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Cranes — Design principles for seismic load

Grues — Principes de calcul des charges sismiques

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Foreword

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ISO 11031 was prepared by Technical Committee ISO/TC 96, *Cranes - Safety*, Subcommittee SC 10, *Design principles and requirements*.

Cranes — Design principles for seismic load

1 Scope

This standard establishes general methods for calculating seismic loads to be used in proofs of competence as defined in ISO 8686-1 for the structural and mechanical components of cranes as defined in ISO 4306-1 with the exception of mobile cranes.

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

The seismic design of cranes takes also into account such dynamic effects as the regional seismic conditions and the ground surface conditions of the crane location.

In addition, the seismic design of cranes takes into account the operational conditions of the crane as well as the risks resulting from seismic damage.

The fulfilment of the seismic design requirements can correspond to the imposition of two given limit states, called here: serviceability and ultimate.

Serviceability limit state imposes that the crane should suffer no damage to its main load carrying structure, and consequently it should be designed in the elastic range.

Ultimate limit state imposes that the crane structure may be damaged or yielded, but the safety of the public, operators and workers is safe guarded.

This standard deals with the serviceability limit state only.

NOTE The use of Ultimate Limit State allowing a permanent deformation of the crane structure after a severe earthquake, without collapse or load release is outside the scope of the current issue of this standard. The proof of competence including plastic deformations could be done with reference to ISO 10721.

2 Normative references

The following referenced documents are indispensable for the application 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 4306 all published parts, *Lifting appliances — Vocabulary*

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

ISO 20332-1; *Cranes — Proof of competence of steel structure — Part 1: General*

3 Terms and definitions

The main symbols used in this standard are given in Table 1.

Table 1 — Main symbols

Symbol	Description	Reference
K_H	Horizontal seismic design coefficient	Various
K_v	Vertical seismic design coefficient	Various
A_{bg}	Normalised basic acceleration	Various
A_{sg}	Normalised surface ground acceleration	Various
β_2	Soil surface amplification factor	Various
β_3	Acceleration response factor	Various
β_3^*	β_3 of the crane whose damping ratio is 0,025 and given by Figure 1	Various
γ_n	Risk factor	Various
η	Damping correction factor	Various
δ	Response amplification ratio	Various
ζ	Damping ratio	Various
h	Height of the mount base of the crane	Various
H	Height of the supporting structure from the ground	Various
c	Vertical influence factor	Various
F_H	Horizontal seismic design force	Various
F_V	Vertical seismic design force	Various
F_R	Lifting load effect	Various

4 Seismic Design Concept

There are three main types/methods of seismic response analyses used in seismic design procedures:

- Modified Seismic Coefficient Method,
- Maximum Response Spectrum Method,
- Time History Response Method.

In the Modified Seismic Coefficient Method the applied, seismic load are calculated as products of crane masses and quasi-static seismic design coefficients which take into account basic dynamic characteristics of the crane (incl. geographical location, natural frequencies and the damping characteristics).

In the Maximum Response Spectrum Method the seismic loads are calculated in terms of the maximum response accelerations using selected vibration modes of crane structures.

In the Time History Response Method the seismic response is evaluated by solving the equations of motions using the numerical step-by-step in time integration, for crane structure and ground excitation data under consideration.

The “Modified Seismic Coefficient Method” is the basis of the standard due to, its simplicity and adequacy for most applications. However the Maximum Response Spectrum Method and the Time History Response Method are available as alternative methods of seismic design where more accurate seismic response data of the crane structure is required (see Annex D).

The Modified Seismic Coefficient Method is executed in an iterative process, indicated in the flow chart in Annex A.

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 structures with enhanced risk coefficient γ_n can be applied, in accordance with Annex C and clause 5.5.

5.2 Calculation of horizontal seismic design coefficient K_H

5.2.1 General

The horizontal seismic design coefficient K_H shall be calculated in two orthogonal directions as follows

$$K_H = A_{bg} \times \beta_2 \times \beta_3 \times 0.4 = A_{sg} \times \beta_3 \times 0.4 \quad (1)$$

where

K_H is the horizontal seismic design coefficient

A_{bg} is the normalised basic acceleration (See 5.2.2)

A_{sg} is the normalised surface ground acceleration

β_2 is the soil surface amplification factor (see 5.2.3)

β_3 is the acceleration response factor for the direction under consideration (see 5.2.4)

5.2.2 Determination of Normalised Basic Acceleration A_{bg}

Normalised basic acceleration A_{bg} is calculated from the equation 2 below

$$A_{bg} = a_g / g \quad (2)$$

where

a_g is the maximum horizontal basic acceleration, in [m/s^2] (see Annex F)

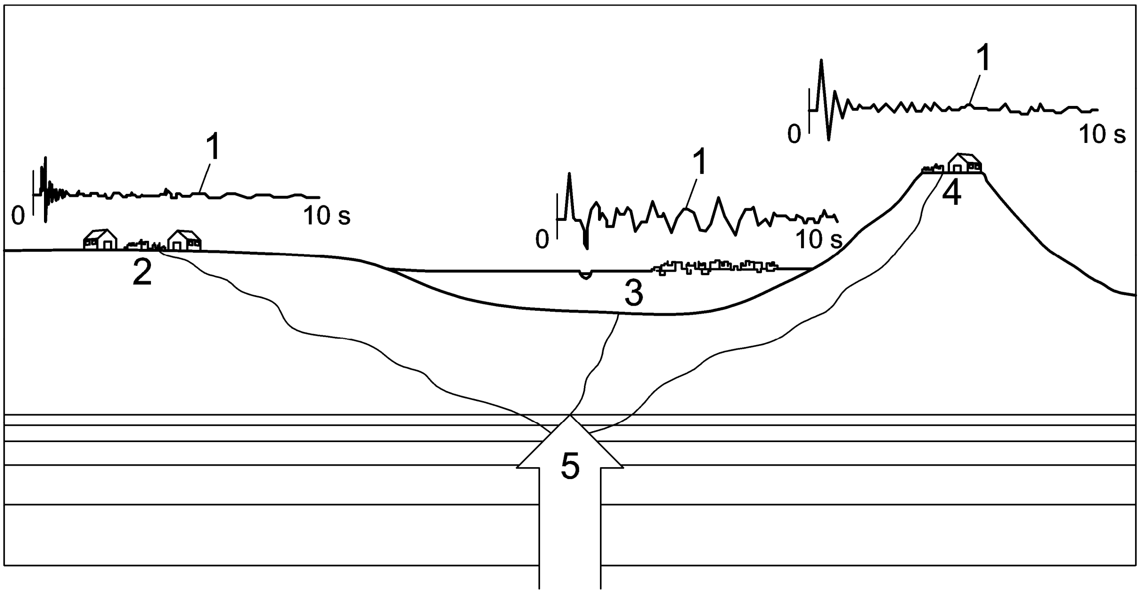
g is the gravity acceleration, in [m/s^2]

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.

The accelerations A_{bg} and A_{sg} shall be based on the return period of 475 years (see B.1).

5.2.3 Determination of Soil Surface Amplification Factor β_2

The soil surface 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 effect on the surface (recorded seismograms)

2 Rock

3 Soft to medium stiff ground

4 Stiff ground

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

Figure 1 — Illustration of the amplification factor due to the soil (β_2)

β_2 shall be determined according to regional subsoil categorization as shown in Table 2.

The soil surface categories are expressed as a function of $v_{s,30}$, which is the average shear-velocity through the upper 30 meters of soil.

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 characteristic of crane support structure where applicable

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

— the damping ratio of the mode

— the soil category at crane location.

The natural period or frequency may be determined by experimental measurement or using recognised computational techniques.

β_3 shall be defined as

$$\beta_3 = \beta_3^* \times \eta \times \delta \tag{3}$$

where

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

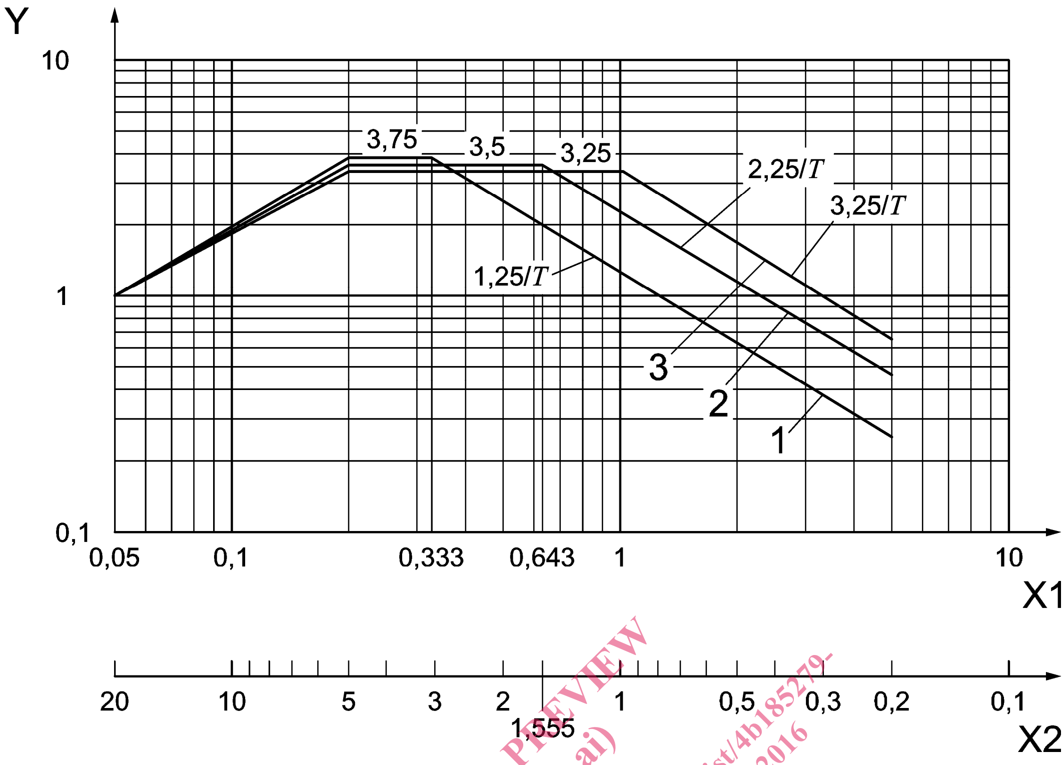
η is the damping correction factor (see 5.2.4.3)

δ is the response amplification ratio (see. 5.2.4.4)

5.2.4.2 Basic acceleration response factor β_3^*

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

Its values as a function of crane natural period or frequency and soil category are shown in Figure 2.



Key

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 acceleration response factor β_3^*

1 Categories 0 and 1

2 Category 2

3 Category 3

Figure 2 — Definition of β_3^* by subsoil categorization

5.2.4.3 Damping correction factor η

Damping correction factor η in equation (3) shall be defined according to damping ratio of the crane structure as described in Table 3.

Table 3 — Damping correction factor η

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

Typical values of damping ratio are $\zeta = 0{,}025$, for welded construction, $\zeta = 0{,}04$ for bolted construction, and $\zeta = 0{,}03$ for combined, welded and bolted crane construction, all remaining well within the elastic range. For the same types of constructions stressed close to the elastic limit higher values may be used.

Alternatively damping ratios can be obtained by accepted methods such as;

— measurement

— for non-linear behaviour of structural members and/or dry friction at joints by evaluating the hysteresis of force-displacement curve.

5.2.4.4 Response amplification ratio 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 (See Figure 2, e.g. building, pier, jetty) the value of δ may be determined from the simplified equation (4) or more accurately following the procedure in Annex E.

$$\delta = \frac{3\left(1+\dfrac{h}{H}\right)}{1+\left(1-\dfrac{f_s}{f_c}\right)^2} - 0{,}5 = \frac{3\left(1+\dfrac{h}{H}\right)}{1+\left(1-\dfrac{T_c}{T_s}\right)^2} - 0{,}5 \qquad (4)$$

where

H is the height of the supporting structures from the ground surface as shown in Figure 3.

h is the height of the mount base of the crane as shown in Figure 3.

f_c is the natural frequency of the crane

f_s is the natural frequency of the supporting structure (without the crane)

T_c is the natural period of the crane

T_s is the natural period of the supporting structure (without the crane)

