



BSI Standards Publication

Safety of amusement rides and amusement devices

Part 1: Design and manufacture

National foreword

This British Standard is the UK implementation of ISO 17842-1:2023. It supersedes BS ISO 17842-1:2015, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/3/4, Fairground and amusement park machinery and structures - Safety.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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2023-09

Safety of amusement rides and amusement devices —

Part 1: Design and manufacture

*Sécurité des manèges et des dispositifs de divertissement —
Partie 1: Conception et fabrication*



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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.

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 document 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).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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

This document was prepared by Technical Committee ISO/TC 254, *Safety of amusement rides and amusement devices*.

This second edition cancels and replaces the first edition (ISO 17842-1:2015), which has been technically revised.

The main changes are as follows:

- the normative references have been updated;
- the terms and definitions have been revised;
- alignment with EN 13814 series from 2019;
- the general risk assessment has been supplemented by the operator-side risk assessment;
- the safety distances of passenger units have been fundamentally revised;
- the requirements for personal restraint systems have been supplemented by additional monitoring;
- new [Annex I](#) contains the acceleration effects on passengers to align with ASTM F2291-21.

A list of all parts in the ISO 17842 series can be found on the ISO website.

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

Safety of amusement rides and amusement devices —

Part 1: Design and manufacture

1 Scope

This document specifies the minimum requirements necessary to ensure the safe design, calculation, manufacture and installation of mobile, temporary or permanently installed amusement ride machinery and structures, which are intended for use by persons as a leisure activity. The amusement rides and amusement devices include for example, roundabouts, swings, boats, Ferris wheels, roller coasters, chutes, booths, side shows and structures for artistic aerial displays. They are intended to be installed both repeatedly without degradation or loss of integrity, and temporarily or permanently in fairgrounds and amusement parks or any other locations.

This document is not applicable to grandstands, construction site installations, scaffolding, removable agricultural structures, simple coin operated children's amusement devices, carrying up to three children, and recreational devices like waterslides or summer toboggan runs, playground equipment, rope courses, climbing wall, inflatable, trampolines, swimming pool equipment, etc.

NOTE For all the equipment not covered by the requirements of ISO 17842-1, the relevant standards apply.

Nevertheless, this document can be used in the design of any similar structural or passenger carrying amusement device not explicitly mentioned herein.

2 Normative references

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

ISO 898-1, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs with specified property classes — Coarse thread and fine pitch thread*

ISO 1141, *Fibre ropes — Polyester — 3-, 4-, 8- and 12-strand ropes*

ISO 1181, *Fibre ropes — Manila and sisal — 3-, 4- and 8-strand ropes*

ISO 1346, *Fibre ropes — Polypropylene split film, monofilament and multifilament (PP2) and polypropylene high-tenacity multifilament (PP3) — 3-, 4-, 8- and 12-strand ropes*

ISO 2307, *Fibre ropes — Determination of certain physical and mechanical properties*

ISO 3834-2, *Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements*

ISO 3834-3, *Quality requirements for fusion welding of metallic materials — Part 3: Standard quality requirements*

ISO 3834-4, *Quality requirements for fusion welding of metallic materials — Part 4: Elementary quality requirements*

ISO 4014, *Fasteners — Hexagon head bolts — Product grades A and B*

ISO 4016, *Fasteners — Hexagon head bolts — Product grade C*

- ISO 4017, *Fasteners — Hexagon head screws — Product grades A and B*
- ISO 4018, *Fasteners — Hexagon head screws — Product grade C*
- ISO 4032, *Fasteners — Hexagon regular nuts (style 1)*
- ISO 4413, *Hydraulic fluid power — General rules and safety requirements for systems and their components*
- ISO 4414, *Pneumatic fluid power — General rules and safety requirements for systems and their components*
- ISO 5817, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*
- ISO 9554, *Fibre ropes — General specifications*
- ISO 9606-1, *Qualification testing of welders — Fusion welding — Part 1: Steels*
- ISO 9606-2, *Qualification test of welders — Fusion welding — Part 2: Aluminium and aluminium alloys*
- ISO 9692-1, *Welding and allied processes — Types of joint preparation — Part 1: Manual metal arc welding, gas-shielded metal arc welding, gas welding, TIG welding and beam welding of steels*
- ISO 9692-2, *Welding and allied processes — Joint preparation — Part 2: Submerged arc welding of steels*
- ISO 9692-3, *Welding and allied processes — Types of joint preparation — Part 3: Metal inert gas welding and tungsten inert gas welding of aluminium and its alloys*
- ISO 10042, *Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections*
- ISO 10325, *Fibre ropes — High modulus polyethylene — 8-strand braided ropes, 12-strand braided ropes and covered ropes*
- ISO 10474:2013, *Steel and steel products — Inspection documents*
- ISO 10547, *Polyester fibre ropes — Double braid construction*
- ISO 10554, *Polyamide fibre ropes — Double braid construction*
- ISO 10556, *Fibre ropes of polyester/polyolefin dual fibres*
- ISO 10572, *Mixed polyolefin fibre ropes*
- ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction*
- ISO 13854:2017, *Safety of machinery — Minimum gaps to avoid crushing of parts of the human body*
- ISO 13849-1, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design*
- ISO 13849-2, *Safety of machinery — Safety-related parts of control systems — Part 2: Validation*
- ISO 13857, *Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs*
- ISO 14118, *Safety of machinery — Prevention of unexpected start-up*
- ISO 14119, *Safety of machinery — Interlocking devices associated with guards — Principles for design and selection*
- ISO 14120, *Safety of machinery — Guards — General requirements for the design and construction of fixed and movable guards*
- ISO 14731, *Welding coordination — Tasks and responsibilities*

ISO 14732, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials*

ISO 17635:2016, *Non-destructive testing of welds — General rules for metallic materials*

ISO 17842-2:2022, *Safety of amusement rides and amusement devices — Part 2: Operation and use*

ISO 17842-3, *Safety of amusement rides and amusement devices — Part 3: Requirements for inspection during design, manufacture, operation and use*

IEC 60204-1:2005, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*

IEC 60204-32, *Safety of machinery — Electrical equipment of machines — Part 32: Requirements for hoisting machines*

IEC 60364-4-41, *Low-voltage electrical installations — Part 4-41: Protection for safety — Protection against electric shock*

IEC 60364-5-54, *Electrical Installation of buildings — Part 5-54: Selection and erection of electrical equipment — Earthing arrangements, protective conductors and protective bonding conductors*

IEC 60364-7-740, *Electrical Installation of buildings — Part 7-740: Requirements for special installations or locations — Temporary electrical installations for structures, amusement devices and booths at fairgrounds, amusement parks and circuses*

IEC 61558-1, *Safety of power transformers, power supplies, reactors and similar products — Part 1: General requirements and tests*

IEC 61800-5-2, *Adjustable speed electrical power drive systems — Part 5-2: Safety requirements — Functional*

IEC 62061, *Safety of machinery — Functional safety of safety-related electrical, electronic and programmable electronic control systems*

IEC 62305 (all parts), *Protection against lightning*

EN 818 (all parts), *Short link chain for lifting purposes — Safety*

EN 1069-1+A1, *Water slides — Part 1: Safety requirements and test methods*

EN 1090-2, *Execution of steel structures and aluminium structures — Part 2: Technical requirements for steel structures*

EN 1090-3, *Execution of steel structures and aluminium structures — Part 3: Technical requirements for aluminium structures*

EN 1090-3:2008, *Execution of steel structures and aluminium structures — Part 3: Technical requirements for aluminium structures*

EN 1261, *Fibre ropes for general service — Hemp*

EN 1677 (all parts), *Components for slings — Safety*

EN 1993-1-1, *Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings*

EN 1993-1-8, *Eurocode 3: Design of steel structures — Part 1-8: Design of joints*

EN 1993-1-9:2005, *Eurocode 3: Design of steel structures — Part 1-9: Fatigue*

EN 1999-1-1, *Eurocode 9: Design of aluminium structures — Part 1-1: General structural rules*

EN 12195-2, *Load restraint assemblies on road vehicles — Safety — Part 2: Web lashing made from man-made fibres*

EN 12385 (all parts), *Steel wire ropes — Safety*

EN 13411 (all parts), *Terminations for steel wire ropes — Safety*

EN 13889+A1, *Forged steel shackles for general lifting purposes — Dee shackles and bow shackles — Grade 6 — Safety*

EN 14399 (all parts), *High-strength structural bolting assemblies for preloading*

EN 50172, *Emergency escape lighting systems*

3 Terms and definitions

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

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1
amusement device
arrangement of equipment that produces the desired effect of amusement or entertainment when the *patron* (3.26) moves through it or on it primarily by his or her own action, or any other system that is not covered by the term *amusement ride* (3.2)

Note 1 to entry: In this document, the term “amusement device” is used to refer to an amusement device or *amusement ride* (3.2).

3.2
amusement ride
device that is designed to entertain the *passengers* (3.26) during motion including the consequence of biomechanical effect

Note 1 to entry: In this document, the term “amusement device” is used to refer to an *amusement device* (3.1) or amusement ride.

Note 2 to entry: See ISO/TS 17929 for the definition of biomechanical effect.

3.3
attendant
competent person (3.6) appointed to work under the supervision of an *operator* (3.25), to assist in the operation of a device available for use by the public

3.4
barrier
device intended to prevent the user from falling and from passing beneath a barrier

Note 1 to entry: A barrier can also be used as a fence.

3.5
closed restraint
restraint in a position in which the *restraint* (3.35) is intended to remain during the operation of the amusement device in order to restrain the *passenger* (3.26)

3.6
competent person
person who can demonstrate the knowledge and skills acquired through training, qualifications or experience, or a combination of all, enabling that person to perform a specified task

3.7**controller**

person or organisation having overall control of an *amusement device* (3.1)

Note 1 to entry: This may be either an individual or corporate body owning an *amusement device* (3.1) or the concessionaire or lessee who has been granted control of the amusement device, by the owner, for a specified period.

3.8**design review**

document detailing the review of all the applicable design documents to determine the suitability for use of an *amusement device* (3.1)

3.9**design risk assessment****DRA**

document produced by the *designer* (3.10) as a tool to ensure a safe design within the agreed scope of supply

3.10**designer****engineer**

person or body responsible for the design of an *amusement device* (3.1) (or modifications thereof), including, but not limited to, establishing and describing the configuration of the *amusement ride* (3.2) or *amusement device* (3.1), conducting appropriate risk assessment(s), establishing strength (including fatigue strength), designing and specifying electrical/electronic control systems, defining the acceptable quality level for production, defining inspection criteria and including the provision of the necessary documentation

3.11**amusement device log**

book and/or electronic data file containing all the necessary information about the use and history of any *amusement device* (3.1)

3.12**fail safe**

characteristic of a system, component or device the failure of which maintains a safe state

3.13**fence**

structure designed to restrict or prevent movement across a boundary without change of elevation

3.14**gate**

section of *fence* (3.13) or *barrier* (3.4) that can be opened to provide access or egress

3.15**guardrail**

rail intended to prevent a user from falling

3.16**guest**

person who interacts with an *amusement device* (3.1)

3.17**handrail**

rail intended to assist the user to balance

3.18

initial approval

design and calculation review process, including verification, examinations and tests executed by the inspecting body before an *amusement ride* (3.2) is first made available for public use

3.19

latching restraint

restraint (3.35) which is held secure against opening except by intentional action of the *passenger* (3.26) or the *operator* (3.25)

Note 1 to entry: This can include *restraints* (3.35) (e.g. drop bars) held in place by gravity, detents or other means.

3.20

locking restraint

restraint (3.35) which is held secure against opening except by intentional action of the *operator* (3.25) or other means not accessible by the *passenger* (3.26)

3.21

machinery component

component which forms part of an assembly in which at least one component moves (excluding vibration and deformation)

3.22

major modification

safety-related alteration to the hardware or software of an *amusement device* (3.1), including the introduction of a new *safety-related component* (3.39) or the substitution of a *safety-related component* (3.39), which results in a deviation from the current design specification

3.23

manufacturer

individual or commercial entity responsible for a product with the view to placing it on the market under his/her own name

Note 1 to entry: Any commercial operator that either places a product on the market under his/her own name or trademark or modifies a product in such a way that conformity with applicable requirements is affected, should be considered as the manufacturer and should assume the obligations of the manufacturer.

3.24

operation and use risk assessment

OURA

document produced by the *controller* (3.7) that details all of the considered risks inherent during all modes of *amusement device* (3.1) operation and the means taken to mitigate against them

Note 1 to entry: This term is explained in detail in 5.1.2.2.

3.25

operator

competent person appointed by the *controller* (3.7) to be in charge of the operation of an *amusement device* (3.1) when it is available to the public

3.26

passenger

patron

person using an *amusement device* (3.1)

3.27

passenger containment

components (e.g. seating, foot wells, handrails, passenger restraints) designed to prevent *passengers* (3.26) from moving outside a predetermined area on a ride either as a result of biomechanical effects, the ride forces or the reasonably foreseeable behaviour of the *passenger* (3.26)

3.28**passenger reach envelope**
reach envelope

physical space around a *passenger* (3.26) during a ride cycle while properly positioned, as defined by the ride analysis, in the *amusement ride* (3.2) or *amusement device* (3.1) and limited only by the vehicle, seat geometry and restraint system

3.29**passenger unit**
PU

part or parts of an *amusement ride* (3.2) in or on which the *passengers* (3.26) are intended to ride

3.30**permit**

authorization to operate an *amusement device* (3.1) in a particular state granted by the legally authorized body after successful approval and/or examination

3.31**platform**

horizontal or slightly inclined surface raised above the level of an adjacent area

3.32**reasonably foreseeable misuse**

use of an *amusement device* (3.1) in a way not intended by the *designer* (3.10), but which can result from readily predictable human behaviour

Note 1 to entry: [Annex F](#) gives a non-exhaustive list of guest behaviour.

[SOURCE: ISO 12100:2010, 3.24, modified — "machine" has been replaced with "amusement device", Note 1 to entry has been added.]

3.33**redundancy**

application of more than one device or system, or part of a device or system, with the objective of ensuring that in the event of one failing to perform its function, another will perform that function

3.34**repair**

restoration of components or assemblies to a technically acceptable condition

Note 1 to entry: See also ISO 17842-2:2022, 4.3.8.3.

3.35**restraint**

system, device, or characteristic that is intended to inhibit or restrict the body movement and/or maintain the body position to allow the *passenger* (3.26) to tolerate accelerations while on the *amusement ride* (3.2) or *amusement device* (3.1)

3.36**safe stop**

stop of an *amusement ride* (3.2) in a safe way and in a final safe stable position

3.37**safety envelope**
clearance envelope

area in which *passengers* (3.26) are prevented from being injured while moving in an *amusement ride* (3.2) or *amusement device* (3.1)

Note 1 to entry: This is the *passenger reach envelope* (3.28) plus a suitable margin as defined in [Annex H](#).

3.38

safety-related control system

SRCS

assembly of components that can be electronic, electric, electro-mechanical, hydraulic, pneumatic or mechanical combined to monitor and control a device so as to reduce risks to *guests* (3.15)

3.39

safety-related component

component of an *amusement device* (3.1) on which the safety of the *passengers* (3.26) is dependent as identified in the *design risk assessment* (3.9) and/or the *operation and use risk assessment* (3.24)

3.40

service

replacement or replenishment and check of conditions of components, including fluids which are designated to be replaced or replenished and/or checked at specified intervals

3.41

sideshow

booth or similar enclosed structure containing shows, activities or games for the entertainment of the public, where the *guest* (3.15) is not transported in any way by the structure

3.42

spectator

person in the vicinity of an *amusement device* (3.1), either watching the operation of the *amusement device* (3.1) or waiting to access to the use the *amusement device* (3.1)

3.43

structural component

calculated load bearing part which has not been classified as *machinery components* (3.21) by the *designer* (3.10)

3.44

sustained acceleration

acceleration with duration greater than or equal to 200 ms

Note 1 to entry: See [Annex I](#).

3.45

temporarily installed amusement device

amusement device (3.1) designed to be installed and uninstalled and whose installation period does not exceed more than three months

3.46

thorough examination

procedures and investigations necessary for the inspection body to decide whether the *amusement device* (3.1) can continue to be operated safely or whether it requires defects to be remedied immediately or within a specified time

3.47

trial run

proving run of an *amusement device* (3.1) during which no *passengers* (3.26) are carried

4 Requirements for design analysis and examination

4.1 Design documents

4.1.1 General

The construction documents include all the documents required for the assessment of the stability and operational safety of the device, including the Design Risk assessment (DRA). They shall be available for any subsequent approval by the inspection bodies. These documents shall encompass all the design conditions pertaining to the operation of the amusement devices or structures. A description of the construction, operation and operational safety, design drawings and a comprehensive stress, fatigue and stability analysis as specified in [5.1.4](#) are required for this purpose.

4.1.2 Design risk assessment

See [5.1.2.1](#).

4.1.3 Description of design and operation of an amusement device

The amusement device, in particular its design, modes of operation and its structure shall be explained in this description. Adequate details of mechanical (hydraulic, pneumatic), electrical and electronic equipment, including the control system shall be listed. The description shall include details of the particular features of the device and of any alternative modes of installation which may exist. Also details of the main dimension and of motion spaces extending beyond these dimensions, limitations, design particulars and materials, motion systems, types of drive, velocities, accelerations, electrical equipment, work cycle and operating sequence and of any restrictions regarding the circle of users which may exist, shall be described.

4.1.4 Design and manufacturing drawings

Design and manufacturing drawings are required for all assemblies, subassemblies and individual components, the fracture or failure of which can endanger the stability or operational safety of the amusement device. The drawings shall feature all the dimensions and cross-section values required for testing and approval, including details of materials, structural components, fasteners, connectors, and also relevant velocities.

The drawings shall include as a minimum, as applicable:

- general drawings in plan view, elevation and sections, in a legible scale, depending on the size of the device; indication of the necessary clearance around the moving parts;
- detail drawings showing all the structural subassemblies which are not clearly discernible on the general drawings, as well as detail drawings of connections and individual items of a structural, mechanical or electrical nature, which can affect the safety of the amusement device and its operation, shall be drawn to a larger scale. Illustrations of the following items may be necessary for this purpose:
 - slewing gear, hoisting and swivelling mechanisms, including their support arrangements, drives and controls, lifting and swivelling ranges;
 - carriages, gondolas and similar, illustrated in all the required views and cross sections, with details of the overall dimensions, the internal dimensions of importance to the passengers (seats, side and back rests, leg and foot room), hand and foot holds and locking and securing devices;
 - motion gear with details of load, guide, and upstop wheels, bearings, axles, shafts and their attachment, freedom of movement in relation to the vehicle, steering and control, anti-rollback

devices, safety devices against derailment and overturning, buffers, trailer devices, protection devices, drives and brakes and anchoring to the foundation;

- pneumatic and hydraulic circuits, and electrical and electronic wiring diagrams.

4.1.5 Principles of analysis

All calculated load bearing parts can be classified as either structural components or machinery components.

The designer shall formalize the classification of all calculated load bearing parts before beginning the analysis.

All design calculations for a particular component shall be consistent with a defined design base standard. The respective manufacturing requirements of design standards shall be taken into account.

This classification guides the designer towards the appropriate analysis methods which can be used.

Verification shall comprise the following:

- ultimate limit states analysis;
- fatigue limit states analysis;
- stability limit states analysis: i.e. bar buckling, plate, shell and torsional buckling;
- if required, verification of deformation limit states;
- verification of safety against overturning, sliding and lifting off;
- dynamic analysis (excluding seismic analysis).

The afore-mentioned verifications shall include at least the following details:

- design loads, taking into account the possible operating conditions or alternative installations. In the case of moving parts, the velocity or the rotational speed and acceleration shall be stated. Special loads imposed during erection (e.g. parts walked on which are not designed for that purpose) should be specified and separately listed;
- main dimensions and cross-section values of all load bearing structural components and details relating to the assessment of the fatigue strength;
- details of materials and components;
- determination of the most unfavourable (maximum/minimum stress and stress range) stresses and details relating to the strength of the load bearing structural components and fasteners. If calculation seems insufficient to evaluate limit states of assemblies, the analysis may be replaced by testing to the relevant testing standard. The testing laboratory shall conduct the appropriate number of tests, prepare samples, the testing procedure, the reporting according to the relevant European Standards or in absence of those to equivalent national standards;
- details of elastic deformations (flexure, torsion), when such details affect the stability or operating safety of the device;
- details of those structural components which require special examination and inspection in accordance with [4.7](#).

4.2 Selection of materials

4.2.1 General

Only materials in respect of which design data are featured in international and/or national standards may be used.

Unless other materials have been established and proven for their serviceability, the designer shall give special consideration to structural joints which are to be welded and the weldability of the selected metals.

4.2.2 Recommended steels

4.2.2.1 General

Steel grades for which standardized technological material data (mechanical and chemical properties) are featured may be used.

4.2.2.2 Steels for structural components

Steels used for structural components should be in accordance with EN 10025.

Minimum values are:

Yield:	$R_{eH} = 235 \text{ MPa}$
Ultimate:	$R_m = 350 \text{ MPa}$
Notch impact energy:	$K = 27 \text{ J at } T = +20 \text{ C, Charpy V specimen}$

Depending on the loads (impact and fatigue), the temperature and the thickness, the notch impact energy will possibly need to be increased, e.g. $K = 27 \text{ J at } T = -20 \text{ C, Charpy V specimen}$.

Other steel grades for which technological material data (mechanical and chemical properties) is available may also be used.

4.2.2.3 Steels for machinery and mechanisms

The steels shall comply with available technological material data (mechanical and chemical properties) or guidelines, which meet the design requirements.

4.2.3 Aluminium alloys

Aluminium alloys shall be selected in accordance with international and/or national standards and internationally accepted guidelines.

EN 1999-1-1 can be suitable.

Aluminium alloys with an elongation (rupture) of $\varepsilon < 8 \%$ should be avoided for dynamically loaded structures.

4.2.4 Timber

Selection of timber shall be in accordance with international and/or national standards or internationally accepted guidelines.

EN 1995-1-1 can be suitable.

4.2.5 Plastic composites

Plastic composites for which technological material data (mechanical and chemical properties) are featured and the use can be approved in a traceable way may also be used.

4.2.6 Concrete

The selection of concrete grade shall be in accordance with international and/or national standards.
EN 1992-1-1 can be suitable.

4.2.7 Fasteners for structural components

Bolts, screws and studs shall be in accordance with ISO 898-1 and EN 14399.

Property class 12.9 shall not be used.

For machinery and mechanisms, other bolts according to appropriate international and/or national standards can be used.

Rivets and blind rivets can be used when their capacity for the assigned purpose is experimentally proven in accordance with EN 1993-1-8 and [4.1.5](#).

4.2.8 Standards relating to ropes, chains, safety devices, connectors and adapters

4.2.8.1 General

In addition to the calculation of the load-bearing capacity of materials or accessories, which relate directly to the safety of passengers or public, certificates, manufacturer's markings or testing results shall also be provided.

When ropes, chains, safety devices, connectors and adapters are used, the following standards in particular shall be referred to.

4.2.8.2 Steel ropes

Steel wire ropes: EN 12385.

Termination for steel wire ropes — Safety: EN 13411.

Clamps for wire ropes: EN 13411.

Components for slings: EN 1677 (all parts).

Shackles: EN 13889.

4.2.8.3 Fibre ropes

Fibre ropes for general service — Determination of certain physical and mechanical properties: ISO 2307.

Fibre ropes for general service — General specifications: ISO 9554.

4.2.8.3.1 Synthetic fibre ropes

Polyamide fibre ropes. Double braid construction: ISO 10554.

Polyester fibre ropes. Double braid construction: ISO 10547.

Polyester 3- 4- and 8-strand ropes: ISO 1141.

Fibre ropes of polyester/polyolefin dual fibres: ISO 10556.

Mixed polyolefin fibre ropes: ISO 10572.

Fibre ropes — Polypropylene split film, monofilament and multifilament and polypropylene high tenacity 3-, 4- and 8-strand ropes: ISO 1346.

Fibre ropes — High modulus polyethylene. 8-strand braided ropes, 12-strand braided ropes and covered ropes: ISO 10325.

4.2.8.3.2 Natural fibre ropes

Fibre ropes. Manila and sisal. 3-, 4- and 8-strand ropes: ISO 1181.

Fibre ropes for general service — Hemp: EN 1261.

4.2.8.4 Chains

Short link chain for lifting purposes — Safety: EN 818.

4.3 Design loads

4.3.1 General

In general actions, load, design as well as any structural assumptions for load bearing parts of devices shall be chosen in the following sequence:

- a) according to the provisions of this document;
- b) to an official national standard of the country of use of the device, only if superseding local conditions (e.g. wind, seismic) require it.

The following prevailing detailed rules, adjustments and considerations in relation to building and structural standards, shall be used in all general applications, due to the special nature of amusement rides and devices.

4.3.2 Permanent actions

For amusement rides and devices the load assumption for permanent actions shall be determined.

Where variations can occur, the values $G_{k,sup}$ and $G_{k,inf}$ shall be taken into account when assessing the most probable structural response. Elsewhere a single characteristic value G_k is sufficient. The values are defined as follows:

G_k	characteristic value of permanent action;
$G_{k,sup}$	upper characteristic value;
$G_{k,inf}$	lower characteristic value.

The actual dead load of the load bearing structure, the accessories and the technical equipment required for the operation, including cladding, fabrics and other decorative elements are included in the above values. The wet and dry condition of material is accounted for in $G_{k,sup}$ and $G_{k,inf}$.

The actual weight of machine components, electrical equipment, and passenger units like carriages or gondolas shall be verified.

4.3.3 Variable actions

4.3.3.1 Imposed loads

4.3.3.1.1 General

Imposed loads consist of the external loads and imposed deformations (e.g. imposed loads, gyroscopic loads, dynamic loads, wind and snow loads, temperature or settlement) acting on a structural component, which can vary in magnitude, direction and point of application (variation in time and space) during normal operation.

4.3.3.1.2 Vertically imposed loads

4.3.3.1.2.1 Passenger-carrying units

On passenger-carrying units (vehicles, cars, gondolas), the following loads shall be assumed.

Vertically imposed loads (Q_k) for each person over 10 years of age:

- where Q_k is 0,75 kN for all fatigue calculations;
- where Q_k is 0,75 kN for static calculations for more than four passengers per compartment;
- where Q_k is $1,35 \text{ kN} - (n - 1) \times 0,15 \text{ kN}$ where $1 \leq n \leq 4$ for static calculation only and the load transferring members from the seat into centre assemblies for individually supported or suspended seats with $n = 1$ to 4 passengers per single compartment.

These static loads are not an operational and general weight limit or requirement and shall not be used for overall calculations (e.g. sliding, overturning) of the compartment or ride itself.

The above-mentioned values of load assumptions shall be corrected when using special compartments for larger persons.

NOTE 1 The designer can consider higher weight depending on the seat configuration and type of ride.

For each person of 10 years or less:

$Q_k = 0,40 \text{ kN}$ in both fatigue and static cases.

Where the reduced loadings for a person of 10 years or less are used, the restrictions shall be clearly indicated at the ride and in the manual.

4.3.3.1.2.2 Other vertical loads

The following vertical imposed loads (where q_k is an area load) shall be applied for any area designed for access by foot.

Open to public access:

$q_k = 3,5 \text{ kN/m}^2$	for floors, stairways, landings, ramps, entrances, exits and other similar features in rides and facilities;
$q_k = 5,0 \text{ kN/m}^2$	for grandstands and their stairways and landings with fixed seats; and a superior value, if particularly dense crowds are anticipated for the above-mentioned categories;
$q_k = 7,5 \text{ kN/m}^2$	for grandstands and their stairways and landings without seats or non-fixed seats; and a superior value, if particularly dense crowds are anticipated for the above-mentioned categories;

$q_k = 2,0 \text{ kN/m}^2$	for the revolving or boom area walked on by the public during operation (load and unload); or twice the full passenger load of all passenger units and carriages according to 4.3.3.1.2.1 , whichever is the more unfavourable, in order to make the necessary allowance for change of passengers;
$Q_k = 1,0 \text{ kN/step}$	for stairs; alternatively, an area load as listed above, whichever is the more unfavourable;
$q_k = 1,5 \text{ kN/m}^2$	for seat boards of rows of seats per seat run and for floors between fixed rows of seats, unless higher loads result from the application of area loads ($q_k = 3,5 \text{ kN/m}^2$).

Not open to public access:

$q_k = 1,5 \text{ kN/m}^2$	for all floors, platforms, ramps, staircases, catwalks, stages and other areas which are walked over by individual person, or
$Q_k = 1,5 \text{ kN}$	for individual loads,

whichever is the more unfavourable.

4.3.3.1.2.3 Horizontal imposed loads

The following horizontal imposed loads shall be applied for:

- for raised platforms designed for access by foot, use 10 % of vertical imposed loads as stated in [4.3.3.1.2.2](#);
- barriers, parapets, fences, railings, wall panels, and other similar features.

When bounding floors intended for public access designed for $q_k = 3,5 \text{ kN/m}^2$:

$p_k = 0,5 \text{ kN/m}$	at hand rail height;
$p_k = 0,1 \text{ kN/m}$	at intermediate rail height.

When bounding floors intended for public access designed for $q_k = 5,0 \text{ kN/m}^2$ and $q_k = 7,5 \text{ kN/m}^2$:

$p_k = 1 \text{ kN/m}$	at hand rail height;
$p_k = 0,15 \text{ kN/m}$	at intermediate rail height.

When bounding floors not intended for public access designed for $q_k = 1,50 \text{ kN/m}^2$:

$p_k = 0,30 \text{ kN/m}$	at hand rail height;
$p_k = 0,10 \text{ kN/m}$	at intermediate rail height.

For wall panels where there is no special handrail, the above values shall be applied at handrail height, but, where appropriate, not higher than 1,2 m.

4.3.3.2 Driving forces and braking forces

Driving forces and braking forces shall be calculated for the drive and brake selected (e.g. d.c. motor, three-phase a.c. motor, hydraulic drive), and they shall be used in the calculation. In the case of hydraulic cylinders, the influences arising from start-up and braking shall be kept within manageable limits by suitable design measures, and shall be taken into account in the calculation.

In general, the braking and starting forces, B , shall be calculated according to the actual brake and motor performance (acceleration/deceleration):

$$B = a_b \times (m_v + m_p) \quad (1)$$

where

a_b is the braking/starting acceleration;

m_v is the mass of moving parts without passengers;

m_p is the total mass of passengers according to [4.3.3.1.2.1](#).

In the case of circular movements, the appropriate parameters shall be applied in [Formula \(1\)](#). Care needs to be taken to allow for speed reduction units (e.g. transmissions, gearboxes). An eventual impact factor shall be taken into account (see [4.3.5.2](#)).

In the case of speeds not exceeding 3 m/s, the driving forces and braking forces can be derived with $a_b = 0,7 \text{ m/s}^2$, if a more precise evaluation is not carried out.

Emergency stop (E-Stop) is a static load case.

4.3.3.3 Bracing and restraint loads

Bracing and restraint loads shall be taken into account when designing passenger restraints and containment, handrail or guardrail and bracing devices the passenger unit. All significant situations during the ride cycle including loading, unloading and emergency situations shall be considered. Allowance shall also be made for the forces caused by passengers bracing themselves against restraints and other parts of the containment (e.g. footrests). The magnitudes of maximum bracing forces are dependent upon the detailed design of the containment and as a result of passenger's deliberate actions. However, forces used in any calculations should never be less than 500 N per person.

4.3.3.4 Wind loads

4.3.3.4.1 General

In general, standards for wind actions on buildings and structures shall be chosen in the following sequence:

- a) according to the provisions of this document;
- b) to an official national standard of the country of use of the device, only if superseding local conditions (e.g. wind, seismic) require it.

NOTE Dynamic effects due to wind can occur on flexible structures.

4.3.3.4.2 Wind loads out of service

The wind loads for permanently installed amusement devices shall be taken from the local wind code.

EN 1991-1-4 can be applied.

The wind loads (out of service) for temporarily installed amusement devices may be reduced by applying the following factor on the basic wind speed:

— $c_{\text{prob}} = 0,85$ if the installation period is shorter than three months.

Additional shelter and/or strengthening means may be specified by the designer. In this case, the designer shall provide detailed shelter and/or strengthening procedures and corresponding wind speeds.

4.3.3.4.3 Wind loads in service

The wind loads for permanently installed amusement devices in operating state (in service) shall be taken from the local wind code, considering a basic 10 min wind speed of $v_{b,0} = 15$ m/s and a gust wind speed (3 s gust) of 21 m/s, measured at a height of 10 m.

For temporarily installed rides, [Table 1](#) shall be applied:

Table 1 — Gust wind speeds and pressures for temporarily installed rides

<i>H</i> (height) m	<i>q</i> velocity pressure kN/m ²	<i>V</i> wind speed m/s
0 < 8	0,20	17,89
8 < 20	0,30	21,9
20 < 35	0,35	23,7
35 < 50	0,40	25,3

The wind load area from the imposed load (e.g. the passengers' envelope) shall be taken into account in the calculation.

4.3.3.5 Snow loads

Snow loads shall be applied in accordance with an official national standard of the country or international standards.

Snow loads shall not be taken into account for amusement devices if they are:

- installed in areas where there is no likelihood of snow or operated at a time of the year where the likelihood of snow can be discounted;
- designed and operated so that snow settling on the device is prevented;
- operated while adopting preventative action which stops snow from settling on the device.

This last condition can be achieved if all of the following conditions are met:

- sufficient heating equipment is installed and is ready for use;
- the heating is started prior to snow fall;
- the device is heated in such a way, that the roof cladding has an external surface temperature of not less than +2 °C on all parts.

A reduced snow load of 0,2 kN/m² can be applied for devices on the overall roof area, where a snow depth not exceeding $h = 8$ cm can be ensured at any time by removing snow.

The above restrictions concerning snow loads shall be stated in the device log.

4.3.3.6 Inertia forces (centrifugal forces, gyroscopic forces and Coriolis forces)

Inertia forces shall be determined according to the prevailing circumstances in each case.

4.3.3.7 Intentional collision during operation

The effects of collision loads shall only be taken into consideration in respect of the structural components directly affected and their associated fixings.

Collision shall be assumed to occur at the most unfavourable point of the structural component concerned, and the calculation shall be based on the mass of the fully occupied vehicle, m_{tot} , except

when intentional collision only can occur with empty vehicles. If collision can only occur at angles $\alpha \leq 90^\circ$, the collision force F (in Newtons) shall be assumed to be

$$F = 9,81 \times m_{\text{tot}} \times \sin \alpha \quad (2)$$

where

m_{tot} is the mass of the fully occupied vehicle, in kg;

α is the angle between the vehicle and the structure.

But in any case, the value for the calculation shall be not less than

$$F = 9,81 \times m_{\text{tot}} \times 0,3 \quad (3)$$

Alternatively, a dynamic analysis can be performed.

Where collision is not intended to be part of the ride design or purpose, collision shall be assumed to be an accidental action (see [4.3.6.3](#)).

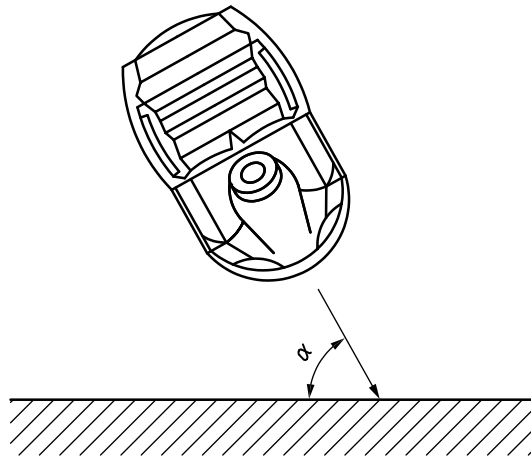


Figure 1 — Angle of collision (α)

4.3.4 Seismic forces

Seismic forces shall only be considered by special requests; they shall not be combined with wind load cases.

The need to consider seismic forces shall be documented in the DRA.

Seismic forces shall be applied in accordance with an official national standard of the country or international standards.

4.3.5 Applicable coefficients

4.3.5.1 General

Moving and/or varying loads induced by track bound passenger units for example, may amplify the stresses of directly loaded structural parts. Therefore, load amplifying factors/coefficients for individual or combined impact and vibrating effects shall be considered.

4.3.5.2 Impacts

If impact forces are likely to arise in the structure or their individual parts during the travel motion (for example from the rail joints or from abrasive wear), then the moving loads under consideration (dead load and imposed load) shall be multiplied by an impact factor of not less than

$$\varphi_1 = 1,2$$

unless the type of structure demands an even higher value. If substantially greater impact forces (e.g. due to rail joints) are ascertained during trial runs on the completed structures, and if these impact forces cannot be reduced to their design value by construction, then the impact factor shall be increased accordingly in a revised calculation.

Forces arising from start-up and braking, e.g. in the case of hydraulic cylinders, are not considered to be impact forces (but normal imposed loads); see also [4.3.3.2](#) in this respect.

4.3.5.3 Vibration of structural track components

In general, as a result of the vibration response of structural track components, e.g. the track of a roller coaster, all resultant stresses shall be multiplied by the vibration coefficient $\varphi_2 = 1,2$.

If proof can be provided, a lower coefficient, $1,0 \leq \varphi_2 \leq 1,2$, may be adopted. The following items may be calculated without taking into account the vibration coefficient:

- supports or suspensions of the structural components directly travelled over;
- ground pressures;
- settling;
- stability and resistance to sliding.

Additional structural measures for certain structures can be required in order to reduce or attenuate inadmissible vibrations (e.g. resonance).

4.3.5.4 Combined impact and vibration factors

One coefficient for combination impact and vibration effects can be used in the special case when both effects do not occur at the same time and location. The internal member forces or stresses of all directly loaded structural parts shall be multiplied by a combined impact-vibration factors of not less

$$\varphi_{1\&2} = 1,2$$

(e.g. rail tracks).

If the impact influence is known to be greater than 1,2, the individual impact factors φ_1 shall be applied with the realistic value.

4.3.6 Load combinations

4.3.6.1 General

The assessment of limit states for amusement devices shall be made using the following combinations and partial safety factors.

4.3.6.2 Fundamental combinations

The design values of the actions shall be combined according to [Formulae \(4\)](#) and [\(5\)](#):

$$\sum \gamma_G G_k = \sum 1,35 \cdot G_k \quad (4)$$

$$\sum \gamma_G G_k + \sum \gamma_Q Q_{k,i} = \sum 1,1 \cdot G_k + \sum 1,35 \cdot Q_{k,i} \quad (5)$$

Both cases shall be checked,

where

- $\gamma_G = 1,35$ is the partial safety factor for permanent actions only (no variable actions);
- $\gamma_G = 1,10$ is the partial safety factor for permanent actions together with one or more variable actions;
- $\gamma_G = 0,90$ is the partial safety factor for favourably acting permanent actions;
- $\gamma_Q = 1,35$ is the partial safety factor for variable actions;
- G_k is the characteristic value of permanent actions;
- $Q_{k,i}$ is the characteristic value of the variable actions.

The permanent actions shall be taken into account with a superior and an inferior value, if the permanent action is variable.

4.3.6.3 Accidental combination

$$1,0 \cdot G_k + A_d + \sum 1,0 \cdot Q_{k,i} \quad (6)$$

where

- $Q_{k,i}$ is the characteristic value of the variable actions;
- A_d is the design value of the accidental actions.

Accidental actions (e.g. seismic forces) only need to be considered by special requests. In such cases, [Formula \(7\)](#) shall be applied.

4.3.7 Fatigue combinations

Each partial stress range contributing to a complete design stress spectrum of the respective individual part to be dimensioned shall be introduced in the verification by a partial safety factor for fatigues actions

$$\gamma_{Ff} \geq 1,00$$

No combination factors shall be applied.

4.4 Structural analysis — Principles

4.4.1 General

The structural analysis shall prove that the limit states shall never be reached due to any individual and combined action given in [4.3](#). The limit states are defined by the design resistances.

It shall be verified that the design value of internal forces or moments does not exceed the corresponding design resistance of the respective part and that the ultimate and serviceability limit states are not exceeded. For tests, see [4.1.5](#). Special consideration shall be given to the limit state verification regarding deformation and stability for structures, where the deformation limit can be a decisive value. Any favourable effect using the methods of the theory of the 2nd order (non-linear calculation of the system on the deformed system) may be taken into account.

All verifications shall be performed for the most unfavourable loading. In this respect, the permanent, variable and accidental actions, as well as the dynamic (inertia) forces, shall always be assumed to have the position and magnitude which result in the most unfavourable limit states for the structural and mechanical components to be analysed. For structural, mechanical components and items of equipment which are not permanent fixtures, it shall also be ascertained as to whether more unfavourable conditions are likely to arise when such items are displaced or removed.

Non-standard formulae shall be recorded in writing with the symbols. The sources of such formulae shall be stated if these sources are publicly available. In other cases, the derivations of the formulae shall be presented to such an extent that their validity can be verified.

If computer processing for calculation is used, special consideration shall be given to the requirements for the review of computer calculations during the design approval. Clear information concerning for example the software, formulae and units shall be submitted. Input and output data of importance for design shall be printed in their entirety. The review of such calculations shall be performed by independent parallel calculations and/or independent software. The correctness of the assumptions regarding the input and the output data shall be comprehensively reviewed during design approval.

Design resistance, R_d , shall be evaluated according to [Formula \(7\)](#).

$$R_d = \frac{R_k}{\gamma_M} \quad (7)$$

where

R_k	is the characteristic value of the resistance (e.g. material property);
$\gamma_M = 1,10$	is the partial safety factor of the resistance in static load combinations (e.g. material property);
γ_{Mf}	is the partial safety factor of the resistance in fatigue load combinations (see Table 5 , e.g. material property);
$\gamma_{Ma} = 1,00$	is the partial safety factor of the resistance (e.g. material property) in accidental combinations.

For materials other than steel the values for the available γ_M shall be used.

4.4.2 Analysis principles for various types of devices

4.4.2.1 Conditions for calculating rotating type devices

Amusement rides and devices shall be calculated in operative, inoperative, fully loaded, partially loaded and unbalanced conditions. One-sided loading shall be considered when only seats situated on 1/4 or 3/4 of the perimeter are occupied. The verification of the ultimate limit state shall be carried out for these one-sided loading conditions.

The overturning moment caused by one-sided loading when seats on at least 1/6th of the perimeter are occupied shall not exceed the stability moment in existence at that time, without taking the anchor ties into consideration. For this one-sided loading, the fatigue strength shall be verified. This shall be done also for a one-sided loading on 5/6th of the perimeter. The corresponding sector portions shall be

selected for the most unfavourable case, and the seats situated at the edge of the sector concerned shall be included in the count.

An analogous procedure shall be adopted for multi-seated gondolas in lieu of single seats. If there are 18 or more seats uniformly distributed around the perimeter, a higher one-sided loading may be the determining factor in respect of an adequate safety against overturning in certain cases. In this regard it shall be assumed that the ratio between $M_{Rk, stb}$ (stabilizing moment) and $M_{Ek, dst}$ (overturning destabilizing moment) takes into account the partial safety factors according to [Table 2](#).

If a device is also intended by design to rotate in reverse, then both directions of travel shall be taken into consideration when dimensioning the components of the device.

4.4.2.2 Design and analysis principles for passenger-carrying units

The seats and gondolas shall be sized by taking into account the forces resulting from dead loads, imposed loads and motion. If seats are mounted on pin joints, they shall be arranged in such a way that no constraints can arise.

The fastening of the seats onto outriggers shall also be designed for these forces.

The arm rests, back rests, safety straps, chains, ropes and associated locking devices shall be capable of absorbing the aforementioned forces arising from the passenger load. The structure of seats and gondolas shall be designed and analysed in such a way that the forces arising (e.g. start-up and braking forces, impact forces, out-of-balance forces and forces exerted from the passengers onto restraints and railings) are securely transmitted into the structure and fatigue problems are excluded.

4.4.2.3 Roundabouts with several motions

4.4.2.3.1 General

For roundabouts, in which the moving parts are rotated about several axes in different planes, all the forces which arise shall be determined. This shall be done by considering, as a minimum, the angular velocities, centrifugal forces, Coriolis forces due to the change of direction of one or more of the rotational axes, gyroscopic forces, starting and braking forces and any impact forces which can arise.

4.4.2.3.2 Roundabout with planar motion only

Where the roundabout undergoes planar motion with constant speed rotation about two parallel axes only, the absolute velocities and accelerations (taking into account the relative motions and Coriolis' accelerations) shall be calculated.

4.4.2.3.3 Roundabouts with outriggers running on rail tracks

4.4.2.3.3.1 Roundabouts with arms centrally guided, with internal or external location of drive unit

On such roundabouts, due attention shall be paid to possible constraints and the bending and torsion moments in the arms which arise from the type of attachment of the gondolas or seats. The rails or running track shall be sized in such a way that the deflection due to wheel load does not exceed 1/500 of the span between track supports.

4.4.2.3.3.2 Roundabouts without a central guide

Safety against overturning of the cars shall be ensured by banking of the rails or by safety rollers and the like, or if necessary by both these precautions. In the first step the calculation of the safety against overturning of the substructure with a total partial safety factor of at least $\gamma = 1,0$, the anchorage in the foundation soil shall not be taken into consideration. In order to reach safety against overturning with

partial safety factors in accordance with [4.5.1](#), the anchorage may be taken into consideration in the calculation.

4.4.2.3.3 Roundabouts with undulating track

On these installations, the inertial forces arising from the movement in space of the gondolas shall be taken into consideration.

4.4.2.3.4 Roundabouts with several rotation gears

On these installations, particular attention shall be paid to the effects of the Coriolis and Gyration forces on the structure.

In the case of rotary motions which are not positively actuated (i.e. either free spinning or passenger actuated or both), the effects of the individual rotation of the individual rotation gears shall be investigated. For boom type roundabouts (e.g. round-ups, twistlers, hully-gullies), where gondolas can rise, the effects of the forces arising during vertical movement, starting up and braking, shall be taken into account, with due consideration for any unfavourable effects of impact forces and centrifugal forces.

In this context, the effects of the above-mentioned forces on each outrigger, on the complete roundabout and on the safety against overturning of the roundabout shall be investigated for the most unfavourable position in each case under static load combinations. The general out of balance load assumptions of [4.3.3](#) shall be considered. Fatigue calculations in accordance with [4.7.3](#) shall be carried out.

The telescopic jacks shall be supported without constraint and shall be sized adequately to withstand buckling.

The same applies, if appropriate, for lift roundabouts. Unavoidable accelerations on the telescopic jack at the beginning and at the end of a lifting stroke shall be taken into consideration by making a suitable allowance for increased loading when the roundabout components are being sized, unless these accelerations are attenuated with damping elements.

If the pressure lines of the lifting cylinders fail, the lowering speed shall not exceed twice the normal operational lowering speed and in any case no more than 1,0 m/s. The requirements of [5.3.2.7](#) shall be applied.

4.4.2.4 Roller coasters with rail track-bound vehicles

4.4.2.4.1 General (dynamics)

The longitudinal gradient of the rail shall be limited in such a way that the resultant force at angles perpendicular to it does not fall below 0,2 g. This value also applies for the passenger unit with the highest speed in the case of trains. If the resultant force falls below the above value, the passengers shall be secured against lift-off in accordance with [5.1.7.2.2](#).

The maximum transverse inclination of the rail, at the spots at which the car is likely to come to a full stop for operational reasons (e.g. at safety brakes), shall be limited to a maximum value of 25° unless the design of the passenger containment system and the biomechanical effects analysis allow for a higher value. The path of the rail track shall be designed in such a way, that the instantaneous theoretical step in acceleration is limited to 2 g. This is related to the centre of mass and does not exclude the necessity for other calculations to be made for accelerations on passengers' bodies. The velocity, accelerations and forces can be determined for the centre of mass. The overall centre of mass may be used where there are multiple coupled cars.

A simulation of the motion over the time shall be carried out in order to determine speed, accelerations and forces.

Because the friction coefficients are subject to considerable variations in magnitude as a result of the running in time, the design, the surface finish of the rail and the weather, it is necessary to carry out a measurement of the actual velocity and accelerations. The data of the measurement shall be in the limit of design.

To determine the individual wheel forces, additional calculations are necessary.

For high speed track having tight loops or helices, the need for rigid body dynamics shall be considered.

4.4.2.4.2 Supporting framework

Effects of settlement shall not be taken into account for fatigue calculations.

For exposed support columns without cladding anchored by the continuous rail in the overall structure, the assessment of the wind load may be ignored for the verification of the stability and of the safety against sliding.

The safety of the installation against overturning, when it is subjected to wind load need not be verified as a general rule, unless exceptionally large horizontal forces are likely to arise, as a result of a particularly unfavourable shape, exceptionally large wind load areas of the framework components (decorations, lighting strips), or as a result of partial or total cladding of the framework or track.

4.4.2.4.3 Passenger units

All forces arising in the chassis and superstructures shall be followed in the calculation from their point of origin, down to the supports. Thus, for example, in the case of passenger units with one oscillating and one rigid axle, the moments from forces transverse to the car above the oscillating axle, can only be absorbed by the rigid axle.

Forces transverse to the car, for example, can only be transmitted through wheels which run against the side of the rail.

If the load wheels are not designed in such a way that they are also capable of absorbing lateral forces, then special guide rollers shall be provided for this purpose.

The vehicles shall be equipped with devices for the prevention of derailment and lift-off. Safety devices against lift-off (rollers or claws) shall in any case be calculated for the actual forces acting on them. As a minimum they shall be sized for 50 % of the fully loaded vehicle weight, even when there is no lift-off.

4.4.2.4.4 Brakes

Each stopping or speed regulation brake (at the end of a descent, stopping after each journey) shall be designed in such a way that the braking deceleration does not exceed a maximum value of $5,0 \text{ m/s}^2$. Greater deceleration is permitted on condition that special devices for the protection (e.g., lap bars) of the passenger are provided; see [5.1.7.2](#).

Safety brakes shall be arranged for the planned minimum distance between successive cars or trains in such a way that there will always be sufficient braking elements between any two cars or trains to prevent collision.

Each safety brake shall be designed in such a way that the braking deceleration does not exceed a maximum value of $7,0 \text{ m/s}^2$, unless a greater deceleration is permitted in which case special devices for the protection (e.g., lap bars) of the passenger shall be provided; see [5.1.7.2](#).

Fatigue need not be considered for safety brakes, which are only operated in emergency cases. The maximum deceleration shall be assessed by using the highest attainable friction coefficient for the selected brake surface materials with the minimum load.

With regard to the sizing of the effective deceleration length, it shall be assumed that the car is still able to come to a full stop, when applying a safety factor of 1,2 (related to the friction coefficient), to

the minimum friction coefficient experienced due to weather influences, wear, maximum speed and load. The limiting values shall be checked on the finished installation. During such tests the minimum friction and maximum speed shall be produced as far as possible using wet rails, wet brake elements and wet fins.

Speed regulation brakes shall be calculated by using fatigue load cases.

4.4.2.4.5 Anti-rollback devices

Installations, on which the cars or trains are conveyed on the ascent ramp by means of chains, ropes, friction wheels or by self-propulsion, shall be provided with either safety devices to prevent running back, or with automatically acting brakes to prevent running back.

When several cars or trains are planned to be at the same time on the section of track situated between the end of the lift or ascent ramp and the station, or the brake situated before the station, then safety devices to prevent running back shall also be fitted in the uphill sections of the track after the valleys.

However, if a passenger unit or train is intended to be able to travel backwards along the track and through the station then safety devices against running back can be omitted from the ascent ramps.

When several cars or trains are on the track, safety devices against running back on the uphill sections may be dispensed with, on condition that the individual track sections are safeguarded by a fail safe block-zone system, with automatically controlled brakes.

When it is intended by design that only one single car or one single train be on the track one at a time, safety devices against running back can be omitted from the uphill stretches after the valleys or when the car is intended to roll backwards.

The fatigue strength need not be verified for the anti-rollback devices. If the car is stopped by the anti-rollback device with a sudden impact, an impact factor shall be assumed for dimensioning purposes. This value shall be at least one half of the vertical maximum running back height [h in centimetres (cm)], if no exact verification is carried out, and in any case shall not to be less than 2,0. A load of $\varphi \times Q$ shall be assumed for dimensioning purposes where Q is defined as the dead load of the car plus the live load of passengers (fully loaded roller coaster car).

$$\varphi \geq 0,5 \times h$$

$$2,0 \leq \varphi$$

The two conditions above shall be satisfied.

If the deflection is known or can be determined reliably, the [Formula \(8\)](#) shall be applied:

$$\varphi \geq 1 + \sqrt{1 + \frac{2h}{\delta_0 \sin \alpha}} \quad (8)$$

where

δ_0 is the total deflection of the centre of mass along the slope;

α is the slope angle (see [Figure 1](#));

h is the height (see [Figure 1](#)).

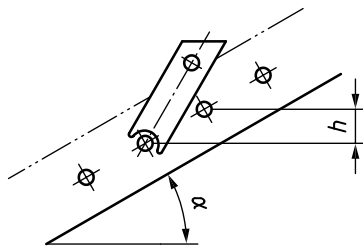


Figure 2 — Impact factor/running back elevation

Measured data and/or dynamic analysis can also be used to determine impact forces.

4.4.3 Other railways with track-bound vehicles

4.4.4 Conventional railways

Conventional railways are, for example, children's railways, children's traffic gardens, ghost railways and similar installations, with both conventional and suspended vehicles.

The requirements outlined in [4.4.3](#) shall apply for dimensioning and for the operating safety, as far as applicable.

If track girders and supports form an integral part of the roofing structure, fatigue loading due to oscillating loads shall be taken into account during the design.

Ghost railways which have more than one level shall have anti-rollback devices in the rising sections. In all inclined sections, the necessary brake device to control velocity and de-railing shall be provided.

4.4.5 Suspended railways (or coasters)

An analysis of the dynamic behaviour of track-bound rides having suspended cars with one (or more) degree(s) of freedom to swing or rotate, shall be conducted.

For suspended railways, free spaces of an order of magnitude of the calculated swinging motion, with an added safety margin, shall be provided both to the excursion side and to the opposite side, in addition to the clearance for rail track-bound vehicles specified in [5.1.7.1](#).

The added safety margin shall be not less than 20 % of the calculated angle of swing, with a minimum value of 10°. The oscillation behaviour shall be taken into consideration when calculating the angle of swing. The accelerations arising from the oscillatory motion of the gondola shall be taken into account in the calculations for the vehicle, the rail and the supports.

If the lateral oscillations of pendulum gondolas are damped, and if the clearance is inadequate for an undamped oscillation, pendulum movement limitations shall be provided. This pendulum movement limitation may be provided by suitably designed and documented redundant dampers.

At the beginning of route sections in which pendulum gondolas are guided (e.g. in the region of passenger transfers) guides shall be provided, which are capable of grasping the gondolas at least twice the value of the calculated angle of swing, and of guiding them in as smoothly as possible while taking into consideration the travelling speed.

The DRA shall determine the method, if required, of locking pendulum gondolas for the purpose of passenger transfers (e.g. suitable dampers).

4.5 Verification of stability

4.5.1 General

Proof shall be provided of safety against overturning (see 4.5.2), sliding (see 4.5.3) and lifting (see 4.5.4) of amusement devices and their components. Favourably acting imposed loads and dead loads of components and accessories which are not always present shall not be taken into account, when providing proof of safety against overturning, sliding and lifting. Only the lowest value of continuously acting favourable influences including material variations (e.g. G_{sup} , G_{inf}) shall be taken into account.

For foundations, official available data shall be applied to the prevailing rules of 4.5.1. A frost-free foundation for amusement devices is only required in cases where lifting or lowering/settling due to frost can lead to damage or failure.

Only the lowest value of continuously acting favourable influences shall be taken into account.

If an adequate degree of safety cannot be achieved by virtue of the dead load of a structure alone, then further additional steps shall be taken to ensure it, such as counterweights, anchors and buttresses.

As the weight of amusement devices can be determined and verified accurately, the safety factors can be determined more precisely as defined in Table 2).

Table 2 — Safety factor against overturning, sliding and lifting

Loading ^a		γ
1	Favourably acting proportions of the dead load	1,0
2	Unfavourably acting proportions of the dead load	1,1
3	Unfavourably acting wind loads	1,2 ^b
4	Accidental combinations	1,0
5	Unfavourably acting proportions of loads other than the loads listed in items 2, 3 and 4.	1,3
^a If loads are resolved into components, then these components shall be multiplied by the same value of γ .		
^b For devices higher than 20 m, $\gamma = 1,2$ shall be replaced by $\gamma = 1,2 + 0,3 \times (h - 20)/40$ where h is the total height of device in metres. For devices higher than 60 m $\gamma = 1,5$ shall be used as a minimum.		

4.5.2 Overturning

The safety against overturning shall be calculated using Formula (9):

$$\sum \gamma M_{\text{Rk, stb}} \geq \sum \gamma M_{\text{Ek, dst}} \quad (9)$$

where

γ are the partial safety factors in accordance with Table 2;

$M_{\text{Rk, stb}}$ are the stabilizing moment proportions;

$M_{\text{Ek, dst}}$ are the overturning destabilizing moment proportions.

Care shall be taken to ensure that the loads entered in the calculation can be accommodated by the shear stiffness of the structure.

4.5.3 Sliding

The safety against sliding shall be calculated using Formula (10):

$$\mu \cdot \sum \gamma N_k \geq \sum \gamma H_k \quad (10)$$

where

γ are the partial safety factors in accordance with [Table 2](#);

N_k are the vertical load components;

H_k are the horizontal load components;

μ is the coefficient of friction in accordance with [Table 3](#).

The coefficients of friction in [Table 3](#) may be assumed for the determination of the frictional forces, unless higher values determined by tests are available in individual cases, or unless the effect of moisture requires the adoption of lower values.

Table 3 — Coefficient of friction μ

	Wood	Steel	Concrete
Wood	0,40	0,40	0,60
Steel	0,40	0,10	0,20
Concrete	0,60	0,20	0,50
Clay ^a	0,25	0,20	0,25
Loam ^a	0,40	0,20	0,40
Sand and gravel	0,65	0,20	0,65

^a Of consistency of stiffness at least in accordance with ISO 14688-2.

It shall be taken into consideration that loosening by vibration can occur in the case of supports subject to vibrating stress.

If stability is not obtained by static friction alone, then the structure shall be anchored in the ground. In such cases, the safety against sliding shall be calculated in conjunction with the action of soil anchors. Under these conditions, the coefficients of friction in accordance with [Table 2](#) shall only be entered in the calculation at 70 % of the listed values.

$$\bar{\mu} \cdot \sum \gamma N_k + Z_{h,d} \geq \sum \gamma H_k \quad (11)$$

where

$\bar{\mu} = 0,7\mu$ and μ is the coefficient of friction in accordance with [Table 3](#);

$Z_{h,d}$ is the horizontal design load bearing capacity of the anchor (see [4.6](#)).

4.5.4 Lifting

The safety against lifting shall be calculated using [Formula \(12\)](#):

$$\sum \gamma N_{Rk,stab} \geq \sum \gamma N_{Ek,dst} \quad (12)$$

where

γ is the partial safety factor in accordance with [Table 2](#);

$N_{Rk,stab}$ are the vertical stabilizing load components;

$N_{Ek,dst}$ are the vertical lifting destabilising load components.

With anchor ties, the following relationship shall be applied:

$$\sum \gamma N_{Rk, stb} + Z_{v,d} \geq \sum \gamma N_{Ed, dst} \quad (13)$$

where $Z_{v,d}$ is the vertical design load bearing capacity of the anchor (see 4.6).

4.6 Ground anchorages

4.6.1 General

Varying soil conditions and the type of loading require the following experimentally assessed values for anchor ties to be applied, which already include inherent partial safety factors. The following calculation principles shall be used. [Subclause 4.6](#) is applicable and restricted to:

- weight anchors, e.g. ballast bodies placed on the surface of the ground or buried;
- rod anchors, e.g. metal rods fitted with eyelets or with an upset head, not permitted in long-term installations.

Concerning special anchors such as wing anchors, folding anchors, screw anchors and sectional steel anchors, the determination of their load bearing capacities requires loading tests.

Where rod anchors shorter than 80 cm are used for subordinate devices and are required from the results of a calculation, loading tests or other acceptable evidence shall be provided.

4.6.2 Design load bearing capacity of weight anchors

When calculating the design load bearing capacity of fully or partially buried anchors, the passive earth pressure shall only be taken into account on the condition that the anchor is capable of performing small displacements and rotations without any danger to the structure, and that the foundation soil characteristics are known sufficiently.

4.6.3 Design load bearing capacity of rod anchors

The design load bearing capacity of simple rod anchors with a circular cross section and with a minimum driving-in depth of 80 cm shall be determined in accordance with the empirical formulae given in [Table 4](#).

Table 4 — Design load bearing capacity of anchors Z_{Rd}

Angle of acting tensile force to the vertical β	Design load bearing capacity of rod anchors Z_{Rd} N
$\beta = 0^\circ$	$Z_{Rd} \hat{=} f_{load} \cdot dl' = 6,5dl'$ for stiff cohesive and for dense cohesionless soils
$\beta = 0^\circ$	$Z_{Rd} \hat{=} f_{load} \cdot dl' = 8,0dl'$ for very stiff cohesive soils
$\beta \geq 45^\circ$	$Z_{Rd} \hat{=} f_{load} \cdot dl' = 10,0dl'$ for cohesive soils of at least medium to stiff consistency
$\beta \geq 45^\circ$	$Z_{Rd} \hat{=} f_{load} \cdot dl' = 17,0dl'$ for dense cohesionless soils
$0^\circ < \beta < 45^\circ$	The load bearing capacity for the soil types shall be determined by interpolation (see Figure 3 and Figure 4).

The symbols used in [Table 4](#), [Formula \(14\)](#) and [Formula \(15\)](#) and [Figure 2](#) and [Figure 3](#) are:

$Z_{Rd} = Z_u / \gamma_M$	is the design load bearing capacity of the anchor, in N (Newtons);
Z_u	is the lowest value of the test due to 4.6.4 ;
$\gamma_M = 1,5$	is the partial safety factor for a material property, also accounting for model uncertainties and dimensional variations;
$Z_{h,Rd}$	is the horizontal design load bearing capacity of anchor, in N;
$Z_{v,Rd}$	is the vertical design load bearing capacity of anchor, in N;
d	is the anchor diameter, in cm;
l'	is the depth of penetration (minimum length 80 cm);
α	is the angle of penetration;
β	is the angle of acting tensile force to the vertical;
f_{load}	is the factor for determining the load bearing capacity of rod anchors.

The formulae in [Table 4](#) are only valid on the condition that the anchor will “pull” when driven in. For $\beta = 0^\circ$ the friction shall be effective along the entire length of the rod; for $\beta \geq 45^\circ$, the angle of penetration α shall be 90° . At this driving-in angle, the obliquely loaded anchor will reach its maximum design load bearing capacity. In order to prevent any bending of anchors subjected to shear loading, the following minimum diameter shall be respected, for simple round steel rod anchors:

$$d_{min} = 0,025l' + 0,5 \quad (14)$$

with l' in cm.

The point of application of the force on rod anchors subjected to bending stress shall be situated either as close to the ground surface as possible, or beneath it.

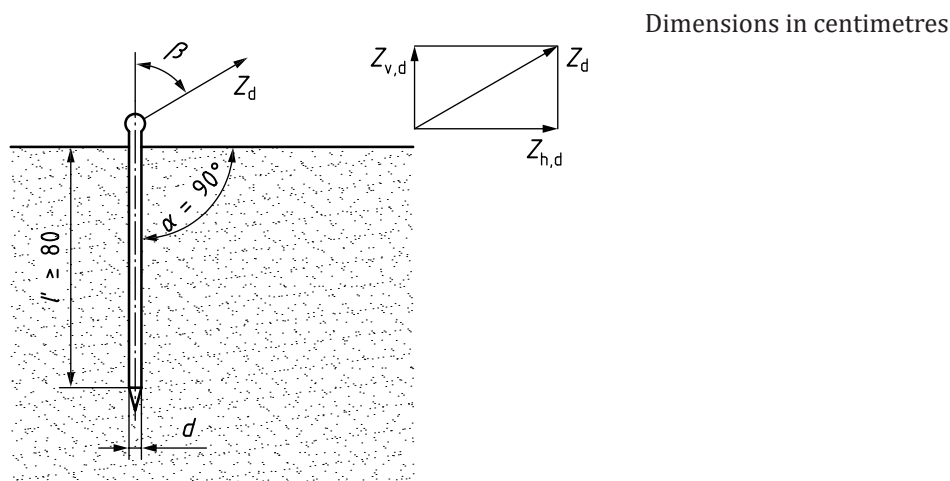
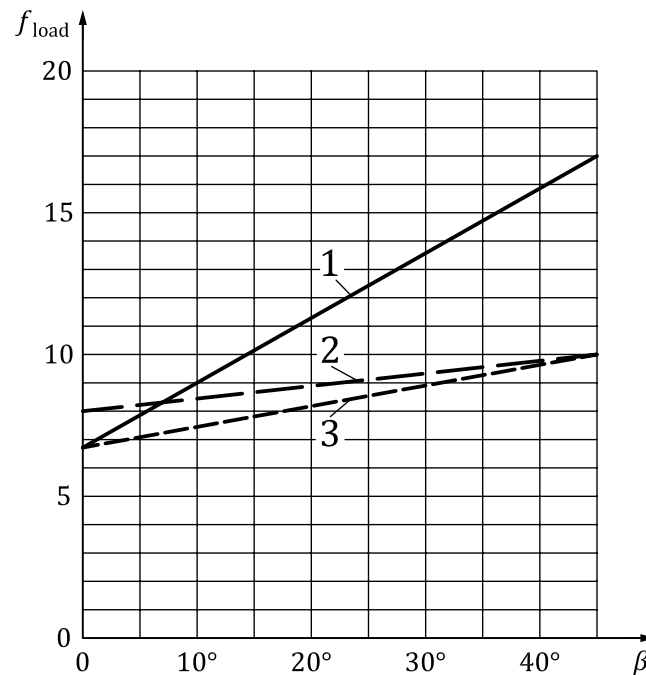


Figure 3 — Rod anchor

**Key**

- 1 dense cohesionless soils
- 2 very stiff cohesive soils
- 3 stiff cohesive soils

Figure 4 — Factors for determining the load bearing capacity of rod anchors

4.6.4 Testing of anchors (numbering)

The calculated design load bearing capacities may be exceeded, if this can be substantiated by loading tests, or if experimental data relating to the installation site are available. When test loading an anchor, at least three tests shall be carried out. A safety factor of $\gamma = 1,5$ shall be applied to the lowest test value (Z_u) in order to determine the design capacity (Z_{Rd}) in subsequent calculation. The design load bearing capacity determined in this manner shall not result in anchor movement which can result in stresses, deformations or instability which cannot be accommodated by the structure.

If the foundation conditions are comparable, loading tests carried out in another location may be adopted for substantiation purposes.

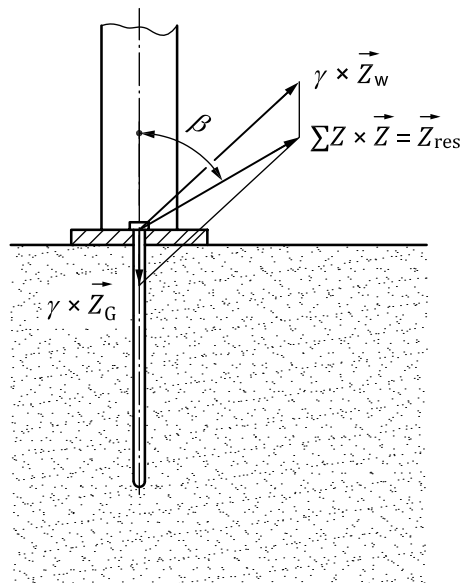
The safety factors featured in [Table 2](#) shall be taken into consideration when determining the permissible load.

4.6.5 Calculation of loads on anchors

The resulting load Z_{res} acting on the anchorage shall be determined by vector summation, taking into account the partial safety factors as shown in [Table 2](#). This load Z_{res} shall be less than the permissible loading of the anchorage according to [4.6.3](#):

$$Z_{res} \sum \gamma Z \leq Z_{Rd} \quad (15)$$

See also [Figure 5](#).



Key

- Z_G favourably acting resultant of permanent actions;
- Z_W unfavourably acting portion of variable actions;
- γ safety factor in accordance with [Table 2](#);
- β angle of acting tensile force to the vertical.

Figure 5 — Anchor loading

4.6.6 Further requirements

When displacements in excess of 2 cm occur on loaded rod anchors or similar devices, the load bearing capacity of the anchor is no longer fully ensured. An increase of the resistance against pull-out failure can be achieved either by means of additional anchors or by driving in wooden wedges. In the case of pure tensile stress in the direction of the axis of the rod anchor, the danger of a complete failure of the anchor arises when very small movements occur.

The foot of the anchor (pointed tip) shall not exhibit any widening of the cross section in the case of rod anchors, so as to prevent any reduction of the skin friction in the zone of the anchor shank.

After the driving in of a rod anchor, the soil on the surface shall be tamped against the anchor, as far as practicable, in order to prevent the infiltration of surface water.

If groups of anchors are used, each individual anchor may only be assessed in the calculation at its full, calculated load bearing capacity on the condition that the spacing between adjoining anchors amounts to not less than five times the anchor diameter. Dynamic loads can lead to the loosening of an anchorage, consequently, repeated checks of the anchors are essential. For groups of anchors consisting of more than six anchors, the load bearing capacity of such groups of anchors has to be verified by calculation. Without further verification, an angle of excavation of 45° starting from the outer anchor can be assumed for this calculation.

4.6.7 Ground support for packing

Only small contact stresses are permitted for packing, because of the lack of embedding in the soil and also because of the relatively small bearing widths used in practice. Packing is subject to sink into the soil and cause considerable settlements. Packing shall be kept under observation when placed on particularly yielding soils. In the event of yielding or loosening, an underlay shall be provided and the bearing surfaces shall be enlarged as necessary.

For a foundation soil with a low load bearing capacity, additional measures shall be adopted. If several elements are laid side by side without any gaps in order to increase the bearing widths, an interconnection shall be created, e.g. by cross-stacking.

For a foundation soil which can be travelled over (e.g. by trucks), the following design soil pressures can be used in the calculation for square and rectangular packing with dimensions:

$$1 \leq l/b \leq 3$$

where

l is the length of packing in the ground contact zone;

b is the width of packing in the ground contact zone;

$b = 20 \text{ cm}$: $P = 100 \text{ kN/m}^2$;

$b = 30 \text{ cm}$: $P = 150 \text{ kN/m}^2$;

$b \geq 40 \text{ cm}$: $P = 200 \text{ kN/m}^2$;

p is the design value of the allowable soil pressure (resistance).

Interpolation should be conducted for intermediate values.

For installation on strengthened (consolidated) locations, higher design soil pressures can be considered.

NOTE When using the design soil pressure value, all the partial load factors are set to $\gamma_M = 1,0$ and $\gamma_f = 1,0$.

4.7 Verification of strength

4.7.1 General

A distinction shall be made between predominantly static stress and predominantly fluctuating stress. Fluctuating stress occurs both in the form of pulsating stress (stress which fluctuates within two limiting values without any change of sign,) and in the form of alternating stress (stress which fluctuates between two limiting values and changes its sign). For both situations, the stress range $\Delta\sigma = \max \sigma - \min \sigma$ is significant for the calculation.

Fatigue calculation of welded structural items shall be performed based on the stress range $\Delta\sigma$ concept. If the minimum life time requirements in [4.7.3.1.4](#) are applied and a partial safety factor according to [Table 5](#) at 95 % survival probability or equivalent is maintained, EN 1993-1-9, EN 13001-3-1+A2 or other equivalent standards can be used.

The resistance of notch details shall be determined as statistical value with 95 % of survival probability and confidence interval of 75 %.

The resistance of welded notch details may be improved (only weld transitions) by post-weld treatment (e.g. TIG dressing, hammer peening or grinding).

The minimum life time requirements in [4.7.3.1.4](#) with at least the partial safety factors of [Table 5](#) shall be considered.

Structures subjected to fluctuating stress which are likely to be exposed to more than $n = 10^4$ stress cycles during their expected service life, shall be dimensioned by calculation of fatigue strength.

NOTE Recognized state of art literature such as the Forschung Kuratorium MaschinBau Analytical strength assessment of components in mechanical engineering (FKM) guideline can be used.

4.7.2 Predominantly static stress

Permissible stresses of materials used for structural components shall be taken from 4.2.

With regard to general stress analysis of machinery components made of steel, including components which act simultaneously as structural components, [Formulae \(16\)](#) and [\(17\)](#) shall apply:

$$R_d \leq \frac{R_{eH}}{\gamma_{M0}} \quad (16)$$

and

$$R_d \leq \frac{R_m}{\gamma_{M2}} \quad (17)$$

where

R_d is the design material resistance;

R_{eH} is the yield strength;

R_m is the ultimate strength;

$\gamma_{M0} = 1,1$ is the partial safety factor for elastic strength resistance (yield);

$\gamma_{M2} = 1,5$ is the partial safety factor for ultimate strength resistance when $R_{eH}/R_m < 0,75$;

$\gamma_{M2} = 2,0$ is the partial safety factor for ultimate strength resistance when $R_{eH}/R_m > 0,75$.

The smaller of the two R_d values above shall be used.

4.7.3 Fluctuating stress

4.7.3.1 Fatigue assessment of structural components

4.7.3.1.1 General

An assessment of fatigue life as a result of repeated fluctuation of stress shall be carried out.

4.7.3.1.2 Partial safety factors for fatigue where EN 1993-1-9 is specified

For fatigue loads, a partial safety factor shall be applied:

$$\gamma_{Ff} = 1,0$$

The following values for the partial safety factors for steel shall be applied:

Table 5 — Partial safety factor for fatigue resistance in stress range concept

Examination and access	Rupture will not affect collapse	Rupture will affect collapse
Structural part accessible during regular thorough examination	$\gamma_{Mf} = 1,0$	$\gamma_{Mf} = 1,1$
Structural part not accessible during regular thorough examination	$\gamma_{Mf} = 1,05$	$\gamma_{Mf} = 1,15$

4.7.3.1.3 Fatigue loads

When calculating $\Delta\sigma$ or $\Delta\tau$, the influence of dead loads which do not change in position, the components of variable actions which do not vary in time and position, snow loads, temperature loads, loads due to assembly and wind loads (without induced oscillation) need not be considered.

In the case where wind loads induce oscillation, the wind pressure can be set to 50 % of the in-service-wind loads (4.3.3.4.3), if there is no other calculated critical value of the wind pressure due to the wind speed, at the natural frequency. An investigation of wind induced oscillation shall be performed to evaluate additional fatigue loads.

When calculating $\Delta\sigma$ or $\Delta\tau$, the following actions shall be taken into account as a minimum:

- a) dead loads with change of position;
- b) moving imposed loads;
- c) driving and braking forces according to 4.3.3.2;
- d) load coefficients for impact and vibrations of parts directly travelled over;
- e) intentional collision forces;
- f) inertia forces;
- g) centrifugal and Coriolis force;
- h) gyroscopic effect.

Where there is movement of dead loads, when assessing $\Delta\sigma$ or $\Delta\tau$ (e.g. for lifted booms), the maximum and minimum stresses shall be calculated including dead loads according to [Formulae \(18\)](#) and [\(19\)](#):

$$\Delta\sigma = \sigma_{\max} - \sigma_{\min} \quad (18)$$

$$\Delta\tau = \tau_{\max} - \tau_{\min} \quad (19)$$

For amusement devices with a similar periodic loading, such as roller coasters tracks, roundabouts, ferris wheels, the amplitude stress $\Delta\sigma$ can be assumed as equivalent constant amplitude stress $\Delta\sigma_E$ according to EN 1993-1-9.

If unbalanced load conditions have to be considered the stress range due to 1/6 and 5/6 one-sided load according to 4.4.2.1 shall be assumed for 100 % of fatigue life.

NOTE E.g. rotational rides, Ferris wheels and carousels.

4.7.3.1.4 Number of load cycles

The fatigue assessment of load bearing parts shall consider the following number of load cycles, if no more precise calculation about load cycles and life time can be provided.

- a) Fatigue limit at 35 000 h: At least 35 000 operating hours shall be assumed in the fatigue calculation of amusement devices not including loading and unloading time. The number of load cycles shall be determined for each specific amusement device and its components.
- b) Endurance limit: Safety-related components shall be designed for endurance limit. In this context, the stress range $\Delta\sigma_D$ is understood to be the constant amplitude fatigue limit. When no stress range is higher than $\Delta\sigma_D$ for the respective detail category, infinite fatigue life can be assumed. If no detail calculation of the load cycles will be provided endurance limit life calculation shall be used.
- c) Standard products: Mass-produced replaceable safety-related machinery components used as structural parts (e.g. bearings and slewing rings) for which company standards are available, are

excluded. These shall be dimensioned for at least 5 000 operating hours. The replacement frequency of components shall be based on the calculated lifetime in hours or number of cycles. A theoretical lifetime calculation shall be submitted. Any safety related standard product item with a wear limit of less than 5 000 operating hours shall be mentioned in the manual.

4.7.3.2 Fatigue assessment of machine component (welded and non-welded)

Machine components are, for example, axles, pins, shafts, wheel bogies, coupling bars and restraint bars.

Assessment of welded parts may also follow the procedure given in [4.7.3.1](#) or international standards or guidelines, e.g. FKM or FEM 1.001 (Fédération Européenne de la Manutention).

Fatigue assessment is requested for parts with more than 10 000 load cycles.

Vehicles and trains for track-bound amusement devices shall be analysed by using the full, imposed load for the complete fatigue life.

4.7.3.2.1 Fatigue resistance

The fatigue resistance shall take into account:

- a) material strength;
- b) construction parameters;
- c) size effects;
- d) shape effects;
- e) corrosion influence;
- f) surface influence;
- g) alternate strength;
- h) endurance limit strength;
- i) service strength.

The strength values shall consider notch case and stress ratio.

4.7.3.2.2 Fatigue stress

Nominal stress or structural stress shall be used for fatigue assessment. Stresses shall be determined in accordance with the general principles of stress analysis.

Nominal stress method can be used for beam like systems. Nominal stresses σ , τ shall be investigated.

Structural stress methods and notch stress methods based on finite element analysis are possible for shell or volume investigations. Minimum and maximum principal stresses may require investigation.

4.7.3.2.3 Partial safety factor

The partial safety factor depends on the standard or guideline used.

4.7.4 Bolts

Bolts conforming to ISO 898-1, ISO 4014, ISO 4016, ISO 4017 or ISO 4018, nuts conforming to ISO 4032 and bolt and nut assemblies to EN 14399 (all parts), assigned to property classes 4.6, 5.6, 8.8 and 10.9 shall be used.

The calculation of limit states shall be made in accordance with EN 1993-1-1.

Where EN 1993-1-1 is not applied, the following shall be used for bolts assigned to the property grades referred to in [Table 6](#) and [Table 7](#).

- Bolted connections with bolts subject to vibrating forces normal to the axis of the bolt shall provide means to inhibit transverse displacements of the connecting parts either by the provision of shear keys, pins, cotter pins, bushes or by using tight-fit bolts or by providing a friction-type connection considering a friction coefficient of $2/3 \min. \mu$.
- The value to be adopted for $\min. \mu$ shall be the lowest coefficient of friction, which can occur in operation under the most unfavourable conditions.
- In the case of single-shear joints, the eccentricity shall be taken into consideration.
- Permissible shear strengths in accordance with [Table 6](#).
- Permissible calculated pressure on the face of the bolt hole for shear bearing pressure joints in accordance with EN 1993 (all parts) (or in absence of this with equivalent national standards) for non-prestressed bolts.
- Permissible additional transmissible tensile force in the direction of the bolt axis per prestressed bolt or fitted bolt in accordance with [Table 7](#); with F_v in accordance with [Table 6](#); a partial safety factor of $\gamma_G = \gamma_Q = \gamma_{E,f} = 1,0$ can be applied.
- Permissible pre-stressing force and tightening torques in accordance with [Table 6](#).

Bolts in connections designed for transport or dismantling may be used again on the condition that they have not been stressed beyond the yield point.

The torque values shall be confirmed by the bolt manufacturer or the supplier.

For detachable joints of structural devices other bolts with the same material properties may be used.

Table 6 — Design shear stress τ_m for a predominantly static stress per bolt, and for a shearing area perpendicular to the axis of the bolt

Property class	8.8	10.9
Design shear stress, τ_m , N/mm ²	300	360

Table 7 — Pre-stressing forces and tightening torques for bolts — ISO 4014, ISO 4017, ISO 4032, and EN 14399-3, EN 14399-4, EN 14399-6

Thread size	Pre-stressing force F_v (kN) for property class		Tightening torque M_a (Nm) for property class		Tightening torque M_a (Nm) for property class	
			Bolting assemblies according to EN 14399-3, EN 14399-4 and EN 14399-6		Bolts according to ISO 4014, ISO 4017 and ISO 4032	
			Surface condition: hot galvanised and MoS2 lubricated nut or as built and MoS2 lubricated nut $\mu = 0,10$		Slightly oiled $\mu = 0,14$ (as built)	
	8.8	10.9	8.8	10.9	8.8	10.9
M 12 ^a	35	50	70	100	80	120
M 16 ^a	70	100	170	250	210	300
M 20 ^a	110	160	300	450	410	590
M 22 ^a	130	190	450	650	520	760
M 24 ^a	150	220	600	800	660	970
M 27 ^a	200	290	900	1 250	1 000	1 450
M 30 ^a	245	350	1 200	1 650	1 370	1 950
M 36 ^a	355	510	2 100	2 800	2 350	3 380
M 42 ^b		710		4 500		
M 48 ^b		930		6 500		
M 56 ^b		1 280		10 000 ^a		
M 64 ^b		1 680		15 000 ^a		
^a Values are taken from EN 1993-1-8:2005.						
^b See References [12], [21] and [24].						

In general, the resistance forces of bolts according to [Table 7](#) shall be determined according to EN 1993-1-8 and the fatigue resistance should consider the fluctuating stress in the pre-stressed connection. Bolt resistances of a pre-stressed connection can be determined according to [Table 8](#), if sufficient compression body can be established.

Table 8 — Simplified definition of bolt resistances

Predominantly static stress	Vibrating stress
$N_{R,d} = 0,8 F_v$	$N_{R,FAT} = 0,6 F_v$

4.7.5 Ropes, chains, safety devices, connectors and adapters

4.7.5.1 Ropes, chains, belts and straps

4.7.5.1.1 Partial safety factor calculation

The partial safety factor will depend on the intended application. The relationship as given in [Formula \(20\)](#) shall apply:

$$Z_{Rd} \geq \gamma Z_k \quad (20)$$

where

- Z_{Rd} is the minimum load at fracture;
- Z_k is the maximum characteristic load;
- γ is the partial safety factor.

It is possible that other limit states may also need to be checked.

Wire rope with diameters smaller than 4 mm shall be avoided for amusement devices. Rope clamps shall not be used for fastenings onto drive mechanisms or impact loaded safety devices.

4.7.5.1.2 Ropes and chains under fluctuating loads (suspension of passenger-carrying devices e.g. chairs, gondolas)

For steel chains, a partial safety factor of $\gamma = 6$ shall be used.

For steel wire ropes the values for permissible stresses are given in [Table 9](#). Extrapolation of the permissible stress values in [Table 9](#) for higher nominal strength categories is not allowed. If individual wires with a nominal strength category exceeding 1 570 MPa are used, the permissible stress shall be assessed independently.

For other materials than steel, special investigation shall be required.

This does not apply however to safety equipment in accordance with [4.7.5.2](#).

Table 9 — Design stress for wire ropes for suspension of structural components made from individual wires of 1 570 MPa nominal strength category, for the purpose of verification of fatigue strength

Diameter of wire rope d mm	Permissible stress σ_f for wire ropes N/mm ²
$4 \leq d \leq 5^a$	$540 + 67 \kappa$
$5 < d \leq 20$	$337 + 270 \kappa$
$20 < d \leq 30$	$270 + 337 \kappa$
$30 < d \leq 40$	$202 + 405 \kappa$

^a For design reasons, wire rope diameters smaller than 4 mm shall be avoided.

κ is defined in [Formula \(21\)](#) as

$$\kappa = \frac{\min \sigma}{\max \sigma}; 0 \leq \kappa \leq 1 \quad (21)$$

Verifications shall be done with the factor $\gamma = 1,0$ on the load side and are compared directly with the values in [Table 9](#).

4.7.5.1.3 Ropes and chains under predominantly non-fluctuating load

Ropes and chains under predominantly non-fluctuating load are, for example, guy ropes, stay ropes, anchoring ropes and chains.

For steel chains, a partial safety factor of $\gamma = 4,0$ shall be used.

For wire ropes made from individual wires with a nominal strength category of 1 570 MPa, a partial safety factor of $\gamma = 3,0$ shall be taken for the general stress analysis.

For web lashing made from man-made fibres according to EN 12195-2 under predominantly non-fluctuating loads, an additional partial safety factor of $\gamma = 2,0$ on lashing capacity (LC) shall be used.

Regarding fibre ropes made from natural and/or synthetic fibres, the values given in [Table 10](#) shall apply.

Table 10 — Partial safety factors for natural or synthetic fibre ropes

Rope diameter mm	Partial safety factor γ
12	4,0
14	3,3
16	3,3
18	2,7
20 and thicker	2,7

The respective partial safety factors γ_f shall be taken into account and be compared with the respective breaking load divided by the partial safety factor.

4.7.5.2 Passenger safety devices

A total safety factor of $\gamma_M = 6$ shall be adopted for safety devices such as safety belts and safety harnesses in loop-the-loop swings. The ultimate limit state is based on the fracture load.

For foot strap buckles in loop-the-loop swings, the following minimum sizes shall be adopted for roller buckles:

- steel buckles: belt width not less than 25 mm;
- aluminium alloy buckles: belt width not less than 30 mm.

In any case the minimum design strength shall not be less than 2 kN for foot strap buckles in loop-the-loop swings.

4.7.5.3 Connectors and adapters

In the absence of International Standards for hooks and eyelets of turnbuckles, connectors and adapters can be used in accordance with national standards. Their permissible loading shall be determined with the aid of the partial safety factors for steel chains (where $\gamma = 4$ or 6) in accordance with [4.7.5.1.1](#).

The permissible loadings for approved load data may be trebled for statically stressed shackles. For dynamically stressed shackle for approved load data shall apply. Shackle pins shall be secured against loosening in dynamically loaded connections.

4.8 Structural design and construction

4.8.1 Arrangement, accessibility

Structural components which are designed in accordance with [Table 5](#), Row 1 (partial safety factor $\gamma_{Mf} = 1,1$ or 1,0) shall be made accessible for checking, if necessary in dismantled conditions.

4.8.2 Locking and safety devices for fasteners

Bolts, nuts, tapered washers and other fasteners, the slackening of which, as a result of fluctuating stresses, can result in incident or injury, shall be secured by well recognized methods, e.g. pre-stressing, cotter pin, retaining compound, counter nut, self-lock nut, spring washers, toothed lock washers, fan type (serrated) lock washers.

On pre-stressed bolts (according to [Table 7](#)), the pre-stressing is considered as security against loosening.

However, as pre-stressed screwed connections are also subject to loosen, particularly in the initial stages as a result of settlement, for example in the case of ball bearing slewing gear, a reference shall be made in the assembly and operating instruction manual to carry out the necessary checks.

4.8.3 Joints intended for regular dismantling

Spring washers, toothed lock washers, fan type (serrated) lock washers and similar locking devices are not permitted on screwed connections fitted with bolts assigned to property class 8.8 and 10.9.

If open hooks are used, it is necessary to assess the consequences of unhooking. Hooks with a safety catch are not considered to be open hooks.

As a general rule, it shall be taken into consideration that any modification of timber members resulting in weakening the timber section shall be avoided. This applies in particular to timbers exposed to impacts or subjected to alternating or pulsating stresses. Drill holes in timber components for connecting bolts, which are subjected to alternating and pulsating loads or on which the bolts are regularly removed during assembly and dismantling operations, shall be relieved from stress by the provision of suitable load spreading plates or dowel pins.

Tensile forces in drill holes acting at right angles to or obliquely to the direction of the grain, which can lead to the splitting or tearing of the wood, shall be absorbed by load spreading (wrap-around) plates on either side of the drilled holes, or by other suitable means. Bolted connections which are not protected in such a way, shall be provided with washers. Appropriate measures such as steel plates or enlarged washers shall be used to prevent damage to timber due to compression under bolt head or nuts. Star washers and similar devices (toothed insert dowels) shall not be used in timber joints which can be dismantled.

Rope connections shall be formed in such a way that there is neither a possibility of kinks or knots arising, nor of excessive stressing of individual wires.

Ropes of any kind shall not bear on sharp edges.

4.8.4 Designing of components subject to fluctuating loads

Abrupt transitions in cross section (sudden changes in stiffness) and notches shall be avoided in components subject to fluctuating stresses.

4.8.5 Supports

Extendable columns and jack screws (pot jacks and similar) which transmit loads onto the surface of the ground shall, if necessary, be cross-braced or secured in another way to take applied horizontal forces.

4.8.6 Central masts

Central masts subject to fluctuating stresses shall not be made of wood.

4.8.7 Prevention of corrosion and rot

Prevention of corrosion and rot shall be provided for steel components, light alloy components and timber components according EN 1090, EN 1993, EN 1999 and EN 1995.

5 Requirements for design and manufacture of rides and structures

5.1 Risk reduction by prevailing design and safety measures

5.1.1 General

The majority of devices in [Clause 5](#) has been categorised in order to unify design approval, examination and safety precautions. The groups are intended to highlight the relevant additional precautions required. Any single device can fall into more than one category, e.g. dark rides, which include rail-guided devices travelling through water.

5.1.2 Risk assessment

5.1.2.1 General

The DRA and OURA are keystone documents, paramount to the total safety management of the amusement device and also considered as dynamic documents. They are required to be reviewed periodically and to follow any relevant change to the design or operation of the amusement device.

These risk assessments shall assess the hazards that the amusement device can pose, the likelihood of those hazards causing a risk and the control measures that are necessary to control those risks adequately. The risk assessments shall identify hazards, estimate and evaluate the risk to which guests, spectators, and operational and maintenance staff are exposed.

5.1.2.2 Design risk assessment (DRA)

The DRA shall be produced by the designer of every device. It shall be used to guide the designer into making the correct decisions in the total design ethos (e.g. material selection, PLC program, ergonomic characteristics, biomechanical effects) so that an acceptable level of risk resides (residual risk) from each design decision. Although not an operation and use risk assessment, the DRA shall be used to guide the structure and content of the operating and maintenance procedures.

5.1.2.3 Operation and use risk assessment (OURA)

The OURA shall be produced by the controller and operator of every device. It shall be used to guide the operator and controller into making the correct decisions in the total operation ethos (e.g. age/height limit, loading/offloading of passengers, foreseeable misuse) so that an acceptable level of residual risk from each hazard is analysed. It shall be elaborated in close consultation with the designer and the DRA and shall demonstrate the management of residual risks highlighted in the DRA. See [Figure 6](#).

5.1.2.4 Hazard analysis

For guidance on general principles, see ISO 12100 and the specific applicable hazards for the amusement devices listed in [Annex E](#).