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**Cranes — Principles for seismically
resistant design**

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Contents

	Page
Introduction	1
1 Scope	1
2 Normative references	2
3 Terms and definitions, and symbols	2
4 Concept of seismic design	5
4.1 General	5
4.2 Modified Seismic Coefficient Method	5
4.3 Maximum Response Spectrum Method	6
4.4 Time History Response Method	6
5 Calculation of seismic design loads by Modified Seismic Coefficient Method	7
5.1 General	7
5.2 Calculation of horizontal seismic design coefficient, K_H	7
5.3 Calculation of vertical seismic design coefficient, K_V	13
5.4 Calculation of seismic design loads	13
6 Calculation of seismic design loads based on Maximum Response Spectrum Method	14
6.1 General	14
6.2 Calculation procedure for total seismic response (<i>TSR</i>)	15
7 Combinations of seismic and non-seismic effects	17
7.1 General	17
7.2 Proof of static strength : load combinations in accordance with JIS B 8833-1	17
7.3 Proof of static strength : load combination according to SRSS Method	17
7.4 Proof of global stability	18
7.5 Proof of competence for crane structures	18
8 Calculation of seismic design loads by Time History Response Method	19
8.1 Calculation of seismic design loads using Level 1 earthquake ground motion	19
8.2 Calculation of seismic design loads using Level 2 earthquake ground motion	19
9 Base-isolated and vibration-controlled cranes	20
Annex A (informative) Seismic design by Modified Seismic Coefficient Method	21
Annex B (normative) Design accelerations	22

Annex C (informative)	Maximum Response Spectrum Method	24
Annex D (informative)	Time History Response Method and a comparison of Maximum Response Spectrum Method and Modified Seismic Coefficient Method	26
Annex E (informative)	Relation between basic acceleration, Mercalli and Richter scales	29
Annex F (informative)	Vertical influence factor	30
Annex JA (informative)	Calculation of subsoil amplification factor, β_2	31
Annex JB (informative)	Simple calculations of the natural period of a crane	33
Annex JC (informative)	Basic idea of risk factor, γ_n	36
Annex JD (informative)	Comparison table between JIS and corresponding In- ternational Standard	38

Foreword

This Japanese Industrial Standard has been established by the Minister of Health, Labour and Welfare and the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal for establishment of Japanese Industrial Standard submitted by Japan Crane Association (JCA)/Japanese Standards Association (JSA) with a draft being attached, based on the provision of Article 12, paragraph (1) of the Industrial Standardization Act.

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Cranes — Principles for seismically resistant design

Introduction

This Japanese Industrial Standard has been prepared based on **ISO 11031** : 2016, Edition 1, with some modifications of the technical contents to take into account the specific seismic environment of Japan.

The vertical lines on both sides and dotted underlines indicate changes from the corresponding International Standard. A list of modifications with the explanations is given in Annex JD.

Because cranes are long and narrow structures, their capacity of absorbing earthquake energy via plastic deformation of their structural members at the time of an earthquake is considered to be generally less than that of building structures or the like, and this is an important point to be taken into consideration in designing seismically resistant cranes.

An economically acceptable protection against the effects of earthquake is usually based on two design limit states, serviceability limit state (SLS) and ultimate limit state (ULS), which specify the required crane response to a moderate earthquake that the crane may be exposed to during its service life and a severe earthquake that may occur at the installation site, and which are expressed in comparison to the ultimate limit states. Given the limited capacity of cranes to absorb seismic energy, this Standard treats the calculation of seismic design loads for the proof of competence in terms of SLS as mandatory, and that in terms of ULS as optional. The proof of competence in terms of SLS is based on the Modified Seismic Coefficient Method for a moderate earthquake.

1 Scope

This Standard provides requirements regarding the seismic loads and combination of seismic loads for crane structures of all the crane types (excluding mobile cranes) specified in **JIS B 0146** standard series or their structural members and machine elements (hereafter referred to as crane structural members).

This 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 Standard lays out the general concept of ULS, but 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.

NOTE The International Standard corresponding to this Standard and the symbol of degree of correspondence are as follows.

ISO 11031 : 2016 *Cranes — Principles for seismically resistant design* (MOD)

In addition, symbols which denote the degree of correspondence in the contents between the relevant International Standard and **JIS** are IDT (identical), MOD (modified), and NEQ (not equivalent) according to **ISO/IEC Guide 21-1**.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS B 0146 (standard series) *Cranes — Vocabulary*

NOTE Corresponding International Standard : ISO 4306 (all parts) *Cranes — Vocabulary*

JIS B 8822-1 *Cranes and lifting appliances — Classification — Part 1 : General*

JIS B 8829 *Cranes — Proof of competence of steel structures*

NOTE Corresponding International Standard : ISO 20332 *Cranes — Proof of competence of steel structures*

JIS B 8833-1 *Cranes — Design principles for loads and load combinations — Part 1 : General*

NOTE Corresponding International Standard : ISO 8686-1 *Cranes — Design principles for loads and load combinations — Part 1 : General*

3 Terms and definitions, and symbols

3.1 Terms and definitions

For the purpose of this Standard, the terms and definitions given in **JIS B 0146-1**, **JIS B 0146-3** and **JIS B 0146-5**, and the following apply.

3.1.1

earthquake

sudden slip of underground rocks constituting the earth that occurs at the break surface between rocks called the fault surface

3.1.2

earthquake ground motion

motion on and below the surface of ground at a specific point reached by the propagation of seismic waves

3.1.3

Serviceability Limit State (SLS)

limit state imposing that the crane should withstand moderate earthquake ground motions that may occur at the installation site during the crane's service life and remain operational without losing its function should it be subjected to such a ground motion

3.1.4

Ultimate Limit State (ULS)

limit state imposing that the crane structure should not collapse nor experience similar forms of structural failure even after plastic deformation due to severe earthquake ground motions that may occur at the installation site, as well as that crane derailment should not occur, the suspended load, or any part of the crane should not fall and the safety of the operators or workers, and the public properties should be safe guarded

3.1.5

Level 1 earthquake ground motion

ground motion with a high probability of occurrence during the service life of a crane, based on which SLS is examined

3.1.6

Level 2 earthquake ground motion

ground motion of a high seismic coefficient with a limited probability of occurrence during the service life of a crane, based on which ULS is examined

3.1.7

seismic coefficient

ratio of the magnitude of the maximum acceleration of an earthquake ground motion to the gravitational acceleration

3.1.8

modal participation factor

factor which shows to what extent each vibration mode regarded as a multi-degree-of-freedom system contributes to the response of a crane as a whole

It indicates, by its degree, which vibration mode is dominant in an earthquake.

3.1.9

damping ratio

in a vibration system composed of a mass point, dashpot (viscous damper) and spring, the ratio of the size of an actual dashpot to the critical damping equal to a critical size of the dashpot by which the vibration quantity decreases monotonously without oscillation

It is also called the damping constant.

3.1.10

risk factor

factor determined by taking account of the possibility of personal damages and second-

ary damages, used in calculation of basic seismic design loads and a seismic design load due to a suspended load (see Annex JC)

3.1.11

natural mode of vibration

inherent vibration shape consisting of nodes and antinodes when each point in a vibrating system is making a simple harmonic motion for a specific frequency (in the case of a linear system)

NOTE In a multi-degree-of-freedom system, two or more natural modes of vibration may be included simultaneously.

3.1.12

effective vibration mode mass

mass component of a spring-mass system corresponding to each natural mode of vibration

The total sum of the mass components agrees with the total mass of the system.

3.1.13

service life

period of time of use estimated in designing a crane

3.2 Main symbols

The main symbols used in this 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 surface ground acceleration
f_{con}	conversion factor for return period of earthquake ground motion and risks
β_2	subsoil amplification factor
β_3	acceleration response factor
β_3^*	basic acceleration response factor of a crane whose damping ratio is 0.025
γ_n	risk factor

Table 1 (concluded)

Symbol	Description
η	damping correction factor for acceleration response factor
δ	response amplification factor due to supporting structure
ζ	damping ratio (damping constant)
c	vertical influence factor
F_H	horizontal seismic design force <u>not taking account of risk factor</u>
F_V	vertical seismic design force <u>not taking account of risk factor</u>
F_{RH}, F_{RV}	seismic design forces (horizontal and vertical) on suspended load, <u>not taking account of risk factor</u>
F_{Hr}	<u>horizontal seismic design force taking account of risk factor</u>
F_{Vr}	<u>vertical seismic design force taking account of risk factor</u>
F_{RHr}, F_{RVr}	<u>seismic design forces (horizontal and vertical) on suspended load, taking account of risk factor</u>

4 Concept of seismic design

4.1 General

There are three main methods of seismic response analysis used in seismic design: Modified Seismic Coefficient Method, Maximum Response Spectrum Method, and Time History Response Method. The basis of this Standard is the stress design (limit state design) within the elastic region based on the Modified Seismic Coefficient Method applied for Level 1 earthquake ground motion taking account of the structural characteristics of the crane, region of installation, its subsoil characteristics and other factors.

When the stress design is carried out based on the Modified Seismic Coefficient Method, however, depending on the crane model or structure, it may be impossible to ignore responses other than those of the primary natural mode of vibration even if the structural members of the crane show elastic responses. Further, it may be difficult to perform an appropriate verification if a base isolation or damping device is installed. In these cases, a designing method which makes proof of seismic resistance in the following sequence may be selected: establishing a detailed analytical model using a finite element method (FEM) or the like, performing an analysis by the Maximum Response Spectrum Method or Time History Response Method using appropriate seismic waves, calculating the stresses, displacements and the like, and comparing the calculated results with design limit stresses or other permissible values.

Provided that seismic waves corresponding to Level 1 earthquake ground motion taking into account the subsoil characteristics of the crane location have been obtained, and the necessary conditions have been set for the safety and functional assessment by the Time History Response Method etc., it may be taken into consideration that the structural members of the crane exceed the yield stresses locally and enter the plastic region to a degree that the crane functions are not impaired. In this case, the interested parties shall agree on the performance requirements to be applied, such as one requiring that the crane retain its basic functions and safety even if some local plastification occurred.

4.2 Modified Seismic Coefficient Method

In the Modified Seismic Coefficient Method (see Clause 5), the crane structure is regarded as a one degree-of-freedom system, and the seismic design load calculated as the product of the seismic coefficient obtained from the crane's vibration characteristics and the load due to the mass of the crane (vertical static load) is used as the static load acting on the crane structure. The evaluation of seismic coefficients takes into account the crane location, its subsoil 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 relatively simple, and its procedure is executed as part of the design iterative process indicated in the flow chart in Annex A.

4.3 Maximum Response Spectrum Method

The Maximum Response Spectrum Method (see Clause 6) is a method for calculating the seismic response of a crane from multiple vibration modes that affect the seismic response by regarding the crane structure as a multi-degree-of-freedom system. This method is 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 responses 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 the seismic characteristics at the crane location and the damping characteristics of crane structure) together with the calculated mode shapes, frequencies or periods and mass distribution of the crane.

4.4 Time History Response Method

The Time History Response Method (see Clause 8) is a method for determining the seismic response of a crane by modelling the crane structure by using the FEM etc. and applying earthquake ground motions varied over time to the ground surface. This method is used where :

- only an accurate seismic response of crane is acceptable (see Annex D);
- nonlinearities (plastic deformations, elasto-plastic properties of material and 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 Response Method, the seismic response is evaluated by using numerical step-by-step integration in time to solve the formula of motions for crane structure (including supporting structure of the crane if necessary) and ground excitation under consideration, selected to represent seismic condition at crane site.

5 Calculation of seismic design loads by Modified Seismic Coefficient Method

5.1 General

The seismic coefficient is determined by focusing on the most significant primary natural mode of vibration of the crane that is excited when an earthquake occurs, and stresses, displacements, etc. acting on the crane members are calculated by combining the seismic design load corresponding to the determined seismic coefficient with the load due to the mass of the crane (vertical static load) and other loads. The proof of seismic resistance is made by comparing these calculated values with the design limit stresses or other permissible values. The procedure of this verification is shown in Annex A.

If stress design based on the Modified Seismic Coefficient Method is not used, it is possible to choose a method such as dynamic response analysis using appropriate input seismic waves, for example, only if there is a rational basis for doing so. Even in this case, however, a primary evaluation shall be conducted based on the Modified Seismic Coefficient Method, and if comparison of the results of the two methods reveals a difference, the cause of the difference shall be analyzed and the validity of the two results evaluated.

The seismic design load or design seismic acceleration acting on the crane is calculated using the horizontal and vertical seismic design coefficients (K_H , K_V). A risk factor, γ_n , of 1 or more specified in Clause 7 is applied according to the risk of the crane.

5.2 Calculation of horizontal seismic design coefficient, K_H

5.2.1 General

The horizontal seismic design coefficient, K_H , shall be calculated according to Formula (1) :

$$K_H = A_{bg} \times \beta_2 \times \beta_3 \times f_{con} = A_{sg} \times \beta_3 \times f_{con} \dots\dots\dots(1)$$

where, A_{bg} : normalized basic acceleration (see 5.2.2)
 A_{sg} : normalized surface ground acceleration
 β_2 : subsoil amplification factor (see 5.2.3)
 β_3 : acceleration response factor (see 5.2.4)
 f_{con} : conversion factor for return period of earthquake ground motion and risks

The conversion factor is $f_{con} = 0.16$ 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, with also the risk factor considered.

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

K_H shall be determined using Formula (2) taking the friction coefficient of slip into consideration, when the seismic load acts in the direction parallel to the rails (referred to as the rail direction) and the crane is not restricted by the foundation ground or the like.

$$K_H = 0.3 \times \frac{b}{a} \dots\dots\dots (2)$$

where, K_H : horizontal seismic design coefficient
 a : total number of wheels
 b : number of braking wheels

For a crane whose aspect ratio of the overall height to the wheel width is large and the number of the braking wheels is not equal between both legs, K_H shall be determined taking the moment into consideration. The minimum value of K_H shall be 0.10.

5.2.2 Determination of normalized basic acceleration, A_{bg}

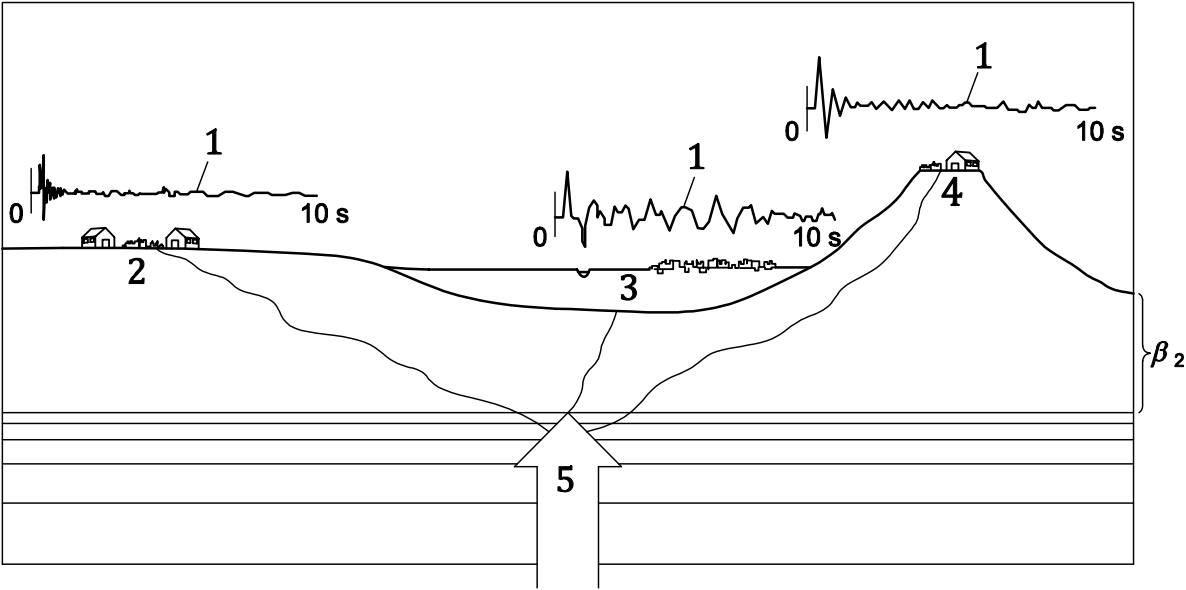
Normalized basic acceleration, A_{bg} , is calculated according to Formula (3) by referring to Annex B :

$$A_{bg} = a_g / g \dots\dots\dots (3)$$

where, a_g : maximum horizontal basic acceleration (m/s²)
 g : acceleration of free fall (gravity acceleration) (m/s²)

5.2.3 Determination of subsoil amplification factor, β_2

The subsoil amplification factor, β_2 , expresses the influence of the soil surface on the intensity and the frequencies of the seismic excitation as the ground motion travels from the bedrock through the ground to the ground surface. The principle of this influence is illustrated in Figure 1.



- 1 seismic effects on the surface (recorded seismograms), represented by A_{sg} as the maximum value in this 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-wave 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 (see Annex JA).

Table 2 Determination and values of subsoil amplification factor, β_2

Category	Subsoil	Average shear-wave velocity $V_{s,30}$ [m/s]	β_2
Category 0	Rock of the Tertiary period or older	$V_{s,30} > 800$	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 supporting 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 primary 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

$$\beta_3 = \beta_3^* \times \eta \times \delta \quad \dots\dots\dots(4)$$

where, β_3^* : basic acceleration response factor of the crane whose damping ratio is 0.025 (see 5.2.4.2)

η : damping correction factor for acceleration response factor (see 5.2.4.3)

δ : response amplification factor due to supporting structure (see 5.2.4.4)

5.2.4.2 Basic acceleration response factor, β_3^*

The values of β_3^* as a function of the natural period or frequency of the crane and of

subsoil category at crane location are shown in Figure 2.

The natural period of a gantry crane such as an overhead crane and a container handling crane may be determined by the simplified calculation described in Annex JB.

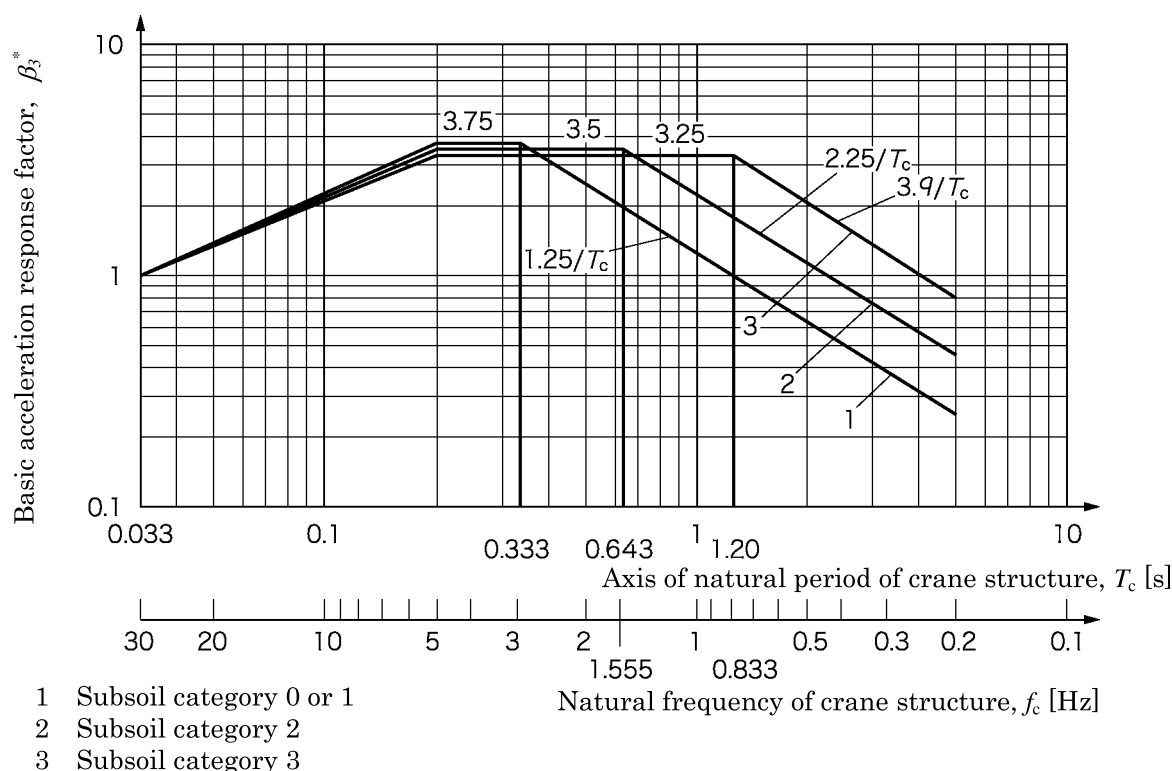


Figure 2 Basic acceleration response factor, β_3^* (as a function of crane natural period or frequency and of subsoil category at crane location)

5.2.4.3 Damping correction factor, η , for acceleration response factor

The damping correction factor, η , for acceleration response factor given in Formula (4) 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 , for acceleration response factor

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 within the elastic limit, are $\zeta = 0.025$ for welded construction, $\zeta = 0.04$ for bolted construction and $\zeta = 0.03$ for welded and bolted construction combined. Higher values of damping ratios may be used for the same types of construction stressed near the elastic limit of the material.