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Vibrations in buildings – Part 3: Effects on structures, English translation of DIN 4150-3:2016-12

Erschütterungen im Bauwesen –
Teil 3: Einwirkungen auf bauliche Anlagen,
Englische Übersetzung von DIN 4150-3:2016-12

Vibrations dans les bâtiments –
Partie 3: Effets sur les construction,
Traduction anglaise de DIN 4150-3:2016-12

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Contents

Foreword

This standard has been prepared by Working Committee NA 005-51-05 AA "Vibrations in construction; Actions on structures and elements of structures" of *DIN-Normenausschuss Bauwesen* (DIN Standards Committee Building and Civil Engineering). It supersedes DIN 4150-3:1999-02.

DIN 4150, *Vibrations in buildings* consists of the following parts:

— Part 1: *Prediction of vibration parameters*

— Part 2: *Effects on persons in buildings*

— Part 3: *Effects on structures*

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. DIN [and/or DKE] shall not be held responsible for identifying any or all such patent rights.

Amendments

This standard differs from DIN 4150-3:1999-02 as follows:

a) the standard has been revised in form and substance;

b) subclauses 3.4 (peak vibration velocity), 3.7 (topmost floor), 6.3 (start-up and shutdown operations) and Table 2 (guideline values for underground cavities) have been included;

c) an alternative method for evaluating effects of short-term vibration in foundations has been specified;

d) the topmost floor has been specified as the part of the building where structural vibration is to be measured and assessed;

e) the provisions relating to vibration measurement in buildings have been summarized in Clause 7;

f) the status of Annex C has been changed to be normative.

Previous editions

DIN 4150-3: 1975-09, 1986-05, 1999-02

1 Scope

This standard specifies methods of determining and evaluating the effects of vibration on structures designed for predominantly static loading. It covers structures which do not need to be designed to specific standards or codes of practice on dynamic loading.

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.

DIN 1311 (all parts), *(Mechanical) vibrations, oscillations and vibration systems*

DIN 4150-1, *Vibrations in buildings — Part 1: Prediction of vibration parameters*

DIN 4150-2, *Vibrations in buildings — Part 2: Effects on persons in buildings*

DIN 45669-1, *Measurement of vibration immission — Part 1: Vibration meters — Requirements and tests*

DIN 45669-2, *Measurement of vibration immission — Part 2: Measuring method*

DIN EN 1594, *Gas infrastructure — Pipelines for maximum operating pressure over 16 bar — Functional requirements*

3 Terms and definitions

For the purposes of this standard, the terms and definitions given in DIN 1311 (all parts) and the following apply.

3.1
vibration
mechanical oscillation of solid bodies that has the potential to cause discomfort to persons or damage to structures

3.2
damage
any permanent consequence of an action that reduces the serviceability of a structure or one of its components

3.3
guideline value
a value obtained by experience, compliance with which ensures that damage does not occur

3.4
peak vibration velocity
$v_{\mathrm{i, max}}$
maximum absolute value of the signal $v(t)$ in the direction of measurement i ($i = x, y, z$)

3.5
short-term vibration
vibration that does **not** occur often enough to cause material fatigue and whose development over time and duration is **not** suitable for producing a significant increase in vibration due to resonance in the particular structure

3.6
long-term vibration
any type of vibration not covered by the definition of "short-term vibration"

3.7
topmost floor
uppermost floor of a building that is supported by structural walls and normally has a stiffening effect in both horizontal directions

4 Principles of determining and evaluating the effects of structural vibration

4.1 Suitable methods

Vibration measurements on which this standard is based have proven to be a suitable means of determining and evaluating the effects of structural vibration.

If such measurements are not available, then the effects of vibration shall be evaluated by determining the dynamic stresses occurring in the structure by measurement or analysis, and subsequently comparing the results with the resistance capacity, taking their frequency of occurrence into account. Note that both methods are unsuitable for assessing minor damage (see also 4.5).

In some cases, vibration cannot be classified as being only short-term or only long-term. In such cases, it shall be evaluated separately on the basis of both Clause 5 and Clause 6.

In particular cases, foundation displacement as an indirect consequence of vibration is also to be taken into consideration (see also 4.6).

Where tunnelling work involves blasting operations or in case of outdoor blasting operations, structural vibration may also be induced by an air blast wave. In this case, the guideline values given in this standard also apply.

4.2 Vibration measurements

Vibration occurring in a structure can be detected directly using an accelerometer, a displacement transducer or a velocity transducer (see Clause 7). The evaluation is made on the basis of absolute peak vibration velocity values. A distinction is made between short-term vibration (see Clause 5) and long-term vibration (see Clause 6).

This document gives guideline values for vibration velocities obtained by experience from numerous measurements.

Experience shows that **no** damage due to vibration adversely affecting serviceability (see 4.5) will occur if these guideline values are complied with. If damage nevertheless occurs, it is to be assumed that other causes are responsible. Exceeding the guideline values does not necessarily lead to damage. Should they be exceeded, however, further investigations may be necessary, such as determining and evaluating the stresses as detailed in 4.3 and 4.4.

4.3 Determination of stresses

By measuring strain in a vibrating building component and applying the constitutive equation, the dynamic stresses can be inferred.

By measuring vibration displacement, velocity or acceleration, the amplitude and frequency of these vibration parameters can be determined and used in stress/strain calculations.

Stresses in beams or slabs vibrating close to resonance can be approximated on the basis of the vibration velocity amplitude, provided the measurement is made at the point of the greatest amplitude. In this case, the boundary conditions and stiffness of the component need not be known to enable an estimation of the stresses (see also Clause 6).

As an alternative, stresses can also be determined by calculation only.

Local measurements of strain in single building components (e.g. foundations) are unsuitable for adequately assessing the effects on the structure as a whole.

4.4 Resistance capacity

Verification of load bearing capacity shall be carried out using the safety factors specified in the relevant standards and codes of practice for additional dynamic loading, taking into account the type and duration of the dynamic loads, the measurement method, the properties of the building materials and the type of construction.

Where necessary, load-bearing capacity shall also be verified taking fatigue strength into account. If fatigue strength diagrams are available, these can be used to establish, as a function of the number of expected stress reversals, the stress limits, displacement amplitudes, deformations and similar parameters for the building materials, building components and joints.

A more rigorous analysis of fatigue strength may be dispensed with if, for the verification of the load-bearing capacity, the dynamic load components are multiplied by a fatigue coefficient of 3.

Fatigue analysis is not required if the dynamic load component is less than 10 % of the permissible static load.

4.5 Evaluation standards

Examples of reduced serviceability of a building or building components due to the effects of vibration include:

— impairment of the stability of the building;

— a reduction in the load-bearing capacity of floors and other components.

For buildings as in lines 2 and 3 of Tables 1, 4 or B.1, the serviceability is considered to have been reduced if, for example

— cracks form in plastered or rendered surfaces of walls;

— existing cracks in a structure are enlarged;

— partitions become detached from load-bearing walls or floor slabs.

These effects are deemed “minor damage”.

For buildings as in line 1 of Tables 1, 4 or B.1, “minor damage” is deemed not to reduce serviceability.

“Minor damage” caused by slight vibration is considered to be the result of a particular sensitivity (of a structure) to vibration (as in line 3 of Table 1, 4 or B.1)..

4.6 Effects of vibration on soil

Strong vibration can cause subsidence of soil, primarily in the case of loose to medium-dense, non-cohesive soil such as sand and gravel; this can lead to foundation settlement. This is particularly the case where there is long-term vibration, uniformly graded sand or soil below groundwater level. For more information, see Annex C.

5 Short-term vibration

5.1 Evaluation of structures

5.1.1 Evaluation of the structure as a whole

The evaluation shall be based on the horizontal vibration velocities occurring in the topmost floor, taking the maximum of the two horizontal components as a basis. Measurements taken at this point usually provide the maximum horizontal response of the structure to the excitation at the foundation.

As an alternative to evaluating the effects of short-term vibration by direct measurement at the topmost floor, measurements can also be taken at the foundation. The evaluation is based on the maximum value $v_{\mathrm{i,\,max}}$ of the three components $i = x, y, z$ of the vibration velocity $v(t)$ at the foundation.

Guideline values for $v_{\mathrm{i,\,max}}$ at the foundation and at the plane of the topmost floor (where $i = x, y$) are given in Table 1 for various types of building. The frequency-dependent guideline values for vibration at the foundation allow for the transmission of vibration from the foundation to the topmost floor. The values from columns 2 to 4 of Table 1 have been plotted in Figure 1.

To determine which frequency ranges shown in Table 1 apply, that frequency shall be taken which occurs within the relevant velocity range, with special care being applied to low frequencies. By making use of analytical methods, the character of the signal shall also be taken into consideration, for instance by means of suitable window functions (see also Annex D).

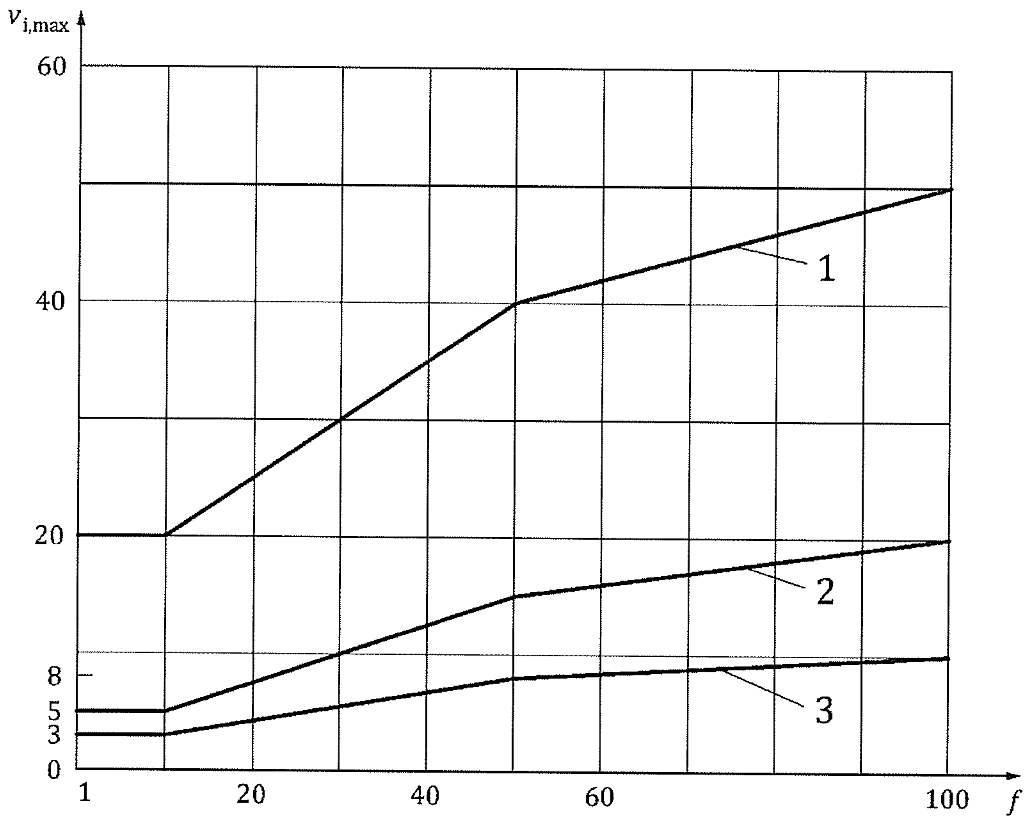
As an alternative, the equivalent evaluation method described in Annex B can also be used, which is an automatable measurement and evaluation method. In this case the maximum values of the frequency-weighted vibration velocities are to be compared directly with the relevant guideline values, which are not frequency-dependent.

Table 1 — Guideline values for vibration velocity, $v_{i, max}$, for evaluating the effects of short-term vibration on structures

-	Type of structure	Guideline values for $v_{i, max}$ in mm/s				
		Foundation, all directions, i = x, y, z, at a frequency of			Topmost floor, horizontal direction, i = x, y	Floor slabs, vertical direction, i = z
		1 Hz to 10 Hz	10 Hz to 50 Hz	50 Hz to 100 Hz [a]	All frequencies	All frequencies
Line \ Column	1	2	3	4	5	6
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	20	20 to 40	40 to 50	40	20
2	Residential buildings and buildings of similar design and/or occupancy	5	5 to 15	15 to 20	15	20
3	Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 **and** are of great intrinsic value (e.g. listed buildings)	3	3 to 8	8 to 10	8	20 [b]
NOTE	Even if guideline values as in line 1, columns 2 to 5, are complied with, minor damage cannot be excluded.					

[a] At frequencies above 100 Hz, the guideline values for 100 Hz can be applied as minimum values.

[b] Paragraph 2 of 5.1.2 shall be observed.



Key

1	Line 1
2	Line 2
3	Line 3
f	Frequency (Hz)
$v_{i,\,max}$	Peak vibration velocity (mm/s)

Figure 1 — Graphical representation of guideline values specified in Table 1 for velocities measured at the foundation

5.1.2 Evaluation of floor slabs

Where short-term vibration causes floor slabs to vibrate, if $v_{i,\,max} \leq 20$ mm/s when measured in vertical direction ($i = z$) at the point of maximum velocity (which is usually at the centre of the floor slab), a reduction in serviceability of the floors is not to be expected (see also Table 1, column 6). As an alternative to a direct measurement, the vertical vibration at the foundation (see also Table 1, columns 2 to 4) may be used for the purposes of the evaluation.

In the case of building types as in Table 1, line 3, it may be necessary to lower the relevant guideline value markedly to prevent minor damage.

5.2 Evaluation of massive structural components and underground structures

For civil engineering structures such as reinforced concrete constructions used as abutments or block foundations, a value of 80 mm/s shall be used as a guideline value, provided no hazards arise as a result of soil mechanical processes in the ground.

For evaluating the effects on linings of tunnels, galleries and cavities in rock, the guideline values given in Table 2 shall be used. It shall be assumed that the lining has been manufactured and applied using current technology; otherwise, lower values will need to be applied.

Table 2 — Guideline values for $v_{i, max}$, for evaluating the effects of short-term vibration on the lining of underground cavities

Line	Lining material	Guideline values for $v_{i, max}$, in mm/s perpendicular to lining surface
1	Reinforced or sprayed concrete, tubbing segments	80
2	Concrete, stone	60
3	Masonry	40
NOTE The guideline values were measured during nearby mine blasting operations and apply only to the lining of underground structures, but not to any associated installations.		

5.3 Evaluation of buried pipework

Table 3 gives guideline values for evaluating the effects of vibration on buried pipework.

It shall be assumed that the pipes have been manufactured and laid using current technology; if this is not the case, special considerations will have to be made. This also applies if soil mechanical processes in the ground could have deleterious effects on pipes, or where there are different conditions of restraint (e.g. at junctions with structures).

The guideline values for foundations also apply to the first 2 m (nearest to the building) of service pipes connected to premises (for further information regarding gas supply pipes, see DIN EN 1594).

Table 3 — Guideline values for $v_{i, max}$, for evaluating the effects of short-term vibration on buried pipework

Line	Pipe material	Guideline value for $v_{i, max}$, in mm/s at the pipe
1	Steel, welded	100
2	Vitrified clay, concrete, reinforced concrete, prestressed concrete, metal (with or without flange)	80
3	Masonry, plastics	50

Drain pipes shall be evaluated using the values given in Table 3, line 3.

6 Long-term vibration

6.1 Evaluation of structures

6.1.1 Evaluation of the building as a whole

The evaluation shall be based on the maximum horizontal vibration velocities normally expected to occur in the topmost floor. Therefore, vibration shall be measured directly at this place. The evaluation is based on the maximum value of the two horizontal components.

Guideline values for various types of building are given in Table 4.

When vibration is to be measured and monitored over a longer period of time, measurements can also be carried out at the foundation as an alternative to direct measurements at the topmost floor, provided that the transmission of vibration from the foundation to the topmost floor has been determined beforehand with sufficient accuracy and the results allowed for in the evaluation. This determination should preferably be made by measurement. Optionally, the determination can also be made by calculation or on the basis of experience. In all cases, when determining the vibration transmission, due consideration shall be given to the excitation frequency range and the signal characteristics of the vibration source.

Table 4 — Guideline values for $v_{i,\,max}$, for evaluating the effects of long-term vibration on buildings

	Type of building	**Guideline values for $v_{i,\,max}$, in mm/s**	
		Topmost floor, horizontal direction, all frequencies	**Floor slab, vertical direction, all frequencies**
Column / Line	1	2	3
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	10	10
2	Residential buildings and buildings of similar design and/or occupancy	5	10
3	Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 **and** are of great intrinsic value (e.g. listed buildings)	2,5	10 [a]
NOTE	Even if guideline values as in line 1, column 2, are complied with, minor damage cannot be ruled out.		
[a]	6.1.2 shall be observed.		

6.1.2 Evaluation of floor slabs

Experience has shown that a vertical vibration velocity up to 10 mm/s does not cause damage in floor slabs of structures as in Table 4, lines 1 and 2, even if the maximum static design stresses are fully utilized. Such vibration is very clearly perceptible. In the case of structures as in Table 4, line 3, it may be necessary to lower the relevant guideline value markedly to prevent minor damage. In the evaluation of floor slab vibration, the specifications of 6.1.1 regarding measurements to be performed at the foundation apply by analogy.

Where vibration occurs in floor slabs and building components, the dynamic loading may be determined as described in 4.3 und 4.4.

In the case of flexural vibration close to resonance, the additional dynamic stress can be approximated as described in the following: For beams and uniaxially stressed solid slabs with constant stiffness and uniform load for vibration in normal mode, the relationship between the maximum bending stress σ_{max} and the peak vibration velocity $v_{i,\,max}$ is defined by Equation (1), regardless of the dimensions of the vibrating system.

$$\sigma_{max} = y_{max}/i \; \left(E_{dyn} G_{ges} \; \rho / G_{balken}\right)^{0,5} k_n v_{i,max} \qquad (1)$$

where

y_{max}	is the outer fibre distance;
i	is the radius of inertia;
$v_{i,\,max}$	is the peak vibration velocity at the point of maximum deflection;
E_{dyn}	is the dynamic modulus of elasticity of the material;
ρ	is the material density;
G_{ges}	is the self-weight of the beam, plus any additional loads;
G_{ges}/G_{balken}	is the coefficient of loading, where the beam is subjected to evenly distributed loads in addition to its self-weight;
k_n	is the (dimensionless) normal mode index.

For rectangular cross sections, $y_{max}/i = \sqrt{3} = 1{,}73$.

The normal mode index k_n is dependent on the boundary conditions and the degree of the mode. Both of these have only a slight influence, however; in practice, the value of k_n generally lies between 1 and 1,3. For biaxially stressed slabs, the bending stress so calculated represents a maximum.

6.2 Evaluation of buried pipework

The guideline values given in Table 3 may be reduced by 50 % without further analysis when evaluating the effects of long-term vibration on buried pipework.

The restrictions set out in 5.3 apply here by analogy.

6.3 Start-up and shutdown operations

In the case of start-up and shutdown operations of construction machinery or similar operations, the vibration velocity is allowed to exceed the guideline values specified in Table 4, since the exceedance of these values is only short-term. Evaluations may be based on the guideline values as in Table 1, columns 5 and 6.

7 Performing vibration measurement

Instruments used to perform measurements as in this standard shall meet the requirements specified in DIN 45669-1. The procedure shall be as in DIN 45669-2, which also contains information regarding the mounting of the transducers. Measurement points shall preferably be arranged on that side of the structure facing the vibration source. The vibration shall initially be recorded as a function of time. For buildings with a large floor area, measurements shall be taken at different points simultaneously

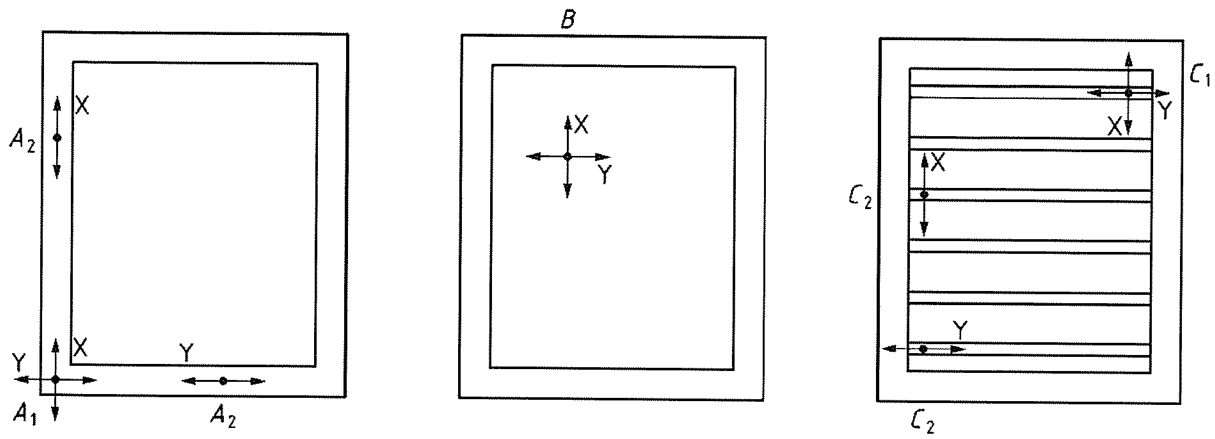


Figure 2 — Arrangement of transducers and their orientation on the topmost floor
(showing a simple floor plan by way of example)

The objective of measurements taken on the topmost floor (as in 5.1.1 and 6.1.1) is to detect vibration ($i = x, y$) at points where the maximum horizontal movements of the structure as a whole are to be expected. This will be ensured by taking measurements within the plane of and parallel to the outer walls. The transducers shall be placed in horizontal directions x and y that are perpendicular to each other (see Figure 2). Usually, this requires horizontally directed single transducers (A_2), unless the measuring point can be located in a corner of the structure (A_1).

For biaxially stressed (concrete) floors, horizontal vibrations may also be detected at any point on the floor (see also Figure 2 (B)). For uniaxially stressed floor slabs (e.g. timber joist floors) measurements can be taken on the floor at the joist supports next to the outer wall (see Figure 2 (C_1, C_2)). Where measurement points on the topmost floor are not accessible, other points representative of the vibration behaviour of the structure shall be used.

Vertical vibration in the floor slab ($i = z$) is to be measured at points where maximum amplitudes are to be expected (this is normally in the centre of the floor).

NOTE The maximum vertical vibration does not necessarily occur on the topmost floor.

For measuring vibration at the foundation, the transducers for the three components ($i = x, y, z$) shall be placed on the lowest floor of the structure under investigation, either directly next to the foundation of the outer wall, or on the outer wall, or in any recesses in the wall. One transducer should be directed parallel to one of the outer walls of the structure. The point of measurement should be located at a height not more than 0,5 m above ground level.

If a building is subjected to long-term harmonic vibration in a higher mode, measurements shall be taken on several floors simultaneously in order to reliably capture the maximum amplitudes. Evaluation of the maximum vibration velocities shall be based on the guideline values given in Table 4. For buildings with up to three full storeys above ground level, measurements on the topmost floor will normally suffice.

When evaluating horizontal vibration in the structure as a whole, it may be necessary in special cases to consider any possible rotational movement in the floor plane and any possible rigid-body movement (the latter being mainly stress-free).

For vibration measurements on pipework, the transducers should be placed directly on the pipes if possible, taking into account the fact that any insulation at the point of measurement can distort the results. When measurements are taken at ground level above the pipes, values can only be estimated (see also Annex D.1).

A measurement report according to Annex A shall be drawn up for each measurement of vibration.

Annex A
(normative)

Sample measurement report

The report shall include at least the information given in Table A.1.

Table A.1 — Measurement report (1 of 2)

Line	Scope	Examples
1	General Testing agency Client Contract identification Person carrying out measurement Date and period of measurement Reason for measurement	
2	Type of vibration a) Source b) Operating conditions c) Extraneous vibration sources/sources of interference	 Blasting (blasting parameters) Pile driving (equipment used, type of piles used) Traffic (rail traffic types, trucks) Machinery-induced vibration (rotating speed, load, etc.) Frequency of occurrence Human-induced vibration
3	Site and location of sources including sketches with distance information	
4	Environmental conditions	Any special conditions: weather (ground frost, storm, extreme temperatures) type of soil/rock, ground water conditions
5	Object to be investigated a) Designation b) Classification c) Description	 Location (address) Type of building (as classified in the tables of this standard) Type of construction, size, type of foundation, structural condition
6	Points of measurement a) Location and orientation of transducers b) Mounting of transducers c) Measurement period at particular point d) Serial numbers of transducers e) Sketches with distance information	 Mounting as in DIN 45669-2

Table A.1 (2 of 2)

Line	Scope	Examples
7	Measuring chain a) Type of transducer b) Connecting equipment c) Recording devices d) Latest date of calibration e) Tools for analysis	 Accelerometer, velocity or displacement transducers Filters, amplifiers Type of vibration meter, Frequency analyzer, PC with evaluation software
8	Parameters to be recorded a) Working frequency range; sampling rate b) Mode of recording c) Threshold value for recording	 1 Hz to 80 Hz, 1 Hz to 315 Hz Recording time-dependent signals, peak values Trigger value for recording
9	Any subjective or specific observations during measurement	Perceptibility, secondary effects (e.g. rattling of objects)
10	Results of measurement a) Measured maximum vibration values and frequencies b) Derived quantities c) Duration of vibration and frequency of occurrence d) Assessment of occurrences affecting the results	
11	Signatures	

Annex B
(normative)

Alternative measuring and evaluation method

For evaluating short-term vibration at foundations, the alternative method described in DIN 45669-1:2010-09, Annex E, can be applied, which is an evaluation method using frequency-independent guideline values. The method involves the use of weighting filters which suppress higher frequencies in the vibration signal according to the frequency weighting as shown in Table 1 and Figure 1. The maximum value of the filtered signal shall be compared with the (constant) guideline value according to Table B.1. Both methods are to be considered equivalent. The alternative procedure is particularly suitable for real-time evaluation of vibration in foundations. The procedure shall be as follows:

As with the standard method, the type of structure is first to be determined. This gives the guideline value in Table B.1, which is independent of frequency. Table B.1 also specifies which filter is to be used for frequency weighting.

By filtering, the peak value $|v|_{\mathrm{iBn,\,max}}$ of the three components $i = x, y, z$ of the frequency weighted vibration velocity $v_{\mathrm{iBn}}(t)$ is determined and then directly compared with the constant guideline value in accordance with the building type $n = 1, 2, 3$.

If the type of building cannot be established at the time of measurement, it shall be ensured by suitable means that this can be done later on.

Table B.1 — Frequency-independent guideline values for evaluating short-term vibration effects on structures

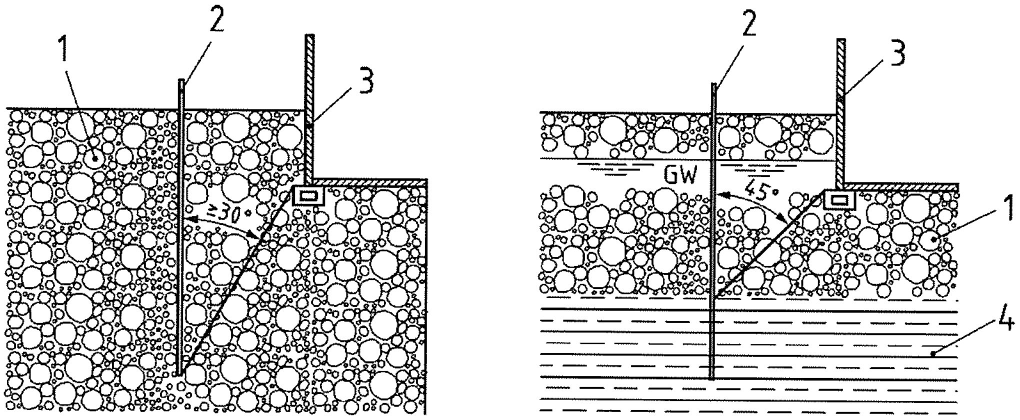
Line	Type of building	Transfer function of filter as in DIN 45669-1	Designation of vibration velocity guideline	Guideline value mm/s
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	H_{vB1}	vB1	20
2	Residential buildings and buildings of similar design and/or occupancy	H_{vB2}	vB2	5
3	Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 **and** are of great intrinsic value (e.g. listed buildings)	H_{vB3}	vB3	3

Annex C
(normative)

Effects of vibration on soil

Non-cohesive soil tends to **settle**, for instance near the use of vibratory hammers for sheet pile driving. For this reason, the distance to buildings should be chosen in such a way that an angle of at least 30° to the vertical is formed between the vibration source and the building foundation. For piling below the ground water table, an angle of 45° can be more suitable, as shown in Figure C.1.

The risk of settlement is considerably reduced in the case of impact pile driving (e.g. when using diesel or pneumatic hammers).



Key
1 Sand, gravel
2 Sheet pile
3 Building
4 Clay, silt

GW – Ground water level

Figure C.1 — Schematic presentation showing critical distances between sheet piling and structure

Even at great distances from the vibration source, vibration-induced **foundation displacement** can still occur at vibration levels which are normally not expected to cause structural damage by direct vibration effect. However, for this to occur, the soil has to be very sensitive to vibration (as is non-cohesive, uniformly graded sand or silt, for instance), and the vibration has to be continuous or very frequent.

Any dynamically-induced settlement will depend on the local conditions; it is therefore recommended that expert advice be sought.

Another effect vibration has on soil is **liquefaction**, when sand or silt below the ground water level suddenly loses all of its bearing capacity as a result of dynamic effects. During earthquakes, this process can lead to damage as serious as the collapse of buildings. Since the vibration level covered by this standard normally lies well under the vibration magnitudes which occur during major earthquakes, these effects are only to be expected under the most unfavourable circumstances.

Annex D
(informative)

Measurements and evaluations

D.1 Information on measurements on pipework

Measurements carried out to evaluate the effects of vibrations on pipework should preferably be performed directly on the pipes. Wherever possible, buried pipes should be exposed only at the point of measurement. Transducers shall be mounted as described in DIN 45669-2. The vibrations as a function of time shall be measured in the *z* direction (i.e. vertical) and in the *x* and *y* (i.e. horizontal, perpendicular to each other) directions, one of which should run parallel to the pipe axis.

Any insulation at the point of measurement can lead to a distortion of results, although thin solid coatings have little effect on results. To provide the transducer with a horizontal support surface, a concrete or plaster base can be installed on the pipe.

Often, mounting transducers directly on the pipe can be a relatively laborious process. In cases where the vibration source is not located immediately next to the pipework or nearby, but deeper than the pipe, measurements can instead be carried out on the ground surface. Previous investigations have shown that vibration measured on the surface is usually greater than that measured directly on pipes.

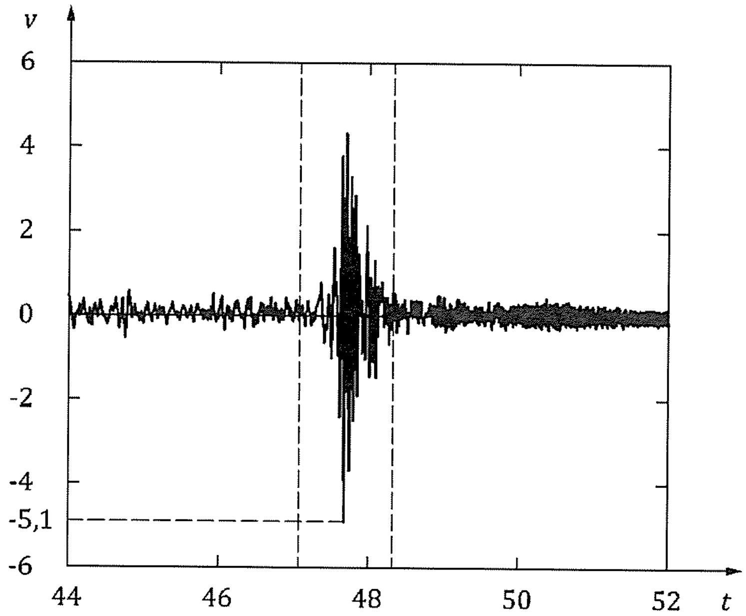
D.2 Frequency determination

Table 1 gives guideline values for short-term vibration at foundations of various types of buildings as a function of frequency. It is assumed the following procedures will be carried out:

1) find the peak vibration velocity, $v_{i,\,max}$, in the time dependent signals $v_i(t)$;
2) determine the significant frequencies, f_i, for $v_i(t)$;
3) compare the peak vibration velocities, $v_{i,\,max}$, with the guideline values given in Table 1 for the significant frequencies.

NOTE Narrow-band spectra are particularly suitable for determining frequency f_i. To reduce distortions of the spectra caused by the duration and form of the data window, the location and length of the latter are to be fitted to the $v_i(t)$ function. Frequency weighting as in DIN 4150-2 using weighting filters is not necessary.

EXAMPLE During demolition work short-term vibration occurs. The vibration components, $v_x(t)$, $v_y(t)$, and $v_z(t)$, measured at the foundation of a nearby building have qualitatively similar time-dependent signals, as do the spectra. The peak value of the vertical component $v_{z,\,max}$ is considerably greater than the peak values of the horizontal components $v_{i,\,max}$ (with $i = x, y$). The horizontal components are therefore disregarded. Figure D.1 shows the time-dependent signal of the vertical component $v_z(t)$ with a peak vibration value $v_{z,\,max}$ of 5,1 mm/s.



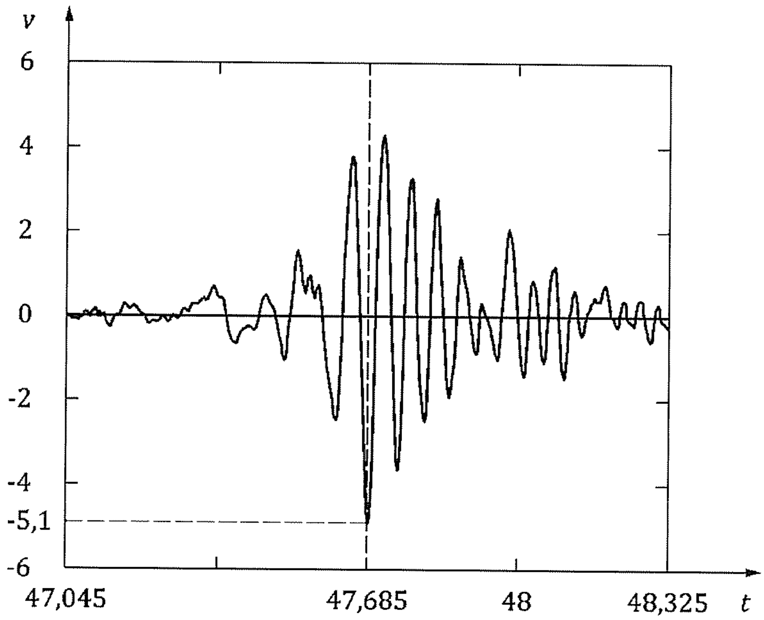
Key

t Time (s)

v Vibration velocity (mm/s)

Figure D.1 — Vertical component $v_z(t)$ as a function of time; maximum $v_{z,\,max}$ = 5,1 mm/s

The section of the time-dependent signal enclosed by dashed lines and enlarged in Figure D.2 contains the main part of the vibration signal.



Key

t Time (s)

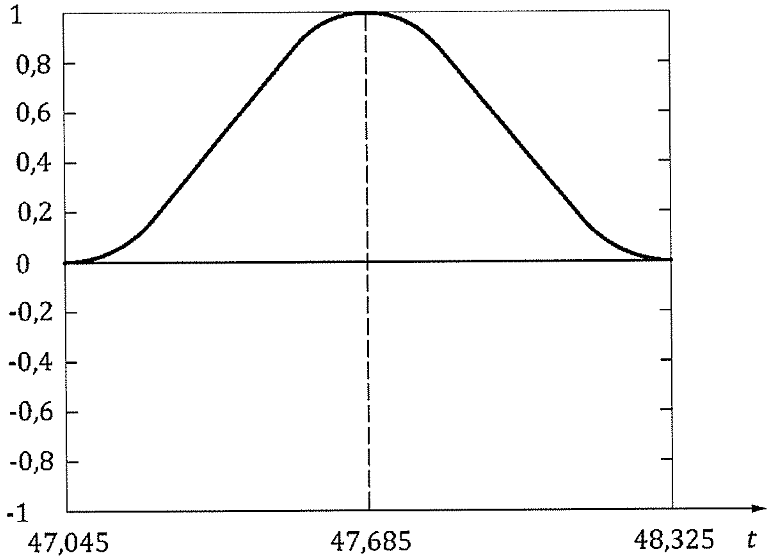
v Vibration velocity (mm/s)

Figure D.2 — Enlarged section of time of vertical component $v_z(t)$ from Figure D.1: duration 1,28 s

Before being transformed into the frequency domain, the $v_z(t)$ function as illustrated in Figure D.2 shall be multiplied by the shifted window function ("Hanning window") shown in Figure D.3. This is expressed by the following equation:

$$h_w(t) = \begin{cases} (1 - \cos(2\pi(t - t_0)/T_0))/2 & \text{for } t_0 \le t \le T_0 + t_0 \\ 0 & \text{otherwise} \end{cases} \quad \text{(D.1)}$$

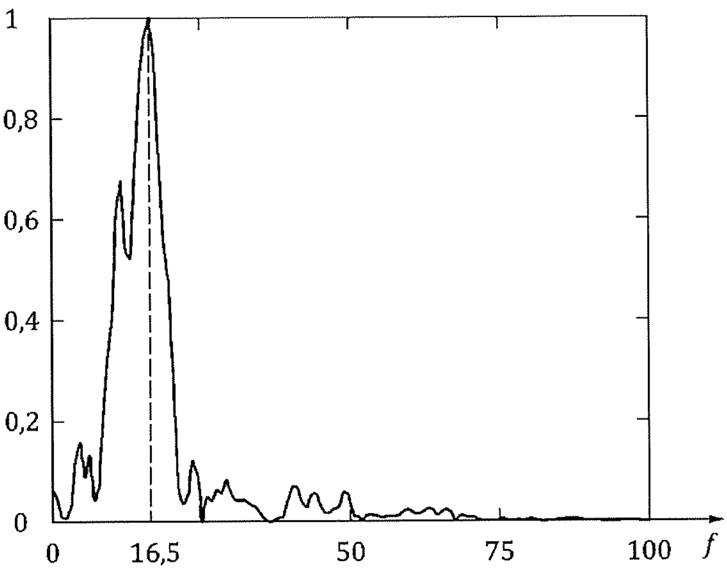
The peak of the Hanning window coincides with the peak of v_z; the length of the window has been adjusted to suit the length of the enlargement $v_z(t)$ in Figure D.2.



Key
t Time (s)

Figure D.3 — Hanning window, $h_w(t)$, **adjusted to** $v_z(t)$ (with t_0 = 47,045 s and T_0 = 1,28 s)

The product $h_w(t) \cdot v_z(t)$ is transformed into a frequency spectrum using a discrete Fourier transformation. The spectrum is shown in Figure D.4 as a normalized amplitude spectrum where the maximum value of f_z is 16,5 Hz.



Key
f Frequency (Hz)

Figure D.4 — Normalized amplitude spectrum

Using Figure 1, the guideline value given in Table 1, line 2 for a residential building and a frequency f_z = 16,5 Hz is 6,6 mm/s. The measured maximum of 5,1 mm/s lies beneath this guideline value.

Annex E
(informative)

Minimizing the effects of vibration

Usually, vibration is transmitted through the ground. It decays with increasing distance from its source. For this reason, the effects of vibration can be reduced by increasing the distance between the vibration source and the affected object. (Airborne vibration plays a role only under special circumstances.)

Depending on the local conditions and the mode of vibration, measures according to E.1 to E.3 will possibly minimize the effects of vibration.

E.1 Measures that can be taken at the vibration source

E.1.1 Stationary harmonic vibration, generated by machinery

e.g. vibrating screens, engines, motors, compressors, sawmills:

- balance the machine;
- provide or improve balancing masses;
- change the speed in case of resonance;
- isolate against vibration by placing the installation on elastic elements (for excitation at frequencies over 3 Hz).

E.1.2 Shock generated by machinery

e.g. forge hammers, presses, mills:

- provide the machinery with vibration insulation.

E.1.3 Traffic-induced vibration

- build and maintain smooth surfaces (on roads and railway tracks);
- reduce speed.

E.1.4 Vibration generated by blasting

- modify blasting technique (e.g. change explosive load for ignition stage, ignition order or hole depth).

E.1.5 Vibration generated by construction work

- introduce low-vibration techniques;
- use vibratory hammers with higher vibration frequencies;
- avoid resonance.

E.2 Measures taken at the structure affected by vibration

- install tuned mass dampers (especially effective against resonance and where there is minimal inherent damping in the structure);
- isolate the structure against vibration (for excitation frequencies above 5 Hz);
- modify the structure to avoid resonance.

E.3 Measures taken along the transmission path

- increase the distance between the source and the affected object (structure);
- in special cases, place trenches or elements in the ground near the vibration source or the object;
- where vibration causes differential settlement, a settlement-reducing foundation (e.g. deep foundation) is beneficial in preventing damage.

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