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Cranes — Principles for seismically resistant design

Appareils de levage à charge suspendue — Principes pour une conception résistante à la sismicité

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Foreword

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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).

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The committee responsible for this document is ISO/TC 96, *Cranes*, Subcommittee SC 10, *Design principles and requirements*.

This corrected version of ISO 11031:2016 incorporates the following corrections:

— in Formula (9), "a_H" has been changed to "a_V" to signify *vertical*, not horizontal, seismic acceleration;

— in 6.2, in the step describing the use of final design spectrum accelerations and participation factors as inputs for calculating the responses for selected modes, the axis directions have been italicized as *X*, *Y* and *Z*, and a missing cross-reference to Table C.1 reinserted.

Introduction

An economically acceptable protection against the effects of earthquake is usually based on two design limit states which specify the required crane response to a moderate and a severe earthquake and which are expressed in terms of serviceability and ultimate limit states.

— Serviceability limit state (SLS) imposes that the crane should withstand moderate earthquake ground motions which may occur at the site during its service life. The resulting stresses would remain within the accepted limits.

— Ultimate limit state (ULS) imposes that the crane structure should not collapse nor experience similar forms of structural failure due to severe earthquake ground motions, the suspended load, or any part of the crane should not fall and the safety of the public, operators and workers should be safe guarded. The crane is not expected to remain operational after the earthquake. However, in the case of a failure in the main load path, it is still possible to lower the load to the ground after the earthquake.

Cranes — Principles for seismically resistant design

1 Scope

This International Standard establishes general methods for calculating seismic loads to be used as defined in the ISO 8686 series and for proof of competence as defined in ISO 20332, for the structure and mechanical components of cranes as defined in ISO 4306.

This International Standard evaluates dynamic response behaviour of a crane subjected to seismic excitation as a function of the dynamic characteristics of the crane and of its supporting structure.

The evaluation takes into account dynamic effects both of regional seismic conditions and of the local conditions on the surface of the ground at the crane location.

The operational conditions of the crane and the risks resulting from seismic damage to the crane are also taken into account.

This International Standard is restricted to the serviceability limit state (SLS), maintaining stresses within the elastic range in accordance with ISO 20332.

The present edition does not extend to proofs of competence which include plastic deformations. When these are permitted by agreement between crane supplier and customer, other standards or relevant literature taking them into account can be used.

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

ISO 8686 (all parts), *Cranes — Design principles for loads and load combinations*

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

3 Symbols

The main symbols used in this International Standard are given in Table 1.

Table 1 — Main symbols

Symbol	Description
K_H	Horizontal seismic design coefficient
K_V	Vertical seismic design coefficient
A_{bg}	Normalized basic acceleration
A_{sg}	Normalized acceleration at ground surface
f_{con}	Conversion factor
f_{rec}	Recurrence factor
β_2	Subsoil amplification factor
β_3	Acceleration response factor

Table 1 *(continued)*

Symbol	Description
β_3^*	Basic acceleration response factor; β_3 of the crane whose damping ratio is 0,025 and given by Figure 2
γ_n	Risk factor
η	Damping correction factor
δ	Response amplification factor
ζ	Damping ratio
c	Vertical influence factor
F_H	Horizontal seismic design force
F_V	Vertical seismic design force
F_{RH}, F_{RV}	Seismic forces (horizontal and vertical) on suspended load

4 Seismic design methods

There are three main methods of seismic response analysis used in seismic design:

— Modified Seismic Coefficient Method;

— Maximum Response Spectrum Method;

— Time History Response Method.

In the *Modified Seismic Coefficient Method*, the applied quasi-static seismic forces are calculated as a product of seismic coefficients and crane weights. The evaluation of seismic coefficients takes into account crane location, its seismic characteristics, basic dynamic characteristics of the crane, i.e. natural frequency or period and damping characteristics, in three principal orthogonal directions of the crane (one vertical and two horizontal).

The method is the basis of this International Standard on account of its simplicity (see Clause 5) and its procedure is executed as part of the design iterative process indicated in the flow chart in Annex A.

The *Maximum Response Spectrum Method* (see Clause 6) is an alternative method of seismic response analysis used where:

— more accurate seismic response of the crane is required than that produced by the Modified Seismic Coefficient Method;

— demand on significant computational resources is economically acceptable.

Its application is limited only to linear systems and to system where nonlinearities if present can be neglected.

In the Maximum Response Spectrum Method, natural frequencies or periods and associated mode shapes of the crane are calculated first. Seismic forces and the crane response are then calculated for the selected vibration modes of the crane structure, using the maximum response accelerations (selected from the maximum response spectra which again take into account seismic characteristics at crane location and the damping characteristics of crane structure) together with the calculated mode shapes, frequencies and mass distribution of the crane.

The *Time History Response Method* is the third method of seismic response analysis available. It is employed when:

— only an accurate seismic response of crane is acceptable (see Annex D);

— nonlinearities (due to material behaviour, such as plastic deformations and stresses or dynamic behaviour nonlinearities, such as gaps, friction, wheels lifting off the rails, or slack in ropes, etc.), if present, need to be taken into account;

— the associated cost of high computational requirements is acceptable.

In the Time History Method, the seismic response is evaluated by using numerical step-by-step integration in time to solve the formula of motions for crane structure and ground excitation under consideration, selected to represent seismic condition at crane site.

5 Seismic design by Modified Seismic Coefficient Method

5.1 General

In this method, seismic forces and accelerations acting on the crane are calculated using horizontal and vertical seismic coefficients, K_H and K_V. For cranes with an enhanced risk, the risk coefficient, γ_n, with a value greater than unity shall be applied, in accordance with Clause 7.

5.2 Calculation of horizontal seismic design coefficient, K_H

5.2.1 General

The horizontal seismic design coefficient, K_H, shall be calculated as follows:

$$K_H = A_{bg} \times \beta_2 \times \beta_3 \times f_{con} = A_{sg} \times \beta_3 \times f_{con} \tag{1}$$

where

A_{bg} is the normalized basic acceleration (see 5.2.2);

A_{sg} is the normalized surface ground acceleration

β_2 is the subsoil amplification factor (see 5.2.3);

β_3 is the acceleration response factor (see 5.2.4);

f_{con} is the conversion factor f_{con} = 0,16 for a return period of 475 years (see 5.2.2) converted to 72 years appropriate for serviceability limit state (SLS) of a seismically resistant crane.

The direction of the normalized accelerations, A_{bg} and A_{sg}, are considered to be arbitrary unless seismological considerations dictate otherwise. When the direction is arbitrary, it shall be applied to produce the maximum effect.

5.2.2 Determination of normalized basic acceleration, A_{bg}

Normalized basic acceleration, A_{bg}, is calculated from the Formula (2):

$$A_{bg} = a_g / g \times f_{rec} \tag{2}$$

where

a_g is the maximum horizontal basic acceleration, in m/s^2 (see Annex B);

g is the gravity acceleration, in m/s^2;

f_{rec} is a factor depending on the recurrence interval R; for crane design in general a design earthquake, which may recur once in intervals of 100 years to 475 years (R = 100 to R = 475) may be selected:

f_{rec} = 1,0 for R = 475; this is the default value,

f_{rec} = 0,5 for R = 100; used only for cranes intended for temporary use at different sites.

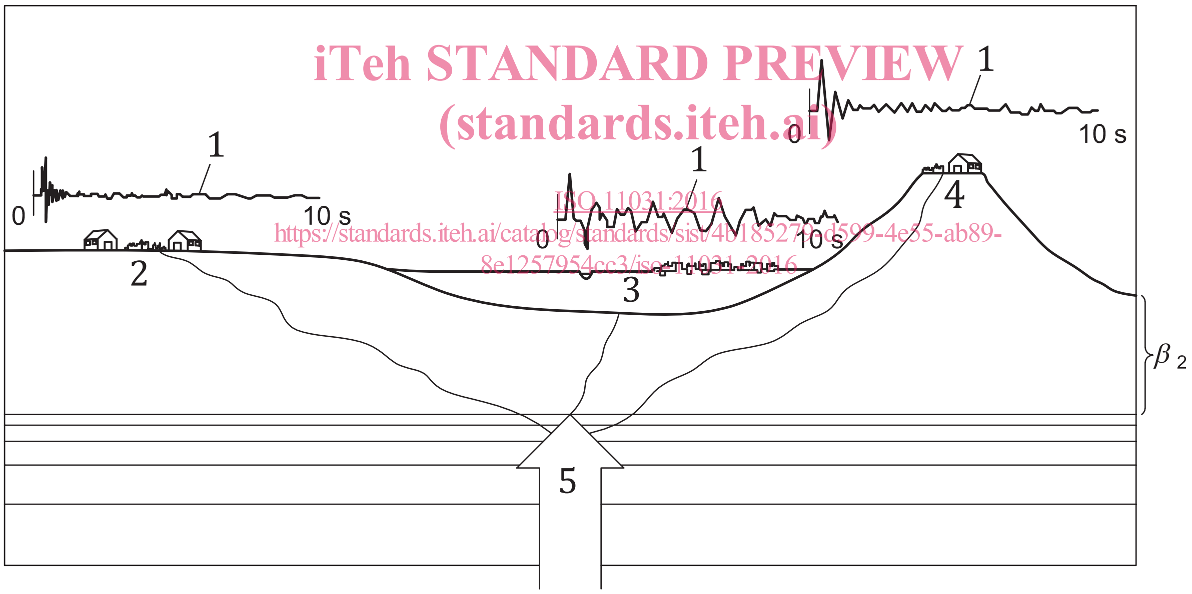
See Annex B for suggested values of A_{bg} and A_{sg}, for different countries, taking into account regional seismic damage experiences and regional seismicity.

In B.1, the accelerations, A_{bg} and A_{sg}, are based on the return period of 475 years (f_{rec} = 1,0).

NOTE 475 years is the most accepted return period used within the seismic data available.

5.2.3 Determination of subsoil amplification factor, β_2

The subsoil amplification factor expresses the influence of the soil surface on the intensity and the frequencies of the seismic excitation. The principle of this influence is illustrated in Figure 1.



Key

1 seismic effects on the surface (recorded seismograms), represented by A_{sg} in this International Standard

2 rock

3 soft to medium stiff ground

4 stiff ground

5 normalized basic accelerations A_{bg} (related to seismic bedrock)

Figure 1 — Illustration of the subsoil amplification factor (β_2)

In Table 2, subsoil categories are classified as a function of $v_{s,30}$, the average shear-velocity through the upper 30 m of soil. The values of β_2 shall be selected from this table, for subsoil category at crane location.

Table 2 — Determination and values of β_2

Category	Subsoil	Shear-wave velocity $v_{s,30}$ m/s	β_2
Category 0	Rock	$v_{s,30} > 800$	1,0
Category 1	Stiff ground composed of hard sandy soil strata where soil types overlying rock are stable deposits of sands, gravels, or stiff clays.	$360 < v_{s,30} \leq 800$	1,4
Category 2	Medium ground excluding categories 1 and 3.	$180 < v_{s,30} \leq 360$	1,6
Category 3	Soft-to-medium-stiff ground composed of alluvial soil strata or muddy soil strata characterized by about 30 m or more soft-to-medium-stiff clay.	$v_{s,30} \leq 180$	2,0

5.2.4 Determination of acceleration response factor, β_3

5.2.4.1 General

The value of acceleration response factor, β_3, shall be determined as a function of

— dynamic characteristics of crane support structure where applicable,

— frequency or period of the most significant mode of the crane in the direction under consideration,

— damping ratio of the same mode, and

— subsoil category at the location of the crane.

The most significant modes of the crane are selected from natural periods or frequencies determined by measurement or by calculation, using recognized computational techniques.

β_3 shall be defined as

$$\beta_3 = \beta_3^* \times \eta \times \delta \quad (3)$$

where

β_3^* is the basic acceleration response factor (see 5.2.4.2);

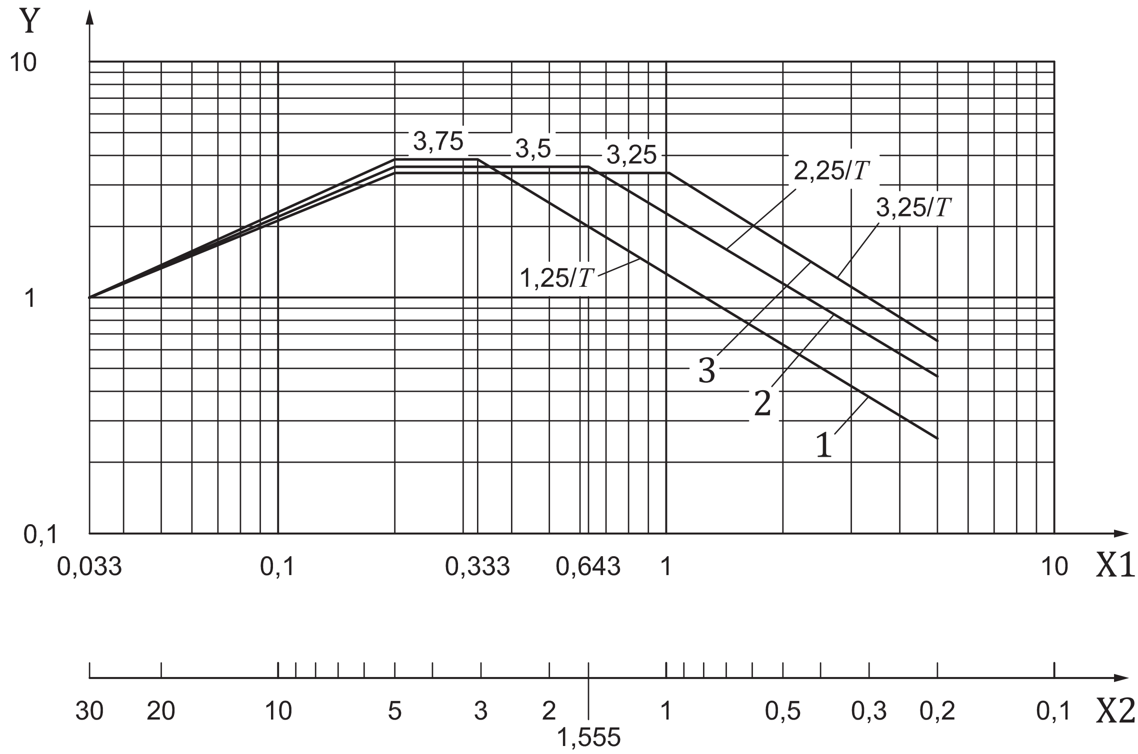
η is the damping correction factor (see 5.2.4.3);

δ is the response amplification factor (see 5.2.4.4).

5.2.4.2 Basic acceleration response factor, β_3^*

β_3^* is the basic acceleration response factor of a crane structure with damping ratio of 0,025.

Its values as a function of the natural period or frequency of the crane and of subsoil category at crane location are shown in Figure 2.



Key

1 subsoil categories 0 and 1

2 subsoil category 2

3 subsoil category 3

X1 axis for natural period T_c [s] of crane structure

X2 axis for natural frequency f_c [Hz] of crane structure

Y axis for the basic acceleration response factor, β_3^*

Figure 2 — Factor β_3^* (as a function of crane natural period or frequency and of subsoil category at crane location)

5.2.4.3 Damping correction factor, η

Damping correction factor, η, in Formula (3) shall be defined according to the value of damping ratio, ζ, of the crane structure as shown in Table 3.

Table 3 — Damping correction factor, η

Damping ratio, ζ	0,01	0,015	0,02	0,025	0,03	0,04	0,05	0,1
η	1,24	1,15	1,06	1,0	0,94	0,87	0,80	0,62

Typical values of damping ratios for structures, with the members generally stressed below 50 % of the elastic limit, are ζ = 0,025 for welded construction, ζ = 0,04 for bolted construction and ζ = 0,03 for welded and bolted construction combined. Higher values of damping ratios may be used for the same types of construction stressed above 50 % of the elastic limit of the material.

Where a buckling failure mode controls the design higher levels of damping shall not be used.

Alternatively, damping ratios can be obtained by accepted methods, such as the following:

— measurement;

— an evaluation of the hysteresis of a force-displacement diagram of nonlinear items such as structural members with nonlinear behaviour or joints with dry friction.

5.2.4.4 Response amplification factor, δ

For cranes operating on rails laid directly on the ground δ shall be defined as unity, $\delta = 1$.

For cranes operating on rails laid on a supporting structure (e.g. building, pier, jetty) the value of δ can be determined from the Formula (4):

$$\delta = 0{,}71 \cdot \sqrt{\frac{1+\lambda^2}{\lambda^2 + \left(1-\lambda^2\right) \cdot \kappa^2}} \geq 1 \qquad (4)$$

where

λ is a factor related to the degree of coupling between crane structure and supporting structure as given in Table 4;

κ is a factor related to the equivalent damping of the coupled structure between crane structure and supporting structure as given in Figure 3, where ζ is the damping ratio of the crane structure (see 5.2.4.3).

Table 4 — Factor λ

Natural period ratio	λ
$T_C/T_P \leq 0{,}9$	$\sqrt{1-(1-\theta)\cdot\left(\frac{1{,}8 \cdot T_c \cdot T_p}{T_c^2 + 0{,}81 \cdot T_P^2}\right)^2}$
$0{,}9 < T_C/T_P \leq 1{,}1$	$\sqrt{\theta}$
$T_C/T_P > 1{,}1$	$\sqrt{1-(1-\theta)\cdot\left(\frac{2{,}2 \cdot T_c \cdot T_p}{T_c^2 + 1{,}21 \cdot T_P^2}\right)^2}$
where	
$\theta = \frac{m_c}{m_c + m_s}$	is the mass ratio of the crane structure and the supporting structure;
m_C	is the mass of the crane as a whole;
m_S	is the mass of the supporting structure as a whole;
T_C	is the largest natural period of the crane structure with the supporting structure assumed rigid;
T_P	is the largest natural period of the supporting structure with the crane structure assumed rigid.