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Mechanical vibration — Ground-borne noise and vibration arising from rail systems —

Part 31:
Guideline on field measurements for the evaluation of human exposure in buildings

Vibrations mécaniques — Vibrations et bruits initiés au sol dus à des lignes ferroviaires —

Partie 31: Lignes directrices de mesurages in situ pour l'évaluation de l'exposition des individus dans les bâtiments

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures*.

A list of all parts in the ISO 14837 series can be found on the ISO website.

Mechanical vibration — Ground-borne noise and vibration arising from rail systems —

Part 31:
Guideline on field measurements for the evaluation of human exposure in buildings

1 Scope

This document gives guidelines to encourage reporting of field measurements of ground-borne noise and vibration in a metric that allows international comparison and future development of empirical models. It also sets out the basic minimum requirements and good practice when taking measurements for the evaluation of human exposure in residential buildings to ensure they are reliable. While national standards or requirements based upon project-specific purposes would normally take priority, this guidance can be used where there are no particular requirements or to provide supplementary guidance. Thereby, this document provides a means of improving general quality and reporting of field measurements in a preferred format.

There are a number of reasons for carrying out field measurements of ground-borne noise and vibration arising from rail operations, from complaint investigations to validation of prediction models, diagnostics and research as detailed in ISO 14837-1:2005, 7.2. In the present document, two levels of evaluation are considered.

— Scope 1 corresponds to basic measurements of floor vibration and noise in rooms in buildings to evaluate the human exposure to ground-borne vibration and ground-borne noise. Requirements are presented under two levels of accuracy:

a) basic measurements with minimum accuracy;

b) measurements with reduced uncertainty, also more reproducible and more appropriate for prediction.

Ground-borne noise is noise generated by vibrating building elements (e.g. floors, walls and ceilings) in the room of interest and is therefore best expressed by both an acoustic and a vibrational quantity. Its identification as ground-borne noise (as opposed to airborne noise, potentially also present) requires simultaneous noise and vibration measurements. Nevertheless, there are also cases of very low frequency vibration (below 10 Hz to 16 Hz) where only vibration measurements are relevant. Rattle can also arise from vibration, which can be from building components or furniture. This document does not set out to characterize this phenomenon, but to note its presence when it occurs.

NOTE In some cases, Scope 1 can relate to measurements on the ground outside a building (to resolve access issues or to comply with national regulations), although measurements at the building are generally preferred.

— Scope 2 corresponds to measurements extended to evaluate the vibration immission to buildings, which includes vibration measurements at or near the building foundations and vibration measurements on ground next to the building so that the building coupling loss and building transmissibility can be estimated.

Vibration measurements near the tracks (on ground surface or in tunnels) for a proper characterization of the source are outside the scope of this document.

Certain requirements are specified in the interest of achieving a consistent minimum data set for each investigation, allowing data comparison between sites.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 1996-2:2017, *Acoustics — Description, measurement and assessment of environmental noise — Part 2: Determination of sound pressure levels*

ISO 14837-1:2005, *Mechanical vibration — Ground-borne noise and vibration arising from rail systems — Part 1: General guidance*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14837-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
building coupling loss
frequency-dependent vibration level difference (typically in the vertical axis and sometimes also in the horizontal plane), in decibels, between the ground surface (free field) and the building foundation (which can be a measurement at or near this foundation), which is influenced by the building as a whole

Note 1 to entry: Care is required to interpret this quantity, which can be approximated in situations where measurements of the ground are performed close to the building such that it is not an ideal free field (see 4.5 and Annex B).

3.2
building transmissibility
frequency-dependent vibration level difference, in decibels, between the building foundation and the building floors

Note 1 to entry: The building transmissibility can be applicable to both the vertical and the horizontal directions. It can be based on either metric, velocity, acceleration, etc. (see Annex B).

3.3
room corner
3D ceiling corner (3D cc) or 3D floor corner (3D fc), which refers to noise measurements in a corner with a vertex formed from three surfaces (two walls and a ceiling, or two walls and a floor), with eight such 3D corners in a rectangular room

Note 1 to entry: A measurement in accordance with this document is usually equidistant from all the surfaces.

Note 2 to entry: A 2D corner is formed from two surfaces, typically two walls of a room (2D ww). In practice, a 2D corner measurement is at a given height from a floor (usually 1,2 m to 1,5 m), whereas the distance from the wall is usually 1 m, but not less than 0,5 m and needs to be measured and stated. A 2D corner could also arise from a floor and a wall (2D fw), or wall and a ceiling (2D wc), but is not used in this document.

3.4
category of rail events
set of rail events corresponding to the same train types passing at a typical speed, within which mean values (and standard deviations) of the exposure descriptors measured for each pass-by can be estimated and used to characterize the category considered

EXAMPLE Train types can be freight, local commuter, intercity, high speed.

4 Requirements for field measurements in buildings

4.1 General

This clause specifies requirements for taking measurements in residential buildings at two levels of detail as shown in Table 1.

Table 1 — Scope details

Scope 1	Evaluation of human exposure to vibration and ground-borne noise
Scope 2	Vibration immission to building

Requirements are presented in Tables 2 to 9 consisting of three columns.

— For Scope 1, minimum requirements are given in the left column and requirements for reduced uncertainty (see ISO/IEC Guide 98-1 or Reference [40]) given in the middle column.

— For Scope 2, requirements are given in the right column.

Complementary guidance and explanation are given in footnotes (which clarify and can include specific requirements) and notes (which only clarify but do not include specific requirements).

4.2 Instrumentation

Requirements on instrumentation for taking measurements to address Scope 1 and Scope 2 are given in Table 2.

Table 2 — Requirements on instrumentation

Scope 1 Evaluation of human exposure		Scope 2 Immission to building
Minimum requirements	**Reduced uncertainty**	
— Ground-borne noise shall be measured when relevant, using a microphone (see Note 1). — The noise meter for audible ground-borne noise typically has a frequency range of 16 Hz (see Note 2) to 250 Hz, or in some cases higher at the top end in case of hard rock sites. — Accelerometers or geophones may be used to sense vibration.[a,b] — Vibration transducers, signal conditioning, recording and measurement equipment shall be suitable for use over the following frequency ranges: 1 Hz to 80 Hz for very low frequency vibration cases or 4 Hz to 250 Hz for cases with ground-borne noise (see Note 3).[c,d,e] — Noise equipment shall be field calibrated, a drift in calibration of 0,5 dB being acceptable.[f,g] Vibration equipment often only requires off-site calibration.[g,h] — Where possible, record the signals for subsequent analysis. — For digital acquisition, the sampling frequency shall satisfy the Nyquist criterion.[i]	— Both vibration and noise shall be measured (see Note 4). — Vibration transducers, signal conditioning, recording and measurement equipment shall be suitable for use over the extended frequency range of 1 Hz to 250 Hz. — Noise equipment shall be field calibrated;[f,g] measurements being discarded if calibration drifts by more than 0,3 dB. — Tolerances of equipment shall be stated in the report. — For digital acquisition, the sampling frequency to characterize time history shall be at least five times the upper frequency of interest.	— Equipment used in Scope 1 can also be used in Scope 2.

Table 2 *(continued)*

NOTE 1 Where the noise meter has the option between free-field and random incidence software correction, either option can be selected as the difference is not significant at the low frequencies typical of ground-borne noise.

NOTE 2 At the bottom end of the frequency range, equipment tolerances become increasingly wider (see IEC 61672-1).

NOTE 3 When both noise and vibration are measured, coupling between structural vibration and noise can easily appear, particularly at low frequencies. It is important to keep vibration recording up to typical frequency limits for ground-borne noise, although ground-borne noise which is audible need not go below 16 Hz.

NOTE 4 It is preferable to use the same data acquisition system and the same time base for simultaneous ground-borne noise and vibration measurements.

[a] Where a geophone is used, its frequency response should be electronically/digitally corrected to compensate for the geophone's resonance frequency. Geophones have a better ability to sense frequencies below 5 Hz, where acceleration signals are often physically low in this range; in the latter case a high sensitivity accelerometer becomes necessary.

[b] When using accelerometers, before integrating for velocity it is important to remove any DC offset and apply a high-pass filter to the data to exclude the frequencies below the range considered. It is also important to verify that the inherent electronic noise of the transducer and the signal acquisition system is not greater than the smallest signal that needs to be measured. The signal-to-noise ratio (SNR) should ideally be a factor of 10, which is not always achievable.

[c] The frequency range should be read as one-third-octave centre frequencies (see IEC 61260-1).

[d] A relaxed range of 4 Hz to 250 Hz for vibration can be acceptable as minimum requirements for different reasons: a) transducer (in the case of geophone) having difficulty covering the high frequencies for ground-borne noise (from 16 Hz) up to 250 Hz simultaneously; b) dominant building element responses occur at frequencies higher than 4 Hz. This limitation at the low frequencies should be reported.

[e] Rattle, which is one of the factors in annoyance, is high-frequency noise which should be reported qualitatively, its level being highly variable and not reproducible.

[f] Field calibration shall be carried out for noise equipment before and after each set of measurements. Any drift in calibration checks shall be noted.

[g] The calibrators used to check test equipment shall have current calibration traceable to national standards, carried out annually, while the test equipment itself can be certified for performance according to the manufacturer's specification or appropriate standards every two years (see, for example, ISO 8041-1) or a longer period in some countries (e.g. three years in Japan).

[h] Vibration equipment is usually stable over time, so does not require field calibration but simply a check of functionality for each set of measurements, and careful note of gain settings. A simple functional test on site, such as tapping the transducer is desirable. The vibration equipment chain should ideally be checked prior to site visits preferably with a traceable reference signal or on site if a field calibrator is practical (with regard to transducer mass and portable calibrator capacity), especially when measurement assurance is critical.

[i] To achieve the Nyquist criterion, either increase sampling frequency and/or impose cut-off filter (anti-aliasing filter) to ensure that the chosen sampling frequency meets the criteria by limiting frequency content in signal.

4.3 Fixing vibration transducers

Requirements on fixing vibration transducers for Scope 1 and Scope 2 are given in Table 3 (see also Annex C).

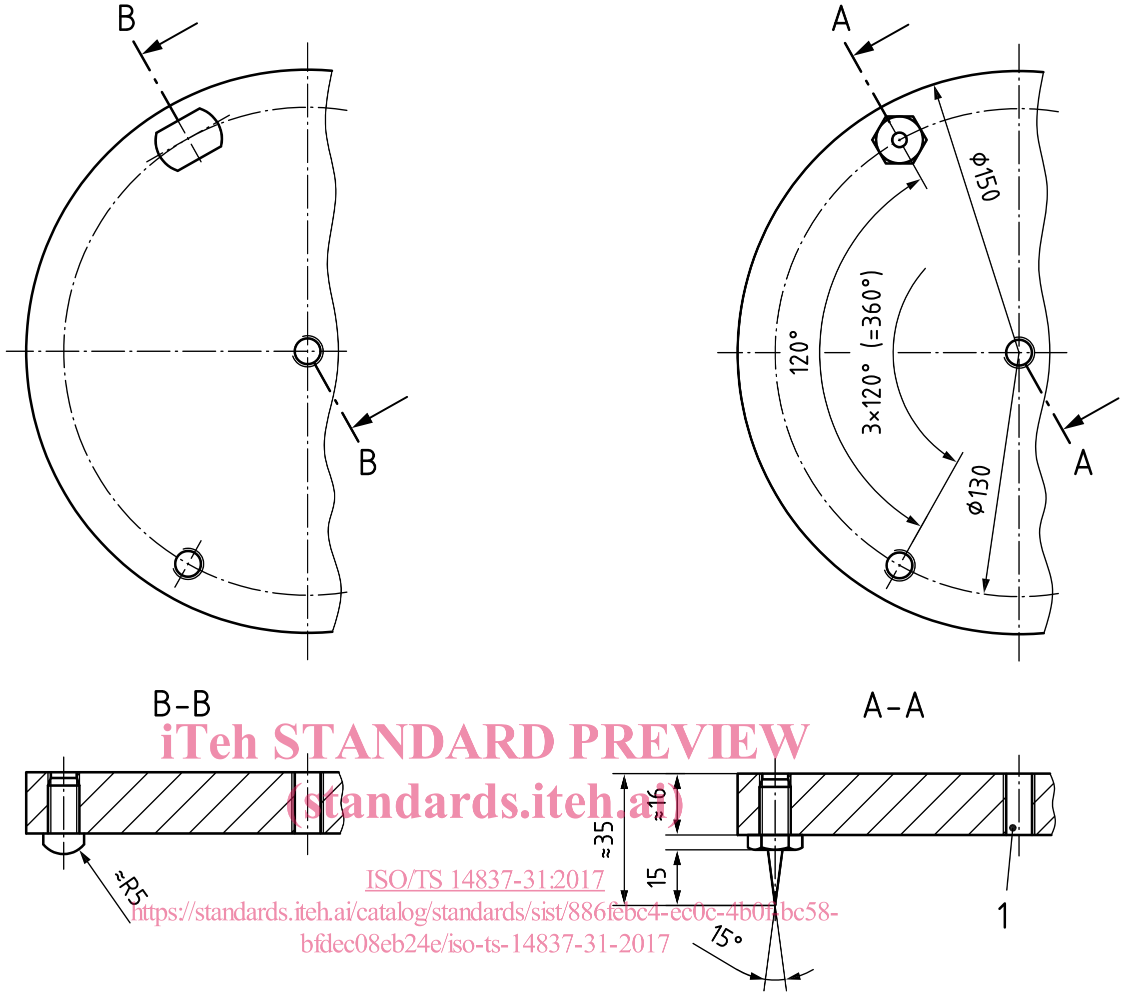
Table 3 — Requirements on fixing vibration transducers

Scope 1 **Evaluation of human exposure**		**Scope 2** **Immission to building**
Minimum requirements	**Reduced uncertainty**	
— Vibration transducers can be fixed directly to the building element (see Note 1)[a]; or using attachment supports such as brackets or cubes (see Notes 1 and 2). — It is acceptable to simply park a heavy[b] attachment plate with three rounded feet (see Figure 1 a) or a heavy metal cube, as vibration magnitudes in buildings from rail systems are likely to have small acceleration values preventing transducer creep. — Where carpet (or linoleum) is present, it is preferable to temporarily lift the carpet to fix transducers directly to the floor. Where this is not possible, transducers may be fixed via a heavy steel plate with no internal resonances in the frequency range of interest supported on three spikes, as shown in Figure 1 b)[c]. — Care shall be taken in the fixing of vibration transducers to avoid effects of any mounted resonances (see Note 3)[d]. — Placement or fixing details shall be clearly stated in the report.	— For fixing vibration transducers, see column minimum requirements.	— For fixing vibration transducer at or near foundations, see Scope 1 requirements. — Several ways of fixing the vibration transducer on the ground next to the building are possible (see Annex C)[e]: — stake pushed into ground, on which the transducer is fixed (see Note 4), — aluminium plate cast into the soil with plaster of Paris (see Note 5), — transducer buried in soil or inside canister buried in soil near the ground surface less than 300 mm depth[f], — transducer attached to a heavy plate or transducer block with three feet, parked or levelled on the ground surface (see Figure 1)[g], and — transducer attached to the ground surface with an appropriate adhesive or expanding anchor bolt[g].
NOTE 1 Transducer fixing arrangements within residential buildings are likely to be constrained by internal finishes and occupant preferences.		
NOTE 2 Transducers can be attached to a cube instead of a bracket for triaxial measurements (cube made from metal or lighter engineering grade plastic; consider impedance contrast, size and properties to avoid resonances in the frequency range of interest). The cube can be attached to concrete floor, or a wall or column of the building using epoxy resin, or just placed with gravity if heavy enough (in the latter care is needed to avoid rocking due to inevitable variations in number and distribution of contact points). Transducers can be attached to the cube, according to the material, for example, magnet, double-sided tape and even thin layer of reusable putty-like adhesive, checked according to the frequency range of interest.		
NOTE 3 There are some floor finishes related to impact sound control that are not coupled to the structural floor, and the coupling situation can be improved with some applied mass, although this can vary according to mass applied and floor finish type.		
NOTE 4 The spike (stake) made as a cruciform or angle section from a length of 30 cm can according to the ground be pushed into the soil, although there are risks that the stake might be loose in the soil, and such a situation can be made worse when the stake is hammered into the ground. It is advisable to use a functional test, such as tapping the stake, which often reveals if the stake is loosely coupled, although such a test does not ensure that there is good coupling.		
NOTE 5 According to Reference [26], using an aluminium plate cast into ground with plaster of Paris or using a stake pushed into the ground leads to similar vibration magnitudes, except at high frequencies.		

Table 3 *(continued)*

[a] Where practical and if vibration magnitudes are strong enough, vibration transducers should be fixed via rigid adhesive to solid structural components of the building; where this is not possible, a thin layer of temporary adhesive – such as beeswax or double-sided adhesive tape – may be used. Where double-sided adhesive tape is used, it shall be a thin version that excludes any supplemental elastic layer. Refer to manufacturer specification for transducer mounting methods based on transducer weight/design, testing surface and anticipated vibration frequencies and amplitude, as well as with regard to environmental influences, electrical noise and their management.
[b] According to the acceleration of the surface being measured, at low levels, a "heavy" attachment can when simply parked provide sufficient friction under the weight to prevent the transducer moving (creep) across the surface. The friction is not just dependent upon weight, but the materials at the interface and the distribution of contact points and their surface condition. However, it shall not be so heavy as to cause a mounted resonance in the frequency range of interest. To ensure this lies outside the range of interest, usually it is desirable to make the attachment as light as possible, so there is a balance to be achieved in that circumstance. However, under high accelerations of the surface to be measured, relative to gravity, an attachment that is simply parked cannot faithfully follow the motion of the surface, and a change to attachment mass cannot improve the coupling. A secure coupling by a stud, magnet or adhesive is then essential, and the consideration of attached mass, depending upon what it is being attached to might affect its frequency. In the absence of detailed consideration of friction and acceleration levels of the surface, a secure coupling is usually preferable.
[c] Where a spiked plate is used, ensure spikes are long and slender enough to get through the thickness of the carpet and underlay. There should be a small clearance between the plate and the carpet so as to ensure the resilient carpet or underlay is not compressed so as to loosen the spiked feet from the underlying hard structure.
[d] Ensure transducer mass (especially for a heavy transducer) does not cause resonance within the frequency range of interest, when for example coupled to a circular plate for floor measurements or brackets that facilitate triaxial measurements.
[e] For surface measurements in urban areas, there may be tarmac or hardstanding which can provide a surface measurement position, albeit there are differences to a ground without such surface treatments. The tarmac or hardstanding should be checked to ensure it is well coupled, this may be obvious from listening to site tapping, or in some special cases could be explored with more detailed mobility measurements to check dynamic response of the chosen location.
[f] The buried transducer can be mounted in a small rigid (and water tight, if needed) canister. The volume of the canister, the material, the wall thickness and the mass of the transducer is combined such that the whole assembly has close to the same mass as its corresponding volume of soil (and preferably its centre of gravity close to its centre). Dig a small hole in the ground, flatten and slightly compact the bottom surface, insert the transducer assembly, and fill back part of the soil, carefully compacting towards the walls of the assembly. The assembly should be fully covered in the ground. It is recognized that such an arrangement may be more appropriate under a research investigation (see Annex C).
[g] Where the ground surface is rock, concrete, asphalt or otherwise hard (such as very compacted dry soils) and using care to avoid any loose surface or laminations, the transducer attached to a heavy plate or transducer block with three feet can be parked and levelled on the ground surface, if vibration magnitudes are low. The coupling for direct transducer attachment to the ground surface can be achieved with an appropriate adhesive or expanding anchor bolt, with simple functional test (e.g. tap or manipulate lightly by hand) to identify any poor coupling. Check that such transducers have not become inadvertently dislodged during tests from passers-by who fail to see hazard cones or markings used to delineate the transducer. In long-term deployments, consider how the ground properties and transducer coupling will change under wet conditions, etc. (see also Annex C).

Dimensions in mm



a) With three rounded feet for mounting on hard surfaces

b) With three spiked feet of tempered steel for mounting on soft surfaces

Key

1 threaded hole for attaching the transducer(s)

NOTE There is a distinction between round and spiked feet. A spiked foot made from tempered steel is sharp enough to penetrate a soft material such as carpet. It can also couple to a (preferably timber) floor, into which the spikes can penetrate. It is a compromise when the floor below the carpet is hard, since on a hard surface it is undesirable to have a sharp point, which could create mounted resonance of the plate on the sharp point, in either the vertical or horizontal axis. Yet the spikes are needed to penetrate a carpet which it is assumed could not be removed. On hard surfaces, the rounded feet are, however, more appropriate.

Figure 1 — Mounting fixtures — heavy attachment plate made from steel (see DIN 45669-2)

4.4 Measurement locations in the building

Requirements on general measurement locations in the building for Scope 1 and Scope 2 are given in Table 4.

Table 4 — Requirements on measurement locations in the building

Scope 1 Evaluation of human exposure		Scope 2 Immission to building
Minimum requirements	**Reduced uncertainty**	
— As a minimum, ground-borne noise shall be measured in the room that is of interest (see Note 1). — As a minimum, vibration shall be measured on the floor in the room that is of interest (see Note 1). — The possibility of fixing vibration transducers on the ceiling shall also be considered[a].	— Additional measurements may be carried out at other locations within the building such as — measurements in other habitable rooms[b, c], — vibration measurements on any building elements that can help distinguish extraneous background events, and — vibration measurements near the railway, which should be synchronized with those measurements at the building.	— Additional measurements shall be carried out at the following locations (see Note 2): — vibration measurements at or near the foundation of the building (see Note 3 and Annex B); — vibration measurements on ground surface next to the building (see Annex B).

NOTE 1 The room of interest may be any habitable room on any floor of a building (including habitable basements) with due regard to locations where any complaints might have arisen.

NOTE 2 Such vibration measurement locations will be used to calculate the building coupling loss and building transmissibility, both common input data for empirical models (see details in Reference [32] and Annex B).

NOTE 3 Such vibration measurement locations can be used to evaluate the possibility of building damage to reassure an occupant or to evaluate mitigation effectiveness or changes over time. Such measurements are less variable, more indicative of the vibration exposure of the building, and can allow better comparison with prediction models; they are also useful to exclude internally generated vibration, not relevant for vibration assessment, by using the foundation transducer as master trigger and the rest as slaves, or for correlating in post processing of the recordings.

a Assuming the ceiling is similar to the base floor and in the absence of suspended ceiling or lining, vibration measurements of the ceiling can serve to estimate floor vibration when direct floor measurements are questionable because of the presence of floor covering. Also in basement rooms, where the floor is often a ground bearing slab (therefore very damped), ceiling vibration might be dominant in radiating ground-borne noise and should be measured.

b Vibration and ground-borne noise do vary with storey height, and so the locations should reflect that of the complainant, but also consider where practicable the exposure of other occupants in the building who could have influenced the adverse comment of the complainant at a particular site.

c Noise measurements conducted in rooms of a façade not facing the railway help minimize the airborne noise contribution, enabling better assessment of ground-borne noise if the latter is source of concern due to very close proximity to an at-grade railway, although the further distance of the room from the source should be a consideration.

4.5 Vibration measurement positions and orientation

It is important to recognize that in the case of ground-borne noise from railways, the predominant wavelengths are likely to be of the same order as wavelengths of plate modes in floors and other room surfaces. This means that the measured amplitude of the vibration of floor and other surfaces is strongly dependent on location, being lowest in the corners for most edge support conditions and highest at antinodes of plate eigenmodes. Careful measurement of the coordinates of chosen measurement locations shall be recorded (see Note). The topic is further discussed in Annex A. Consideration needs to be given to the uncertainty associated with choice of measurement location.

NOTE It is good practice to validate measurement position with dimensions from reference points that are clearly stated. Where *x* and *y* axes for vibration measurements are used, the *x* axis is horizontal, parallel to the wall of the building nearest the axis of the railway track, whereas the *y* axis is horizontal, but perpendicular to that wall.

Requirements on specific measurement positions and orientation of the transducers for Scope 1 and Scope 2 are given in Table 5.

Table 5 — Requirements on measurement positions and orientation

Scope 1 Evaluation of human exposure		Scope 2 Immission to building
Minimum requirements	**Reduced uncertainty**	
— Vibration measurements shall be carried out at one position in the vertical direction at (or near) the mid-span of the floor (see Notes 1 and 2)[a, b]. However, it can in some cases be the horizontal axis that is dominant and should be measured, particularly at higher floor levels in the building or in some wooden framed structures (see Figure 2).	— Additional measurements, less variable, should be carried out on the same floor, close to a load-bearing wall, and performed in two directions (vertical and horizontal perpendicular to the tracks as shown in Figure 2). — Additional measurements can be carried out at other positions within the room (or additional axes), such as for the purpose of evaluating exposure at specific occupant locations, or potential noise sources (see Note 3), or the floor space average vibration magnitude (see Note 4), or the variation in magnitudes throughout the floor (see Note 5)[c, d].	— Additional measurements carried out at or near the foundation of the building should be positioned close to a load-bearing structure (see Figure 2) and performed in a vertical direction (see Note 6). — The additional measurements carried out on the ground surface should be positioned next to (and not in front of) but sufficiently remote from the building, to achieve free-field ground measurement condition and performed in a vertical direction (see Note 7, Figure 2 and Annex B).
NOTE 1 Floor measurement location is relevant as input to receiver and therefore complainant, but measurements are likely to be more variable. Changes in floor layout or support conditions can make measurements near to the centre more susceptible to such changes.		
NOTE 2 The vertical axis for vibration measurement on a floor (typically the first floor) is likely to be the most dominant input, due to floor flexibility, and stronger near the mid-span as a result, which has relevance in terms of human perception of the event and possible annoyance.		
NOTE 3 Vibration measurements of building walls in horizontal orientation can be carried out, particularly when noise is a concern from railways with diesel-electric locomotives or other low-frequency sources, and/or if rattling occurs of windows or wall-hung objects, and/or if the wall is a potential source of ground-borne noise.		
NOTE 4 Three or more measurement positions on the floor (transducer orientation in vertical direction) or any other wall (transducer orientation in horizontal direction), which are potentially sources of ground-borne noise, can be useful to identify such a source and to estimate ground-borne noise from vibration measurements using space average quantities (see 4.6, 4.9 and Annex A). The relationship between vibration measurements and noise levels is sensitive to the relative positions of the measurement locations (see Annex A).		
NOTE 5 Measurement locations can be to determine actual floor response mode shapes. If the natural frequency of a floor is important, the corresponding first mode shape (flexure of the floor) implies the centre of the room and is relevant for the highest magnitude. The even modes of floor vibration are not evident at mid-floor locations and cannot therefore be measured there.		

