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Timber structures — Test methods — Floor vibration performance

Structures en bois — Méthodes d'essai — Comportement vibratoire des planchers

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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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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 165, *Timber structures.*

Introduction

Dynamic properties of timber structures are of critical importance to designers since they govern how these structures respond to seismic, wind and in-service human-induced dynamic excitation. Seismic and wind can cause structural failure, while in-service human-induced motion generally causes serviceability problems related to human discomfort; this is also true to wind-induced building motion. Since occupants are constantly in contact with the floor system, vibration serviceability of floor systems is often of concern to designers of timber structures. Vibrational performance of a timber floor can be assessed using parameters such as natural frequencies, damping ratios, dynamic responses to an impulse (dynamic displacement, velocity, and acceleration), and static deflection under a concentrated load. These parameters have been found to correlate well with human perceptions. Among these parameters, natural frequencies, damping ratios, and static deflection under concentrated load are commonly used to evaluate timber floor vibrational performance. Design procedures have been developed, and in some cases implemented in design standards, for assessing vibration serviceability of timber floors. These design procedures usually include criteria for floor response parameters, such as those listed above, and mathematical procedures to calculate these parameters. As an alternative to calculation, it is also necessary to provide standardized procedures to measure these parameters experimentally. This is the prime motive for the development of this ISO test standard.

Natural frequencies and damping ratios of a test system can be measured using modal testing. ISO published a series of International Standards on the application of modal testing and analysis to determine natural frequencies, modal damping ratios, and other dynamic properties of an object. The theory of modal testing and analysis has been well documented in Reference.[4] This International Standard provides practical procedures that can be applied either in the laboratory or in the field to measure natural frequencies, modal damping ratios and static deflection under a concentrated load of a timber floor. It is assumed that users of the International Standard have the necessary equipment and fundamental knowledge to perform modal testing.

This International Standard does not address acceptance criteria for vibrational serviceability.

Timber structures — Test methods — Floor vibration performance

1 Scope

This International Standard specifies test procedures to measure natural frequencies, modal damping ratios and static deflection under a concentrated load of laboratory or field timber floors. These parameters have been found to correlate well with human perception to timber floor vibration response caused by human-induced excitation under normal use. It is intended that the test procedures can be applied in lieu of calculation to quantify some or all of the above parameters that are used to evaluate the vibrational serviceability of the test floor. The subsequent use of the measured parameters to evaluate vibrational serviceability is, however, outside the scope of this International Standard.

ISO published a series of International Standards on the application of modal testing and analysis to determine natural frequencies, modal damping ratios, and other dynamic properties of a structure. For the measurement of dynamic parameters such as natural frequencies and modal damping ratios, modal testing is proposed in this International Standard. It is assumed that the test operators possess the required equipment and fundamental knowledge to perform such a test. The theory of modal testing and analysis has been well documented in Reference [4].

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
coherence function
indicator of the degree of linearity at each frequency component between the input and output signals, i.e., the noise level at each frequency component in the frequency response function (FRF) spectrum

Note 1 to entry: The value of coherence function is one when there is no noise in the signal, and zero for pure noise in the measured signals.

3.2
damping
parameter relating to the dissipation of energy, or more precisely, to the conversion of the mechanical energy associated with a vibration to a form that is unavailable to the vibration

3.3
natural frequency
frequency, associated with a *vibration mode* (3.12), at which a system naturally vibrates once it has been set into motion with a transient excitation

3.4
frequency response function
response function expressed in frequency domain and normalized to the input force

Note 1 to entry: It is the summation of each mode in the modal space. It shows the response of a system to be a series of peaks. Each peak with identifiable centre-frequency is the natural frequency of the system vibrating as if it was a single degree-of-freedom system.

3.5
leakage
effect on measured frequency due to truncating the infinite time response signal during Discrete Fourier Transform

3.6
modal damping ratio
damping ratio associated with a *vibration mode* (3.12)

3.7
modal testing
measurement of the *frequency response function* (3.4)

3.8
modal analysis
process of determining the *natural frequencies* (3.3), *modal damping ratios* (3.6), and *mode shapes* (3.9) of a structure (floor) for the *vibration modes* (3.12) in the frequency range of interest from the *frequency response function* (3.4)

3.9
mode shape
pattern of movement (i.e., dynamic displacement, velocity, acceleration) of a structure (floor) for a *vibration mode* (3.12)

3.10
nodal point
point of zero displacement on a vibrating system of a *mode shape* (3.9) associated with a *vibration mode* (3.12)

3.11
vibration
oscillation of a system about its equilibrium position

3.12
vibration mode
vibration behaviour of a system or object that is characterized by its *natural frequency* (3.3), *modal damping ratio* (3.6) and *mode shape* (3.9)

Note 1 to entry: The free vibration of a continuous structure such as floor system contains a summation of an infinite number of vibration modes.

4 Abbreviated terms

FFT Fast Fourier Transform

FRF Frequency Response Function

5 Measurement of natural frequencies and modal damping ratios

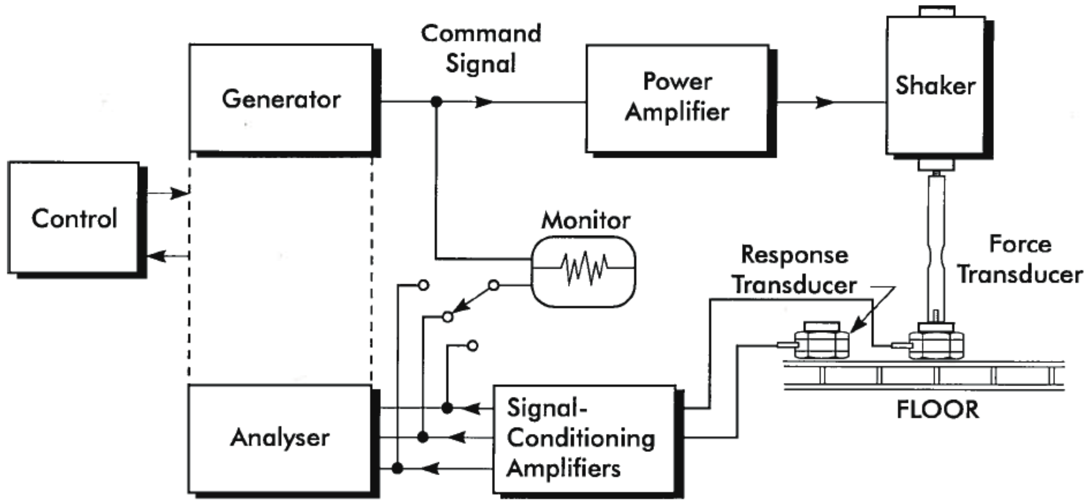
5.1 General

This clause specifies the general procedure of applying modal testing and analysis described in ISO 7626 to timber floors to determine their natural frequencies and damping ratios associated with the vibration modes. Specifically, this clause focuses on two techniques of exciting the out-of-plane vibration of a floor. One technique uses a shaker that is attached to the test floor, and the other uses an impact device that is not attached to the floor.

NOTE A general understanding of the theoretical basis of modal testing is expected in order to apply the procedures described in this clause. This understanding can be acquired by consulting relevant text, e.g. Reference [4].

5.2 Apparatus

The equipment required for modal testing shall consist of three major items: 1) an exciter for inducing vibration; 2) transducers for measuring the time history signal of excitation force and the vibration response; 3) a signal analyser for recording and analysing the time signals and extracting the desired information from the analysis results. Figure 1 illustrates the layout of a modal test system using a shaker as the exciter.



NOTE 1 This figure was a modification of the original figure in Reference [4].

Figure 1 — Layout of a modal test system using a shaker as the exciter

5.2.1 Exciter, shall be provided to initiate vibration in a structure. Generally, a satisfactory exciter for floor testing shall have the following capabilities:

a) Sufficient energy to induce floor vibration so that the modal testing measurements made over the entire frequency range of interest has an adequate signal-to-noise ratio without exciting a nonlinear response;

b) A suitable excitation waveform with frequency content that covers the frequency range of interest.

The exciter shall be either a shaker or an unattached impact device.

5.2.1.1 Attached exciter – shaker, shall be an electro-dynamic, electro-hydraulic, or piezoelectric vibration exciter attached to the test floor. The shaker shall be attached to a selected location on the floor during testing to continuously apply the excitation to the floor.

5.2.1.2 Unattached exciter – impact device, an instrumented hammer with a built-in force transducer or an impact device with a separate force transducer placed on a floor shall be used as the unattached exciter. The impact system shall have sufficient energy and appropriate surface contact characteristics to excite all the frequencies that are of interest. Specific requirements on the impact characteristics are given in 5.3.3.

5.2.2 Transducer and mounting

5.2.2.1 Transducer, for modal testing, both excitation and response signals are required. The transducer shall have sufficient sensitivity and capacity to cover the frequency range of interest and low noise-to-signal ratio, and be insensitive to extraneous environmental effects, such as temperature, humidity, shock, rough field working conditions, etc. It shall also be sufficiently light that its presence on the test floor does not change the dynamic characteristics of the floor. The vibration response shall be measured using accelerometers. A procedure to evaluate any possible influence of mass of transducer is given in 5.3.1.3.

5.2.2.2 Transducer mounting, for an instrumented hammer, the force transducer is built into the hammer. The technique of mounting a force transducer onto a shaker is specified in 5.3.2.1, along with the shaker mounting technique. The accelerometer shall be rigidly attached to the floor structure.

For floors with carpet overlaid on wood-based subfloor, a special mounting base that penetrates the carpet to the subfloor shall be used. The accelerometer shall be attached to the upper face of the base plate of the tripod. A tripod with a heavy metal base plate and pinned legs that can penetrate through the carpet to the subfloor has been found to work well.[5]

For timber floors with floating flooring as finishing or a floating heavy topping, the accelerometer shall be attached to the underside of the floor.

5.2.3 Signal analyser, shall be used to process the time signals and shall use the fast fourier transform (FFT) method to convert the time domain signals into frequency domain. For signal analysers that also acquire the data, the equipment shall have at least two input channels for acquiring the excitation force signal and the floor response signal simultaneously. The sampling frequency shall be at least twice the highest frequency of interest to capture all the target natural frequencies of the test floor. As a minimum, the outputs of the signal analyser shall include the FRF and coherence function.

5.3 Test procedures

5.3.1 General requirements and principles

The following principles shall be followed when performing the test procedure:

— The locations for exciter and response measurement shall be selected in such a way that all the modal parameters of the modes of interest, such as natural frequencies, modal damping ratios, and mode shapes, can be obtained.

— The modal parameters shall be extracted from a set of frequency response measurements between a fixed reference point on the floor and a number of roving points over the floor. The number of frequency response measurements shall be larger than or equal to the number of modes of interest.

The general procedure of modal testing shall consist of the following five steps:

a) Selection of excitation location (see 5.3.1.1);

b) Selection of response measurement location (see 5.3.1.2);

c) Mounting of transducers;

d) Excitation of the test system;

e) Validation of the measurements (see 5.3.1.3)

5.3.1.1 Selection of excitation location

The exciter shall not be placed at the nodal points of the modes of interest and be located as close to the floor centre as possible to ensure that the first natural frequency is excited.

5.3.1.2 Selection of response locations

The response measurements shall be recorded at a sufficient number of locations to allow the full mode shape of each interested mode to be obtained.

For joisted floors, a measurement grid consisting of three equally spaced rows along the span direction and joist lines is recommended.

For plate-like timber slab floors, such as cross laminated timber (CLT) floors, on each of the equally space rows, the accelerometers should be placed at the middle of each timber panel and each joint between two adjacent panels.

5.3.1.3 Measurement check and validation

The measurements shall be checked and validated using the coherence function.

After testing a floor, a reciprocity check shall be performed by interchanging the excitation and response points, then retesting the floor. The FRF measurements shall then be compared with those obtained from the previous test. Any discrepancy between the two sets of measurement may indicate transducer mounting problems, or presence of nonlinearity.

Effects of mass loading caused by presence of a transducer on a floor can be evaluated by modal testing with and without a mass equal to a transducer added on the floor and comparing the FRF measurements. If the difference is greater than 3%, an investigation of the possible cause shall be carried out.

Coherence function can be interpreted as a measure of the noise level in the signals, the degree of correlation between excitation and response signals, errors during averaging, and sign of non-linearity in the response. For reliable characterization of dynamic properties, the value of the coherence function at a resonance frequency should be close to 1. A coherence value significantly less than 1 is an indication of possible poor data quality, or that the vibration response is not excited by the input excitation.

NOTE Comparison of the FRF measurements using one type of excitation with those obtained using an alternate means of excitation gives additional confidence to the results obtained, but this is not always practical.

5.3.2 Shaker test procedure

5.3.2.1 Mounting of shaker

The shaker shall be placed on a solid ground and excite the floor from underneath. If this is not achievable, an alternative configuration is to suspend the shaker from the test structure using spring. If this attachment technique is used, the spring shall be selected in such a way that the natural frequency of the suspended shaker system shall be not more than one-tenth that of the lowest natural frequency of the test floor. The natural frequency of the suspended shaker system can be determined either by testing or calculation using the formula for one-degree mass-spring system with the known mass of the shaker and the spring stiffness.

The force from the shaker shall be applied to the floor through a drive rod or stinger. A suitable drive rod made of Teflon is shown in Figure 2. The drive rod shall have sufficient stiffness in the axial direction to transmit the intended excitation, while being relatively flexible in other directions. Such a drive rod ensures that the shaker is capable of applying a force in axial direction only, which also provides protection to the shaker and the force transducer to avoid damage caused by unintended high lateral force.

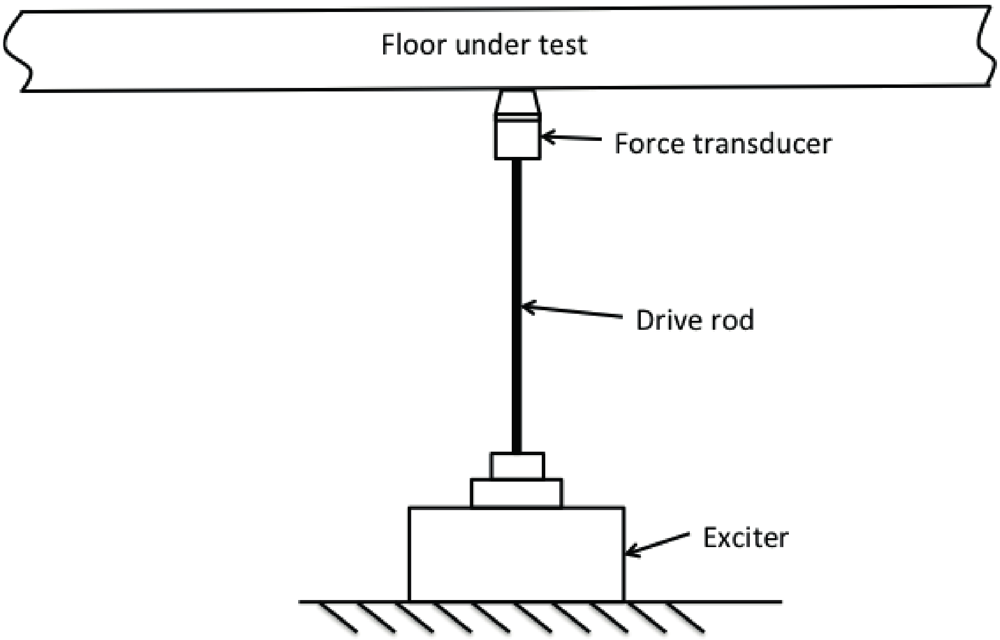


Figure 2 — Coupling of shaker with test system using a drive rod

5.3.2.2 Excitation waveform

Random excitation shall be used to excite the test floor into motion. This waveform tends to excite all frequencies of interest. Windowing of time signal as described in 5.3.2.3 is required to avoid signal leakage problems.

5.3.2.3 Measurement set-up

a) Windowing time signals:

To prevent leakage, the Hanning window shall be used for the response signals. Hanning window is basically an envelope curve that is applied to a signal to artificially force the signal to start from and decay to zero magnitude before the end of the signal.

b) Averaging frequency domain signals:

The coherence function shall be monitored for determining the minimum number of FRF measurements required during a particular floor test.

NOTE Averaging of FRF leads to suppression of noise level in the measured response. Guidance on determining the required number of averaging can be found in ISO 7626-2. As a guide, a minimum of five FRF measurements is usually sufficient to remove any background noises.[5]

c) Frequency resolution:

Frequency resolution of the resulting FRF measurements is dictated by the time signal data sampling duration as shown in Formula (1).

$$\Delta F \cdot T = 1 \quad (1)$$

where

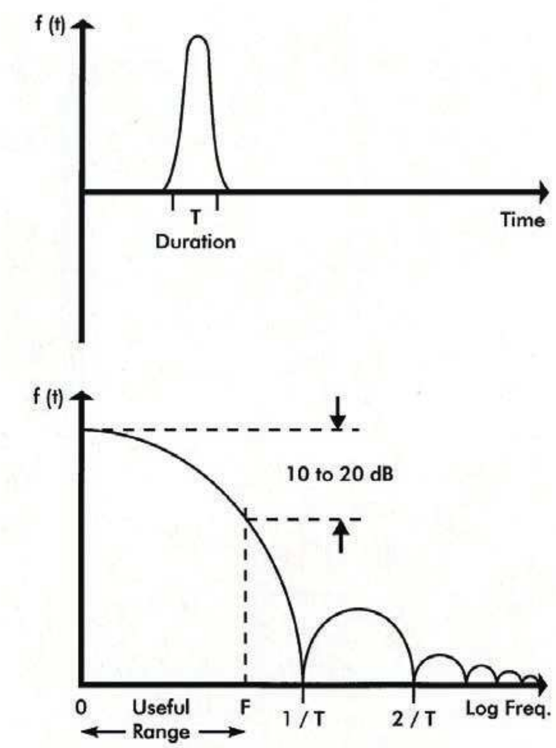
ΔF is the frequency resolution;

T is the time to capture one frame of data.

The selection of the frequency resolution is a compromise between measurement accuracy, equipment capability and test time. To ensure sufficient precision in the measured natural frequencies, measurement setup shall be selected to ensure that ΔF be no greater than 1% of the lowest natural frequency of interest.

5.3.3 Impact test procedure

The impact excitation is a pulse that results in transient vibration. Impact excitation can be generated by one of several means, including hammer, ball drop and heel drop. The waveform produced by an impact is a transient (short duration) energy transfer event. Its spectrum is continuous with a maximum amplitude at 0 Hz, and decaying amplitude with increasing frequency. The useful frequency range is from 0 Hz to a frequency F, at which point the spectrum magnitude has decayed by 10 to 20 dB. Figure 3 illustrates a typical impact force impulse and its spectrum.



NOTE 1 This figure is a modification of the original figure in Reference [6].

Figure 3 — Impact force impulse and its spectrum

As shown in Figure 3, the useful frequency range depends on the duration and magnitude of an impact force pulse. Therefore, for a given pulse, the longer the duration, the narrower the useful frequency range, the lower the magnitude of the pulse, which means that energy will mostly be channelled towards exciting the lower frequencies. The useful range as defined in Figure 3 shall cover the range of interested natural frequencies of the test floor.

5.3.3.1 Measurement setup

a) Averaging of frequency domain signals:

The coherence function shall be monitored for determining the minimum number of FRF measurements required during a particular floor test.

NOTE Averaging of FRF leads to suppression of noise level in the measured response. Guidance on determining the required number of averaging can be found in ISO 7626-2. As a guide, a minimum of five FRF measurements is usually sufficient to remove any background noises.[5]

b) Frequency resolution:

The procedure described in 5.3.2.3 (c) also applies here. The frequency resolution shall not be greater than 1% of the lowest interested natural frequency.

c) Windowing time signals:

A rectangular window is required for the impact force signal to reduce noise included in the analysis. An exponential window shall be used for transient response signals to prevent truncation errors during the FFT processing, and to reduce the effects of leakage error and noise in the frequency response measurements. The selection of the exponential window shall be to ensure that the acceleration response signal decays to 1% of the initial values at the end of the time signal record. The exponential window is not necessary if this condition is met in the time signal.

It should be noted that the application of the exponential window adds artificial damping to the response signal. This should be subtracted from the total measured damping so that the true damping of the test floor is obtained, as discussed in d).

d) Damping correction

The damping of the measured response signals due to application of an exponential window shall be corrected for. The following formula is recommended in ISO 7626-5 and shall be used to estimate the actual modal damping.

$$\varsigma_{\mathrm{r}} = \varsigma_{\mathrm{r}} * - \mathrm{d} / \omega_{\mathrm{r}} \tag{2}$$

where

ζ_r* is the apparent damping factor for the rth mode estimated from the measurement;

d is the decay rate for the exponential window selected and determined from the exponential function;

ω_r is the damped natural frequency for the rth mode;

ζ_r is the actual damping factor.

5.3.3.2 Influence of a human operator on test floor

The test shall be conducted with the human operator isolated from the test floor. If this is not possible, the presence of a human operator on a floor affects the floor damping and natural frequencies, and shall be noted in the test report.

The influence of the mass of the operator on the measured floor natural frequencies can be corrected using a floor dynamic model. For a joisted floor with all four sides simply supported, the following formula can be used to estimate the fundamental natural frequency of a floor with a concentrated mass at the centre of the floor:[7]

$$f_o = \frac{\pi}{2a^2} \sqrt{\frac{EI}{m_f S + m_j + \frac{4W_o}{a(n-1)}}} \tag{3}$$

where

f_o is the fundamental natural frequency of a floor in Hz;

a is the span of a floor with four edges simply supported in m;

EI is the composite bending stiffness of joist in N-m^2;

S is the spacing of joist in m;

n is the total number of joists in the floor;

m_f is the mass per area of subfloor panel in kg/m^2;

m_j is the mass per length of joist in kg/m;

W_o is the additional superimposed concentrated mass at the floor centre in kg.

For plate-type floor system with an orthotropic slab, Formula (4) can be used to correct the fundamental natural frequency due to the presence of an operator at floor centre.

$$f_o = \frac{\pi}{2a^2\sqrt{\rho}}\sqrt{D_x + 2H\left(\frac{a}{b}\right)^2 + D_y\left(\frac{a}{b}\right)^4}\sqrt{\frac{1}{\left(\frac{4W_o}{W_{plate}}\right)+1}} \quad (4)$$

where $D_x = \frac{E_x h^3}{12(1-v_{xy}v_{yx})}$, $D_y = \frac{E_y h^3}{12(1-v_{xy}v_{yx})}$, $H = D_1 + 2D_{xy}$, $D_{xy} = \frac{G_{xy}h^3}{12}$, $D_1 = D_x v_{yx}$, D's are the flexural rigidities and torsional rigidity, E_x, E_y and G_{xy} are the elastic modulus and in-plane shear modulus in N/m^2, v_{xy} and v_{yx} are the Poisson's ratios, and a, b, h are the length (x), width (y) and thickness (z) of the slab in m respectively, ρ is the density of the plate in kg/m^3; W_0 is the additional superimposed concentrated mass at the floor centre in kg; W_{plate} is the total mass of the slab in kg.

The influence of damping cannot be mathematically corrected.

5.4 Modal analysis

The natural frequencies, modal damping ratios, and mode shapes of a test floor shall be extracted from the measured FRF.[4] Determination of the mode shape associated with each dominant FRF peak provides the necessary information to assist with identification of true vibration modes. The construction of the mode shapes to confirm vibration modes is required.

6 Measurement of static deflection under a concentrated load

6.1 General

This section provides a procedure for the determination of the static deflection at the floor centre subjected to a concentrated load. This static deflection test is included because studies have shown that this response parameter, which is related to the orthogonal stiffness properties of a floor system, provides a good indication of the vibrational serviceability of the floor system. The deflection measurement can be taken either from the top floor surface or from underneath a floor depending on the floor construction details and the accessibility of the measurement location. For joisted floors, the floor centre is the mid-span of the centre joist. The deflection measured shall be the deflection of the floor framing for joisted floor systems. For floor systems with a floating flooring, soft layers, finishes or topping, the measurement shall be taken from under the floor joist on the ceiling side if a ceiling is present, and not the top of the floor surface. This is because such measurement may include the deformation of the underlayment which is generally made of non-rigid materials.

6.2 Apparatus

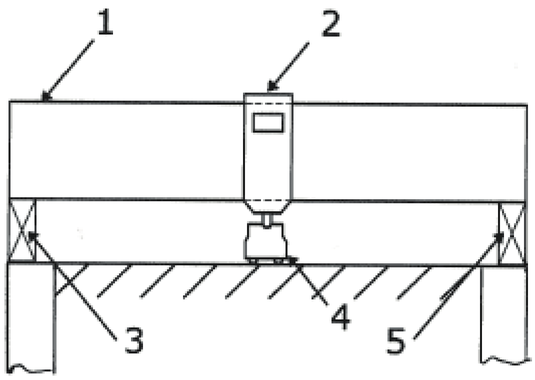
The apparatus required for this test includes a deflection measurement device, measurement reference system, and a load applicator. The deflection at the floor centre is measured with respect to a reference system that is not affected by the positioning of the applied load. For field testing where the floor construction is closed, an additional device may be required to locate the floor joists if the locations of the joists are not obvious from fastening lines.

6.2.1 Deflection measurement device, shall have a precision of 1% of the anticipated deflection.

6.2.2 Deflection reference system and mounting of deflection measurement device, is required so that the deflection at the floor centre can be measured with reference to the floor edge supports. The reference system shall be rigid and stationary during testing.

NOTE For testing in the laboratory where access to both top and bottom of the test floor can be achieved, the use of the reference system may be omitted if it can be shown that the deflection measuring device is mounted on a solid base and that there is no vertical movement of the floor edge support under load.

Figure 4 provides details of a suitable reference system and the mounting of the deflection gauge. The bearing plates shown in Figure 4 shall be placed as close as practicable to the edges of the test floor, so that the measured deflection is referenced to the edge support.



Key

1 reference beam with sufficient stiffness for varied length

2 deflection measurement device

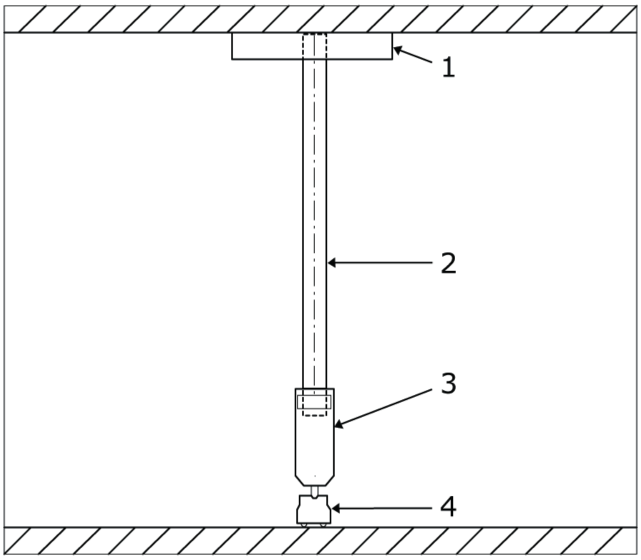
3 bearing plate

4 tripod base with pins attached to the floor surface to provide a solid surface for deflection measurement

5 bearing plate

Figure 4 — Sketch of a suitable deflection measurement reference system, including the deflection gauge and tripod base at between the deflection gauge and the floor surface

To measure the deflection under the floor, the ground or floor below shall be the reference. Figure 5 shows a suitable measurement setup using an extendable rod and the mounting of a deflection transducer. The plunger of the deflection gauge shall not be directly attached to the test or the reference floor surface because the various surface conditions may affect the measurement accuracy. Instead, the plunger shall be in contact with the test or reference floor surface through a solid base sitting on the surface of the floor below or the ground.



Key

1 fixture plate holding component 2 on bottom of test floor

2 extendable rod, a metal tub with sufficient bending stiffness to transfer floor deflection without buckling

3 deflection measurement device

4 tripod base

Figure 5 — Sketch of the rod, deflection gauge mounting and the tripod base between the deflection gauge and the reference floor below for measuring floor deflection under concentrated load

6.2.3 Load application, the concentrated load can be applied using a test machine, a dead mass or a person. The weight of the dead mass or person shall be measured immediately after testing.

6.3 Test procedure

If the deflection at the floor centre is required, the load shall be applied and the change in the deflection transducer readings before and after load application shall be measured. The difference between these readings shall be recorded as the static deflection under a concentrated load. If a dead mass or person is used and it is satisfied that the response of the test floor is elastic, the measured deflection can be prorated linearly to the target load level.

If the deflection profile of a floor under a concentrated load is desired, the normal procedure is to apply the load at the floor centre, and measure the deflection at the centre of each joist, or at the centre of each timber panel for massive timber slab floors. Alternatively, the deflection profile can be obtained by measuring the deflection at the floor centre with the load applied sequentially on each joist or massive timber panel.

7 Environmental condition of test site

Wherever possible, the environmental condition of the test site where the test floor has been stored until equilibrium condition is reached shall be maintained at 20 °C ± 5 °C and 65 % ± 5 % RH. When this condition cannot be met, correction to measured natural frequencies and static deflection shall be applied by adjusting the elastic properties, dimensions and density of the floor components due to moisture content deviation from the standard condition.

8 Test report

The test report shall include the following information:

a) a reference to this International Standard, e.g. ISO 18324:2016;

b) name of laboratory authority or organization that performed the tests;

c) a description of the test floor including

   1) location,

   2) floor construction details,

   3) environmental condition of the test site,

   4) other information as appropriate, such as occupied floor with occupants, furniture, partitions, etc. Where partitions are present, a description of partition wall construction details, locations, and the connections between the partition and the test floor shall be recorded,

   5) test floor plan indicating the locations of joists or slabs, partitions and supports, and floor dimensions;

d) a description of modal testing including

   1) excitation method,

   2) presence of operator and his/her weight, if applicable,

   3) a drawing of floor plan indicating accelerometer and excitation locations, and the operator location on the floor if applicable,

   4) measurement setup including the number of averaging, the frequency range and resolution, and window types applied to time domain signals,

   5) response transducer type, model, size, weight, frequency range, sensitivity,

   6) transducer mounting methods,

   7) exciter information, including type, model, sizes, calibration factor, capacity and mounting method, if applicable;

e) name and producer for the modal analysis software;

f) modal parameters including

   1) summary statistics of natural frequencies and modal damping ratios from all measurement locations,

   2) plots of mode shapes associated with the reported natural frequencies and modal damping ratios,

   3) plots of a typical frequency response function and coherence function;

g) if applicable, a description of concentrated load static deflection testing including

   1) loading method, load and location,

   2) deflection measurement device type, specifications and location.

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