

Fairground and amusement park machinery and structures — Safety

ICS 91.040.99

National foreword

This British Standard is the UK implementation of EN 13814:2004.

The UK participation in its preparation was entrusted by Technical Committee MCE/3, Safeguarding of machinery, to Subcommittee 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 secretary.

WARNING

BSI as a member of CEN, is obliged to publish EN 13814:2004 as a British Standard. However, attention is drawn to the fact that during the development of this European Standard, the UK consistently voted against its approval as a European Standard.

The reason for this disapproval is that during discussion of this standard by BSI Technical Committee MCE/3/4, which mirrors the work of CEN Committee TC 152, the UK expressed the opinion that there are several points which may necessitate additional or different safety measures to be applied to amusement devices that are to be used in the UK.

In the opinion of the committee, it is important that designers should be aware that compliance with requirements of this standard may not be sufficient to ensure compliance with UK law¹⁾.

The BSI committee had particular concerns with:

- fatigue life assessment: EN 13814:2004 does not require the designer to pass on any information regarding fatigue lives exceeding 35 000 hours, nor to cross check that inspection/maintenance instructions are consistent with any of the calculated lives. The committee believes this is inconsistent with Section 6 of the Health and Safety at Work etc. Act 1974;
- control systems: in the opinion of the UK committee a reference to IEC 62061 would be appropriate, which relates to control system design safety;
- passenger containment and clearance envelopes (6.1.6.1.2): the minimum reach distances for passengers as required in 6.1.6.1.2 do not conform to UK legal requirements¹⁾. Risk assessments referencing anthropometric data in relation to the severity of the hazards should be used to determine safe reach distances and in most cases applicable to the UK, the safe distances will be much greater than stated in 6.1.6.1.2;
- wind loading calculations: in 5.3.3.4.1 the latest relevant Eurocodes²⁾ should be taken into account as should higher probable wind loadings in the UK. The possibility of portable rides being used in northern areas with even higher probable wind velocities should also be considered.

¹⁾ It is the intention of BSI Technical Committee MCE/3/4 to draft a national annex NA, which will give additional guidance on implementation, particularly in relation to compliance with UK regulations.

²⁾ The national annex NA to BS EN 1991-1-4 will provide supplementary information and guidance on implementation for UK users. It is anticipated that this document will be available by the end of October 2008. Until the NA is published, BS 6399-2:1997 should be used.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Amendments/corrigenda issued since publication

Date	Comments
30 September 2008	National foreword revised
30 June 2011	Correction to Equation (53) in 5.5.1.2

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English version

Fairground and amusement park machinery and structures - Safety

Machines et structures pour fêtes foraines et parcs
d'attraction - Sécurité

Fliegende Bauten und Anlagen für Veranstaltungsorte
und Vergnügungsparks - Sicherheit

This European Standard was approved by CEN on 19 May 2004.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



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Foreword

This document (EN 13814:2004) has been prepared by Technical Committee CEN/TC 152, "Fairground and amusement park machinery and structures - Safety", the secretariat of which is held by UNI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2005, and conflicting national standards shall be withdrawn at the latest by June 2005.

This European standard has been prepared under the mandate M/233 given to CEN by the European Commission and the European Free Trade Association. A European Directive concerning fairground and amusement machinery does not exist.

This European standard forms part of a series of two documents prepared by CEN/TC 152 for fairground and amusement park machinery and structures. The other document is prEN 13782, "Temporary structures – Tents – Safety"

In its present state this European Standard may require, where mentioned in the different clauses, the application of national standards since some of the basic EN-standards to be used in applying this European Standard are not yet available. The content of this European Standard brings together the different existing national regulations and guidelines as far as possible.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

The object of this document is to define safety rules related to structures and machines, which are either an integral part of, or constitute the amusement device itself. The safety rules are intended to safeguard persons against the risk of accidents caused by deficiencies in design, manufacture and operation of such structures and machinery. This document is based upon past experience and risk analyses.

Annex A is an informative part of this document providing guidance on the calculation of structural steel parts.

Annexes B and C are normative parts of this document giving detailed and necessary calculation or safety rules.

Annex D (normative) deals with electrical installations and control systems.

Annex E (informative) deals with guidance on passenger containment.

Annex F (informative) shows a typical layout of a log book for an amusement device.

Annex G (informative) Acceleration effects on passengers.

Annex H (informative) Provisions prior to use.

Annex I (informative) List of Hazards for amusement rides.

1 Scope

This document specifies the minimum requirements necessary to ensure the safe design, calculation, manufacture, installation, maintenance, operation, examination and testing of the following: mobile, temporary or permanently installed machinery and structures e.g. roundabouts, swings, boats, ferris wheels, roller coasters, chutes, grandstands, membrane or textile structures, booths, stages, side shows, and structures for artistic aerial displays. The above items are hereafter called amusement devices, which 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. Fixed grandstands, construction site installations, scaffolding, removable agricultural structures and simple coin operated children's amusement devices, carrying not more than two children, are not covered by this document.

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

Existing national rules on workers' safety are not concerned by this document.

This document is not applicable to amusement devices which are manufactured before the date of publication of this document by CEN.

2 Normative references

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

EN 2, *Classification of fires.*

EN 3 (all parts), *Portable fire extinguishers.*

EN 286-1, *Simple unfired pressure vessels designed to contain air or nitrogen — Part 1: Pressure vessels for general purposes.*

EN 287 (all parts), *Approval testing of welders — Fusion welding.*

EN 288 (all parts), *Specification and qualification of welding procedures for metallic materials.*

EN 294:1992, *Safety of machinery — Safety distances to prevent danger zones being reached by the upper limbs.*

EN 418, *Safety of machinery — Emergency stop equipment, functional aspects — Principles for design.*

EN 573-3, *Aluminium and aluminium alloys — Chemical composition and form of wrought products — Part 3: Chemical composition.*

EN 696, *Fibre ropes for general service — Polyamide.*

EN 697, *Fibre ropes for general service — Polyester.*

EN 698, *Fibre ropes for general service — Manila and sisal.*

EN 699, *Fibre ropes for general service — Polypropylene.*

EN 700, *Fibre ropes for general service — Polyethylene.*

EN 701, *Fibre ropes for general service — General specification.*

EN 719, *Welding coordination — Tasks and responsibilities.*

EN 729-2, *Quality requirements for welding — Fusion welding of metallic materials — Part 2: Comprehensive quality requirements.*

EN 729-3, *Quality requirements for welding — Fusion welding of metallic materials — Part 3: Standard quality requirements.*

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

EN 919, *Fibre ropes for general service — Determination of certain physical and mechanical properties.*

EN 954-1, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design.*

EN 1050:1996, *Safety of machinery — Principles for risk assessment.*

EN 1176 (all parts), *Playground equipment.*

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

EN 1418, *Welding personnel — Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials*

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

EN 10025, *Hot rolled products of non-alloy structural steels — Technical delivery conditions.*

EN 10027 (all parts), *Designation systems for steels.*

EN 10083-1+A1, *Quenched and tempered steels — Part 1: Technical delivery conditions for special steels.*

EN 10084, *Case hardening steels — Technical delivery conditions.*

EN 10160, *Ultrasonic testing of steel flat product of thickness equal to or greater than 6 mm (reflection method).*

EN 10164, *Steel products with improved deformation properties perpendicular to the surface of the product — Technical delivery conditions.*

EN 10204, *Metallic products — Types of inspection documents.*

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

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

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

prEN 14399 (all parts), *High-strength structural bolting for preloading.*

EN ISO 898-1, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs (ISO 898-1:1999).*

EN ISO 4014, *Hexagon head bolts — Product grades A and B (ISO 4014:1999).*

EN ISO 4016, *Hexagon head bolts — Product grade C (ISO 4016:1999).*

EN ISO 4017, *Hexagon head screws — Product grades A and B (ISO 4017:1999).*

EN ISO 4018, *Hexagon head screws — Product grade C (ISO 4018:1999).*

EN ISO 4032, *Hexagon nuts, style 1 — Product grades A and B (ISO 4032:1999).*

EN ISO 4034, *Hexagon nuts — Product grade C (ISO 4034:1999).*

EN ISO 5817, *Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections (ISO 5817:2003)*

EN ISO 7090, *Plain washers, chamfered — Normal series — Product grade A (ISO 7090:2000)*.

EN ISO 12100-1, *Safety of machinery — Basic concepts, general principles for design — Part 1: Basic terminology, methodology (ISO 12100-1:2003)*.

EN ISO 12100-2, *Safety of machinery — Basic concepts, general principles for design — Part 2: Technical principles (ISO 12100-2:2003)*.

EN 30042, *Arc-welded joints in aluminium and its weldable alloys — Guidance on quality levels for imperfections (ISO 10042:1992)*.

EN 45004, *General criteria for the operation of various types of bodies performing inspection*.

EN 60204-1:1997, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements (IEC 60204-1:1997)*.

EN 60204-32, *Safety of machinery — Electrical equipment of machines — Part 32: Requirements for hoisting machines (IEC 60204-32:1998)*.

EN 60947 (all parts), *Low-voltage switchgear and controlgear*.

EN 61496-1, *Safety of machinery — Electro-sensitive protective equipment — Part 1 : General requirements and tests (IEC 61496-1:1997)*.

prEN 61496-2, *Safety of machinery — Electrosensitive protective equipment — Part 2 : Particular requirements for equipment using active optoelectronic protective devices (IEC 61496-2:-)*.

EN 61558-1, *Safety of power transformers, power supply units and similar — Part 1: General requirements and tests (IEC 61558-1:1997, modified)*.

ENV 1991-2-3, *Eurocode 1: Basis of design and actions on structures — Part 2-3: Actions on structures — Snow loads*.

ENV 1991-2-4:1995, *Eurocode 1: Basis of design and actions on structures — Part 2-4: Actions on structures — Wind actions*.

ENV 1992 (all parts), *Eurocode 2: Design of concrete structures*.

ENV 1993 (all parts), *Eurocode 3: Design of steel structures*.

ENV 1995-1-1, *Eurocode 5: Design of timber structures — Part 1-1: General rules and rules for buildings*.

ENV 1997-1, *Eurocode 7: Geotechnical design — Part 1: General rules*.

ISO 3755, *Cast carbon steels for general engineering purposes*.

ISO 6309, *Fire protection — Safety signs*.

ISO 7413, *Hexagon nuts for structural bolting, style 1, hot-dip galvanized (oversized tapped) — Product grades A and B — Property classes 5, 6 and 8*.

IEC 60364-4-41, *Electrical installations of buildings — 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 — Chapter 54: Earthing arrangements, protective conductors and protective bonding conductors*.

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety related systems*.

3 Terms and definitions

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

3.1

amusement device

any ride, structure, textile, or membrane structure or device, side stall, side show, tent constituting part of a ride, booths, grandstands, etc. which can be installed repeatedly without degradation or loss of integrity as well as temporarily or permanently at fairs, parks or any other locations

3.2

independent inspection body

any independent organisation capable of carrying out third party review, approval, examination and tests of amusement devices

3.3

initial approval

design and calculation review, verification, examinations and tests executed by the independent inspecting body before a ride is first made available for public use

3.4

log book

book or file containing all the necessary information about the use and history of any amusement device, including its design and initial approval

3.5

permit

authorisation to operate an amusement device in a particular member state granted by the legally authorised body after successful approval or examination

3.6

independent thorough examination

procedures and investigations necessary for the independent inspection body to decide whether the amusement device is in such a condition that it can continue to be operated safely, or whether it requires defects to be remedied immediately or within a specified time

3.7

licensing body

any national authorities or bodies legally authorised to issue a permit for operation of an amusement device and its log book

3.8

modification

any alteration to the hardware or software of an amusement device, including the introduction of a new safety critical component or the substitution of a safety critical component, which results in a deviation from the design specification

3.9

repair

restoration of safety critical components or safety critical assemblies to an acceptable condition by the mending of worn, damaged or decayed parts, which does not result in a deviation from the design specification of the original parts

3.10

safety critical component

any type of component of an amusement device on which the safety of the passengers is dependent

3.11

passenger containment

components (for example seating, footwells, handrails and passenger restraints) designed to prevent passengers from moving outside a predetermined area on a ride either as a result of the ride forces or the behaviour of the passenger

3.12

passenger unit

part or parts of an amusement device in or on which the public is intended to ride

3.13

platform

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

3.14

operator

person appointed by the controller to be in charge of the operation of an amusement device at all times when it is intended to be available for the public

3.15

attendant

any person appointed to work under the control or direction of an operator, to assist in the operation of an amusement device available for use by the public

3.16

controller (ride controller)

person or organisation having overall control of an amusement device. This may be either an individual or corporate body owning an amusement device or the concessionaire or lessee who has been granted control of the device, by the owner, for a specified period

3.17

daily check

operational check made before the device is made available to the public, to determine whether or not an amusement device is in such condition that it may continue to be operated safely

3.18

trial run

proving run of an amusement device during which no passengers are carried

3.19

service

replacement or replenishment of components, including fluids which are designated to be replaced or replenished at specified intervals

4 Symbols

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

5 Common requirements for design analysis and examination

5.1 Design documents

5.1.1 General

The construction documents include all the documents required for the assessment of the stability and operational safety of the amusement device. They shall be provided for any subsequent approval by the independent inspecting 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.

5.1.2 Description of design and operation

The amusement device, in particular its design, mode of utilisation 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 amusement 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.

5.1.3 Design and manufacturing drawings

These are required for all assemblies, subassemblies and individual components, the fracture or failure of which might endanger the stability or operational safety of the 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:

- general drawings in plan view, elevation and sections, in a legible scale, depending on the size of the amusement 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 could 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 up stop wheels, bearings, axles, shafts and their attachment, liberty of movement in relation to the vehicle, steering and control, anti roll back 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.

5.1.4 Principles of analysis

5.1.4.1 Verification shall comprise the following:

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

- dynamic analysis.

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

- design loads, taking into account the possible operating conditions or installation alternatives. 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 listed for demarcation;
- 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, samples, the testing procedure, the reporting, etc., according to the relevant European Standard or in absence of those to equivalent national standards;
- details of elastic deformations (flexure, torsion), in as much as 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 5.6.3.2.

5.2 Selection of materials

5.2.1 General

Only materials in respect of which design data are featured in European Standards for buildings may be used for structural components.

Other materials may only be used on condition that proof of their serviceability has been established. The designer shall give special consideration to structural joints which are to be welded and the weldability of the selected metals in accordance with European Standards.

5.2.2 Recommended steels

5.2.2.1 Steels for structural components:

- S235JRG2 in accordance with EN 10025
- S275JR in accordance with EN 10025
- S355JO in accordance with EN 10025
- GS-52 in accordance with (ISO 3755)¹⁾
- 2 C 35 in accordance with EN 10083-1¹⁾

5.2.2.2 Steels for machine components:

- S235JRG2 in accordance with EN 10025
- S355JO in accordance with EN 10025

—	E 295	in accordance with EN 10027 (all parts) ¹⁾
—	E 335	in accordance with EN 10027 ¹⁾ (all parts)
—	E 360	in accordance with EN 10027 (all parts) ¹⁾
—	2 C 22	in accordance with EN 10083-1 ¹⁾
—	16MnCr5	in accordance with EN 10084 ¹⁾
—	20MnCr5	in accordance with EN 10084 ¹⁾
—	2 C 45	in accordance with EN 10083-1 ¹⁾
—	2 C 60	in accordance with EN 10083-1 ¹⁾
—	34CrNiMo6	in accordance with EN 10083-1 ¹⁾
—	41Cr4	in accordance with EN 10083-1 ¹⁾
—	42CrMo4	in accordance with EN 10083-1 ¹⁾
—	51CrV4	in accordance with EN 10083-1 ¹⁾
—	GS-45.3	in accordance with ISO 3755 ¹⁾

Other steel grades for which technological material data (mechanical and chemical properties) are featured in European Standards or in absence of those in equivalent national standards may also be used.

5.2.3 Aluminium alloy

Aluminium alloys shall be selected in accordance with EN 573-3 or other European Standards or equivalent national standards.

For members and fasteners aluminium alloys with a ratio $f_{0,2\%}/f_u > 0,85$ and an elongation (rupture) of less than $\varepsilon \leq 8\%$ shall not be used.

5.2.4 Timber

Selection of timber shall be in accordance with the standards referred to in ENV 1995-1-1.

5.2.5 Plastic composites

Selection of plastic composites shall be in accordance with European Standards, or in absence of those, to national standards for structural use of plastic composites.

5.2.6 Concrete

The selection of concrete grade shall be in accordance with ENV 1992 (all parts) for structural use of concrete.

5.2.7 Fasteners

Screws and bolts shall be selected from property classes 4.6, 5.6, 6.8, 8.8 and 10.9 in accordance with EN ISO 898-1.

1) Not for welded parts.

Rivets shall be selected according to European Standards or in their absence to national standards.

Blind rivets shall be selected according to European Standards or in their absence, to national standards, or when their capacity for the assigned purpose is experimentally proven in accordance with ENV 1993-1-1 and 5.1.4.2.

5.3 Design loads

5.3.1 General

In general all the applicable actions shall be chosen in accordance with ENV 1991 (all parts). Adaptations, due to the special nature of amusement devices, are stated hereafter.

5.3.2 Permanent actions

For amusement devices in general a very precise assumption of the permanent actions is possible. Where variations can occur, the values G_{kh} and G_{kl} shall be taken into account when assessing the most likely structural response. Elsewhere a single characteristic value G_k is sufficient.

- G_k characteristic value of permanent action
- G_{kh} upper characteristic value
- G_{kl} lower characteristic value

Included in the above values is the actual dead load of the load bearing structure, the accessories and the technical equipment required for operation, including cladding, fabrics and other decorative elements. The wet and dry condition of material is accounted for in G_{kh} and G_{kl} .

The permanent actions shall be determined in accordance to ENV 1991 (all parts). The actual weight of machine components, electrical equipment, carriages, gondolas and the like shall be verified.

5.3.3 Variable actions

5.3.3.1 Imposed loads

5.3.3.1.1 General

These 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 may vary in magnitude, direction and point of application (variation in time and space) during normal operation.

5.3.3.1.2 Vertical imposed loads

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

- For each person over 10 years of age
 - $Q_k = 0,75$ kN for all fatigue calculations and for units with two or more passengers;
 - $Q_k = 1,0$ kN for units with one passenger (for static stress calculation only);
- For each person of 10 years or less
 - $Q_k = 0,40$ kN in both cases.

Where the reduced loadings for person of 10 years or less are employed there may be need to refer to 7.4.7.4.

5.3.3.1.2.2 The following vertical imposed loads shall be applied for any area designed for access by foot

Universal, 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, their stairways and landings; and as a superior value, if particularly dense crowds are anticipated for the above mentioned categories.

$$q_k = 2 \text{ kN/m}^2$$

for the revolving or boom area walked on by the public during operation (load and unload); or twice the full passenger load of all carriages according to 5.3.3.1.2.1, whichever is the more unfavourable, in order to make the necessary allowance for change of passengers.

$$Q_k = 1 \text{ kN per step}$$

for stairs; alternatively, an area load in accordance with above clauses, whichever is the more unfavourable.

$$q_k = 1,5 \text{ kN/m}$$

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 for public access:

$$q_k = 1,5 \text{ kN/m}^2$$

for all floors, platforms, ramps, staircases, catwalks, stages and the like which are walked over by individual persons or $Q_k = 1,5 \text{ kN}$ individual load, whichever is the more unfavourable.

5.3.3.1.3 Horizontal imposed loads

5.3.3.1.3.1 The following horizontal imposed loads shall be applied for 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 $q_k = 5,0 \text{ kN/m}^2$:

- $p_k = 1 \text{ kN/m}$
- 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.

5.3.3.1.3.2 In order to achieve an adequate longitudinal and transverse stiffness in the case of grandstands and similar installations with seating or standing accommodation, a horizontal load acting at floor level in the most unfavourable direction in each case shall be entered in the calculation in addition to any eventual wind force in accordance with 5.3.3.4. This horizontal component load shall be taken as 1/10th of the imposed vertical load in accordance with 5.3.3.1.2.2.

5.3.3.2 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 etc.), and they shall be entered in the calculation at these values. 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 shall be calculated according to the actual brake and motor performance (acceleration/deceleration)

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

where

- B is braking/starting force;
- a_b is braking/starting acceleration;
- m_v is mass of moving parts without passengers;
- m_p is total mass of passengers according to 5.3.3.1.2.1.

In the case of circular movements the appropriate parameters shall be applied in the formula. 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 also 5.3.5.1).

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.

5.3.3.3 Bracing and restraint loads

Such loads shall be taken into account when designing passenger restraints and containment, railings and bracing devices within 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. However, forces used in any calculations should never be less than 500 N per person.

5.3.3.4 Wind loads

5.3.3.4.1 Wind loads in general

The wind loads are based on ENV 1991-2-4, adapted to the special nature of amusement devices with regard to the following:

- location;
- duration and period of installation;
- use under supervision of an operator;
- possibilities of protection and strengthening.

The values in Table 1 may be applied for the "average" ride or structure used in areas where the reference wind speed according to the maps in Annex A of ENV 1991-2-4:1995 is $v_{ref,0} \leq 28$ m/s (in out-of-service condition of the ride or structure) and when the ride operation is shut down at a wind speed of $v_{ref} \geq 15$ m/s (in-service condition).

The ride or structure needs to be sheltered or suitably strengthened when actual wind speeds attain $v_{actual} \geq 25$ m/s at a height of 10 m.

In calculating the values in Table 1 the following assumptions have been made:

- $v_{ref(p)} = 0,85 v_{ref,0}$ for "out of service wind" (approximated 5 year return period);
- $c_{tem} = 0,80$ (for heights from 0 to 20 m for out of service loads), which is intentionally applied due to the fact that protection, reinforcement and sheltering is possible (the designer shall specify the means of sheltering and strengthening).

The ride or structure shall not be susceptible to dynamic response since a dynamic factor of $c_d = 0,90$ (not susceptible to dynamic response) has been used to establish values in Table 1.

The following further assumptions have been used to establish values in the table $c_{dir} = 1,0$, $c_{alt} = 1,0$, $c_t = 1,0$, terrain category III.

For any other location where $v_{ref,0} > 28$ m/s (according to the maps in Annex A of ENV 1991-2-4:1995 or due to local situation or the height above sea level) calculations shall be provided for the ride or structure confirming the stability under local conditions. The design calculations shall confirm that suitable means have been adopted in accordance with the particular situation.

Table 1 — Wind pressure values for amusement devices

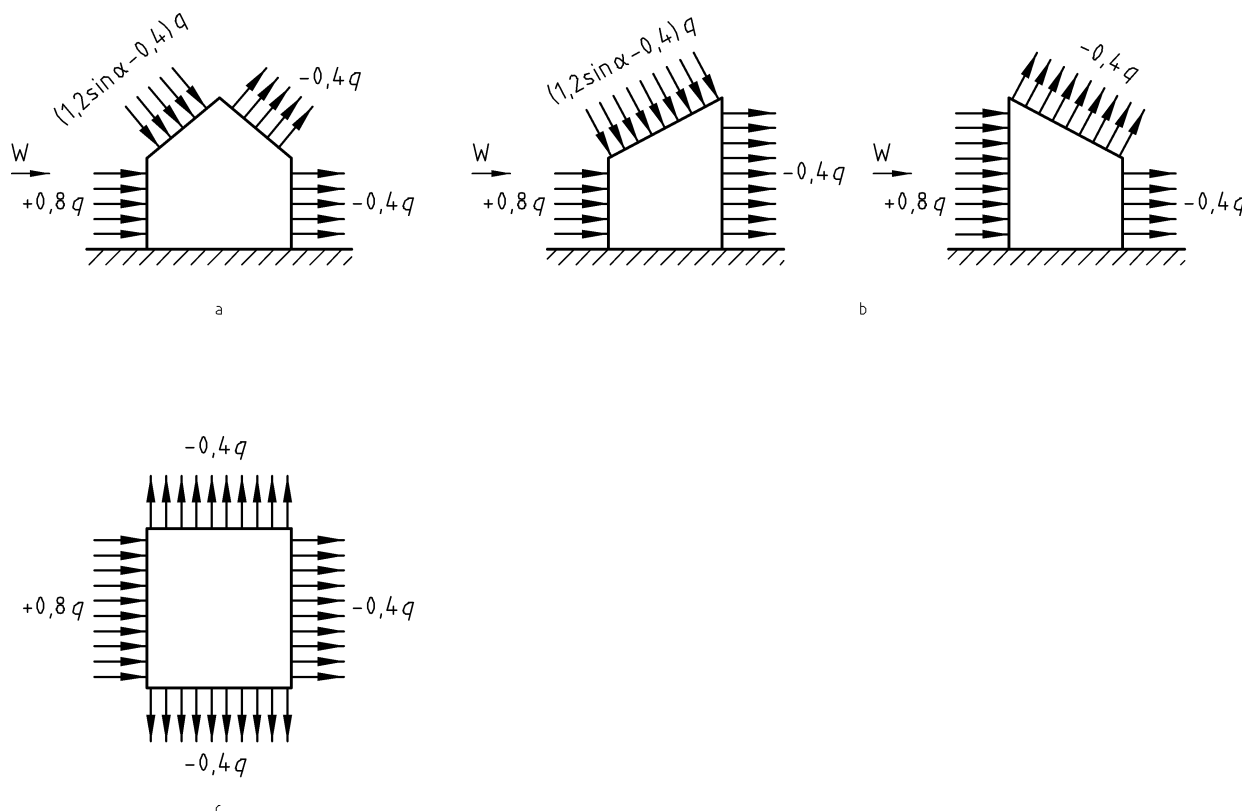
Height of the structure	Pressure $q_{eq} = q_{ref} \times ce(ze) \times c_d$ (kN/m ²) for reference wind speed	
	$v_{ref} \leq 15$ m/s (in service)	$v_{ref,0} \leq 28$ m/s (out of service)
0 ≤ 8 m	0,20	0,35
8 ≤ 20 m	0,30	0,50
20 ≤ 35 m	0,35	0,90
35 ≤ 50 m	0,40	1,00

The wind load on a given surface may be evaluated by the application of the above values in the following formulae:

$$F_w = q_{eq} \times c_f \times A_{ref} \quad (2)$$

For exposed sites (e. g. coastal and alpine sites, that are not terrain category III have different topography and roughness) the wind loads of ENV 1991-2-4 shall be applied using the appropriate local roughness and topographic coefficients, etc.

In general the shape factors for various structures and structural members shall be taken from ENV 1991-2-4.



Key

"c" to be applied for "a" and "b"

Figure 1 — Aerodynamic coefficients for structures of conventional shape

5.3.3.4.2 Wind loads in service

The wind load for operating conditions may be calculated using the pressure given in column 2 of Table 1. Operation shall be stopped if the wind velocity exceeds $v_{10} = 15$ m/s (measured in a height of 10 m). The wind load area from the imposed load (e. g. passengers envelope) shall be taken into account in the calculation.

5.3.3.5 Snow loads

Snow loads shall be applied in accordance to ENV 1991-2-3.

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

- erected 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 may 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 amusement 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;
- the cladding is made and tensioned in such a way, that ponding of water cannot take place.

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

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

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

Inertia forces shall be determined according to the prevailing circumstances in each case; see for example Annex B for the calculation of these forces on different ride types.

5.3.3.7 Intentional collision during operation

The effects of collision loads need 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} in kg).

If collision can only occur at angles $\alpha \leq 90^\circ$, the collision force F (in N) shall be assumed to be $F = 9,81 \times m_{\text{tot}} \times \sin \alpha$ (m_{tot} in kg), but in any case the value for the calculation shall be not less than $0,3 \times 9,81 \times m_{\text{tot}}$.

Where collision is not intended to be part of the ride design or purpose collision shall be assumed to be an accidental action (see 5.3.6.3).

5.3.4 Seismic forces

Seismic forces need only be considered by special request; they do not need to be combined with wind load cases.

5.3.5 Applicable coefficients for impacts, the vibration of structural components directly travelled over and collisions

5.3.5.1 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 5.3.3.2 in this respect.

5.3.5.2 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 may be required in order to reduce or attenuate inadmissible vibrations (e. g. resonance).

5.3.6 Load combinations

5.3.6.1 General

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

5.3.6.2 Fundamental combinations

The design values of the actions shall be combined in the following way:

$$\Sigma \gamma_G G_k \quad (= \Sigma 1,35 G_k) \quad (3)$$

$$\Sigma \gamma_G G_k + \Sigma \gamma_Q Q_{k,i} \quad (= \Sigma 1,1 G_k + \Sigma 1,35 Q_{k,i}) \quad (4)$$

Both cases shall be checked, where

$\gamma_G = 1,1$ or $1,35$ partial safety factor for permanent actions;

$\gamma_Q = 1,35$ partial safety factor for variable actions;

G_k characteristic value of permanent actions;

$Q_{k,i}$ characteristic value of one of the variable actions.

5.3.6.3 Accidental combination

$$1,0 \times G_k + A_d + \Sigma 1,0 \times Q_{k,i} \quad (5)$$

where

$Q_{k,i}$ characteristic value of the variable actions.

A_d design value of the accidental actions.

Accidental actions (e. g. seismic forces) need only be considered by special request. In such cases formula (5) shall be applied.

5.3.6.4 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 of not less than $\gamma_{fr} = 1,00$. No combination factors shall be applied.

γ_{fr} partial safety factor for fatigue actions.

5.4 Structural analysis – Principles

5.4.1 General

The limit states resulting from all different actions shall be determined separately for the individual actions given in 5.3. It shall be verified that no relevant limit state exceeds the design properties. The limit states due to the combinations of actions shall be calculated. 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 5.1.4.2.

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 methods of the theory of 2nd order 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 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 in accordance with European Standards or ISO standards. The sources of such formulae shall be stated, if this source is 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 the software, formulae, units, etc. 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 software. The correctness of the assumptions regarding the input and the output data shall be comprehensively reviewed during design approval.

Design resistance shall be evaluated in accordance with the formula (6).

$$R_d = R_k / \gamma_M \quad (6)$$

where

R_d design value of material properties;

R_k characteristic value of material properties;

$\gamma_M = 1,1$ partial safety factor for material property in static load combinations;

γ_{Mf} partial safety factor for material property in fatigue load combinations (see Table 5).

For materials other than steel the γ_M - values stated in the respective European Standard shall be used.

5.4.2 Analysis principles for various types of rides

5.4.2.1 Conditions for calculating rotating type devices

Amusement rides shall be calculated in operative, inoperative, fully loaded, partially loaded and unbalanced conditions. One-sided loading shall be assumed as meaning that at only those seats which are situated on $\frac{1}{4}$ or $\frac{3}{4}$ 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 $\frac{1}{6}$ th 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 $\frac{5}{6}$ th

of the perimeter (see also 5.6.3.5.1). 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_{St} (stabilizing moment) and M_{Ky} (overturning moment) takes into account the partial safety factors according to Table 2.

If an amusement 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.

5.4.2.2 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 (such as 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.

5.4.2.3 Roundabouts with several motions

5.4.2.3.1 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 may arise. In such roundabouts when there are no angular accelerations and the rotor is well approximated to a top about its spin axis the rigid body moment is:

$$M_{Kr} = \sin \alpha \left[I_3 \omega \omega_p + (I_3 - I_2) \omega_p^2 \cos \alpha \right] \quad (7)$$

where

α angle between spin and precession axes;

I_3 moment of inertia of rotor about its spin axis;

I_2 moment of inertia of rotor about an orthogonal axis.

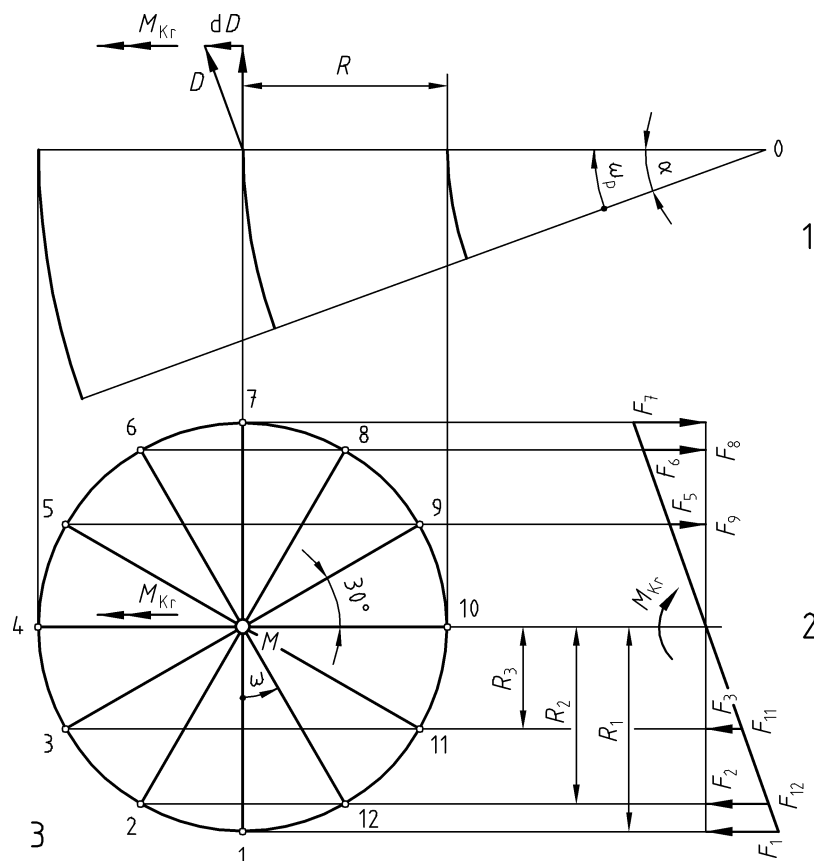
Note also that ω and ω_p may be positive or negative (according to the right hand screw rule).

In the case of a flat shaped rotor and $\alpha = 90^\circ$ the following simplified equation results:

$$\text{Rigid body moment } M_{Kr} = I_3 \times \omega \times \omega_p \quad (8)$$

The resultant load per outrigger from the rigid body moment is:

$$F_i = M_{Kr} \frac{R_i}{\sum_i R_i^2} \quad (9)$$



Key:

- 1 Front view
- 2 Side view
- 3 Top view

D tTwist;

dD Rate of change of twist;

M_{Kr} Rigid body moment;

R_1 Radius;

ω Angular velocity about the spin axis;

ω_p Angular velocity of precession.

Figure 2 — Example for the determination of the rigid body moment and its influence on a slewing gear with 12 outriggers, rotating at an angular velocity ω , and slew angle α

5.4.2.3.2 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) may be calculated by using Figure 3:

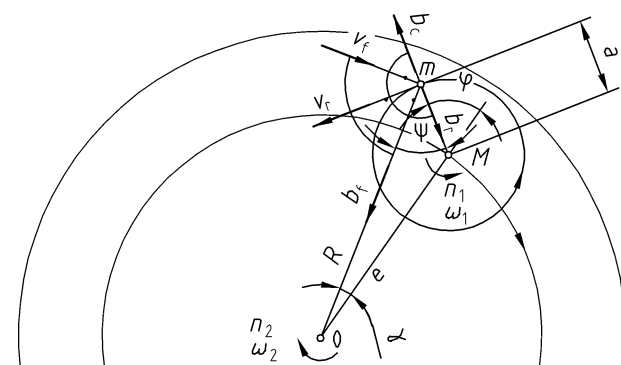


Figure 3 — Velocities and accelerations of mass point m

In Figure 3 is:

M the centre point of rotation in a circle;
 O the stationary centre point of rotation;
 Without subscript – absolute value.

Meaning of the subscripts:

f guided;
 r relative;
 c Coriolis acceleration.

Velocities:

$$\vec{v} = \vec{v}_f + \vec{v}_r \quad (10)$$

$$\vec{v} = \vec{R} \omega_2 \quad (11)$$

$$\vec{v} = \vec{a} \omega_1 \quad (12)$$

$$\vec{R} = \vec{e} + \vec{a} \quad (13)$$

$$R = \sqrt{[e + a - (a - a \cos \varphi)]^2 + [a \sin \varphi]^2} \quad (14)$$

$$= \sqrt{e^2 + 2 e a \cos \varphi + a^2}$$

$$v_{r \parallel \varphi_0} = -v_r \sin \varphi \quad (15)$$

$$v_{r \perp \varphi_0} = +v_r \cos \varphi \quad (16)$$

$$v_{f \parallel \varphi_0} = -+v_f \sin \gamma \quad (17)$$

$$v_{f \perp \varphi_0} = -v_f \cos \varphi \quad (18)$$

$$\sin \gamma = \frac{a \sin \varphi}{\sqrt{e^2 + 2 e a \cos \varphi + a^2}} \quad (19)$$

$$\cos \gamma = \frac{e + a \cos \varphi}{\sqrt{e^2 + 2 e a \cos \varphi + a^2}} \quad (20)$$

$$v = \sqrt{(\sum v_{\parallel f_0})^2 + (\sum v_{\perp f_0})^2} \quad (21)$$

Direction of v :

$$\cot \delta = \frac{v_{\parallel f_0}}{v_{\perp f_0}} \quad (22)$$

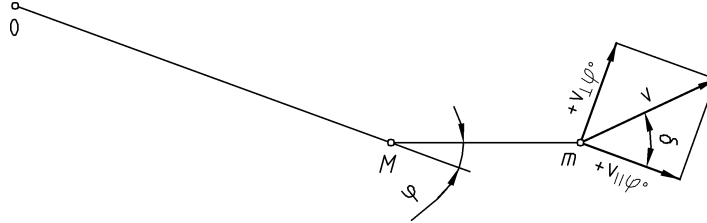


Figure 4 — Resolution of velocity v

Accelerations:

$$\vec{b} = \vec{b}_f + \vec{b}_r + \vec{b}_c \quad (23)$$

$$b_f = R \omega_2^2 \quad (24)$$

$$b_r = a \omega_1^2 \quad (25)$$

$$b_c = 2 \omega_2 v_r \quad (26)$$

$$b_n = b_r - b_c + b_f \cos \psi \quad (\text{normal}) \quad (27)$$

$$b_t = b_f \sin \psi \quad (\text{tangential}) \quad (28)$$

$$R \sin \psi = e \sin \varphi \quad (29)$$

$$\sin \psi = \frac{e}{R} \sin \varphi \quad (30)$$

$$R \cos \psi = e \cos \varphi + a \quad (31)$$

$$\cos \psi = \frac{e \cos \varphi + a}{R} \quad (32)$$

$$b = \sqrt{b_n^2 + b_t^2} \quad (33)$$

The above derivations are only valid when ω_1 , is in the opposite direction to ω_2 .

If ω_1 has the same direction of rotation as ω_2 in Figure 3, the direction of b_c will be reversed.

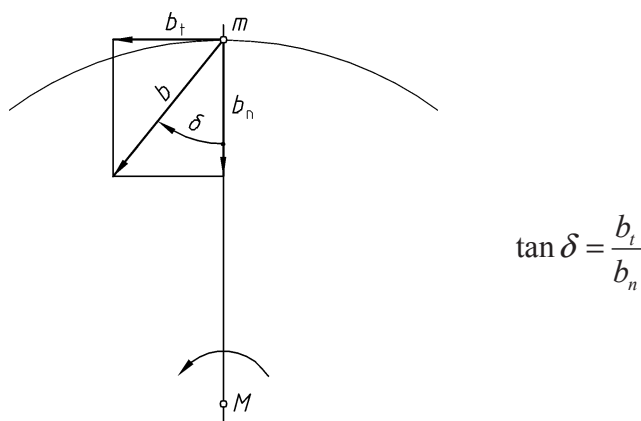


Figure 5 — Direction of acceleration Direction of acceleration b

5.4.2.3.3 Roundabouts with outriggers running on rail tracks

5.4.2.3.3.1 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 torsional 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.

5.4.2.3.3.2 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 attain safety against overturning with partial safety factors in accordance with 5.5.1 the anchorage may be taken into consideration in the calculation.

5.4.2.3.3.3 Roundabouts with undulating track

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

5.4.2.3.3.4 Roundabouts with several rotation gears

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

In the case of rotary motions which are not positively actuated (i. e. free spinning and or passenger actuated), the effects of the individual rotation of the individual rotation gears shall be investigated. For boom type roundabouts (e. g. round-ups, twisters, hully-gullies), the gondolas of which may be raised, 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 5.4.2.1 shall be considered. Fatigue calculations in accordance with 5.6.3 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 6.3 shall be respected.

5.4.3 Roller coasters with rail track bound vehicles

5.4.3.1 Rail

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 in the most unfavourable case. This value also applies for the passenger unit with the highest speed in the case of trains. If the resultant force should fall below the above value, the passengers shall be secured against lift-off in accordance with 6.2.3.3.

The following formula may be used to determine the theoretical transverse inclination α of the rail, which makes the transverse force on the car zero for a particular speed:

$$\tan \alpha = \frac{v^2 \cos^2 \gamma}{R_h \left(g \cos \gamma + \frac{v^2}{R_v} \right)} \quad (34)$$

The angle α shall be measured at right angles to R_h and to the rail.

In formula (34) is

v the velocity of car;

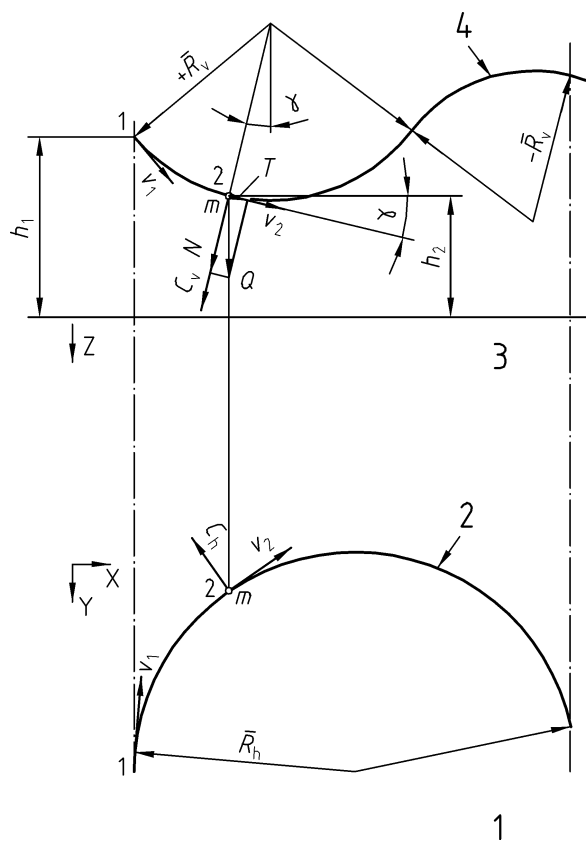
γ the longitudinal gradient of rail;

R_h the horizontal radius;

R_v the vertical radius; (+ trough; – peak).

Use "+" if C_v is directed such as to compress the car to the track and "–" if C_v is directed to uplift the car from the track.

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°. The path of the rail track shall be designed in such a way, that the instantaneous theoretical steps in acceleration do not exceed 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 in accordance with formula (47). Where there are multiple coupled cars the overall centre of mass may be used.



Key

- 1 Plan view
- 2 Rail axis
- 3 Elevation
- 4 Rail axis

Figure 6 — Elevation and plan view of the rail track

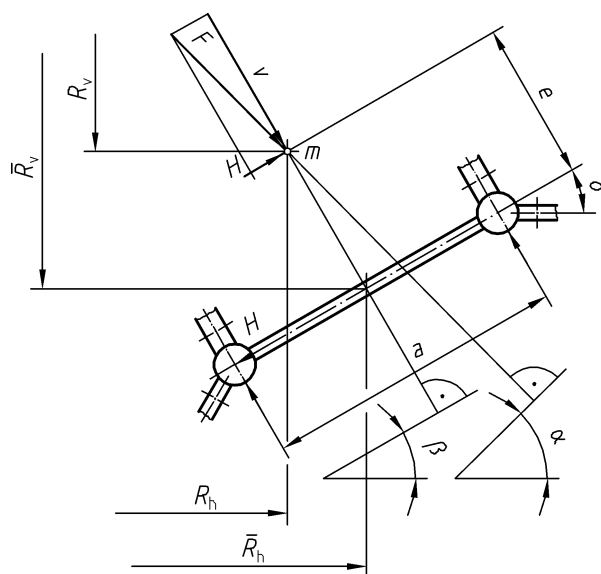


Figure 7 — Rail cross section of rail showing load and guide wheels

Key to symbols used in formulae 34 to 46:

a	wheel gauge;
e	distance of centre of gravity;
g	gravitational acceleration;
α	theoretical transverse inclination of rail;
β	actual transverse inclination of rail;
γ	longitudinal gradient of rail;
δ	guide roller angle;
$\vec{R}_v$	vertical radius of rail axis;
$\vec{R}_h$	horizontal radius of rail axis;
$\pm R_v$	vertical radius of the mass centre of gravity (+ trough; – peak); use + if C_v is directed such as to compress the car to the track and – if C_v is directed to uplift the car from the track. R_h horizontal radius of the mass centre of gravity;
C_v	vertical centrifugal force;
C_h	horizontal centrifugal force;
F_{res}	resultant load;
V	load from R perpendicular to the rail;
H	load from R in the plane of the rail;
μ_1	coefficient of friction between load wheels and rail;
$\overline{\mu}_1$	coefficient of friction between the guide wheels and rail;
f	lever arm of friction;
μ_2	coefficient of friction of the bearings;
A	projected surface area which the car presents to the wind;
c_f	shape coefficient;
h	(= $h_1 - h_2$) differential height;
Q	car load including passenger load;
m	mass;
D_1	diameter of load wheel;
D_2	diameter of guide wheel;
d_1	diameter of load wheel axle;

- d_2 diameter of guide wheel axle;
 v_1 velocity at point 1;
 v_2 velocity at point 2;
 l actual rail length from point 1 to point 2;
 h_1 elevation at point 1;
 h_2 elevation at point 2;
 ρ density of the air.

Formulae:

$$R_h = \bar{R}_h - e \sin \beta \quad (35)$$

$$R_v = \bar{R}_h - e \cos \beta \quad (36)$$

In regions where the track has rapid roll the equations for R_h and R_v may become inaccurate in which case a more careful assessment will be necessary.

$$m = \frac{Q}{g} \quad (37)$$

$$C_v = m \frac{v_m^2}{R_v} \quad (38)$$

$$C_h = m \frac{v_m^2 \cos^2 \gamma}{R_h} \quad (39)$$

$$v_m = \frac{v_1 + v_2}{2} \quad (40)$$

$$F = \sqrt{(Q \cos \gamma + C_v)^2 + C_h^2} \quad (41)$$

$$V = F \cos (\alpha - \beta) \quad (42)$$

$$H = F \sin (\alpha - \beta) \quad (43)$$

$$\tan \alpha = \frac{v_m^2 \cos^2 \gamma}{R_h \left(g \cos \gamma + \frac{v_m^2}{R_v} \right)} \quad (44)$$

Friction coefficients:

$$\mu_1 = \frac{2f}{D_1} \quad (45)$$

$$\bar{\mu}_1 = \frac{2f}{D_2} \quad (46)$$

All forces are related to the centre of the interval, and the interval length shall not exceed 5 m.

$$v_2^2 = v_1^2 + 2g h - c_f A \rho v_m^2 \frac{l}{m} - \left(\mu_1 + \mu_2 \frac{d_1}{D_1} \right) \frac{2l}{m} (V + |H| \tan \delta) - \frac{|H|}{\cos \delta} \left(\bar{\mu}_1 + \mu_2 \frac{d_2}{D_2} \right) \frac{2l}{m} \quad (47)$$

If all values are inserted:

$$\begin{aligned} v_2^2 = & v_1^2 + 2g \times h - c_f \times A \times \rho \times v_m^2 \times \frac{1}{m} - \sqrt{\left(Q \times \cos \gamma + m \frac{v_m^2}{R_v} \right)^2 + \left(m \frac{v_m^2 \times \cos^2 \gamma}{R_h} \right)^2} \\ & \times \cos \left[\arctan \frac{v_m^2 \times \cos^2 \gamma}{R_h \left(g \times \cos \gamma + \frac{v_m^2}{R_v} \right)} - \beta \right] \times \left(\mu_1 + \mu_2 \frac{d_1}{D_1} \right) \frac{2 \times l}{m} \\ & - \frac{1}{\cos \delta} \sqrt{\left(Q \times \cos \gamma + m \frac{v_m^2}{R_v} \right)^2 + \left(m \frac{v_m^2 \times \cos^2 \gamma}{R_h} \right)^2} \times \sin \left[\arctan \frac{v_m^2 \times \cos^2 \gamma}{R_h \left(g \times \cos \gamma + \frac{v_m^2}{R_v} \right)} - \beta \right] \\ & \times \left(\bar{\mu}_1 + \mu_2 \frac{d_2}{D_2} \right) \frac{2 \times l}{m} - \tan \delta \sqrt{\left(Q \times \cos \gamma + m \frac{v_m^2}{R_v} \right)^2 + \left(m \frac{v_m^2 \times \cos^2 \gamma}{R_h} \right)^2} \\ & \times \sin \left[\arctan \frac{v_m^2 \times \cos^2 \gamma}{R_h \left(g \times \cos \gamma + \frac{v_m^2}{R_v} \right)} - \beta \right] \times \left(\mu_1 + \mu_2 \frac{d_1}{D_1} \right) \frac{2 \times l}{m} \end{aligned} \quad (48)$$

The formula shall be evaluated by iteration with

$$v_m = \frac{v_1 + v_2}{2} \quad (49)$$

In the first iteration v_m can be set equal to v_1 .

Because the friction coefficients are liable 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 will be necessary to carry out a measurement of the actual velocity and accelerations. There shall be no significant discrepancy when compared with the calculated values. To determine the individual wheel forces additional calculations will be necessary. For high speed track having tight loops or helices the need for rigid body dynamics shall be considered.

5.4.3.2 Supporting framework

If the calculation is based on a continuous rail track above the support columns, a column settlement by virtue of the reduction by 50 % of the moment at support, and a column heightening by virtue of the increase by 25 % of the moment at support shall be assumed. The increase or reduction of these moments need not be taken into consideration for the verification of fatigue in view of the low numbers of cycles anticipated.

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.

5.4.3.3 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.

5.4.3.4 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 $5,0 \text{ m/s}^2$, as a general rule 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 one brake between any two cars.

Each safety brake shall be designed in such a way that the braking deceleration does not exceed a maximum value of $7,0 \text{ m/s}^2$.

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 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 and wear. If the actuating force has to be increased in order to compensate for varying friction coefficients (ignoring small changes as a result of wear), this shall be taken into consideration. The limiting values shall be checked on the finished installation. During such tests the minimum friction shall be produced as far as is possible with wet rails. In any event the brake surfaces shall be tested, for example by wetting with water.

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

2) Greater deceleration is permitted on condition that special devices for the protection (lap bars, etc.) of the passenger are provided.

5.4.3.5 Anti-roll-back 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.

If it is planned that several cars or trains are to be present 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 one 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.

Moreover if there are several cars or trains 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 blockzone system, with automatically controlled brakes.

The vertical elevation H up to the beginning of the anti roll back device, or the maximum speed which can arise during running back shall not exceed the following limiting values. At least one of the following three limiting values shall be complied with:

$H = 7 \text{ m}$, $v = 42 \text{ km/h}$ for a straight line backward run without transverse rail inclination, when viewed from above:

$H = 5 \text{ m}$, $v = 35 \text{ km/h}$ for a backward run on a wide sweep curve with a transverse rail inclination up to 20° ;
 $H = 3,5 \text{ m}$, $v = 30 \text{ km/h}$ for a backward run on a sharper bend, with a transverse rail inclination exceeding 20° .

Two values shall be specified, because H is a function of the elevation of the centre of gravity of the train, and this elevation need not necessarily be the same as the elevation. Furthermore, the location on the train of the safety device against backward running is of importance for the above-mentioned limiting values.

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

The fatigue strength need not be verified for the anti-roll-back devices. If the car is stopped by the anti-roll-back device with a sudden impact then 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.

$$\varphi \geq 0,5 \times h \quad (50)$$

$$2,0 \leq \varphi \quad (51)$$

The two conditions above shall be satisfied.

If there is only one anti-rollback device without redundancy in one car or train the following formula shall be applied:

$$\varphi \geq 1 + \sqrt{1 + \frac{2h}{\delta_0 \sin \alpha}} \quad (52)$$

where

δ_0 total deflection of centre of mass along slope.

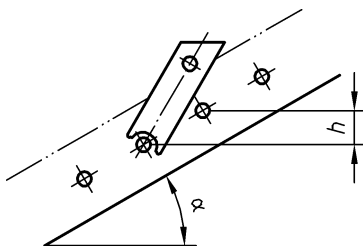


Figure 8 — Impact factor/running back elevation

5.4.4 Other railways with track bound vehicles

5.4.4.1 Conventional railways (e. g. children's railways, children's traffic gardens, ghost railways and similar installations, with both conventional and suspended vehicles).

The requirements outlined in 5.4.3 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.

5.4.4.2 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 (see 6.1.6.1).

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 borne in mind 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, if desired, 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 locking of pendulum gondolas for the purpose of passenger transfers can only be dispensed with on condition that no danger or inconvenience to passengers is caused by the adoption of other means (e. g. suitable dampers).

5.4.5 Grandstands

Grandstands shall be subjected to the verification of limit states in accordance with 5.1.4. Special attention shall be paid to the verification of safety against overturning, if the grandstands are for example roofed over, clad, or if numerous flags or banners are attached to the grandstands.

5.5 Verification of stability

5.5.1 Safety against overturning, sliding and lifting

5.5.1.1 Proof shall be provided of safety against overturning, sliding and lifting 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.

For foundations, ENV 1997-1 shall also be applied in addition to this sub-clause. A frost-free foundation for amusement devices is only required in cases where lifting or lowering/settling due to frost could 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 may be measured accurately this allows a more precise determination of the safety factors to be made:

Table 2 — Safety factor against overturning, sliding and lifting

Loading ^a		γ
1	Favourably acting proportions of the dead load	1
2	Unfavourably acting proportions of the dead load	1,1
3	Unfavourably acting wind loads	1,2
4	Unfavourably acting proportions of loads other than the loads listed in items 2 and 3	1,3
^a If loads are resolved into components, then these components shall be multiplied by the same value of γ .		

5.5.1.2 The safety against overturning shall be calculated from:

$$\sum \gamma M_{St,k} \geq \sum \gamma M_{K,k} \quad (53)$$

where

γ is the safety factor in accordance with Table 2;

$M_{St,k}$ are the stabilising moment values;

$M_{K,k}$ are the overturning moment values.

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

5.5.1.3 The safety against sliding shall be calculated from:

$$\sum \gamma \mu N_k \geq \sum \gamma H_k \quad (54)$$

where

γ is the safety factor in accordance with Table 2;

N_k is the vertical load component;

H_k is the horizontal load component;

μ is the coefficient of friction in accordance with Table 3.

The following coefficients of friction 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 — Coefficients of friction μ

	Wood	Steel	Concrete
Wood	0,4	0,4	0,6
Steel	0,4	0,1	0,2
Concrete	0,6	0,2	0,5
Clay ^a	0,25	0,2	0,25
Loam ^a	0,4	0,2	0,4
Sand and gravel	0,65	0,2	0,65
^a At least of stiff consistency in accordance with ENV 1997-1.			

It shall be borne in mind that loosening by vibration may occur in the case of supports subjected 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 3 shall only be entered in the calculation at 70 % of the listed values.

$$\sum \gamma \bar{\mu} N_k + Z_{h,d} \geq \sum \gamma \times H_k \quad (55)$$

$$\bar{\mu} = 0,7 \mu \quad (56)$$

where

$Z_{h,d}$ is the horizontal design capacity of the anchor (see 5.5.2);

μ is the coefficient of friction in accordance with Table 3.

5.5.1.4 Safety against lifting shall be calculated from:

$$\sum \gamma N_{St,k} \geq \sum \gamma N_{a,k} \quad (57)$$

where

γ is the safety factor in accordance with Table 2;

$N_{St,k}$ are the vertical stabilizing load components;

$N_{a,k}$ are the vertical lifting load components.

With anchor ties the following relationship shall be applied:

$$\sum \gamma N_{St,k} + Z_{v,d} \geq \sum \gamma N_{a,k} \quad (58)$$

where

$Z_{v,d}$ is the vertical design capacity of the anchor (see 5.5.2).

5.5.2 Ground anchorages

5.5.2.1 General

Uncertain soil conditions and the type of loading make it extremely difficult to assess the load bearing capacities of anchor ties accurately. Therefore the following approximation method should be used. This clause will therefore be restricted to:

- a) weight anchors, i. e. ballast bodies placed on the surface of the ground or buried;
- b) rod anchors, i. e. 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 applied for subordinate devices (e. g. inflatable devices, etc.) not required from the results of a calculation, loading tests or other acceptable evidence shall be provided.

5.5.2.2 Load bearing capacity of weight anchors

When calculating the load bearing capacity of fully or partially buried anchors, the passive earth pressure shall only be taken into account on 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.

5.5.2.3 Load bearing capacity of rod anchors

The 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 capacity of anchors

Angle of pull	Design capacity
$\beta = 0^\circ$	$Z_d = f_{\text{load}} d l' = 6,5 d l'$ (59)
	For stiff cohesive and for dense cohesionless soils
	$Z_d = f_{\text{load}} d l' = 8 d l'$ (60)
	For very stiff cohesive soils
$\beta \geq 45^\circ$	$Z_d = f_{\text{load}} d l' = 10 d l'$ (61)
	For cohesive soils of at least medium to stiff consistency
	$Z_d = f_{\text{load}} d l' = 17 d l'$ (62)
	For dense cohesionless soils
$0 < \beta < 45^\circ$	The design capacity for the soil types shall be determined by interpolation (see Figure 10).

In formulae (63) to (66) and in Figures 9 and 10 the following abbreviations are used:

$Z_d = Z_u / \gamma_M$ with $\gamma_M = 1,5$ the design capacity of anchor in N;

$Z_{h, d}$ the horizontal design capacity of anchor in N;

$Z_{v, d}$ the vertical design capacity of anchor in N;

d the anchor diameter, in cm;

l' the depth of penetration (minimum length 80 cm);

α the angle of penetration;

β the angle of acting tensile force to the vertical.

Formulae (63) to (66) 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 attain its maximum load bearing capacity, as shown by experience. 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:

$$d_{\min} = 0,025 l' + 0,5 \quad (\text{with } l' \text{ in cm}) \quad (63)$$

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.

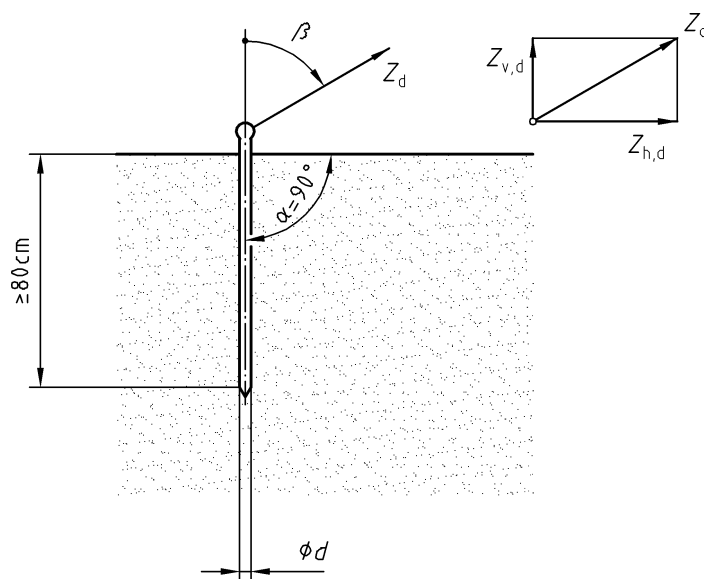
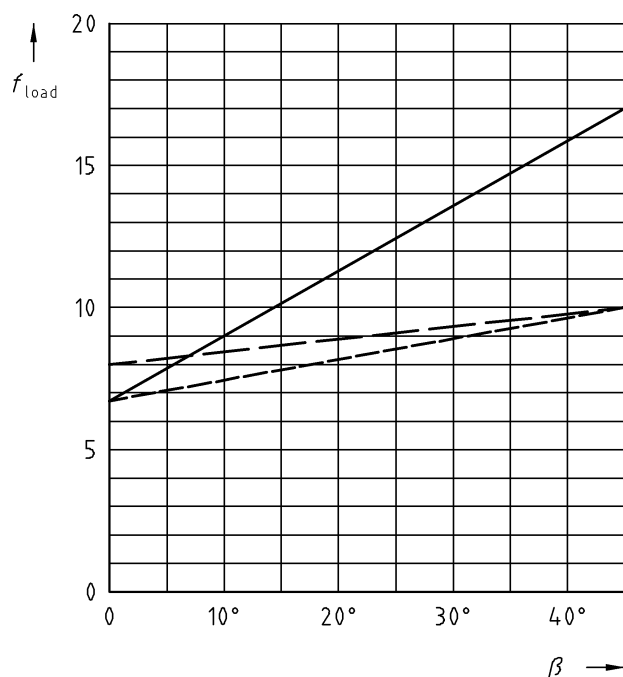


Figure 9 — Rod anchor



Key

- Dense cohesionless soils
- Very stiff cohesive soils
- Stiff cohesive soils
- β = Angle of pull

Figure 10 — Factors for determining the load bearing capacity of rod anchors

5.5.2.4 Testing of anchors

The calculated 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_d) in subsequent calculation. The load bearing capacity determined in this manner shall not result in anchor movement which would result in stresses, deformations or instability which cannot be accommodated by the structure.

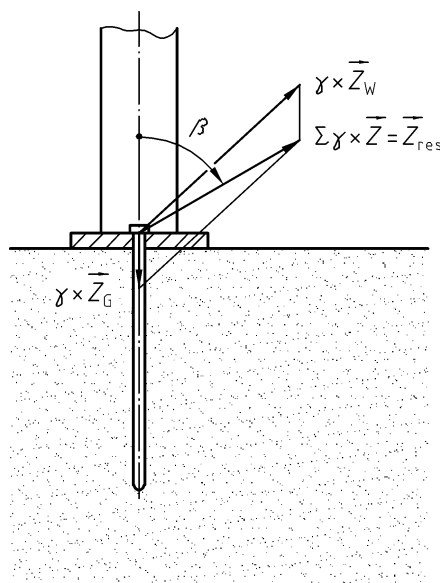
If the foundation conditions are comparable, loading tests carried out in another location may be adopted for substantiation purposes.

The safety coefficients featured in Table 2 shall be taken into consideration when determining the permissible load.

5.5.2.5 Calculation of loads on anchors

The resulting load Z_{res} acting on the anchorage shall be determined by vectorial summation, taking into account the partial safety factors shown in Table 2. This load Z_{res} shall be less than the permissible loading of the anchorage according to 5.5.2.3:

$$Z_{res} = \sum \gamma Z \leq Z_d \quad (64)$$



Key

Z_G is the favourably acting resultant of permanent actions;

Z_W is the unfavourably acting portion of variable actions;

γ is the safety factor in accordance with Table 2.

Figure 11 — Anchor loading

5.5.3 Further requirements

If displacements in excess of 2 cm occur on loaded rod anchors or similar devices, then the load bearing capacity of the anchor will no longer be fully assured. 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 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 6 anchors the load bearing capacity has to be verified. Without further verification an angle of excavation of 45° starting from the outer anchor may be assumed.

5.5.4 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 liable 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 permissible soil pressures may be used in the calculation for square and rectangular packing with dimensions:

$$1 \leq l/b \leq 3 \quad (65)$$

where

l length and

b 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 permissible soil pressure. Interpolation should be conducted for intermediate values.

For installation on hard (paved) locations, higher permissible soil pressures may be considered.

5.6 Verification of strength

5.6.1 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, $\min \sigma / \max \sigma \geq 0$) 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 may also be performed to relevant standards which are based on the $\max \sigma / \min \sigma$ concept if the minimum life time requirements in 5.6.3.4; or infinite life; can be demonstrated.

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. 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.

The particular standard (e. g. EC 3, FEM etc.) selected for the complete analysis of a ride shall be clearly specified and maintained.

5.6.2 Predominantly static stress

Permissible stresses of materials used for structural components shall be taken from those listed in ENV 1993 (all parts). With regard to general stress analysis of machinery components made of steel, including components which act simultaneously as structural components, the following relationships shall apply:

$$R_d \leq f_y / \gamma_{My} \quad \text{and} \quad R_d \leq f_u / \gamma_{Mu} \quad (66)$$

where

R_d is the design material resistance;

f_y is the yield strength according to EN-material standard;

f_u is the ultimate strength according to EN-material standard;

γ_{My} 1,1 partial safety factor (yield);

γ_{Mu} 1,35 partial safety factor (ult. tensile strength).

The smaller of the two values R_d above shall be used. For shear resulting from transverse force and torsion, the value R_d shall be multiplied by $\alpha = 0,58$.

5.6.3 Fluctuating stress

5.6.3.1 Fatigue assessment of structural components

In addition to ensuring that each component satisfies the ultimate limit states for non-fluctuating loads an assessment of fatigue life as a result of repeated fluctuation of stress shall be carried out. For steel, the principles of ENV 1993-1-1:1992, Clause 9 should be applied when the material, fasteners and welding consumables conform with the requirements specified in ENV 1993-1-1:1992, Clause 3. In Annex A some variations from ENV-1-1 are detailed, where this is more appropriate to amusement devices.

5.6.3.2 Partial safety factors for fatigue

For fatigue loads a partial safety factor shall be applied:

$$\gamma_{Ff} = 1,0 \quad (67)$$

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

Table 5 — Partial safety factors for fatigue resistance

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

5.6.3.3 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 values in 5.3.3.4.1, Table 1, column 2, if there is no other calculated critical value of the wind pressure due to the wind speed, at the natural frequency. For more exact evaluation of the need to carry out a fatigue check in the case of wind induced oscillation see ENV 1991-2-4.

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

- dead loads with change of position;
- moving imposed loads;
- driving and braking forces according to 5.3.3.2;
- load coefficients for impact and vibrations of parts directly travelled over;
- intentional collision forces;
- centrifugal and Coriolis forces.

Where there is movement of dead loads, when assessing $\Delta\sigma_i$ or $\Delta\tau_i$ (e. g. for lifted booms), the maximum and minimum stresses shall be calculated including dead loads:

$$\Delta\sigma_i = \max. \sigma - \min. \sigma$$

$$\Delta\tau_i = \max. \tau - \min. \tau$$

5.6.3.4 Number of stress cycles

If more precise assessment of the number of stress cycles for the different load ranges is not possible, the following values shall be used as a minimum:

At least 35 000 operating hours shall be assumed in the fatigue calculation of rides not including loading and unloading time. Mass-produced replaceable safety critical 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. A theoretical lifetime calculation shall be submitted. Although the ratio of loading/unloading time to total operational time can vary from ride to ride, a general value of loading/unloading time shall be limited to a maximum of 30 % of the total operational time. If at the design stage, more unfavourable values are found, these values shall be taken into account.

When using the above minimum operating hours the load cycles (given in Table 6) shall be assumed as a minimum if no higher values are identified as a result of the configuration of the ride.

Table 6 — Minimum load cycle requirement ($N_{\min}$) to be applied in calculation

Type of ride	For all constructional details submitted to fatigue calculation where –	
	– the number of rotations is decisive for the number of load cycles	– the number of ride cycles (load/unload time plus one ride) is decisive for the number of load cycles
coaster or similar (ride cycle time of $\Delta t = 30$ s approx.) for structure and track, etc.	not applicable	$N_{\min} \geq x_1 \times 5 \times 10^6$ load cycles x_1 multiplier for the number the train crosses over the location due to location of detail in the track or supporting construction (e.g. $x_1 = 1$ for one crossing / $x_1 = n$ for 'n' crossings of the train)
coaster or similar: for the vehicles, etc.	not applicable	$N_{\min} \geq x_2 \times 5 \times 10^6 / x_3$ load cycles x_2 multiplier due to the number of max. stress ranges along the track during one ride cycle (e.g. $x_2 = 1$ if the max. stress range appears only once for the vehicle during one full cycle) x_3 multiplier due to the number of trains in one track (ride)
rotational rides $n \approx 8$ to 20 rpm: for the mast or the centre, etc.	$N_{\min} \geq 5 \times 10^6$ no stress range higher than $\Delta\sigma_D$	
rotational rides $n \approx 8$ to 20 rpm: for the arms or the gondolas, etc		$N_{\min} \geq 2 \times 10^6$ equiv. stress range $\Delta\sigma_{E,2}$ not higher than $\Delta\sigma_C$

5.6.3.5 Load patterns

5.6.3.5.1 Roundabouts

For asymmetric loading the stress range due to 1/6- and 5/6-one-sided load according to 5.4.2.1 may be assumed for 100 % of fatigue life.

5.6.3.5.2 Track bound devices

The forces due to the action of anti-roll-back units and safety brakes need not be considered in fatigue life calculations.

Vehicles and trains shall be analysed by using the full, imposed load (6/6) for the complete fatigue life.

5.6.3.6 Fatigue strength of machined components

5.6.3.6.1 Determination of design stresses

For materials not listed in ENV 1993 (all parts), and for those not treated in that standard (e. g. machinery components) the determination of the design stresses in the case of fluctuating stress, shall be carried out in accordance with one of the calculation methods featured in specific standards or in recognised literature at the state of the art.

In this context, the following influences shall be taken into account:

- fatigue notch factor;
- influence of size;
- influence of surface;
- cross-sectional shape;
- corrosion factor;
- if applicable, anisotropy coefficient.

5.6.3.6.2 Determination of resulting stresses

The resulting stresses in machined components (nominal stresses) shall be determined in accordance with the general principles of stress analysis.

5.6.3.6.3 Safety factor γ

The actual safety of the machined component against fatigue failure is:

- for pure tensile, bending or torsional stress:

$$\gamma = \sigma_{AG} / \sigma_a \quad \text{or} \quad \tau_{AG} / \tau_a \quad (68)$$

- for combination stress:

$$\gamma = \sigma_{AG} / \sigma_{av} \quad (69)$$

- against exceeding the yield point or elastic limit:

$$\gamma = \sigma_{SG} / (\sigma_a + \sigma_m) \quad \text{or} \quad \gamma = \sigma_{SG} / (\sigma_{av} + \sigma_{mv}) \quad (70)$$

where

σ_{AG} is the amplitude strength of the machined component dependent on shape;

σ_{SG} is the yield point (elastic limit) of the strength dependent on shape;

σ_a is the alternating stress amplitude;

- σ_m is the mean stress;
- σ_{av} is the combined alternating stress amplitude;
- σ_{mv} is the combined mean stress.

Universally binding resulting safety factors $\min \gamma$ are not capable of being specified with precision. They are governed by the number and weight of uncertainty factors and by the possible consequences in the event of failure. The greater the deformability (ductility) of the material, the lower the safety factor that can be selected.

Sufficient safety factors $\min \gamma$ shall be applied for machinery calculations in respect of fatigue strength while using material parameters σ_{End} on the basis of 90 % survival probability, where σ_{End} is the endurance strength.

Irrespective of the standard to which the machined component is calculated, at a minimum a safety factor of $\gamma_{M,f} \geq 1.2$ on the resistance side need to be applied. Any higher factors from the calculations need to be taken in their actual values. This safety factor is taken under the provision that on the load side an additional importance factor of at least $\gamma_i \geq 1.1$ to 1.5 for the different categories of application (non critical to loss of life) is applied in the calculation. The calculation with these factors requires a conservative assumption choosing the loads to cover the real operational conditions (e.g. impact factors) and the consideration of limited wear and degradation of the part during its life.

In all cases, the following relationship shall be given: $\min \gamma \geq \gamma_{M,f} \cdot \gamma_i \cdot \gamma_u \cdot \varphi$

Following factors shall be applied:

- $\gamma_{M,f}$ minimum safety factor of 1,2 – 2,5 on the resistance side;
- γ_i importance factor of 1,1 – 1,5 on the load side;
- γ_u uncertainty factor of 1,0 – 1,5 on the load side;
- φ impact or vibration factor (see 5.3.5).

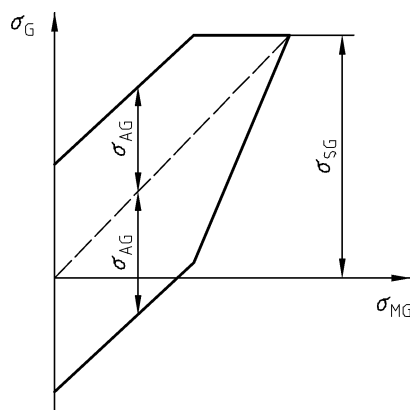


Figure 12 — Fatigue strength diagram according to Smith, for strength dependent on shape

5.6.4 Bolts

Bolts conforming to EN ISO 898-1, EN ISO 4014, EN ISO 4016, EN ISO 4017 or EN ISO 4018, nuts to prEN 14399 (all parts), EN ISO 4032, EN ISO 4034 or ISO 7413 assigned to property classes 4.6, 5.6 and 8.8 shall be used. The calculation of limit states shall be made in accordance with ENV 1993-1-1. The analysis of bolts under fluctuating stresses shall be conducted in accordance with the relevant literature taking into account the present state of the art. ENV 1993-1-1 shall also apply for high strength bolts, nuts and washers conforming to prEN 14399 (all parts) and EN ISO 7090 assigned to property class 10.9.