BRITISH STANDARD

BS 7385-2:
1993

Evaluation and measurement for vibration in buildings —

Part 2: Guide to damage levels from groundborne vibration

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the General Mechanical Engineering Standards Policy Committee (GME/-) to Technical Committee GME/21, upon which the following bodies were represented:

Electricity Association
Federation of Civil Engineering Contractors
Imperial College of Science and Technology
Institute of Sound and Vibration Research
Institution of Mechanical Engineers
Lloyds Register of Shipping
Ministry of Defence
Open University
Power Generation Contractors' Association (BEAMA Ltd.)
Railway Industry Association of Great Britain
Sira Test and Certification Ltd.
Society of British Aerospace Companies Limited
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The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

Association of Consulting Engineers
British Coal Corporation
British Railways Board
British Society for Strain Measurements
Department of the Environment (Building Research Establishment)
Department of Trade and Industry (National Engineering Laboratory)
Department of Transport (Transport Research Laboratory)
Health and Safety Executive
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Institute of Acoustics
Institute of Explosives Engineers
Institution of Environmental Health Officers
University of Leeds

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Contents

Foreword

This Part of BS 7385 has been prepared under the direction of the General Mechanical Engineering Standards Policy Committee. It should be considered together with BS 7385-1:1990 *Guide for measurement of vibrations and evaluation of their effects on buildings.*

More detailed consideration of the methodology for measurement, data analysis, reporting and building classification is given in BS 7385-1, to which the reader is referred for further guidance beyond the basic principles given here.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 10, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Introduction

Groundborne vibration from sources such as blasting, piling, machinery or road/rail traffic can be a source of concern for occupants of buildings in the vicinity. This concern can lead to a need to assess the effect of the imposed vibration on the building structure to ascertain whether damage could occur. This Part of BS 7385 provides guidance on the assessment of the possibility of vibration-induced damage in buildings due to a variety of sources.

There is a lack of reliable data on the threshold of vibration-induced damage in buildings both in countries where national standards already exist and in the UK. This Part of BS 7385 has been developed from an extensive review of UK data, relevant national and international documents and other published data. Although a large number of case histories was assembled in the UK database [1], very few cases of vibration-induced damage were found. It has been necessary therefore, to refer to the results of experimental investigations carried out in other countries into vibration-induced damage thresholds.

This Part of BS 7385 sets guide values for building vibration based on the lowest vibration levels above which damage has been credibly demonstrated. It is intended to provide a standard procedure for measuring, recording and analysing building vibration together with an accurate record of any damage occurring.

1 Scope

This Part of BS 7385 gives guidance on the levels of vibration above which building structures could be damaged. It identifies the factors which influence the vibration response of buildings, and describes the basic procedure for carrying out measurements. Vibrations of both transient and continuous character are considered. A method of assessment which takes into account the characteristics of the vibration, the building and the measured data is given. It is appropriate for the types of investigation given in BS 7385-1, but for detailed engineering analysis, criteria other than the vibration levels may need to be considered.

Only the direct effect of vibration on buildings is considered. The indirect effects on the building structure due to ground movement, the movement of loose objects within buildings, the possibility of damage to sensitive equipment and the effect of vibration on people are outside the scope of this Part of BS 7385. There is a major difference between the sensitivity of people in feeling vibration and the onset of levels of vibration which damage the structure. Levels of vibration at which adverse comment from people is likely are below levels of vibration which damage buildings, except at lower frequencies. The evaluation of human exposure to vibration in buildings is covered in BS 6472.

This Part of BS 7385 does not consider the many other causes of cracking in buildings; cracking commonly occurs in buildings whether they are exposed to vibration or not (see annex A).

Damage due to earthquakes, air overpressure, wind or the sea are also outside the scope of this Part of BS 7385. It is applicable only to vibration transmitted through the ground and not to vibration set up by machinery within a building. Chimneys, bridges and underground structures such as chambers, tunnels and pipelines are not covered.

2 References

2.1 Normative references

This Part of BS 7385 incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on page 10. Subsequent amendments to, or revisions of, any of these publications apply to this Part of BS 7385 only when incorporated in it by updating or revision.

2.2 Informative references

This Part of BS 7385 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on page 10, but reference should be made to the latest editions.

3 Definitions

For the purposes of this Part of BS 7385, the following definitions apply.

3.1
peak particle velocity (p.p.v.)

the maximum instantaneous velocity of a particle at a point during a given time interval

NOTE Whereas the disturbance caused by a vibration source propagates away from that source with a certain wave velocity, ground particles oscillate with a variable particle velocity. At a given location along the propagation path the motion may be defined in terms of three mutually perpendicular components (usually vertical, transverse and longitudinal or radial). In order to ensure that the peak particle velocity is correctly measured, all three components have to be measured simultaneously.

3.2
peak component particle velocity

the maximum value of any one of three orthogonal component particle velocities measured during a given time interval

3.3
dynamic magnification

the motion measured at a given point (usually in the structure) divided by the motion measured at a reference point (usually at the base of the structure or on the foundation)

NOTE 1 The dynamic magnification is not necessarily greater than 1 (values less than 1 indicating a reduction of vibration levels).

NOTE 2 In common practice the dynamic magnification is based on a comparison of values of p.p.v. from time histories, and is therefore frequency independent. The dynamic magnification does however vary with frequency and, when based upon a comparison of spectral peaks, is called a spectral magnification or amplification.

4 Characteristics of building vibration

4.1 Duration

The structural response of a building can be significantly affected by the duration of the vibration to which it is exposed. The time characteristic of various vibration forcing functions is given in Table 1 of BS 7385-1:1990 and **3.2** of BS 7385-1:1990. The limit above which damage may be caused for vibration of a continuous nature may need to be lower than the corresponding limit for transient vibration. If the building is exposed to continuous vibration for a sufficient time (which is dependent on frequency and damping of the structure), it is possible for dynamic magnification to occur if a resonant frequency of the structure is close to the excitation frequency. The possibility of fatigue of building materials would also arise if a vibration source causes a sufficient number of stress reversals, however, no substantiated cases are known to have arisen from groundborne vibration.

4.2 Frequency range

Typical frequency ranges covering the dominant structural response to various sources of vibration are given in Table 1 of BS 7385-1:1990. The lowest frequency originating from man-made sources included in this Part of BS 7385 is 1 Hz and the highest frequency expected from either machinery or close-in construction blasting in hard ground is 1 000 Hz, however a more limited range of 4 Hz to 250 Hz is usually encountered in buildings. For the purpose of selecting guide values from those given in this Part of BS 7385, it is the frequency of the input vibration to the building which is of relevance.

4.3 Sources of vibration

Sources of vibration which are considered include blasting (carried out during mineral extraction or construction excavation), demolition, piling, ground treatments (e.g. compaction), construction equipment, tunnelling, road and rail traffic and industrial machinery.

5 Factors to be considered in building response

5.1 General

The response of a building to groundborne vibration is affected by the type of foundation, underlying ground conditions, the building construction and the state of repair of the building.

5.2 Foundation type and ground conditions

The interaction between the ground and the foundation of the structure can have a major effect on building response. The geology of the ground between the vibration source and the building also affects the input frequency spectrum to the building. In general stiffer foundations result in higher natural frequencies of the building-soil system and higher input frequencies are often associated with harder ground. Categories of foundations and types of soils are given in annex A of BS 7385-1:1990.

The strain imposed on a building at foundation level is proportional to the p.p.v. but is inversely proportional to the propagation velocity of the shear or compression waves in the ground [2]. Since the propagation velocity increases with ground stiffness, a higher p.p.v. measured with harder ground conditions may induce the same strain (cracking potential) as a lower p.p.v. measured with softer ground, provided that it occurs significantly far away from a resonance [3]. Thus where a structure closely follows the movement of the ground, it may be possible to allow a higher p.p.v. with hard ground conditions.

5.3 Type and construction of building

The strains induced in a building by a given vibration excitation will depend upon the dynamic characteristics of the particular type of building, i.e., the natural frequencies, mode shapes and damping. Natural frequencies are determined by the geometry of the building and the components, the degree of fixity of these components in the structure and the stiffness and mass of each component. Older, low-rise masonry structures tend to have higher natural frequencies in comparison with modern lightweight, flexible and taller buildings. Higher levels of strain will result when excitation frequencies are close to natural frequencies.

A classification of buildings is given in annex A of BS 7385-1:1990, with an indication of the relative resistance to vibration.

5.4 Building components

Individual building components such as walls, floors, beams or ceilings have natural frequencies which are usually higher than the frequencies of the building as a whole, and are therefore more susceptible to excitation at resonance by continuously operating machinery, than the building as a whole.

In assessing the effect of vibration on building components it should be noted that the dynamic stresses corresponding to a p.p.v. of 10 mm/s, range typically from only 0.4 % to 2.3 % of the allowable design stress for some specific building materials [4]. A method of estimating peak stress from p.p.v. is given in annex B of BS 7385-1:1990.

6 Measurement of vibration

6.1 General

The general principles for measuring vibration in buildings are given in BS 7385-1:1990. Guidance on specific measurements to be carried out for the purpose of assessing the possibility of vibration-induced damage are given in **6.2** to **6.6**.

6.2 Quantity to be measured

Peak particle velocity has been found to be the best single descriptor for correlating with case history data on the occurrence of vibration-induced damage. Cracking occurs however, due to excessive structural strain, due to either distortion as the building follows movement of the ground or ground motion which causes inertial loading of the building [2]. In some situations, therefore, it may be appropriate to measure strain directly.

The preferred method of measuring p.p.v. is to record simultaneously unfiltered time histories of the three orthogonal components of particle velocity, which allows any desired value to be extracted at a later stage. Where it has been demonstrated that time histories are consistent, then, as indicated in **6.1** of BS 7385-1:1990, it may be adequate to characterize the vibration by a continuous measurement of p.p.v. values. The maximum of the three orthogonal components should be used for the assessment, since the majority of data on which guide values have been based are expressed in peak component particle velocity. True resultant particle velocity is obtained by vectorily summing the three orthogonal components coincident with time. The peak true resultant particle velocity is the maximum value of the true vector sum obtained during a given time interval and should also be derived for reference.

NOTE 1 The use of the maximum vector sum, which takes the maximum of each component regardless of the time when it occurs, is discouraged, because it may include a large unknown safety factor.

NOTE 2 Where measurements are being made for the purposes of a detailed engineering analysis the peak true resultant particle velocity should be used, and the measuring directions should be recorded.

6.3 Measuring positions

Measurements should be taken at the base of the building on the side of the building facing the source of vibration, to define the vibration input to the building. Where this is not feasible, the measurement should be obtained on the ground, outside of the building (see also **7.2.2** of BS 7385-1:1990). One of the horizontal vibration components should be in the radial direction between the source and the building in the case of ground measurements or oriented parallel with a major axis of the building when investigating structural response. Vibration measurements at locations other than the base of the building should be taken for the purposes of a more detailed engineering analysis (see **9.2.4** of BS 7385-1:1990).

6.4 Mounting of transducer

Transducers should be mounted to reproduce faithfully the vibration in the frequency and magnitude ranges in which vibration response may be expected [5,6]. Detailed guidance is given on coupling the transducer to the building structure in **7.2** of BS 7385-1:1990.

6.5 Instrumentation

The measuring system, comprising transducers, signal conditioning and data recording elements should be selected according to the type of investigation intended. The overall system, and in particular the transducer, should have an adequate sensitivity and frequency range to cover the expected range of vibration frequency and velocity magnitudes. The time duration of the recorded time history will depend upon the character of the excitation, but should be such that the maximum response is recorded and the spectral characteristics are established with appropriate accuracy (see **3.2** and **6.1** of BS 7385-1:1990). Requirements for the measuring instrumentation are given in clause **6** of BS 7385-1:1990.

Periodic checks on the function and calibration of the instrumentation should also be carried out [6]. Calibration of the vibration transducer, should conform to BS 6955-0:1988.

6.6 Measurement procedure

The measurement procedure to be adopted depends on the type of investigation required, i.e. a preliminary assessment, a monitoring program, a field survey or a detailed engineering analysis (see **9.2** of BS 7385-1:1990). Where initial desk studies indicate that nearby buildings could be at risk, then trial measurements should be carried out to establish the vibration attenuation between the source and these buildings [2]. The survey record should be consistent with the type of investigation required (see **9.2** of BS 7385-1:1990), but should also include information on the vibration source, the site layout, ground conditions, type of building and condition, instrumentation and results [7,8] (more detailed guidance is given in annex B).

It is essential that data should be fully and correctly reported.

7 Assessment of vibration

7.1 General

The risk of vibration-induced damage should be evaluated taking into account the magnitude, frequency and duration of recorded vibration together with consideration of the type of building which is exposed.

7.2 Basis for damage criteria

Case-history data, taken alone, has so far not provided an adequate basis for identifying thresholds for vibration-induced damage [1,9]. Data from systematic studies [10 to 17], using a carefully controlled vibration source in the vicinity of buildings has therefore been used as the basis for defining damage thresholds. The majority of the data at the higher levels of vibration is usually associated with the effect on residential buildings excited by blasting and constructional activities.

7.3 Estimation of vibration frequency

Strains imposed in a building by ground motion will tend to be greater if lower frequencies predominate [18]. The relative displacements associated with cracking will be reached at higher vibration magnitudes with higher frequency vibration [3]. Thus a frequency-based vibration criterion is given in this Part of BS 7385 and some estimation of the frequency content of the recorded vibration has to be made.

The dominant frequency to use for the assessment is that associated with the greatest amplitude pulse. The method of estimating frequency depends on whether the vibration time history is simple or complex in character. The simplest case consists of a time history record with a single dominant pulse, where the dominant frequency may be taken as the inverse of twice the time interval of the two zero crossings on either side of the peak. This technique is only reliable where the vibration consists of a single frequency [19]. In more critical circumstances or if a visual examination of the vibration time history shows that it is multi-frequency in nature, then frequencies should be determined from an amplitude-frequency plot, with each significant peak being examined in turn [20].

7.4 Vibration guide values

7.4.1 *Nature of vibration guide values*

The vibration levels suggested are judged to give a minimal risk (see **9.7** of BS 7385-1:1990) of vibration-induced damage. Some data [13] suggests that the probability of damage tends towards zero at 12.5 mm/s peak component particle velocity. This is not inconsistent with an extensive review of the case history information available in the UK.

7.4.2 ***Guide values for transient vibration relating to cosmetic damage***

Limits for transient vibration, above which cosmetic damage could occur are given numerically in Table 1 and graphically in Figure 1. In the lower frequency region where strains associated with a given vibration velocity magnitude are higher, the guide values for the building types corresponding to line 2 are reduced. Below a frequency of 4 Hz, where a high displacement is associated with a relatively low peak component particle velocity value a maximum displacement of 0.6 mm (zero to peak) should be used.

Minor damage is possible at vibration magnitudes which are greater than twice those given in Table 1, and major damage to a building structure may occur at values greater than four times the tabulated values.

NOTE Damage categories are defined in **9.9** of BS 7385-1:1990.

7.4.3 ***Guide values for continuous vibration relating to cosmetic damage***

The guide values in Table 1 relate predominantly to transient vibration which does not give rise to resonant responses in structures, and to low-rise buildings. Where the dynamic loading caused by continuous vibration is such as to give rise to dynamic magnification due to resonance, especially at the lower frequencies where lower guide values apply, then the guide values in Table 1 may need to be reduced by up to 50 %.

NOTE There are insufficient cases where continuous vibration has caused damage to buildings to substantiate these guide values but they are based on common practice.

7.5 Special cases

7.5.1 ***Fatigue considerations***

There is little probability of fatigue damage occurring in residential building structures due to either blasting [3, 21, 22], normal construction activities or vibration generated by either road or rail traffic. The increase of the component stress levels due to imposed vibration is relatively nominal and the number of cycles applied at a repeated high level of vibration is relatively low. Non-structural components (such as plaster) should incur dynamic stresses which are typically well below, i.e. only 5 % of, component yield and ultimate strengths [14]. Thus unless calculation indicates that the magnitude and number of load reversals is significant (in respect of the fatigue life of building materials) then the guide values in Table 1 should not be reduced from fatigue considerations.

7.5.2 ***Important buildings***

Important buildings which are difficult to repair may require special consideration on a case-by-case basis. A building of historical value should not (unless it is structurally unsound) be assumed to be more sensitive.

7.5.3 ***Alternative evaluation technique***

In some cases in a detailed engineering analysis, the response spectrum technique [3,13] may be useful in evaluating the vibration of a building. This technique includes the effect of frequency and damping and can be used for any type of time history but has so far been applied mainly to seismic effects and shock.

7.5.4 ***Indirect damage due to soil compaction***

Damage to buildings can sometimes arise indirectly from vibration in certain ground conditions where the vibration is of sufficient magnitude to cause soil compaction (see annex C).

7.5.5 ***Underground constructions***

Structures below ground are known to sustain higher levels of vibration and are very resistant to damage unless in very poor condition.

Table 1 — Transient vibration guide values for cosmetic damage

Line (see Figure 1)	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 Hz to 15 Hz	**15 Hz and above**
1	Reinforced or framed structures Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structures Residential or light commerical type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above

NOTE 1 Values referred to are at the base of the building (see **6.3**).

NOTE 2 For line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded.

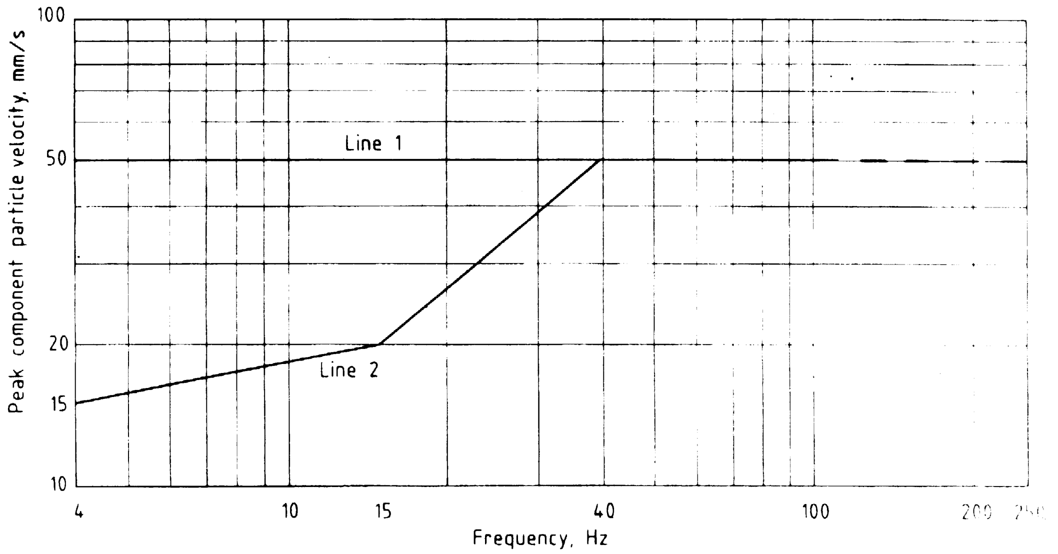

Figure 1 — Transient vibration guide values for cosmetic damage

Annex A (informative) Cracking in buildings

A.1 General

Cracking first occurs in buildings immediately after construction or over a period of several years, depending upon the methods and materials used in construction and change in ground characteristics caused by, for example, the removal of trees. Buildings have different life spans or time periods before deterioration or damage occurs. This time period depends upon the stresses to which the building has been exposed as well as the resistance of the building materials to physical and chemical effects.

Heat, moisture, settlement, occupational loads, prestressing forces, material creep and chemical changes all cause movements in the building. In an optimized design, the build up of stress concentrations in the structural elements should be minimized. If the design does not permit adequate relaxation of these stress concentrations, then cracks will develop which indicate where movement joints are required, or alternatively where further support or reinforcement is needed. Thus cracks normally exist to varying degrees in buildings not subjected to vibration and are not, in themselves, an indication of vibration-induced damage. There are many reasons why buildings crack and care is required to ascertain the true cause [23 to 25].

For a building not exposed to major external disturbances such as vibration, there exists a time rate of cracking due to natural ageing [26]. This natural cracking rate can be significantly increased by an external disturbance triggering cracks instantaneously, which can only be detected by a survey of building cracks immediately before and after the disturbance. A small increase in cracks or crack length however should not be taken as damage due to any imposed vibration. Buildings also expand and contract preferentially along existing weaknesses (cracks) between daytime and night-time and also seasonally. This continually varying expansion and contraction will return normal repair and repainting to the previous cracked state within several years or even months [3].

A.2 Wall or ceiling lining materials

Wall or ceiling lining materials rather than the main building components are often the most sensitive to imposed vibration. For cracking to occur, the vibration induced strain combines with the pre-existing strain so that the critical strain of a wall covering material is exceeded. The lowest critical strain is associated with old plaster and lath walls while the paper backing on gypsum-type wallboard has the highest resistance to imposed strain [14], although cracks can frequently occur at the joints between boards.

A.3 Age and existing condition of building

The age and existing condition of a building are factors to consider in assessing the tolerance to vibration. Older buildings may have soft mortar joints, simple footings or poor cross-bracing. Arches may be effectively articulated off the main structure. Modern buildings have limitations on deflections, deviations, inclinations, curvatures or widths of cracks allowed at the design stage (see ISO 4356). Guidance is available with respect to cracking for modern buildings according to the building materials involved, whether the cracks are surface cracks or through-cracks, whether they are likely to open further or close, whether they are repairable or capable of being covered by decoration, whether water penetration is a factor, and the probable attitude of persons affected, in view of the intended use of the building.

Historical damage due to sources other than vibration may also be masked by recent renovation and redecoration. The existence of major alterations can be a specific cause of an increased rate of cracking. If a building is in a very unstable state, then it will tend to be more vulnerable to the possibility of damage arising from vibration or any other groundborne disturbance.

Annex B (informative) Data to record during a survey

NOTE The following listing is intended to provide comprehensive background information for detailed investigations. The level of detail recorded should be commensurate with the type and purpose of the survey.

B.1 General

The following details should always be recorded:

a) testing organization;

b) name of person(s) carrying out the test;

c) date and time of measurement;

d) weather conditions and ambient temperature.

B.2 Details of vibration source

Details of the vibration source should always be recorded, e.g:

a) blasting: type of blasting (opencast coal, quarry, construction or demolition), charge type, charge weight per delay, initiation, firing pattern;

b) piling:

1) if percussive: hammer type, model number, weight and drop height (or energy);

2) if vibratory: operating frequency, pile type, size and length;

c) dynamic compaction: drop weight and drop height;

d) machine type: repetition rate, drop weight (if impact type of machine), speed, foundation details, workpiece details;

e) rail traffic: type of rail vehicle (locomotive/wagons), axle loading, number of wagons, speed, pass-by frequency; track details: rail shape and fixing, location of joints, railhead condition, type of track support;

f) road traffic: truck types, axle loading, speed, pass-by frequency, road alignment, condition of surface including potholes, manholes, location of expansion joints and other irregularities.

B.3 Site details

The following site details should be recorded:

a) sketch of site and location, photographs from source and receiver positions, section showing any sloping ground;

b) horizontal and vertical distances between source and measuring position at the building facade;

c) directions of measurement, other nearby sources of vibration.

B.4 Ground type

At source location, at the building and in between, the following details of ground type should be recorded:

a) geotechnical details (including borehole logs) at ground level and foundation level;

b) evidence of jointing or faulting and if measurable the orientation and depth;

c) wave velocity data;

d) changes in geology between source location and building location;

e) evidence of ground improvement or indications of made-up ground;

f) any history of underground mining/settlement in the area.

NOTE 1 Also see BS 5930:1981.

NOTE 2 Photographs should be included where appropriate.

B.5 Building structure

B.5.1 *General*

The following details of the building structure should be recorded:

a) description of building, room sizes, layout and site plan and photographs;

b) type of construction, floor plans;

c) type of foundation, estimated depth and width;

d) general condition of the building structure, list of obvious defects, photographs;

e) approximate age of building, details of any major extensions, repairs, renovations (e.g. whether the same type of construction as the original been used).

B.5.2 *Crack inspection report (pre-exposure and post-exposure)*

B.5.2.1 *General*

The dates and times of the pre-exposure inspection and the post-exposure inspection should be recorded.

B.5.2.2 *Internal*

The following internal details of the building should be recorded:

a) location, length, width, age and orientation (i.e. horizontal, vertical or diagonal) of cracks in each room;

b) type of wall finish, presence and orientation [see item a)] of any cracks;

c) ceiling type, presence and orientation of any cracks in the ceiling (i.e. parallel, perpendicular or diagonal with respect to a wall), evidence of any unstable plaster;

d) decorative condition and date last decorated, evidence of paint flaking;

e) windows, whether cracked or loose fitting, evidence of misting in any double glazed units, presence of gaps around the frame or the cill, or evidence of any corner cracks, especially near lintels;

f) door fitting, evidence of expansion due to moisture or cracking at the corners of the door frame;

g) evidence of lack of squareness at the corners of adjoining walls, type of floor and whether level.

B.5.2.3 *External*

The following external details of the building should be recorded:

a) wall construction (brick, concrete blocks or stone), wall condition, evidence of cracking, location, orientation (see item of a) **B.5.2.2**), length, width and age of external cracks, deviation from level of the first brick course, existence and width of gaps between path and wall;

b) evidence of settlement at one corner or along one side, slope of the ground between the source of vibration and the building;

c) evidence of large trees nearby or of large trees recently removed;

d) drainage details and depth of water table;

e) any noticeable settlement of nearby structures.

A photographic record should be taken of all visible cracks and defects. The photographs should be numbered and correlated with the written record.

B.6 Vibration assessment

B.6.1 ***Subjective observations***

The following subjective observations should be made and recorded:

a) whether vibration is detectable through feet or hands, by windows rattling or other audible effects;

b) whether vibration is worse on the ground floor or higher floors or at particular locations;

c) whether the vibration frequency is low or high;

d) the approximate duration and frequency of occurrence of the vibration.

B.6.2 ***Measurement details***

The following measurement details should be recorded:

a) transducer type, serial numbers, operating frequency limits, useable magnitude range, calibration factors;

b) type of signal conditioning or recording system, serial numbers, operating ranges, gain settings, trigger level, fullscale reading, time axis sensitivity, result of calibration procedure or date last calibrated;

c) measurement positions and axes, manner of coupling of the transducer to the building or the ground.

B.6.3 ***Test results***

The following test results should be recorded:

a) maximum p.p.v. including peak component and peak true resultant;

b) individual time histories and duration of vibration;

c) predominant frequencies in time histories and frequency spectra;

B.6.4 ***Assessment***

The following assessment of the test results should be made:

a) comparison of maximum p.p.v. (peak component value) with the vibration limit appropriate to the type of building and the duration of the source.

b) evaluation of the possibility of vibration-induced damage according to the vibration assessment, details of the site and condition of the building structure.

Annex C (informative) Building damage due to soil compaction

Depending upon the type of ground, ground vibration can cause consolidation or densification of the soil [3,22,27], which has been known to result in differential settlement and consequent building damage. Loose and especially water-saturated cohesionless soils are vulnerable to vibration which may cause liquefaction. It has been shown in laboratory tests that there can be a rearrangement of constituent particles at shear strains of 0.0001, and this becomes marked at strains of 0.001. Such soils, which may have shear wave propagation velocities of around 100 m/s start to become vulnerable at p.p.v. values of about 10 mm/s. The damage to the soil structure is then a function of the number of cycles of straining. The loading transmitted to the soil through the foundations may reduce the vulnerability of the soil to such damage, but there are cases where the acceptable vibration limit may be set by considerations of soil-structure interaction, rather than distortion or inertial response of the building itself.

List of references (see clause 2)

Normative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 6955, *Calibration of vibration and shock pick-ups.*

BS 6955-0:1988, *Guide to basic principles.*

BS 7129:1989, *Recommendations for mechanical mounting of accelerometers for measuring mechanical vibration and shock.*

BS 7385, *Evaluation and measurement for vibration in buildings.*

BS 7385-1:1990, *Guide for measurement of vibrations and evaluation of their effects on buildings.*

Informative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 5930:1981, *Code of practice for site investigations.*

BS 6472:1992, *Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz).*

ISO standards publications

INTERNATIONAL STANDARDS ORGANIZATION (ISO), GENEVA. (All publications are available from Customers Services, Publications, BSI.)

ISO 4356:1977, *Bases for the design of structures — Deformations of buildings at the serviceability limit states.*

Other references

[1] MALAM, D., *Groundborne vibration and structural damage*, Paper presented at SECED evening meeting at the Institution of Civil Engineers, 30th September, 1992. Available from the library of the Institution of Civil Engineers.

[2] NEW, B.M., *Ground vibration caused by civil engineering works*, Transport and Road Research Laboratory Research Report 53, 1986. Available from Transport Research Laboratory, Crowthorne, Berkshire, RG11 6AU.

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