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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

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Contents

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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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 8686-1 was prepared by Technical Committee ISO/TC 96, *Cranes.*

ISO 8686 will consist 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 cranes and gantry cranes*

Annexes A and B form an integral part of this part of ISO 8686. Annexes C, D, E and F are for information only.

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Cranes — Design principles for loads and load combinations —

Part 1 : General

1 Scope

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

It is based on rigid-body kinetic analysis and elasto-static analysis but it 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 is intended for two distinct kinds of application :

a) It provides the general form, content and ranges of parameter values for more specific standards to be developed for individual lifting appliance types.

b) It provides a framework for agreement on loads and load combinations between a designer or manufacturer and an appliance purchaser for those types of lifting appliances where specific standards do not exist.

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

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 8686. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 8686 are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 4302 : 1981, *Cranes — Wind load assessment.*

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

ISO 4310 : 1981, *Cranes — Test code and procedures.*

3 Definitions

For the purposes of ISO 8686, the definitions given in ISO 4306, together with the following, apply.

3.1 loads: External or internal actions in the form of forces, displacements or temperature, which cause stresses in the structural or mechanical components of the lifting appliance.

3.2 kinetic analysis of rigid bodies: The study of the movement and the inner forces of systems modelled by elements that are assumed to be non-elastic.

3.3 kinetic analysis for elastic bodies: The 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 lifting appliance	6.1.1
a	Term used in determining the value of ϕ_1	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	6.1.2.3
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
HC_1 to HC_4	Hoisting classes assigned to lifting appliances	6.1.2.1
β_2	Factor assigned to hoisting class	6.1.2.1
β_3	Term used in determining the value of ϕ_3	6.1.2.3
v_h	Steady hoisting speed, in metres per second	6.1.2.2
F_x, F_{x2}, F_{x4}	Buffer forces	6.3.3
γ_{fA}, γ_{fB}, γ_{fC}	Coefficients for calculating allowable stresses	7.3.2
γ_p	Partial load coefficient	7.3.3
γ_m	Resistance coefficient	Annex A
γ_n	Coefficient for high-risk applications	7.3.6
m	Mass of the load	6.1.2.3, 6.3.1
$\eta m = m - \Delta m$	Mass of that part of the hoist load remaining suspended from the appliance	6.3.1
NOTE — Further symbols are used in the annexes and are defined therein.		

5 General

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

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

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 lifting appliance. In addition, there may be limitations on forces that are necessary to assure the stability and/or to avoid unwanted displacement of portions of the appliance or of the appliance itself, for example the jib support ropes becoming unloaded or the appliance sliding.

The effects of differences between actual and ideal geometry of mechanical and structural systems (for example 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.

5.2 There are two general approaches to structural design or proof of competence calculations:

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 load 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 load coefficient 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.

The limit state method generally permits more efficient design because it takes into account greater certainty in determining appliance mass and lesser certainty in values selected to reflect applied loads.

Annex A gives a more detailed description of the application of the allowable stress method and the limit state method.

5.3 To calculate stresses from applied loads, an appropriate model of the appliance 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 appliance operator may be required.

For both the allowable stress method and the limit state method, and for considerations of stability and displacements, loads, load combinations, load factors, allowable stresses and limit states 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 an appliance 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 appliance instructions;

b) features not present in the design;

c) conditions which are prevented or suppressed by the design of the appliance.

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

6 Loads and applicable factors

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

Individual values for specific types of appliance, selected from these ranges, will be found in the parts of this International Standard covering those appliances.

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

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 lifting appliance and the hoist load, as well as from displacements.

b) Occasional loads and effects which occur infrequently are usually 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 lifting appliance 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 an indication of the importance or criticality of that load. For example, 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.

6.1 Regular loads

6.1.1 Hoisting and gravity effects acting on the mass of the lifting appliance

The mass of the appliance includes those components which are always in place during operation, except for the payload itself (see 6.1.2). For some appliances 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 appliance or its parts.

The gravitational force induced by the mass of the appliance (dead weight) shall be multiplied by the factor ϕ_1, where $\phi_1 = 1 \pm a$, $0 \leqslant a \leqslant 0{,}1$. In this way the vibrational excitement of the lifting appliance structure, when lifting the gross 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.

The factor ϕ_1 shall be used in the design of the appliance 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 C gives a general comment on the application of ϕ factors.

6.1.2 Inertial and gravity effects acting vertically on the gross load

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

6.1.2.1 Hoisting class

For the purposes of this clause, lifting appliances are assigned to hoisting classes HC_1 to HC_4 according to their dynamic characteristics. The hoisting classes of appliances are given in table 2 and shall be selected on the basis of experience. Corresponding values of β_2 and ϕ_2 are also given in table 2 and illustrated in figure 1.

The selection of the hoisting class depends on the particular type of lifting appliance and is dealt with in the other parts of this International Standard.

Equally, values of ϕ_2 can be determined by experiment or analysis without reference to hoisting class.

Table 2 — Values of β_2 and ϕ_2

Hoisting class of appliance	β_2	ϕ_2	
		$\phi_{2,\min}$	$\phi_{2,\max}$
HC_1	0,2	1	1,3
HC_2	0,4	1,05	1,6
HC_3	0,6	1,1	1,9
HC_4	0,8	1,15	2,2

6.1.2.2 Hoisting an unrestrained grounded load

In the case of hoisting an unrestrained grounded load, the dynamic effects of transferring the load from the ground to the lifting appliance shall be taken into account by multiplying the gravitational force due to the mass of the gross load by a factor ϕ_2. (See figure 1.)

NOTE — The dynamic effects covered by this clause occur when the drive comes up to speed before the lifting attachment engages the load and are the result of the build-up of kinetic energy and the drive torque.

The factor ϕ_2 shall be taken as follows:

$$\phi_2 = \phi_{2,\min}, \text{ for } v_h \leqslant 0{,}2 \text{ m/s}$$

$$\phi_2 = \phi_{2,\min} + \beta_2 (v_h - 0{,}2), \text{ for } v_h > 0{,}2 \text{ m/s}$$

where

v_h is the steady hoisting speed, in metres per second, related to the lifting attachment, derived from the steady rotational speed of the unloaded motor or engine;

β_2 is a factor assigned to the hoisting class (see table 2);

$\phi_{2,\min}$ is given in table 2 for the hoisting class.

Where the hoist drive control system ensures the use of a steady creep speed, this speed only shall be taken into account to cover normal operation in determining the value of ϕ_2.

Where this is not the case, two conditions shall be considered by taking a value of ϕ_2 to cover normal operation, as in 6.1.2.2.1, and a value of $\phi_{2,\max}$ to cover exceptional occurrences, as in 6.1.2.2.2.

6.1.2.2.1 For normal operation

a) Where a steady creep speed can be selected by the crane driver, this speed shall be used in determining the value of ϕ_2.

b) Where a stepless variable speed control is provided or such control can be exercised by the crane driver, the value of $\phi_{2,\min}$ for the appropriate hoisting class shall be selected from figure 1.

6.1.2.2.2 For exceptional occurrences

For appliances with control of type a) as in 6.1.2.2.1, the value of $\phi_{2,\max}$ shall be based on a value of v_h derived from the maximum nominal speed of the unloaded motor or engine.

For appliances with control of type b) as in 6.1.2.2.1, the value of $\phi_{2,\max}$ for the hoisting class shall be based on a value of v_h derived from a value of not less than 0,5 times the maximum nominal speed of the unloaded motor or engine.

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

6.1.2.3 Effects of sudden release of part of payload

For lifting appliances 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 appliance can be simulated by multiplying the payload by the factor ϕ_3 (see figure 2).

The value of ϕ_3 is given by

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

where

Δm is the released or dropped part of the payload;

m is the mass of the payload;

β_3 = 0,5 for appliances equipped with grabs or similar slow-release devices,

= 1 for appliances equipped with magnets or similar rapid-release devices.

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

6.1.3 Loads caused by travelling on an uneven surface

6.1.3.1 Lifting appliances travelling on or off roadways

The effects of travelling, with or without load, on or off roadways, depend on the appliance configuration (mass distribution), the elasticity of the appliance 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, experiment, or by calculation using an appropriate model for the appliance and the travel surface.

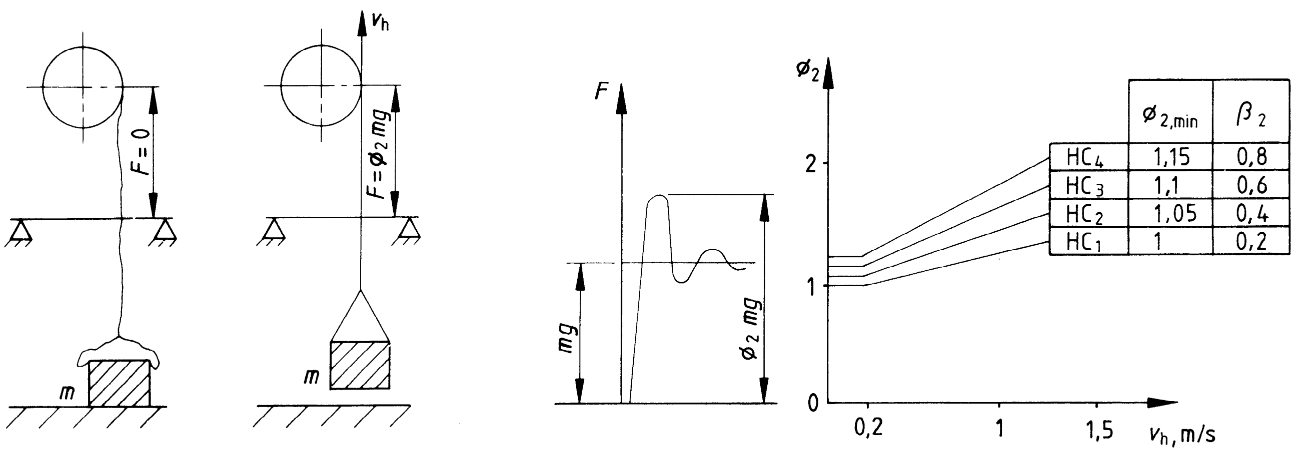


Figure 1 — Factor ϕ_2

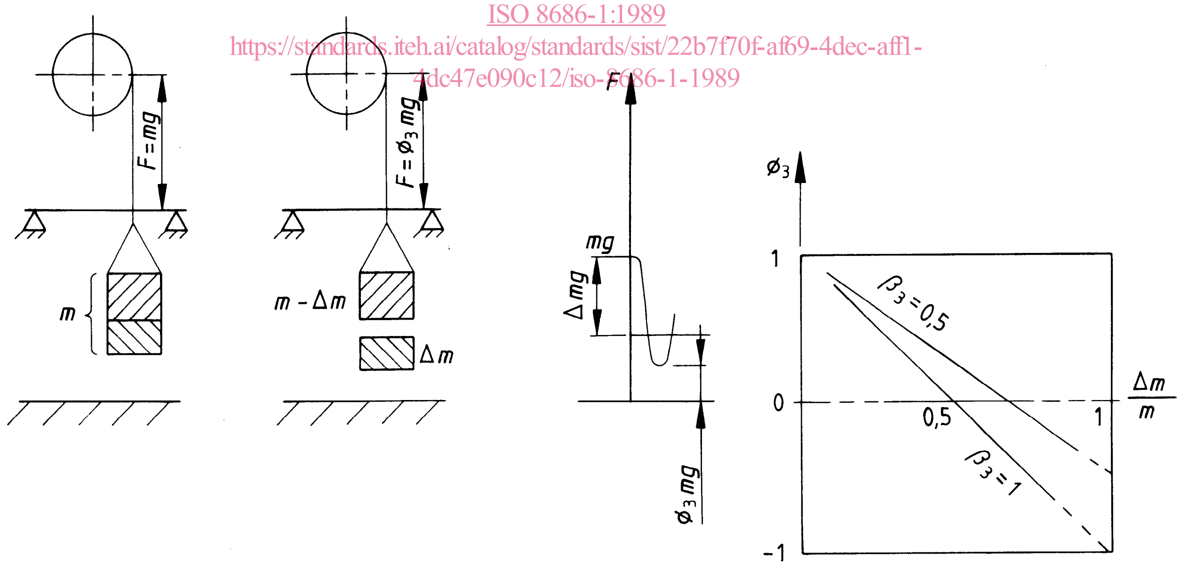


Figure 2 — Factor ϕ_3

6.1.3.2 Lifting appliances 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 appliances depend on the appliance configuration (mass distribution, elasticity of the appliance and/or its suspension), travel speed and wheel diameter. They shall be estimated from experience, experiment, or by calculation using an appropriate model for the appliance and the track.

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

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

Annex D gives an example of a model for estimating the value of ϕ_4 to take account of the vertical accelerations induced at the wheels of an appliance 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 lifting appliance 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 lifting appliance 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 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 appliance and the gross load as well. (See figure 3.)

The range of values for ϕ_5 is $1 \leqslant \phi_5 \leqslant 2$. 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 C gives a general comment on the application of ϕ factors.

Annex E 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.

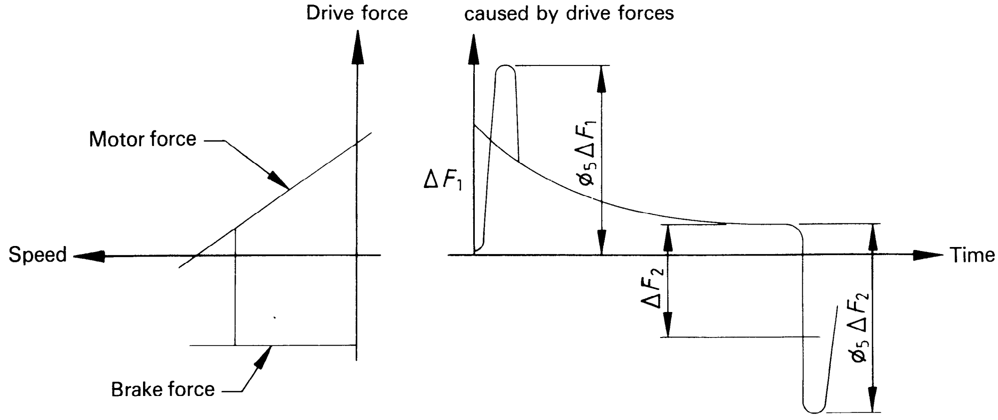


Figure 3 — Factor ϕ_5

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 sub-clause covers skewing loads that occur at the guidance means (such as guide rollers or wheel flanges) of a guided, wheel-mounted appliance 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 which can also cause the appliance 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 and service of the appliance. In individual cases, the frequency of occurrence will determine whether they are taken as occasional or regular loads. Guidance for establishing the magnitude of skewing loads and the category into which they are placed is given in the parts of this International Standard covering those individual appliance types.

Annex F gives an example of a method for analysing skewing loads on a rigid lifting appliance structure travelling at a constant speed. For appliances 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 appliance, ηm, shall be taken into account:

$$\eta m = m - \Delta m$$

where

$m - \Delta m$ is that part of the gross load remaining suspended from the appliance,

m 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

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

where ϕ_2 is calculated in accordance with 6.1.2.

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

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 appliance 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 lifting appliance 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

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

Where the appliance 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).

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. 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 test shall be used. (See note 2 and figure 5.)

NOTES

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

2 Intermediate values of ϕ_7 can be estimated as follows:

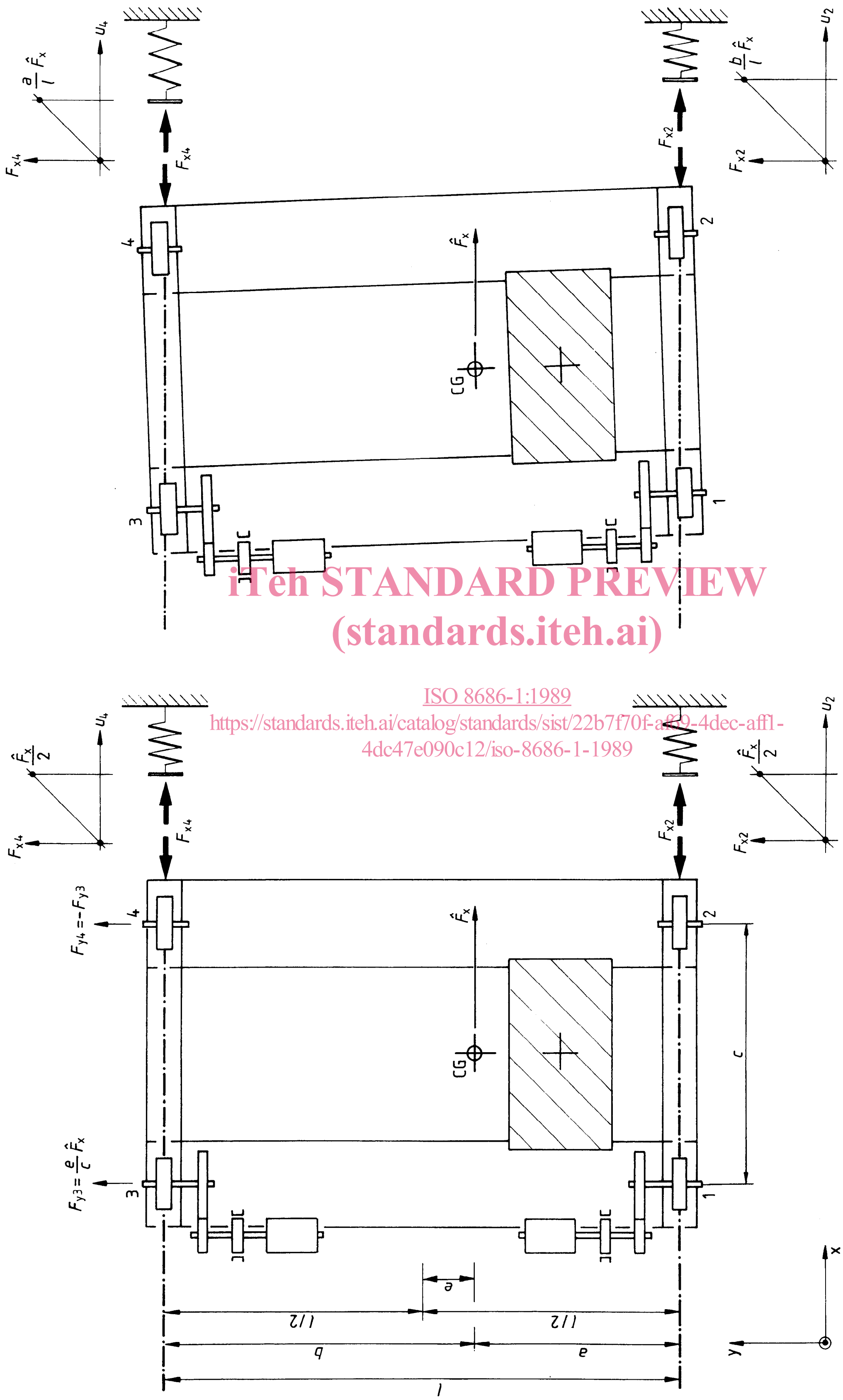
$\phi_7 = 1{,}25$ if $0 \leqslant \xi \leqslant 0{,}5$

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

6.3.4 Tilting forces

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

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



a) Appliance horizontally guided by rails ($u_2 = u_4$)

b) Appliance not restrained against rotation ($F_{y3} = F_{y4} = 0$)

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