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Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration —

Part 4:
Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems

Vibrations et chocs mécaniques — Évaluation de l'exposition des individus à des vibrations globales du corps —

Partie 4: Lignes directrices pour l'évaluation des effets des vibrations et du mouvement de rotation sur le confort des passagers et du personnel dans les systèmes de transport guidé

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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.

Attention is drawn to the possibility that some of the elements of this part of ISO 2631 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 2631-4 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*.

ISO 2631 consists of the following parts, under the general title *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration*:

— *Part 1: General requirements*

— *Part 2: Vibration in buildings (1 Hz to 80 Hz)*

— *Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems*

Annex A forms a normative part of this part of ISO 2631.

Introduction

The purpose of this part of ISO 2631 is to help in the design and evaluation of fixed-guideway passenger systems, with regard to the impact of vibration and repetitive motions on passenger comfort. This information is required because of the following.

Fixed-guideway vehicles provide a predictable but complex multi-axis motion environment that is a function of the guideway, vehicle and seat or berth. Passengers evaluate ride comfort not only based on motion but also on their expectations with regard to the class of service that they have purchased. The duration of the trip has not been demonstrated to be a direct factor in predicting comfort (with the possible exception of kinetosis), but the anticipated duration of the trip is related to the types of activities passengers expect to accomplish while on board. Passengers on trips of more than a few minutes may expect to read, write, eat and drink; on trips of longer duration they will expect to sleep. To the extent that ride-induced vibration interferes with these activities, passengers may rate differently the comfort of vehicles with the same motion environment but different expected levels of service or different trip durations. Passengers are likely to judge comfort based on the interaction of vibration with factors such as acoustic noise, temperature, humidity, air quality and seat design.

Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration —

Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems

1 Scope

This part of ISO 2631 provides guidance on the application of ISO 2631-1 to the evaluation of the effects of mechanical vibration on the comfort of passengers and crew in fixed-guideway systems. It is intended to be used by organizations which purchase, specify or use fixed-guideway systems, to help them to understand the relationship between the design of the guideway as well as other features of the system and the comfort of passengers and crew. These guidelines establish methods for the evaluation of relative comfort between systems, as opposed to absolute levels of comfort.

This part of ISO 2631 is applicable to people in normal health exposed to rectilinear vibration along their x-, y- and z-axes, as well as rotational vibration about these (body-centred) axes. It is intended to provide guidance on the assessment of comfort as a function of motions along and about vehicle axes that produce the body motions. This part of ISO 2631 is not applicable to high-amplitude single transients which may cause trauma, such as those resulting from vehicle accidents or “run-ins” produced by “longitudinal slack action”, nor is it applicable to high-amplitude vibration which may affect health.

For the purposes of this part of ISO 2631, fixed-guideway passenger systems include rail systems (heavy and light rail), magnetically levitated (MAGLEV) systems and rubber tyre metro-type systems, as well as any of the system types listed above that incorporate a tilt capability to compensate for lateral acceleration when traversing curves.

This part of ISO 2631 provides guidance on the effects of very low-frequency accelerations (0,1 Hz to 0,5 Hz) experienced as vertical forces that may cause kinetosis. These forces may be caused by combinations of curve transition, super-elevation and tilt-body technology. However, this part of ISO 2631 is not intended to give guidance on comfort implications of very low-frequency accelerations (below 0,5 Hz) experienced as lateral or longitudinal forces. Such accelerations can be generated by guideway geometry (horizontal alignment and cant).

This part of ISO 2631 gives guidance on the evaluation of ride comfort based on motion environment only.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 2631. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 2631 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 2631-1:1997, *Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration — Part 1: General requirements*.

IEC 61260, *Electroacoustics — Octave-band and fractional-octave-band filters*.

3 Special considerations for fixed-guideway transport systems

Fixed-guideway systems can produce significant repetitive and/or vibratory motions that are known to affect passenger comfort. The motions of interest are translational motion along, and rotational motion around, each of three mutually perpendicular axes of the vehicle. There is evidence that vertical, lateral and roll motions also play important roles in passenger comfort in rail vehicles. The influence of lateral and longitudinal motions could be most important for passengers or crew in a standing position.

Factors including acoustic noise level, visual stimuli, temperature and humidity interact with vibration in the passenger's perception of comfort. The effect of these non-motion factors should be considered when using the results of vehicle motion tests to assess comfort. As an example, acoustic noise has been found to be correlated with judgements of ride comfort in passenger rail cars.

A human body-centred coordinate system is not always well suited for characterizing the comfort/motion relationship for fixed-guideway systems. Passengers may stand, sit or lie down in various orientations relative to the vehicle body. Where practical, measurement at the seat/body interface can give a more complete understanding of the comfort environment provided by the ride motions. Where measurements are taken at the person/seat interface, the guidance provided in ISO 2631-1:1997, Figure 1, on basicentric axes shall be used.

Measurement at the seat/body interface is the preferred method in ISO 2631-1 but it may not always be appropriate for the evaluation of fixed-guideway systems. These measurements are also problematical because of the inherent variability resulting from subjects assuming varying postures and making voluntary movements. The ride environment produced by a fixed-guideway system is made up of contributions from the guideway, vehicle suspension, vehicle body and seats or berths. Seats and berths are not permanent parts of the vehicle and are likely to be replaced a number of times during the life of the vehicle.

Assessing the impact of measured ride motion on passenger comfort is further complicated by passenger expectations and trip duration. The length of a trip can vary from minutes to days; passengers can expect to engage in a wide variety of activities including walking, reading, writing, typing, eating, drinking or sleeping. Not only can certain motions interfere with some of these activities, but involvement in activities requiring visual concentration, particularly reading or writing, can increase the passenger's likelihood of developing kinetosis (motion sickness).

The condition of the test vehicle's suspensions and the conditions of the track or guideway sections used shall be described in order to permit meaningful comparisons between vehicles or systems. In general, tests should be conducted along representative sections of straight and curved track. These sections should include the full range of track/guideway quality appropriate to the car being tested. Similarly, vehicles should be tested when equipped with new wheels and, where practical, also with wheels worn to the maintenance limits.

Tests should be conducted with empty cars and, where practical, also with fully laden cars. Other load conditions may also be examined. The position of the car in the train and, in some cases, the direction of travel can affect the outcome of the tests. Vehicles adjacent to the test car can also influence the tests. The position of the test vehicle in the train or made-up train and the direction of travel should be recorded and reported.

4 Motion characteristics of fixed-guideway vehicles

Motion in a fixed-guideway vehicle is characterized by

a) semi-random translational accelerations (in all three axes) and semi-random angular accelerations (about all three axes) due to imperfections in track/wheel surfaces, track alignment errors, etc.,

b) more or less periodic motions due to instability problems (swaying), motions in suspension, long-wave track irregularities, periodic distances between joints, staggered track, etc.,

c) quasi-static magnitudes of acceleration along both lateral and vertical axes and roll (bank) and yaw motion due to alignment and cant (super-elevation) and quasi-static magnitudes of acceleration along the longitudinal axis due to acceleration or braking of the vehicle, and

d) sudden motions due to large imperfections in track or switches, or changes of quasi-static levels (jerk) due to changes in curve radii with or without transition curves.

The frequency range of motions expected to impact ride comfort significantly in conventional rail vehicles includes 0,1 Hz to 2 Hz on curve transitions (roll), 0,5 Hz to 10 Hz in the lateral and longitudinal directions, and 0,5 Hz to 20 Hz in the vertical direction.

For ultra-high-speed vehicles (250 km/h and faster) and for tilting trains, vertical accelerations in the frequency range 0,1 Hz to 0,5 Hz can occur. Such low-frequency vertical accelerations can induce kinetosis (motion sickness). ISO 2631-1:1997, annex D, provides guidance on a method of calculating a motion sickness dose value based on accelerations in this frequency range.

Two types of rolling motion can occur:

— relatively high-amplitude, very low-frequency rolling motions which happen when entering and leaving a super-elevated section of curved track or guideway; and

— repetitive side-to-side rocking motions resulting from suspension/guideway interactions.

For systems that incorporate significant levels of guideway super-elevation and/or tilt suspension mechanisms, roll (bank) angle and roll velocity (roll rate) should be considered in assessing the effects of motion on comfort.

Sustained bank angles occurring during coordinated turns considerably greater than 24° are commonly encountered in air travel. When such bank angles are achieved gradually and are sustained, they do not appear to cause passenger discomfort. However, repeated exposure to the high roll rates required to reach and return quickly from such roll angles can cause kinetosis. Such high roll rates can occur when using transition curves (curve entry and return transitions). At very high speeds, transition curves of a practical length are a potential source of passenger discomfort and kinetosis.

5 Measurement

The guideway, wheels, suspension, car body structure and interior fittings (seats and berths) all contribute to the vibration experienced by passengers and crew.

When the contribution to comfort of the seat or berth is the primary concern, it is vital to take measurements at the seat/body or berth/body interface. These are the direct contact points between the vehicle structure and the person and have the function of sustaining and guiding the person and of transmitting the weight of the same to the car body itself (see Table 1). Evaluation of an overall vibration total value for a standing, seated or recumbent person should include measurements made at the body interfaces given in Table 1.

NOTE In some situations it can be useful to take measurements for seated passengers at the headrest/neck interface and at the armrest/forearm interface; similarly for recumbent passengers it can be useful to take measurements at the berth/leg interface.

Table 1 — Body interfaces

Position	Interface
Standing	floor/feet
Seated	seat-supporting surface seat-back floor/feet
Recumbent	surface supporting the pelvis, back and head

Fixtures (seats, berths) are usually replaced a number of times during the life of the vehicle and the guideway. Taking measurements at these interfaces may not be as useful as taking measurements on the vehicle structure, therefore it may be more appropriate to take measurements at rigid portions of the vehicle structure, as discussed in ISO 2631-1:1997, note 1 of 5.3.1. Where measurements are made at points on the car structure, the following references should be used:

— z-axis: vertical, upwards (positive)/downwards (negative) perpendicular to the floor;

— x-axis: longitudinal, forwards (positive)/backwards (negative) along the direction of travel;

— y-axis: lateral at right angles to the direction of travel;

— roll: rotational motion about the x-axis.

It is not always correct to treat the vehicle as a rigid body. Therefore measurements should be carried out at both ends of the vehicle and middle (the exception is motion along the x-axis for which a single measurement can suffice). For double-decker vehicles, measurements should be made on the lower deck at both ends of the vehicle, and at the middle, and on the upper deck at the middle of the vehicle. Because vehicle designs vary so widely, the measuring locations should be recorded and reported in detail.

Measurement of roll motion characteristics are only needed on vehicles that have roll (tilt) mechanism or have guideways that have large super-elevations and give large roll (bank) angles.

Roll velocity (roll rate) can be measured by a rate gyroscope mounted on the floor. Roll acceleration can then be calculated as the time derivative of the roll velocity. Low-frequency filtering may be required; the characteristics of such filters should be reported.

Although the preferred method is to use a rate gyroscope as described above, roll acceleration can be measured by two vertical accelerometers mounted on the floor at the same longitudinal position in the vehicle but separated by a lateral distance d (in metres). Then the roll acceleration (in radians per square second) is given by $\left(\ddot{z}_{\text{left}} - \ddot{z}_{\text{right}}\right)/d$, where $\ddot{z}$ is the accelerometer output (in metres per square second).

6 Analysis of motions of fixed-guideway vehicles

With regard to vertical vibration, ISO 2631-1:1997, Table 1, provides general guidance on the choice of the weighting curve to be used under a wide variety of conditions. This table suggests the use of the weighting curve W_k for vertical accelerations. However, the note in C 2.2.1 of ISO 2631-1:1997 indicates that, for the assessment of comfort in rail vehicles, the weighting curve designated W_b is an acceptable approximation of the general curve W_k. W_b is of particular value in the assessment of comfort in rail vehicles and is currently used by many European and some non-European railway companies.

Although weighting curves W_k and W_b can sometimes provide similar results, the use of these two curves can at other times yield substantially different results. Below 8 Hz the weighted value using W_b could be smaller by a factor of 0,8; above 8 Hz the weighted value using W_b could be larger by a factor of 1,2. Figure 1 illustrates the differences between the two frequency weighting curves. The method of calculation of W_b is found in annex A. The appropriate multiplying factors are the same as those given for W_k in ISO 2631-1.

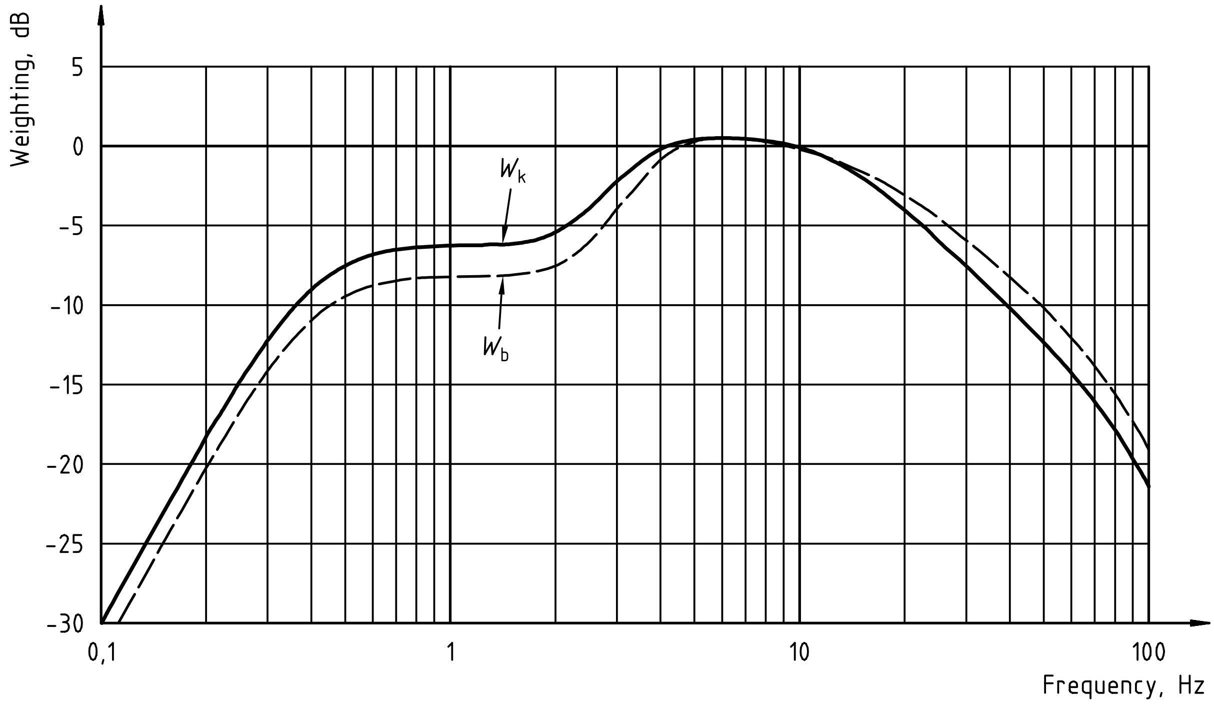

Figure 1 — Frequency weighting curves for W_b and W_k

ISO 2631-1:1997, clause 8, specifies an r.m.s.-based method of evaluation of ride comfort. However, many railway companies use an alternative statistical method of evaluation as described in ISO 10056. The statistical methods take into account fluctuation of vibration and variation between passengers, and they avoid sensitivity to artefactual extremes. An example of the use of these statistical methods is found in reference [5]. In this method the corresponding vibration values are characterized by using the 95 percentile of the weighted r.m.s. values of the accelerations measured at intervals of 5 s over a period of 5 min. At least four such periods shall be taken into consideration.

On fixed-guideway systems, super-elevation and vehicle tilt mechanisms are intended to compensate for lateral accelerations. However, this compensation can result in the perception of low-frequency vertical accelerations. Extended periods of exposure to low-frequency vertical accelerations can result in kinetosis. Guidance on the assessment of extended exposure to low-frequency motion is found in ISO 2631-1:1997, annex D, which provides a dosage method for calculating the motion sickness dose value, $MSDV_z$.

NOTE 1 It has been reported that lateral and roll accelerations can contribute to kinetosis. In addition to its use with vertical accelerations, the method of calculation of motion sickness dose defined in ISO 2631-1:1997, annex D, can be used to express the severity of lateral and roll acceleration. It is not intended that the motion sickness dose values calculated using lateral and roll accelerations be used to predict the prevalence of vomiting but to encourage and assist the reporting of data.

Transient lateral accelerations are a characteristic of the ride of conventional rail systems. These motions are intermittent and can occur when crossing switch points or when the vehicle's lateral motion causes it to reach its suspension stops. Such transient motions are particularly disturbing to standing passengers. Some guidance on the evaluation of transient motion is provided in ISO 2631-1:1997, 6.3.

NOTE 2 Sustained lateral accelerations occur when the vehicle traverses a horizontal curve at a speed that is higher (or lower) than track super-elevation or combined super-elevation and compensating car body tilt. These accelerations are a particular problem for passengers or crew engaged in walking.

7 Direct tests of passenger comfort

Where the overall assessment of the ride comfort of a vehicle is required, it is necessary to take into account not only the motion environment but also factors such as acoustic noise, temperature and humidity. It is also important to consider the expected activities of the system's passengers and crew. One method of achieving this is through the direct recording of human responses. This method can be used if a representative test vehicle and representative sections of test guideway are available, or if an adequate motion simulator is available.

There are a number of difficulties with such tests. Comfort assessments may provide useful information on the global ride environment but may not provide clear insight into the contribution of ride motion. Comfort ratings will vary somewhat between subjects exposed to the same ride segments and will even vary for the same subjects over repetitions from day to day on the same test segments. The impact of such variations on the reliability and validity of measurements can be alleviated by proper statistical design.

Order effects represent a particular complication when assessing the impact of motions that result in kinetosis. The effects of very low-frequency accelerations (0,1 Hz to 0,5 Hz) are known to be strongly cumulative. To compensate for subject variability, an adequate sample of subjects shall be used and they shall be exposed to an adequate number of repetitions of the test conditions. Where potential motion-induced kinetosis is anticipated, a thorough counterbalancing of the order of exposure to the ride segments is critical. This can prove difficult on fixed-guideway systems because usually there are only two practical orders of presentation. Use of simulators to produce these counterbalanced tests is also difficult because few simulators can supply the vertical stroke required to simulate the low-frequency accelerations associated with kinetosis.

If a "within-subjects" test design (one where the subjects act as their own controls) is used, test subjects must participate in a number of tests each with the segments presented in different orders. Because of the cumulative effect of kinetosis, the tests should be separated by a day or more.

Subject responses should be collected using a relatively simple scale that is readily understandable by the test subjects. A bipolar scale is required because often the focus of the research is to determine if new or changed equipment provides ride comfort that is “as good as” the original equipment. Furthermore, the cost of the system may be reduced by designing the system to have satisfactory levels. For example, a system specifier may need to distinguish a system likely to be rated *very comfortable* from one rated *neither comfortable nor uncomfortable* in order to determine if the marginal cost is justified. The following bipolar scale uses terminology essentially derived from the unipolar list of "comfort reactions to vibration environments" in accordance with ISO 2631-1:1997, C.2.3:

— very comfortable;

— comfortable;

— neither comfortable nor uncomfortable;

— uncomfortable;

— very uncomfortable.

Consistency in subject responses will be enhanced by providing the subjects with ride samples representative of the set points before the tests begin. The impact of expectations on consistency will be reduced by carefully briefing the subjects on the type of service being evaluated. If passengers in the system being evaluated are expected to carry out activities such as eating, reading or writing, the test subjects should engage in these activities during the testing.

Some additional considerations will be a function of the goals and resources for each individual study. These include the number of subjects and the conditions to be tested, the number of repeated exposures to each condition necessary to provide adequate statistical power, and the orders and duration of exposure to each condition. Guidance on such issues should be sought from an individual specializing in experimental design.

Annex A
(normative)

Specification of frequency weighting W_b

A.1 Parameters of the transfer function

The parameters of the transfer function are given in Table A.1.

Table A.1 — Parameters of the transfer function of the frequency weighting W_b

Band-limiting			**Frequency weighting**							
f_1 Hz	f_2 Hz	Q_1	f_3 Hz	f_4 Hz	f_5 Hz	f_6 Hz	Q_4	Q_5	Q_6	K
0,4	100	0,71	16	16	2,5	4	0,55	0,90	0,95	0,4

A.2 Transfer functions

The band-limiting (band-pass filter) is given by:

$$H_b(p) = \frac{p^2 \cdot 4\pi^2 f_2^2}{\left(p^2 + \frac{2\pi f_1}{Q_1} \cdot p + 4\pi^2 f_1^2\right)\left(p^2 + \frac{2\pi f_2}{Q_1} \cdot p + 4\pi^2 f_2^2\right)} \tag{A.1}$$

The pure frequency weighting for W_b is given by:

$$H_w(p) = \frac{(p + 2\pi f_3)\left(p^2 + \frac{2\pi f_5}{Q_5} \cdot p + 4\pi^2 f_5^2\right)}{\left(p^2 + \frac{2\pi f_4}{Q_4} \cdot p + 4\pi^2 f_4^2\right)\left(p^2 + \frac{2\pi f_6}{Q_6} \cdot p + 4\pi^2 f_6^2\right)} \cdot \frac{2\pi K f_4^2 \cdot f_6^2}{f_3 \cdot f_5^2} \tag{A.2}$$

where

f_n are resonance frequencies with n = 1 to 6;

Q_n is the selectivity (resonant quality factors) with n = 1, 4, 5, 6;

K is a constant gain;

$H(p)$ is the transfer function of the filter with $p = j2\pi f$.

Values of the frequency weighting W_b in one-third-octave bands, frequency band limitation included, are given in Table A.2.

Table A.2 — Frequency weighting W_b in one-third-octave bands, frequency band limitation included

Frequency band number [a] x	Frequency f Hz	W_b factor × 1 000	W_b dB
–10	0,1	25,0	–32,04
–9	0,125	38,9	–28,20
–8	0,16	63,2	–23,98
–7	0,2	97,3	–20,23
–6	0,25	146	–16,71
–5	0,315	211	–13,51
–4	0,4	282	–10,98
–3	0,5	334	–9,53
–2	0,63	367	–8,71
–1	0,8	381	–8,38
0	1	385	–8,29
1	1,25	386	–8,27
2	1,6	392	–8,07
3	2	417	–7,60
4	2,5	494	–6,13
5	3,15	662	–3,58
6	4	889	–1,02
7	5	1025	0,21
8	6,3	1055	0,46
9	8	1025	0,21
10	10	974	–0,23
11	12,5	907	–0,85
12	16	810	–1,83
13	20	708	–3,00
14	25	600	–4,44
15	31,5	492	–6,16
16	40	393	–8,11
17	50	313	–10,09
18	63	239	–12,43
19	80	171	–15,34
20	100	116	–18,72
21	125	70,8	–23,00
22	160	37,3	–28,56
23	200	19,9	–34,03
24	250	10,4	–39,69
25	315	5,22	–45,65
26	400	2,56	–51,84

a Index x is the frequency band number according to IEC 61260.

Bibliography

[1] ISO 8727, *Mechanical vibration and shock — Human exposure — Biodynamic coordinate systems*.

[2] ISO 10056, *Mechanical vibration — Measurement and analysis of whole-body vibration to which passengers and crew are exposed in railway vehicles*.

[3] ISO 10326-2, *Mechanical vibration — Laboratory method for evaluating vehicle seat vibration — Part 2: Application to railway vehicles*.

[4] ENV 12299, *Railway applications — Ride comfort for passengers — Measurement and evaluation*.

[5] CLEON, L.-M. and LAURIKS, G. Evaluation of Passenger Comfort in Railway Vehicles, *J. Low Frequency Vibration*, **15**, No. 2, 1996, pp. 53-69.

[6] European Rail Research Institute. *Application of ISO 2631 to railway vehicles. Comfort index* N_{MV} *comparison with the ISO/SNCF comfort note and with the* W_z. Report No. ERRI B 153/RP 21, 1993.

[7] FÖRSTBERG, J. Motion related comfort levels in trains: A study of human responses to different tilt control strategies for a high speed train, *VTI sartryck*, No. 274, 1997.

[8] FÖRSTBERG, J., ANDERSSON, E. and LEDIN, T. Influence of different conditions for tilt compensation on symptoms of motion sickness in tilting trains, *Brain Research Bulletin*, **47**, No. 5, 1998, pp. 525-535.

[9] FÖRSTBERG, J. and LEDIN, T. Discomfort caused by low frequency motion: A literature survey of hypotheses and possible causes of motion sickness, *VTI meddelande*, No. 802A, 1996.

[10] GRIFFIN, M.J. *Handbook of human vibration*. Academic Press, London, 1990.

[11] HIGGINBOTHAM, R. Ride-quality evaluation and technology in intercity rail passenger car specifications. *Transportation Research Record*, **894**, 1982, pp. 26-29.

[12] PEPLER, R.D., VALLERIE, L.L., JACOBSON, I.D., BARBER, R.W. and RICHARDS, L.G. *Development of techniques and data for evaluating ride quality*. Vol. II: *Ride-quality research*. U.S. Department of Transportation Report No. DOT-TSC-RSPD-77-1, 1978.

[13] RICHARDS, G.L. *On the psychology of passenger comfort*. In: *Human factors in transport research*. Vol. 2. Oborne & Lewis (eds.), Academic Press, London, 1980.

[14] SUSSMAN, E.D., POLLARD, J.K., MENGERT, P. and DISARIO, R. *Study to Establish Ride Comfort Criteria for High Speed Magnetic Levitation Transportation Systems*. U.S. Department of Transportation Report No. DOT-VNTSC-FRA-93-14, 1993.

[15] SUSSMAN, E.D. and WORMLEY, D.N. Measurement and evaluation of ride quality in advanced ground transportation systems. *Transportation Research Record*, **894**, 1982, pp. 9-17.

[16] WICHANSKY, A.M. *The effects of the ride environment on intercity train passenger activities*. Transportation Research Board Meeting, Washington, DC, 1979.

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