TECHNICAL SPECIFICATION

ISO/TS 17929

First edition
2014-09-15

Biomechanical effects on amusement ride passengers

Effets biomécaniques sur les passagers des manèges

Reference number
ISO/TS 17929:2014(E)

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Published in Switzerland

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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 on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 254, *Safety of amusement rides and amusement devices*.

Introduction

Most passenger-carrying devices, e.g. vehicles, transport systems, elevators, cableways, and other similar structures, are deliberately designed to minimize biomechanical effects on passengers. Amusement rides are different in that the biomechanical effects are deliberately introduced in order to amuse people through stimulation of their sensory system.

Thus, in addition to mechanical, electrical and other hazards, amusement rides could feature significant biomechanical hazards for passengers. Passengers being moved by amusement rides are subject to inertia forces. The magnitude, direction, duration of exposure to, and rate of change of, these forces could create risks that need to be minimized. The risks may be increased by the use of entertaining effects.

Design of the amusement ride in accordance with this Technical Specification, together with ISO 17842, minimizes any risks from these biomechanical effects.

When it is important for safety reasons, passenger weight, height, and age also need to be considered.

Moreover, amusement ride passengers can have different states of health or well-being during a ride cycle and there is a probability of injury not due to any amusement ride defect but owing to the individual health state of a passenger. When a designer, manufacturer or operator provides a warning before the ride entrance for guests, making them aware of ride use restrictions considering their state of health (see Annex D), this can limit legal liability for possible harm to passengers in poor health.

Biomechanical effects on amusement ride passengers

1 Scope

This Technical Specification has been drawn up with the objective of ensuring the safety of amusement ride passengers, based on the international experience of manufacture and operation of such structures throughout the world gained over decades prior to its publication.

It enables the identification of potential hazards and classification of biomechanical effects, including information on recommended acceleration limits, rate of their onset and their duration, to ensure acceptable degrees of biomechanical risks at the stage of amusement ride design, as well as to take such risks into account during development of operational procedures and information on use limitations for amusement ride guests.

It gives recommendations regarding use limitations for amusement rides in accordance with the health condition and the well-being of passengers. It also specifies body dimensions of passengers 1,20 m to 2,0 m in height for motion risk analysis on amusement rides. These body dimensions can be taken into account when designing passenger containments and restraints.

It does not cover devices used in the circus, theatre or sports, or other devices intended for use only by specially trained people. Nevertheless, it can be used in the design of any similar structural or passenger-carrying device even if it does not explicitly mention the device.

This Technical Specification is not applicable to amusement rides put into operation before the date of its publication.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 17842 (all parts)—[1)], *Safety of amusement rides and amusement devices*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
amusement ride
equipment that is designed to entertain the passengers during motion, including biomechanical effects

3.2
biomechanical effects
effects of forces on passengers of amusement rides associated with their motion

3.3
degree of potential biomechanical risk
likelihood of causing harm as a result of biomechanical effects of different values considering the possible severity of consequences

1) To be published.

3.4
entertaining effect
psycho-emotional effect
action on the human sense organs associated with the use of visual effects, illumination, darkness, fire, water, wind, sounds, smells, etc. with the purpose of entertaining people

3.5
fence
structure designed to restrict or prevent movement across a boundary

3.6
high potential biomechanical risk degree
RB-1
potential of causing fatal harm to a passenger or passengers resulting from biomechanical effects

3.7
low potential biomechanical risk degree
RB-3
potential of causing harm with temporary disability of a passenger or passengers resulting from biomechanical effects.

3.8
medium potential biomechanical risk degree
RB-2
potential of causing severe harm to health of a passenger or passengers resulting from biomechanical effects

3.9
motion risk envelope
zones around the bodies of passengers carried by the amusement ride within the reach envelopes in which, if it is intruded by any structures or foreign obstacles, the passengers may be exposed to harm of varying degrees of severity

3.10
negligible potential biomechanical risk degree
RB-4
potential of causing harm without any form of disability to a passenger or passengers resulting from biomechanical effects

3.11
passenger containment
components (e.g. seating, foot wells, handrails, and passenger restraints) designed to prevent passengers from moving outside a predetermined area on a ride either as a result of biomechanical effects or the ride forces or the behaviour of the passenger

3.12
rate of onset of acceleration
value that characterizes the rate of acceleration growth during the given time interval (third derivative of movement in time)

3.13
restraint
system, device, or characteristic that is intended to inhibit or restrict the body movement and/or keep the body position to tolerate accelerations of the passenger(s) while on the amusement ride

3.14
use limitation
limitation for passengers with health deviations including but not limited to reasons related to their age, height or weight as well as for guests who are not feeling well to use an amusement ride safely

4 Degrees of potential biomechanical risks for amusement rides

When people are being moved by an amusement ride, the respective potential risks of harm may be present depending on the potential fall height, values of velocity and accelerations, angle of the seat inclination or turnover. Therefore, measures to reduce or eliminate risks shall be taken with regard to the types and degrees of biomechanical effects acting on passengers. In order to analyse the risks and possible consequences of failures, it is important to take into account how people are exposed to biomechanical effects and the frequency of such exposure.

Biomechanical effects produced by amusement rides are not always suitable for people with health problems or who are simply not feeling well at the time, and therefore it is necessary to warn people of how extreme the amusement ride may be and of any use limitations.

Types of injuries depending on the severity of harm to the human body can include but are not limited to

a) traumatic brain injury (TBI),

b) vascular injury due to turning upside down,

c) cardiac arrhythmia due to stress and/or accelerations action,

d) severe injury of internal organs due to impact,

e) injury of a musculoskeletal system when exposed to high accelerations, and

f) loss of consciousness due to accelerations.

If the safety measures taken are not adequate, any biomechanical effects of an RB-1 value may cause catastrophic harm to health or life of people, those effects may, for example, include falling from the height of over 8 m; being hit against an obstacle at a speed of higher than 20 m/s; ejection of an unrestrained passenger out of a passenger unit; falling of an unrestrained passenger headlong out of a turned over passenger unit or seat from the height of more than 3 m.

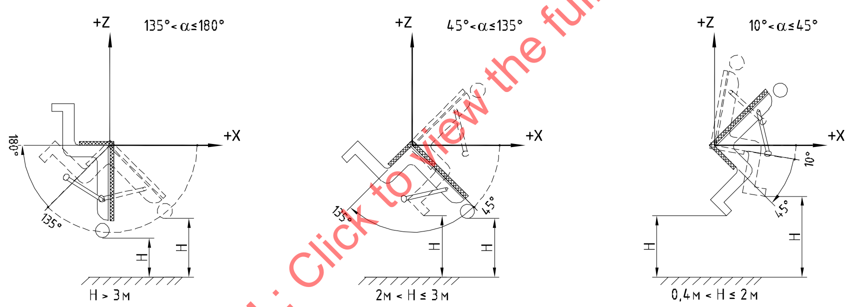
Similarly, any biomechanical effects of an RB-2 value may cause critical harm to health, including a severe injury or disability, and any biomechanical effects of an RB-3 value may cause harm to health such as temporary disorder. It should be noted that, if safety measures are insufficient and any unfavourable events or situations occur, increased biomechanical effects may result in high risk which will require risk analysis.

Identification of types and values of effects and degree of potential biomechanical risks shall be performed using Table 1. Figures 1 a), 1 b), and 1 c) illustrate inclination types of passenger seats.

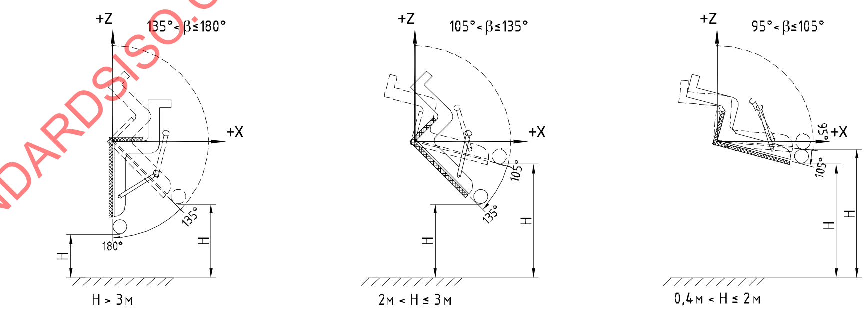
Table 1 — Types and values of effects to which passengers are exposed and degrees of potential biomechanical risks

Type of biomechanical effect	Notation	Degree of potential biomechanical risk			
		RB-1	**RB-2**	**RB-3**	**RB-4**
Lift to or drop from a relative height[a]	H, m	$H > 8$	$2 < H \leq 8$	$0{,}4 < H \leq 2$	$H \leq 0{,}4$
Travel at a relative velocity	V, m/s	$V > 20$	$10 < V \leq 20$	$3 < V \leq 10$	$V \leq 3$
Lift or drop in seat with inclination:	H, m	$H \geq 3$	$2 < H \leq 3$	$0{,}4 < H \leq 2$	$H \leq 0{,}4$
— forward inclination [Figure 1 a)]	α, degrees	$135 < \alpha \leq 180$	$45 < \alpha \leq 135$	$10 < \alpha \leq 45$	
— backward inclination [Figure 1 b)]	β, degrees	$135 < \beta \leq 180$	$105 < \beta \leq 135$	$95 < \beta \leq 105$	
— sideward inclination [Figure 1 c)]	γ, degrees	$120 \leq \gamma \leq 180$	$60 \leq \gamma \leq 120$	$30 < \gamma \leq 60$	

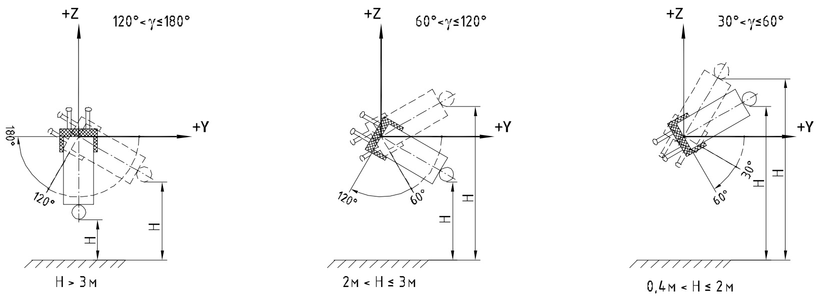
[a] The degrees of biomechanical risks are based on the statistics regarding consequences of injuries to people when falling from height.



a) Forward inclination



b) Backward inclination



c) Sideward inclination

Figure 1 — Degrees of potential biomechanical risks depending on height and/or inclination for a seated unrestrained passenger

5 Measures for elimination or reduction of hazards due to biomechanical effects

Biomechanical risk analysis and risk classification for amusement rides concentrate the attention of those who make and maintain amusement rides on the elements and parameters most important for the safety of amusement rides.

Biomechanical risks arising from the types of effects listed below shall be eliminated or reduced by means of the following basic methods, in accordance with ISO 17842-1, and the necessity for redundancy depends on the risk analysis:

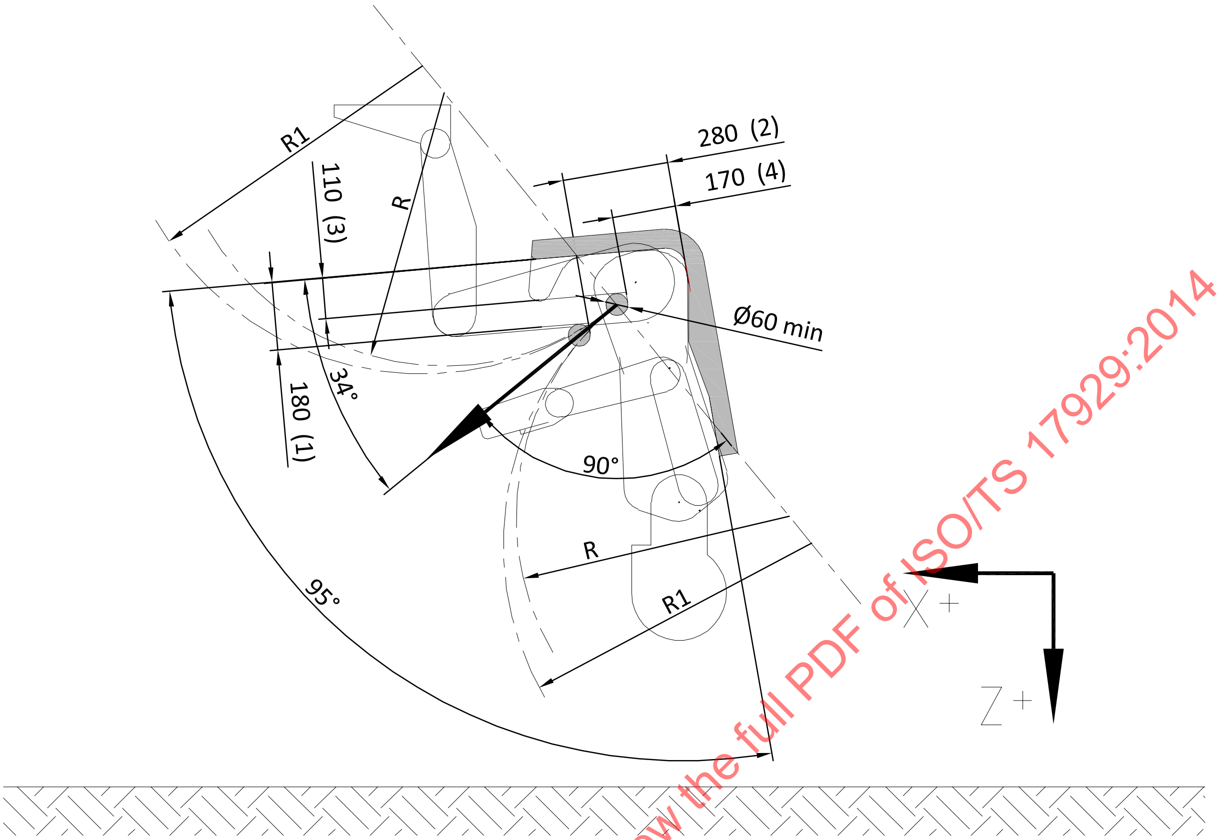
— when passengers are at a height of more than 2 m, reliable load-carrying structures and fences with due allowance for wind effects shall be provided as well as appropriate lifts and hoists;

— when passengers are being moved at a high speed (more than 3 m/s), appropriate containment devices shall be provided to prevent falling or potential ejection of passengers taking into account effects of inertia — measures shall be taken to remove obstacles that may cause harm getting into the relevant motion envelopes of passengers;

— when passengers are moved with high accelerations comparable with allowable limits for each axis, the passenger's body shall be secured with a restraint in order to ensure that accelerations are safely tolerated and to eliminate risk of passenger ejection due to acceleration (including under normal and emergency braking);

— when seats or passenger units are turned over and there is a probability of passengers falling out, appropriate passenger containment shall be provided.

Passenger containment may include restraints as part of the containment system. Figure 2 provides an example of the geometry of the contact of a lap-bar type restraint with a passenger.



Key

(1) thigh clearance (the highest point of the thigh above the sitting surface) (measurement 27, Reference [8])

(2) body depth, sitting – a horizontal distance between the seat back and anterior protrusion of the body (measurement 36, Reference [8])

(3) thigh clearance for an anthropometric model of 1200 mm in height (scaling down of measurement 27 given in Reference [8])

(4) horizontal distance between the seat back and anterior protrusion of the body for an anthropometric model of 1200 mm in height (scaling down of measurement 36 given in Reference [8])

Figure 2 — Example of the size and position of a restraint bar to hold passengers when turning upside down in emergency

A complete passenger containment system shall be designed and verified by ergonomic testing.

To accommodate a passenger in an upside down position, other passenger containment systems may be designed.

These provisions are applicable for passengers of 1,20 m to 2,0 m in height.

To take necessary design and organizational safety measures for minimising risks originated from amusement rides, the experience of the designers, manufacturers, and operators shall be in conformity with the complexity of an amusement ride and with the degree of its biomechanical hazard.

Elimination or reduction of high degree biomechanical risks shall be provided using the following safety measures:

— designing amusement rides in accordance with the ISO 17842-1 standard requirements;

— using seats and restraint systems ensuring the permanence of the passenger's position; safety of the position is confirmed by mathematic simulation of accelerations acting on the passenger;

— limiting accelerations acting on the passenger with parameters specified in this Technical Specification;

— advising passengers of possible harm while using the amusement ride depending on their state of health. Warnings shall be clear and legible and shall be displayed at the entrance of an amusement ride as well as duplicated at the loading platform.

The safety measures taken at the design stage shall be continuously maintained and verified at all the relevant stages of the ride manufacture and operation.

6 Effects of accelerations on passengers

When designing amusement rides where passengers are exposed to accelerations, it is necessary to take into consideration possible unfavourable effects of accelerations on the human body.

The manifestations of such effects are described in Annex B.

Annex B also contains consolidated diagrams of recommended limit accelerations for different directions of their actions.

7 Zones of potential biomechanical risk in the reach envelope of passengers for motion risk analysis and unscheduled braking risk analysis

The risk of injury for passengers during riding results from potential intrusion of obstacles into the relevant zone around the passenger. Sizes of the zones taking into account the severity of injuries depend on the anthropometric data of passengers, restraint systems, and speed of relative motion. Obstacles, such as people, animals and birds, decorations, tents, branches of trees, etc. may cause injury, so it is required to provide measures, according to the risk analysis, for the zones to be enlarged and to surround the relevant area with fencing or to remove all obstacles within the appropriate space.

Sizes of envelopes when passengers are being moved and those for unscheduled braking are given in Annex A.

Annex A
(informative)

Body dimensions of passengers from 1,20 m up to 2,0 m tall for motion risk analysis and unexpected braking risk analysis

Sizes of motion risk envelopes are calculated for passengers from 1,20 m up to 2,0 m tall using a method of allowable movement of the human body and limbs based on 99th percentile with the stature of 1 900 mm having been adjusted to 2 000 mm (according to Reference [8]). The size of motion risk envelopes is given in Figures A.1 to A.6.

Measurements shown in the figures are taken from the sources listed below.

An anthropometric model to produce the following Figures A.1 to A.6 has been made by scaling up of the original model with height of 1 900 mm (99th percentile as per Reference [8]) up to 2 000 mm (99th percentile as per ISO 15534-3:2000, 1 944 mm).

(1) Head turning angle (Reference [5], angle γ_3, Figure 1c), Table 1)

(2) Lower leg turning angle (Reference [5], angle γ_6, Figure 1 c), Table 1)

(3) Body inclination until it reaches the position when the height of the lifted arm is maximum

(4) Turning until contacting the side wall of the seat with height of 200 mm

(5) Maximum body (shoulder) breadth — horizontal breadth across the shoulders, measured to the protrusions of the deltoids with arms hanging freely downwards (measurement 17, Reference [8])

(6) Maximum horizontal distance between the deltoid of the left arm hanging freely and fingertips of the right arm stretched out sideways (measurement 14, Reference [8])

(7) Sitting height — vertical distance from the sitting surface to the vertex (measurement 22, Reference [8])

(8) Maximum vertical distance between the seat surface and fingertips of the arm stretched out upwards (compilation of measurements of other postures as per Reference [8])

(9) Shoulder joint range of motion, vertically (experimental data)

(10) Head turning angle (Reference [5], angle α_3, Figure 1 a), Table 1)

(11) Vertical arm reach, standing (measurement 21, Reference [8])

(12) Stature (body height) (measurement 1, Reference [8])

(13) Foot turning angle (Reference [5], angle α_8, Figure 1 a), Table 1)

(14) Maximum body depth (anterior-posterior dimension), standing — horizontal distance between the vertical reference planes going through the anterior and posterior protrusions of the body (measurement 18, Reference [8])

(15) Vertical adjustment of the passenger restraint system

(16) Turning angle of the shoulder joint (Reference [5], angle β_4, Figure 1 b), Table 1)

(17) Arms outstretched (span) (measurement 13, Reference [8])

(18) Hand turning angle (Reference [5], angle β_1, Figure 1 b), Table 1)

(19) Forward arm reach (measurement 19, Reference [8])

Figures A.1 to A.6 show dimensions of motion risk envelopes for passengers of amusement rides.

Zone 1 — zone with potential biomechanical risk of high degree (RB-1) at a motion speed V > 3 m/s — a mandatory zone.

Zone 2 — zone with potential biomechanical risk of medium degree (RB-2), for speed V > 3 m/s — a mandatory zone; and zone with biomechanical risk of low degree (RB-3), for speed V ≤ 3 m/s — a recommended zone.

Figures A.1 to A.6 show dimensions of motion risk envelopes for passengers of amusement rides during braking.

Zone 1a — zone with potential biomechanical risk of high degree at off-nominal (emergency) braking (RB-2) – a mandatory zone.

Zone 2a — zone with potential biomechanical risk of low degree at abrupt deceleration (RB-3) — a recommended zone.

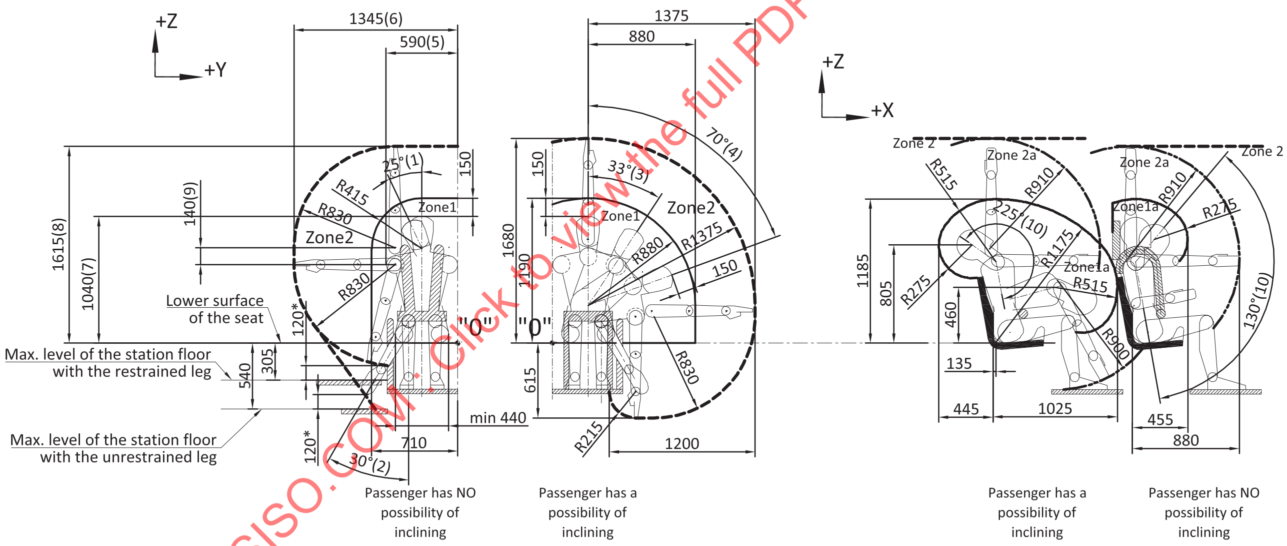


Figure A.1 — Zone of potential biomechanical risks in reach envelopes for passengers in a sitting position, along x-axis (back and forward)

Dimensions in millimetres

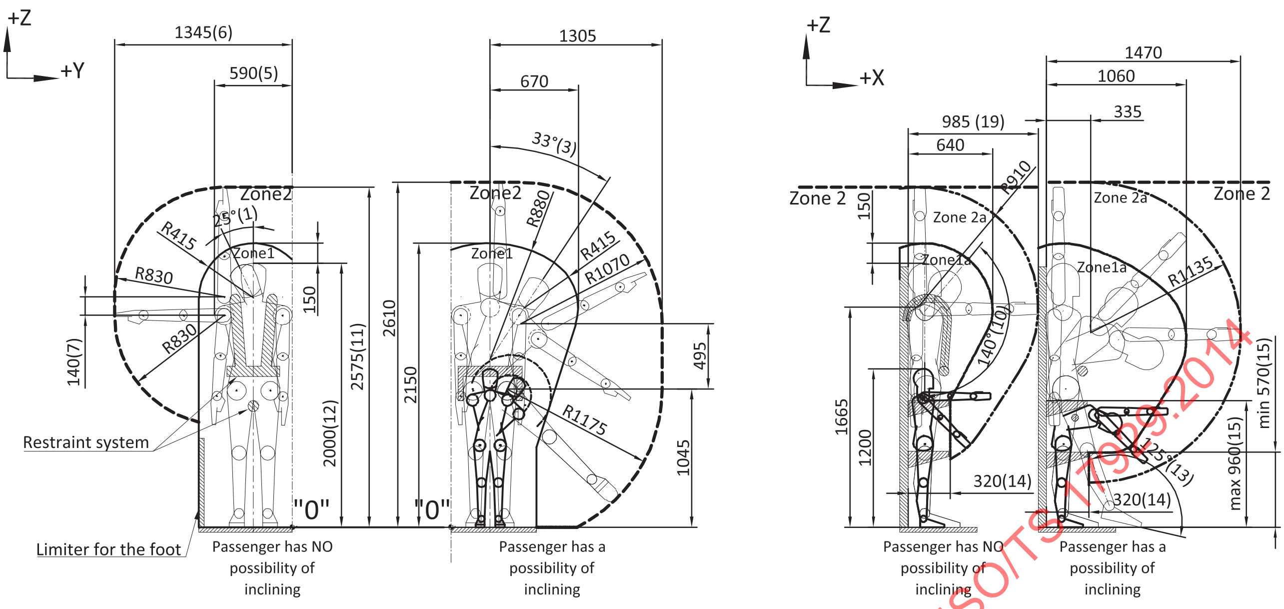


Figure A.2 — Zones of potential biomechanical risks in reach envelopes for passengers in a standing position, along x-axis (back and forward)

Dimensions in millimetres

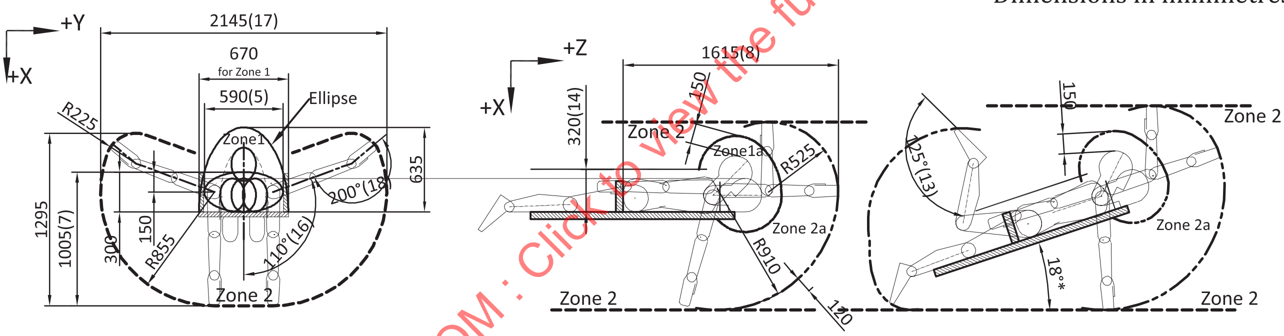


Figure A.3 — Zone of potential biomechanical risks in reach envelopes for passengers in a prone position, along Z-axis (back and forward)

Dimensions in millimetres

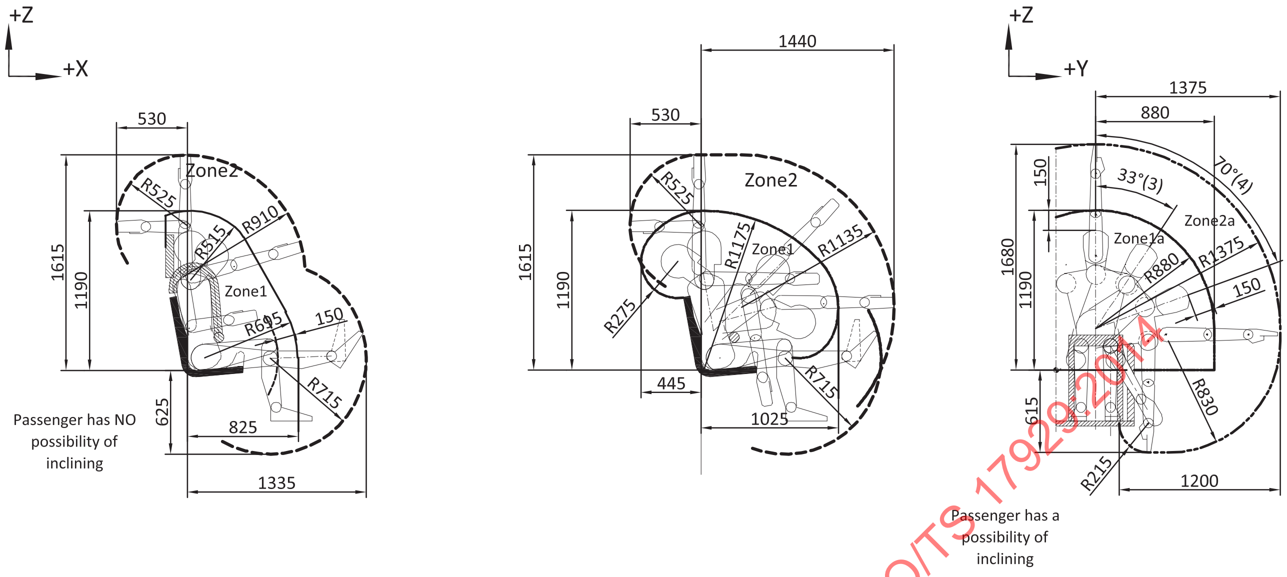


Figure A.4 — Zone of potential biomechanical risks in reach envelopes for passengers in a sitting position, along y-axis (sideward)

Dimensions in millimetres

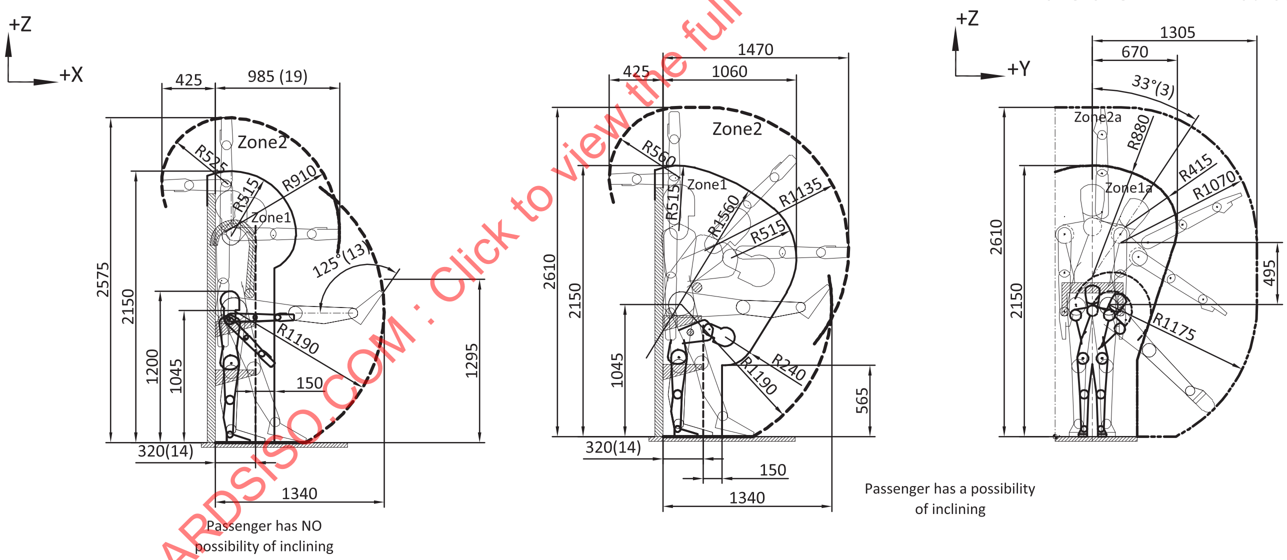


Figure A.5 — Zone of potential biomechanical risks in reach envelopes for passengers in a standing position, along y-axis (sideward)

Dimensions in millimetres

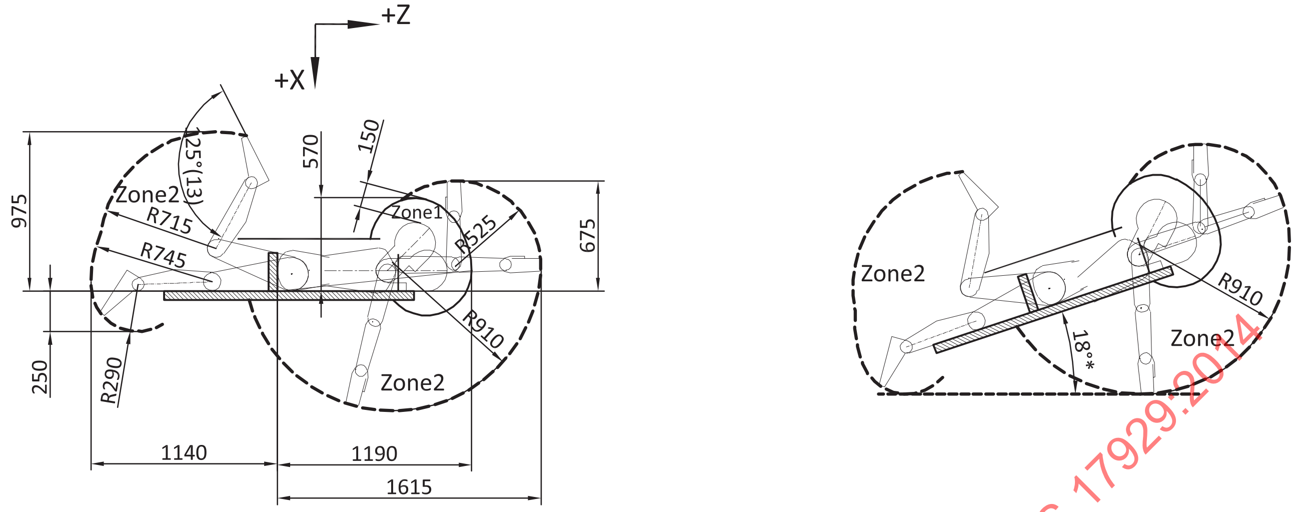


Figure A.6 — Zone of potential biomechanical risks in reach envelopes for passengers in a prone position, along y-axis (sideward)

Annex B
(informative)

Recommended acceleration limits

B.1 General

Unfavourable effects of accelerations on the human body may show themselves through the following:

— displacement of the body or its parts under inertia forces, collision with surrounding objects and secondary injuries;

— deformations of tissues and organs resulting in disorders of blood circulation and respiratory disturbance.

Risk of injuries and adverse effects due to accelerations can be minimized by means of the following measures:

— application of appropriate passenger containment and restraint;

— use limitations for persons with physical restriction or health problems;

— application of Annex B for limiting the accelerations to which passengers are exposed on amusement rides.

Accelerations acting on passengers when using amusement rides should be limited to a tolerable level. Recommended acceleration values given below ensure safety of apparently healthy passengers but some values can cause discomfort, for example, motion sickness.

Limiting values are given below. For the different directions of accelerations the passenger coordinate system with orthogonal axes X, Y, and Z as shown in Figure B.1 applies. The Z-axis direction is defined along the spine (±5° tolerance).

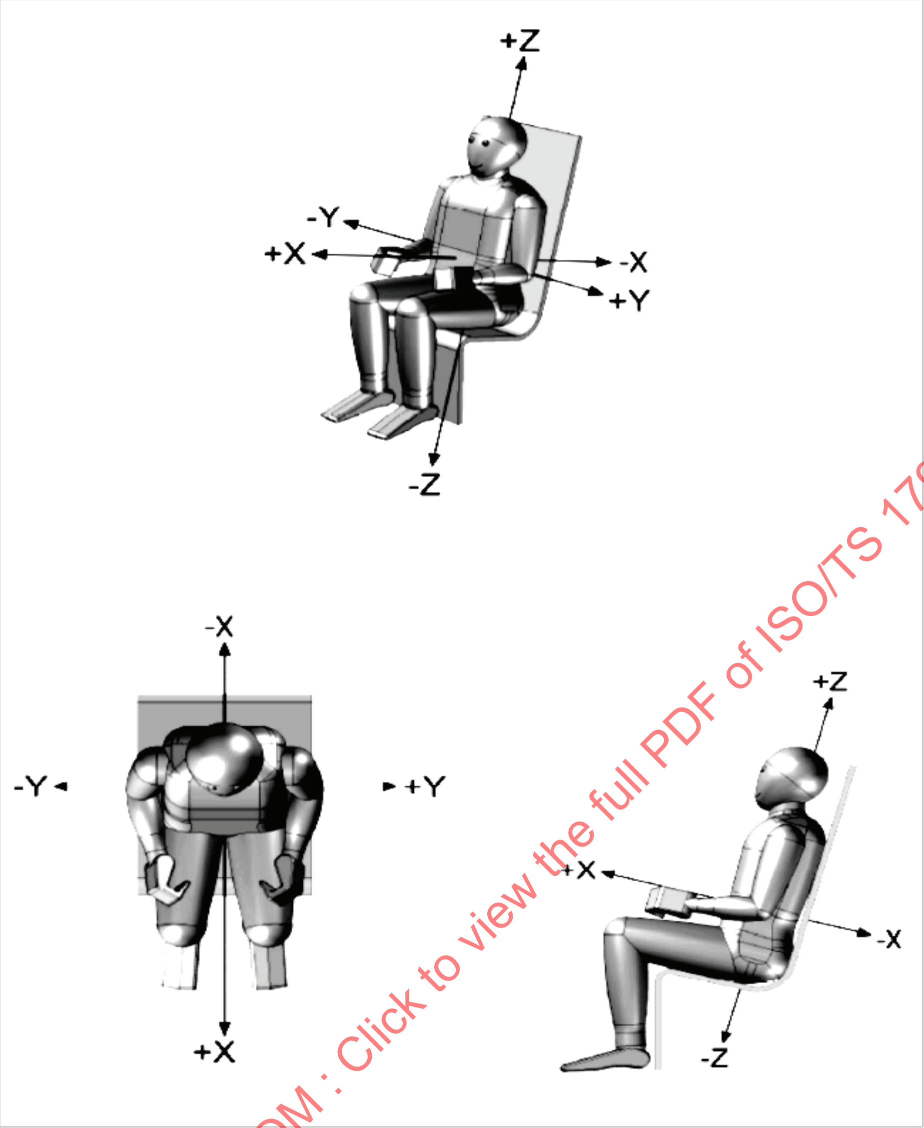


Figure B.1 — Human body coordinate system

B.2 Rides

B.2.1 General

All passenger units need to be equipped with suitable seats (with regard to lateral guidance, padding, head rests, etc.) and appropriate restraint devices. The values stated are not applicable for persons with impaired health conditions.

Measurements should be taken according to Reference [30]. The acquired Standardized Amusement Ride Characterization (SARC) test data shall be post-processed with a 4-pole, single pass, Butterworth low pass filter using a frequency of 5 Hz.

The reference point for calculated or measured accelerations is 600 mm above seat-level of the vehicle (SARC-EN test in Reference [30], Chapter 13).

In the design stage, it is recommended that the permissible acceleration values be reduced by a minimum of 10 %.

B.2.2 General definitions and limitations

B.2.2.1 Limitations/excluded influences

Accelerations of less than 200 ms duration are not addressed in this Technical Specification.

The limits are for passengers 1,20 m in height and above. Accelerations to passengers with specific physical disabilities are not addressed either; they are assumed to be able to accommodate accelerations subject to all types of passengers.

The steady-state values of accelerations with the duration of more than 40 s and up to 90 s are valid for accelerations acting in X and Y directions.

This Technical Specification does not address a duration of the effect for the steady-state acceleration values with the duration of more than 40 s in Z direction.

B.2.2.2 Accelerations

The positive directions of acceleration (a_x, a_y, or a_z) are defined in the figures of this annex for the coordinate system as follows:

— $+a_z$ presses the body into the seat downwards, described as “eyes down”;

— $-a_z$ lifts the body out of the seat, described as “eyes up”;

— $+a_y$ presses the body sideward to the right, described as “eyes right”;

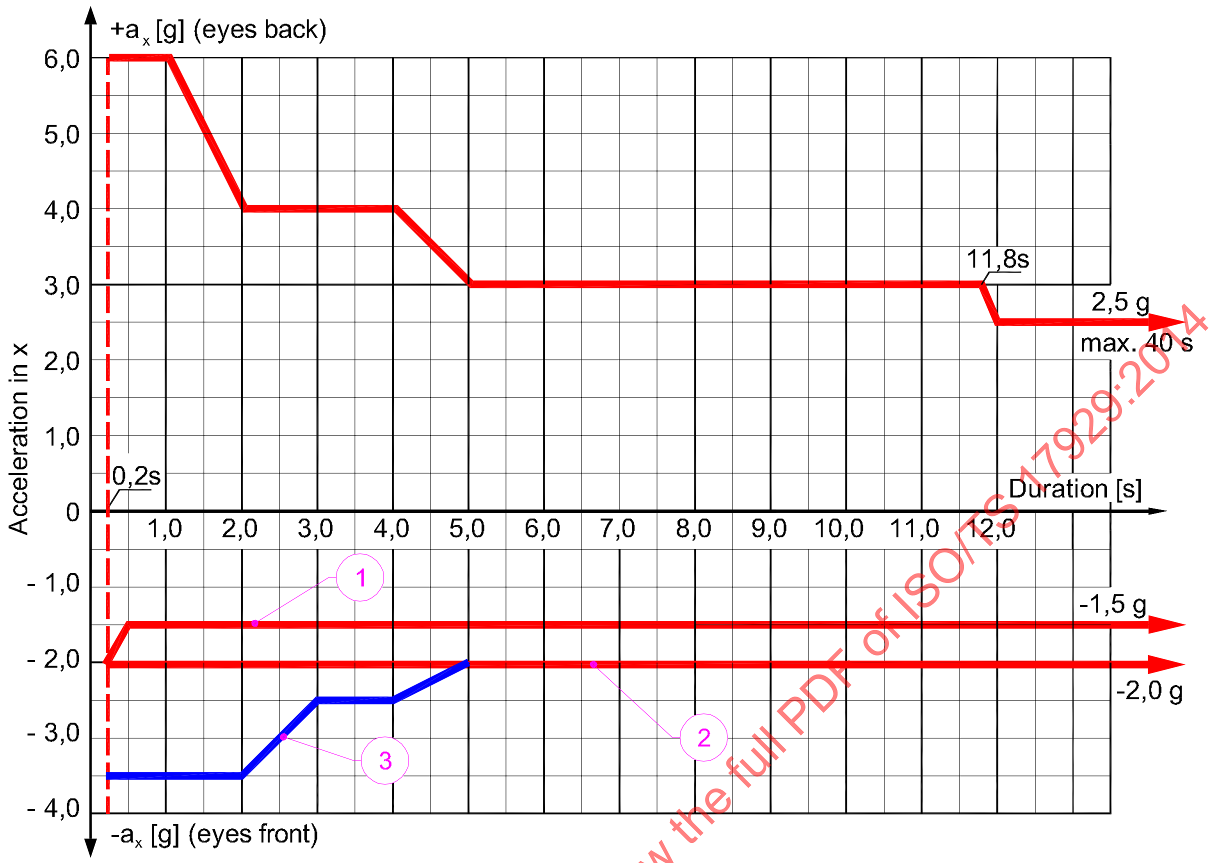
— $-a_y$ presses the body sideward to the left, described as “eyes left”;

— $+a_x$ presses the body into the seat backward, described as “eyes in”;

— $-a_x$ pushes the body out of the seat forward, described as “eyes out”.

B.2.3 Acceleration in X-direction

For measured acceleration versus time graphs, the permissible values in the X-direction according to Figure B.2 shall be observed.



Key

1 base case

2 over the shoulder restraint

3 prone restraint

Figure B.2 — Time duration limits for allowable accelerations in X-direction (perpendicular to spine)

The total duration of steady-state accelerations should not exceed 40 s.

NOTE 1 Base case is the individual body restraint.

NOTE 2 Over-the-shoulder restraint minimizes passenger forward motion.

NOTE 3 Over-the-shoulder limits are increased to prone limits providing the acceleration onset rate is less than 15 g/s and the restraint is appropriately padded.

NOTE 4 Prone restraint assumes human body is supported by appropriately padded restraint.

NOTE 5 Acceleration values along +x-axis with the amplitude of 4 g and more are valid for the case where a passenger is in a seat with headrest.

B.2.4 Acceleration in Y-direction

For measured acceleration versus time graphs, the permissible values in Y-direction according to Figure B.3 shall be observed.

NOTE Limits in Figure B.3 are valid for a passenger with the pelvis and shoulder restrained.

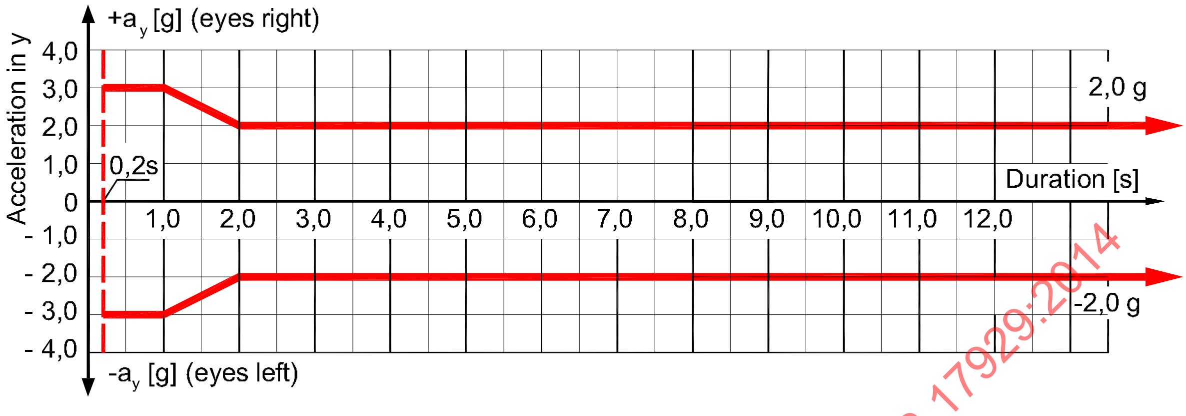
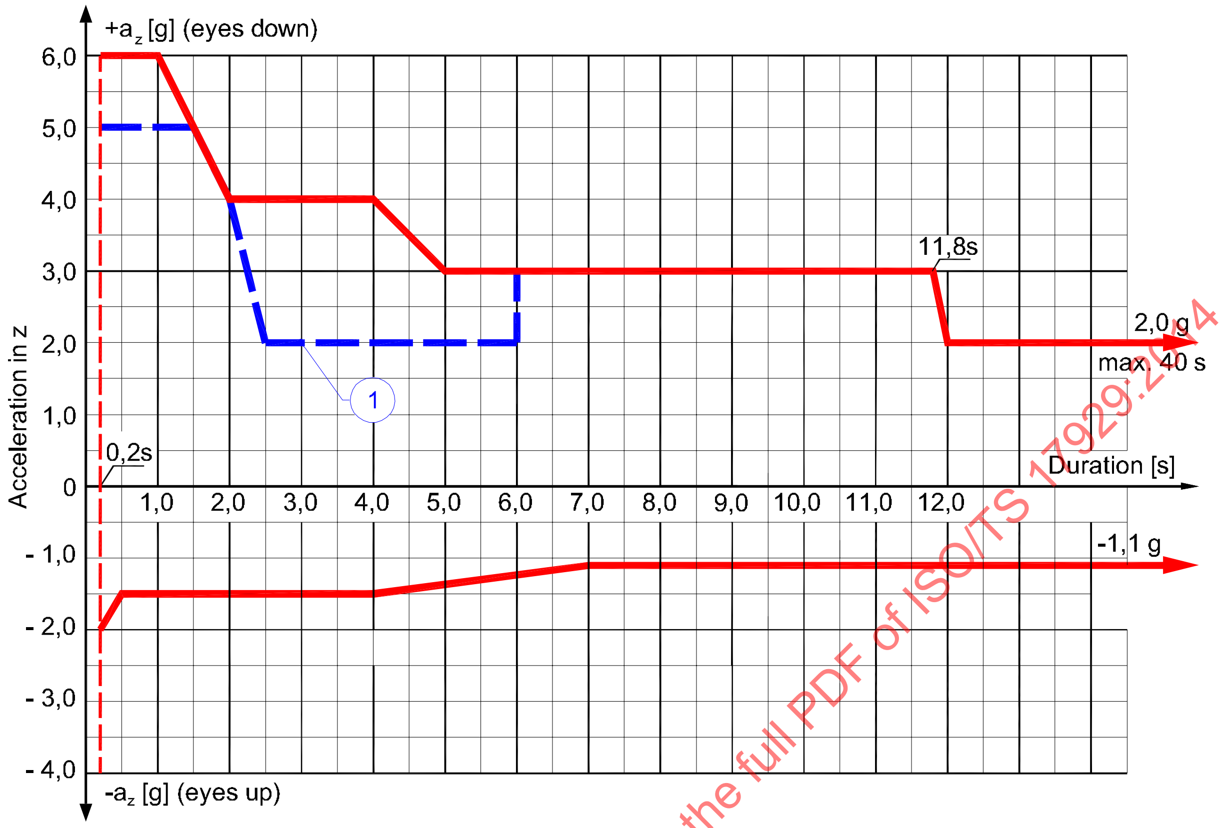


Figure B.3 — Time duration limits for allowable accelerations in Y-direction

B.2.5 Acceleration in Z-direction (parallel to spine)

For measured acceleration versus time graphs, the permissible values in Z-direction according to Figure B.4 shall be observed.



Key

1 + Gz limits if preceded by 3 s or more of – Gz

Maximum duration of +a_z (eyes down) = 2,0 g is limited to 40 s.

Figure B.4 — Time duration limits for accelerations in Z-direction (parallel to spine)

B.2.6 Combinations

When simultaneous or consecutive a_x, a_y, or a_z acceleration values occur, the combination shall be checked.

Based on the assumption that the graphs are an assembly of elliptical curves, the combined effect of accelerations can be checked for acceptability by using the Formulae (B.1) to (B.3) below:

$$\left(\frac{a_x}{\text{adm } a_x}\right)^2 + \left(\frac{a_y}{\text{adm } a_y}\right)^2 \leq 1{,}0 \tag{B.1}$$

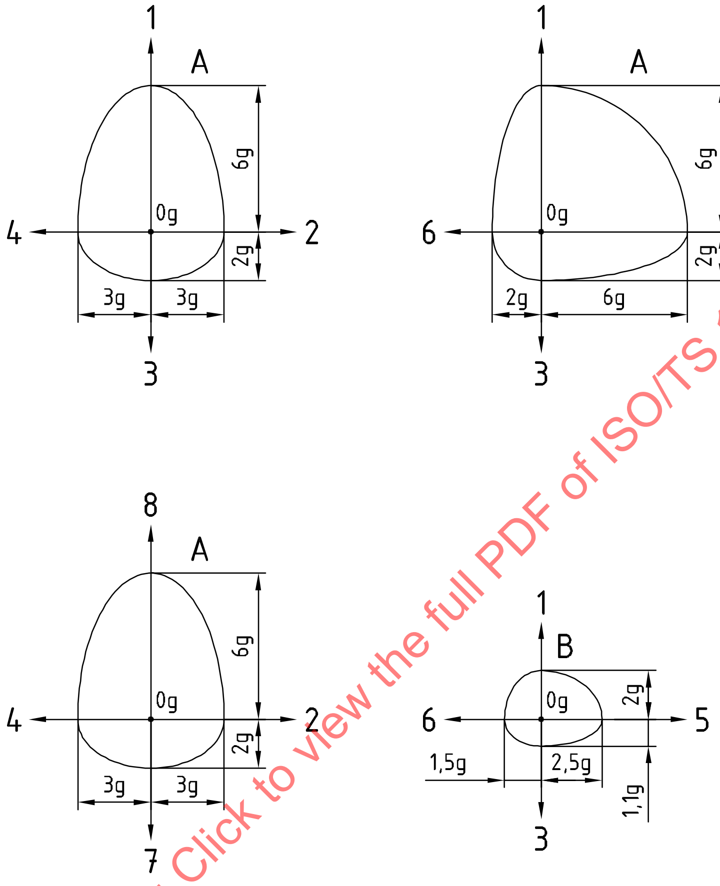
$$\left(\frac{a_x}{\text{adm } a_x}\right)^2 + \left(\frac{a_z}{\text{adm } a_z}\right)^2 \leq 1{,}0 \tag{B.2}$$

$$\left(\frac{a_z}{\text{adm } a_z}\right)^2 + \left(\frac{a_y}{\text{adm } a_y}\right)^2 \leq 1{,}0 \tag{B.3}$$

Admissible accelerations (adm a_x, adm a_y, or adm a_z) for selected durations shall be taken from Figures B.2 to B.4.

Where there is a combination of accelerations, in order to keep the passenger's position, appropriate restraints should be provided. Combined accelerations for less than 200 ms are excluded.

Figure B.5 shows some examples of the allowable combined magnitude of X, Y, and Z accelerations. In the graphs, the terms are not divided by adm a_x, adm a_y or adm a_z and the shape is ellipsoid.



Key

A combination for t = 0,2 s

B combination for t > 12 s

1 + a_z [g] (eyes down)

2 + a_y [g] (eyes right)

3 − a_z [g] (eyes up)

4 − a_y [g] (eyes left)

5 + a_x [g] (eyes in)

6 − a_x [g] (eyes out)

7 − a_x [g] (eyes out)

8 + a_x [g] (eyes in)

Figure B.5 — Examples of allowable combined magnitudes of a_x, a_y, and a_z accelerations