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

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

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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.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 5982 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*.

This second edition cancels and replaces the first edition (ISO 5982:1981) and ISO 7962:1987, of which it constitutes an amalgamation and technical revision.

Major changes to previously given ranges of idealized values for the driving-point mechanical impedance and seat-to-head transmissibility of the seated human body were considered necessary in view of the indications that these were most probably derived by combining data sets determined over too broad a range of varying experimental conditions. The indications that several conditions associated with feet and back support, posture, excitation amplitude and subject mass could have a significant influence on measured biodynamic response led to the conclusion that the definition of a range of idealized values would only be feasible if it were based on data sets known to have been determined under a well-defined and restricted range of similar conditions. As part of this International Standard, a range of idealized values is defined only for seated individuals, exposed to sinusoidal or broad-band random vertical vibration with unweighted r.m.s. acceleration lower or equal to 5 m/s^2, while the feet are resting flat on the vibrating platform (this also includes feet hanging freely for applications to seat-to-head transmissibility), the back is unsupported, and the individual body masses are within 49 kg to 93 kg. Only those data sets satisfying all of the above conditions were considered as part of the data synthesis performed to construct the envelopes defining the range of most probable values.

This International Standard incorporates the most recent data to have been published on driving-point mechanical impedance and/or apparent mass and seat-to-head transmissibility, while satisfying the conditions specified above. The frequency range for defining these values is now limited to 0,5 Hz to 20 Hz since predominant vertical vibration is known to occur within that range for several types of off-road, heavy road and industrial vehicles. As part of the annexes, an analytical model of the seated human body is provided to satisfy the range of idealized values defined for the driving-point mechanical impedance/apparent mass and seat-to-head transmissibility functions. Alternatively, mathematical expressions in the form of transfer functions are provided to approximate the mean (target) values defined for these functions. Finally, values for driving-point mechanical impedance and apparent mass are computed for specific body masses on the basis of the given model.

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

This corrected and reprinted version of ISO 5982:2001 incorporates corrections to the Key to Figures D.1 and D.2.

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). Knowledge of these functions under conditions representative of those encountered while driving specific types of vehicles may 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 could form the basis for developing a mechanical system capable of simulating the human body or for deriving functions that could account for the human interface when the tests are being conducted with rigid masses. Such functions may further form the basis for developing analytical models representing the human body, which through combination with suitable suspension seat models, could provide numerical means of estimating the seat performance and of achieving optimal seat suspension and cushion design. Notwithstanding the above applications, this International Standard 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 might be more applicable to drivers of off-road, heavy road and industrial vehicles.

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

— subject mass,

— posture and back support,

— feet support, and

— excitation amplitude.

In this International Standard, the driving-point mechanical impedance, the apparent mass and the seat-to-head transmissibility are employed to describe the biodynamic response characteristics of the seated human body to forced vertical motion of the buttocks, as a function of frequency. Alternatively, a model of the human body is provided to satisfy both simultaneously the driving-point mechanical impedance/apparent mass and seat-to-head transmissibility functions. The values for these functions have been derived from the results of driving-point mechanical impedance/apparent mass and seat-to-head transmissibility measurements performed on groups of live subjects, by different investigators while maintaining the conditions within the range mentioned in the foreword.

The unexplained differences between the mean modulus and phase values of mechanical impedance, 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 (see annex A and the bibliography). The most probable range of values of driving-point mechanical impedance, 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 International Standard. Any data that fall within the range of idealized values defined by upper and lower limit envelope curves may be considered to be acceptable representation of the biodynamic response functions of the seated human body under the specific conditions defined.

No modulus or phase presented as a function of frequency in this International Standard 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.

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

1 Scope

This International Standard describes the range of idealized values of the driving-point mechanical impedance, apparent mass and seat-to-head transmissibility modulus and phase applicable to seated individuals subjected to z-axis sinusoidal or broad-band random vibration under specific experimental conditions. Additionally, a human body model is provided to satisfy the range of idealized values defined for driving-point mechanical impedance/apparent mass and seat-to-head transmissibility. This model is further used to compute values of driving-point mechanical impedance and apparent mass for fixed body masses which are recommended to be used as test loads in current standards defining laboratory seat testing methodologies. Alternatively, mathematical expressions in the form of transfer functions are provided to approximate the weighted mean (target) values defined for all three biodynamic response functions.

The ranges of idealized values defined in this International Standard are considered to be valid for seated subjects supported on a rigid platform, with feet supported and vibrated, and maintaining an erect seated posture without backrest support. Provisionally, the range of idealized seat-to-head transmissiblity values is considered to be applicable also to the condition with the feet hanging freely. The values are defined over the frequency range 0,5 Hz to 20 Hz for subjects within the 49 kg to 93 kg mass range, subjected to sinusoidal or broad-band random vibration of unweighted r.m.s. amplitude lower than or equal to 5 m/s^2. 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 at present not covered by this International Standard in view of the lack of a meaningful data base 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 three 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 may 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.

A mathematical representation of the seated human body that falls within the upper and lower limit envelope curves defined for driving-point mechanical impedance/apparent mass and seat-to-head transmissibility is also provided in annex B, while mathematical expressions approximating the weighted mean (target) values for these functions are given in annex C. Model values of driving-point mechanical impedance and apparent mass computed for fixed body masses equal or close to those recommended in specific laboratory seat testing standards are also provided in annex D.

2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the normative document 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 5805, *Mechanical vibration and shock — Human exposure — Vocabulary*

3 Terms and definitions

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

3.1
driving-point mechanical impedance
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

$$Z(f) = \frac{F(f)}{v(f)} \tag{1}$$

NOTE 1 The driving-point mechanical impedance is a complex quantity (i.e. it possesses real and imaginary parts) from which the modulus and phase can be computed.

NOTE 2 This International Standard is based on measurements in which both force and velocity were measured at the same point, this being the point of introduction of vibration to the body, namely the buttocks or seat-body interface.

NOTE 3 In the case of non-harmonic vibration, driving-point mechanical impedance is determined from the force and velocity spectra.

3.2
apparent mass
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

$$M(f) = \frac{F(f)}{a(f)} = -\mathrm{j}\frac{Z(f)}{2\pi f} \tag{2}$$

NOTE 1 The relationship between apparent mass and mechanical impedance is entirely determined by the fixed relationship between velocity and acceleration for which a 90° phase difference exists under periodic excitation. In the above expression, $\mathrm{j} = \sqrt{-1}$ represents the complex phasor between the mechanical impedance and apparent mass.

NOTE 2 In the case of non-harmonic vibration, apparent mass is detemined from the force and acceleration 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 or seat-body interface

NOTE 1 The ratio may be one of displacements, velocities or accelerations.

NOTE 2 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 In the case of non-harmonic vibration, seat-to-head transmissibility is determined from the motion spectra.

4 Driving-point mechanical impedance and apparent mass of the seated body under vertical vibration

4.1 Definition of values of driving-point mechanical impedance and apparent mass

The modulus and phase of the driving-point mechanical impedance and apparent mass of the seated body are given in Tables 1 and 2 respectively and (for illustration) in Figures 1 and 2 as a function of frequency, for the vertical direction of excitation. In accordance to the definitions, the modulus is given in terms of newton seconds per metre for impedance and kilograms for apparent mass. Each table and diagram contains 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 driving-point mechanical impedance and 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 bold continuous curves in Figures 1 and 2. The central value at each frequency, shown by fine solid 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 that generate/employ values of driving-point mechanical impedance and apparent mass between the upper and lower limits given in Tables 1 and 2 at any frequency satisfy the requirements of this International Standard, 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 20 Hz.

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

NOTE 1 The curves in Figures 1 and 2 are derived from the data identified in annex A for driving-point mechanical impedance and apparent mass. The synthesis is performed by transforming all data to the driving-point mechanical impedance function and averaging by weighting the data according to the population of subjects involved in deriving the data. Upper and lower limiting values represent maximum and minimum values of the data sets determined at each frequency. The resulting range of idealized driving-point mechanical impedance values is further transformed to derive the corresponding range of idealized apparent mass values.

NOTE 2 The curves in Figures 1 and 2 relate to 101 test subjects within the mass range 49 kg to 93 kg. Both sinusoidal and broad-band random vibration with unweighted root-mean-square acceleration between 0,5 m/s^2 and 3 m/s^2 and frequency-weighted root-mean-square acceleration less than or equal to 2 m/s^2 have been used in deriving the data. Some evidence suggests that non-linearities in driving-point mechanical impedance and apparent mass responses may arise with variations in vibration amplitudes, particularly when lower vibration magnitudes are involved.

4.2 Applicability of values of driving-point mechanical impedance and apparent mass

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

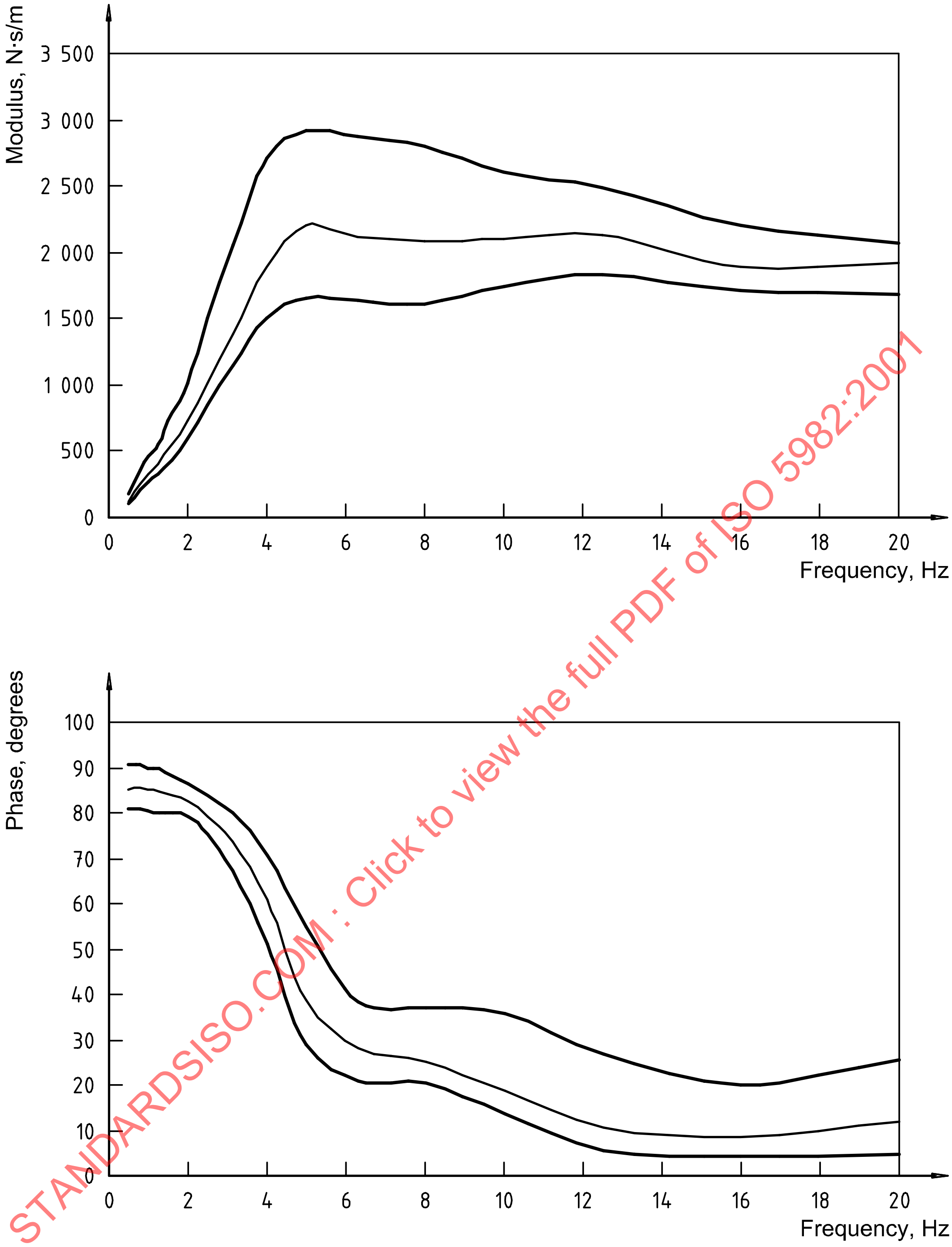
a) the posture is described as erect seated without backrest support, while the feet are supported and vibrated;

b) the mass of the subjects ranges from 49 kg to 93 kg;

c) the r.m.s. amplitude of unweighted sine and random excitation is between 0,5 m/s^2 and 3,0 m/s^2 with predominance of frequencies within the range from 0,5 Hz to 20 Hz. Frequency-weighted r.m.s. amplitudes less than or equal to 2 m/s^2 were also part of the vibration excitations considered.

Table 1 — Modulus and phase of the mean (target) and range of idealized driving-point mechanical impedance of the seated body under vertical vibration

Frequency Hz	Modulus N·s/m				Phase degrees			
	Mean	Upper limit	Lower limit	Standard deviation	Mean	Upper limit	Lower limit	Standard deviation
0,5	157	222	128	44	85,4	90,8	81,0	3,2
0,63	199	282	163	57	85,6	90,8	81,0	3,4
0,8	256	362	211	71	85,5	90,6	81,0	3,0
1	327	459	270	56	84,9	89,9	80,3	3,7
1,25	418	587	343	66	84,6	89,6	80,2	3,3
1,6	553	789	452	74	83,7	88,2	79,9	2,9
2	728	1 019	596	131	82,4	86,3	79,0	2,4
2,5	953	1 408	811	171	79,8	84,4	76,2	1,8
3,15	1 349	2 005	1 117	246	74,2	80,2	68,2	3,2
4	1 894	2 705	1 506	373	60,7	70,6	51,1	6,5
5	2 201	2 919	1 657	428	38,6	54,8	29,0	12,1
6,3	2 120	2 883	1 641	362	28,0	39,0	20,9	5,4
8	2 088	2 797	1 611	373	25,2	36,9	20,3	6,6
10	2 095	2 609	1 748	282	18,8	35,9	13,7	9,9
12,5	2 139	2 492	1 836	258	10,8	27,3	5,8	8,6
16	1 898	2 204	1 714	172	8,6	20,2	4,4	7,6
20	1 922	2 075	1 679	335	12,1	25,5	4,8	10,2

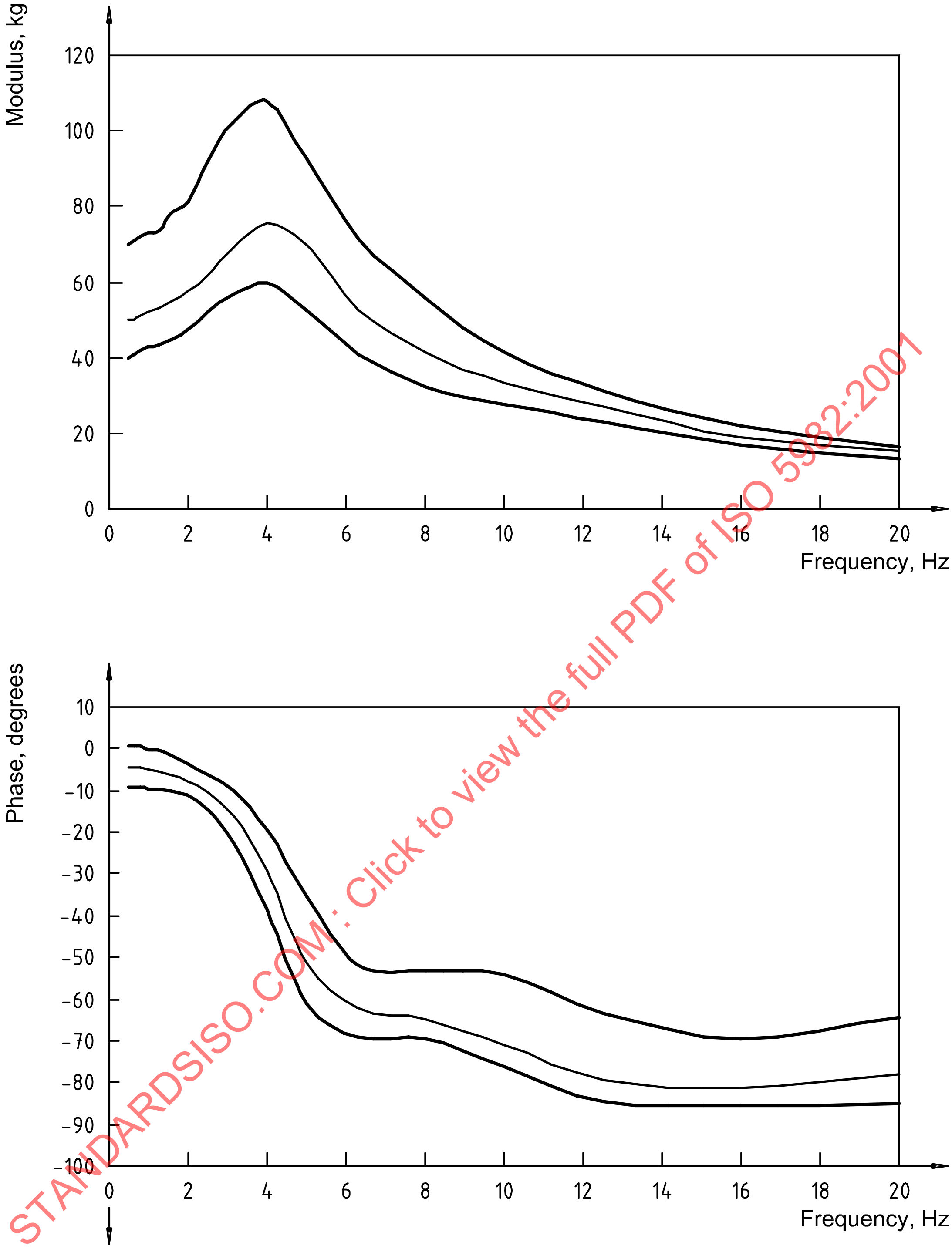


NOTE For an explanation of the lines, see 4.1.

Figure 1 — Mean (target) and range of idealized values for the driving-point mechanical impedance of the seated body under vertical vibration

Table 2 — Modulus and phase of the mean (target) and range of idealized apparent mass of the seated body under vertical vibration

Frequency Hz	Modulus kg				Phase degrees			
	Mean	Upper limit	Lower limit	Standard deviation	Mean	Upper limit	Lower limit	Standard deviation
0,5	50,0	70,7	40,7	14,0	–4,6	0,8	–9,0	3,2
0,63	50,3	71,2	41,2	14,4	–4,4	0,8	–9,0	3,4
0,8	51,0	72,0	42,0	14,1	–4,5	0,6	–9,0	3,0
1	52,0	73,0	43,0	8,9	–5,1	–0,1	–9,7	3,7
1,25	53,2	74,7	43,7	8,4	–5,4	–0,4	–9,8	3,3
1,6	55,0	78,5	45,0	7,4	–6,3	–1,8	–10,1	2,9
2	57,9	81,1	47,4	10,4	–7,6	–3,7	–11,0	2,4
2,5	60,7	89,6	51,6	10,9	–10,2	–5,6	–13,8	1,8
3,15	68,2	101,3	56,4	12,4	–15,8	–9,8	–21,8	3,2
4	75,4	107,6	59,9	14,8	–29,3	–19,4	–38,9	6,5
5	70,1	92,9	52,7	13,6	–51,4	–35,2	–61,0	12,1
6,3	53,6	72,8	41,4	9,1	–62,0	–51,0	–69,1	5,4
8	41,5	55,7	32,0	7,4	–64,8	–53,1	–69,7	6,6
10	33,3	41,5	27,8	4,5	–71,2	–54,1	–76,3	9,9
12,5	27,2	31,7	23,4	3,3	–79,2	–62,7	–84,2	8,6
16	18,9	21,9	17,1	1,7	–81,4	–69,8	–85,6	7,6
20	15,3	16,5	13,4	2,7	–77,9	–64,5	–85,2	10,2



NOTE For an explanation of the lines, see 4.1.

Figure 2 — Mean (target) and range of idealized values for the apparent mass of the seated body under vertical vibration

5 Seat-to-head transmissibility of the seated human body under vertical vibration

5.1 Definition of values of seat-to-head transmissibility

The modulus and phase of the seat-to-head transmissibility of the seated body are given in Table 3 and (for illustration) in Figure 3 as a function of frequency, for the vertical direction of excitation. In accordance with the definition, the modulus is non-dimensional and represents the ratio of acceleration transmitted to the head to the acceleration measured at the buttocks. The table and diagram contain three values of modulus and phase at each frequency. Numerical values are quoted up to three significant figures for the purpose of calculation, and do not reflect the precision of knowledge of the seat-to-head transmissibility. Linear interpolation is permitted to obtain values at frequencies other than those listed in Table 3 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 bold continuous curves in Figure 3. The central value at each frequency, shown by fine solid curves in Figure 3, 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 Table 3.

Applications that generate/employ values of seat-to-head transmissibility between the upper and lower limits given in Table 3 at any frequency satisfy the requirements of this International Standard, and represent “through the body” transfer functions applicable to the seated human body under the conditions specified and over the frequency range of 0,5 Hz to 20 Hz.

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

NOTE 1 The curves in Figure 3 are derived from the data identified in annex A for seat-to-head transmissibility. The synthesis is performed by averaging once the individual data sets have been weighted according to the population of subjects involved in deriving the data. Upper and lower limiting values represent maximum and minimum values of the data sets determined at each frequency.

NOTE 2 The curves in Figure 3 relate to 32 test subjects within the mass range 56 kg to 90 kg. The majority of data sets have been produced under sinusoidal vibration at frequencies lower than 20 Hz and for r.m.s. unweighted accelerations lower than 5 m/s^2. Head acceleration was measured using a bite bar technique for most data sets involved in the data synthesis. Furthermore, some data sets originate from studies in which the feet were unsupported. Current evidence suggests that seat-to-head transmissibility is not likely to be influenced in any significant manner by the inclusion or not of foot support provided that the leg position is the same.

NOTE 3 Seat-to-head transmissibility data have often been produced using vibration excitations at levels which tended to be considerably higher than those used for driving-point mechanical impedance and apparent mass. Increased sensitivity to posture and backrest support might have been responsible for the wide variability observed amongst various data sets reported by different investigators.

NOTE 4 There is at present limited evidence to suggest that the seat-to-head transmissibility modulus shown in Figure 3 could perhaps provide overestimations of the values to be applied in cases involving vibration excitations of similar amplitudes but characterized mostly by narrow-band low-frequency vibration containing shocks.

5.2 Applicability of values of seat-to-head transmissibility

The values of seat-to-head transmissibility are applicable to the seated human body subjected to sinusoidal or broad-band random vertical vibration, while seated on a rigid surface with the back being unsupported. Both conditions of feet being supported on a vibrating platform and hanging freely are integrated for the purpose of defining seat-to-head transmissibility. The limits of applicability approximately correspond to the range of measurement conditions over which data were obtained, as follows:

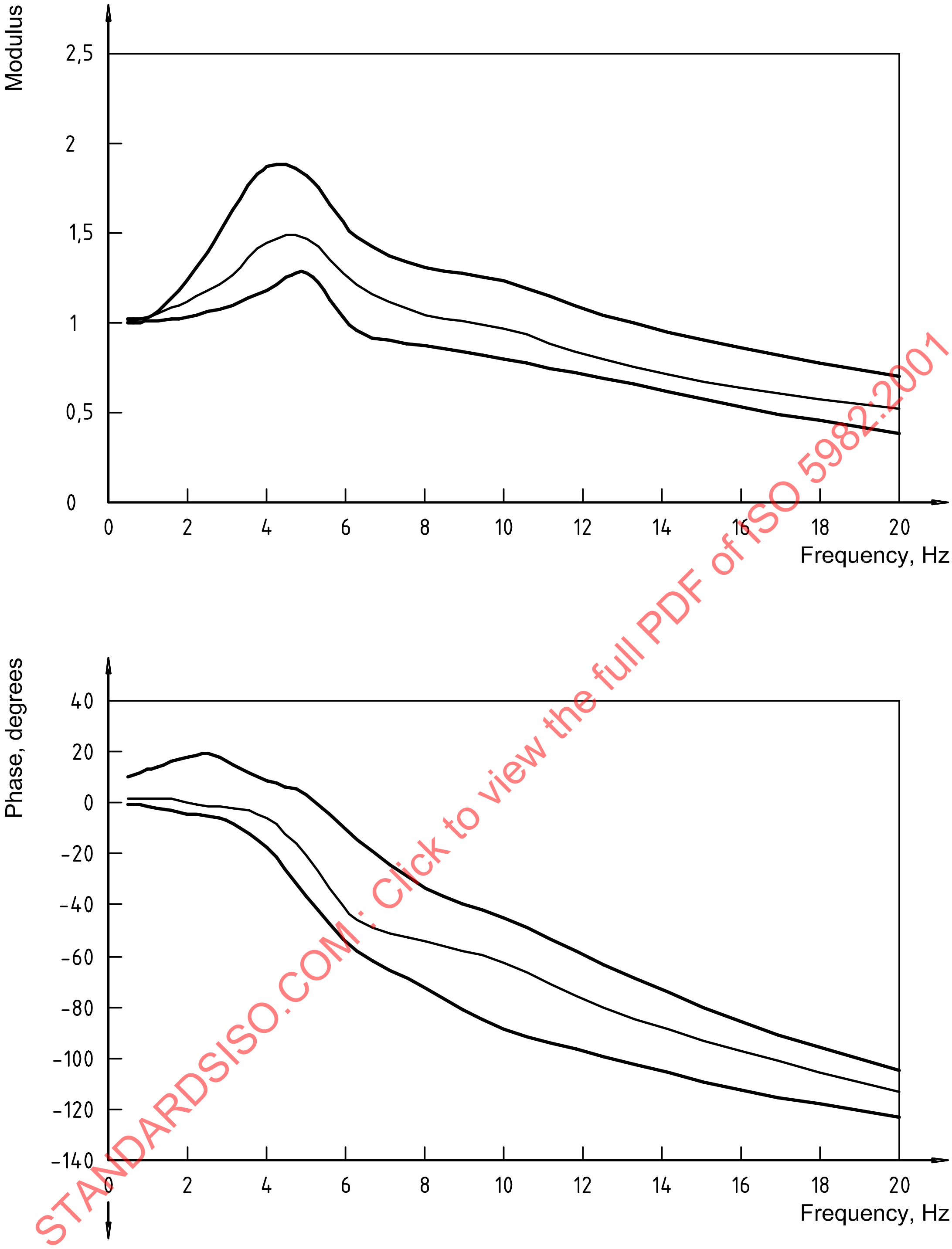
a) the posture is described as erect seated without backrest support, while the feet may be supported or not;

b) the mass of the subjects ranges from 56 kg to 90 kg;

c) the unweighted r.m.s. amplitude of sine and broad-band random excitation is between 1 m/s^2 and 5 m/s^2, with a higher proportion of subjects submitted to sinusoidal rather than to random vibration over the frequency range from 0,5 Hz to 20 Hz.

Table 3 — Modulus and phase of the mean (target) and range of idealized seat-to-head transmissibility of the seated body under vertical vibration

Frequency Hz	Modulus				Phase degrees			
	Mean	Upper limit	Lower limit	Standard deviation	Mean	Upper limit	Lower limit	Standard deviation
0,5	1,01	1,02	1,00	0,01	2,0	10,0	–0,5	0,1
0,63	1,01	1,02	1,00	0,01	2,0	11,0	–0,5	0,1
0,8	1,02	1,02	1,00	0,01	2,0	12,0	–0,8	0,1
1	1,03	1,03	1,01	0,01	2,0	13,0	–1,2	0,1
1,25	1,05	1,07	1,01	0,02	2,0	14,0	–1,8	1,2
1,6	1,08	1,14	1,02	0,05	2,0	16,0	–3,1	2,0
2	1,12	1,23	1,03	0,08	0,0	18,0	–4,4	19,8
2,5	1,16	1,36	1,06	0,10	–0,9	19,5	–5,2	12,6
3,15	1,26	1,61	1,10	0,19	–1,9	15,4	–8,0	10,5
4	1,45	1,87	1,18	0,30	–5,9	8,8	–17,5	10,3
5	1,47	1,82	1,28	0,22	–20,4	2,9	–36,3	16,8
6,3	1,23	1,49	0,98	0,21	–44,2	–13,3	–56,8	9,4
8	1,04	1,31	0,87	0,18	–54,3	–33,6	–72,4	17,1
10	0,97	1,23	0,80	0,13	–62,7	–45,1	–88,6	19,2
12,5	0,81	1,04	0,69	0,10	–79,4	–62,2	–98,8	18,1
16	0,64	0,86	0,53	0,10	–97,0	–85,5	–112,7	7,9
20	0,52	0,70	0,38	0,19	–113,0	–104,6	–122,8	6,9



NOTE For an explanation of the lines, see 5.1.

Figure 3 — Mean (target) and range of idealized values for the seat-to-head transmissibility of the seated body under vertical vibration

6 Applications

6.1 Model of the seated human body

A model of the seated human body that complies with the provisions of this International Standard is provided in annex B. The model possesses three degrees of freedom. Annex B is provided to facilitate mathematical modelling, and to provide the basis for constructing a mechanical analogue of the human body for possible applications in seat testing rigs. Such a mechanical system could possibly avoid the use of human subjects to perform laboratory seat testing. Furthermore, the human body model, in combination with a suitable suspension seat model, could provide means of estimating the seat performance and of achieving optimal seat suspension and cushion design. Alternatively, mathematical expressions in the form of transfer functions are provided in annex C to approximate the weighted mean (target) values defined for the modulus and phase of the driving-point mechanical impedance/apparent mass and seat-to-head transmissibility. Such expressions could find applications in characterizing the human-interface on seat cushions in the eventuality that seat tests were to be conducted while using a rigid load instead of a human subject.

6.2 Computation of biodynamic response functions for fixed body masses

Values for the driving-point mechanical impedance and the apparent mass are given in annex D for total body masses of 55 kg, 75 kg and 90 kg. These values are computed directly from application of the model derived in annex B for subjects within the 56 kg to 90 kg mass range. The body masses chosen are as close as possible to the individual subject masses which are required to act as seat loads in standards defining laboratory procedures for evaluating the performance of suspension seats (see ISO 5007, ISO 7096 and ISO 10326-1). Although the values are strictly computed from the model defined in annex B, they are generally found to fall within the range of idealized measured data applicable to subjects within the 56 kg to 90 kg mass range as shown in Figures D.1 and D.2. Such values, computed for specific body masses, are not intended to be compared directly with any measured data that may have been found to apply to subjects of similar masses under the conditions defined in this International Standard.

NOTE While the model computed driving-point mechanical impedance modulus shown in Figure D.1 indicates negligible mass effect at frequencies above 10 Hz, there are somewhat limited measured data to suggest that beyond a mass of 80 kg, the modulus of impedance may perhaps increase with body mass at frequencies higher than 10 Hz.

Annex A
(informative)

Identification of the data used to define the range of idealized driving-point mechanical impedance/apparent mass and seat-to-head transmissibility data

A set of selection rules are defined for selecting the published data to be used for the synthesis. Only those data sets satisfying all of the following conditions were considered.

a) Data sets specifying either individual or group mean body mass of the test subject population, with limitations to the 49 kg to 93 kg range, corresponding to the range for which the most numerous number of data sets are available.

b) Data sets on driving-point mechanical impedance and apparent mass acquired with feet of the subjects supported and vibrated. Data sets for seat-to-head transmissibility include studies in which the feet were either resting on the vibrating platform or unsupported. It has been shown that there is no difference in seat-to-head transmissibility to be expected under these conditions.

c) Data sets acquired under vibration excitation r.m.s. unweighted amplitudes below 5 m/s^2, with the nature of the excitation specified as being either sinusoidal or broad-band random.

d) Data sets acquired under vibration excitations including spectral components within the 0,5 Hz to 20 Hz frequency range.

e) Data sets acquired under vibration excitations constrained to the vertical direction.

f) Data sets acquired with subject population clearly identified, with particular analysis of those sets based on single subject populations.

g) Data sets reporting the subject posture as being erect seated without backrest support, irrespective of the hands position.

The data sets reporting either the modulus, or both the modulus and phase of the biodynamic response functions were included for the synthesis.

Table A.1 identifies the data sets considered for driving-point mechanical impedance and apparent mass, while Table A.2 identifies those considered for seat-to-head transmissibility. Bibliographical references to these data sets are given in the bibliography.

Table A.1 — Characterization of the data sets considered for mechanical impedance and apparent mass

Bibliographic reference	Subjects		Excitation			Reported function
	Number	Mass kg	Type	Amplitude	Frequency range Hz	
[10]	1	63	Random Gaussian	1 m/s² r.m.s. unweighted	0,25 to 20	Apparent mass Modulus and phase
[14]	4	56 to 83	Sinusoidal	3 m/s² r.m.s. unweighted	2 to 12	Mean apparent mass Modulus and phase
[15]	30	54 to 93 mean 70	Sinusoidal	0,5 m/s² unweighted	2 to 100	Mean normalized mechanical impedance Modulus and phase
[8]	15	49 to 74	Sinusoidal sweep	1,6 m/s² r.m.s. unweighted	1 to 10	Mean mechanical impedance Modulus and phase
[8]	15	49 to 74	Broad band Random	1,6 m/s² r.m.s. unweighted	1 to 10	Mean mechanical impedance Modulus and phase
[19]	6	52,7 to 87,2	Random	1,0 m/s² r.m.s. unweighted	1 to 25	Individual apparent mass Modulus and phase
[11]	8	57 to 85	Random	1,0 m/s² r.m.s. unweighted	0,5 to 20	Individual apparent mass Modulus and phase
[20]	11	60 to 70	Random (off-road machinery)	$\leqslant$ 1,4 m/s² weighted (ISO 2631-1:1985)	0,5 to 20	Mean mechanical impedance Modulus
[20]	14	70 to 80	Random (off-road machinery)	$\leqslant$ 1,4 m/s² weighted (ISO 2631-1:1985)	0,5 to 20	Mean mechanical impedance Modulus
[22]	6	58 to 73	Random White noise	1 m/s² to 2 m/s² unweighted	0,5 to 20	Mean apparent mass Modulus and phase
[5]	6	69,6 to 80,9 mean 75,4	Sinusoidal sweep	1 m/s² to 2 m/s² weighted (ISO 2631-1:1985)	0,5 to 10	Mean mechanical impedance Modulus and phase
[5]	6	69,6 to 80,9 mean 75,4	Random White noise	1 m/s² to 2 m/s² weighted (ISO 2631-1:1985)	0,5 to 10	Mean mechanical impedance Modulus and phase

Table A.2 — Characterization of the data sets considered for seat-to-head transmissibility

Bibliographic reference	Subjects		Excitation			Reported component
	Number	Mass kg	Type	Amplitude	Frequency range Hz	
[17]	9	57 to 90	Sinusoidal	4 m/s² r.m.s. unweighted	2 to 20	Mean modulus and phase
[14]	4	56 to 83	Sinusoidal	1,5 m/s² r.m.s. unweighted	2 to 12	Mean modulus and phase
[14]	4	56 to 83	Sinusoidal	3 m/s² r.m.s. unweighted	2 to 12	Mean modulus and phase
[18]	12	58 to 81 mean 70,8	Random Gaussian	1,75 m/s² r.m.s. unweighted	< 25	Individual modulus and phase
[7]	1	84	Sinusoidal	< 5 m/s² r.m.s. unweighted	< 20	Modulus
[22]	6	58 to 73	Random White noise	1 m/s² to 2 m/s² r.m.s. unweighted	0,5 to 20	Mean modulus and phase

Annex B
(informative)

Model

The model (see Figure B.1) constitutes a three-degrees-of-freedom system for which the masses, springs and dampers do not correspond to physiological structures within the body. The input force is considered to be applied to mass m_0 for which the resulting displacement is represented by x_0. The model parameters listed in Table B.1 were derived to obtain closest agreement with the weighted mean (target) values defined for driving-point mechanical impedance/apparent mass and seat-to-head transmissibility as given in Tables 1, 2 and 3. The model predictions are illustrated by dashed lines in Figures B.2, B.3 and B.4 where they are compared with the range of idealized values defined respectively for driving-point mechanical impedance, apparent mass and seat-to-head transmissibility. The model parameters listed in Table B.1 would most likely apply to a subject with total body mass of 75 kg, while assuming that 73 % of the mass is resting on the seat. Values are supplemented in annex D for total body masses of 55 kg and 90 kg simply by modifying the parameter value for m_3. For the purpose of computing seat-to-head transmissibility, mass m_2 may tentatively be taken to represent the head.

Table B.1 — Values for the parameters of the model (body mass of 75 kg)

Parameter	Mass kg				Stiffness N/m			Damping coefficient N·s/m		
	m_0	m_1	m_2	m_3	k_1	k_2	k_3	c_1	c_2	c_3
Value	2	6	2	45	$9{,}99 \times 10^3$	$3{,}44 \times 10^4$	$3{,}62 \times 10^4$	387	234	$1{,}39 \times 10^3$

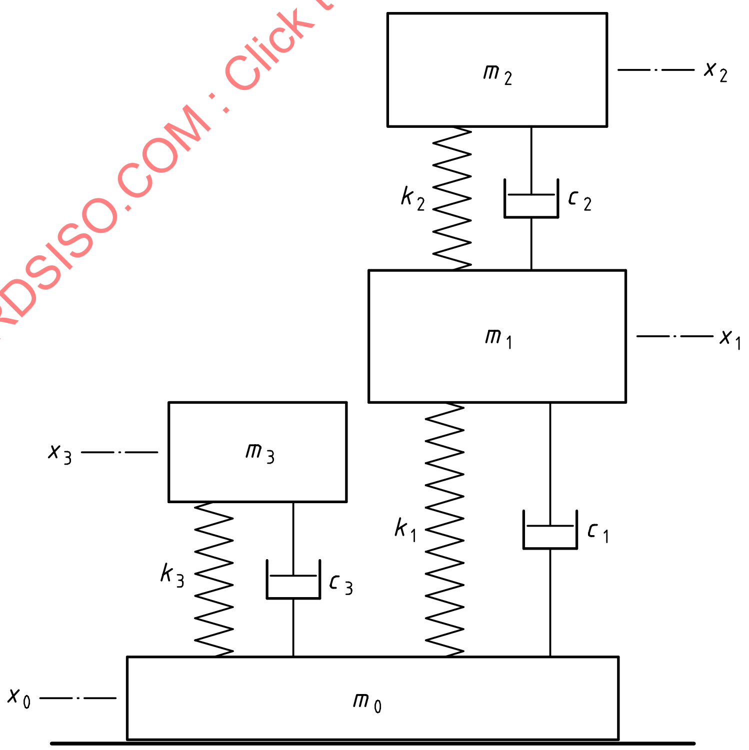
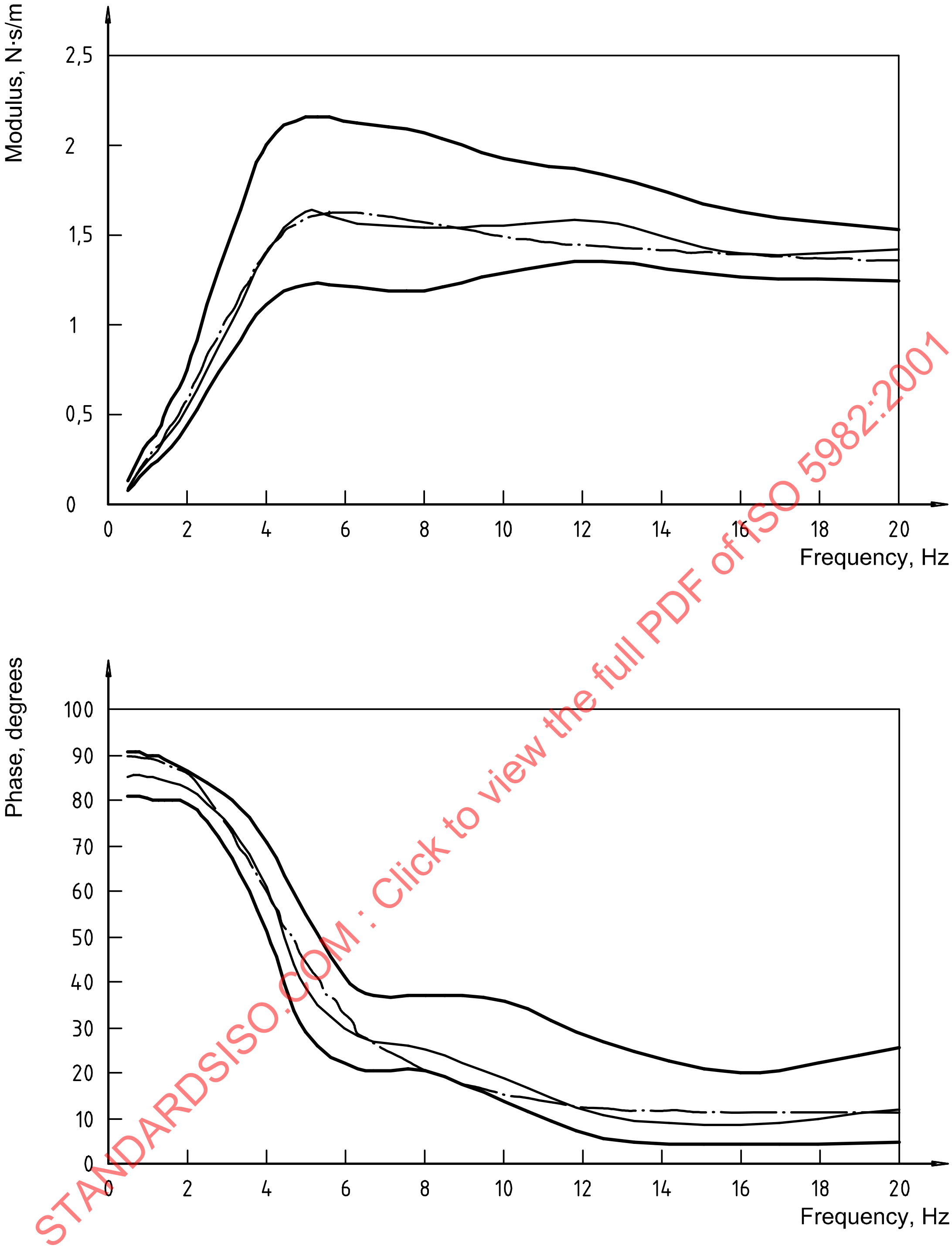
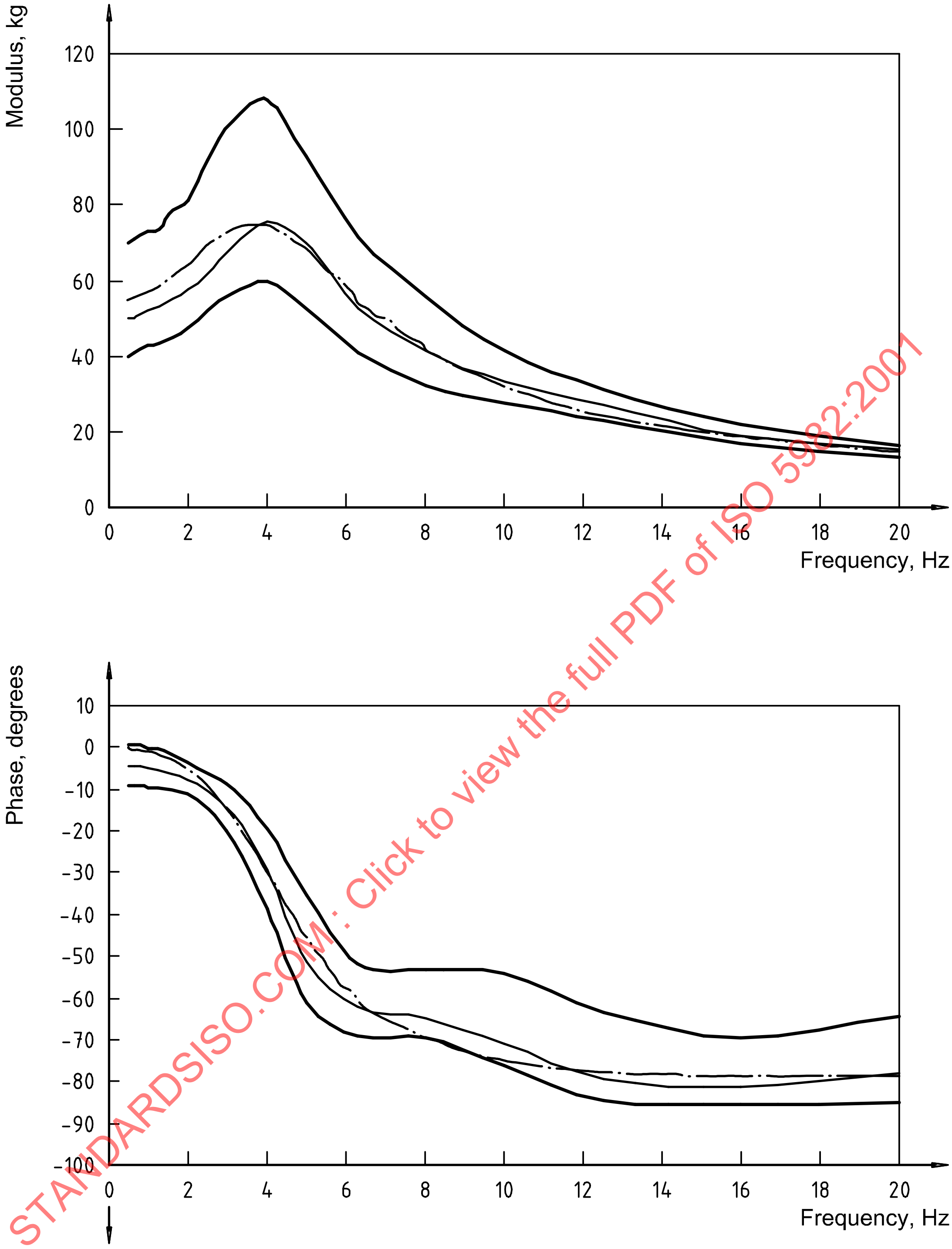


Figure B.1 — Biodynamic model of the seated human body



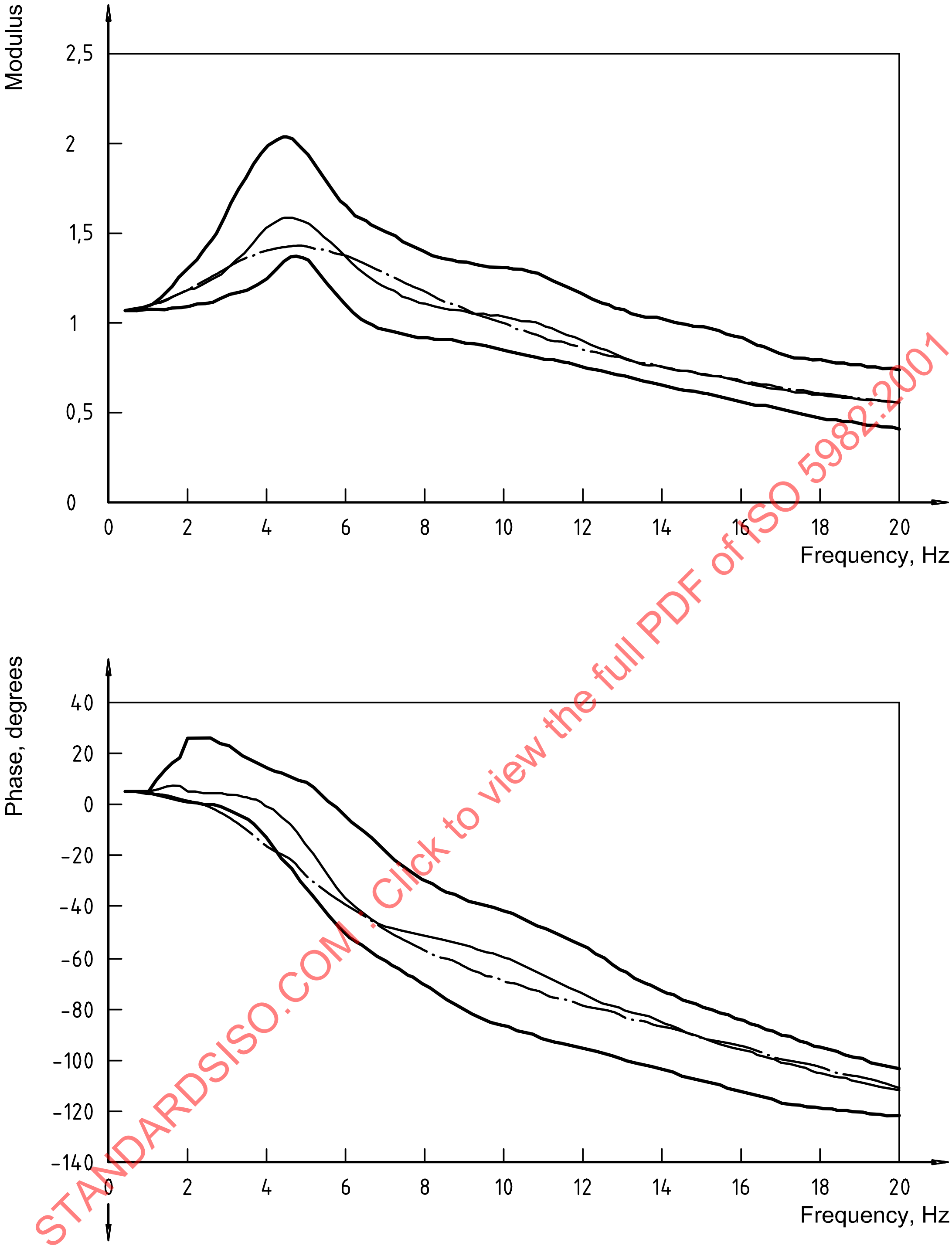
NOTE For an explanation of the lines, see 4.1.

Figure B.2 — Comparison between model (dashed line) predictions and the range of idealized values for driving-point mechanical impedance



NOTE For an explanation of the lines, see 4.1.

Figure B.3 — Comparison between model (dashed line) predictions and the range of idealized values for apparent mass



NOTE For an explanation of the lines, see 5.1.

Figure B.4 — Comparison between model (dashed line) predictions and the range of idealized values for seat-to-head transmissibility

Annex C
(informative)

Mathematical expressions for the mean (target) biodynamic response functions

Mathematical expressions in the form of transfer functions denoted by $Z(s)$ and $H(s)$ are defined to approximate the weighted mean (target) values defined at each frequency in Figures 1 and 3 for driving-point mechanical impedance and seat-to-head transmissibility, respectively. The coefficients of the transfer functions are given in Table C.1 for both $Z(s)$ and $H(s)$. The computed responses resulting from these equations are illustrated by dashed lines in Figures C.1, C.2 and C.3 where they are compared with the mean and range of idealized values defined respectively for driving-point mechanical impedance, apparent mass and seat-to-head transmissibility. In performing the calculations, the apparent mass transfer function is determined directly from the driving-point mechanical impedance function.

$Z(s)$ and $H(s)$ are given by

$$Z(s) = 2\pi\, K \frac{s \cdot P(s)}{Q(s)} \tag{C.1}$$

$$H(s) = K \frac{P(s)}{Q(s)} \tag{C.2}$$

where

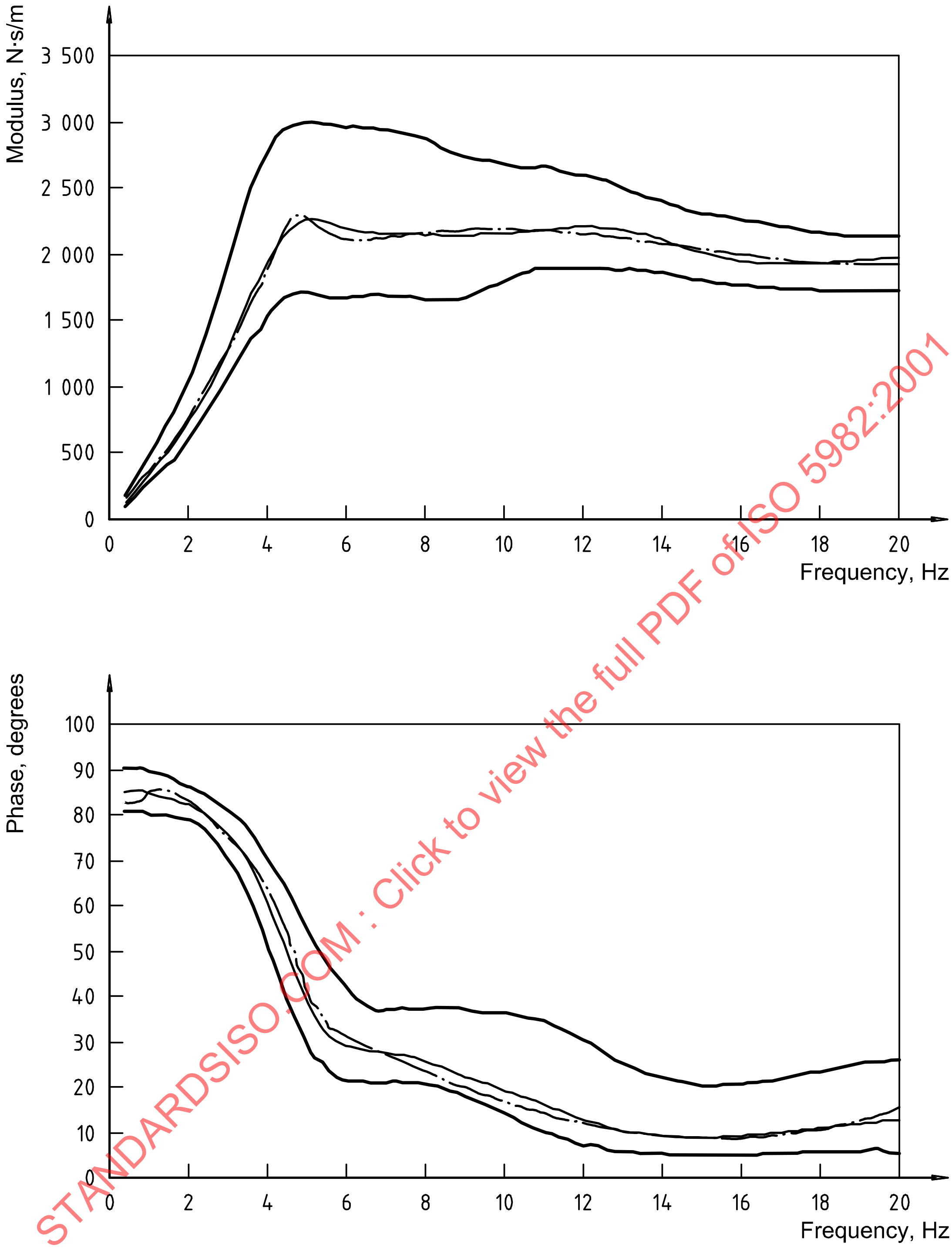
$$P(s) = (s^2 + A_1 \cdot s + B_1) \cdot (s^2 + A_2 \cdot s + B_2) \cdot (s^2 + A_3 \cdot s + B_3)$$

$$Q(s) = (s^2 + C_1 \cdot s + D_1) \cdot (s^2 + C_2 \cdot s + D_2) \cdot (s^2 + C_3 \cdot s + D_3) \cdot (s^2 + C_4 \cdot s + D_4)$$

$$s = \mathrm{j}\, f$$

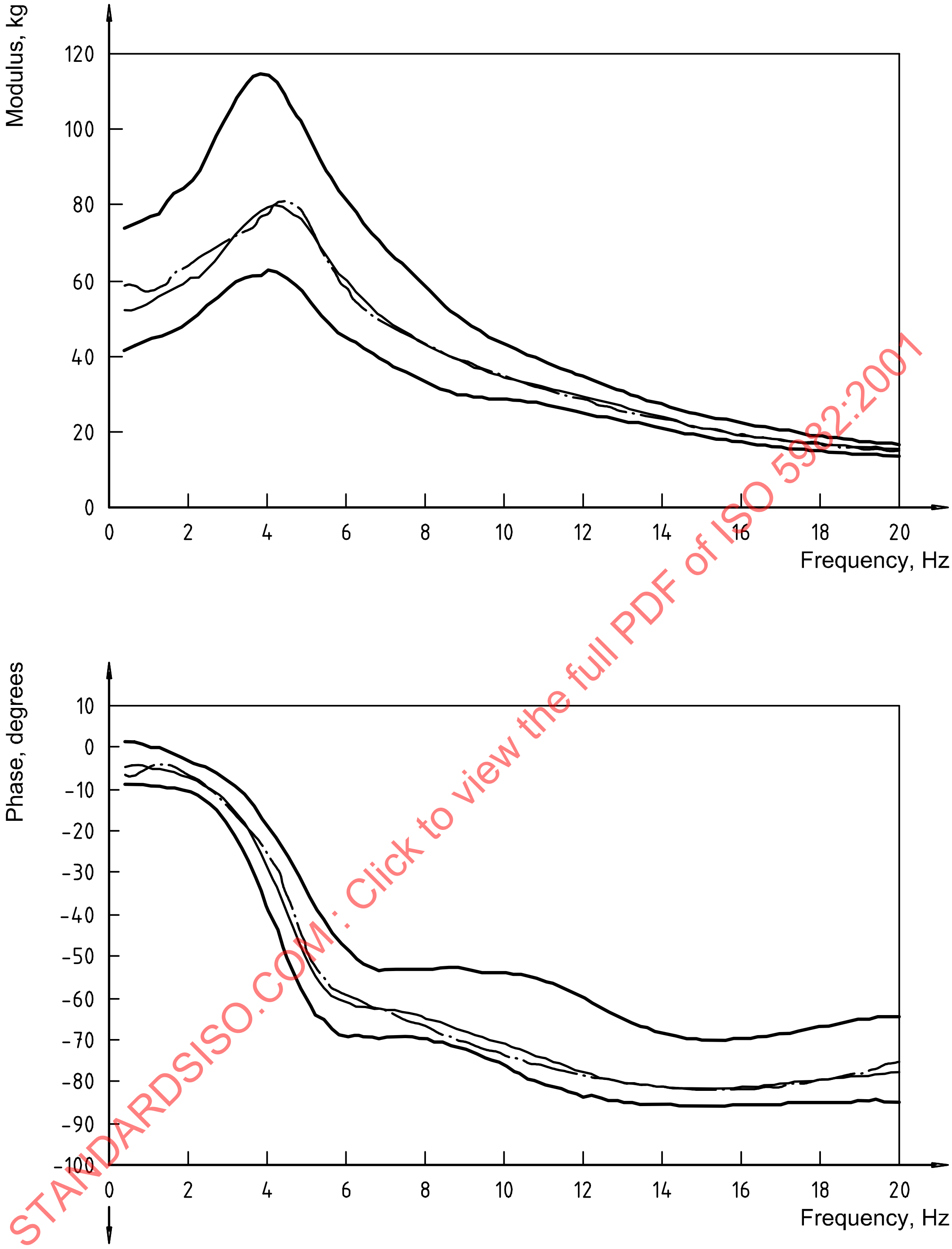
Table C.1 — Coefficients of the transfer functions

Coefficient	$Z(s)$	$H(s)$	Coefficient	$Z(s)$	$H(s)$
K	17179	275	C_1	9,50	28,21
A_1	14,66	13,16	C_2	23,91	10,69
A_2	2,35	4,24	C_3	1,74	3,67
A_3	1,93	3,62	C_4	6,37	3,78
B_1	583,88	149,65	D_1	1015,2	324
B_2	23,52	38,0	D_2	47,02	121
B_3	1,22	9,83	D_3	22,40	30,25
			D_4	4,23	12,96



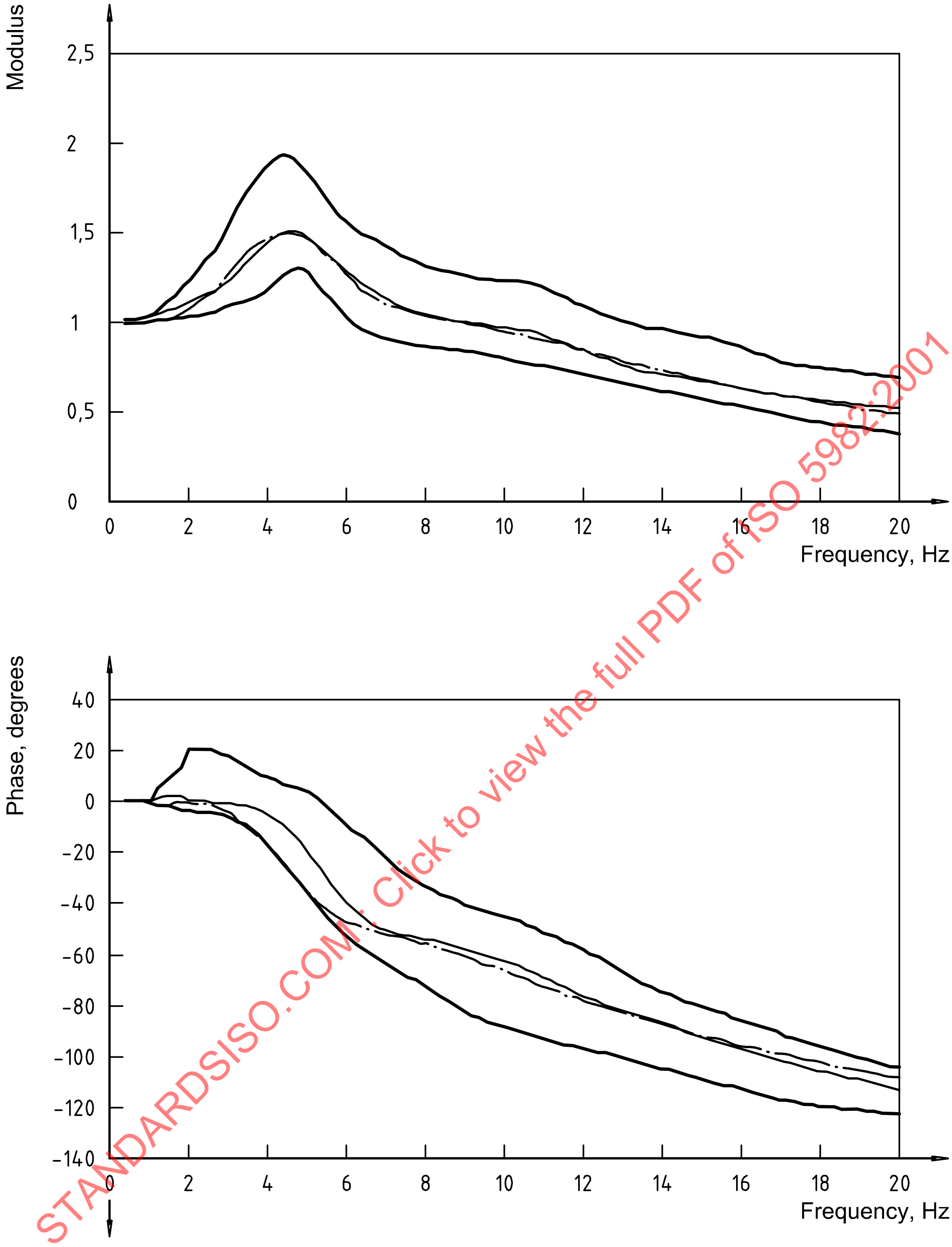
NOTE For an explanation of the lines, see 4.1.

Figure C.1 — Comparison between transfer function (fine dashed line) predictions and the range of idealized values for driving-point mechanical impedance



NOTE For an explanation of the lines, see 4.1.

Figure C.2 — Comparison between transfer function (fine dashed line) predictions and the range of idealized values for apparent mass



NOTE For an explanation of the lines, see 5.1.

Figure C.3 — Comparison between transfer function (fine dashed line) predictions and the range of idealized values for seat-to-head transmissibility