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Mechanical vibration — Measurement of vibration generated internally in railway tunnels by the passage of trains

Vibrations mécaniques — Mesurage des vibrations produites à l'intérieur des tunnels ferroviaires par le passage des trains

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Annexes

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10815 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 2, *Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures.*

Annexes A to C of this International Standard are for information only.

Introduction

Railway tunnels are regularly exposed to vibration originating from internal sources (trains and service carriages, maintenance work, etc.).

In this International Standard only vibration resulting from the passage of trains is considered.

Vibration is measured in tunnels for different purposes, which are summarized as follows.

When a tunnel is reported to be exposed to vibration which might cause concern regarding its integrity, suitable measurements (see 9.1) should be taken to assess whether the levels are acceptable.

Measurements of vibration might be carried out in the following cases:

— when the maximum allowable vibration level has been established and a regular check is required (see 9.2);

— when the dynamic performance of a newly built tunnel has been predicted and performance must be checked against design data (see 9.1);

— a special situation may arise when the tunnel has been exposed to abnormal external action (e.g. due to fires, earthquakes, blasting, pile drivers or demolition of nearby buildings) and the integrity of the structure has to be checked (see 9.1);

— when any modification to the track and/or internal vibration sources (e.g. load on vehicle axles) has been made.

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Mechanical vibration — Measurement of vibration generated internally in railway tunnels by the passage of trains

1 Scope

This International Standard establishes the basic principles for measuring, processing and evaluating vibration generated internally in railway tunnels by the passage of trains.

By establishing a standard procedure, comparative data may be obtained on response of the tunnel elements from time to time, provided that the excitation source is the same. Data obtained in different tunnels may also be compared.

The measurements considered in this International Standard concern the response of the structure and secondary elements mounted in the tunnel. They do not concern the response of persons in the tunnel or in its vicinity, or of passengers on trains running through the tunnel.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 1683:1983, *Acoustics — Preferred reference quantities for acoustic levels.*

ISO 4866:1990, *Mechanical vibration and shock — Vibration of buildings — Guidelines for the measurement of vibrations and evaluation of their effects on buildings.*

ISO 5348:1987, *Mechanical vibration and shock — Mechanical mounting of accelerometers.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 tunnel: An underground structure in which passenger trains, freight trains or service trains travel.

3.2 background noise: Sum of all the signals except the one under investigation.

4 Factors affecting vibration

4.1 Tunnel-related factors

The dynamic characteristics of a tunnel depend largely on its geometry, the secondary elements, depth of the tunnel and the soil properties.

A lined tunnel is usually a system of discrete elements (e.g. concrete, ventilation channels, etc.) each coupled with the soil. They may have different response characteristics and coupling with the surrounding soil and/or rock.

4.1.1 Tunnel types and conditions

There are many kinds of tunnels, all of which respond to vibration in a different way. Examples are given in annex B.

4.1.2 Natural frequencies and damping ratios

For this International Standard, the frequencies of interest are likely to relate to the response of the tunnel elements and not to a fundamental frequency of the tunnel cavity in the surrounding medium. The natural frequencies of these elements can be determined as follows:

— measurement of the response of the tunnel elements when they are affected by a large, transient external influence such as, for instance, pile driving or blasting;

— the use of a shaker as a mono-frequency source together with measurement of the response amplitude;

— measurement of the response using ambient excitation and spectrum analysis.

Accurate determination of damping is a difficult task, especially for tunnels containing both lightly damped elements, such as beams, and elements which are in firm contact with the tunnel surfaces and therefore are highly damped due to wave radiation.

4.1.3 Soil

The soil surrounding the tunnel has an important effect on the stiffness of the tunnel and on the tunnel response to vibration, and as such is therefore of main concern when making predictions about response. Its characteristics depend on soil particle size, compaction, saturation, underground water level and bedding, and upon amplitude, frequency and duration of the excitation.

4.2 Source-related factors

The vibration produced by the passage of trains may be classified according to the signal type, the duration and the frequency range (see ISO 4866).

The signal depends on the mechanical properties of the train, the track, the wheel-rail contact and on the loading and speed of the train.

The frequency range to be analysed depends on the spectral distribution of the excitation forces and the transfer function from the source to the tunnel walls or linings.

The frequency range from 1 Hz to 100 Hz covers the responses of different elements of the tunnel. On the rail, the frequency range of interest is usually up to 2 kHz, although higher frequencies are often present.

5 Quantities to be measured

In the frequency range of interest for tunnel vibration, usually a kinematic value such as velocity or acceleration is measured.

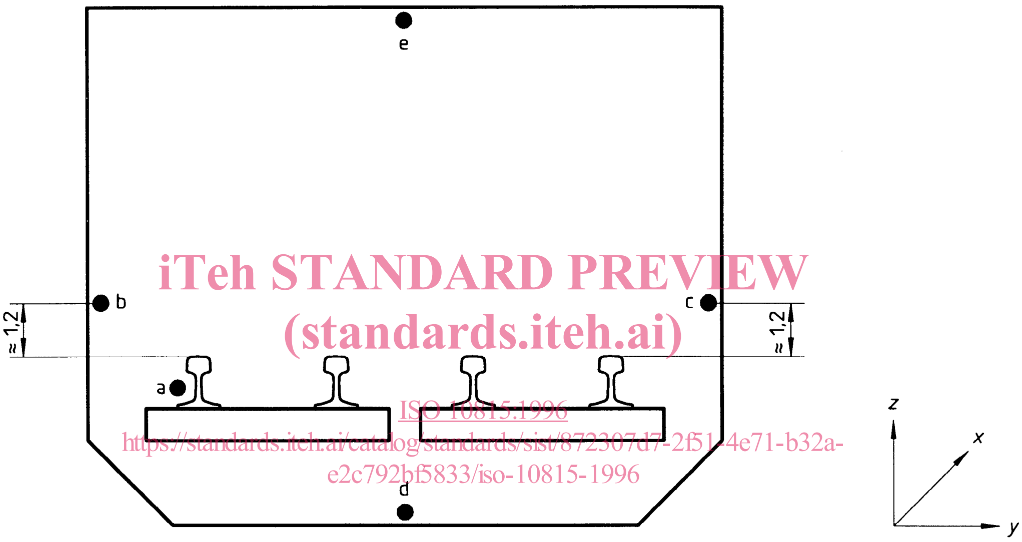
In the lower frequency range, velocity measurement is preferred although in the higher frequency range instrumental factors dictate that acceleration be measured.

6 Measurement methods

6.1 Positioning the pick-ups with respect to the passage of trains

Ideally, a straight stretch of the tunnel, at least 200 m long, should be available for the readings. The pick-ups should be placed away from any visible singular features (major cracks, water seepages, switch points and crossings), unless the effect of such a feature is to be investigated. To investigate the tunnel response, the pick-ups should preferably be oriented in line with the three principal axes of the tunnel (one vertical, two horizontal; see figure 1).

Dimensions in metres



Type of test	Measurement points
Full (see 9.1)	a, b, c, d, e
Limited (see 9.2)	b, d, e

Figure 1 — Measurement points at a cross-section, depending on the type of test

In the following assignment of measurement points, it is assumed that the train is running over the left track (see figure 1).

For full and limited tests (see 9.1 and 9.2), the pick-ups should be arranged:

— on the invert at the cross-section vertical centreline (point d of figure 1), between two sleepers in the case of tracks laid on ballast, or between two successive fasteners or rail spikes for other types of track;

— on the vault (point e of figure 1), directly above point d;

— on the tunnel wall close to the track where the train will run, 1,20 m above the level of the rails (point b of figure 1).

In order to investigate the relationship between trains as excitation sources and vibration transmitted to the tunnel, measurements should be made on the foot of the rail perpendicular to the plane of the rails (point a of figure 1).

Position a is prone to local effects and its typicality and stability should be established before its selection as a control point for a limited test.

Allowance should be made for the slope shaping the foot of the rail (see figure 2).

If the invert is not accessible, the pick-up should be placed at the nearest suitable point, and any element between the pick-up and the invert should be indicated.

For full tests (see 9.1), readings shall also be taken at other two sections away from the middle section (typically 20 m) in order to minimize local influences. However, when the signal issuing from two corresponding points on two sections placed 20 m away from each other are equal, measurements may be taken at one section only.

If, however, such readings differ systematically by more than 25 % (2 dB), they should be discarded and a third section considered.

When the readings taken at all three sections are in disagreement, the local conditions should be examined and another measurement section selected.

6.2 Fastening the pick-ups

The pick-ups should be mounted in accordance with ISO 5348, so as to reproduce the motion of the vibrating elements, minimizing the response due to the mounting system.

The mounting, therefore, shall be rigid and as light as possible.

When fixing pick-ups to the foot of a rail, a shaped steel plate should be rigidly fixed between the pick-up and the rail (preferably welded to the rail), otherwise the pick-ups cannot be mounted perpendicular to the foot of the rail (see figure 2).

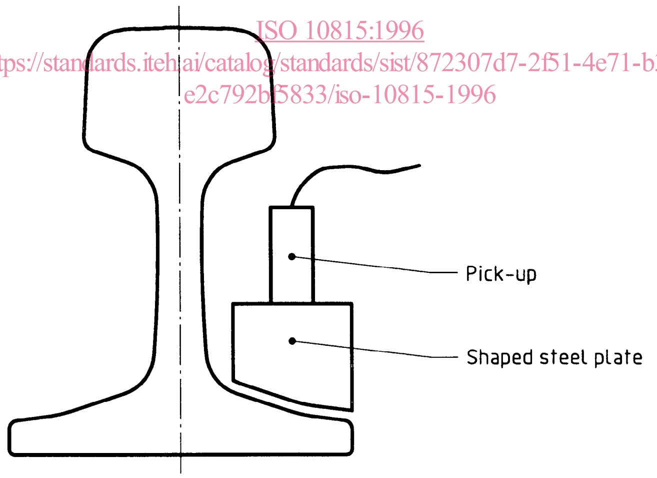


Figure 2 — Measurement point at the foot of a rail

It is very important that the system of pick-ups, mounting support and bolt has a mounting resonance frequency much higher than the upper frequency of the range of interest (see ISO 5348).

It may be noted that accelerometers can be very sensitive to air-coupled response during the passage of a train. It is, therefore, necessary to protect them from airborne sound.

6.3 Signal-to-noise ratio

It is advisable to measure the background noise (see 3.2), whenever possible, deactivating the sources of vibration to be measured. For instance, when the vibration caused by a passing train is recorded, the signal present in the absence of the train should be recorded and processed in the same way. The results of both are then compared; their ratio is the signal-to-noise ratio S/N.

When the signal is more than three times higher than the noise ($S/N > 10$ dB), the readings can be accepted without correction. When the signal is between two and three times higher than the noise (6 dB $\leqslant S/N \leqslant$ 10 dB), the readings should be corrected and this should be mentioned in the test report.

When the signal is less than twice as high as the noise ($S/N < 6$ dB), the readings are unreliable and merely have an indicative value.

7 Measuring instruments

The choice of pick-ups is important for correct evaluation of vibratory motion (see ISO 4866). It should be made with regard to the quantity to be measured, taking into account its frequency (see 4.2) and amplitude ranges and the environment in which it must function.

Particularly important is the resonance and the phase response of pick-ups, and the complex transfer function of integrators, which can lead to different results for the same mechanical input.

In most measurements on a rail an accelerometer is used; on the other points it is suggested that geophones be used with a natural frequency lower than the minimum investigated frequency.

The measuring chain should be calibrated before and after the sequence of measurements and at least every 2 years the components of the measuring chain should be calibrated by an accredited laboratory, which issues the relevant certification.

It is recommended that, except on a rail, a velocity pick-up be used and values expressed in millimetres per second. Each measured velocity component should be reported with its frequency of oscillation. If a decibel scale is used, the reference quantity is 10^{-6} mm/s according to ISO 1683 (see note).

If there is a need to compare the results of an accelerometer with the velocity outputs of other pick-ups, an integration (preferably digital) should be performed with the original acceleration time history and Fourier spectrum reported. Electronic integration, such as via a low-pass filter, may produce different results, depending on the amplitude and phase components of the original signal and complex function of the integrators.

For the decibel scale, the reference acceleration is 10^{-6} m/s^2 according to ISO 1683.

NOTE — The decibel scale widely used in acoustics may give rise to some confusion when adopted for structural vibration if the kinematic quantity upon which it is based, i.e. velocity (mm/s) or acceleration (m/s^2), is not stated along with the appropriate reference value (see ISO 1683). This is especially the case where vibration is to be compared.

8 Measurement for internal sources

8.1 Conditions of the track

For the tests according to 9.1 and 9.2, the track should be in good condition, free from visible flaws and corrugation.

8.2 Conditions of the train

For the tests according to 9.1 and 9.2, the vehicle should be in a well-maintained condition. Specifically, wheels should be free of flats and other visible flaws. The vehicle should travel empty, a driver and signal and inspection crew being alone on board. The train composition should be as for normal operation. Passenger vehicle speeds should be as follows:

11 m/s (40 km/h) for tramcars;

17 m/s (60 km/h) for metropolitan railway trains;

22 m/s (80 km/h) for rapid transit vehicles;

the maximum speed allowed at the measurement section.

During vibration recording, the vehicle should be coasting, except for the last condition (maximum speed).

9 Types of test

The tests can be of two types: full tests and limited tests.

In any test, for recording of levels with analog instruments, an integration time of 1 s should be used.

9.1 Full tests

These tests are designed to establish that the tunnel system is performing within the required specifications. They are also carried out to check the effect of any significant structural modification. These tests should provide information for full dynamic analysis.

In this case:

- there are three measuring sections 20 m apart, as specified in 6.1;
- three single pick-ups, one for each orthogonal cartesian axis, or a triaxial unit should be placed at each measurement point (see 6.1);

- a minimum of three passages of the train through the measurement section, in one direction of travel only, should be recorded;
- with analog instruments, the highest r.m.s. value of the time history should be read; integration time 1 s;
- the three values that do not differ by more than 11 % (1 dB) in overall value and 40 % (3 dB) in each frequency band should be taken as true values; the arithmetic means should then be calculated to obtain the values of each of the velocity components v_x, v_y, v_z;
- the S/N ratio (see 6.3) should be higher than 10 dB as overall values and at least 6 dB in each frequency band;
- three orthogonal components should be recorded.

9.2 Limited tests

Limited tests are intended to monitor specific characteristics, and are routinely performed at regular time intervals.

In this case:

- one measurement section only is needed;
- at each point one pick-up only is needed, perpendicular to the relevant plane (see 6.1);
- examination of the time history is likely to be sufficient;
- it is sufficient when S/N $\geqslant$ 6 dB (see 6.3);
- a minimum of three passages should be recorded; the three values that do not differ by more than 3 dB shall be taken as true, and the arithmetic mean calculated and rounded off to the nearest whole decibel.