BRITISH STANDARD

Guide to evaluation of human exposure to vibration in buildings

Part 1: Vibration sources other than blasting

ICS 13.160

British Standards

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Contents

Annexes

List of figures

List of tables

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 21 and a back cover.

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Foreword

Publishing information

This part of BS 6472 was published by BSI and came into effect on 30 June 2008. It was prepared by Subcommittee GME/21/6, *Human exposure to mechanical vibration and shock*, under the authority of Technical Committee GME/21, *Mechanical vibration, shock and condition monitoring*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

Together with BS 6472-2:2008 this part of BS 6472 supersedes BS 6472:1992, which is withdrawn.

Information about this document

This British Standard contains guidance on the evaluation of vibration with respect to human response not available in ISO 2631-2:2003.

The frequency weighting function for vertical vibration has changed from W_g to W_b compared with BS 6472:1992 (withdrawn) and hence vibration evaluations will not be the same as those made previously. The differences depend on the vibration spectrum and may be small, but a difference of a factor of two is possible. This difference could be a factor of 1.4 lower for vibrations that are predominantly at the lowest frequency, or could be a factor up to two higher for vibrations with dominant components at the top end of the frequency range. The frequency weightings introduced for vertical and horizontal vibration mean that the effective frequency range is 0.5 Hz to 80 Hz.

The standard no longer uses basi-centric coordinates that move with the orientation of the human body but uses the geocentric coordinate system in which the vertical and horizontal axes are earth-centred and hence the weightings for supine subjects exposed to motion in the back-to-chest and foot-to-head axes are exchanged compared with previous versions of the standard.

BS 6472-1 and BS 6472-2 contain guidance that takes account of recent developments in the subject. The layout of the standards differs substantially from previous editions. These present versions are intended to be more logical and approachable in their presentation of the background to human perception, in their descriptions of the assessment procedures involved, and in the measurement and evaluation guidance offered.

BS 6472-1 offers guidance on how people inside buildings respond to building vibration: the judgement criteria are more stringent at higher frequencies than in the superseded standard due to changes in the vertical frequency weighting.

BS 6472-2 deals with the particular problems associated with periodic blasting within range of inhabited buildings: the guidance is a formalization of established, widely recognized techniques common in industry.

BS 6472-1 advises use of the estimated vibration dose value *only* as an approximation to the vibration dose value for vibration that is not time-varying in magnitude and has a crest factor which is below about six. Use of the estimated dose value is not recommended for vibration with time-varying characteristics or shocks.

A bibliography of appropriate supporting data published elsewhere is included.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

Structural vibration in buildings can be detected by the occupants and can affect them in many ways; their quality of life can be reduced, as can their working efficiency.

The first overt sign of an unfavourable reaction to building vibration is adverse comment, whereby occupants express negative responses to the vibration. The prevalence of adverse comment depends on specific circumstances, which can include parallel effects such as re-radiated noise. The acceptable magnitudes for building vibration might depend similarly on these parallel effects. This British Standard provides best available information on the application of methods of measuring and evaluating vibration in order to assess the likelihood of adverse comment.

1 Scope

This part of BS 6472 provides guidance on predicting human response to vibration in buildings over the frequency range 0.5 Hz to 80 Hz. Frequency weighting curves for human beings exposed to whole-body vibration are included, together with advice on measurement methods to be employed. Methods of assessing continuous, intermittent and impulsive vibration are presented.

This part of BS 6472 describes how to determine the vibration dose value, VDV, from frequency-weighted vibration measurements. The vibration dose value is used to estimate the probability of adverse comment which might be expected from human beings experiencing vibration in buildings. Consideration is given to the time of day and use made of occupied space in buildings, whether residential, office or workshop.

NOTE 1 In critical work areas, where vibration criteria more stringent than those for human perception are appropriate, this British Standard does not apply.

NOTE 2 Annex A outlines the way in which methods, results and assessments are to be reported, since great care is needed if satisfactory, repeatable conclusions are to be obtained. Annex B provides worked examples of how measurements and predictions might be interpreted in terms of human reaction. Annex C provides examples of the derivation of values appropriate to this British Standard from historic data.

This British Standard does not give guidance on the probability of equipment malfunction, structural damage or injury to occupants in buildings subject to vibration. Neither is guidance given on legal liability or methods of vibration limitation, although beneficial means to the latter are often implied.

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.

BS 6841, *Guide to Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock*

BS EN ISO 8041, *Human response to vibration – Measuring instrumentation*

3 Evaluation of building vibration with respect to human response

3.1 General

In homes, adverse comment about building vibrations is likely when the vibration levels to which occupants are exposed are only slightly above thresholds of perception. In workplaces, adverse comment often arises at rather higher levels, although people in sedentary occupations respond more like home residents. In general, the satisfactory magnitudes referred to in this standard relate to adverse comments by building occupants and are not determined by factors such as short-term health hazard or working efficiency.

Vibration magnitudes that would normally result in adverse comment can sometimes be tolerated, particularly for temporary disturbances or infrequent brief events; an example would be a construction project. However, to reduce adverse comment, the affected community would usually need to be advised of the likely effects, the duration of the activity and that the likelihood of building damage is very low even when vibration levels are well above perception thresholds. This is usually best carried out by a formal programme of public liaison, often in conjunction with the local authority. In cases of long term vibration, adverse comments can be modified by familiarization.

The criteria to be used when assessing human response require consideration of the expected building occupation (homes, offices or workshops) and the activity of the occupants. The criteria should be applied to each occupied room of a building.

Whether at home or at work, the vibration tolerance of people varies over a wide range. As well as a large range of individual vibration sensitivity over the population, specific values depend on social and cultural factors, psychological attitudes and the expected degree of intrusion.

Building vibrations as they affect people can be classified usefully according to a combination of descriptions. The time history of the vibration input to the subject can be:

- continuous;
- intermittent; or
- occasional.

Each of these categories of time history can have one of the following characteristics of vibration:

- constant amplitude;
- variable amplitude; or
- impulsive.

Impulsive vibration is most likely to startle subjects, particularly if irregularly or rarely occurring.

The vibration dose summation procedure, as described in **3.5**, allows comparison of all types of vibration exposure on a common basis, i.e. the severity of impulsive and/or intermittent vibration is evaluated on a basis applicable equally to continuous vibration.

3.2 Frequency weighting

3.2.1 General

The way in which people perceive building vibration depends on various factors, including the vibration frequency and direction. Different frequency weightings are required for different axes of motion. **3.2.2** describes frequency weighting curves to be applied to vibration so that the resulting overall levels can be interpreted in terms of perception, comfort or adverse comment for whole-body vibration. The frequency range concerned is 0.5 Hz to 80 Hz for the three translational axes: fore-and-aft, lateral and vertical.

NOTE In previous versions of the standard, the frequency weightings have been specified with reference to the basi-centric coordinate system. The current view is that the vibration weightings appropriate to the geocentric coordinate system (earth-centred vertical and horizontal) should be applied (see BS 6841) and hence the weightings for supine subjects exposed to motion in the back-to-chest and foot-to-head axes are exchanged compared with previous versions.

3.2.2 Frequency weighting curves

The weighting curve modulus for vertical acceleration is shown in Figure 1. A different weighting curve applies for horizontal vibration. Its modulus is shown in Figure 2. The weightings W_b (for vertical motion) and W_d (for horizontal motion) are defined in BS 6841. The weightings demonstrate maximum sensitivity to vertical acceleration in the frequency range 4 Hz to 12.5 Hz and to horizontal acceleration in the range 1 Hz to 2 Hz.

The mathematical definitions of the frequency weightings are given in BS 6841.

NOTE W_b is the most appropriate frequency weighting network for use with vertical vibration when the levels of vibration are clearly above the threshold of perception. At and just above the threshold of perception it seems that even W_b gives insufficient weight to vibration at the higher frequencies of the range considered.

Figure 1 **Frequency weighting curve (W_b) appropriate for vertical vibration**

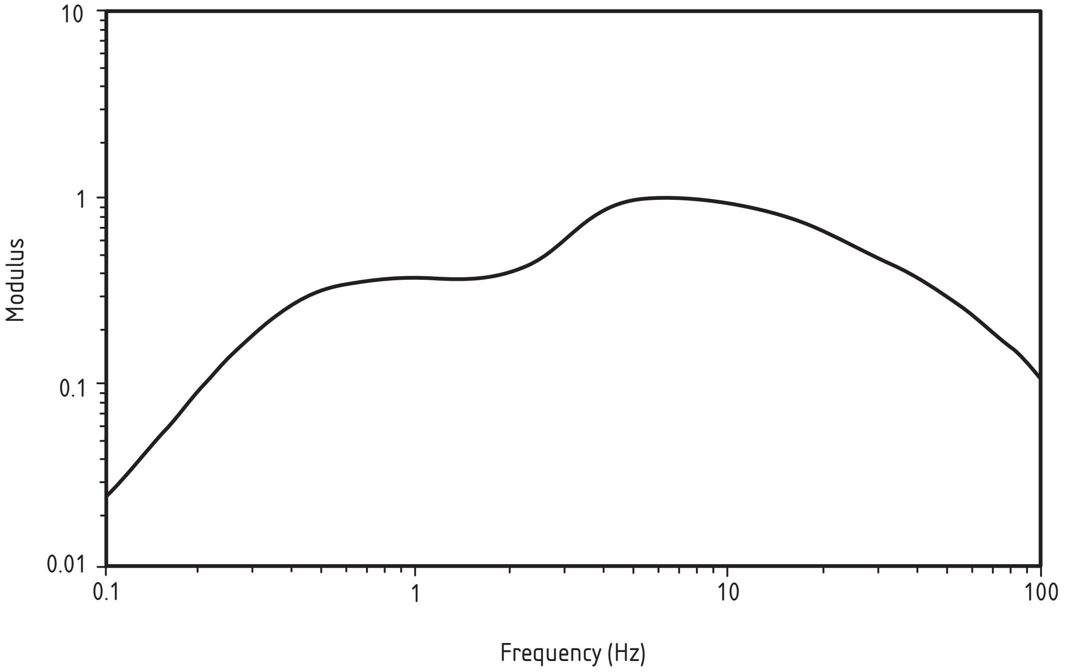
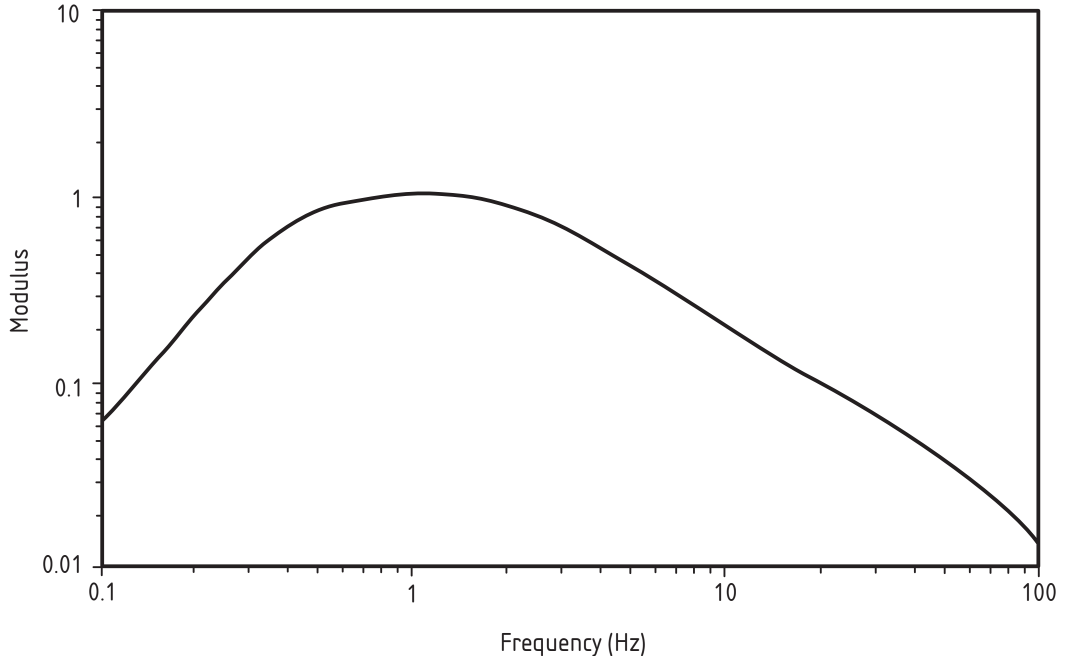


Figure 2 **Frequency weighting curve (W_d) appropriate for horizontal vibration**



3.3 Thresholds of perception

Perception thresholds for continuous whole-body vibration vary widely among individuals. Approximately half the people in a typical population, when standing or seated, can perceive a vertical weighted peak acceleration of 0.015 $m{\cdot}s^{-2}$. The weighting used is W_b. A quarter of the people would perceive a vibration of 0.01 $m{\cdot}s^{-2}$ peak, but the least sensitive quarter would only be able to detect a vibration of 0.02 $m{\cdot}s^{-2}$ peak or more. Perception thresholds are slightly higher for vibration duration of less than about 1 s.

3.4 Time history of vibration occurrence

3.4.1 General

Building vibration can be continuous, intermittent, or occasional. It can also contain impulsive events, such as in shocks, in whole or in part.

3.4.2 Continuous vibration

Vibration is continuous when it is uninterrupted for the assessment period. This can be either a daytime period of 16 h, e.g. 7h00 to 23h00, or a night-time period of 8 h, e.g. 23h00 to 7h00.

3.4.3 Intermittent vibration

Intermittent vibration is vibration which is perceived in separately identifiable repeated bursts. Its onset can be sudden, or there might be a gradual onset and termination bounding a more sustained event. Bursts may happen several to many times in a day or night period.

3.4.4 Occasional vibration

Occasional vibration occurs less often than intermittent vibration, and might be less predictable.

3.4.5 Impulsive vibration

Impulsive vibration, whether continuous, intermittent or occasional, is a rapid build-up to a peak, which might or might not be sustained for a while, followed by a decay that might or might not involve several cycles of vibration (depending on frequency and damping).

3.5 Vibration dose summation

The effect of building vibration on the people within is assessed by finding the appropriate vibration dose. Present knowledge shows that this type of vibration is best evaluated with the vibration dose value (VDV).

The VDV defines a relationship that yields a consistent assessment of continuous, intermittent, occasional and impulsive vibration and correlates well with subjective response. Use of the vibration dose value to assess the acceptability of building vibration with respect to human response is described in Clause **6**. The vibration dose value is defined in Equation 1.

$$\mathrm{VDV}_{\mathrm{b/d,day/night}} = \left(\int_0^T a^4(t)dt \right)^{0.25} \tag{1}$$

Where:

$\mathrm{VDV}_{\mathrm{b/d,day/night}}$ is the vibration dose value (in $\mathrm{m{\cdot}s^{-1.75}}$);

$a(t)$ is the frequency-weighted acceleration (in $\mathrm{m{\cdot}s^{-2}}$), using W_b or W_d as appropriate;

T is the total period of the day or night (in s) during which vibration can occur.

NOTE The VDV should be identified with the vibration acceleration weighting function applied by adding a subscript, that is, VDV_b *or* VDV_d *as appropriate. Where other identifying subscripts are necessary, they should follow the weighting function subscript, separated from it by a comma, e.g.* $\mathrm{VDV}_{\mathrm{b,day}}$.

The VDV is given by the fourth root of the time integral of the fourth power of the acceleration after it has been frequency-weighted. Where possible, the VDV should be determined from a measurement obtained over the full exposure to vibration.

If the dominant direction of weighted acceleration is clear, it is only necessary to determine the VDV in that direction. If the most significant direction is unclear, preliminary estimates to determine which direction will give the greatest weighted acceleration should be made. Where there is no clear dominant direction, assessments in the most significant directions should be made.

Where the vibration conditions are constant or repeated regularly, only one representative sample, of duration τ seconds, needs to be measured. If the vibration dose value determined is $\mathrm{VDV}_{\mathrm{b/d},\tau}$ then the total vibration dose value for the day, $\mathrm{VDV}_{\mathrm{b/d,day}}$ will be given by equation 2.

$$\mathrm{VDV}_{\mathrm{b/d,day}} = \left(\frac{t_{\mathrm{day}}}{t_\tau} \right)^{0.25} \times \mathrm{VDV}_{\mathrm{b/d},\tau} \tag{2}$$

Where: t_{day} is the duration of exposure per day (s).

If, during any assessment period, there is a total of N vibration episodes of various durations t_n each with a vibration dose value of $\mathrm{VDV}_{\mathrm{b/d},t_n}$, the total vibration dose value for the day or night period is given by equation 3.

$$\mathrm{VDV}_{\mathrm{b/d,day/night}} = \left(\sum_{n=1}^{n=N} \mathrm{VDV}^4_{\mathrm{b/d},t_n} \right)^{0.25} \tag{3}$$

The VDV is much more strongly influenced by vibration magnitude than by duration. A doubling or halving of the vibration magnitude is equivalent to an increase or decrease of exposure duration by a factor of sixteen.

For continuous vibration that is not time-varying in magnitude and has a crest factor which is between about three and six, an approximation to the vibration dose value may be determined from the estimated vibration dose value (eVDV) (see Annex C). Use of the estimated dose value is not recommended for vibration with time-varying characteristics or shocks.

3.6 Parallel effects

3.6.1 General

The extent to which people in buildings react to vibration at a given dose level might also depend on related or unrelated effects which occur at the same time. It is important that any investigation should consider whether such parallel effects occur: they should always be reported in writing (see Annex A) and be quantified if possible. The more common parallel effects are described here.

3.6.2 Structure-borne noise

Noise arising from the vibration of building structures (whether caused by ground-borne vibration, acoustic excitation from external sources, or from internal sources) is sometimes heard within buildings. It is typically characterized by low-frequency noise in the spectral region below about 100 Hz. An example is the rumble noise from underground trains, but it can also be due to internal building sources.

The structure-borne noise heard might be a consequence of the vibration perceived; the perceived vibration might also result from acoustic excitation by airborne noise. Structure-borne noise should be measured at that location in the room where its effect is considered to be most disturbing. It might often be masked by ambient noise from other sources, making its unambiguous determination difficult or impossible.

NOTE Current common practice is to measure structure-borne noise using the maximum A-weighted level and "slow" response. The severe attenuation of low frequencies imposed by the A-weighting and the wide tolerance allowed at low frequencies by the A-weighting specification need to be remembered where this is adopted. Any A-weighted measurement should be complemented by unweighted one-third octave band spectra extending down to 20 Hz. See BS ISO 14837-1.

3.6.3 Airborne noise

Airborne noise heard in buildings at the same time as vibration is felt might or might not be related to the vibration source. The presence of noise simultaneously with the perceived vibration might affect a person's response. A noise measurement could be performed. If the noise includes a significant low-frequency component, the reservations of **3.6.2** should be observed.

During evaluation of the airborne noise it should be considered whether monitoring is carried out with windows open or closed. Caution is necessary: windows might themselves be rattling, and their behaviour might change with orientation. Whatever option is selected, it should be reported.

3.6.4 Induced rattling

Effects such as the rattle of windows, furniture, fittings or ornaments might be due to vibration or to acoustic excitation, but their occurrence might emphasize the presence of vibration and should be measured if appropriate, and reported.

3.6.5 Visual effects

In the case of low-frequency vibration, visual effects might be observed, such as the motion of foliage, swinging of suspended features or the periodic displacement of reflected images. These factors might emphasize vibration perception and should be reported.

3.6.6 Influence of a third party

It is likely that the possibility of adverse comment increases if the subject has been influenced to take interest in the reported vibration by suggestion from third parties, perhaps by way of publicity, questionnaire administration or interview. A subjective influence of this type will be difficult or impossible to quantify, but the effect might be strong and needs to be reported.

4 Characteristics of building vibration

4.1 General

During vibratory motion a building might move as an entity on its foundations, or individual building components, such as floors, might exhibit their own vibration characteristics.

Motion of the whole building might occur at frequencies from a fraction of a hertz to a few hertz. These are the lowest frequencies of vibration likely to be perceived in a building and will usually involve bending, twisting or rocking of the whole building. The magnitude and direction of the vibration will depend on the location within the building.

Higher frequencies involve excitation of floors, usually in the range from a few to tens of hertz.

4.2 Causes of building vibration

4.2.1 General

Building vibration might be caused by ground-transmitted vibration or by acoustic excitation from an external noise field. Vibration can also be caused by sources within the building.

4.2.2 External sources

Building excitation is commonly caused by vibration carried through the ground. This might be due to traffic passing (on roads, or on surface or underground rail), industrial sources such as forging or presswork, and construction or demolition work. The vibration might also be due to explosive mineral extraction, see BS 6472-2.

The vibration passing into the building depends on the transfer function between the ground and the building. The dynamic characteristics of a building can lead to much higher vibration levels at some frequencies than are present in the ground. In general, as the frequency rises, there is progressive decoupling between the building and the ground. Great care should be taken in attempting to estimate building vibration from measured ground vibration.

It is also possible for buildings to vibrate due to wind or external airborne acoustic excitation; the latter might be due to passing heavy vehicles or severe aircraft noise. Air overpressure from blasting might also be responsible, see BS 6472-2.

NOTE For further guidance see Annex D.

4.2.3 Internal sources

Internal sources are often the most common, but least noticed, vibration excitation, often comparable with external sources which cause comment.

Internal sources of excitation can generally be separated into two categories; mechanical excitation and human induced excitation. Examples of sources of mechanical excitation in commercial premises are: lifts, air-conditioning or ventilation plant and the heavier office machinery. In household premises, appliances such as vacuum cleaners and washing machines together with door slamming can be sources of unwanted vibration excitation.

Human induced vibration is generally created by dynamic human activity, such as walking, running, jumping, dancing, etc. Such excitation can be rhythmic (e.g. dancing in time with music or walking at a steady pacing rate) or impulsive (e.g. jumping down after standing on a chair).

Particular problems are possible in buildings with mixed usage, where vibrations caused by human activities in one part of a building are transmitted to more sensitive areas elsewhere in the building. Examples might be a quiet office in a building that contains a gymnasium or a hospital with busy corridors close to occupied rooms.

4.3 Low frequency and high frequency floors

A convenient distinction is often made by structural engineers between low and high frequency floors on the basis of their response to human dynamic excitation.

Floors with natural frequencies lower than about 7 Hz –10 Hz are sometimes known as “low frequency” floors. These are susceptible to a resonant build-up of vibration due to periodic human activity such as walking, running, jumping, etc. In such cases, the amplitude of vibration depends on the magnitude of the excitation and the mass and damping of the floor engaged. More massive floors with greater damping exhibit lower vibration response for the same excitation.

Floors with natural frequencies higher than about 7 Hz –10 Hz are sometimes known as "high frequency" floors. Such floors are unlikely to be excited in resonance by human activities. Instead, the vibration response of such floors can usually be considered as a series of transient responses to individual impulses (e.g. footfall impacts).

NOTE Typical examples of "low frequency" floors are long span and slender pre-stressed and conventionally reinforced concrete floors and long-span composite steel-concrete floor systems. "High frequency" floors include relatively shorter span versions of these floor systems and light timber floors.

5 Measuring and estimating building vibration

5.1 General

Whether a person in a building senses a given vibration magnitude depends on what the individual is doing, where the individual is in the building, how the person is coupled to the building and the dominant direction of the vibration.

A person moving around is less likely to notice vibration than a person who is still.

If the person is standing on the floor, the coupling is most direct. If the person is seated, the coupling is less direct, particularly if the seat is upholstered. The seat construction might provide some vibration isolation, or seat resonance might increase vibration.

The dynamic response of a supine person's bed can have a powerful influence. A bed structure can amplify the vibration received from the building and increase the vertical or horizontal vibration.

In the determination of vibration that is or will be experienced by people in buildings, the vibration should be either measured or estimated appropriately, so that the VDV can be derived.

5.2 Measurement of building vibration

5.2.1 General

The instrumentation appropriate for the measurement of building vibration with respect to human response is defined in BS EN ISO 8041.

5.2.2 Direction of measurement

The object of measurement is to quantify the frequency weighted acceleration of the motion and to derive from it the VDV for the exposed person(s) over day and/or night evaluation periods.

Unless the direction of vibration having the dominant effect is known, the motion should be recorded in three orthogonal axes. The fore-and-aft and lateral axes should be chosen, as appropriate, to represent the principal axes of the building occupied by the person or the radial and tangential directions relative to the source. If the direction of the dominant motion is known, the motion may be measured uniaxially along the axis in which the weighted acceleration amplitude is greatest. Transducers should be mounted so as to reflect faithfully the motion of the object or surface being measured. There should be no loss-of-contact or resonance to affect the measurement over the relevant frequency range. Guidance on transducer mounting can be found in BS EN ISO 8041. The transducer mounting system used should be reported.

The vibration is to be evaluated for the single axis, whether determined by uniaxial sampling or from triaxial measurement, in which the magnitude of weighted acceleration is greatest.

Preferably, the unweighted, band-limited acceleration time history should be recorded and retained and the required VDV obtained by subsequent analysis. Alternatively, the weighted acceleration may be evaluated directly in the field, or another parameter measured and the required VDV obtained indirectly. Whatever method is adopted, the instruments and settings used should be reported and a complete technical description given of any indirect method employed.

NOTE Vibration caused by blasting is usually measured as a peak particle velocity. Guidance on the measurement of blasting vibration is provided in BS 6472-2.

5.2.3 Location of measurement

The primary aim in the selection of the measurement location should be to establish the vibration level at the point of entry to the body. However, it is seldom possible to identify such a position uniquely and therefore it is more normal to measure at a location that would be expected to give rise to the highest levels of vibration to which the occupants would be exposed. Where measurements are made other than at the point of entry of vibration to the body, an allowance should be made for the transfer function between the measurement point and the point of entry to the body. It is essential that this allowance is reported with the measurements.

Vibration should normally be measured on the floor of the room implicated (where any complaint originates, or where the greatest adverse comment is predicted.) at or near the point of greatest weighted acceleration. The way in which a floor responds usually depends on two factors: whether the excitation is external or internal and whether the floor is “low frequency” or “high frequency”.

For external excitation (e.g. ground-borne vibration), it is likely that the response of a floor will be dominated by rigid body motion or by its lowest “dish-shaped” mode of vibration. In this case, one or two measurement points in a suitable available area, preferably in the central part within one-third and two-thirds of the width/length, are sufficient to determine the vibration response of the floor to this form of excitation.

For internal excitation (e.g. pedestrian footfalls), it is likely that the response of the floor will vary according to the modal properties (natural frequencies, mode shapes and damping) of both “low frequency” and “high frequency” floors. Assessment should be made at or near the place(s) where most adverse comment has been generated, with a typical walking path and pacing rate as excitation.

If particular furniture is implicated in a complaint, it might be possible for the transfer function between the furniture/complainant and the floor surface to be estimated. The estimate and justification should be reported in detail.

5.3 Estimation of building vibration

In cases where it is not possible to measure within buildings, either because of denial of access or for a building yet to be constructed, it will be necessary to estimate the vibration environment to be expected within the building.

NOTE General guidance is given in Annex D.

6 Assessment of building vibration with respect to human response

When the appropriately-weighted vibration measurements or predictions have been used to derive the VDV for either 16 h (daytime) or 8 h (night-time) at the relevant places of interest, their significance in terms of human response for people in those places can be derived from Table 1. The judgement made is of the probability that the determined vibration dose might result in adverse comment by those who experience it.

Table 1 **Vibration dose value ranges which might result in various probabilities of adverse comment within residential buildings**

Place and time	**Low probability of adverse comment** $m \cdot s^{-1.75}$ [1]	**Adverse comment possible** $m \cdot s^{-1.75}$	**Adverse comment probable** $m \cdot s^{-1.75}$ [2]
Residential buildings 16 h day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8 h night	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

NOTE For offices and workshops, multiplying factors of 2 and 4 respectively should be applied to the above vibration dose value ranges for a 16 h day.

These values represent the best judgement currently available and may be used for both vertical and horizontal vibration, provided that they are correctly weighted. It is inevitable that the criteria have to be presented as ranges rather than discrete values. This stems largely from the widely differing susceptibility to vibration evident among members of the population, but also from their differing expectations of the vibration environment. Parallel effects can also exert some influence. Because there is a range of values for each category, it is clear that the judgement can never be precise.

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[1] Below these ranges adverse comment is not expected.

[2] Above these ranges adverse comment is very likely.

Annex A (informative) Suggested format and content of an assessment report

The assessment report needs to cite the person or body to whom it is addressed and refer to this British Standard.

In completing this report, it should be a conscious objective that sufficient information is provided to enable an experienced investigator to confirm the findings. The information to be reported needs to include some or all of the following, depending on the particular situation.

a) General information:
   - location(s);
   - dates and times;
   - person/people carrying out measurement(s) and assessment(s).

b) Information about the vibration under investigation:
   - character of the vibration: continuous, intermittent, occasional, impulsive;
   - frequency of occurrence and durations;
   - receptor locations, building/floor/ground types, and vibration direction(s);
   - information about source of vibration (e.g. type of train, track, etc., type of plant or machinery).

c) Instrumentation and analysis:
   - transducer(s) and calibrators: types and serial numbers, calibration history;
   - signal processing and recording equipment;
   - post-processing/analysis equipment, including details of software.

d) Measurement procedure:
   - locations of transducer(s);
   - method(s) of fixing transducer to measurement object or surface;
   - vibration parameters measured, number, times and duration of measurements;
   - calibration procedure(s);
   - background levels of vibration (in absence of source);
   - information about measurement surface, e.g. floor or ground, description of any preliminary tests carried.

e) Analysis procedure(s):
   - full explanation of how VDVs are derived from measurement results;
   - information about any measured or estimated transfer functions used in the analysis (e.g. of seats, beds, or from external ground to floor of building).

f) Statement of results:
  - statement of measurement uncertainty and/or confidence limits of measured values.

g) Results of predictions of levels of vibration:
  - results of any predictions, accompanied by details of the prediction method, of any assumptions or limitations involved, and of the input data.

h) Information about parallel effects:
  - all information about any parallel effects, as described in **3.5**: structure-borne noise, airborne noise, induced rattling, visual effects, influence of a third party.

i) Assessment:
  - assessment method and results of the assessment(s), e.g. in terms of probability of adverse comment.

j) Subjective observations:
  - any other relevant observations not already included e.g. subjective impressions by the person carrying out the measurements, or anecdotal information conveyed to him or her by third parties.

Annex B (informative) Calculation examples of evaluations and assessments

B.1 Example 1: Repeated exposures – determination of VDV over the day

Thirty repeated vertical vibration events, each of duration τ seconds, occur during a 16 h day. The VDV for each event is $0.15\ \text{m·s}^{-1.75}$. The VDV over the day is calculated and assessed as follows.

$$\text{VDV}_{\text{b/d,day}} = \left(\frac{t_{\text{day}}}{t_{\tau}}\right)^{0.25} \times \text{VDV}_{\text{b/d},\tau}$$

$$\text{VDV}_{\text{b},\tau} = 0.15\ \text{m·s}^{-1.75}$$

$$\text{VDV}_{\text{b,day}} = 30^{0.25} \times 0.15 \ = 0.35\ \text{m·s}^{-1.75}$$

There is a low probability of adverse comment according to Table 1.

B.2 Example 2: Repeated exposures – determination of eVDV over one day

Ten occurrences, each of duration 25 s and frequency-weighted r.m.s. acceleration of 0.10 m·s^{-2} r.m.s., occur during a 16 h day. The eVDV (see **C.4**) is calculated as follows.

$$\mathrm{eVDV} = 1.4 \times a(t)_{\mathrm{r.m.s.}} \times t^{0.25}$$

$$= 1.4 \times 0.1 \times (10 \times 25)^{0.25}$$

$$= 0.56\ \mathrm{m{\cdot}s}^{-1.75}$$

Referring to Table 1, it is concluded that adverse comments are possible.

Annex C (informative) Derivation of values appropriate to this British Standard from historic data

C.1 General

Previous editions of BS 6472 used evaluation methods that seemed appropriate in the light of knowledge and experience then available.

In the light of more recently maturing knowledge and experience, this version of the standard uses VDV as its preferred derived unit of evaluation and a different frequency weighting function for vertical vibration.

There might be situations where it is desirable to examine results derived in the past in the light of the revisions now introduced. This annex suggests how and to what extent this might be done for a number of cases.

C.2 Case 1: Full unweighted vibration recordings still available

This is the simplest case. The revised weighting can be applied to derive the updated VDV, and comparison made with the present criteria.

C.3 Case 2: W_g-weighted vibration recordings still available

It should be possible to operate on the recorded data to introduce the difference in weighting function. These weighting functions are defined in BS 6841.

C.4 Case 3: One-third octave weighted or unweighted time histories available

In this case it is necessary to use the eVDV, in place of the VDV, and then operate on the recorded data to introduce the different weighting function. The values of the weighting functions at one-third octave intervals, and their ratios/differences are tabulated in Table C.1.

The limitations of one-third octave filtered recorded results need to be kept in mind, particularly if there are substantial low frequency contributions to the signal. The settling time of a filter at the low end of the frequency range will be several seconds. Hence the slew-rate of the signal which can be followed reasonably faithfully is very low.

The eVDV is defined in Equation C.1.

$$\text{eVDV} = 1.4 \times a(t)_{\text{r.m.s.}} \times t^{0.25} \tag{C.1}$$

Where:

eVDV is the estimated vibration dose value (in m·s$^{-1.75}$). As with VDV, the eVDV should be identified with the vibration acceleration weighting function applied by adding a subscript, that is, eVDV$_g$, eVDV$_b$ or eVDV$_d$ as appropriate. Where other identifying subscripts are necessary, they should follow the weighting function subscript, separated from it by a comma, e.g. eVDV$_{b,day}$;

$a_{\text{r.m.s.}}$ is the root-mean-squared value of the frequency-weighted acceleration, using W_g, W_b or W_d as appropriate (in m·s^{-2});

t is the total duration of vibration exposure (in s).

The factor 1.4 in the relationship for the eVDV has been determined empirically from typical vibration environments having low crest factors. It has been shown that for continuous vibration which is not time varying in magnitude and which has a crest factor below about six, the eVDV provides a useful approximation to the true VDV. The eVDV tends to be higher than the VDV for very low crest factors (3) and lower than the VDV for high crest factors (6). Where there is any doubt or difference between the true VDV and the eVDV, the VDV should be determined directly. The use of eVDV is not appropriate for the assessment of shocks and other time-varying conditions. For these types of motion, the true VDV should be determined.

NOTE One-third octave magnitudes of acceleration a m·s^{-2} may be converted into vibration levels (dB) using the equation $L_A = 20.\log(a_w / a_0)$ where $a_0 = 1 \times 10^{-6}$ m·s^{-2}.

Table C.1 **W_b and W_g frequency weightings including band limiting, and their differences in arithmetic and logarithmic form corresponding to true one-third-octave centre frequencies**

Nominal one-third octave band centre frequency Hz	**True one-third octave band centre frequency** Hz	**W_b-weighting** factor	**W_g-weighting** factor	**W_b-weighting/ W_g-weighting**	**W_b-weighting** dB	**W_g-weighting** dB	**W_b-weighting minus W_g-weighting** dB
0.5	0.5012	0.3347	0.1617	2.0704	−9.51	−15.83	6.32
0.63	0.631	0.3666	0.2404	1.5251	−8.72	−12.38	3.67
0.8	0.7943	0.3808	0.3330	1.1437	−8.39	−9.55	1.17
1	1	0.3853	0.4237	0.9094	−8.28	−7.46	−0.82
1.25	1.259	0.3864	0.5053	0.7647	−8.26	−5.93	−2.33
1.6	1.585	0.3916	0.5855	0.6688	−8.14	−4.65	−3.49
2	1.995	0.4168	0.6757	0.6169	−7.60	−3.41	−4.20
2.5	2.512	0.496	0.7817	0.6345	−6.09	−2.14	−3.95
3.15	3.162	0.6653	0.8986	0.7404	−3.54	−0.93	−2.61
4	3.981	0.885	1.002	0.8830	−1.06	0.02	−1.08
5	5.012	1.026	1.050	0.9771	0.22	0.42	−0.20
6.3	6.31	1.0554	1.009	1.0448	0.46	0.08	0.38
8	7.943	1.026	0.8939	1.1478	0.22	−0.97	1.20
10	10	0.9745	0.7499	1.2995	−0.22	−2.50	2.28
12.5	12.59	0.9042	0.6110	1.4800	−0.87	−4.28	3.41
16	15.85	0.8144	0.4908	1.6592	−1.78	−6.18	4.40
20	19.95	0.7088	0.3918	1.8092	−2.99	−8.14	5.15
25	25.12	0.5973	0.3116	1.9168	−4.48	−10.13	5.65
31.5	31.62	0.4906	0.2471	1.9854	−6.19	−12.14	5.96
40	39.81	0.395	0.1950	2.0261	−8.07	−14.20	6.13
50	50.12	0.3118	0.1521	2.0497	−10.12	−16.36	6.23
63	63.1	0.2389	0.1158	2.0634	−12.44	−18.73	6.29
80	79.43	0.1734	0.0837	2.0711	−15.22	−21.54	6.32

C.5 Case 4: Only the historic VDV is known

If there is no other information, then compared with a contemporary assessment, the original VDV could be between about one half and one-and-a-half times the value now thought appropriate.

If the vibration was known to be dominated by frequencies at the high end of the range, then the historic VDV will be low by a factor of two.

If the vibration was known to be dominated by frequencies near the low end of the range, the historic VDV could perhaps be up to 50% too high.

C.6 Case 5: Only the historic eVDV is known

This is the least favourable case: the potential difficulties of Case 3 and Case 4 are both involved.

Annex D (informative) Estimation of building vibration

D.1 General

Mathematical modelling might be used to predict structural vibration levels in cases where measurements cannot be made. Typical examples are in existing structures to which access is denied or during the design of a new structure. In the former case, the structural configuration is already defined and the purpose of the predictions is to estimate its real-life vibration behaviour. In the latter case, the purpose of the mathematical modelling is to aid the design and help determine an optimum structural solution which is likely to have a satisfactory vibration performance.

The problem of structural vibration prediction in buildings can be addressed by simulating the vibration response of the structure to external and/or internal excitation. To do this the structural mass, stiffness and damping properties need to be defined in addition to the excitation.

D.2 Vibration excitation

The vibration that occurs within a building can result from an external source. Examples of this are road traffic, particularly heavy vehicles traversing discontinuities such as rough road surfaces or speed humps, and railway traffic. The fluctuating force on the ground thus generated creates three main wave types, among others, which allow the vibrational energy to propagate to the foundations of buildings. These are compression waves (P-waves), shear waves (S-waves) and surface (Rayleigh) waves.

In order to predict the vibration within the building, it is essential that the forces input to the ground be calculated, together with the manner in which the energy dissipates as it spreads from source to receiver. The force into the ground can be modelled by considering the dynamic characteristics of the forcing mechanism, usually in terms of the mass, stiffness and damping of vibrating components. Propagation can then be modelled by a range of techniques of varying complexity, such as the analysis of an elastic half space, two-dimensional or three-dimensional finite element techniques, finite difference techniques, semi-infinite finite-element techniques and boundary-element techniques.

Homogeneous ground characteristics might be assumed, or layering might be accounted for. The characteristics of the ground that are important in determining propagation behaviour are its density, loss factor, Poisson's Ratio and Young's Modulus. These characteristics can vary from layer to layer, and are also dependent on the degree to which the soil is saturated with water, with this latter characteristic potentially fluctuating significantly with time, depending on rainfall. The presence of a building tends to compress the ground locally by virtue of its weight, which therefore affects the vibration propagation in its vicinity.

Internal sources of excitation of the building under consideration might include machinery and human activity. Dynamic forces produced by machinery may be estimated using manufacturer's data or through measurements. Attenuation of vibration caused by machinery in buildings is usually achieved using vibration isolation techniques or modification (e.g. balancing) of the machinery. However, in the case of human activity, it is usually impossible to isolate the vibration source from the structure. A reasonable definition of human dynamic forces therefore needs to be made. Numerous suggestions exist as to models of human dynamic excitation for various activities (walking, running, jumping, etc.), although research is continuing in this area. The reader is guided to other references for such information [1], [2].

D.3 Calculation of building vibration response

Calculation of building vibration response is performed by considering the mass, stiffness and damping properties of the structure, and by applying the pre-defined excitation function.

For simple structures it might be possible to calculate the vibration response using closed-form solutions available in the literature [3]. An example of such a structure might be a rectangular floor plate subject to a harmonic or impulsive excitation.

Numerical modelling, such as finite element analysis (FEA), can be used to produce reliable estimates of the vibration response to specified dynamic excitation for arbitrary structural configurations and excitation functions. This is true provided that the problem is well understood by the analyst and best practice FEA modelling procedures are followed [4]. FEA is implemented in numerous commercially available software packages which can be used to perform the required simulation of vibration response. Detailed guidance for the dynamic FEA modelling of buildings and/or building components are beyond the scope of this standard and can be found elsewhere [4].

When calculating vibration responses, it is particularly important to use a realistic estimate of structural damping, based on previous experience with floors of similar construction.

D.4 Use of simplified methods to estimate building vibration response

Simplified methods exist to calculate the building vibration response under both internal and external excitation.

Prediction of building vibration response due to ground-borne excitation is possible by making use of previously measured transfer functions between the ground and other similar buildings [5]. When using measured ground vibration responses from a proposed building location as the excitation function, an allowance needs to be made for the presence of the building which is likely to alter the characteristics of the ground vibration in its vicinity.

Simplified calculation procedures have been produced for specific types of floors ([1], [6]) under human dynamic loading. However, such guidelines have tended to be developed for ease of use rather than a rigorous examination of the vibration problem. As a result, they are often highly over-conservative but have also been shown to be under-conservative in some cases. Also, extrapolation of guidelines for a specific type of floor to other types of floors where guidance does not exist has proved to be problematic.

It is therefore clear that great care needs to be taken when using simplified methods as they rarely provide highly accurate estimations of response.

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