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Indian Standard

EVALUATION OF HUMAN EXPOSURE TO WHOLE-BODY VIBRATION

PART 2 CONTINUOUS AND SHOCK-INDUCED VIBRATION IN BUILDINGS (1 Hz TO 80 Hz)

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Indian Standard

EVALUATION OF HUMAN EXPOSURE TO WHOLE-BODY VIBRATION

PART 2 CONTINUOUS AND SHOCK-INDUCED VIBRATION IN BUILDINGS (1 Hz TO 80 Hz)

NATIONAL FOREWORD

This Indian Standard, which is identical with ISO 2631-2 : 1989 'Evaluation of human exposure to whole-body vibration — Part 2 : Continuous and shock-induced vibration in buildings (1 to 80 Hz)', issued by the International Organization for Standardization (ISO), was adopted by the Bureau of Indian Standards on the recommendations of the Mechanical Vibration and Shock Sectional Committee (LM 04) and approval of the Light Mechanical Engineering Division Council.

The text of ISO standard has been approved as suitable for publication as Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standard. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker in ISO Standard while in Indian Standard the current practice is to use point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards which are to be substituted in their place are listed below alongwith their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 2041 : 1975	IS 11717 : 1985 Vocabulary on vibration and shock	Identical
ISO 2631-1 : 1985	IS 13276 (Part 1) : 1992 Evaluation of human exposure to whole body vibration : Part 1 General	Identical
ISO 5805 : 1981	IS 13281 : 1991 Mechanical vibration and shock affecting man — Vocabulary	Identical

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0 Introduction

Structural vibration in buildings can be detected by and affect the occupants in many ways. The quality of life can be reduced just as can the working efficiency.

This part of ISO 2631 offers guidance on the application of ISO 2631-1 to human response to building vibration. This part of ISO 2631 is also intended to encourage the uniform collection of data on human response to building vibration.

No guidance is given on complaint levels from occupants of buildings subject to vibration or to any acceptable magnitudes or limits of building vibration, but this part of ISO 2631 does contain weighting curves for human response to vibration of buildings.

1 Scope and field of application

Primarily with respect to annoyance of human beings subject to building vibration, this part of ISO 2631 is limited to the following considerations :

a) continuous vibration;

b) intermittent vibration.

The state of the art on transient (impulsive) vibration is presented in annexes A and B.

General guidance is given on human response to building vibrations and weighting curves of frequency response for equal annoyance of humans are included together with measurement methods to be used.

Consideration is given to the time of the day and the use made of the occupied space in the building, whether workshop, office, residential, hospital operating-theatre or other critical area.

Acceptable magnitudes of vibration are not stated in this part of ISO 2631 since these cannot be specified rigidly and depend upon specific circumstances. Tentative guidance is given in annex A on the magnitude of vibration at which adverse comment may begin to arise. In cases where sensitive equipment or delicate operations impose more stringent criteria than human comfort, the corresponding more stringent values should be applied.

Adjustments and variances may be allowed for short-term engineering works (for example foundation excavation and tunnelling) where good public relation practices are followed and prior warning is given.

This part of ISO 2631 is not intended to provide guidance as to the likelihood of structural damage to buildings or injury to occupants of buildings subject to vibration, as defined in ISO 2631-1.

This part of ISO 2631 is concerned only with tactile perception and does not take into account auditory perception of re-radiated sound.

2 References

ISO 2041, *Vibration and shock — Vocabulary.*

ISO 2631-1, *Evaluation of human exposure to whole-body vibration — Part 1 : General requirements.*

ISO 5805, *Mechanical vibration and shock affecting man — Vocabulary.*

3 Characteristics of building vibration

3.1 Direction of vibration

As a building may be used for many different human activities, for example standing, sitting, lying or a combination of all three, vertical vibration of the building may enter the body as either z-axis, x-axis or y-axis vibration, as shown in figure 1.

The measured vibration should normally be referred to the appropriate axis. If it is not clear which direction is appropriate, it may be more convenient to consider the combined curve as explained in 4.2.3.

3.2 Multi-frequency vibration

There is evidence from research concerning the building environment to suggest that there are summation effects for vibration at different frequencies. Therefore for the evaluation of building vibration with respect to the annoyance and comfort effects on occupants, overall weighted vibration values are preferred, as described in ISO 2631-1. A suitable weighting curve for investigation is described in 3.5.

3.3 Characterization of transient, continuous and intermittent vibration with respect to human response

The borderline between transient and intermittent vibration is difficult to define. For the purpose of this part of ISO 2631, transient (sometimes called impulsive) vibration is defined as a rapid build-up to a peak, followed by a damped decay which may or may not involve several cycles of vibration (depending on frequency and damping). It can also consist of several cycles at approximately the same amplitude, providing that the duration is short (i.e. less than 2 s).

Intermittent vibration is a string of vibration incidents, each of short duration, separated by intervals of much lower vibration magnitudes. Intermittent vibration may originate from impulse sources (for example pile drivers and forging presses) or repetitive sources (for example pavement breakers) or sources which operate intermittently, but which would produce continuous vibration if operated continuously (for example intermittent machinery, lifts, railway trains and traffic passing by).

In this part of ISO 2631, continuous vibration is vibration which remains uninterrupted over a time period under consideration (see annex A).

Single high-magnitude events, such as blasting, which occur only a few times per day are a special case. It is generally recommended that operations of this nature should not take place at night in order to avoid disturbance. During the daytime, they should be limited to a small number of events. An event may comprise a single significant impulse vibration or a group of transient vibrations with individual impulses separated by a short period (with the group lasting no longer than 1 min).

Under practical conditions, vibration due to impulsive events may be acceptable even if it is an order of magnitude greater than those due to traffic and general building vibration. The magnitudes of vibration for minimum adverse comment will depend upon the time period over which events occur in an area.

3.4 Classification of buildings and building areas

The classification with respect to human response should be performed solely on the basis of the expected occupation, tasks performed by the occupants and the expected freedom from intrusion. Each occupied room of a building shall be analysed with respect to these criteria.

NOTE — For state-of-the-art guidance, see annex A.

3.5 Measurement of vibration

The preferred measurement technique is one which records unfiltered time histories from which any desired value can later be determined. If possible, building vibrations should be measured in acceleration terms, but in some cases it may be found appropriate to measure in terms of velocity or displacement.

The preferred method for assessing the influence of continuous vibrations is to determine the r.m.s. value of the weighted acceleration (as recommended in ISO 2631-1).

NOTE — For methods dealing with crest factors other than small crest factors, see annexes A and B.

If the position of the occupants with respect to the vibration environment is constant and known, the weighting functions established for the z-direction and the x-, y-directions shall be used. If the position of the occupants varies or is unknown with respect to the interfering or annoying vibration, then either the most stringent of z-, x- and y-directions or a weighting characteristic obtained by the combination of the z-axis and x-, y-axes can be used. Where the combined weighting function is used it has a corner frequency of 5,6 Hz and an attenuation given by:

$$\text{attenuation} = \sqrt{1 + (f/5{,}6)^2}$$

where f is the frequency, in hertz. (See curves explained in 4.2.3.)

There are insufficient data on human response to transient (impulsive) vibration to justify inclusion here of a preferred method for analysing such motions. Guidance on assessment currently used in some countries is illustrated in annex A and additional methods at present being researched and tested are identified in annex B.

Measurement of vibration should be taken on a structural surface supporting the human body at the point of entry to the human subject.

NOTE — In some conditions, measurements may have to be made outside the structures or on some surface other than points of entry to the human subject. In these cases, transfer functions need to be determined.

Measurements should be taken along the three orthogonal axes and reference should be made to the appropriate human axis curve. Alternatively, the combined x-, y- and z-curve could be considered in relation to the worst case found (see 4.2.3).

4 Characterization of building vibration with respect to human response

4.1 Criteria of satisfactory magnitude with respect to human response

All the following proposals are based on the recommendations for general vibration on humans given in ISO 2631-1.

Experience has shown in many countries that complaints regarding building vibrations in residential situations are likely to arise from occupants of buildings when the vibration magnitudes are only slightly in excess of perception levels. In general, the satisfactory magnitudes are related to the minimum adverse comment level by the occupants and are not determined by any other factors, such as short-term health hazard and working efficiency. Indeed, in practically all cases the magnitudes are such that there is no possibility of fatigue or other vibration-induced symptoms. Situations exist where motion magnitudes above those for minimum adverse comment level can be tolerated, particularly for temporary disturbances and infrequent events of short duration. An example is a construction or excavation project. Any startle factor can be reduced by warning signals, announcements and/or regularity of occurrence and a proper programme of public relations. Only in extremely rare cases should it be necessary to consult the "fatigue-decreased proficiency boundary" and "exposure limits" as given in ISO 2631-1 as guidance.

For situations in which vibration occurs over an extended period, long-term familiarization may give rise to a change in adverse comments.

4.2 Base curves

The base curves represent magnitudes of approximately equal human response with respect to human annoyance and/or complaints about interference with activities. The base curves for acceleration and for velocity are given in figures 2a, 3a and 4a, and in figures 2b, 3b and 4b, respectively. Satisfactory vibration magnitudes in rooms and buildings should be specified in multiples of the base curve magnitudes specified in 4.2.1, 4.2.2 and 4.2.3. At vibration acceleration and/or velocity magnitudes below the values corresponding to the base curves shown in figures 2a, 3a and 4a and/or figures 2b, 3b and 4b in general no adverse comments, sensations or complaints have been reported. However, this statement does not imply that, depending on circumstances and expectations, annoyance and/or complaints shall be expected at higher magnitudes.

NOTE — Weighted acceleration values shall be evaluated with respect to the base acceleration magnitudes in the frequency band of maximum sensitivity as stated in ISO 2631-1.

Establishing design criteria and aims by raising the base curves shown in this part of ISO 2631 should be done by consulting state-of-the-art experience and proper consideration should be given to social, public relations and economic factors.

NOTES

1 Annex A summarizes the state of the art of multiplication factors frequently used in connection with the base curves shown in this part of ISO 2631. It is hoped that use of this part of ISO 2631 facilitates uniform collection of additional data.

2 The base curves presented do not take into account the possibility that, at frequencies above approximately 30 Hz, wall vibration can introduce undesired acoustical disturbances.

4.2.1 Base curves for foot-to-head (z-axis) vibration

For z-axis vibration, the base curves are shown in figures 2a and 2b. Table 1 gives the corresponding acceleration and velocity/frequency values at the preferred one-third octave band centre frequencies for the curves in figures 2a and 2b.

At magnitudes of acceleration below the base curve, adverse comment is very rare. This does not mean that values above this curve will give rise to adverse comment, as the magnitude which is considered to be satisfactory depends on circumstances.

4.2.2 Base curves for side-to-side or back-to-chest (x- or y-axis) vibration

For x- and y-axis human vibration, different base curves apply which are shown in figures 3a and 3b. Table 1 gives the corresponding acceleration and velocity/frequency values at the preferred one-third octave band centre frequencies for the curves in figures 3a and 3b.

For frequencies from 1 to 2 Hz, an acceleration magnitude of $3{,}6 \times 10^{-3}$ m/s^2 will apply.

For frequencies greater than 2 Hz, a constant velocity curve applies.

It will be noted that the base curves for x- and y-axis vibration are more stringent than the z-axis case at low frequencies. This is due to the sensitivity of the human body to x- or y-axis motion at these low frequencies.

4.2.3 Combined-standard base curves for undefined axes of human vibration exposure

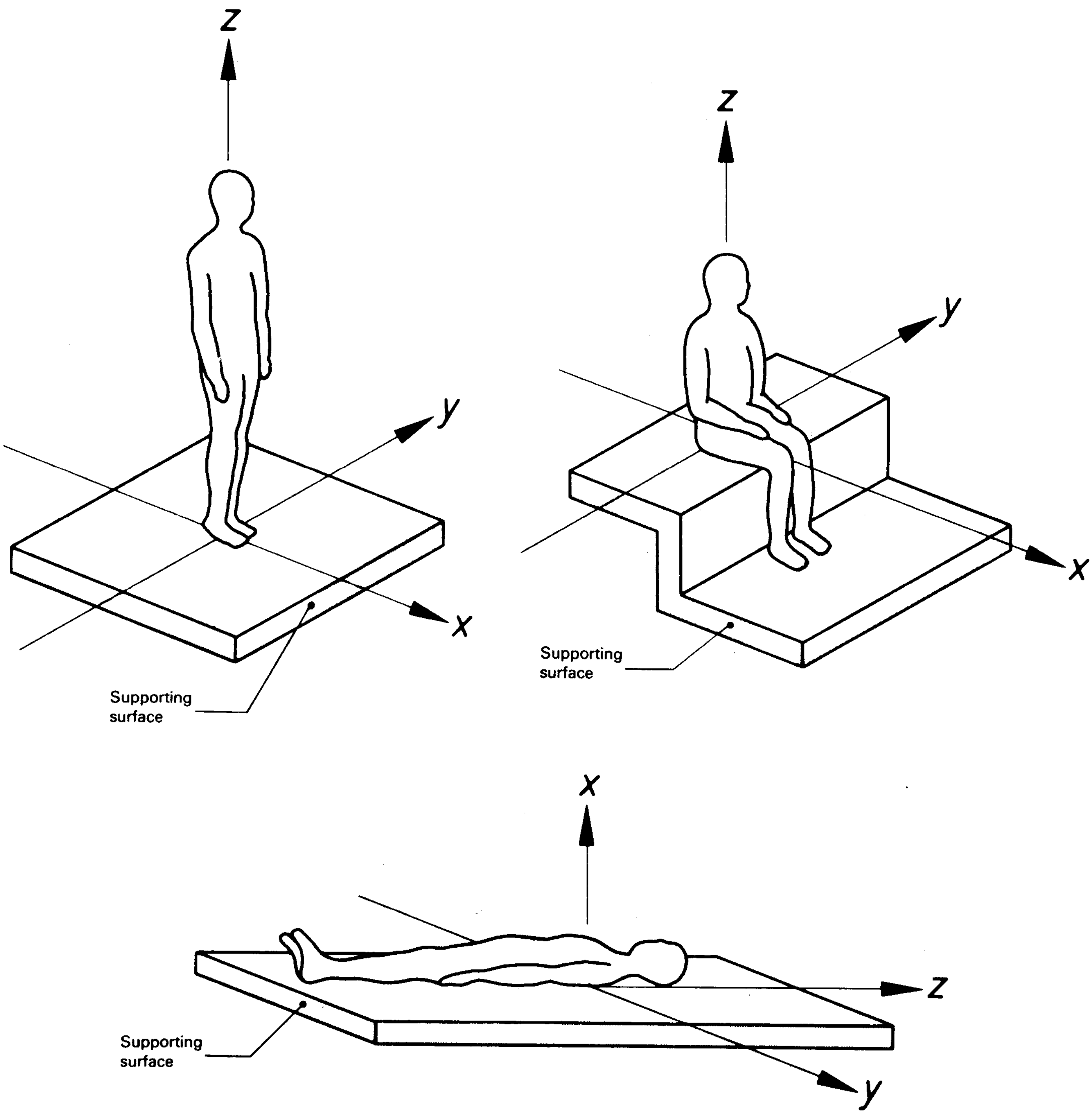
In many situations the same building area may be used by humans in both the lying and standing positions at different times of the day. If this is the case, then a combined standard using the worst case combination of both the z-axis and x- and y-axis conditions may be applied. This has to be obtained by using the z-axis response from 8 to 80 Hz and the x/y-axis response from 1 to 2 Hz. For frequencies between 2 and 8 Hz, there is an interpolation between the two curves. These combination curves are shown in figures 4a and 4b. Table 1 gives the corresponding acceleration and velocity/frequency values for the curves in figures 4a and 4b.

These combined standard base curves (see annex A and figure 5a) could be used for preliminary investigations to decide whether further investigation is necessary.

NOTE — In some countries it is preferred to use the z and x, y base curves separately rather than the provisional combined weighting curve.

Table 1 — Acceleration and velocity at the one-third octave band centre frequencies for the base curves shown in figures 2a, 2b, 3a, 3b, 4a and 4b

Frequency (Centre frequency of one-third octave band) Hz	**Acceleration** (r.m.s.) m/s²			**Velocity** (r.m.s.) m/s		
	Base curve figure 2a	Base curve figure 3a	Base curve figure 4a	Base curve figure 2b	Base curve figure 3b	Base curve figure 4b
1	1×10^{-2}	$3,6 \times 10^{-3}$	$3,6 \times 10^{-3}$	$1,59 \times 10^{-3}$	$5,73 \times 10^{-4}$	$5,73 \times 10^{-4}$
1,25	$8,9 \times 10^{-3}$	$3,6 \times 10^{-3}$	$3,6 \times 10^{-3}$	$1,13 \times 10^{-3}$	$4,58 \times 10^{-4}$	$4,58 \times 10^{-4}$
1,6	8×10^{-3}	$3,6 \times 10^{-3}$	$3,6 \times 10^{-3}$	$7,96 \times 10^{-4}$	$3,58 \times 10^{-4}$	$3,58 \times 10^{-4}$
2	7×10^{-3}	$3,6 \times 10^{-3}$	$3,6 \times 10^{-3}$	$5,57 \times 10^{-4}$	$2,87 \times 10^{-4}$	$2,87 \times 10^{-4}$
2,5	$6,3 \times 10^{-3}$	$4,51 \times 10^{-3}$	$3,72 \times 10^{-3}$	$4,01 \times 10^{-4}$	$2,87 \times 10^{-4}$	$2,37 \times 10^{-4}$
3,15	$5,7 \times 10^{-3}$	$5,68 \times 10^{-3}$	$3,87 \times 10^{-3}$	$2,88 \times 10^{-4}$	$2,87 \times 10^{-4}$	$1,95 \times 10^{-4}$
4	5×10^{-3}	$7,21 \times 10^{-3}$	$4,07 \times 10^{-3}$	$1,99 \times 10^{-4}$	$2,87 \times 10^{-4}$	$1,62 \times 10^{-4}$
5	5×10^{-3}	$9,02 \times 10^{-3}$	$4,3 \times 10^{-3}$	$1,59 \times 10^{-4}$	$2,87 \times 10^{-4}$	$1,36 \times 10^{-4}$
6,3	5×10^{-3}	$1,14 \times 10^{-2}$	$4,6 \times 10^{-3}$	$1,26 \times 10^{-4}$	$2,87 \times 10^{-4}$	$1,16 \times 10^{-4}$
8	5×10^{-3}	$1,44 \times 10^{-2}$	5×10^{-3}	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
10	$6,3 \times 10^{-3}$	$1,8 \times 10^{-2}$	$6,3 \times 10^{-3}$	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
12,5	$7,81 \times 10^{-3}$	$2,25 \times 10^{-2}$	$7,8 \times 10^{-3}$	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
16	1×10^{-2}	$2,89 \times 10^{-2}$	1×10^{-2}	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
20	$1,25 \times 10^{-2}$	$3,61 \times 10^{-2}$	$1,25 \times 10^{-2}$	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
25	$1,56 \times 10^{-2}$	$4,51 \times 10^{-2}$	$1,56 \times 10^{-2}$	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
31,5	$1,97 \times 10^{-2}$	$5,68 \times 10^{-2}$	$1,97 \times 10^{-2}$	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
40	$2,5 \times 10^{-2}$	$7,21 \times 10^{-2}$	$2,5 \times 10^{-2}$	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
50	$3,13 \times 10^{-2}$	$9,02 \times 10^{-2}$	$3,13 \times 10^{-2}$	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
63	$3,94 \times 10^{-2}$	$1,14 \times 10^{-1}$	$3,94 \times 10^{-2}$	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$
80	5×10^{-2}	$1,44 \times 10^{-1}$	5×10^{-2}	$9,95 \times 10^{-5}$	$2,87 \times 10^{-4}$	$9,95 \times 10^{-5}$



a_x, a_y, a_z = acceleration in the directions of the x-, y-, z-axes

x-axis = back-to-chest

y-axis = right side to left side

z-axis = foot-(or buttocks-)to-head

Figure 1 — Directions of basicentric coordinate systems for mechanical vibrations influencing humans

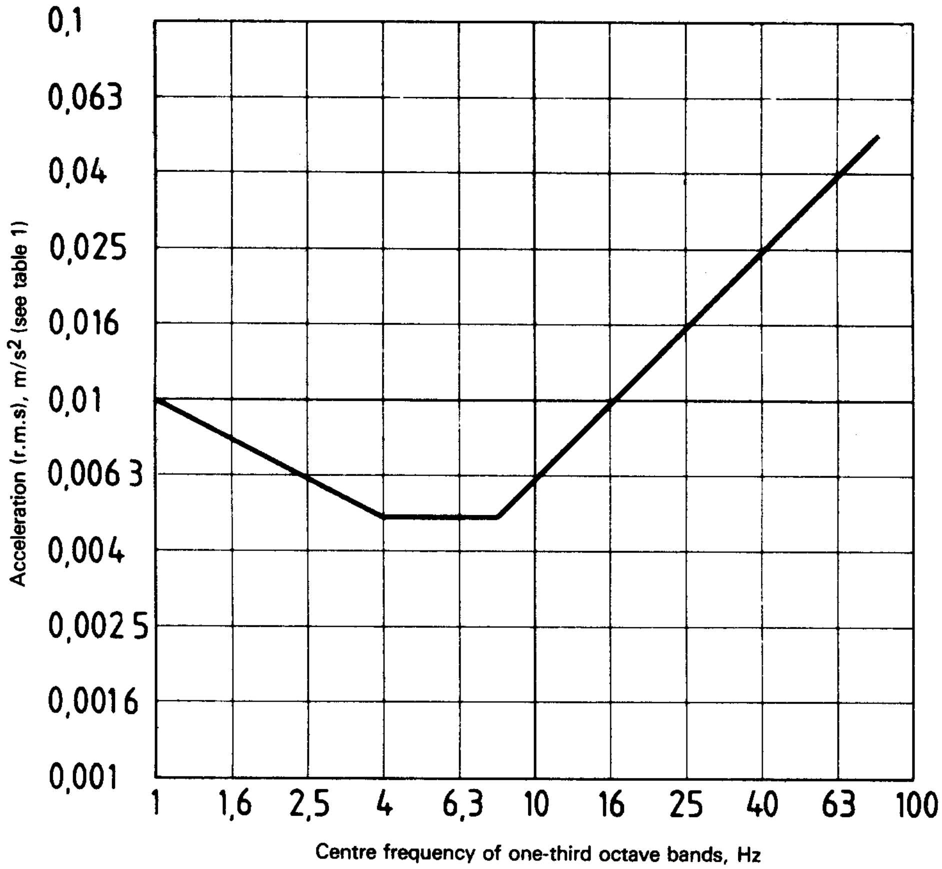


Figure 2a — Building vibration *z*-axis base curve for acceleration
(this represents the foot-to-head vibration base curve, see 4.2.1)

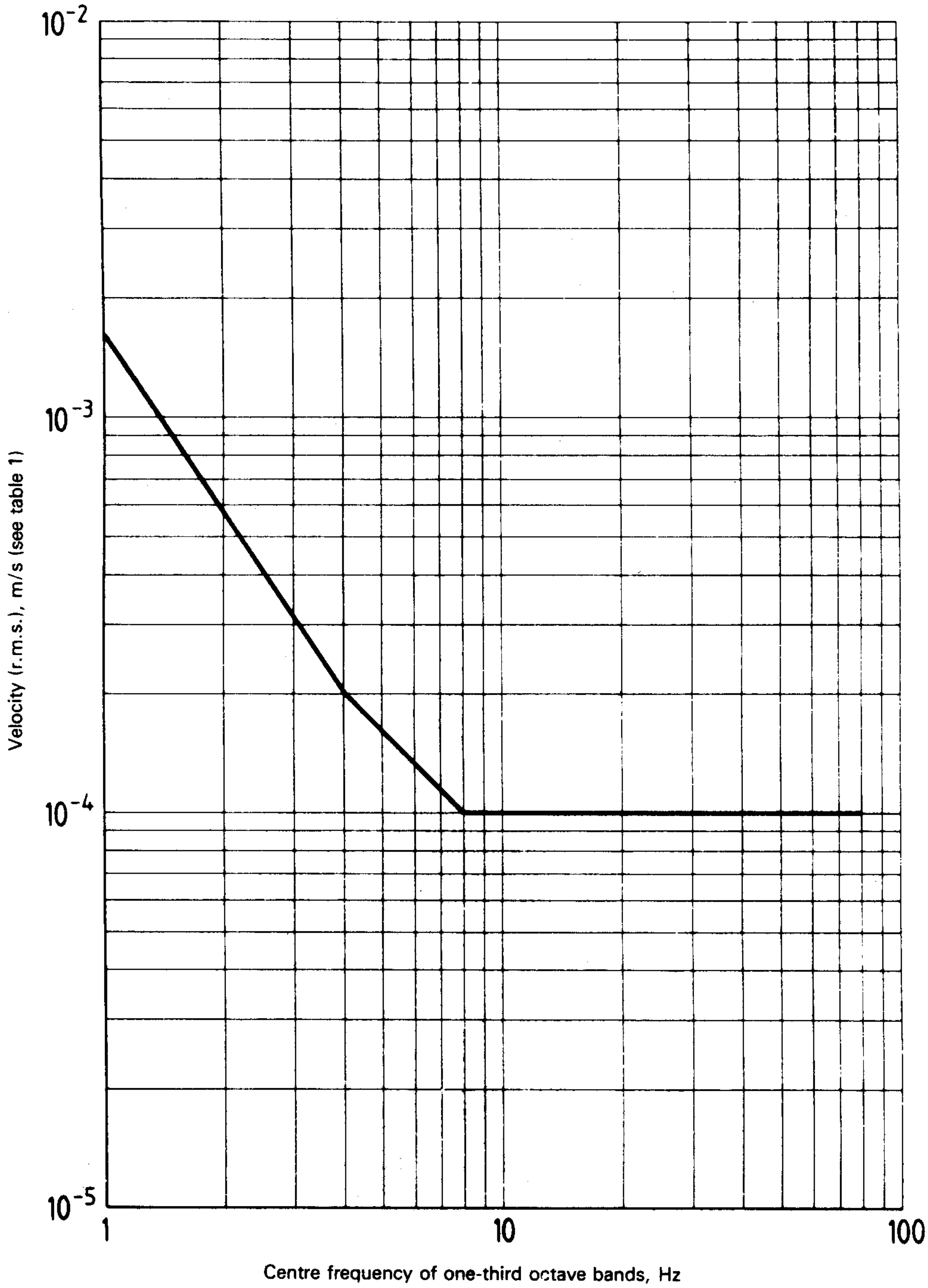


Figure 2b — Building vibration *z*-axis base curve for velocity
(this represents the foot-to-head vibration base curve, see 4.2.1)

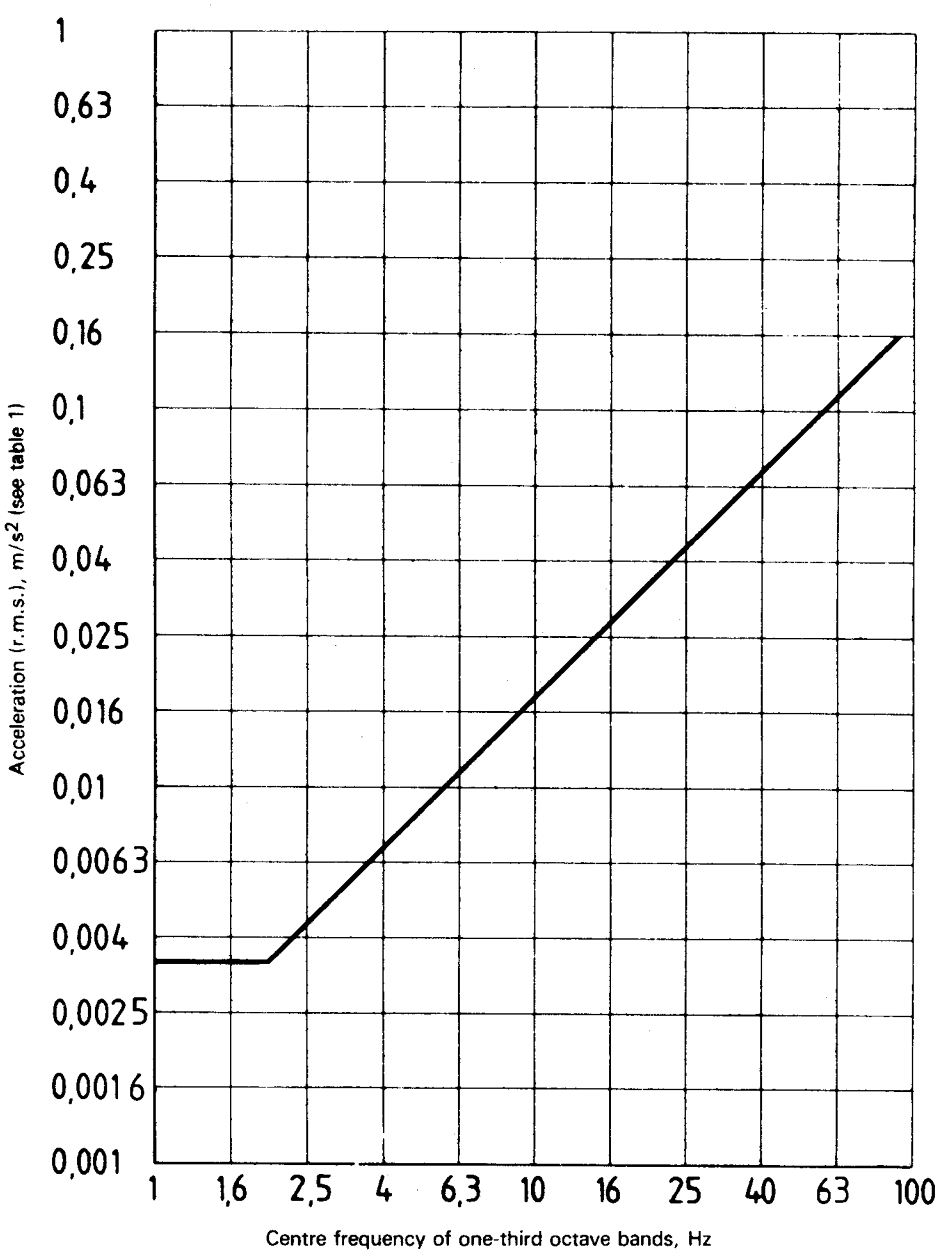


Figure 3a — Building vibration *x*- and *y*-axis base curve for acceleration
(this represents the side-to-side and back-to-chest vibration base curve, see 4.2.2)

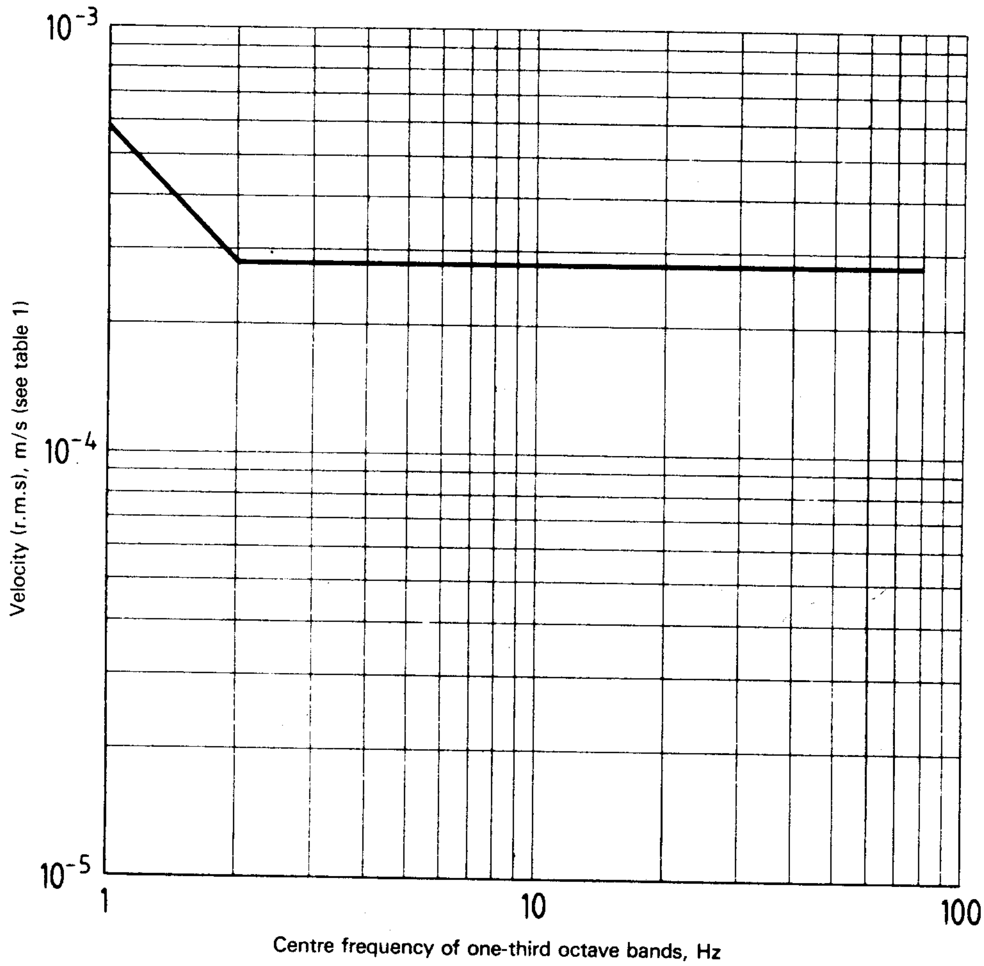


Figure 3b — Building vibration *x*- and *y*-axis base curve for velocity
(this represents the side-to-side and back-to-chest vibration base curve, see 4.2.2)

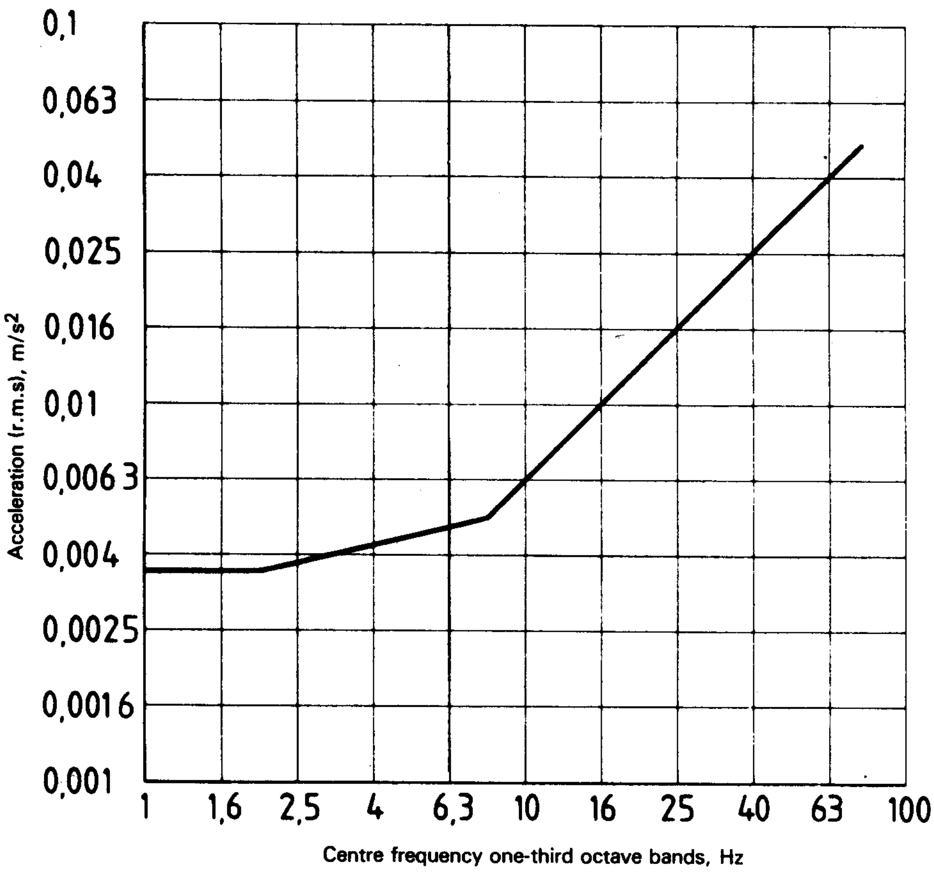


Figure 4a — Building vibration combined direction (*x*- , *y*- , *z*-axis) acceleration base curve (this curve shall be used when the direction of the human occupants varies or is unknown with respect to the most interfering or annoying vibration. See 4.2.3)

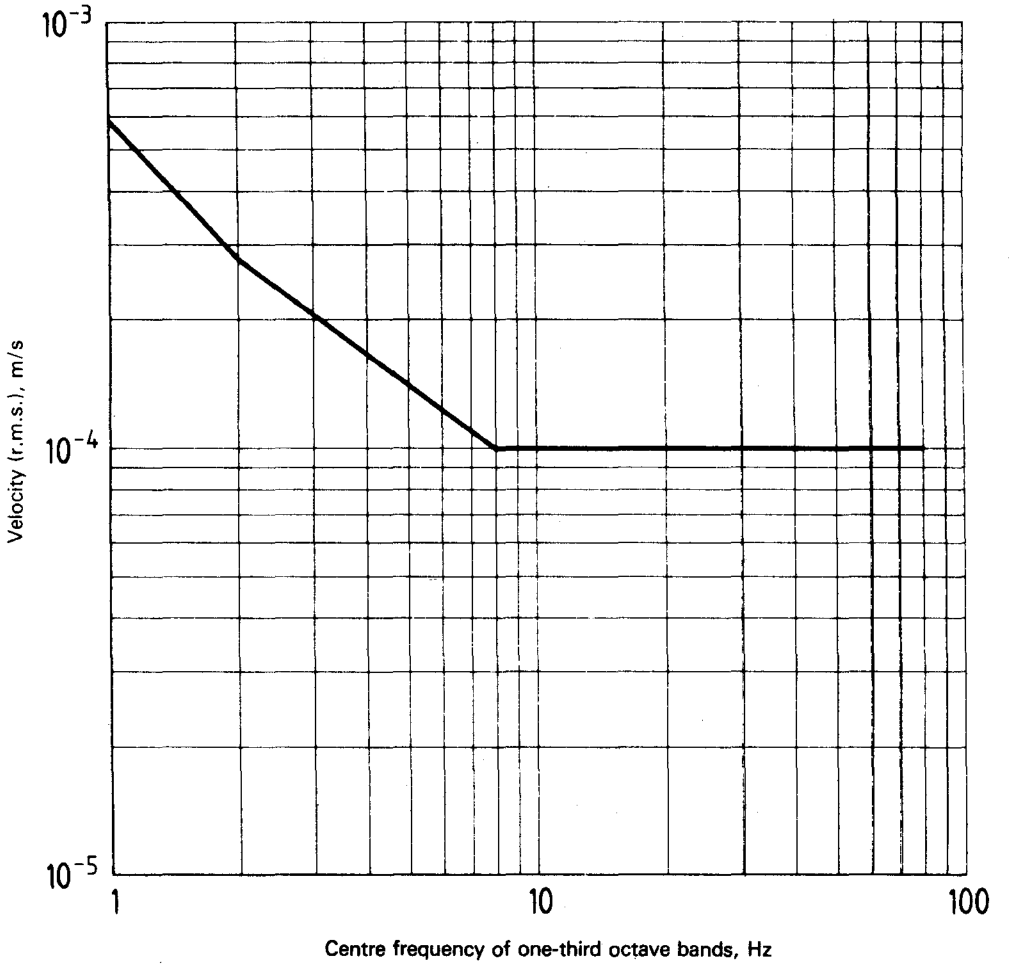


Figure 4b — Building vibration combined direction (*x*-, *y*-, *z*-axis) velocity base curve (this figure shall be used when the direction of the human occupants varies or is unknown with respect to the most interfering or annoying vibration. See 4.2.3)

Annex A

Information on currently used evaluation criteria

(This annex does not form an integral part of the standard.)

State-of-the-art information on the results of surveys on the magnitudes of building vibration found to be satisfactory with respect to human response is presented in table 2.

The various criteria curves specified by table 2 for the combined-direction base curves of figures 4a and 4b are illustrated in figures 5a, 5b and 5c.

Table 2 — Ranges of multiplying factors used in several countries to specify satisfactory magnitudes of building vibration with respect to human response
[these factors have been applied to the basic curves shown in figures 2a, 3a and 4a 1)]

Place	Time	Continuous or intermittent vibration 2)	Transient vibration excitation with several occurrences per day
Critical working areas (for example some hospital operating-theatres, some precision laboratories, etc.)	Day Night	1	1 2), 3)
Residential	Day	2 to 4 4)	30 to 90 4), 5), 6), 7)
	Night	1,4	1,4 to 20
Office	Day Night	4 8)	60 to 128 8)
Workshop 9)	Day Night	8 8), 10)	90 to 128 8), 10)

1) Table 2 leads to magnitudes of vibration below which the probability of reaction is low. (Any acoustic noise caused by vibrating walls is not considered.)

2) Also includes quasi-stationary vibrations caused by repetitive shocks. Shock is defined in ISO 2041 : 1975, clause 3, and is sometimes referred to as transient (impulsive) vibration.

3) Magnitudes of transient vibration in hospital operating-theatres and critical working places pertain to periods of time when operations are in progress or critical work is being performed. At other times, magnitudes as high as those for residence are satisfactory provided that there is due agreement and warning.

4) Within residential areas there are wide variations in vibration tolerance. Specific values are dependent upon social and cultural factors, psychological attitudes and expected interference with privacy.

5) The "trade-off" between number of events per day and magnitudes is not well established. The following provisional relationship shall be used for cases of more than three events a day pending further research into human vibration tolerance. This involves further multiplying by a number factor $F_n = 1{,}7\ N^{-0{,}5}$ where N is the number of events per day. This "trade-off" equation does not apply when values are lower than those given by the factors for continuous vibration. When the range of event magnitudes is small (within a half amplitude of the largest), the arithmetic mean can be used. Otherwise only the largest need be considered.

6) For discrete events with durations exceeding 1 s, the factors can be adjusted by further multiplying by a duration factor, F_d :

$F_d = T^{-1{,}22}$ for concrete floors and T is between 1 and 20

$F_d = T^{-0{,}32}$ for wooden floors and T is between 1 and 60

where T is the duration of the event, in seconds, and can be estimated from the 10 percentage (– 20 dB) points of the motion time histories.

7) In hard rock excavation, where underground disturbances cause higher frequency vibration, a factor of up to 128 has been found to be satisfactory for residential properties in some countries.

8) The magnitudes for transient vibration in offices and workshop areas should not be increased without considering the possibility of significant disruption of working activity.

9) Vibration acting on operators of certain processes, such as drop forges or crushers which vibrate working places, may be in a separate category from the workshop areas considered here. Vibration magnitudes, for the operators of the exciting processes, which are specified in ISO 2631-1, will then apply.

10) Doubling the suggested vibration magnitudes for continuous or intermittent vibration and repeated transient vibration (fourth column) may result in adverse comment and this may increase significantly if the levels are quadrupled (where available, dose/response curves can be consulted).

This part of ISO 2631 is intended to be forward looking, in that users are encouraged to collect vibration data, together with descriptions of human response. Advice has been included on methods of data acquisition and recording methods to allow for future re-analysis of the records. It is hoped that additional data thus provided on human response to different forms of vibration, at a range of frequencies and magnitudes in a variety of situations and resulting from numerous force actions, can be used to update future editions of this International Standard.

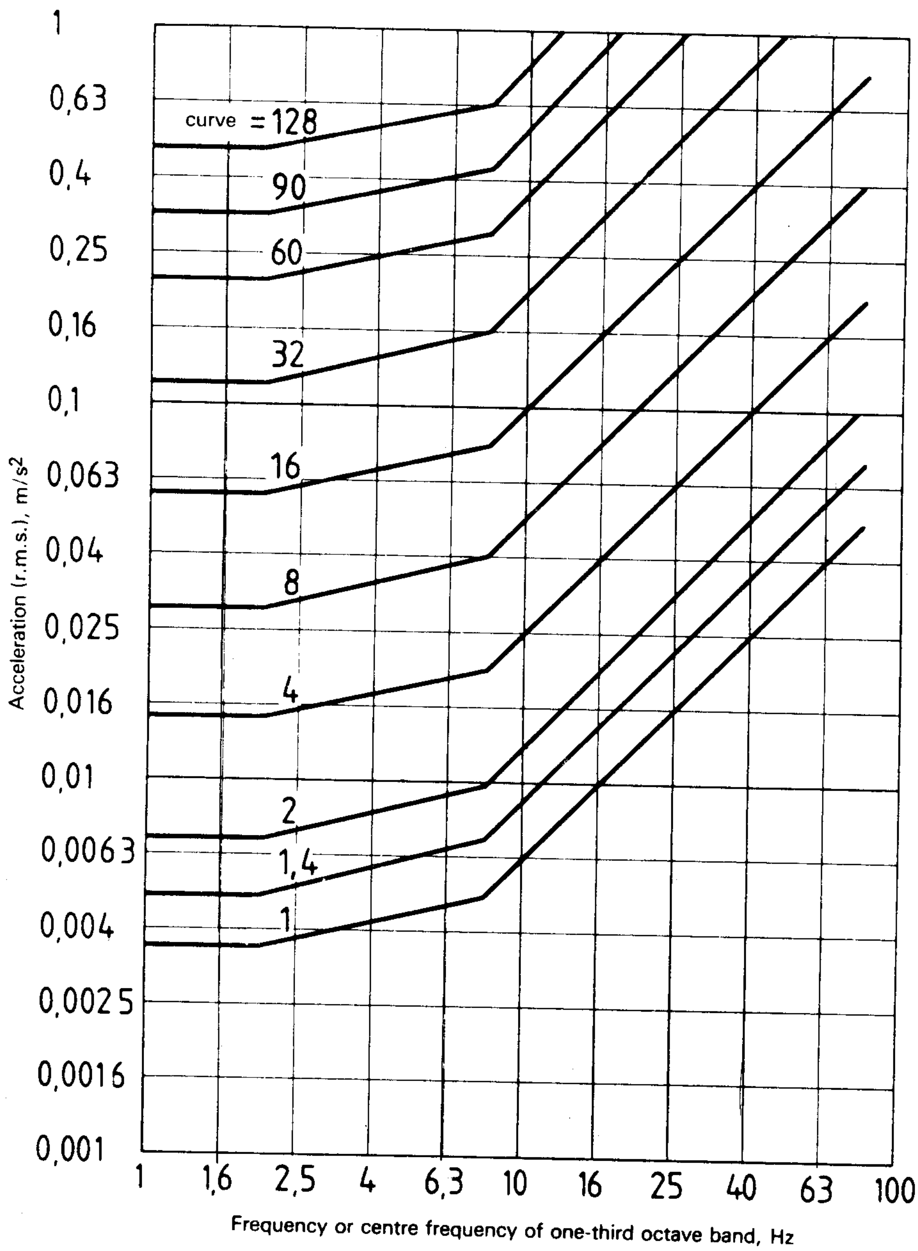


Figure 5a — Vibration in buildings — Combined-direction criteria curves (this represents a combination for the worst case for all three axes as explained in 4.2.3. Curves are shown corresponding to the various multiplying factors given in table 2)

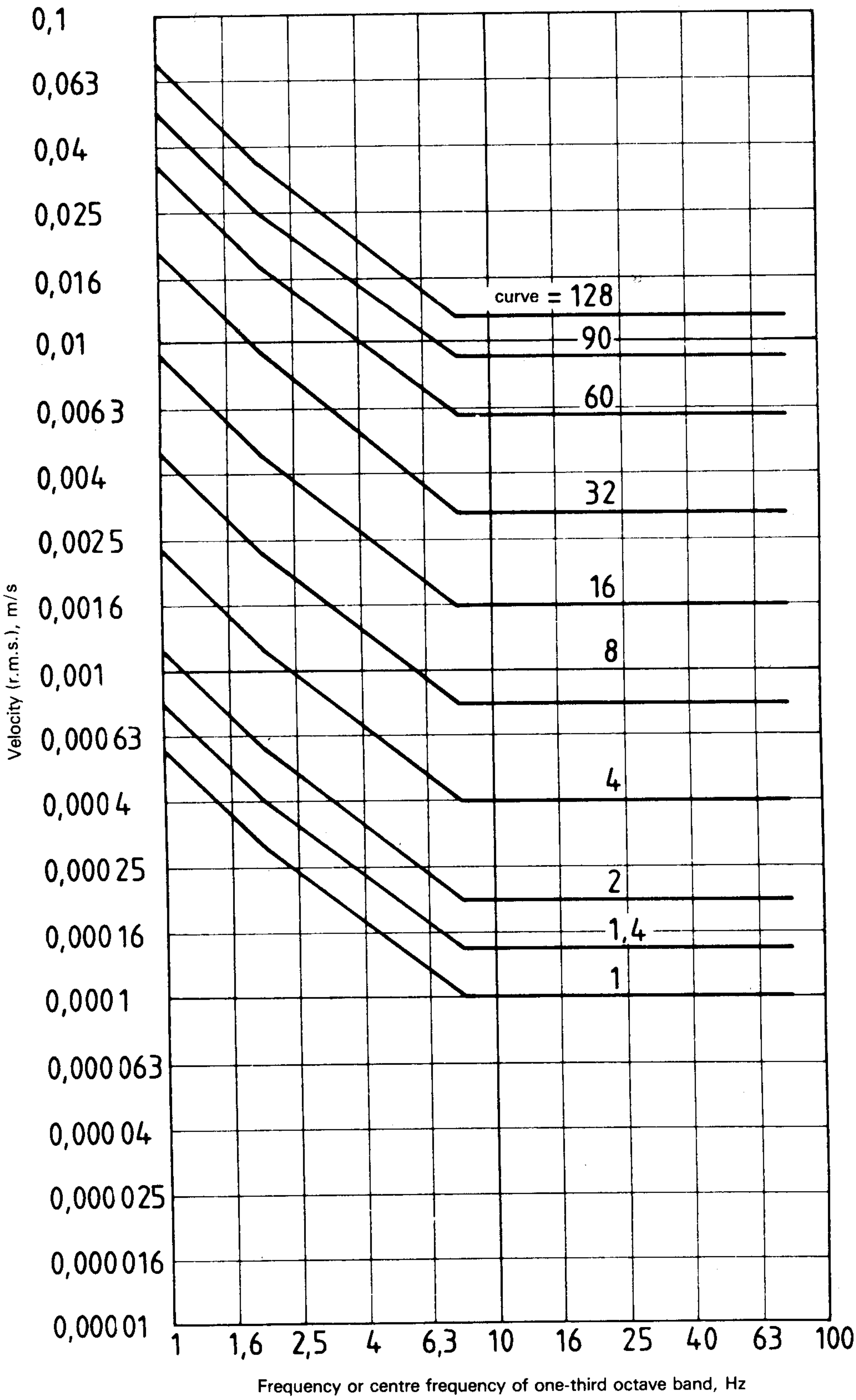


Figure 5b — Vibration in buildings — Combined-direction criteria curves (this represents a combination for the worst case for all three axes as explained in 4.2.3. Curves are shown corresponding to the various multiplying factors given in table 2)

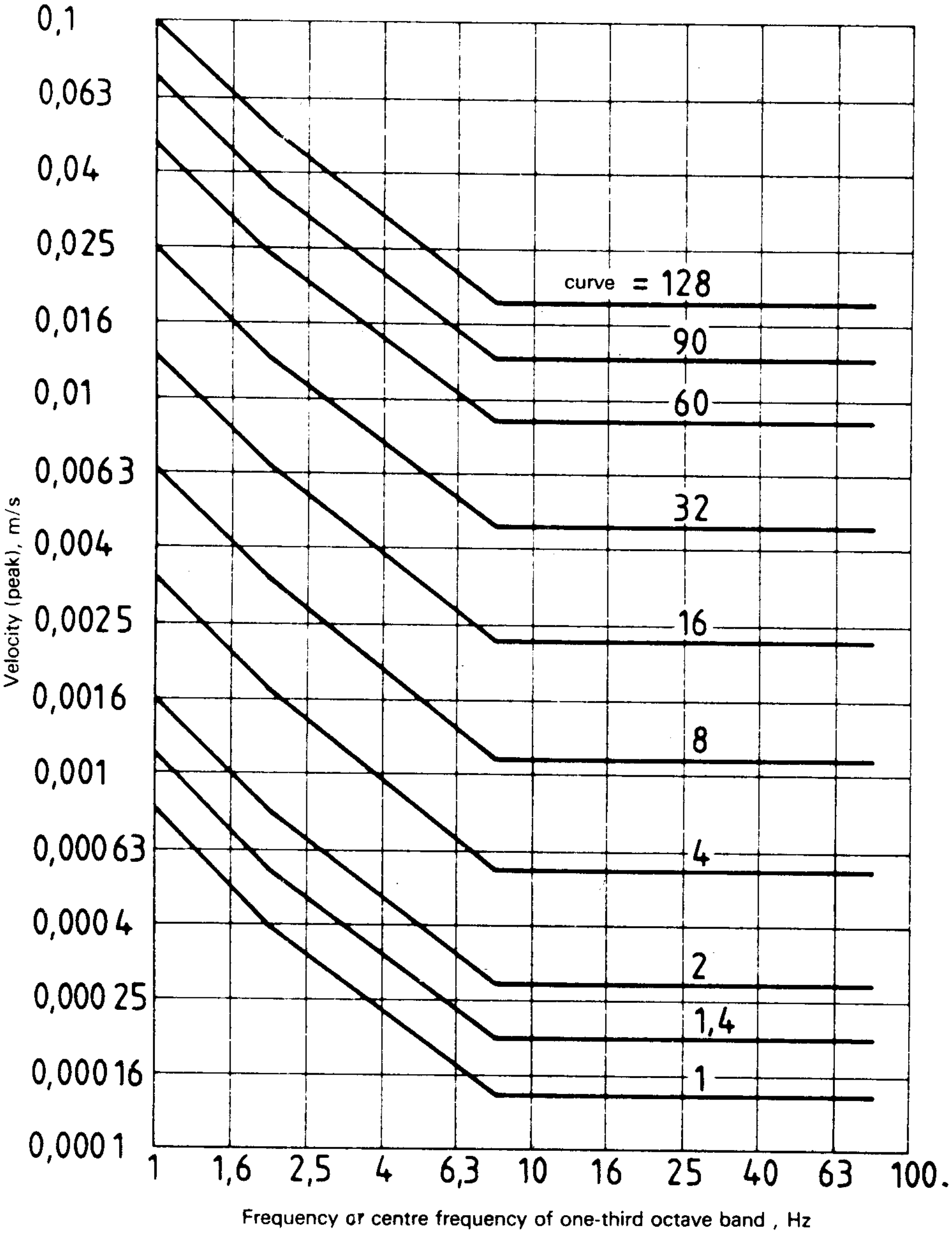


Figure 5c — Vibration in buildings — Combined-direction peak velocity curves (this represents a combination for the worst case for all three axes as explained in 4.2.3. Curves are shown corresponding to the various multiplying factors given in table 2. Vibration criteria in terms of velocity are frequently stated as peak values, which are by a factor 2 above the corresponding r.m.s. value)

Annex B

Evaluation methods under development

(This annex does not form an integral part of the standard.)

This annex lists the evaluation methods for a more detailed characterization of the annoyance effects of impulsive vibration which are currently being researched and tested.

B.1 Peak method

This method has been in use for some time and in this case the values resulting from the use of table 2 are multiplied by $\sqrt{2}$.

B.2 Impulsive extended r.m.s. method

The frequency-weighted vibration signal is passed through an r.m.s. exponential averaging circuit with a time constant of 125 ms the peak of which is time-extended with a decaying time constant of 60 s. (All time constants refer to the squared signal.)

B.3 "Root mean quad" method

The root mean quad [r.m.q. = $\left[\frac{1}{t}\int_0^t a^4(t)\,dt\right]^{1/4}$] of the weighted acceleration signal $a(t)$ may be used to assess the severity of individual shocks.

The same relation between duration and acceleration may be used to accumulate the exposure to intermittent vibration which occurs throughout the day [i.e. accumulated value = $\int_0^t a^4(t)\,dt$].

The value obtained by this method should be related to the value corresponding to the boundaries for continuous vibration. The method allows greater magnitudes with shorter and/or less frequent periods of intermittent vibrations.

B.4 Response spectra method

The ability of the impulse to induce responses in simple physical systems is used as a basic criterion for the severity of the impulse.

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