INTERNATIONAL STANDARD

ISO 8608

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Mechanical vibration — Road surface profiles — Reporting of measured data

Vibrations mécaniques — Profils de routes — Méthode de présentation des résultats de mesures

Reference number
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Foreword

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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 8608 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, B, C, D and E of this International Standard are for information only.

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Introduction

The purpose of this International Standard is to facilitate the compilation and comparison of measured vertical road profile data from various sources. It therefore specifies a uniform method of reporting data from one-track and multiple-track measurements.

It specifies how measurements shall be reported, but not how the measurements shall be made. The measuring equipment may influence the results of the measurement; therefore certain characteristics of the measuring system shall be reported.

Annex A is an example of a report which meets the minimum requirements of this International Standard.

Annex B gives means of approximately characterizing specific road profiles in order to facilitate the division of road profiles into general classifications. A general classification is also given. A curve-fitting method is suggested for characterizing spectral data.

Annex C provides general guidance for the use of road profile statistical data for simulation studies and for related studies such as evaluation of comfort, suspensions and road profiles.

Annex D discusses the processing of the Power Spectral Density (PSD) with the Fast Fourier Transform (FFT) technique. A discussion on the statistical precision is also given.

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Mechanical vibration — Road surface profiles — Reporting of measured data

1 Scope

This International Standard specifies a uniform method of reporting measured vertical road profile data for either one-track or multiple-track measurements.

It applies to the reporting of measured vertical profile data taken on roads, streets and highways, and on off-road terrain. It does not apply to rail-track data. Measurement and processing equipment and methods are not included.

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 2041:1990, *Vibration and shock — Vocabulary.*

IEC 1260:—[1], *Electroacoustics — Octave-band and fractional-octave-band filters.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 2041 and the following definitions apply.

3.1 spatial frequency: Reciprocal of the wavelength. It is expressed in cycles per metre.

3.2 Power Spectral Density (PSD): The limiting mean-square value of a signal per unit frequency bandwidth. For a one-sided spectrum, the area located between the graphic plot and the horizontal axis in a linear plot should be equal to the variance (σ^2) of the original signal for the evaluated frequency range. This leads to a doubling of the spectral amplitude when the calculation process is only estimating the spectrum for positive frequencies.

3.3 displacement PSD: PSD of the vertical road profile displacement.

3.4 velocity PSD: PSD of the rate of change of the vertical road profile displacement per unit distance travelled (slope of the vertical road profile).

3.5 acceleration PSD: PSD of the rate of change of the slope of the vertical road profile per unit distance travelled.

3.6 decolouring: Procedure to eliminate the influence of the transfer function of the measuring system on the PSD, i.e. the raw PSD should be decoloured before any further processing by dividing it by the square of the modulus of the measuring equipment transfer function.

3.7 smoothing: An averaging process in which a data block is shifted and averaged.

NOTE 1 In this International Standard "unsmoothed PSD" means the PSD as calculated from the measured data, i.e. with the bandwidths used in or following from the calculations and which are different from those indicated in table 2. The term "smoothed PSD" is the PSD which is obtained after using the averaging process described in 5.1.2.

1) To be published. (Revision of IEC 225:1966)

4 Symbols

See table 1.

Table 1 — Symbols

Symbol	Description	Unit
B_e	Frequency resolution	cycles/m
f	Time frequency	Hz
G_d (.)	Displacement PSD	m^3
G_v (.)	Velocity PSD	m
G_a (.)	Acceleration PSD	m^{-1}
G_1 (.)	PSD of track 1	—
G_2 (.)	PSD of track 2	—
G_{12} (.)	Cross spectrum between tracks 1 and 2	—
l	Wheelbase	m
n	Spatial frequency	cycles/m
s	Track width	m
t	Time	s
v	Vehicle speed	m/s
y^2	Coherence function	—
λ	Wavelength	m
ω	Angular frequency (= $2\pi f$)	rad/s
Ω	Angular spatial frequency (= $2\pi n$)	rad/m

NOTE — The indication (.) means that the parameter of the function can be spatial frequency (n) or angular spatial frequency (Ω).

5 Uniform method of reporting

5.1 One-track data

5.1.1 Description of the road profile

The road profile shall be described by one or both of the following two methods, with preference for the first, the displacement PSD.

The reporting of the non-smoothed data is always required.

5.1.1.1 First method — Displacement PSD: $G_d(.)$

The road profile shall be described by the PSD of its vertical displacement. The report shall include the displacement PSD *versus* spatial frequency, both on logarithmic axes. The dimensions are metres cubed *versus* reciprocal metres.

Two scales shall be given on the ordinate, one for $G_d(n)$ and one for $G_d(\Omega)$. Both n and Ω scales shall be indicated in the abscissa. The grid, however, shall only be drawn for $G_d(n)$ and n.

5.1.1.2 Second method — Acceleration PSD: $G_a(.)$

The acceleration PSD is an allowed alternative method of reporting data.

In this case, the road profile shall be described as the PSD of its acceleration in terms of the rate of change of the slope of the road surface per unit distance travelled. The dimension of the PSD shall be in reciprocal metres.

The scales shall be logarithmic on both axes. Two scales shall be given on the ordinate, one for $G_a(n)$ and one for $G_a(\Omega)$. On the abscissa both n and Ω shall be indicated. The grid, however, shall only be drawn for $G_a(n)$ and n.

The relationship between the two reporting methods is given by

$$G_a(n) = (2\pi n)^4 \cdot G_d(n)$$

$$G_a(\Omega) = \Omega^4 \cdot G_d(\Omega)$$

5.1.1.3 Spatial frequency range

The reported PSD shall be restricted between the limits allowed by the measuring equipment. For the report the user may select any spatial frequency range appropriate to his particular road surface, problem and product.

NOTES

2 Figure C.1 gives the relationship between the vehicle speed, the spatial frequency and the time frequency. Knowledge of the frequency and speed characteristics for a given class of vehicles makes it possible to choose the useful limits for that class of vehicle (for example, on- or off-road vehicles).

3 For the lower limit, the spatial frequency need not in general be measured lower than 0,01 cycles/m for on-road vehicles and 0,05 cycles/m for off-road vehicles.

4 The enveloping effect of the tyre acts as a low-pass filter for the road vibration input to the vehicle. This effect depends on the size and construction of the tyre. For general on-road measurements, this results in a recommended upper limit of 10 cycles/m. Of course for suspension vibration purposes, the interesting upper limit depends on the maximum allowed speed on the particular road. For noise purposes, the interesting upper limit may be much higher, and may go as high as 1 000 cycles/m.

5 Due to the tyre width there is also an enveloping effect in the lateral direction. This means that for vibration purposes the mean of the footprint is usually measured. The width depends on the problem (for example, vibration, noise) and the product (for example, motorcycle tyres, truck

tyres). For general on-road measurements not intended for a specific product, a track of about 100 mm wide is often used for vibration purposes. For noise purposes, a point measurement is often used.

The measured surface depends on the measuring equipment, which has a certain smoothing effect. This equipment is to be reported (see 5.3.4.2.1).

6 For off-road measurements, care should be taken when interpreting the high frequencies. For soft (for example, sandy) surfaces, short undulations could be flattened by the wheel load and filtered out. For hard (for example, stone) surfaces, however, only the enveloping effect of the tyre acts as a filter. In this situation the surface is to be described accurately in the data sheet (see 5.3.4.3.2).

7 Annex B gives recommended methods for the characterization of the road profile and for the fitting of the measured data.

5.1.2 Presentation of the smoothed power spectral density

When the PSDs are calculated with a constant bandwidth method, their representation in a log-log diagram will give an appearance or visual impression at high frequencies which over-emphasizes the fluctuations of the PSD generated by the real power distribution and by the statistical noise.

For this reason, the PSD shall also be represented in a smoothed form, i.e. by the mean PSD in the following frequency bands:

— octave bandwidth from the lowest calculated frequency (except zero) up to a centre frequency of 0,031 2 cycles/m (0,196 3 rad/m);

— third-octave bands from the last octave band up to a centre frequency of 0,25 cycles/m (1,570 8 rad/m);

— the rest, twelfth-octave bands up to the highest calculated frequency.

The centre frequencies to be used for the calculation of the smoothed PSD are given in table 2.

The mean PSD in a defined band should be calculated in the following way:

$$G_s(i) = \frac{[(n_L + 0{,}5)\cdot B_e - n_l(i)]\,G(n_L)}{n_h(i) - n_l(i)} + \frac{\sum_{j=n_L+1}^{n_H-1} G(j)\cdot B_e}{n_h(i) - n_l(i)} + \frac{[n_h(i) - (n_H - 0{,}5)\cdot B_e]\cdot G(n_H)}{n_h(i) - n_l(i)}$$

where

$G_s(i)$ is smoothed PSD in smoothing band i;

$$n_H = \mathrm{INT}\left(\frac{n_h(i)}{B_e} + 0{,}5\right) \quad (n_h\text{: see table 2});$$

$$n_L = \mathrm{INT}\left(\frac{n_l(i)}{B_e} + 0{,}5\right) \quad (n_l\text{: see table 2}).$$

The other symbols are as defined in table 1.

The first and the third terms of the right side of the equation calculate respectively the parts of the original band n_L and n_H, in the calculated smoothed band i.

If this scheme cannot be followed, due to the calculations, the differences shall be noted in the report.

The same rules shall be followed when the smoothing is to be done in angular spatial frequency.

The same rules shall be followed for analog computation.

A small and easy supplementary calculation following the processing of the smoothed PSD leads to the characterization of the road profile as described in annex B.

5.2 Multiple-track data

The multiple-track road profile data shall be described as the PSD curves of each track as described in 5.1, and their relationship curves expressed as their coherence function

$$\gamma^2 = \frac{G_{12}(.)^2}{G_1(.)\cdot G_2(.)}$$

When more than two tracks are measured, the most travelled track near the edge of the road shall be taken as the reference track for the calculation of coherence functions.

The curve shall be smoothed as described in 5.1.2.

5.3 Report

The report shall contain one or more curve sheets and general information.

5.3.1 One-track data curve sheet

The curve sheet for one-track data shall contain the non-smoothed PSD and the smoothed PSD. When the information is given on one sheet, the separate curves should be carefully differentiated.

The PSD curve sheet shall also include the information given in 5.3.3.1.3, 5.3.3.1.4, 5.3.3.1.5, 5.3.4.3.1 and 5.3.4.3.2.

It is also recommended to indicate on the data sheet the road profile characterization described in annex B, i.e. the general and octave band characterization of the road and the fitted PSD (for examples see figures A.2 and A.4).

5.3.2 Multiple-track data curve sheet

For multiple-track data, the sheets of each PSD shall be reported as described in 5.3.1, together with a similar curve sheet for their coherence function. This sheet shall contain the smoothed coherence curve. The track width shall be indicated on this sheet.

When the information is given on one sheet, the separate curves should be carefully differentiated.

5.3.3 Parameters of analysis

5.3.3.1 For all forms of spatial analysis, the following information shall be reported.

5.3.3.1.1 The analysis method used, analog or digital.

5.3.3.1.2 Pre-processing filters shall be reported in terms of cut-off spatial frequency, slope (dB/octave) and type of filter (for example Butterworth). In the case of the digital analysis, this includes the anti-aliasing filter.

5.3.3.1.3 The resolution bandwidth: in the case of a relative constant bandwidth analysis, it is sufficient to state the proportion octave bandwidth only.

5.3.3.1.4 The real distance travelled of the data, in metres, analysed and reported.

In order to quantify wavelengths of 100 m with a statistical precision of 0,6 at a spatial frequency resolution of 0,01 m^{-1}, the distance travelled shall be at least 1 000 m.

In some cases it may be impossible or perhaps of no interest to reach this limit, for example for short roads or for the study of special forms of surfaces. In this case a remark in the report is required. For a discussion of statistical precision, see annex D.

5.3.3.1.5 The statistical precision of spectral estimates of the data: in the case of a relative constant bandwidth analysis, the statistical precision of the narrowest bandwidth shall be reported. The statistical precision shall be stated as ± % value, calculated for a 95 % confidence level (i.e. the statistical precision shall be stated as 1,96 times the normalized standard error) on the basis of random error.

5.3.3.2 For analog spectral analyses, the following information shall be reported, in addition to that specified in 5.3.3.1.

5.3.3.2.1 The class of bandwidth filters in accordance with IEC 1260.

5.3.3.2.2 The slopes (dB/octave) and type of constant bandwidth filter.

5.3.3.3 For digital spectral analyses, the following information shall be reported, in addition to that specified in 5.3.3.1.

5.3.3.3.1 The specific method used (such as Fast Fourrier Transform, Mean Lagged Product, Continuous Digital Filter).

5.3.3.3.2 The sampling spatial frequency.

5.3.3.3.3 The sampling window function and correction factor used.

5.3.3.3.4 The reported resolution bandwidth, if it is different from the analysis bandwidth (for example when frequency-smoothing is used).

5.3.4 Test conditions

5.3.4.1 The date of the measurement shall be reported.

5.3.4.2 The instrumentation used shall be reported as follows.

5.3.4.2.1 Short description of the measuring system.

a) Mechanical design.

b) Scanning device

— in the case of a contacting device (for example, a wheel): description of the design (for example, a soft wheel), mass, tyre pressure, tyre dimensions, effective diameter, nominal test load and dimensions of the contact area under nominal test load;

— in the case of a non-contacting device (for example, a radar system): resolution, dimensions of the effective measured area, etc.

c) The capability of the equipment to take into account slope bias and transverse slope effects over long distances and long wavelengths.

5.3.4.2.2 A flowchart showing transducers, telemetry, tape recorder, filters, etc.

5.3.4.2.3 The instrumentation and calibration chain of the measuring system should be carefully reported. Details of the design, the guaranteed transfer function and the accuracy should be given, either in the report or in a source reference.

5.3.4.2.4 The cut-off frequencies of any filter used in conjunction with the recording of the data.

5.3.4.3 The road or terrain description shall be reported as follows.

5.3.4.3.1 Definition of the road: country, road number, location, village, direction and, if possible, a small map. Also traffic density [annual average daily traffic (AADT), when possible], typical vehicle speed and other relevant descriptive information shall be reported.

5.3.4.3.2 The road profile shall be reported with respect to at least the type of surface (concrete pavement, compacted soil, cobblestone, etc.) and the surface condition (new pavement, rutted road, poorly maintained, etc.), the grade (longitudinal slope), the cross-fall (lateral slope) and the curve radius (if any). In the case of off-road measurements, the cone penetration resistance of the soil should be reported together with a reference or a description of the measurement method used (see, for instance, reference [13]).

5.3.4.3.3 Definition of the measured track: distance from the measured track to the near side of the road. A sketch of the road, with indication of the tracks reserved for bicycles, parking and traffic is recommended. All unusual facts should be indicated.

5.3.4.3.4 A photograph of the road shall be included. It shall be taken from a height of 1,4 m (approximately the height of the eyes of the driver of a passenger car). The photograph shall also show a two-dimensional scale indication and the position of the measured tracks.

5.3.4.3.5 If two- or multiple-track data are given, they shall be described as in 5.3.4.3.3. The distance between the tracks shall also be given.

Table 2 — Centre frequencies and cut-off frequencies for PSD smoothing, expressed in spatial frequency n

a) Octave bandwidth

EXP	n_l m^{-1}	n_c m^{-1}	n_h m^{-1}
− 9	0,001 4	0,002 0	0,002 8
− 8	0,002 8	0,003 9	0,005 5
− 7	0,005 5	0,007 8	0,011 0
− 6	0,011 0	0,015 6	0,022 1
− 5	0,022 1	0,031 2	0,044 2

b) Third-octave bandwidth

EXP	n_l m^{-1}	n_c m^{-1}	n_h m^{-1}
− 4,333	0,044 2	0,049 6	0,055 7
− 4	0,055 7	0,062 5	0,070 2
− 3,667	0,070 2	0,078 7	0,088 4
− 3,333	0,088 4	0,099 2	0,111 4
− 3	0,111 4	0,125 0	0,140 3
− 2,667	0,140 3	0,157 5	0,176 8
− 2,333	0,176 8	0,198 4	0,222 7
− 2	0,222 7	0,250 0	0,280 6

NOTES

8 n_l = lower cut-off frequency

n_c = centre frequency

n_h = upper cut-off frequency

$n_c = 2^{EXP}$

9 A small overlap exists between the lowest twelfth-octave bandwidth and the highest third-octave bandwidth. This overlap maintains the values 0,5; 1; 2; 4 as centre frequencies in the twelfth-octave bands. This makes it convenient to calculate the road characterization (see B.3) immediately from the twelfth-octave band smoothing.

c) Twelfth-octave bandwidth

EXP	n_l m^{-1}	n_c m^{-1}	n_h m^{-1}
− 1,833	0,272 6	0,280 6	0,288 8
− 1,750	0,288 8	0,297 3	0,306 0
− 1,667	0,306 0	0,315 0	0,324 2
− 1,583	0,324 2	0,333 7	0,343 5
− 1,500	0,343 5	0,353 6	0,363 9
− 1,417	0,363 9	0,374 6	0,385 6
− 1,333	0,385 6	0,396 9	0,408 5
− 1,250	0,408 5	0,420 4	0,432 8
− 1,167	0,432 8	0,445 4	0,458 5
− 1,083	0,458 5	0,471 9	0,485 8
− 1	0,485 8	0,5	0,514 7
− 0,917	0,514 7	0,529 7	0,545 3
− 0,833	0,545 3	0,561 2	0,577 7
− 0,750	0,577 7	0,594 6	0,612 0
− 0,667	0,612 0	0,630 0	0,648 4
− 0,583	0,648 4	0,667 4	0,687 0
− 0,500	0,687 0	0,707 1	0,727 8
− 0,417	0,727 8	0,749 2	0,771 1
− 0,333	0,771 1	0,793 7	0,817 0
− 0,250	0,817 0	0,840 9	0,865 5
− 0,167	0,865 5	0,890 9	0,917 0
− 0,083	0,917 0	0,943 9	0,971 5
0	0,971 5	1	1,029 3
0,083	1,029 3	1,059 5	1,090 5
0,167	1,090 5	1,122 5	1,155 4
0,250	1,155 4	1,189 2	1,224 1
0,333	1,224 1	1,259 9	1,296 8
0,417	1,296 8	1,334 8	1,374 0
0,500	1,374 0	1,414 2	1,455 7
0,583	1,455 7	1,498 3	1,542 2
0,667	1,542 2	1,587 4	1,633 9
0,750	1,633 9	1,681 8	1,731 1
0,833	1,731 1	1,781 8	1,834 0
0,917	1,834 0	1,887 7	1,943 1
1	1,943 1	2	2,058 6
1,083	2,058 6	2,118 9	2,181 0
1,167	2,181 0	2,244 9	2,310 7
1,250	2,310 7	2,378 4	2,448 1
1,333	2,448 1	2,519 8	2,593 7
1,417	2,593 7	2,669 7	2,747 9
1,500	2,747 9	2,828 4	2,911 3
1,583	2,911 3	2,996 6	3,084 4
1,667	3,084 4	3,174 8	3,267 8
1,750	3,267 8	3,363 6	3,462 1
1,833	3,462 1	3,563 6	3,668 0
1,917	3,668 0	3,775 5	3,886 1
2	3,886 1	4	4,117 2
2,083	4,117 2	4,237 9	4,362 0
2,167	4,362 0	4,489 8	4,621 4
2,250	4,621 4	4,756 8	4,896 2
2,333	4,896 2	5,039 7	5,187 4
2,417	5,187 4	5,339 4	5,495 8
2,500	5,495 8	5,656 9	5,822 6
2,583	5,822 6	5,993 2	6,168 8
2,667	6,168 8	6,349 6	6,535 7
2,750	6,535 7	6,727 2	6,924 3
2,833	6,924 3	7,127 2	7,336 0
2,917	7,336 0	7,551 0	7,772 3
3	7,772 3	8	8,234 4

Annex A
(informative)

Example of a report

This annex contains fictitious data arranged to form an example for two-track reporting which meets the minimum requirements of this International Standard. However, the photograph is omitted.

NOTES

10 The numbers in parentheses refer to the subclauses in this International Standard.

11 The parts of figure A.2 and figure A.4 placed in a double frame are the recommended characterizations of the road profile described in annex B. They are not required, but recommended.

12 The format of the data sheets is not standardized.

A.1 Parameters of analysis

Analysis (5.3.3.1.1, 5.3.3.3.1): FFT

anti-aliasing filter (5.3.3.1.2): 48 dB/octave

Butterworth: 0,5 cycles/m low-pass

Sampling spatial frequency (5.3.3.3.2):

1,4 cycles/m

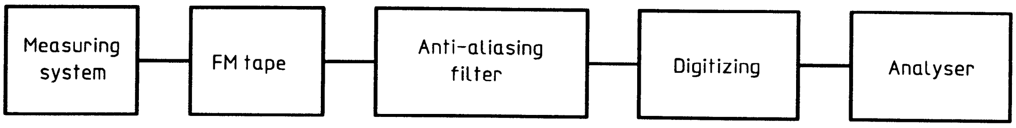
Sampling window function (5.3.3.3.3): Hanning

Correction factor (PSD) (5.3.3.3.3): $1{,}63^2$

A.2 Test conditions

Measuring system (5.3.4.2.1, 5.3.4.2.3, 5.3.4.2.4): see Verschoore, R. *Het gebruik van de wegsimulator en de analoge rekenmachine in het onderzoek van voertuigsuspensies*. Gent, 1973.

Flow chart (5.3.4.2.2):



A.3 Road description

Road definition (5.3.4.3.1) (see figure A.1):

traffic: AADT, 4 200 vehicles/day

typical vehicle speed: 90 km/h

Road profile (5.3.4.3.2):

concrete pavement, 10 years old

grade 0 %

slope 0,06 %

no curve

Photograph (5.3.4.3.4) (omitted in this example)

A.4 Road characterization

See figures A.1 to A.4.