INTERNATIONAL STANDARD

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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
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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.

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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

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

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.

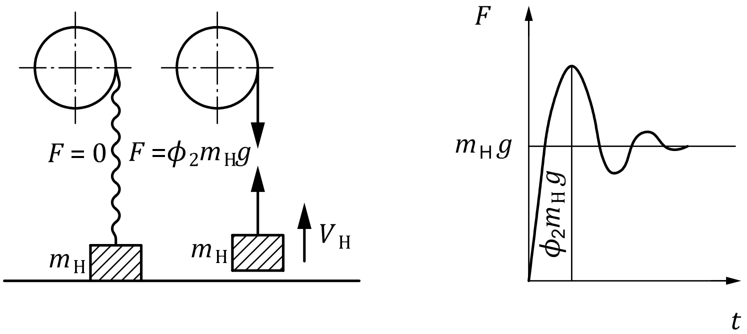


Figure 1 — Dynamic effects when hoisting grounded load

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 $\phi_{2,\text{min}}$.

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	$v_{h,\text{max}}$	$v_{h,\text{CS}}$	$v_{h,\text{CS}}$	$0{,}5v_{h,\text{max}}$	$v_h = 0$
C1	$v_{h,\text{max}}$	$v_{h,\text{max}}$	$0{,}5v_{h,\text{max}}$	$v_{h,\text{max}}$	$0{,}5v_{h,\text{max}}$

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

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

$v_{h,\text{CS}}$ 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 $\phi_{2,\text{min}}$

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 $\phi_{2,min}$ 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).

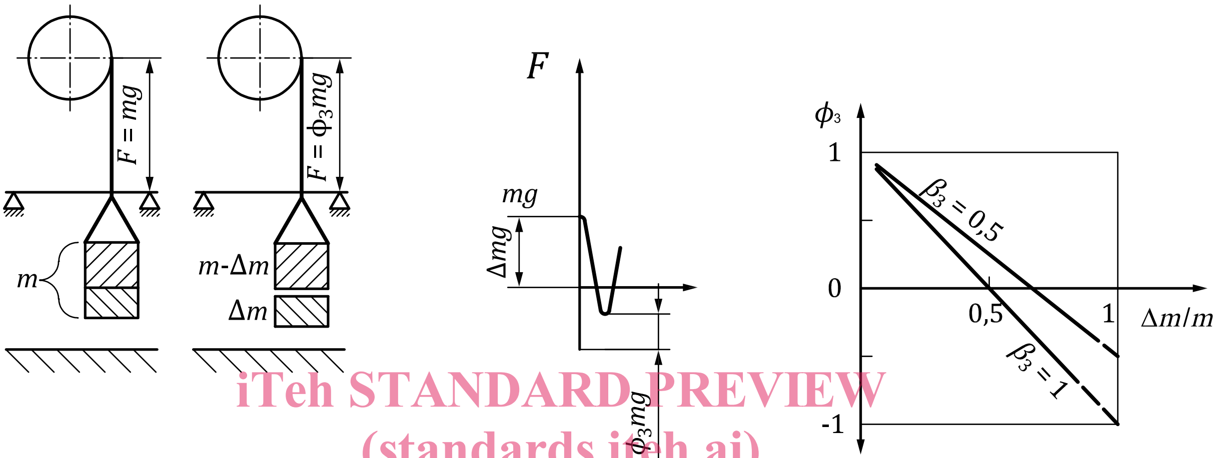


Figure 2 — Factor ϕ_3

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.

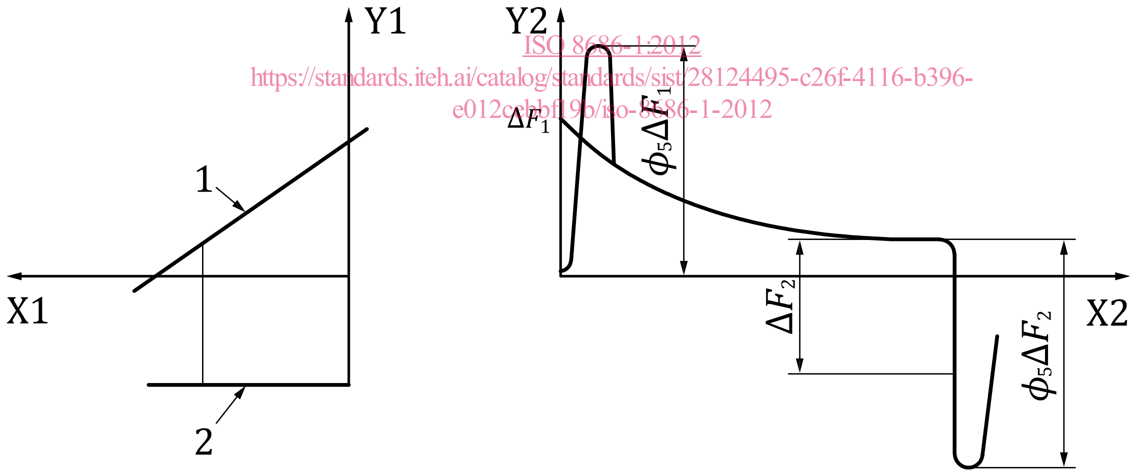
Annex B gives a general comment on the application of the ϕ factors.

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:

$$\eta m = m_H - \Delta m_H \quad (4)$$

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

$$\phi_6 = 0,5\left(1 + \phi_2\right) \quad (5)$$

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

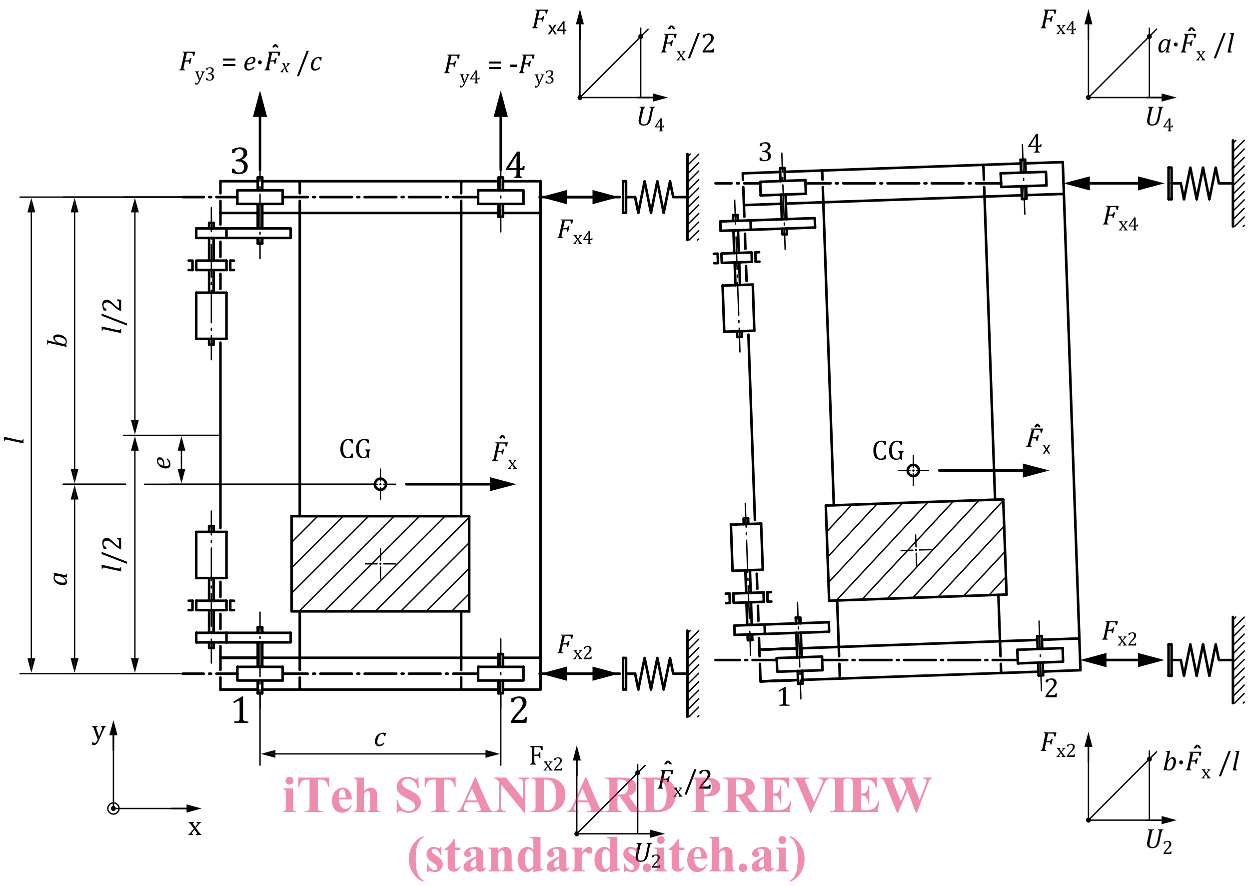
Where buffers are used, the forces on the crane structure arising from collision with them shall be calculated from the kinetic energy of all relevant parts of the crane moving in general at 0,7 to 1 times the nominal speed. Lower values may be used where they are justified by special considerations 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

$$F_{x2} = F_{x4} = \hat{F}_x/2 \quad (6)$$

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.

