

Biomechanical Effects on Amusement Rides Passengers

1 Scope

The present standard has been drawn up with the objective of ensuring safety of amusement ride passengers based on the international experience of manufacturing and operation of such structures throughout the world gained over the last decades.

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

The standard gives recommendations regarding use limitations for amusement rides in accordance with health conditions and well-being of passengers.

The standard gives body dimensions of passengers from 1.20 up to 2.0 meters tall for motion risk analysis on amusement rides.

The standard gives the norms of weight for amusement ride passengers with height from 1.2 up to 2.0 meters.

These body dimensions of passengers may be taken into account when designing passenger containments and restraints.

The standard does not cover circus, theatre, sports or other devices intended for use by specially trained people only.

Nevertheless this standard may be used in the design of any similar structural or passenger carrying device not explicitly mentioned herein.

The standard is not applicable to amusement rides which were put into operation before the date of this standard coming into effect.

2 Normative references

The following referenced documents are indispensable for the application 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 2631-4:2001, *Mechanical vibration and shock. Evaluation of human exposure to whole-body vibration. Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems*

ISO 12100:2010, *Safety of machinery - General principles for design - Risk assessment and risk reduction*

ISO 15534-3:2000, *Ergonomic design for the safety of machinery - Part 3: Anthropometric data*

ISO 17842-1¹, *Safety of amusement rides and amusement devices - Part 1: Design and manufacture*

¹ To be published

ISO/CD 17929

ISO 17842-2² *Safety of amusement rides and amusement devices - Part 2: Operation, maintenance and use*

ISO/TR7250-2:2010, *Basic human body measurements for technological design - Part 2: Statistical summaries of body measurements from individual ISO populations*

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

3.4

entertaining (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

a structure designed to restrict or prevent movement across a boundary

3.6

high potential biomechanical risk degree (RB-1)

potential of causing harm to health of a passenger or passengers resulting from biomechanical effects and associated with at least one fatality according to the risk analysis

3.7

low potential biomechanical risk degree (RB-3)

potential of causing harm to health of a passenger or passengers resulting from biomechanical effects and associated with temporary disability (incapacitation) according to the risk analysis

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 according to the risk analysis

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

² To be published

3.10**negligible potential biomechanical risk degree (RB-4)**

potential of causing harm to health of a passenger or passengers resulting from biomechanical effects and not associated with temporary disability (incapacitation) according to the risk analysis

3.11**passenger containment**

components (for example 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

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 Symbols (and abbreviated terms)

Any symbols connected with the respective units will be explained in the clauses concerned.

5 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 degree 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 fragile health or not feeling well and, therefore, it is necessary to warn people of how extreme the amusement ride is and of any limitations for using the amusement ride.

The degree of severity for potential harm to passengers in case of biomechanical effect of RB1 and RB 2 values is

- (1) brain injury;
- (2) damage of blood vessels due to turning upside down;
- (3) disorder of heart activity due to stress and/or accelerations action;
- (4) severe injury of the body and/or internal organs due to, e.g., falling down or collision;
- (5) injury of a locomotive system when exposed to high accelerations.
- (6) loss of consciousness due to accelerations;

If the safety measures taken are not adequate, any biomechanical effects of 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 meters; being hit against an obstacle at a speed of higher than 20 m/sec; 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 meters.

Similarly, any biomechanical effects of RB-2 value may cause critical harm to health, including a severe injury or disability, and any biomechanical effects of 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 estimation.

Identification of types and values of effects and degree of potential biomechanical risks shall be performed using Table 1. Figures 1, 2 and 3 illustrate inclination types of passenger seats.

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

| Types of biomechanical effects | Notation | Degrees of potential biomechanical risks | | | |
|--|---|---|---|---|--------------|
| | | RB-1 | RB-2 | RB-3 | RB-4 |
| | | Values of biomechanical effects | | | |
| | | High | Increased | Moderate | Small |
| Fall 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 | $V > 20$ | $10 < V \leq 20$ | $3 < V \leq 10$ | $V \leq 3$ |
| Falling out of an inclined seat with head first: - forward inclination (Fig. 1) - backward inclination (Fig. 2) - sideward inclination (Fig. 3) | H, m α , degrees β , degrees γ , degrees | $H \geq 3$ $135 < \alpha \leq 180$ $135 < \beta \leq 180$ $120 \leq \gamma \leq 180$ | $2 < H \leq 3$ $45 < \alpha \leq 135$ $105 < \beta \leq 135$ $60 \leq \gamma \leq 120$ | $0.4 < H \leq 2$ $10 < \alpha \leq 45$ $95 < \beta \leq 105$ $30 < \gamma \leq 60$ | $H < 0.4$ |

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

Falling out of an inclined seat with head first for potential biomechanical risk estimation

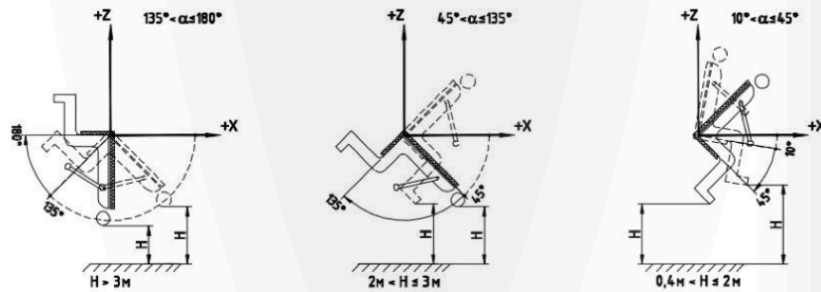


Figure 1 – Forward inclination

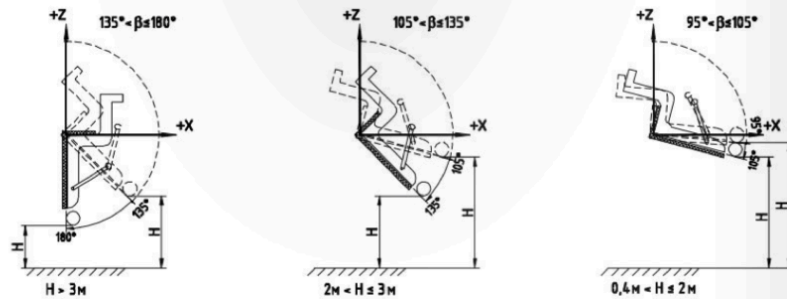


Figure 2 – Backward inclination

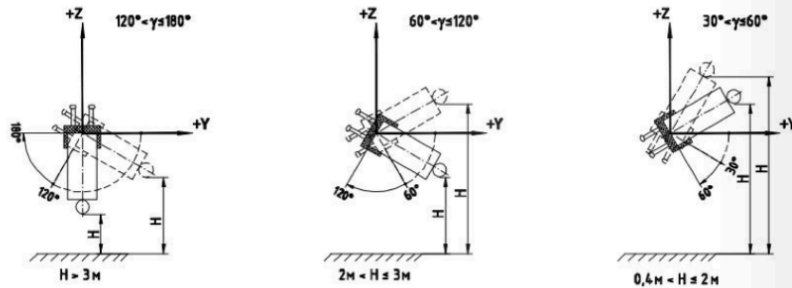


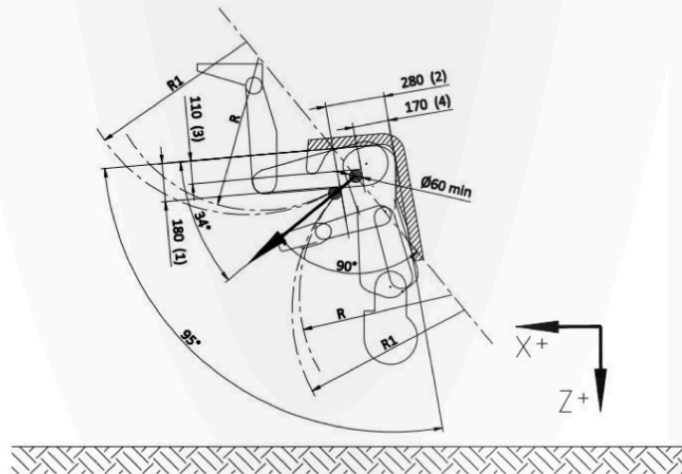
Figure 3 – Sideward inclination

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

Biomechanical risk analysis and risk classification for amusement rides concentrates 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 loads-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/sec), 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 restraints shall be provided. In addition to other devices Figure 4 shows an example of the design and dimensions of a restraint bar which holds a passenger in the seat with minimal traumatisation of the thighs or internal organs in the abdominal zone.

**Key**

- (1) Thigh clearance (the highest point of the thigh above the sitting surface) (measurement 27, [8])
- (2) Body depth, sitting – a horizontal distance between the seat back and anterior protrusion of the body (measurement 36, [8])
- (3) Thigh clearance for an anthropometric model of 1200 mm in height (scaling down of measurement 27 given in [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 [8])

Figure 4 – Recommendations for size and position of a restraint bar to hold passengers when turning upside down

These recommendations are applicable for passengers of 1.20m – 2.0m in height with a normal weight in accordance with Table A1 and Figure A1 of Annex A.

To take necessary design and organizational safety measures for minimising risks originated from amusement rides, the experience of 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 standard;

- 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.

7 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 C.

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

Annex E contains recommended limit values of parameters for each value of allowable linear accelerations in the form of graphic functions of acceleration versus time with indication of onset and drop rates.

8 Zones of risk in 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 B.

Annex A (informative)

Recommendations for use of amusement rides due to stature or weight. Weight norms with respect to the stature of amusement ride passengers (according to [24])

On amusement rides which feature considerable accelerations in accordance with Annex D and Annex E or possibility of passenger inclination or turnover it is required to hold passengers in their seats by means of a restraint or passenger containment for better tolerance of accelerations and to keep them in the given position. For reasons of ensuring safety of passengers for amusement rides with high risk levels (RB1 and RB2) and/or seat inclinations in accordance with Figures 1, 2 and 3 it is recommended to use restraints or passenger containments for people having height and weight from 1.20m and 30kg, respectively, up to 2.0 m and 140kg, respectively.

A tangible weight deficit of a passenger (having body mass index (BMI) less than 16 as per the recommendations of the World Health Organization), including anorexia conditions, may result in a severe injury of a locomotive system if exposed to high and increased accelerations. The risk may be even higher if the restraint is not individually adjustable for each passenger which particularly relates to amusement rides with considerable side-to-side accelerations. The designer can set use limitations for people who are underweight.

Deviations of weight for people with obesity of degree II or III may cause not only an injury of a locomotive system but also difficulties with use of restraints for safe holding and protecting of passengers with variable stature from falling out. The designer can set use limitations for people who are overweight.

On amusement rides that feature accelerations higher than 3g in +z direction in accordance with Annex D and Annex E, as well as on amusement rides with control of passengers weight, recommendations as shown in Fig. A.1 and Table A.1 may apply.

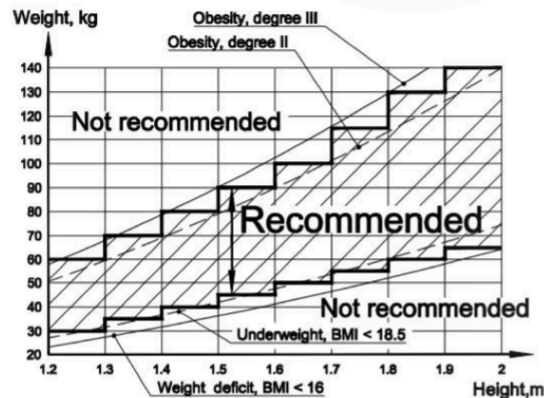


Figure A.1

Table A.1

| Min. weight, kg | Height, cm | Max. weight, kg |
|-----------------|------------|-----------------|
| 30 | 120-129 | 60 |
| 35 | 130-139 | 70 |
| 40 | 140-149 | 80 |
| 45 | 150-159 | 90 |
| 50 | 160-169 | 100 |
| 55 | 170-179 | 115 |
| 60 | 180-189 | 130 |
| 65 | 190-200 | 140 |

and/or height of passengers. It is advisable to place information on the ride use limitations next to the rules of behaviour for the ride guests.



Figure A.2 – Weight restrictions



Figure A.3 – Height restrictions

A relevant warning sign (Figures A.2, A.3), and at the discretion of the park Table A.1, a height gauge and weighing equipment, should be available at amusement rides which have use limitations related to weight

Annex B (informative)

Body dimensions of passengers from 1.20m up to 2.0m tall for motion risk analysis and unexpected braking risk analysis

Sizes of motion risk envelopes are calculated for passengers from 1.20m up to 2.0m tall using a method of allowable movement of the human body and limbs based on 99th percentile with the stature of 1900 mm having been adjusted to 2000 mm (according to [8]). The size of motion risk envelopes is given in Figures B.1 - B.6.

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

An anthropometric model to produce the following Figures has been made by scaling up of the original model with height of 1900 mm (99th percentile as per [8]) up to 2000 mm (99th percentile as per ISO 15534-3:2000 – 1944 mm).

- (1) Head turning angle ([5], angle γ_3 , Fig. 3, Table 1)
- (2) Lower leg turning angle ([5], angle γ_6 , Fig. 3, 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, [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, [8])
- (7) Sitting height – vertical distance from the sitting surface to the vertex (measurement 22, [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 [8])
- (9) Shoulder joint range of motion, vertically (experimental data)
- (10) Head turning angle ([5], angle α_3 , Fig. 1, Table 1)
- (11) Vertical arm reach, standing (measurement 21, [8])
- (12) Stature (body height) (measurement 1, [8])
- (13) Foot turning angle ([5], angle α_8 , Fig. 1, 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, [8])
- (15) Vertical adjustment of the passenger restraint system
- (16) Turning angle of the shoulder joint ([5], angle β_4 , Fig. 2, Table 1)
- (17) Arms outstretched (span) (measurement 13, [8])

- (18) Hand turning angle ([5], angle β_1 , Fig. 2, Table 1)
- (19) Forward arm reach (measurement 19, [8])

Figures B.1 - B.6 show dimensions of motion risk envelopes for passengers of amusement rides.

Zone 1 – zone with biomechanical risk of catastrophic degree (RB-1) at a motion speed $V > 3$ m/sec – a mandatory zone.

Zone 2 – zone with biomechanical risk of critical degree (RB-2), for speed $V > 3$ m/sec – a mandatory zone; and with biomechanical risk of minimal degree (RB-3), for speed $V \leq 3$ m/sec – a recommended zone.

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

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

Zone 2a – zone with biomechanical risk of minimal degree at abrupt deceleration (RB-3) – a recommended zone.

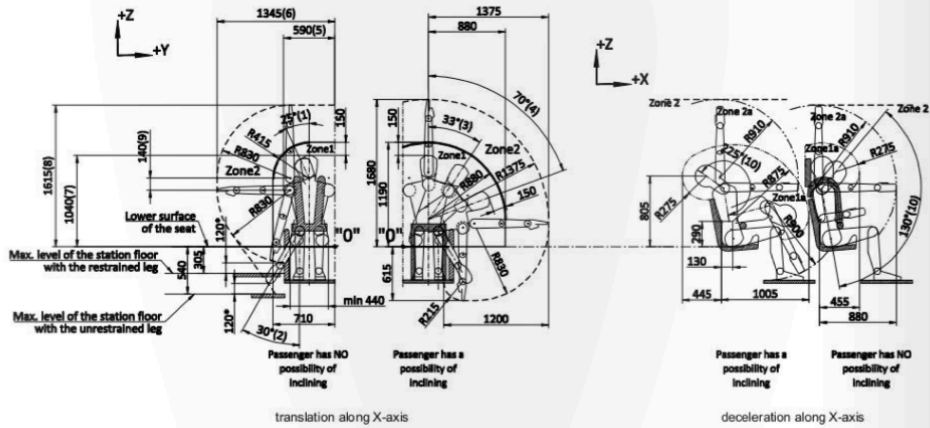


Figure B.1 – Zone of risks in reach envelopes for passengers in a sitting position, along X-axis (back and forward), dimensions are in millimetres

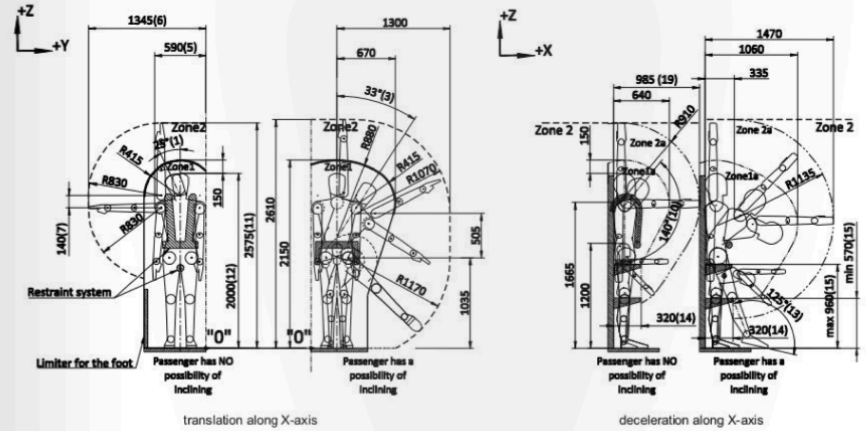
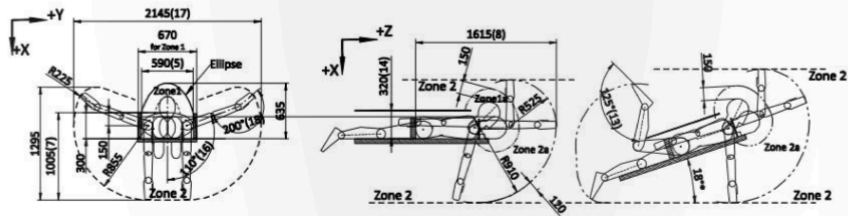


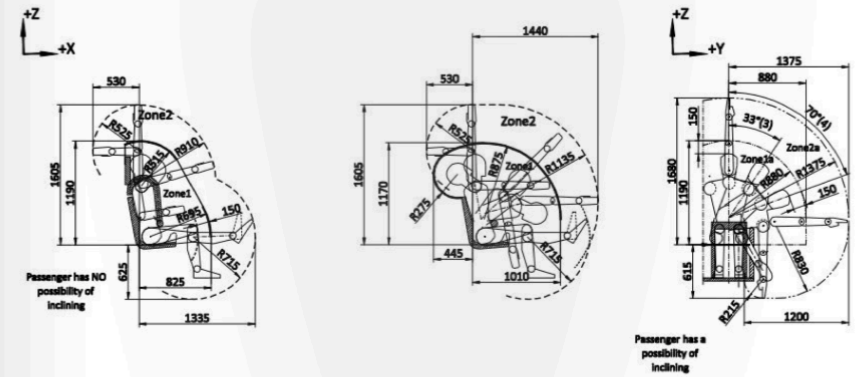
Figure B.2 – Zones of risks in reach envelopes for passengers in a standing position, along X-axis (back and forward), dimensions are in millimetres



translation along Z-axis

deceleration along Z-axis

Figure B.3 Zone of risks in reach envelopes for passengers in a prone position, along Z-axis (back and forward), dimensions are in millimetres



translation along Y-axis

deceleration along Y-axis

Figure B.4 – Zone of risks in reach envelopes for passengers in a sitting position, along Y-axis (sideward), dimensions are in millimetres

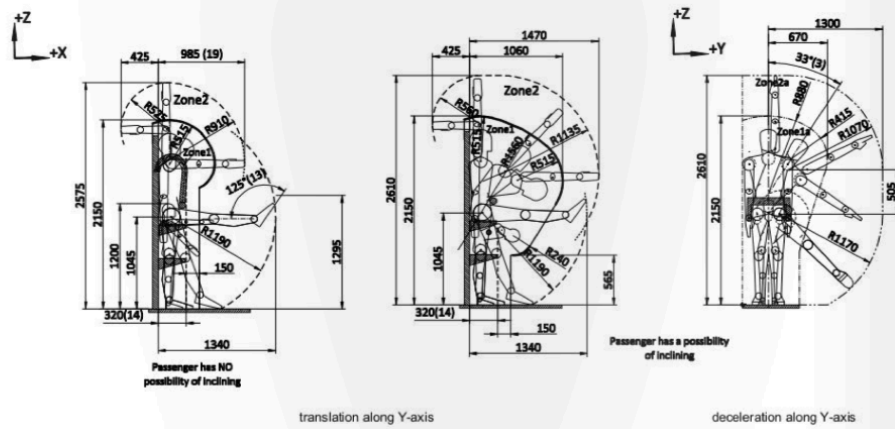


Figure B.5 – Zone of risks in reach envelopes for passengers in a standing position, along Y-axis (sideward), dimensions are in millimetres

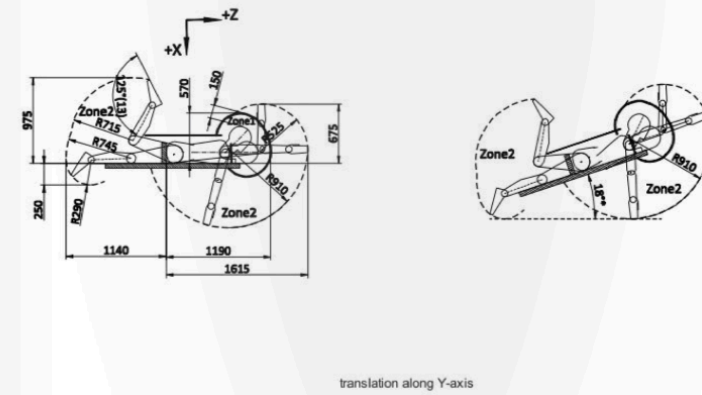


Figure B.6 – Zone of risks in reach envelopes for passengers in a prone position, along Y-axis (sideward), dimensions are in millimetres

Annex C (informative)

Effects of accelerations on passengers

Unfavourable effects of accelerations on the human body may show itself 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;
- excessive excitation of reflexogenic zones and disorders of the body control that may even include a shock.

The closer the magnitude of the acceleration coincides with the axis of the main blood vessels directed along the spine, the stronger is the effect of inertial redistribution of blood and other fluids of the human body into the human responses.

"Pelvis-to-head" accelerations result in the blood relocation from the head to the lower parts of the body provoking a disorder of the brain nutrition and of the visual organ (the retina) in the first place. Upon reaching a certain point the tunnelling of peripheral vision ("grey-out") then transient loss of vision ("blackout") and loss of consciousness come in succession which in some cases is accompanied by clonic convulsions. Restoration of blood supply results in the regression of the symptoms.

"Head-to-pelvis" accelerations drain the blood from the lower parts of the body toward the head, and in doing so result in the disturbance of blood supply, nutrition of the brain and visual organ, which shows itself in the overflow of their blood vessels and increase of the intracranial pressure which is accompanied by sharp bursting headaches, lacrimation, vision disorders and in the worst cases, by haemorrhages.

Transverse accelerations ("back-to-chest", "chest-to-back") result in the deformation of the internal organs, primarily the lungs and mediastinal organs, which comes together with a pain syndrome, an external respiration disturbance (that may include dyspnoea and even apnoea) and a heart rhythm disorder.

There is a pain syndrome due to mechanical compression of the soft tissues against the supporting surface (e.g. the soft tissues of the back under "back-to-chest" acceleration).

When exposed to lateral accelerations while being totally secured with restraints the human body features the displacement and deformation of the internal organs and, primarily, mediastinal organs (the heart and the related vascular fascicle) which is characterised by severe disorders of the heart rhythm.

Prevention of injuries and prophylaxis of adverse effects due to accelerations can be ensured for passengers by means of the following measures:

- application of reliable means of a passenger body containment and restraint
- use limitations for persons with health problems, for those who are underweight or overweight, too short or tall;
- application of Annex D and Annex E for limiting the accelerations to which passengers are exposed on amusement rides;

Values of biomechanical effects of an amusement ride should be taken into consideration for analysing whether it is advisable to use amusement rides repeatedly. Repeated use of amusement rides with high accelerations in accordance with Annex D and Annex E is only recommended for apparently healthy people with at least 5 to 10 minutes intervals between riding sessions and not more than 3 riding sessions in succession. To have more riding sessions on extreme amusement rides a relaxation (recovery) time should be allowed of 15 minutes or more depending on the way a passenger feels and their state of health.

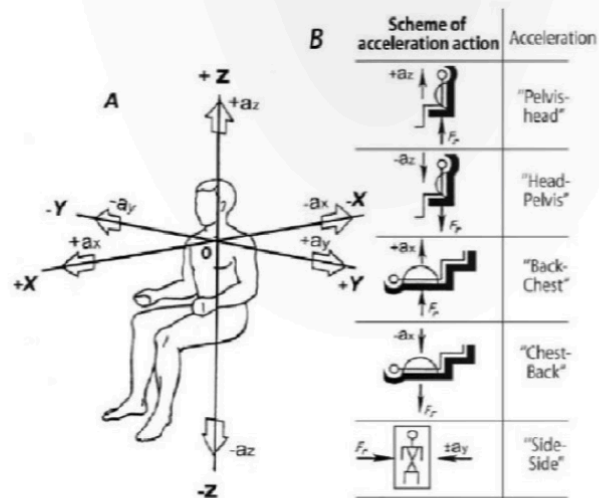
Annex D (informative)

Recommended acceleration limits

D.1 General

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 is given in Figure D.1 applies. The Z-axis direction is defined along the spine (+/- 5° tolerance).



Key

- + 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 back";
- a_x pushes the body out of the seat forward, described as "eyes front"

A area of passenger location

B names and letter designation of accelerations

Fr external force

Figure D.1 — Human body coordinate system

D.2 Rides

D.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 [30]. The acquired Standardized Amusement Ride Characterization (SARC) Test Data shall be post-processed with a 4-pole, single pass, Butterworth low pass filter or shall be filtered with use of Fourier's series. The measurement results shall be filtered with 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 [30], Chapter 13).

In the design stage it is recommended to reduce the permissible acceleration values by a minimum of 10%.

D.2.2 General Definitions and Limitations

D.2.2.1 Limitations

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

Passengers with physical disabilities should be warned about the limitation to use extreme amusement rides before riding.

The steady-state acceleration values shown in this standard should not exceed the durations specified by this standard.

If the operation cycle of the amusement ride includes several single pulses of limit values in accordance with Annex D and Annex E, the total dynamic ride time is recommended to be limited to 90 seconds.

D.2.2.2 Accelerations

For the following figures the positive directions of acceleration (a_x , a_y or a_z) are defined in accordance with 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 back";

- a_x pushes the body out of the seat forward, described as "eyes front".

D.2.3 Acceleration in X-Direction

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



Key

- 1 base case
- 2 over the shoulder restraint
- 3 prone restraint

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

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

Notes: -Base case is the individual lower body restraint and hand rests.

- Over-the-shoulder restraint minimises passenger forward motion
- Over-the-shoulder limits are increased to prone limits providing the acceleration onset rate is less than 15g/s and the restraint is appropriately padded
- Prone restraint assumes human body is supported by appropriately padded restraint
- Limit value of $+a_x$ acceleration relates to passengers in seats with headrests

D.2.4 Acceleration in Y-Direction

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

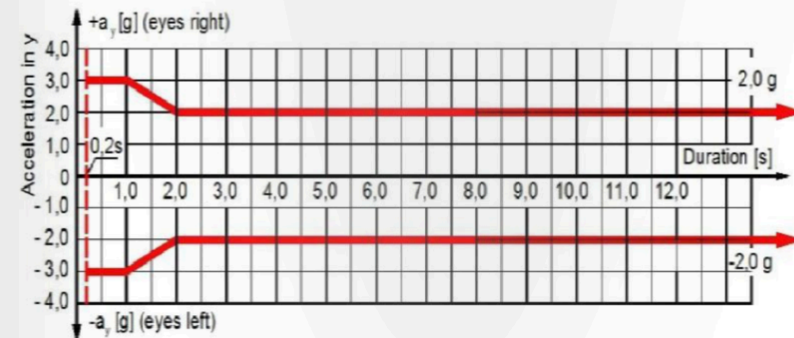
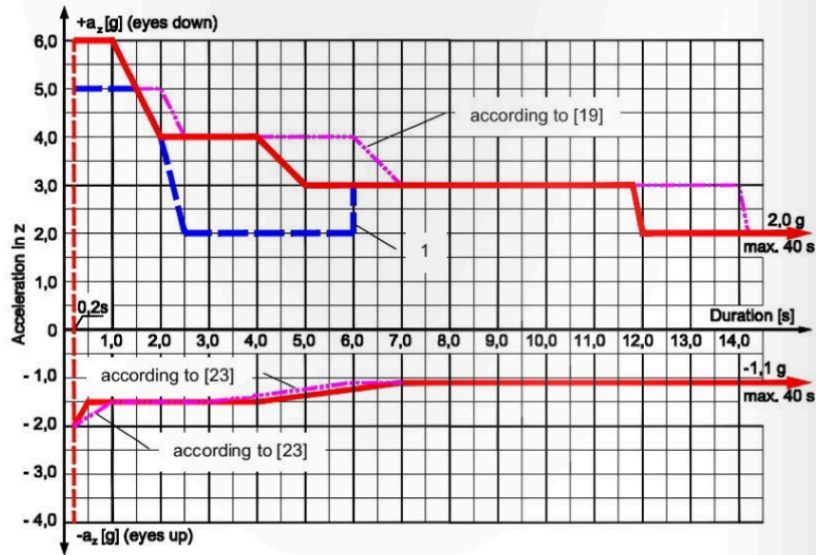


Figure D.3 — Time duration limits for allowable accelerations in Y-direction

The time duration limits for allowable accelerations in Y direction (along the side-to-side line) under condition of restraint of the pelvis and shoulder girdle; the total recommended duration of the steady-state accelerations is not more than 40 seconds.

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

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



Key

1 + G_z limits if preceded by 3 or more seconds of $-G_z$

The dash-and-two-dot line is based on physiological tests (see Bibliography [19], [23]).

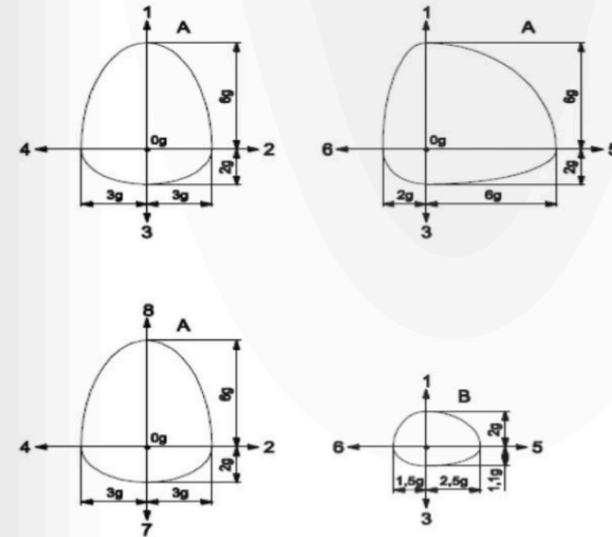
Figure D.4 — Time duration limits for accelerations in Z-direction (parallel to spine)

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

D.2.6 Combinations

The limit values of simultaneously acting accelerations a_x , a_y and a_z should be defined in accordance with equations D.1 – D.4 and diagram Fig. D.5 if the restraint of passenger's body ensures passenger's position keeping, and the maximum values of acting accelerations a_x , a_y , a_z are simultaneous or differ in time negligibly.

Where there is a combination of accelerations, in order to keep the passenger's position, pelvis restraint, shoulder restraint and side supports should be provided.



Key

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 front)

8 + a_x [g] (eyes back)

A combination for $t = 0,2$ s

B combination for $t > 12$ s

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

Admissible accelerations (adm. a_x , adm. a_y or adm. a_z) for selected durations are given in table D.1 (from Figures D.2 - D.4).

Table D.1 — Examples for admissible accelerations

| Accelerations | 0.2s | | 1.5s | | > 12 s | |
|---------------|-------|-------|-------|-------|--------|-------|
| | max. | min. | max. | min. | max. | min. |
| adm a_x | -2.0g | +6.0g | -1.5g | +5.0g | -1.5g | +2.5g |
| adm a_y | -3.0g | +3.0g | -2.5g | +2.5g | -2.0g | +2.0g |
| adm a_z | -2.0g | +6.0g | -1.5g | +5.0g | -1.1g | +2.0g |

Based on the assumption that the "egg" graphs are an assembly of elliptical curves, the combined effect of accelerations can be checked for acceptability by using the formulae below:

$$\left(\frac{a_x}{adm\ a_x}\right)^2 + \left(\frac{a_y}{adm\ a_y}\right)^2 \leq 1.0 \quad (D.1)$$

$$\left(\frac{a_x}{adm\ a_x}\right)^2 + \left(\frac{a_z}{adm\ a_z}\right)^2 \leq 1.0 \quad (D.2)$$

$$\left(\frac{a_y}{adm\ a_y}\right)^2 + \left(\frac{a_z}{adm\ a_z}\right)^2 \leq 1.0 \quad (D.3)$$

$$\left(\frac{a_x}{adm\ a_x}\right)^2 + \left(\frac{a_y}{adm\ a_y}\right)^2 + \left(\frac{a_z}{adm\ a_z}\right)^2 \leq 1.0 \quad (D.4)$$

NOTE Formula (D.4) is applied if all terms $\left(\frac{a_x}{adm\ a_x}\right)^2 \frac{a_x}{adm\ a_x}$, $\left(\frac{a_y}{adm\ a_y}\right)^2 \frac{a_y}{adm\ a_y}$ or $\left(\frac{a_z}{adm\ a_z}\right)^2 \frac{a_z}{adm\ a_z}$ exceed the value of 0.25.

Figure D.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.

Annex E (informative)

Maximum recommended linear accelerations

The acceleration limits nominated in the present Annex are recommended for passengers of amusement rides, having height between 120 cm and 200 cm and weight between 30 kg and 140 kg, practically healthy, i.e. capable of coping with the normal circumstances of common life, including traveling on public transport, as well as the emotional and physical strain of the working day.

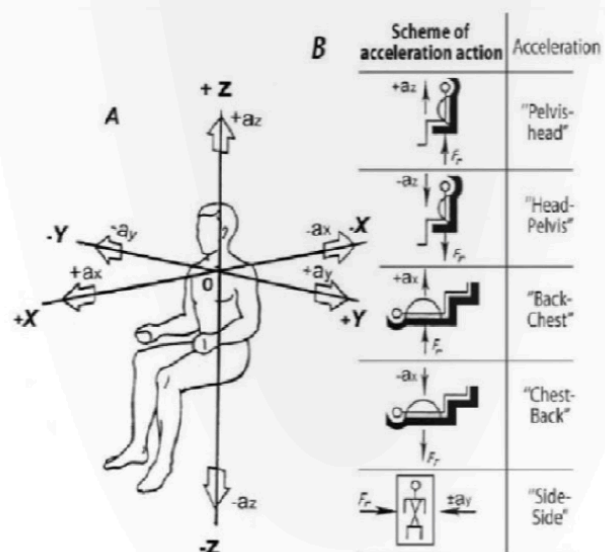
The present Annex gives recommended acceleration limits, which can act on the passenger of the amusement rides for more than 0.2 seconds.

Amusement rides and other amusement devices should be designed so that accelerations, measured on firm strong surface, on which the passenger of the amusement ride is situated, as well as at the point, situated at the seat at height of 60 cm from the flat of the seat, should not exceed the recommended limits. Measurements should be taken according to [30]. The acquired Standardized Amusement Ride Characterization (SARC) Test Data shall be post-processed with a 4-pole, single pass, Butterworth low pass filter or shall be filtered with use of Fourier's series. The measurement results shall be filtered with frequency of 5 Hz.

For amusement rides with acceleration of more than 3g in +z direction recommendations of Annex A on passengers' height and weight should be followed.

The present Annex gives acceleration limits recommended for the passenger of the amusement ride at the single effect of the impulse of acceleration along one of the axis connected with the body of the person:

Lengthwise ("head"- "pelvis", "pelvis"- "head") or across ("back-chest", "chest"- "back"), or sidewise ("side"- "side"). The directions of linear accelerations in coordinate axis connected with the body of a human being and their descriptions are shown in Fig.E.1.



Key

- $+a_z$ 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 back";
- $-a_x$ pushes the body out of the seat forward, described as "eyes front"

A area of passenger location

B names and letter designation of accelerations

Fr external force

Figure E.1 — Human body coordinate system

The parameters of recommended linear acceleration for the passenger of the amusement ride, restrained in the seat, at the single effect of the impulse are shown in Fig. E.2 – Fig. E.26.

Designations in the Figures:

min – minimum rate of acceleration onset, 0.5 g/s**max** – maximum rate of acceleration onset, up to 15 g/s, depending on the achieved acceleration.

The diagrams are actual for the average rate of acceleration onset from min to max.

The recommended limit of acceleration includes the natural gravity of 1g.

Acceleration "pelvis"- "head" / "head"- "pelvis"

Fig. E.2. – Fig. E.6 show recommended limit parameters of single linear acceleration "pelvis"- "head" for the passengers, placed in the sitting position, restrained in the seat, in case there is no preliminary effect of negative linear acceleration "head"- "pelvis".

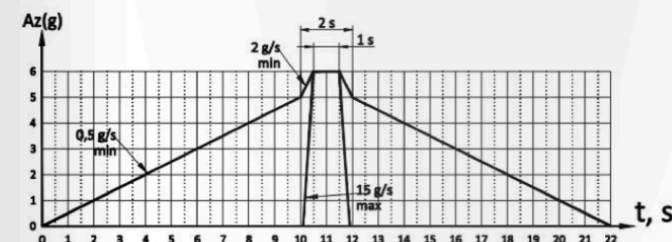


Figure E.2 – The parameters of recommended linear acceleration limits "pelvis-head" for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 6g.

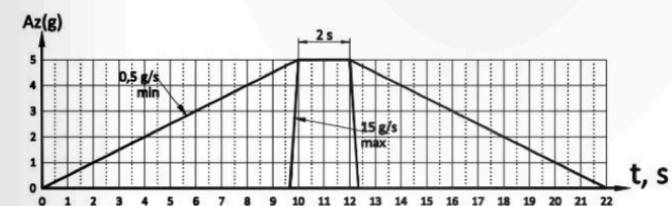


Figure E.3 - The parameters of recommended linear acceleration limits "pelvis-head" for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 5g

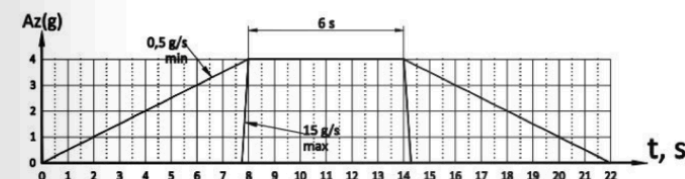


Figure E.4 - The parameters of recommended linear acceleration limits "pelvis-head" for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 4g

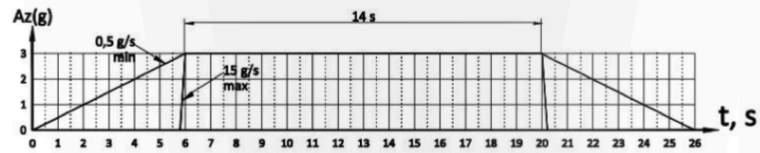


Figure E.5 - The parameters of recommended linear acceleration limits "pelvis-head" for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 3g

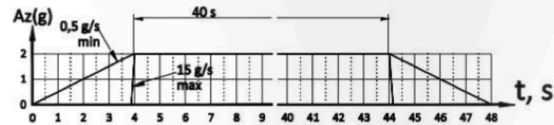


Figure E.6 - The parameters of recommended linear acceleration limits "pelvis-head" for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 2g

Stability of a human being to the linear accelerations "pelvis-head" after the preliminary effect of negative linear acceleration "head-pelvis" is reduced. Recommended parameters of single linear acceleration limits "pelvis-head" in these cases are shown in Fig. E.7 - Fig. E.10

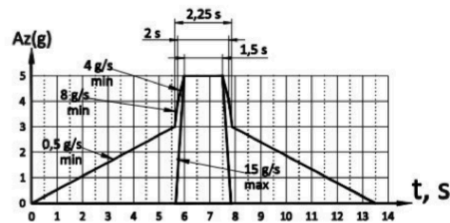


Figure E.7 - The parameters of recommended linear acceleration limits "pelvis-head" (after the preliminary effect of negative linear acceleration "head-pelvis" in z direction in accordance with Fig. E.11, E.12, E.13) for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 5g

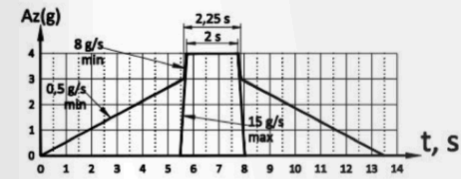


Figure E.8 - The parameters of recommended linear acceleration limits "pelvis-head" (after the preliminary effect of negative linear acceleration "head-pelvis" in z direction in accordance with Fig. E.11, E.12, E.13) for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 4g

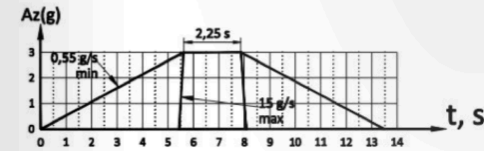


Figure E.9 - The parameters of recommended linear acceleration limits "pelvis-head" (after the preliminary effect of negative linear acceleration "head-pelvis" in z direction in accordance with Fig. E.11, E.12, E.13) for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 3g

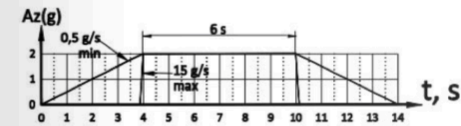


Figure E.10 - The parameters of recommended linear acceleration limits "pelvis-head" (after the preliminary effect of negative linear acceleration "head-pelvis" in z direction in accordance with Fig. E.11, E.12, E.13) for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of 2g

Fig. E.11 – Fig. E.13 show recommended parameters of singular linear acceleration limits “head-pelvis” for the passengers of the amusement rides, placed in the sitting position and restrained in the seat.

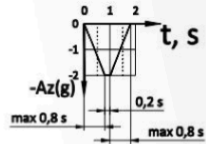


Figure E.11 - The parameters of recommended linear acceleration limits “head-pelvis” for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of $-2g$

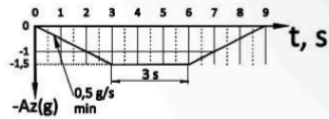


Figure E.12 - The parameters of recommended linear acceleration limits “head-pelvis” for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of $-1.5g$

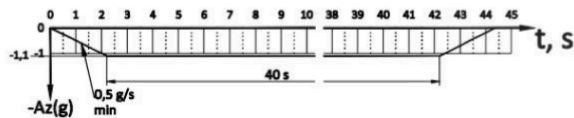


Figure E.13 - The parameters of recommended linear acceleration limits “head-pelvis” for the passengers of the amusement rides, placed in the sitting position and restrained in the seat. Value of $-1.1g$

Accelerations “head-pelvis” are less able to be tolerated than accelerations from other axes.

Acceleration “side-side”

Fig. E.14 - Fig. E.16 show recommended limit parameters of single linear acceleration “side”-“side” for the passengers, placed in the sitting position, under condition of restraining the pelvis and upper body.

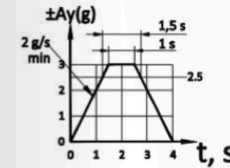


Figure E.14 - The parameters of recommended limit linear acceleration “side”-“side” for the passengers, placed in the sitting position, in condition of supporting the pelvis and upper body. Value of $3g$

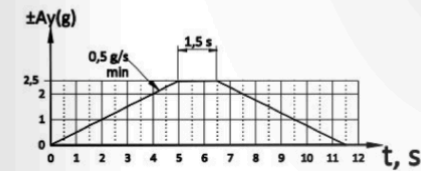


Figure E.15 - The parameters of recommended limit linear acceleration “side”-“side” for the passengers, placed in the sitting position, in condition of supporting the pelvis and upper body. Value of $2.5g$

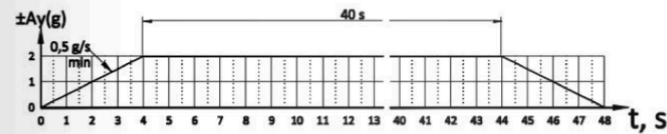


Figure E.16 - The parameters of recommended limit linear accelerations “side”-“side” for the passengers of amusement rides, placed in the sitting position, in condition of supporting the pelvis and upper body. Value of $2g$

Acceleration "back-chest" / "chest-back"

Fig.E.17 – Fig.E.21 show the recommended limit parameters of single linear acceleration "back-chest" for passengers, placed in the sitting position and restrained in the seat.

It is recommended to use headrests where there are accelerations of 1g and over with the duration over 5 sec.

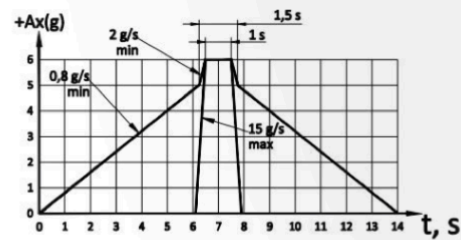


Figure E.17 - Parameters of recommended limit linear accelerations "back-chest" for passengers of amusement rides, placed in the sitting position and restrained in the seat. Value of 6g

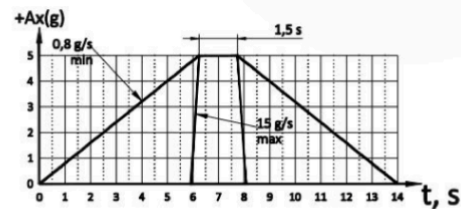


Figure E.18 - Parameters of recommended limit linear accelerations "back-chest" for passengers of amusement rides, placed in the sitting position and restrained in the seat. Value of 5g

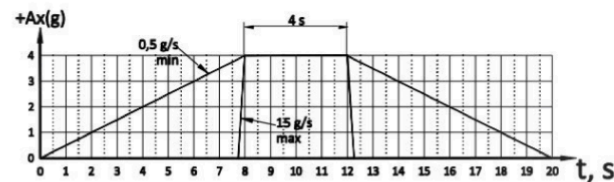


Figure E.19 - Parameters of recommended limit linear accelerations "back-chest" for passengers of amusement rides, placed in the sitting position and restrained in the seat. Value of 4g

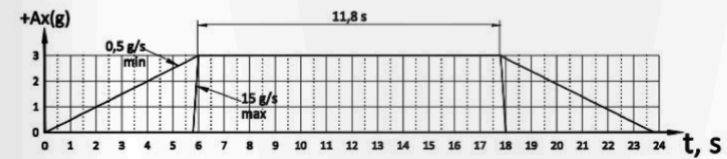


Figure E.20 - Parameters of recommended limit linear accelerations "back-chest" for passengers of amusement rides, placed in the sitting position and restrained in the seat. Value of 3g

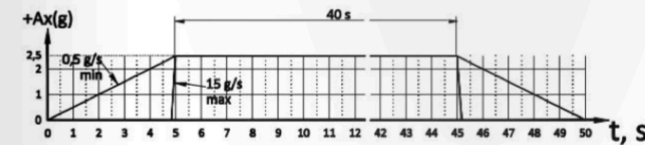


Figure E.21 - Parameters of recommended limit linear accelerations "back-chest" for passengers of amusement rides, placed in the sitting position and restrained in the seat. Value of 2.5g

Fig.E.23 – Fig.E.24 show recommended limit parameters of single linear accelerations "chest-back" for passengers, placed in the sitting position in condition of restraining the pelvis and upper body. In case of placing the passenger in the laying position with using the restraining system and providing the permanence of passenger position under the effect of acceleration "chest-back", accelerations given in the Fig.E.22, Fig.E.25, and Fig.E.26 may be recommended.

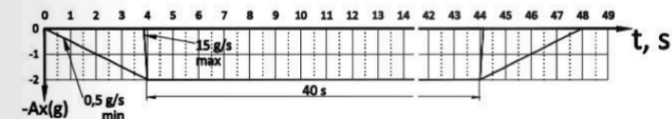


Figure E.22 - Parameters of recommended limit linear accelerations "chest-back" for passengers of the amusement rides, placed in the sitting/laying position under condition of restraint of the pelvis and upper body. Value of -2.0g

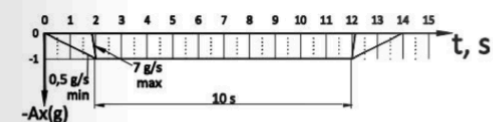


Figure E.23 - Parameters of recommended limit linear accelerations "chest-back" for passengers of the amusement rides, placed in the sitting position under condition of restraint of the pelvis. Value of -1.0g

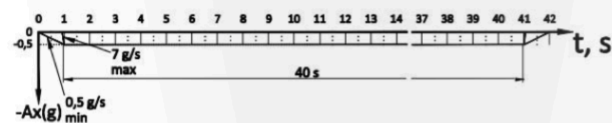


Figure E.24 - Parameters of recommended limit linear accelerations "chest-back" for passengers of the amusement rides, placed in the sitting position under condition of restraint of the pelvis. Value of $-0.5g$

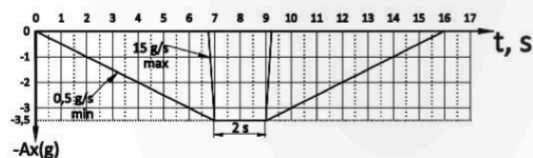


Figure E.25 - Parameters of recommended limit linear accelerations "chest-back" for passengers of the amusement rides, placed in the laying position at using the restraint system, providing the permanence of the passenger position in process of acceleration effect. Value of $-3.5g$

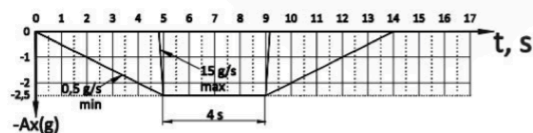


Figure E.26 - Parameters of recommended limit linear accelerations "chest-back" for passengers of the amusement rides, placed in the laying position at using the restraint system, providing the permanence of the passenger position in process of acceleration effect. Value of $-2.5g$

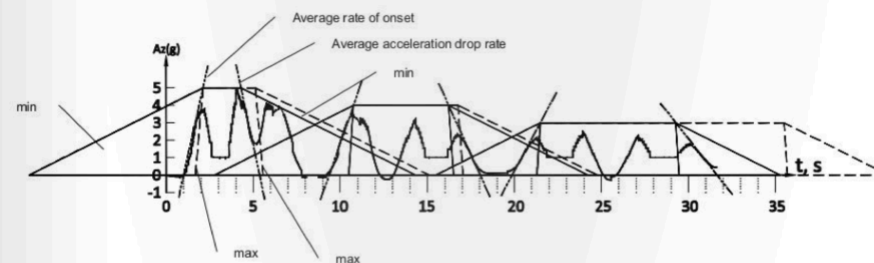


Figure E.27 An example of analysis of linear acceleration diagram for roller coaster

Annex F (informative)

Hazard of passengers being held in an upside down position

Amusement rides where passengers can be held in an upside down position feature risks of blood vessels damage in the brain for people in general and people with weakened blood vessels, people with hypertension or atherosclerosis, or for those in a state of alcohol intoxication.

It is recommended to display information and warning signs on use limitations for people with cardiovascular and neurological diseases or for those under the influence of alcohol with such information to be displayed at the entrance of such amusement rides.

In order to eliminate the risk of brain vessels damage in case of an unexpected stop of an amusement ride with passengers in an upside down position, design or organizational measures should be provided for evacuation of the passengers safely within the shortest possible time.

Evacuation should be carried out beginning with the oldest or obviously most susceptible passengers first.

Amusement rides which feature "head-to-pelvis" accelerations higher than 1.5 g shall be fitted with warning signs (Figure 10) with explanations.



Figure F.1 – Riding upside down

Annex G (informative)

Use of amusement rides considering the state of health or well-being of passengers. Use of warning signs to advise passengers

It is recommended to use amusement rides only for those who feel well. In order to avoid potential incidents when riding, it is advisable that rules, recommendations and advice for use are displayed at the entrance of each amusement ride.

With some health or well-being deviations from the norm amusement rides may cause harm, therefore the designer or the controller of a ride can introduce use limitations for pregnant women, for people with cardiovascular diseases, disorders of a locomotive system and/or neuropsychic disorders.

Dizziness and nausea may be caused by carousels, roundabouts, swings and other amusement rides which feature repeated rotational motion or revolutions, flashing or flickering lights etc. when people have weak vestibular system, exhaustion, or are intoxicated with alcohol or drugs. Appropriate warning signs should be placed to warn the passengers of the potential harms.

Amusement rides on which passengers are exposed to high accelerations may cause injuries to people who have diseases or disorders of a locomotive system, cardiovascular system, pregnant women or to those who are under the influence of alcohol or drugs.

Amusement rides which should not be used due to health conditions or the way a guest feels shall be fitted with appropriate warning signs. It is advisable to display these warnings next to the rules of behaviour for the passengers of an amusement ride.

The ride operator will not always be able to determine the condition of a guest and to prevent him from riding, therefore the relevant warnings displayed at amusement rides lay the responsibility for consequences of using an amusement ride when having health deviations from the norm or in a state of intoxication upon the person himself. The recommended warning signs are shown in Figures 5-9. However, it is possible to use other understandable signage.



Figure 5 – Cardiovascular diseases



Figure 6 – Locomotive system disorders



Figure 7 – Nervous system diseases



Figure 8 – Pregnancy



Figure 9 – Intoxication (under the influence of alcohol, drugs, medicines)

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