, the dynamic additional force is directly proportional to the hoisting speed, with a coefficient that depends upon the stiffness properties and mass distribution of the crane (β_2 in ISO 8686-1:2012, 6.1.2.1.1).

In physical crane operation, there are other factors that influence the actual dynamic effect, such as control systems, dampening and flexibility of other than main components (e.g. hoist slings, other lifting devices, load itself, crane foundation). These dependencies and determination of factor ϕ_2 are represented by hoisting classes in ISO 8686-1:2012, 6.1.2.1.2.

For determination of ϕ_2, the following principles shall be used:

— calculation by selection of a hoisting class;

— determination by alternative methods, see 5.1.3.5.

The hoisting class and the factor ϕ_2 shall be calculated either

— in accordance with ISO 8686-1:2012, 6.1.2.1.2, or

— in accordance with 5.1.3.2 to 5.1.3.4.

The hoisting speed used for the determination of the dynamic coefficient shall reflect the actual use and possible exceptional events of the crane in a realistic way. Two events shall be considered as follows:

— crane in normal use where hoisting commences at a mechanism controlled speed from a slack rope condition — load combination A and B as per ISO 8686-1:2012, Table 2b;

— exceptional case where hoisting commences at mechanism maximum speed from slack rope condition — load combination C as per ISO 8686-1:2012, Table 2b.

5.1.3.2 Determination of a dynamic factor, ϕ_{2t}

The determination of a hoisting class as defined in ISO 8686-1 shall be selected by the theoretical dynamic factor, ϕ_{2t}. It shall be estimated in one of the following ways.

— Make a complete dynamic simulation taking into account the elastic, inertial and dampening properties. The maximum force in the hoisting medium during time of the first 3 s represents the hoist load multiplied by factor ϕ_{2t}.

— Use one of the simplified Formulae (2) applicable to the hoist.

a) for a crane with a rope hoist

b) for a crane with a chain hoist

$$\phi_{2t} = 1 + \frac{2{,}8 \times v_{h,max}}{0{,}45 + \left(\frac{R_r \times l_r}{1\,500 \times Z_a} \right)^{1/2}} \qquad \phi_{2t} = 1 + \frac{2{,}8 \times v_{h,max}}{0{,}45 + \left(\frac{f_{uc} \times l_c}{150 \times Z_a} \right)^{1/2}} \qquad (2)$$

where

$v_{h,max}$	is the maximum steady hoisting speed in metres/second;
R_r	is the rope grade, in N/mm^2;
f_{uc}	is the ultimate strength of the chain steel, in N/mm^2;
l_r, l_c	is the length of rope/chain fall in metres;
Z_a	is the actual coefficient of utilization of the rope/chain (total breaking force of the rope/chain reeving system/hoist load).

The length, l_r/l_c, shall be taken as the typical distance between the upper and lower rope sheaves/chain sprockets, when hoisting a grounded load. Where a loaded part or all of the hoist media deviates from the vertical, the length of the rope/chain fall shall be adjusted to give the equivalent flexibility in vertical direction.

NOTE This simplified formula takes into account the rigidity and the masses of the crane parts and load.

The hoisting class shall be determined in accordance with Table 2.

Table 2 — Selection of hoisting class

Condition for calculation result			Hoisting class of ISO 8686-1:2012
	ϕ_{2t} ≤	1,07 + 0,24 × $v_{h,max}$	HC1
1,07 + 0,24$v_{h,max}$	< ϕ_{2t} ≤	1,12 + 0,41 × $v_{h,max}$	HC2
1,12 + 0,4$v_{h,max}$	< ϕ_{2t} ≤	1,17 + 0,58 × $v_{h,max}$	HC3
1,17 + 0,58$v_{h,max}$	< ϕ_{2t}		HC4

5.1.3.3 Selection of hoisting speed

The hoisting speed representing the normal use in load combinations A and B, and an exceptional occurrence in load combination C, shall be selected according to the hoist drive class, HD, provided by the system and ISO 8686-1:2012, Table 2b.

5.1.3.4 Calculation of factor, ϕ_2

The factor ϕ_2 shall be calculated in accordance with ISO 8686-1:2012, 6.1.2.1.2, using the selected hoisting class and speed determined in 5.1.3.2 and 5.1.3.3.

5.1.3.5 Determination of ϕ_2 by testing

The dynamic factor, ϕ_2, can also be determined by measurement from an equivalent crane. The values measured with different hoisting speeds shall be directly used in calculations, without reference to a hoisting class.

The dynamic increment of deflections found by measurement or dynamic simulation may include the dynamic effects from the mass of the crane including the trolley; see 5.1.2. The portion represented by the factor a could be removed from the evaluation of the final ϕ_2 to avoid it being considered twice in ϕ_1 and also in ϕ_2.

5.1.4 Loads caused by travelling on an uneven surfaces

The dynamic effects on the crane by travelling, with or without hoist load, on or off roadway or on rail tracks shall be considered by the specific factor, ϕ_4.

For continuous rail tracks or welded rail tracks with finished ground joints without notches (steps or gaps) the specific factor $\phi_4 = 1{,}0$.

For roadways or rail tracks with notches (steps or gaps), the specific factor, ϕ_4, shall be calculated according to ISO 8686-1. For rubber tyred cranes, the flexibility of the tyre shall be taken into account.

5.1.5 Loads caused by acceleration of drives

For crane drive motions, the change in load effect, ΔS, caused by acceleration or deceleration is presented by Formula (3):

$$\Delta S = S_{(f)} - S_{(i)} \tag{3}$$

where

$S_{(f)}$ is the final load effect;

$S_{(i)}$ is the initial load effect.

NOTE The change in load effects, ΔS, is caused by the change of drive force, ΔF, given by the formula: $\Delta F = F_{(f)} - F_{(i)}$, where $F_{(f)}$ is the final drive force and $F_{(i)}$ is the initial drive force.

Loads induced in a crane by acceleration or deceleration caused by drive forces may be calculated using rigid body kinetic models. The load effect, S, shall be applied to the components exposed to the drive forces and where applicable to the crane and the hoist load as well. As a rigid body analysis does not directly reflect elastic effects, the load effect, S, shall be calculated by using an amplification factor, ϕ_5, in accordance with of ISO 8686-1:2012, 6.1.4 as in Formula (4):

$$S = S_{(i)} + \phi_p \times \phi_5 \times a \times m \tag{4}$$

where

$S_{(i)}$ is the initial load effect caused by $F_{(i)}$;

ϕ_5 is the amplification factor for dynamic loads arising from acceleration of crane drives;

ϕ_p is the factor for effect of sequential positioning movements, see 5.1.6;

a is the acceleration or deceleration value;

m is the mass for which a applies.

The factor ϕ_5 shall be taken from Table 3 and Table 4 unless more accurate factors are available from elastic model calculations or measurements. The factor, ϕ_p, shall be taken from Table 6.

Where the force, S, is limited by friction or by the nature of the drive mechanism, this frictional force shall be used instead of calculated force, S.

Table 3 — Factor ϕ_5 for travel, traverse and slewing mechanism

Drive type	Factor ϕ_5	
	Typical backlash for gearbox	Considerable backlash, e.g. open gears
Stepless speed control	1,2	1,5
Multi-step speed control	1,6	2,0
Two-step speed control	1,8	2,2
Single-step speed control	2,0	2,4

Table 4 — Factor ϕ_5 for hoist mechanism

Drive type	Factor ϕ_5 lifting	Factor ϕ_5 lowering
Stepless speed control	1,05	1,10
Multi-step speed control	1,15	1,20
Two-step speed control	1,20	1,35
Single-step speed control	1,20	1,30

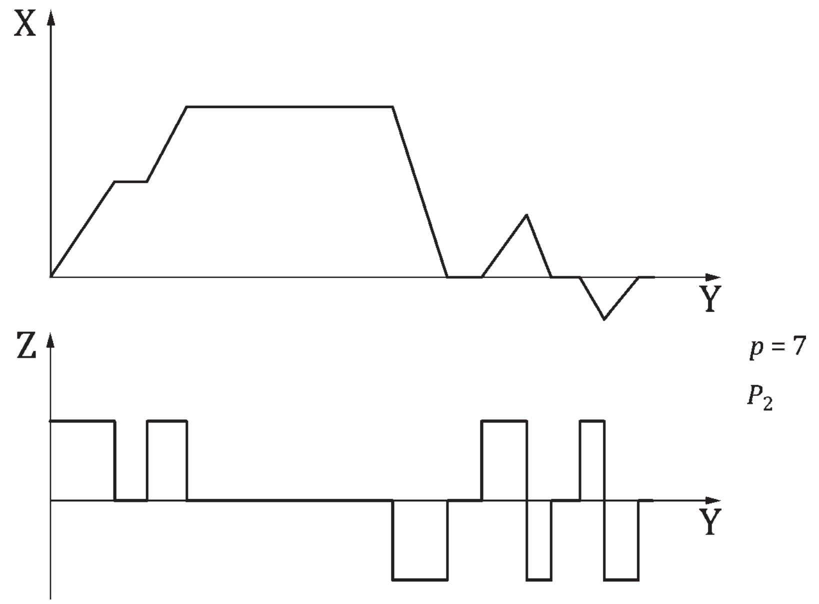
NOTE Factors in Tables 3 and 4 take account for switching on/off the speed and speed change.

5.1.6 Positioning of loads

The number of intended and additional accelerations of any drive to reach the intended position of the load shall be taken into account in the proof of competence. This shall be done by using average number of accelerations, P, in accordance with ISO 4301-1:2016, 7.6 classified in Table 5 and illustrated in Figure 1.

Table 5 — Average number of accelerations

Class	Average number of accelerations
P_0	$p = 2$
P_1	$2 < p \leq 4$
P_2	$4 < p \leq 8$
P_3	$8 < p$



Key

x speed

y time

z acceleration

Figure 1 — Example for class *P*

Table 6 — Factor ϕ_p

Class of load positioning according to Table 5	ϕ_p
P_0 and P_1	1,0
P_2	1,15
P_3	1,3

Positioning movements may increase the total load effects, when made in non-optimal manner. This is taken into account by factor ϕ_p dependent upon the class *P*.

5.1.7 Loads induced by displacements

Account shall be taken of loads arising from displacements included in the design in accordance with ISO 8686-1:2012, 6.1.5.

Where displacements related to rail span variations or support deflections remain within the limit values specified in ISO 12488-1:2012, 6.2, their effect need not to be taken into account in the stress analysis.

5.2 Occasional loads

5.2.1 General

Occasional loads and effects which occur infrequently shall be considered in proof of competence calculations against failure by yielding elastic instability and may usually be neglected in fatigue evaluations in accordance with ISO 8686-1 and the following amendments.

5.2.2 Loads caused by skewing

5.2.2.1 General

In general, the skewing forces are usually taken as occasional loads and shall be addressed to load combination B, but their frequency of occurrence varies with the type, configuration, accuracies of wheel axle parallelism and service of the crane or trolley. In individual cases, the frequency of occurrence will determine whether they are taken as occasional or regular loads.

In cases where anti-skew devices are provided, the forces calculated without the effect of anti-skew devices shall be addressed to load combination C. If the crane can be used without anti-skew devices functioning, the forces shall be addressed to load combination B.

Skewing forces for top-running cranes and trolleys shall be calculated in accordance with 5.2.2.2 to 5.2.2.4 and Annex A, which provide simplified methods for calculating the forces generated when considering both RIGID and FLEXIBLE crane structures. Skewing forces for underhung cranes shall be calculated in accordance with 5.2.2.5.

NOTE 1 The method given in ISO 8686-1:2012, 6.2.2 is applicable to rigid structures. Bridge and gantry cranes can possess both RIGID and FLEXIBLE characteristics; therefore, a more general method is required as given here. With this method, in addition, flexible structures, uneven number of wheels, unequally distributed wheel loads, as well as different types of guide means and anti-skewing devices, can be considered.

NOTE 2 Forces arising from skewing are generated when the resultant direction of rolling movement of the travelling crane no longer coincides with the direction of the runway rail and when the front positive guiding means come into contact with the rail. This is caused by tolerances and inaccuracies, which arise in the manufacture of the crane (bores of track wheels) and that of the runway's rail (bends, kinks). The values and distribution of these forces depend chiefly upon the clearances between the runway rail and the wheel flanges or guide rollers and the latter's location, also on the number, arrangement, bearing arrangement and rotational speed synchronisation of the track wheels and structural flexibility.

NOTE 3 The use of anti-skew devices with travel motions reduces the guiding forces between the rail and guiding means. It also reduces the lateral slip forces of the wheels, but some lateral slip remains due to wheel alignment tolerances and lateral deformations of structures, which effect should be considered.

5.2.2.2 Skew angle

The skew angle shall be calculated as follows:

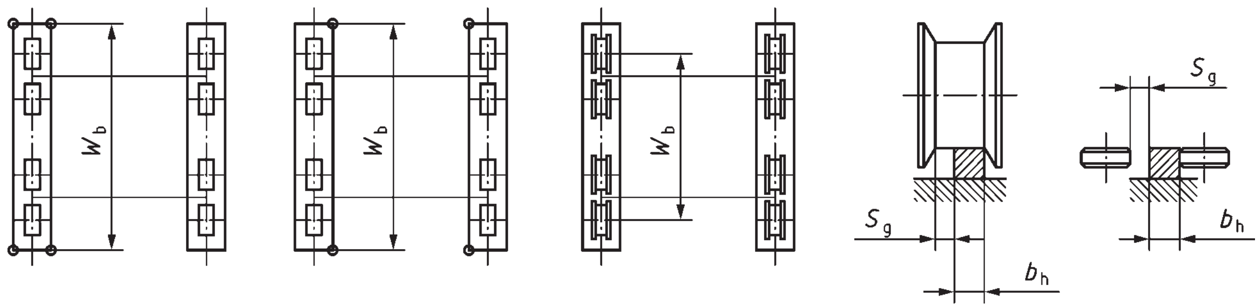


Figure 2 — Parameters of skew angle

The total skew angle to be considered in design is shown in Formula (5):

$$\alpha = \alpha_g + \alpha_w + \alpha_t \tag{5}$$

where

α is the skew angle to be considered in design;

α_g is the skew component due to track clearance s_g/w_b;

α_w is the component due to wear — rail and wheel flange/guide roller;

α_t is the component due to alignment tolerances of rail/wheel.

The values for skew angles shall be determined according to ISO 8686-1:2012, Table E.2.

The skew angle shall be $\alpha \le 0{,}015$ rad in order to achieve good travel behaviour of the crane or the trolley.

NOTE For larger track clearances, the skew angle is reduced to 75 % because bridge and gantry cranes and their trolleys use the full track clearance only rarely. Usually, only the forward guide means is in contact with the rail.

5.2.2.3 Friction slip relationship

The following simplified empirical relationship, as shown in Formula (6), shall be used to calculate the friction coefficient for longitudinal and lateral slip:

$$\mu_f = \mu_0(1 - e^{-250 \times \sigma}) \tag{6}$$

where

μ_f is the friction slip coefficient (f in ISO 8686-1:2012, E.2);

μ_0 is 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 is the base of natural logarithms, 2,718;

σ is the slip factor.

NOTE The slip factor, σ, is the ratio of the slip distance — transverse and/or longitudinal — to the corresponding travel distance. For the transverse slip, the slip factor, σ, is equal to the instantaneous total skewing angle (α or $\alpha + \Delta\alpha$). See A.2.2.

5.2.2.4 Selection of calculation methods

Either of two simplified calculation methods shall be used: Either a RIGID or FLEXIBLE method. The RIGID method assumes the structures of the crane and the runway to be rigid. The FLEXIBLE method assumes the structure to be flexible. In cases of doubt, the FLEXIBLE method should be utilized.

Calculation models to be adopted relative to the crane/trolley structural configuration are listed within Table 7.

Table 7 — Calculation models of bridge and gantry cranes

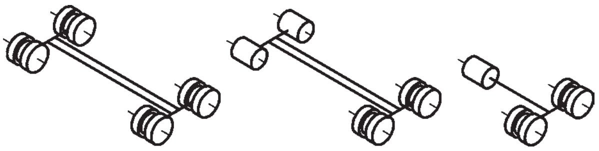
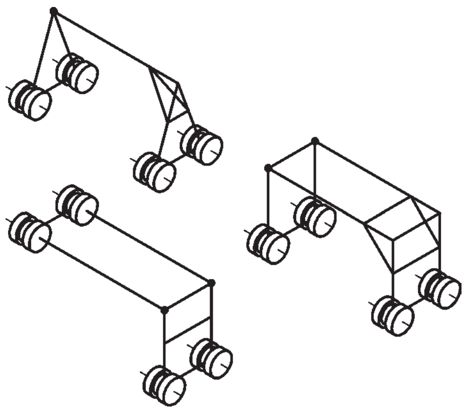
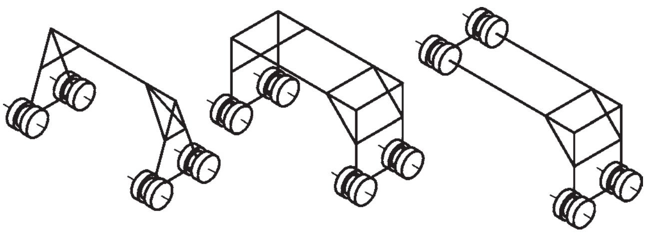
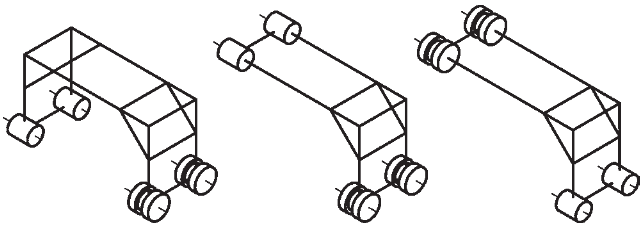
Type	Structural configuration	Applicable method for calculation of loads due to skewing
A	 Bridge crane, trolley. Bridge crane, trolley. Even, horizontal, almost stiff. Guide means on one or both end carriages.	Method RIGID.
B	 Crane with articulation, respectively crane with flexible support (• = articulation about an axis parallel with crane track). Guide means on both end carriages.	Each end carriage shall be calculated separately with the method RIGID. Concerning the skewing forces, the crane divides into two almost independent, individually guided carriages.
C	 Crane without articulation. Guide means on both end carriages.	Method RIGID.

Table 7 *(continued)*

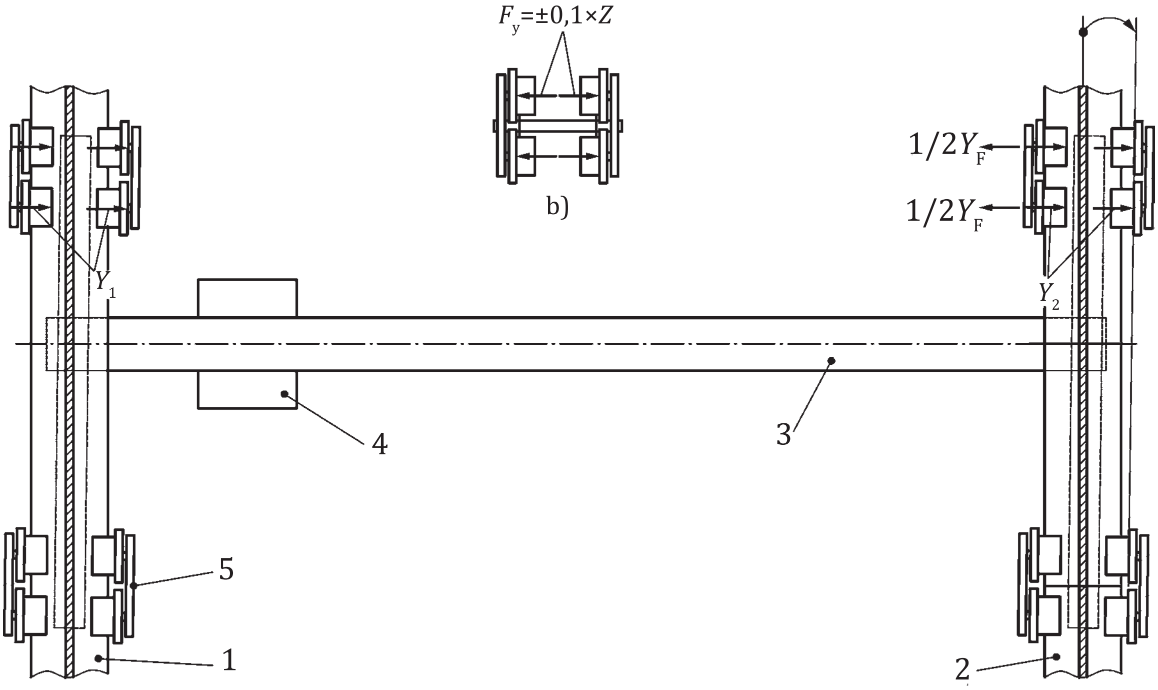
Type	Structural configuration	Applicable method for calculation of loads due to skewing
D	 Crane without articulation. Guide means on only one end carriage.	The method depends on the flexibility of the structure. The decision is made by the result of the method RIGID.
	Procedure: a) Calculate the skewing forces with the method RIGID. b) Supply a fixed support for the end carriage with guide means. Supply a floating support for the un-guided end carriage [see Figure A.2 c)]. Apply the forces calculated with method RIGID to the floating end carriage. The originally parallel end carriages receive an angle position $\Delta\alpha$ to each other. c) If $\mu_f\,(\alpha + \Delta\alpha)/\mu_f(\alpha) > 1{,}1$, then the skewing forces have to be calculated with the method FLEXIBLE. Otherwise, the calculation with the method RIGID is sufficient. E.g. $\mu_f(\alpha + \Delta\alpha) = \mu_0\{1 - e^{[-250(\alpha + \Delta\alpha)]}\}$ and $\mu_f(\alpha) = \mu_0[1 - e^{(-250\alpha)}]$.	

5.2.2.5 Skewing forces for underhung cranes

The skewing forces of the underhung cranes, having rigid structure and running on the bottom flanges of rigidly fixed runway beams, shall be calculated with the same principles as the top running cranes. See A.3. However, the guiding force Y_F (F_y in ISO 8686-1:2012, E.2) may be divided on two-wheel flanges of a leading bogie. The minor lateral forces of the trailing bogies may be ignored. Figure 3 represents an example of the structures and one possible set of the most critical skewing force combinations.

For configurations where either a runway beam (or both of them) or the bogies on one of the runways can float laterally, the lateral forces Y_1 and Y_2 are balanced by separate guiding forces Y_F on both leading bogies.

In these cases, the guiding forces ½ Y_F (see Figure 3) shall be taken conventionally as 20 % of the maximum static vertical force Z of the wheel. Frictional forces, Y_1 and Y_2, are then 10 % of the vertical wheel force of each wheel. The guiding forces, Y_F, and frictional forces, Y, balance each other separately on both runways, forming internal force systems within the bogies [see b) in Figure 3] and also local internal force systems within the bottom runway flanges. These forces balanced locally do not impose external forces on the crane structure.



Key

1 bottom flange and cut web of runway beam No. 1

2 bottom flange and cut web of runway beam No. 2

3 crane girder; end carriage beams under the runways not shown

4 hoist trolley with load

5 4-wheel bogies at each corner of the crane

Y_1 transverse frictional skewing forces applied between the wheels and the top surface of the bottom flange of the runway 1

Y_2 transverse frictional skewing forces applied between the wheels and the top surface of the bottom flange of the runway 2

Y_F guiding force applied to the wheel flanges of the guiding bogie (F_y in ISO 8686-1:2012, E.2)

F_y minimum transverse forces to be also considered in bogie design as shown in b)

Z maximum dynamic wheel force in vertical direction

Figure 3 — Skewing forces of underhung crane

Besides the skewing, the lateral forces on the bogies of the underhung cranes are created also by acceleration of the crane loaded asymmetrically and by acceleration of the hoist trolley and load. These forces shall be considered according to 5.1.3.3.

5.3 Exceptional loads

5.3.1 General

Exceptional loads and their effects are also infrequent and may likewise usually be excluded from fatigue consideration evaluations in accordance with ISO 8686-1 and the following additions and modifications. 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.

5.3.2 Test loads

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

The sum of the lifted masses suspended from the crane in test load condition shall be multiplied by a factor ϕ_6 in accordance with ISO 8686-1:2012, 6.3.2.

In the proof calculation for testing situations, the minimum level of wind as defined in ISO 8686-1 shall be taken into account for outdoor applications only.

5.3.3 Loads due to buffer forces

Where buffers are used, the forces arising from collision calculated by rigid body analysis shall be multiplied by a factor ϕ_7 to account for dynamic effects in accordance with ISO 8686-1:2012, 6.3.3 and the following amendments.

Buffer forces shall be calculated from the kinetic energy of 85 % of the nominal travelling speed of the moving crane masses excluding the freely suspended load (free to sway horizontally) and for trolleys from the kinetic energy of 100 % of the nominal travelling speed of the moving masses of the trolley excluding the freely suspended load.

Where braking is actuated by a limiting function before the buffer collision occurs:

— for cranes and trolleys not exposed to wind forces, the buffer forces shall be calculated from the kinetic energy of 70 % of the nominal travelling speed of the moving masses excluding the freely suspended load;

— for cranes and trolleys exposed to wind forces, the buffer forces shall be calculated from the kinetic energy of 85 % of the nominal travelling speed of the moving masses excluding the freely suspended load. Where the wind forces are included in the buffer calculation, 70 % of the nominal travelling speed may be applied.

In both cases, the friction grip type (slip resistant) connections of the supporting end stops of the buffers shall, however, be designed with a specific resistance factor γ_{SS} = 1,8, in accordance with ISO 20332:2016, 5.2.3.2.

In the calculation, the resistance to motion due to the frictional contact between wheels and rails may be allowed for by means of a factor f = 0,18.

5.3.4 Loads caused by emergency cut-out

Loads caused by emergency cut-out shall be calculated in accordance with ISO 8686-1:2012, 6.3.6 with the following amendment.

The value of the factor ϕ_5 shall be either set equal to 2 or be determined experimentally or by dynamic analysis.

5.3.5 Loads caused by apprehended failure of mechanism or components

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

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

Resulting load due to failure mentioned above shall be calculated in accordance with 5.1.5, taking into account any resulting impacts.

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

— Regular loading condition, where all the components of the mechanism operate as a whole sharing the hoisted load. This shall be assigned to load combination A and used in the proof of fatigue and static strength.

— Exceptional loading, taking into account a failure of any single component of the mechanism. The loading on the remaining part of the mechanism during the failure incident shall be assigned to load combination C and used in the proof of static strength of the remaining part. Dynamic impact factor ϕ_5 due to a failure may be determined through dynamic analysis or otherwise, ϕ_5 shall be taken equal to 1,5. The factor shall be applied on the total load carried by the effective system remaining after the failure.

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

Where hoists of cranes are equipped with lifting force limiters, the resulting force on the crane shall be taken into account in the proof of competence calculations.

When hoisting a load, a lifting force-limiting device limits the force on the crane to a level depending on type of the limiter, the drive control system and the mechanical properties of the crane.

There are two different types of limiters:

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

b) indirectly acting lifting force (IAL) limiter, where the force on the system is measured and a second device is activated to stop the motion.

The force-limit factor, ϕ_L, depends on the type of limiter.

$\phi_L = \phi_{DAL}$ in case of direct acting limiter (see 5.3.6.1).

$\phi_L = \phi_{IAL}$ in case of indirect acting limiter (see 5.3.6.2).

5.3.6.1 Loads due to dynamic cut-off of hoisting movement by directly acting lifting force limiters

The maximum force, $F_{max.L}$, which is applied to the crane when the direct acting lifting force limiter operates, shall be calculated as Formula (7):

$$F_{max.L} = (\phi_{DAL} \times m_{RC} + m_H - m_{RC}) \times g \qquad (7)$$

where

$F_{max.L}$ is the maximum force, in N;

ϕ_{DAL} is the force-limit factor for direct acting lifting force limiters [–];

m_{RC} is the mass of the rated hoist load, in kg;

m_H is the mass of the hoist load (gross load), in kg;

g is the gravity constant 9,81 m/s^2.

For hydraulic systems, the factor ϕ_{DAL} shall be less than, or equal to 1,4, with friction torque limiters or pneumatic systems this factor shall be less than, or equal to 1,6.

5.3.6.2 Loads due to dynamic cut-off of hoisting movement by indirectly acting lifting force limiters

The maximum force, $F_{max.L}$, which is applied to the crane, resulting from the operation of the indirect acting lifting force limiter in an overload, stall load and if relevant, in a snag load case, shall be calculated as Formula (8):

$$F_{(max.L)} = (\phi_{IAL} \times m_{RC} + m_H - m_{RC}) \times g \qquad (8)$$

where

$F_{max.L}$	is the maximum force, in N;
ϕ_{IAL}	is the force-limit factor for indirect acting lifting force limiters [–];
m_{RC}	is the mass of the rated hoist load, in kg;
m_H	is the mass of the hoist load (gross load), in kg;
g	is the gravity constant 9,81 m/s^2.

The $F_{max.L}$ represents the final load in the hoist system after the triggering has operated and the hoist motion is brought to rest. It shall be calculated with due consideration to stiffness of the hoist mechanism and structures as a whole and functioning of the indirect acting limiter.

The force-limit factor for indirect acting lifting force limiters ϕ_{IAL} for indirect acting lifting force limiters shall be calculated as Formula (9):

$$\phi_{IAL} = \alpha + \frac{\left[C_H \times v_h \left(t_{IAL} + t_{br} + \frac{t_{st}}{2}\right)\right]}{(m_{RC} \times g)} \qquad (9)$$

where

α	is the triggering-factor [–];
v_h	is the maximum hoisting speed at which the indirect acting force limiter may be triggered, in m/s;
m_{RC}	is the mass of the rated hoist load, in kg;
t_{IAL}	is the response-time of the indirect acting lifting force limiter, in s;
t_{br}	is the reaction time of the braking, in s;
t_{st}	is the time to stop the mechanism in stall condition by effects of the braking and increasing rope force, in s;
C_H	is the elasticity factor of crane structure and rope system at the load suspension point, in N/m.

In general, the triggering-factor α shall be less or equal to 1,25.

In cases where in normal operation the factor ϕ_2, when the weight of a grounded load is transferred on the hoisting medium, is above the triggering factor, a delayed triggering system may be needed. If this is provided, it should be 5 % above the level of ϕ_2.

5.4 Miscellaneous loads

Miscellaneous loads include erection and dismantling loads, as well as loads on platforms and means of access, and shall be taken into account in accordance with ISO 8686-1:2012, 6.4.

6 Applicable loads, load combinations and factors

The ϕ_n factors taken into account for dynamic effects shall be used for load combinations and are given in Table 8.

Table 8 — ϕ_n factors

Table 9 line No.	ϕ_n	Reference to ISO 8686-1:2012	Values for factors ϕ_n, or values for loads, or relevant International Standards
1	ϕ_1	6.1.1	See 5.1.2.
2	ϕ_2	6.1.2.1	See 5.1.3.
	ϕ_3	6.1.2.2	See ISO 8686-1.
3	ϕ_4	6.1.3.2 and Annex C	The value of ϕ_4 shall be estimated as shown in ISO 8686-1:2012, Annex C, with the amendment of 5.1.4.
4 and 5	ϕ_5	6.1.4 and Annex D	See 5.1.5.
6		6.1.5	See 5.1.6.
7		6.2.1.1	See ISO 4302:2016, Clause 5.
8		6.2.1.2	See applicable regional snow- and ice-load conditions.
9		6.2.1.3	See applicable ambient and localized temperature variations.
10		6.2.2	See 5.2.2 and Annex A.
11	ϕ_2	6.1.2.1.3	See 5.1.2.
12		6.3.1	See ISO 4302:2016, Clause 6.
13	ϕ_6	6.3.2	See 5.3.2.
14	ϕ_7	6.3.3	See 5.3.3.
15		6.3.4	See ISO 8686-1.
16	ϕ_5	6.3.6	See 5.3.4.
17	ϕ_5	6.3.7	See 5.3.5.
18		6.3.8	See ISO 8686-1.
19			See 5.3.6.
20	ϕ_9	6.3.5	See ISO 8686-1.
21		6.4.1	See ISO 8686-1.

The load combinations shall be in accordance with the principles of ISO 8686-1 and are given in Table 9.

Table 9 — 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	C10	C11	
Regular (see ISO 8686-1:2012, 6.1)	Gravitation, acceleration impacts	1) Mass of the crane	a	ϕ_1	ϕ_1	1	—	a	ϕ_1	ϕ_1	1	—	—	a	ϕ_1	1	ϕ_1	1	1	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	ϕ_L	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 5.1.6	b	1	1	1	1	b	1	1	1	1	1	b	1	1	1	1	1	1	1	1	1	1	1	—
Occasional (see ISO 8686-1:2012, 6.2)	Effects of climate	1) In-service wind loads		—	—	—	—	1,22	1	1	1	1	1	1,16	—	—	1	—	—	—	—	—	—	—	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 5.2.2		—	—	—	—	1,16	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—		10
Exceptional (see ISO 8686-1:2012, 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_7	—	—	—	—	—	—	—	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) Dynamic cut-off by lifting force limiters			—	—	—	—		—	—	—	—	—	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

Table 9 *(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**	**C10**	**C11**	
Strength coefficient γ_f (allowable stress method)		1,48					1,34						1,22												

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 ISO 8686-1:2012, 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) and 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.

[a] For values of the partial safety factor to be applied, see ISO 8686-1:2012, Table 4.

[b] For values of the partial safety factor to be applied to loads due to displacements, see ISO 8686-1:2012, 7.3.8.

7 Combination of acceleration effects

In the case of overhead travelling and portal bridge cranes, the load is moved by hoisting (H), travelling (Lt), traversing (Ct) and, possibly, by slewing (SI) mechanisms (see Figure 4).

The acceleration effects of these mechanisms acting simultaneously on the crane depend on the control systems and service conditions of the crane and whether a load is hoisted from the ground or a suspended load is hoisted.

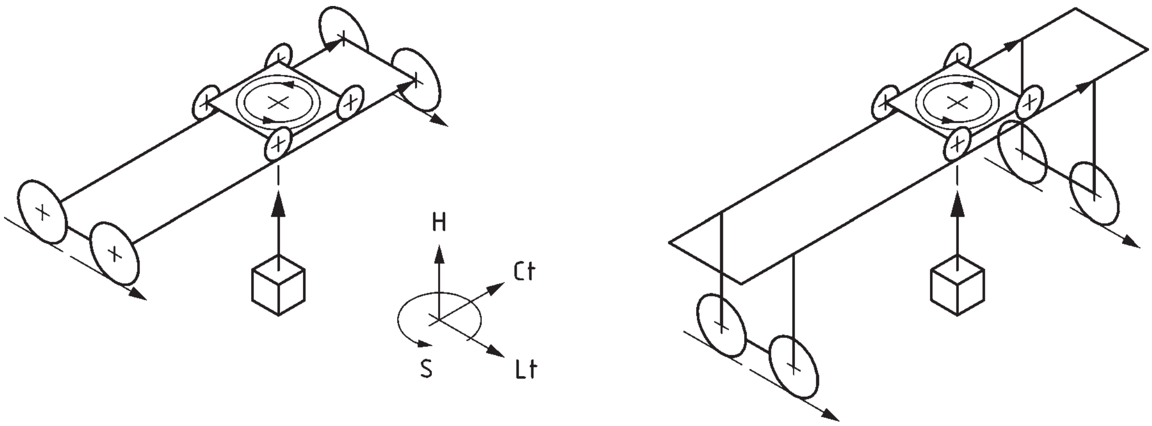


Figure 4 — Moving directions

Taking the above into account, the accelerations given in Table 9 are assumed to be acting simultaneously.

The gross loads m_H shall be multiplied within the individual load combinations by the following factors:

— load combinations A1 and B1: ϕ_2

— load combinations A2 and B2: ϕ_3

— load combinations A3 and B3: $\left(1+\phi_p \times \phi_5 \times \frac{m_H \times a}{m_H \times g}\right)$

where: m_H is the mass of the gross load (see ISO 8686-1:2012, Table 1)

— load combinations A4 and B4: ϕ_4

— load combinations C3: ϕ_6

— Drive forces can change significantly in a short time interval. Thus, the dynamic factor ϕ_5 shall be calculated

a) for starting the movement,

b) for braking the steady-state movement, and

c) for braking the movement during the starting process, or

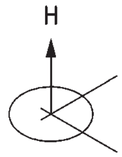
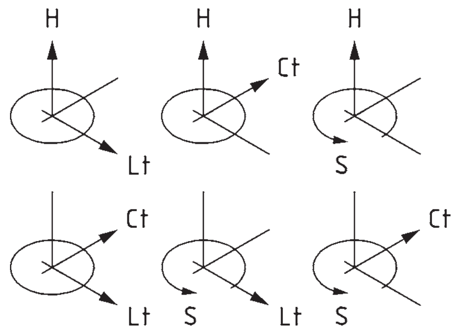
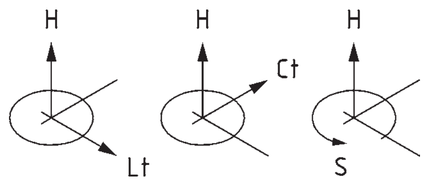
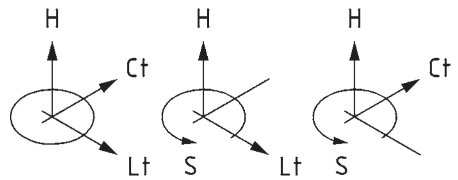
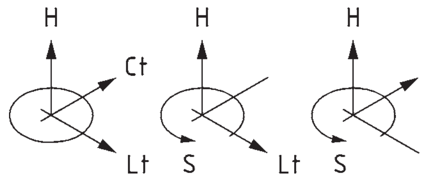
d) for accelerating the movement during the braking process (positioning).

Thus, the calculated rigid body acceleration forces shall be multiplied by the factor ϕ_p in addition.

When considering the positioning effects, only one such effect is combined with other movements.

In load combination C6 or C7 or C9, only the dynamic effects of the "emergency cut-out", or of the "failure of mechanism or components" or the "dynamic cut-off by lifting force limiters" shall be considered without other dynamic effects, assuming the case of starting during steady-state motion.

Table 10 — Combination of acceleration effects

<table>
<tr><th rowspan="2"></th><th>Hoisting a grounded load</th><th colspan="2">Hoisting a suspended load</th></tr>
<tr><th>Load combinations A1, B1, C1</th><th colspan="2">Load combinations A2 to A4, B2 to B4, C3</th></tr>
<tr><td>Control by push-button panel or bi-directional control levers</td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="4">Control by multi-directional control levers</td><td>Power station cranes
Erection cranes
Workshop cranes</td><td>Power station cranes
Erection cranes
Workshop cranes</td><td>Ship unloaders
Stockyard cranes
Steel mill cranes</td></tr>
<tr><td></td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Ship unloaders
Stockyard cranes
Steel mill cranes</td></tr>
<tr><td></td></tr>
</table>

Annex A
(informative)

Skewing loads: Assumptions for simplified calculating methods

A.1 General

The calculating methods given in this annex are simplified methods based upon the following.

The front guide means (roller or wheel flange) of the crane contacts the rail in the skew angle, α, while the crane is travelling.

a) Method RIGID:

Crane and track are represented completely rigidly. A linear form of the friction slip relationship regarding to α is allowed. The linear form is not allowed if $\mu_0 < 0{,}2$ is used.

b) Method FLEXIBLE:

The frame is represented flexibly. The carriages may be represented rigidly. A linear form of the friction slip relationship is not allowed. The change of the wheel loads due to warping of the frame may be neglected.

For both methods, the following apply.

The position of the trolley is located in such a way that the maximum skewing forces are computed. This is usually a location at the remote extreme of span to that of the guidance system with uncoupled drives. In cases of a mechanically coupled drives, the trolley is set in a manner to provide equal loading on the drive wheels, usually mid-crane span. Electrically coupled drives are considered to be uncoupled.

These methods assume no accelerations, even horizontal crane track, all angles are small and that the geometrical tolerances are ignored.

NOTE The statements given for a crane and its tracks are applicable also for a trolley and its tracks.

A.2 Calculation of skewing forces by method RIGID

A.2.1 Calculation model

Procedure: (see Figure A.1) Select a travel direction. Assign a number j = 1, 2, ..., n to each wheel. Calculate the sums S, S_d and S_{dd} with Formula (A.1). Calculate the intermediate value b with Formula (A.2) a). The forces Y_j in the centre of wheel contact and the force YF at the guide means are derived from Formula (A.3).

$$\text{a) } S = \sum Z_j = m_T \times g \qquad \text{b) } S_d = \sum Z_j \times d_j \qquad \text{c) } S_{dd} = \sum Z_j \times d_j^2 \qquad \text{(A.1)}$$

$$\text{a) } b = \frac{S_d}{S_{dd} + W \times l^2} \qquad \text{b) } \mu_f = \mu_0 (1 - e^{-250 \times \sigma}) \qquad \text{(A.2)}$$

$$\text{a) } Y_j = \mu_f \times Z_j (1 - d_j \times b) \qquad \text{b) } Y_f = \mu_f (S - S_d \times b) = \sum Y_j \qquad \text{(A.3)}$$

where

μ_f is the friction slip coefficient regarding the skewing angle α, with $\sigma = \alpha$ in radians according to 5.2.2.3;

Z_j is the vertical wheel force of wheel j, (j = 1, 2, ..., n with n = number of wheels); see explanation below;

d_j is the distance in the travel direction from the front guide means to wheel j (d_j will be negative for wheels which run ahead of the front guide means);

W is set to $W = 0$, if shaft coupling is not present; otherwise, consider A.2.2;

m is the total mass of the loaded crane;

l is the span of crane. Only required if $W \neq 0$.

Z_j is the actual vertical wheel force for wheels where the bearing arrangement transfers horizontal forces Z_j is set to zero for wheels where the bearing arrangement does not transfer horizontal forces.

Result values:

Y_j is the lateral force at the contact point of wheel j (F_{yij} in ISO 8686-1:2012, E.2);

Y_F is the lateral force at the guide means (F_y in ISO 8686-1:2012, E.2).

For a crane with four wheels, flange guide, without shaft coupling (W = 0) and wheel numbers j according to Figure A.1 a), Formulae (A.1) to (A.3) can be reduced as shown in Formula (A.4):

a) $Y_1 = \mu_f \times Z_1$ b) $Y_2 = Y_3 = 0$ c) $Y_4 = \mu_f \times Z_4$ d) $Y_F = Y_1 + Y_4$ (A.4)

A.2.2 Shaft coupling

If wheels of the crane are connected between the carriages by shafts, the skewing forces increase. The largest skewing forces are computed if the wheel loads for both wheels of a shaft have the same value.

Procedure: [see Figure A.1 e)] Calculate the resulting wheel force W_i of each shaft i, by Formula (A.5) a). Add up the W_i to W, by Formula (A.5) b). The value W is required for Formula (A.2) a). The force X_i of each individual shaft is obtained from Formula (A.5) c).

a) $W_i = \dfrac{Z_{1i} \times Z_{2i}}{Z_{1i} + Z_{2i}}$ b) $W = \Sigma W_i$ c) $X_i = \mu_f \times l \times b \times W_i$ (A.5)

where

Z_{1i} is the wheel load of the 1st wheel of shaft i; ($Z_{1i} > 0$); (i = 1, ... m with m Z_{1i} number of shafts);

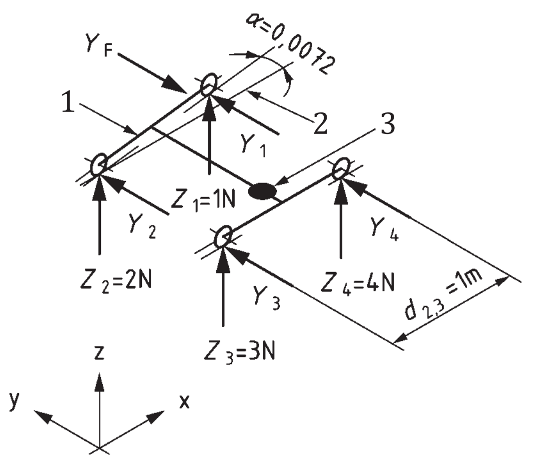
Z_{2i} is the wheel load of the 2nd wheel of shaft i; $Z_{2i} > 0$;

l is the span of crane;

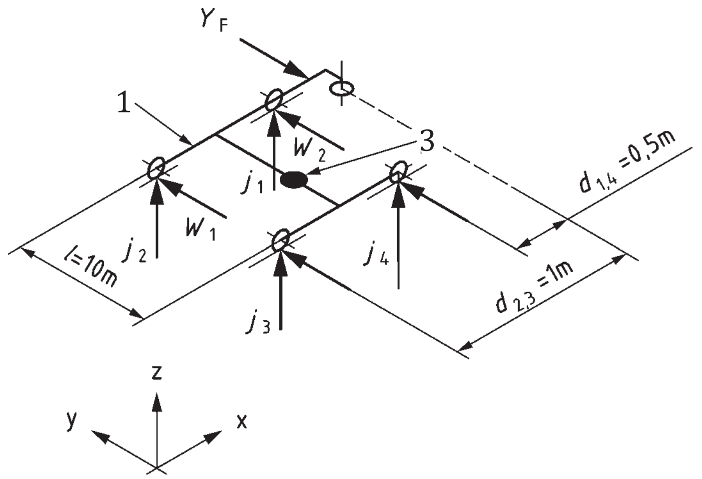
W is the resulting wheel force.

If shaft coupling exists, the position of the trolley should be set in a manner to have equal wheel loads (usually middle of the crane span).

A.2.3 Examples

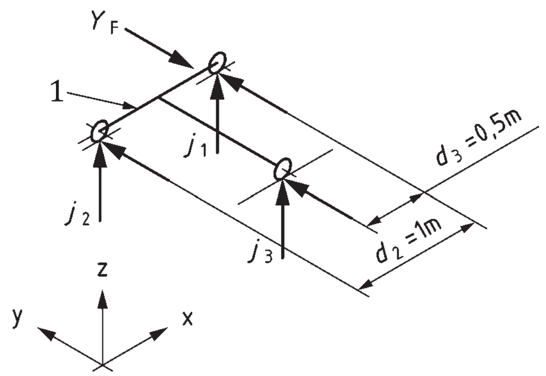


a)



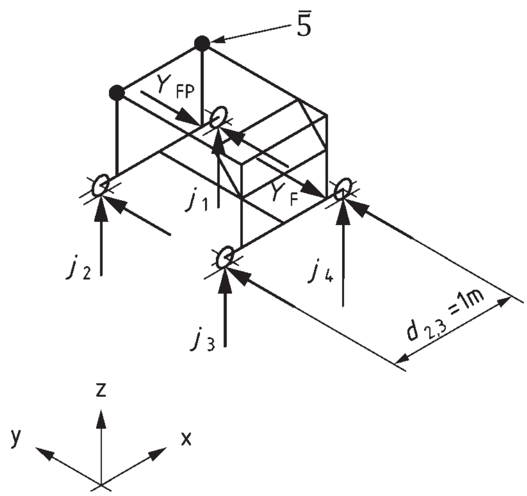
EXAMPLE $Z_{1,2,3,4}$ = 1 N; α = 0,007 2

b)



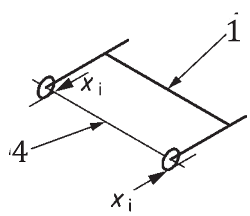
EXAMPLE $Z_{1,2}$ = 29,5 kN; Z_3 = 59 kN; α = 0,003

c)



EXAMPLE $Z_{1,2}$ = 2 N; $Z_{3,4}$ = 1 N; α = 0,007 2

d)



e)

Key

1 rigid structure
2 direction of rail
3 trolley
4 shaft coupling
5 articulation

Figure A.1 — Cranes and three-wheel trolley

Vectors j_1 to j_4 represent both wheel force components Y_j and Z_j; j = 1 to 4.

a) Figure A.1 a): Bridge crane with flange guiding.

With Formulae (A.1) to (A.3) and 5.2.2.3: μ_f = 0,25; S = 10 N; S_d = 5 Nm; S_{dd} = 5 Nm^2; b = 1 m^{-1}; Y_F = 1,25 N; $Y_{1,2,3,4}$ = {0,25 0 0 1} N.

Or directly with Formula (A.4): $Y_{1,2,3,4}$ = {0,25 0 0 1} N; Y_F = 1,25 N

b) Figure A.1 b): Bridge crane with guide rollers and with and without shaft coupling.

Without shaft coupling: μ_f = 0,25; S = 4 N; S_d = 3 Nm; S_{dd} = 2,5 Nm^2; b = 1,2 m^{-1}; Y_F = 0,1 N; $Y_{1,2,3,4}$ = {0,1 − 0,05 − 0,05 0,1} N.

With one shaft coupling W_1 [Figure A.1 e)]: W_1 = 0,5 N; W = 0,5 N; b = 0,057 m^{-1}; Y_F = 0,96 N; $Y_{1,2,3,4}$ = {0,24 0,24 0,24 0,24} N; X_1 = 0,071 N.

With two shaft couplings W_1 and W_2: $W_{1,2}$ = {0,5 0,5} N; W = 1 N; b = 0,029 m^{-1}; Y_F = 0,98 N; $Y_{1,2,3,4}$ = {0,25 0,24 0,24 0,25} N; $X_{1,2}$ = {0,036 0,036} N.

c) Figure A.1 c): Trolley with three wheels. μ_f = 0,158; S = 118 kN; S_d = 59 kNm; S_{dd} = 44,25 kNm^2; b = 1,33 m^{-1}; Y_F = 6,3 kN; $Y_{1,2,3}$ = {4,7 − 1,5 3,1} kN.

d) Figure A.1 d): Gantry crane with hinged leg. μ_f = 0,25. Carriage of hinged leg: $Y_{1,2}$ = {0,5 0} N; Y_{FP} = 0,5 N. Carriage of fixed leg: $Y_{3,4}$ = {0 0,25} N; Y_F = 0,25 N.

A.2.4 Notes

Where W = 0 structures with more than two rails can be calculated with the method above.

Derivation of formulae for Method RIGID:

Formulae (A.1) to (A.3) can be derived from A.3.2, Formulae (A.6) to (A.11). All s_j are set to s_j = 0. The friction slip relationship is linear form regarding the skew angle α: $\mu_f(\sigma) = \mu_f(\alpha)\sigma/\alpha = \mu_f\,\sigma/\alpha$. Formula (A.7) changes to $Y_j = \mu_f\,\sigma_j Z_j/\alpha$. If Formula (A.6) is inserted into this expression, a part of it can be resumed to $\dot{\alpha}/(\alpha\dot{x}) = -b$. Shaft coupling causes longitudinal slip $\sigma_x = l\,d\alpha/d_x = l\dot{\alpha}/\dot{x}$. The forces $X_W = \mu_f(\sigma_x)W = \mu_f\sigma_x W/\alpha$ resulting from longitudinal slip cause, with the span l, the moment $M_W = l\,X_W$. If X_W is replaced by the expression given before, also here a part can be resumed $\dot{\alpha}/(\alpha\dot{x}) = -b$. Formula (A.10) is extended with the influence of the shaft coupling: $0 = M_W + \sum Y_j d_j$. Therein, only b is unknown and after transformation b can be calculated as shown in Formula (A.2).

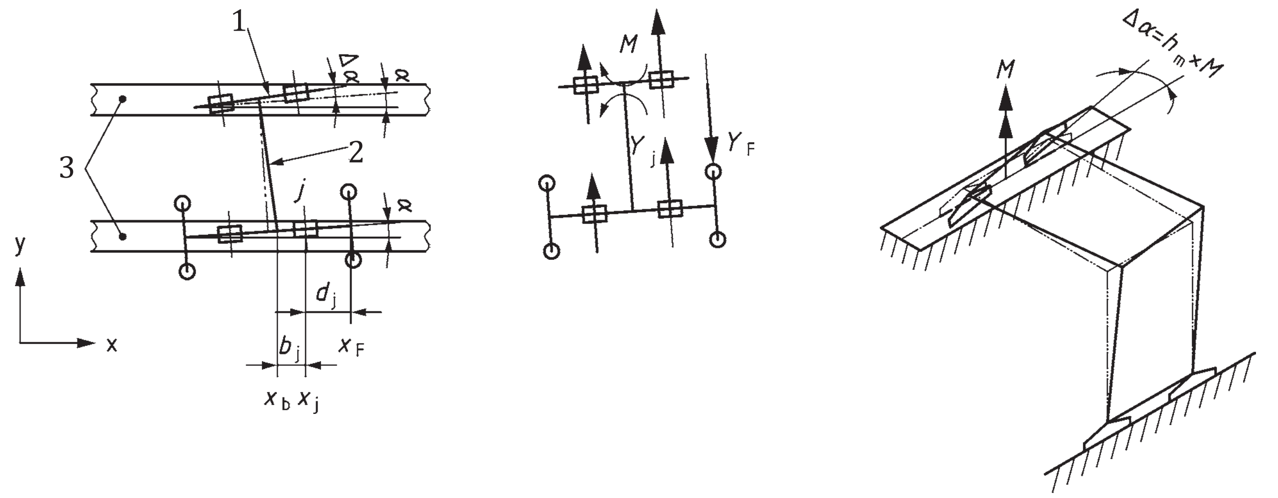
A.3 Calculation of skewing forces by method FLEXIBLE

A.3.1 General

The following calculation method represents the frame as flexible. The carriage is represented as rigid. This approach is of significance for gantry cranes with single side guidance means.

A.3.2 Calculation model

Figure A.2 a) shows the model characteristics with a four-wheel crane with guide rollers as example. The portal is flexible. Both carriages are assumed as rigid. The skewing angle, α, is assigned to the guided carriage. The leading guide roller is in contact with the rail. Figure A.2 b) shows the forces. The eccentrically acting force Y_F affects with the moment M the non-guided carriage. According to the flexibility of the frame, the non-guided carriage's skewing angle is increased by $\Delta\alpha$. All angles are small.



a) Geometry   b) Forces and moments   c) Example: Semi gantry crane

Key

1 carriage assumed as rigid

2 frame, deformed

3 rail

Figure A.2 — Geometry, forces and support conditions

Procedure: Select a travel direction. Assign a number j = 1, 2 ... n to each wheel. Set up the equation set Formulae (A.6) until (A.10). The formula set may be reduced to Formulae (A.9) and (A.10) including only the two unknown variables $\Delta\alpha$ and $(\dot{a}/\dot{x})$. Solve it numerically. Calculate the forces Y_j with Formula (A.7). The force Y_F at the guide means is defined by Formula (A.11).

$$\sigma_j = \alpha + s_j \times \Delta\alpha + d_j \left(\frac{\dot{\alpha}}{\dot{x}} \right) \tag{A.6}$$

$$Y_j = \mu_f(\sigma_j) Z_j \tag{A.7}$$

$$M = \sum s_j \times b_j \times Y_j \tag{A.8}$$

$$\Delta\alpha = h_M \times M \tag{A.9}$$

$$0 = \sum Y_j \times d_j \tag{A.10}$$

$$Y_F = \sum Y_j \tag{A.11}$$

where

α is the skewing angle in radian (respectively m/m) according to 5.2.2.2;

Z_j is the vertical wheel force of wheel j, ($Z_j \geq 0$), (j = 1, 2...n with n = number of wheels)

The trolley carries maximum load. The trolley should be positioned on the crane's side, which has no guide means.

s_j selection factor:

s_j = 0 setting for wheels of the carriage with guide means,

s_j = 1 setting for wheels of the carriage without guide means;

M is the moment turning the floating end carriage by forces Y_j applied to the wheels of that carriage;

h_M is the flexibility of the portal in angle per moment (e.g. rad/Nm). See Figure A.2 c): Fixed support at the carriage with guide means. Floating support and an external moment acting at the unguided carriage. (Find out the change of angle with a statics program, or manually in simple cases).

d_j = $x_F - x_j$. Distance in travel direction from the front guide means to wheel j; (d_j will be negative for wheels which run ahead of the front guide means);

b_j = $x_j - x_b$. Distance in travel direction from wheel j to the neutral line x_b. (This line is neutral concerning the bending around the plumb line; see the figure in A.3.3. x_b marks the coordinate where a single force F_y applied to the floating carriage will not result in any change of $\Delta\alpha$) (b_j will be negative for wheels which run behind the neutral line).

The friction slip relationship is according to 5.2.2.3:

$$\mu_f(\sigma_j) = \mu_0(1 - e^{-250 \times |\sigma j|} \cdot \operatorname{sgn}(\sigma_j) \quad \text{(A.12)}$$

where

$\mu_f(\sigma_j)$ is the friction coefficient of wheel j by lateral slip σ_j;

μ_0 is the adhesion factor

μ_0 = 0,3 for cleaned rails, and
μ_0 = 0,2 for non-cleaned rails (i.e. in a normal operation and environment);

e is the base of natural logarithms, 2,718;

σ is the slip factor;

sgn is the signum function = sgn(x) = {−1 for $x < 0$; 0 for $x = 0$; 1 for $x > 0$}.

Calculation values:

σ_j is the lateral slip of wheel j;

$\mu_f(\sigma_j)$ is the friction coefficient of wheel j by lateral slip σ_j according to 5.2.2.3;

$\Delta\alpha$ is the additional skewing angle due to flexible deformation;

M is the moment between the portal and the unguided carriage;

$(\dot{\alpha}/\dot{x})$ is the portal turning speed per travel speed. ($\dot{x}$ > 0). A separate value for $\dot{x}$ is not required;

Y_j is the lateral force at the contact point of wheel j (F_{yij} in ISO 8686-1:2012, E.2);

Y_F is the lateral force at the contact point of wheel j (F_{yij} in ISO 8686-1).

A.3.3 Example

<table>
<tr>
<td>Semi gantry crane with guide rollers, single sided guiding (Figure at side). The girder and the leg are solid round bars.

Data:

h = 4 m, l = 6 m, d = 0,3 m

E = 210 000 N/mm², G = 81 000 N/mm²

Z_j = {120 119 27 35}kN

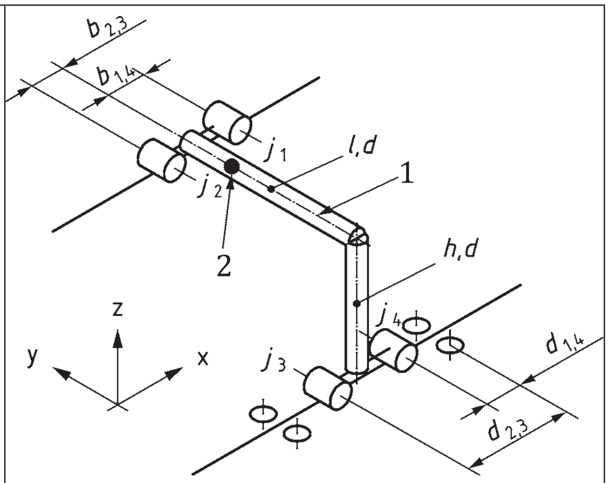
d_j = {0,25 2,75 2,75 0,25}m

b_j = {1,25 −1,25 −1,25 1,25}m

s_j = {1 1 0 0} m

α = 0,003 3 rad

Intermediate calculation:

$h_M = \frac{l}{E \times l_{ax}} + \frac{h}{G \times l_p}$
$= \frac{l \times 64}{E \times \pi \times d^4} + \frac{h \times 32}{G \times \pi \times d^4}$
$= 0{,}000\,134 \frac{\text{rad}}{\text{kNm}}$</td>
<td>

1 = neutral line x_b according bending around vertical.

2 = trolley</td>
</tr>
<tr>
<td colspan="2">Result: Y_j = {30,2 2,2 −5,4 5,0} kN; Y_F = 32 kN; $\Delta\alpha$ = 0,004 68 rad; $\dot{\alpha}/\dot{x}$ = −0,002 81 rad/m</td>
</tr>
</table>

A.3.4 Notes

The linear form of the friction slip relationship $\mu_f(\sigma_f)$ regarding α is not applicable for FLEXIBLE models $\alpha + \Delta\alpha$. A linear model would result in unnaturally high frictional values resulting in unnaturally high skewing forces.

Derivation:

The eccentrically acting force Y_F causes turning $\dot{\alpha}/\dot{x}$ of the crane during the travel. The lateral slip of a wheel is $\sigma_j = \alpha + s_j \Delta\alpha - \dot{y}_j/\dot{x}$. It is affected by the angle position of the carriage and by the distance d_j of this wheel to the guide means. With $-\dot{y}_j/\dot{x} = d_j\dot{\alpha}/\dot{x}$, follows Formula (A.6). Formula (A.7) defines the wheel's lateral force. Formula (A.8) defines the moment acting between the portal and the unguided carriage. The moment is calculated regarding the neutral fibre's position. Thus, in Formula (A.9), the deformation of the portal is determined. Formula (A.10) forms the sum of the moments for the entire crane around the guide means. Formula (A.11) sums up all forces.

Bibliography

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

[2] ISO 11031, *Cranes — Principles for seismically resistant design*

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