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Mechanical vibration and shock — Range of idealized values to characterize human biodynamic response under whole-body vibration

Vibrations et chocs mécaniques — Enveloppes de valeurs probables caractérisant la réponse biodynamique d'individus soumis à des vibrations globales du corps

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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 of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*.

This third edition cancels and replaces the second edition (ISO 5982:2001), which has been technically revised. The main changes compared to the previous edition are as follows:

— Previously given ranges of idealized values for the apparent mass of the seated human body have been updated.

— The range of idealized values is now defined for seated individuals, with and without a back support, exposed to sinusoidal or broad-band random vibration in the *x*-axis, *y*-axis and *z*-axis with unweighted RMS acceleration lower or equal to 2 m/s^2.

— Idealized values of apparent mass for standing individuals, while exposed to vertical vibration (*z*-axis), have been added.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The biodynamic response of the seated human body subjected to vibration has widely been assessed in terms of driving-point mechanical impedance or apparent mass and seat-to-head transmissibility. While the first two functions relate to the force and motion at the point of input of vibration to the body ("to the body" transfer functions), the last function refers specifically to the transmission of motion through the body ("through the body" transfer function). Since biodynamic responses are non-linear with respect to vibration magnitude, those functions are defined for a specific range of vibration magnitudes. Knowledge of these functions under conditions representative of those encountered while driving specific types of vehicles can find applications in current laboratory procedures defined for assessing vehicle seat performance and for predicting whole-body vibration exposure levels on platforms of mobile machinery. Although such procedures currently require that specific tests be conducted with human subjects acting as test loads, these functions can form the basis for developing a mechanical system capable of simulating the human body or for deriving functions that can account for the human interface when the tests are being conducted with rigid masses. Such functions can further form the basis for developing analytical models representing the human body, which through combination with suitable suspension seat models can provide numerical means of estimating the seat performance and of achieving optimal seat suspension and cushion design. Notwithstanding the above applications, this document provides unification of available published data on the driving-point mechanical impedance, apparent mass and seat-to-head transmissibility response functions satisfying a specific set of conditions. In view of the restrictions imposed on posture and vibration excitation levels, the values defined for each of these functions can be more applicable to drivers of off-road, heavy road and industrial vehicles.

The response of the human body subjected to whole-body vibration is dependent on several factors, including

a) subject mass,

b) posture and back support,

c) feet support and

d) excitation amplitude.

In this document, the apparent mass and the seat-to-head transmissibility are employed to describe the biodynamic response characteristics of the human body to forced translational motion of the buttocks or feet, as a function of frequency.

The unexplained differences between the mean modulus and phase values of apparent mass and seat-to-head transmissibility reported in studies conducted independently, under a similar range of experimental conditions, has dictated the form in which the standardized values for these functions is presented. A synthesis of measured values has been performed using data published in the literature. The most probable range of values of apparent mass and seat-to-head transmissibility modulus and phase are defined as a function of frequency by upper and lower limit envelope curves, which encompass the mean values of all data sets, at each frequency. The smoothened envelopes have been constructed from successive piecewise approximations using a fixed number of points while creating an overlap. The mean of the accepted data sets, weighted according to the number of subjects involved, and standard deviation computed with respect to the weighted mean, are defined as a function of frequency, and represent the target values for all applications of this document. Any data that fall within the range of idealized values defined by upper and lower limit envelope curves can be considered to be an acceptable representation of the biodynamic response functions of the human body under the specific conditions defined.

No modulus or phase presented as a function of frequency in this document corresponds precisely to the mean value measured in a single investigation involving human subjects at all frequencies. Furthermore, measured data for a single subject can appear out of range of the upper and lower limit envelope curves.

Major changes to previously given ranges of idealized values for the apparent mass of the seated human body were considered necessary in view of the new data available since the publication of the second edition (ISO 5982:2001). The second edition only considered the driving-point mechanical impedance/apparent mass of seated individuals, without a back support, exposed to vertical vibration (*z*-axis). As part of this document, a range of idealized values is defined for seated individuals, with and without a back support, exposed to sinusoidal or broad-band random vibration in the *x*-axis, *y*-axis and *z*-axis with unweighted RMS acceleration lower or equal to 2 m/s^2. Idealized values of apparent mass for standing individuals, while exposed to vertical vibration (*z*-axis), have also been added. Values for seat-to-head transmissibility (STHT) remained mostly unchanged and are still provided for seated individuals without a back support while exposed to *z*-axis vertical vibration.

This document incorporates the most recent data to have been published on the apparent mass and seat-to-head transmissibility, while satisfying the conditions specified above. Annex A provides information on the selection of published data to define the range of idealized values of apparent mass and seat-to-head transmissibility. The frequency ranges for defining these values are limited to 0,5 Hz to 20 Hz for vertical vibration (*z*-axis) and to 0,5 Hz to 10 Hz for lateral (*y*-axis) and fore-aft (*x*-axis) vibration, since predominant vibrations are known to occur within those ranges for several types of off-road, heavy road and industrial vehicles. In Annex B, an analytical model of the seated human body is provided to satisfy the range of idealized values defined for the apparent mass and seat-to-head transmissibility functions. Alternatively, mathematical expressions in the form of transfer functions are provided in Annex C to approximate the mean (target) values defined for these functions. Finally, values for the apparent mass are provided in Annex D for three specific body masses ranges on the basis of a study involving 27 male subjects.

Mechanical vibration and shock — Range of idealized values to characterize human biodynamic response under whole-body vibration

1 Scope

This document describes the range of idealized values of the apparent mass modulus and phase applicable to seated individuals with and without a back support subjected to *x*-, *y*- and *z*-axis sinusoidal or broad-band random vibration and to standing individuals subjected to *z*-axis sinusoidal or broad-band random vibration under specific experimental conditions. Additionally, this document describes the range of idealized values of seat-to-head transmissibility modulus and phase applicable to seated individuals without a back support subjected to *z*-axis sinusoidal or broad-band random vibration.

The ranges of idealized values defined in this document are considered to be valid for subjects on a rigid seat (or standing on a rigid platform for *z*-axis only), with feet supported and vibrated. The range of idealized seat-to-head transmissibility values is considered to be applicable also to the condition with the feet hanging freely. For seated individuals subjected to sinusoidal or broad-band random vibration, the apparent mass values are defined over the frequency range of 0,5 Hz to 10 Hz for the *x*-axis and *y*-axis, and over the frequency range of 0,5 Hz to 20 Hz for the *z*-axis. The frequency and amplitude characteristics of the vibration fall within the range for which most vibration exposure is likely to predominate while driving vehicles such as agricultural tractors, earth-moving machinery and fork-lift trucks. Application to automobiles is not covered by this document in view of the lack of a meaningful database for conditions involving posture and vibration excitation levels most likely associated with car driving.

The upper and lower values of modulus and phase defined at each frequency for each of the biodynamic response functions considered represent the range of most probable or idealized values. The middle values represent overall weighted means of the human data and define the target values for general applications. Such applications can involve the development of mechanical analogues for laboratory seat testing, or of functions to correct for the human interface when representing the body as a rigid mass, or the development of analytical human body models to be used for whole-body vibration exposure estimations or for seat and cushion design optimization.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5805, *Mechanical vibration and shock — Human exposure — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5805 and the following apply.

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

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

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

3.1
apparent mass
$M(f)$
complex ratio of applied periodic excitation force at frequency f, $F(f)$, to the resulting vibration acceleration at that frequency, $a(f)$, measured at the same point and in the same direction as the applied force, as given by Formula (1)

$$M(f)=\frac{F(f)}{a(f)} \tag{1}$$

Note 1 to entry: The apparent mass is a complex quantity (i.e. it possesses real and imaginary parts) from which the modulus and phase can be computed.

Note 2 to entry: This document is based on measurements in which both force and acceleration were measured at the same point, this being the point of introduction of vibration to the body, namely the buttocks (seat-body interface) or the feet.

Note 3 to entry: In the case of non-harmonic vibration, apparent mass is determined from the force and acceleration spectra.

3.2
driving-point mechanical impedance
$z(f)$
complex ratio of applied periodic excitation force at frequency f, $F(f)$, to the resulting vibration velocity at that frequency, $v(f)$, measured at the same point and in the same direction as the applied force, as given by Formula (2)

$$z(f)=\frac{F(f)}{v(f)}=\mathrm{j}2\pi f M(f) \tag{2}$$

where

$M(f)$ is the apparent mass;

j represents the complex phasor between the mechanical impedance and apparent mass $\left(\mathrm{j}=\sqrt{-1}\right)$.

Note 1 to entry: The relationship between driving-point mechanical impedance and apparent mass is entirely determined by the fixed relationship between velocity and acceleration for which a 90° phase difference exists under periodic excitation.

Note 2 to entry: In the case of non-harmonic vibration, driving-point mechanical impedance is determined from the force and velocity spectra.

3.3
seat-to-head transmissibility
complex non-dimensional ratio of the response motion of the head to the forced vibration motion at the buttocks (seat-body interface)

Note 1 to entry: The ratio can be one of displacements, velocities or accelerations.

Note 2 to entry: The seat-to-head transmissibility is a complex quantity (i.e. it possesses real and imaginary parts) from which the non-dimensional modulus and the phase can be computed.

Note 3 to entry: In the case of non-harmonic vibration, seat-to-head transmissibility is determined from the motion spectra.

4 Definition of values of apparent mass of the human body under vibration

4.1 Apparent mass of the seated body under *x*-axis vibration

The modulus and phase of the apparent mass of the seated body with and without a back support are given in Tables 1 and 2, respectively, and (for illustration) in Figures 1 and 2 as a function of frequency, for the *x*-axis direction of excitation. According to the definitions, the modulus is given in terms of kilograms for apparent mass. The table and diagram contain three values of modulus and phase at each frequency. Numerical values are quoted up to four significant figures for the purpose of calculation, and do not reflect the precision of knowledge of the apparent mass. Linear interpolation is permitted to obtain values at frequencies other than those listed in Tables 1 and 2 at one-third-octave band centre frequencies.

The upper and lower limiting values at each one-third-octave band centre frequency encompass the mean values of all data sets selected, and are shown by continuous curves in Figures 1 and 2. The central value at each frequency, shown by dashed curves in Figures 1 and 2, provides an estimate of the weighted mean of all data sets selected, and forms the target value for all applications. The standard deviations computed with respect to the weighted mean (target) values are also listed in Tables 1 and 2.

Applications shall generate/employ values of apparent mass between the upper and lower limits given in Tables 1 and 2 at any frequency, and represent "to the body" transfer functions applicable to the seated human body under the conditions specified and over the frequency range of 0,5 Hz to 10 Hz.

If an application only satisfies the requirements of this document at certain frequencies, then those frequencies should be stated in any description of the application.

4.2 Applicability of values of apparent mass of the seated body under *x*-axis vibration

The values of apparent mass are applicable to the seated human body, subjected to sinusoidal or broad-band random fore-aft vibration, while seated on a rigid surface with the feet resting flat on the base platform and the back being supported and unsupported. The limits of applicability approximately correspond to the range of measurement conditions over which data were obtained, as follows:

a) the posture is described as erect seated with or without backrest support, while the feet are supported and vibrated;

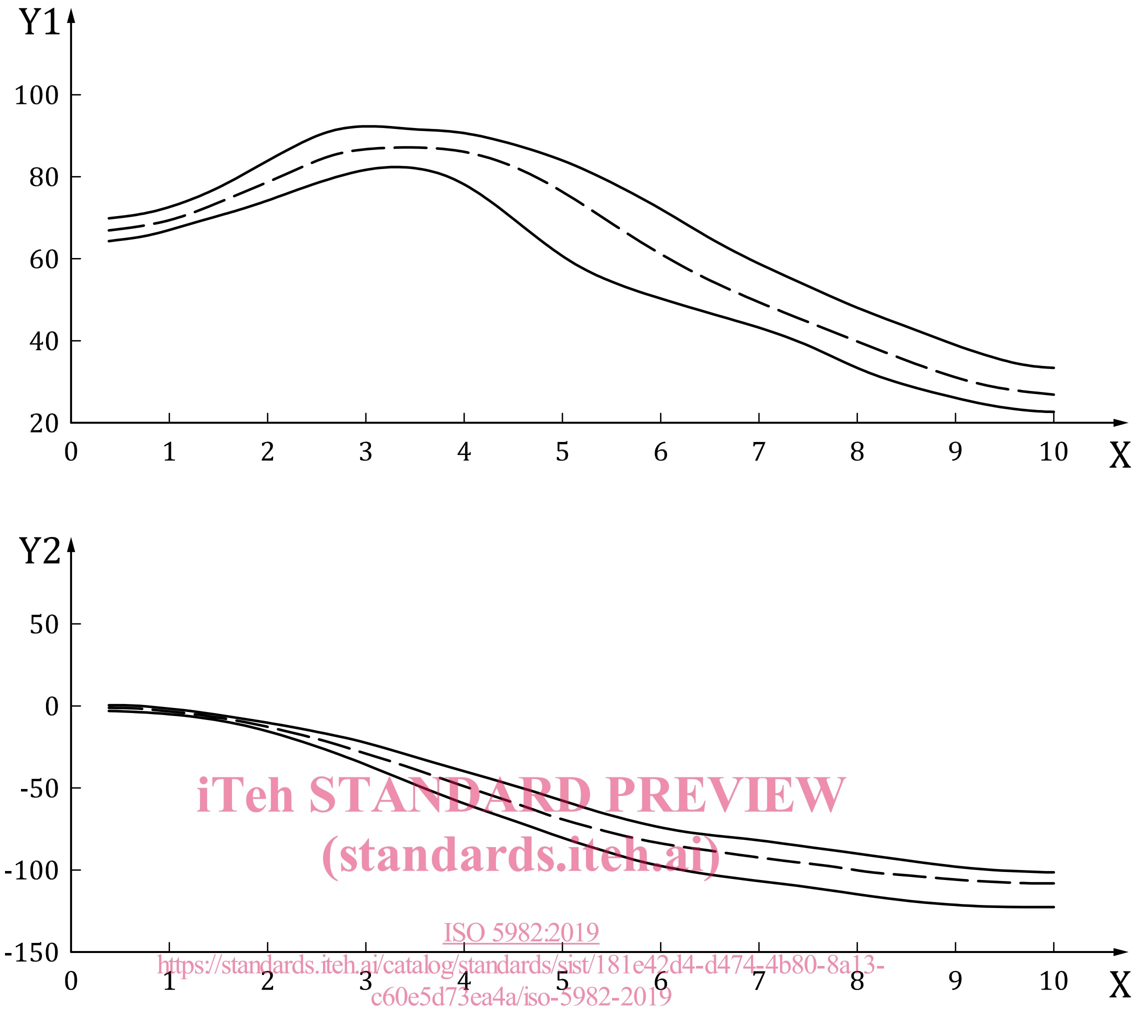
b) the angle for the back support is ranging from 90° to 102° for the condition with a backrest support;

c) the mass of the subjects ranges from 57 kg to 92 kg for the condition with a backrest support, and from 55 kg to 103,6 kg for the condition without a backrest support;

d) the RMS amplitude of unweighted sine and random excitation is between 0,4 m/s^2 and 1,0 m/s^2 within the frequency range of 0,5 Hz to 10 Hz.

Table 1 — Modulus and phase of the mean (target) and range of idealized apparent mass of the seated body with a back support under *x*-axis vibration

Frequency Hz	Modulus kg				Phase °			
	Mean	Upper limit	Lower limit	Standard deviation	Mean	Upper limit	Lower limit	Standard deviation
0,5	65,3	68,8	62,8	2,4	−0,1	1,8	−2,8	1,9
0,63	65,6	68,5	63,8	1,8	−0,3	1,2	−2,7	1,6
0,8	68,2	70,0	66,7	1,2	−1,2	−0,9	−1,8	0,4
1	69,5	72,1	67,8	1,7	−1,8	−1,2	−2,4	0,5
1,25	71,5	74,9	68,9	2,3	−4,7	−3,8	−5,9	0,8
1,6	74,8	78,3	71,1	2,7	−8,2	−7,3	−9,4	0,9
2	78,7	83,4	73,8	3,8	−12,2	−10,3	−14,6	1,9
2,5	85,2	92,5	79,3	5,3	−20,1	−15,0	−24,7	4,5
3,15	87,5	92,5	82,8	3,9	−31,4	−24,0	−38,4	6,6
4	86,4	90,8	78,9	4,9	−49,2	−40,6	−60,7	8,5
5	76,1	83,8	60,1	9,4	−69,7	−58,5	−80,8	8,9
6,3	56,7	67,3	47,8	7,4	−87,1	−77,4	−101,3	9,7
8	39,4	47,8	33,3	6,8	−100,6	−90,7	−115,2	9,5
10	28,4	35,3	23,6	5,6	−107,6	−100,3	−122,2	8,9



Key

X frequency in Hz

Y1 modulus in kg

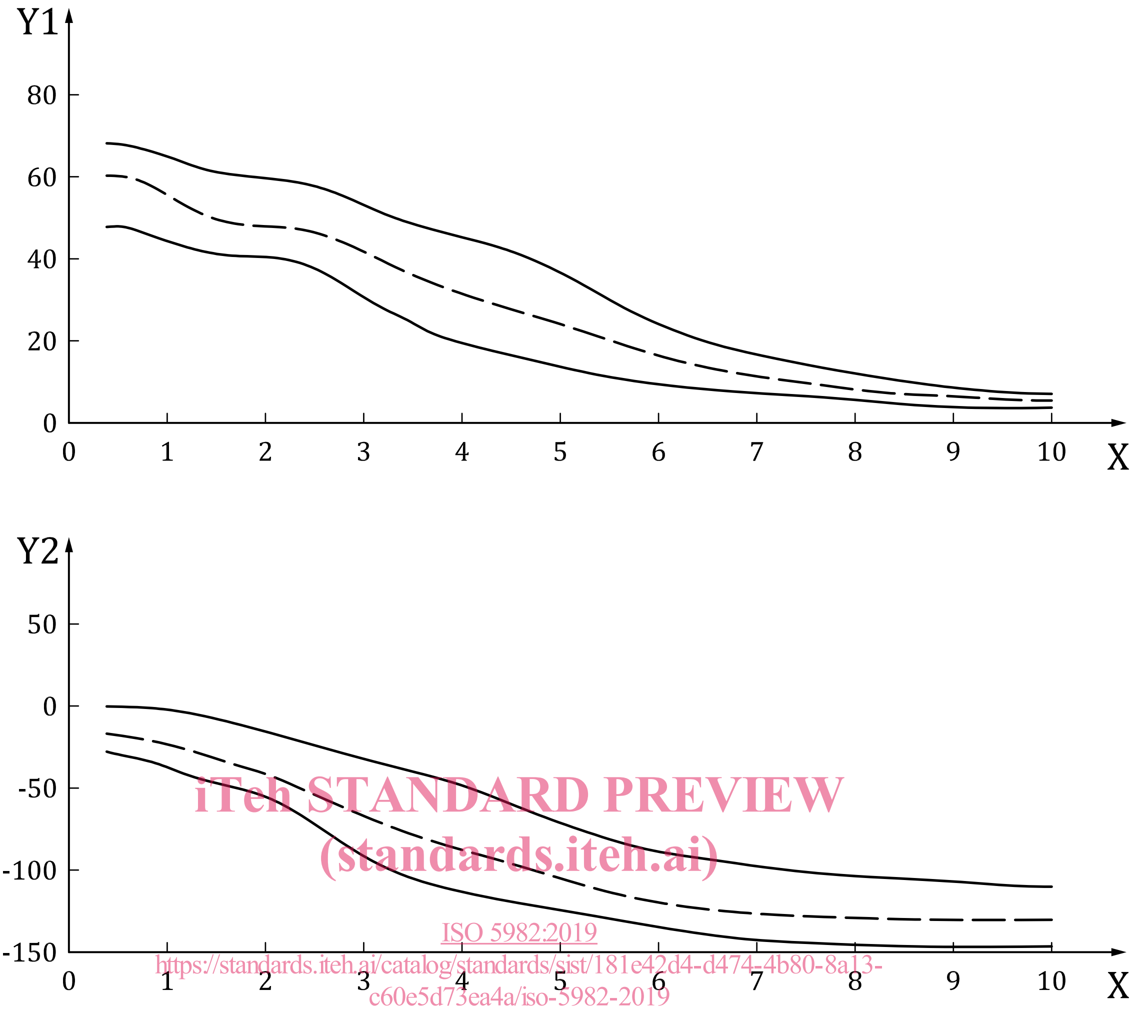
Y2 phase in °

NOTE For an explanation of the curves, see 4.1.

Figure 1 — Mean (target) and range of idealized values for the apparent mass of the seated body with a back support under *x*-axis vibration

Table 2 — Modulus and phase of the mean (target) and range of idealized apparent mass of the seated body without a back support under *x*-axis vibration

Frequency Hz	Modulus kg				Phase °			
	Mean	Upper limit	Lower limit	Standard deviation	Mean	Upper limit	Lower limit	Standard deviation
0,5	62,9	70,3	48,6	8,2	−12,8	1,4	−20,1	9,8
0,63	63,6	71,0	48,5	8,7	−13,6	1,2	−21,6	10,3
0,8	61,7	68,2	48,5	7,1	−19,7	−1,0	−34,0	14,2
1	58,5	66,9	46,8	7,0	−25,3	−1,2	−40,1	17,4
1,25	49,5	62,7	40,2	8,5	−28,7	−4,3	−45,5	16,7
1,6	46,3	58,5	39,1	6,4	−33,5	−9,3	−48,4	14,0
2	48,7	60,1	41,8	6,8	−39,3	−14,6	−50,1	13,0
2,5	47,9	59,4	38,8	7,3	−54,9	−24,6	−72,9	16,9
3,15	40,3	51,5	28,6	6,9	−71,1	−33,7	−97,5	21,1
4	31,4	45,3	19,1	8,4	−87,5	−49,3	−113,8	22,1
5	23,8	36,3	13,6	8,0	−105,6	−71,6	−124,8	19,2
6,3	14,5	21,2	8,5	4,3	−122,6	−92,0	−137,9	16,8
8	8,2	12,0	5,4	2,3	−129,1	−103,7	−145,5	15,1
10	5,7	7,5	3,6	1,3	−130,2	−108,6	−147,2	14,3



Key

X frequency in Hz

Y1 modulus in kg

Y2 phase in °

NOTE For an explanation of the curves, see 4.1.

Figure 2 — Mean (target) and range of idealized values for the apparent mass of the seated body without a back support under *x*-axis vibration

4.3 Apparent mass of the seated body under *y*-axis vibration

The modulus and phase of the apparent mass of the seated body with and without a back support are given in Tables 3 and 4, respectively, and (for illustration) in Figures 3 and 4 as a function of frequency, for the *y*-axis direction of excitation. According to the definitions, the modulus is given in terms of kilograms for apparent mass. The table and diagram contain three values of modulus and phase at each frequency. Numerical values are quoted up to four significant figures for the purpose of calculation, and do not reflect the precision of knowledge of the apparent mass. Linear interpolation is permitted to obtain values at frequencies other than those listed in Tables 3 and 4 at one-third-octave band centre frequencies.

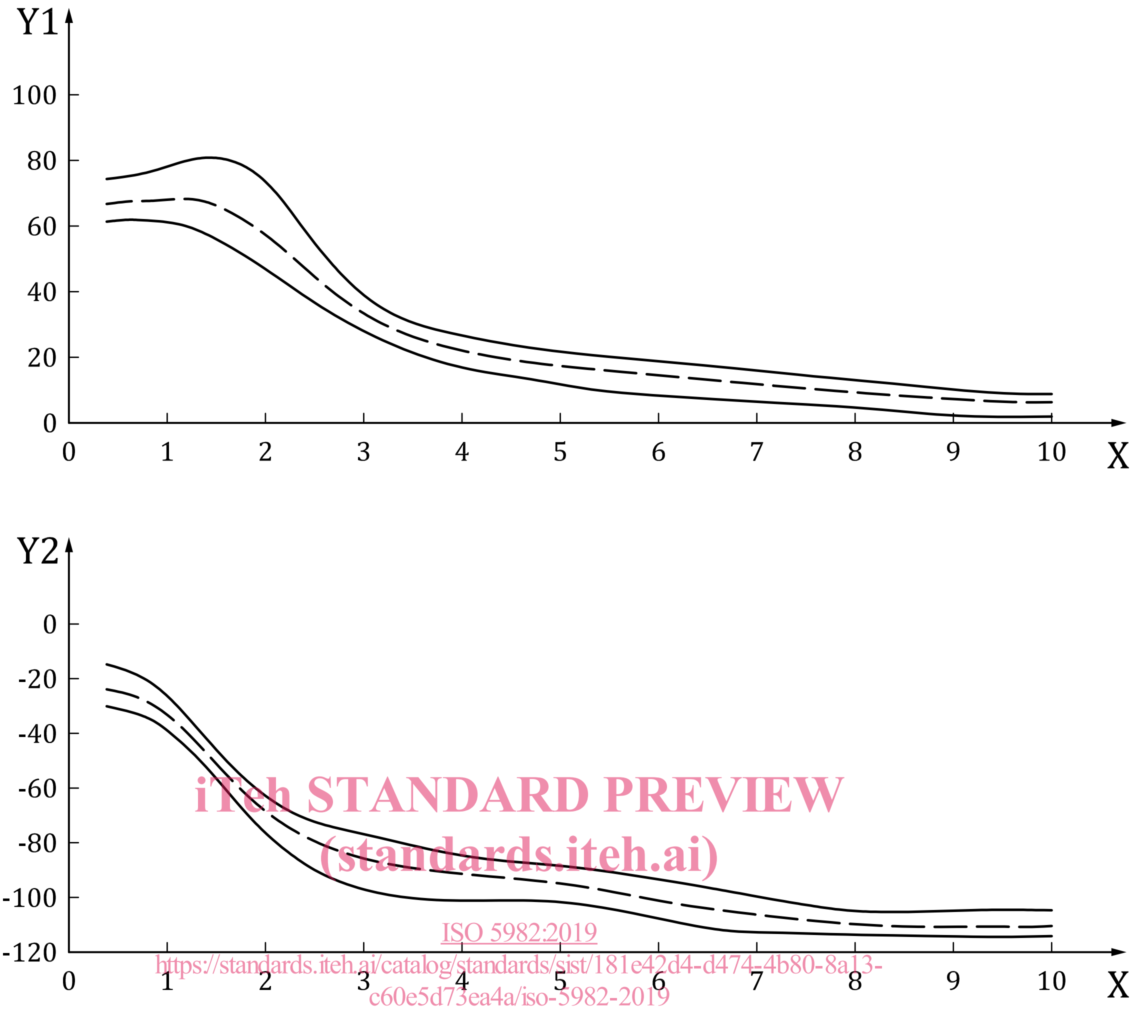
See 4.1 for more details.

4.4 Applicability of values of apparent mass of the seated body under *y*-axis vibration

The values of apparent mass are applicable to the seated human body, subjected to sinusoidal or broad-band random lateral vibration, while seated on a rigid surface with the feet resting flat on the base platform and the back being supported and unsupported. The limits of applicability approximately correspond to the range of measurement conditions over which data were obtained, and are identical to those described in 4.2.

Table 3 — Modulus and phase of the mean (target) and range of idealized apparent mass of the seated body with a back support under *y*-axis vibration

Frequency Hz	Modulus kg				Phase °			
	Mean	Upper limit	Lower limit	Standard deviation	Mean	Upper limit	Lower limit	Standard deviation
0,5	65,3	72,9	59,7	5,3	−19,8	−9,8	−26,7	6,5
0,63	65,6	74,0	59,8	5,8	−19,6	−10,6	−25,7	5,7
0,8	67,8	77,0	63,0	5,7	−23,4	−17,1	−28,1	4,2
1	70,6	79,1	64,6	5,6	−29,7	−22,8	−34,8	4,7
1,25	70,9	82,7	63,0	7,4	−39,7	−33,8	−44,8	4,7
1,6	67,1	83,3	55,2	11,7	−56,9	−52,8	−61,5	3,9
2	58,9	80,1	46,4	13,5	−71,5	−66,6	−79,4	5,0
2,5	43,3	52,0	36,0	6,4	−80,7	−73,0	−92,1	7,1
3,15	30,5	34,4	26,2	3,2	−86,9	−77,5	−98,7	8,0
4	21,7	26,5	16,7	3,3	−91,4	−85,3	−101,1	6,6
5	17,3	21,7	11,5	3,6	−95,3	−88,4	−101,9	5,6
6,3	13,4	17,6	7,7	3,6	−103,1	−96,0	−110,0	5,6
8	9,2	12,8	4,1	3,2	−109,5	−104,4	−113,6	3,7
10	6,5	9,1	1,8	2,7	−110,7	−104,5	−114,3	3,9



Key

X frequency in Hz

Y1 modulus in kg

Y2 phase in °

NOTE For an explanation of the curves, see 4.1.

Figure 3 — Mean (target) and range of idealized values for the apparent mass of the seated body with a back support under *y*-axis vibration