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Temporary structures

Code of practice for design and construction

DIN 4112

Fliegende Bauten; Richtlinien für Bemessung und Ausführung

This standard, supersedes DIN 4112, March 1960 edition and supplement to DIN 4112, October 1962 edition

In keeping with current practice in standards published by the International Organization for Standardization (ISO), a comma has been used throughout as the decimal marker.

This standard has been prepared by Technical Committee *Einheitliche Technische Baubestimmungen* of the *Normen-ausschuss Bauwesen* (Building Standards Committee). It has been recommended to the *Laender* building inspectorates by the *Institut für Bautechnik* (Institute for Building Technology), Berlin, for inclusion in the *Laender* building regulations.

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Translation
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1 General

The design, calculation and construction of temporary structures for fairgrounds, amusement parks and the like, and also their erection and dismantling, operation and repair demand a thorough knowledge of the structural and operational requirements of these installations, also a knowledge of the properties of the materials to be used and adequate experience in connection with the assembly of the individual components in view of the numerous occasions on which these installations are erected, dismantled and transported. Consequently, only experts and companies which possess this knowledge and experience, and which can therefore guarantee a completely satisfactory design and construction, shall design, calculate, manufacture and maintain these structures.

1.1 Field of application

This standard applies to structures which are suitable for and, as a general rule, also intended for repeated assembly and dismantling, e.g. roundabouts, swing boats, Ferris wheels, switchback railways and chutes, grandstands, booths and tents, structures for artistic aerial displays. In addition, cars which are used operationally in a stationary state for given periods of time also come within the scope of this standard.

This standard also applies to the dimensioning of temporary structures in amusement parks, with the exception of the foundations.

Fixed grandstands, construction site installations, scaffolding and movable agricultural structures are not regarded as temporary structures.

2 Construction documents

2.1 General

The construction documents include all the documents required for the assessment of the stability and operating safety during the preparation of the construction proposal and during the subsequent acceptances. These documents shall encompass all the construction conditions for the operation of the temporary structure. For this purpose, a description of the construction and operation, design drawings and a verification of stability as specified in subclause 2.4 and of operating safety are required.

2.2 Description of construction and operation

The temporary structure, in particular its design and utilization and its static system shall be explained in this description. Adequate details of mechanical and electrical equipment shall be listed.

The description shall include details of the particular features of the temporary structure and of any alternative modes of installation which may exist, also details of the main dimensions 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.

2.3 Construction drawings

These are required for all subassemblies and individual components, the fracture or failure of which might jeopardize the stability or operating safety of the plant. The construction drawings shall feature all the dimensions and cross section values required for testing and acceptance, also details of materials, structural components, fasteners and connectors, and of velocities.

The construction drawings shall comprise the following:

a) General drawings in plan view, elevation and sections, to one of the following scales, depending on the size of the temporary structure: 1 : 100, 1 : 50 or 1 : 20. The necessary clearance for the moving parts shall be indicated.

b) Detail drawings relating to all the structural subassemblies not clearly discernible on the general drawings, also detail drawings of connections and of individual items of structural, mechanical and electrical nature which are likely to affect the safety of the temporary structure and of its operation, drawn to a larger scale, e.g. 1 : 10, 1 : 5, 1 : 2,5 or 1 : 1. 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 or gondolas and the like, illustrated in all the required views and cross sections, with details of the overall dimensions, of the internal dimensions of importance to the passengers (seats, side and back rests, leg and foot room), facilities for holding fast, locking and securing devices;

   – travelling gear with details of travelling and safety rollers, bearings, axles, shafts and their attachment and possibility of movement in relation to the vehicle, steering and control, also safety devices against running back, safety devices against derailment and overturning, buffers, trailer devices, protection devices, drives and brakes, anchoring to the foundation;

c) if required, electric, pneumatic and hydraulic circuit and wiring diagrams.

2.4 Verification of stability

2.4.1 Verification of stability shall comprise the following:

a) general stress analysis;

b) verification of operational strength;

c) stability analysis;

d) verification of safety against overturning, sliding and lifting off;

e) if required, proof of stability against deformation.

2.4.2 The above-mentioned verification shall include the following details, amongst others:

a) 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;

b) main dimensions and cross section values of all load bearing structural components and details relating to the assessment of the operational strength;

c) details of materials;

d) determination of the most unfavourable stresses and details relating to the permissible stresses of the load bearing structural components and of the fasteners;

e) details of elastic deformations (flexure, torsion), inasmuch as such details affect the stability or operating safety of the plant;

f) details of those structural components which require special checking in accordance with subclause 7.3.1.

3 Materials

3.1 General

As a general rule, materials in respect of which design data are featured in technical building regulations may be used for structural components.

Other materials may only be used on condition that proof of their serviceability has been established by general building inspectorate approvals[1]), or, in individual cases, on condition that the *Laender* building inspectorates have given their agreement to the use of said materials.

3.2 Commonly used steels

3.2.1 Steels for structural components

St 35	in accordance with DIN 1629 Part 1
St 37-2	in accordance with DIN 17 100
St 52-3	in accordance with DIN 17 100
GS-52	in accordance with DIN 1681
C 35	in accordance with DIN 17 200

1) In the United Kingdom referred to as agrément.

3.2.2 Steels for structural and non-structural machine components

St 37-2	in accordance with DIN 17 100
St 50-2	in accordance with DIN 17 100
St 52-3	in accordance with DIN 17 100
St 60-2	in accordance with DIN 17 100
St 70-2	in accordance with DIN 17 100
C 15	in accordance with DIN 17 210
16 MnCr 5	in accordance with DIN 17 210
20 MnCr 5	in accordance with DIN 17 210
C 45	in accordance with DIN 17 200
C 60	in accordance with DIN 17 200
40 Mn 4	in accordance with DIN 17 200
41 Cr 4	in accordance with DIN 17 200
42 CrMo 4	in accordance with DIN 17 200
50 CrV 4	in accordance with DIN 17 200
GS-45.3	in accordance with DIN 1681

Materials in respect of which technological data are featured in other standards or in works standards may also be used for machine components.

3.2.3 Fasteners

Screws and bolts assigned to property classes 4.6, 5.6, 6.9, 8.8 and 10.9 in accordance with DIN ISO 898 Part 1.

3.3 Aluminium alloys

Aluminium alloys for predominantly static stressing in accordance with DIN 4113 Part 1.

3.4 Timber

In accordance with DIN 1052 Part 1.

4 Types of load and design loads

4.1 Dead loads

Included in the above category are the self weight of the load bearing structure, of the accessories and of the technical equipment required for operation, also the fabric coverings, decorations and the like.

The dead loads shall be determined in accordance with DIN 1055 Part 1 and Part 2. The self weight of machine components, electrical equipment, carriages, gondolas and the like shall be analyzed.

The self weight of dry canvas shall be assumed as being 0,005 kN/m^2 for the calculation of the structures in respect of wind pressure from below, which is required for the assessment of the safety against overturning and for the sizing of the anchoring; for all other purposes, it shall be assumed as specified in DIN 1055 Part 1.

4.2 Imposed loads

These consist of the external forces acting on a structural component, which may vary in respect of magnitude, direction and point of application during normal operation (see also clause 5).

4.2.1 Vertical loads

4.2.1.1 The load per adult shall be assumed at 0,75 kN and per child at 0,50 kN. If the structural installation is intended for use by adults and children, or by children only, then the permissible number of persons per unit of groups of seats (e.g. per gondola) shall be indicated by means of a notice or placard.

4.2.1.2 An imposed load of 3,5 kN/m^2 shall be assumed for floors, stairways with universal access, landings, ramps, entrances and exits and the like. If particularly dense crowds are anticipated, the imposed load shall be increased to 5 kN/m^2. This shall apply to circuses for example in all cases. Grandstands with fixed seating accommodation shall be sized for an imposed load of 5 kN/m^2, and grandstands without fixed seating accommodation shall be sized for an imposed load of 7,5 kN/m^2. An imposed load of 7,5 kN/m^2 shall be assumed for the stairways of grandstands and for their landings.

4.2.1.3 Floors, rostrums, ramps, staircases, catwalks and the like which are walked over by individual persons, but which are not destined for general use, shall be sized for a 1 kN individual load at the most unfavourable spot, or for a load of 1 kN/m^2.

4.2.1.4 For roundabouts, an imposed load on the floors of the revolving area or boom area walked on by the public during operation, equal to twice the number of people as can be accommodated on the seats of the carriages or figures shall be assumed, in order to make the necessary allowance for change of passengers; alternatively, an imposed load of 2 kN/m^2 shall be assumed for the calculation. The less favourable of these two values shall be the decisive one for the dimensioning.

4.2.1.5 The seat boards of rows of seats shall be sized for an imposed load of 1,5 kN/m. This is also valid for floors between fixed rows of seats, unless higher loads result from the application of subclause 4.2.1.2.

4.2.1.6 For stairs without risers or of stairs with only one central string, a concentrated load of 1 kN per step in the most unfavourable load position shall be assumed; alternatively, an area load in accordance with subclause 4.2.1.2 or subclause 4.2.1.3 shall be assumed.

4.2.2 Horizontal loads

4.2.2.1 For parapets and railings, and also of wall panels, the horizontal component force shall, as a general rule, be assumed at 0,5 kN/m at cross beam height (hand rail height). For temporary structures likely to be exposed to particularly heavy crowd pressure, this value shall be increased to 1 kN/m. The intermediate cross beam shall be sized for a horizontal component force of 0,1 kN/m.

4.2.2.2 A horizontal component force of 0,15 kN/m at cross beam height shall be assumed for the railings of service staircases and service walkways in accordance with subclause 4.2.1.3.

4.2.2.3 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 component force 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 subclause 4.5; this horizontal component force shall be assumed at $^1/_{10}$th of the imposed load in accordance with subclause 4.2.1.2.

4.3 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 the case of slow speed vehicles or slewing gear, with speeds not exceeding 3 m/s, the driving forces and braking forces may be assumed at 1/15th of the moving dead load and imposed load, if a more precise evaluation is not carried out.

4.4 Additions for impacts, for the vibration of structural components directly travelled over and for collision

4.4.1 Impacts

If impact forces are likely to arise in the structure or in individual parts thereof 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 φ_1 not less than 1,2, unless the type of operation and 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 structure, and if these impact forces cannot be eliminated by constructive measures, then the φ_1 value shall be increased accordingly.

Forces arising from start-up and braking, e.g. in the case of hydraulic cylinders, do not count as impact forces, see also subclause 4.3 in this respect.

4.4.2 Vibration of structural components directly travelled over

Because of the vibration actions in structural components directly travelled over, e.g. the rails of switchback railways, all stress resultants in the vehicle and in the structural components directly travelled over shall be multiplied by the vibration coefficient $\varphi_2 = 1{,}2$.

If satisfactory proof can be adduced, a slightly lower coefficient, viz. $1{,}0 \leq \varphi_2 < 1{,}2$ may be adopted. The following items shall be calculated without taking into account the vibration coefficient:

supports or suspensions of the structural components directly travelled over;

ground pressures;

deformations;

stability and resistance to sliding.

4.4.3 Collision

Collision shall be assumed at the most unfavourable point of the structural component concerned, and the magnitude shall be the mass of the fully occupied vehicle $(1{,}0 \cdot Q)$.

If collisions can only occur at angles α less than 90°, the collision shall be assumed at $Q \cdot \sin \alpha$, but the value for the calculation shall be not less than $0{,}3 \cdot Q$.

The influence arising from this collision need only be taken into consideration in respect of the structural components directly affected, and of their anchorings.

4.5 Wind loads

4.5.1 DIN 1055 Part 4, with the following dynamic pressures, shall apply to wind loads:

0,50 kN/m² for temporary structures not exceeding 8,00 m in height; 0,80 kN/m² for temporary structures over 8,00 m but not exceeding 20,00 m in height.

On the basis of past experience with tents of conventional design, the wind load on this type of tent design can be determined with the aid of the aerodynamic coefficients of figure 1 below.

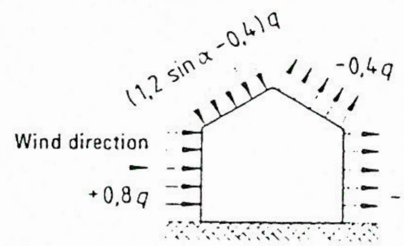


Figure 1. Aerodynamic coefficients for tents of conventional design

4.5.2 By way of departure from subclause 4.5.1, the dynamic pressure on temporary structures, up to a height of 5,00 m above ground level, may be assumed at $q = 0{,}3$ kN/m², with the exception of fixed tents with a height exceeding 5,00 m or with a width exceeding 10,00 m, and also with the exception of circular tents with a diameter exceeding 15,00 m.

4.5.3 For temporary structures which are in the operating condition, the wind load may be assumed at a dynamic pressure of 0,15 kN/m² up to 5,00 m above ground level, and at 0,25 kN/m² above this height, on condition that operations are shut down if the wind intensity exceeds 8 or if the wind velocity exceeds 20 m/s. The wind load area from the imposed load shall be taken into account.

4.6 Snow loads

DIN 1055 Part 5 shall apply to snow loads.

4.7 Inertia forces, e.g. centrifugal forces, gyroscopic forces and Coriolis forces

These forces shall be determined according to the prevailing circumstances in each case, see for example subclause 5.5.1 and subclause 5.4.4.1.

4.8 The loads in accordance with subclause 4.5 are additional loads within the meaning of DIN 1050.

5 Principles of structural analysis

5.1 General

The limiting values of normal forces, moments, transverse forces and bearing forces shall be determined separately for the individual loads in accordance with clause 4. The stresses shall be determined from these limiting values and shall be compared with the permissible stresses.

5.1.2 All proofs shall be calculated for the most unfavourable loading. In this connection, the moving loads, including the operating loads resulting therefrom and the position of the moving parts, shall always be assumed to be in the position and of the magnitude and velocity which result in the most unfavourable operating stresses for the structural components to be calculated. For structural components and items of equipment which are not permanent fixtures, it shall also be ascertained whether more unfavourable conditions are likely to arise when such items are removed.

5.1.3 Comparatively unknown formulae shall initially be recorded in writing with the symbols in accordance with DIN 1080 Part 1. The source of such formulae shall be stated, if this source is acessible to everyone. In other cases, the formulae shall be developed to the point where their correctness can be verified.

5.1.4 If automatic calculators are used, the provisional directives relating to the setting up and checking of electronic stability calculations[1]) shall be observed.

5.2 Swings

5.2.1 The following specifications shall apply to swings without motor drive, with the exception of subclause 5.2.7.

5.2.2 Swings shall be calculated for a deflection of max ϑ = 120° in relation to the position at rest. For children's swings, where the distance from the bottom of the gondola to the suspension axis does not exceed 2,00 m, an angle of max ϑ = 90° will suffice.

5.2.3 For loop-the-loop swings, the full deflection of max ϑ = 180° shall be entered in the calculation.

5.2.4 For loop-the-loop swings with a counterweight, the excess weight of the gondola shall be taken into account in each case as one-sided overload, in addition to the weight of the passengers.

5.2.5 On the assumption that the bases of the struts are situated in the same horizontal plane, and that the angle of inclination of the struts is the same, the following simplified calculation method can be adopted for conventional boat swings (without counterweight).

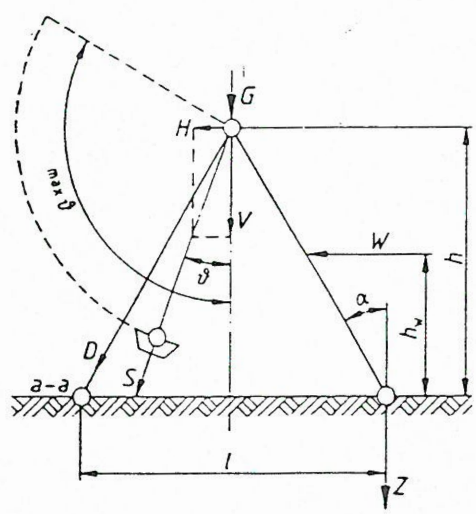


Figure 2. Boat swing

In figure 2

G is the load of the fixed components (framework of swing, head beam and bearing) (the self weight of the platform may only be included in G on condition that the platform is firmly attached to the struts and is erected together with the struts in every case);

Q is the self weight and imposed load of the moving parts (link rods, gondola and passengers);

W is the wind load;

S is the thread force of pendulum equivalent to the swinging gondola;

H, V are the horizontal and vertical components of the thread force S;

l is the span of the swing;

h is the height of the swing;

h_w is the height of application point of the wind above the tilting axis $a - a$;

α is the inclination of struts in relation to the vertical;

ϑ is the deflection angle in relation to the vertical;

max ϑ is the maximum deflection angle in relation to the vertical;

D is the compression force in the strut of the swing;

Z is the anchoring force,

$a - a$ is the tilting axis.

The forces arising during swinging are the following:

$$S = Q\,(3 \cdot \cos\vartheta - 2 \cdot \cos \max\vartheta) \quad (1)$$

$$H = S \cdot \sin\vartheta \quad (2)$$

$$V = S \cdot \cos\vartheta \quad (3)$$

In table 1, the forces which arise at various deflection angles are listed for the maximum gondola deflections max ϑ = 90°, 120° and 180° in relation to the position at rest, on the basis of the above formulae.

5.2.5.1 Forces on struts

Force on strut due to self weight G:

$$D_g = \frac{G}{2 \cdot \cos\alpha} \quad (4)$$

Force on strut due to centrifugal force:

$$D_f = \frac{1}{2} \cdot \left(\frac{V}{\cos\alpha} + \frac{H}{\sin\alpha}\right) \quad (5)$$

The maximum vlaue of the force on the strut D_f shall be determined from the ratio D_f/Q for various deflection angles ϑ, using the V/Q and H/Q values in accordance with table 1.

The use of formula (5) presupposes that an effective non-yielding anchorage exists at the bases of the struts. If this is not the case, the values for D_f shall be multiplied by a factor of 2.

Force on strut due to wind:

$$D_w = \frac{\Sigma\, W \cdot h_w}{l \cdot \cos\alpha} \quad (6)$$

The wind load area for gondola and passengers can be assumed roughly at 1,0 m^2 of perpendicularly hit area for swing positions between ϑ = 0° and ϑ = 60°. The point of application of this wind force shall be assumed to be at the level of the suspension (axis). Wind loads on notice boards and display boards, roofings and the like shall also be taken into account if necessary.

In any event an investigation shall be carried out as to whether higher stresses are likely to occur under conditions of full wind load and operational state of rest.

The total strut force therefore amounts to:

$$\Sigma\, D = D_g + \max D_f + D_w \quad (7)$$

[1]) Reprinted e.g. in the *Ministerialamtsblatt* (Ministerial Official Gazette) NW 1966, page 666.

Table 1. **Pendulum forces for various gondola deflections**

max ϑ = 90°				max ϑ = 120°				max ϑ = 180°			
ϑ	S/Q	V/Q	H/Q	ϑ	S/Q	V/Q	H/Q	ϑ	S/Q	V/Q	H/Q
90°	0,00	0,00	0,00	120°	−0,50	+ 0,25	−0,43	180°	−1,00	+ 1,00	0,00
80°	+ 0,52	+ 0,09	+ 0,51	110°	−0,03	+ 0,01	−0,02	170°	−0,96	+ 0,94	−0,17
70°	+ 1,03	+ 0,35	+ 0,96	100°	+ 0,48	−0,08	+ 0,47	160°	−0,82	+ 0,77	−0,28
60°	+ 1,50	+ 0,75	+ 1,30	90°	+ 1,00	0,00	+ 1,00	150°	−0,60	+ 0,52	−0,30
50°	+ 1,93	+ 1,24	+ 1,48	80°	+ 1,52	+ 0,27	+ 1,50	140°	−0,30	+ 0,23	−0,19
45°	+ 2,12	+ 1,50	+ 1,50	70°	+ 2,03	+ 0,69	+ 1,90	130°	+ 0,07	−0,05	+ 0,05
40°	+ 2,30	+ 1,76	+ 1,48	60°	+ 2,50	+ 1,25	+ 2,16	120°	+ 0,50	−0,25	+ 0,43
30°	+ 2,60	+ 2,25	+ 1,30	50°	+ 2,93	+ 1,88	+ 2,24	110°	+ 0,97	−0,33	+ 0,92
20°	+ 2,82	+ 2,65	+ 0,97	40°	+ 3,30	+ 2,53	+ 2,12	100°	+ 1,48	−0,26	+ 1,46
10°	+ 2,96	+ 2,91	+ 0,51	30°	+ 3,60	+ 3,11	+ 1,80	90°	+ 2,00	0,00	+ 2,00
0°	+ 3,00	+ 3,00	0,00	20°	+ 3,82	+ 3,59	+ 1,31	80°	+ 2,52	+ 0,44	+ 2,48
				10°	+ 3,96	+ 3,90	+ 0,69	70°	+ 3,03	+ 1,04	+ 2,84
				0°	+ 4,00	+ 4,00	0,00	60°	+ 3,50	+ 1,75	+ 3,03
								50°	+ 3,93	+ 2,53	+ 3,01
								40°	+ 4,30	+ 3,29	+ 2,76
								30°	+ 4,60	+ 3,98	+ 2,30
								20°	+ 4,82	+ 4,53	+ 1,65
								10°	+ 4,96	+ 4,88	+ 0,86
								0°	+ 5,00	+ 5,00	0,00

5.2.5.2 Safety of the swing against overturning

The ϑ-fold overturning moment, related to the tilting axis $a - a$, amounts to

$$M_{K_v} = 1{,}3 \cdot \left(H \cdot h - V \cdot \frac{l}{2}\right) + 1{,}2 \cdot \Sigma\, W \cdot h_w \qquad (8)$$

The values for V and H are to be obtained from table 1 for the relevant angle of deflection max ϑ.

The stability moment, related to the tilting axis $a - a$, amounts to

$$M_{St} = \frac{\bar{G} \cdot l}{2} \qquad (9)$$

As far as $\bar{G}$ is concerned, only the minimum mass which can be assumed safely to exist at all times shall be entered in the equation (woods in the fully dried out state). The relationship $M_{St} \geq M_{K_v}$ shall be attained.

For $\dfrac{M_{St}}{M_{K_v}} < 1{,}0$ it will be necessary to provide an additional anchorage of the lean-to struts in accordance with the equation

$$\text{erf } Z_v = \frac{M_{K_v} - M_{St}}{l} \qquad (10)$$

The relationship $Z \geq$ erf Z_v shall be attained.
See subclause 6.2.1 for Z.

5.2.6 The suspension rods of the gondola shall be checked by calculation in respect of tension, and also in respect of buckling for deflection angles ϑ exceeding 120°. If the bearings for the suspension of the gondolas are arranged eccentrically in relation to the head beam, then the head beams will also be subjected to torsional stress, and consequently the struts of the framework will be subjected to bending stress. This shall be borne in mind for the calculation, as shall also the influence of the eccentricity on the head beam bearings and on the strut joints.

5.2.7 For motor-driven swings, the driving forces and braking forces resulting from the motor drive shall be taken into consideration as well.

5.3 Ferris wheels

5.3.1 Loads

The wheel webs of Ferris wheels consisting of n sectors shall be calculated in respect of the loads depicted in figure 3:

$$Q_\varphi = \varphi \cdot (G_g + P) + G_R \qquad (11)$$

$$Q \;= (G_g + P) + G_R \qquad (11a)$$

$$Q_r = \frac{Q}{g} \cdot \omega^2 \cdot R \qquad (12)$$

$$Q_t = \frac{Q}{g} \cdot \varepsilon \cdot R \qquad (13)$$

W_t and W_r

where

φ = 1,2 (impact factor);

G_g is the dead load of one gondola including suspension;

P is the imposed load in a fully occupied gondola.

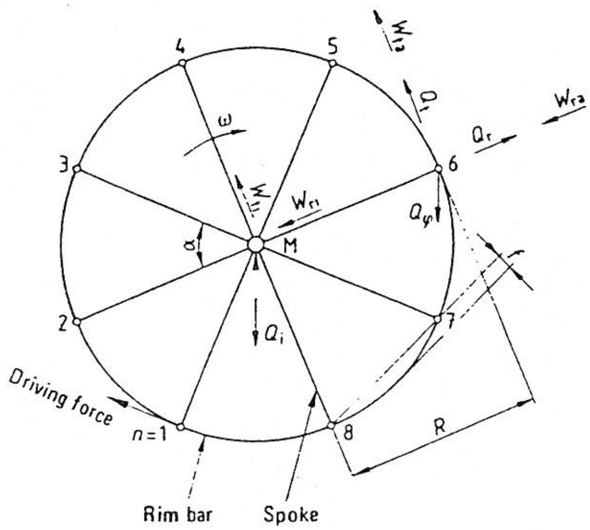


Figure 3. n = 8 sector Ferris wheel
Load illustrated only at point i = 6.

In figure 3

G_R is the pro rata load of wheel attributable to one gondola;

Q_i is the pro rata internal load of spoke at the hub;

g is the gravitational constant;

ω is the angular velocity of wheel;

R is the wheel radius

$\varepsilon = \dfrac{\omega}{t}$ (angular acceleration of wheel);

t is the start-up or slowing down time of the wheel, to be calculated on the basis of the drive and brake selected;

W_{ta} is the wind load in tangential direction of the wheel, arising from the gondola and the share due to the spoke;

W_{ti} is the wind load in tangential direction of the wheel, arising from the share due to the spoke;

W_{ra} is the wind load in radial direction of the wheel, arising from the gondola, the rim bars and the share due to the spoke;

W_{ri} is the wind load in radial direction of the wheel, arising from the share due to the spoke.

The forces arising from drive or braking, which are in equilibrium with the wheel about point M, shall be applied and derived at the point of origin; for example, in the case of a drive at the shaft, the bending moment shall be applied in the spokes and the torsional moment in the shaft, whilst in the case of a friction wheel drive, the contact pressure and the tangential friction force shall be applied to the rim bar.

5.3.2 Dominant loading cases

Full occupancy (loading case a):

All the gondolas of the Ferris wheel are fully occupied. This results in the greatest stresses in the rim bars.

Part occupancy (loading case b):

The one-sided loading of the Ferris wheel shall be assumed to consist of two adjoining fully occupied gondolas or of two adjoining empty gondolas, with the remaining gondolas occupied.

Centrifugal force Q_r: loading case c.

Load effective when starting up or slowing down Q_t: loading case d.

Wind load parallel to the wheel: loading case e 1.

Wind load perpendicular to the wheel: loading case e 2.

If more than two gondolas are to be run fully loaded on one side of the wheel, this shall be allowed for in the calculation.

5.3.3 Calculation

The bar forces on the spokes and rim bars of the Ferris wheel shall, as a general rule, be determined in accordance with the theory of elasticity (truss with one statically indeterminate member). For this purpose, the spokes shall be assumed to be attached at the centre point of the shaft. For all loading cases, the loads resulting from the drive (or from the braking) shall be entered as true to reality as possible.

If Q_r, Q_t, W_r and W_t are insignificant in relation to $Q\varphi$

$$\left(Q_r \leq \frac{Q\varphi}{5},\ Q_t \leq \frac{Q\varphi}{10},\ \sqrt{W_t^2 + W_r^2} \leq \frac{Q\,\varphi}{4}\right),$$

then the following formulae can be used for the calculation of the centre webs of Ferris wheels with n sectors. They are valid for loads Q = 1.

Further prerequisites: the modulus of elasticity shall be the same for all bars.

In formulae (14) to (19)

A_S is the cross sectional area of a spoke, to be identical for all spokes;

A_K is the cross sectional area of a rim bar, to be identical for all rim bars;

I_K is the second degree area moment (moment of inertia) of a rim bar, to be identical for all rim bars;

(n) is the subscript designating an arbitrary nodal point of the Ferris wheel with n sectors;

α is the central angle included between two adjoining spokes (to be identical for all spokes);

S_{0S} or S_{0K} are the bar forces on the statically determinate system in the spokes or in the rim bars as a result of $Q_1 = 1, Q_2 = 1 \ldots Q_n = 1$;

S_{1S} or S_{1K} are the bar forces on the statically determinate system in the spokes or in the rim bars as a result of $X_1 = 1$.

$$f = R\left(1 - \cos\frac{\alpha}{2}\right) = \text{height of arc above chord} \quad (14)$$

$$c' = \frac{A_S}{A_K} \quad (15)$$

$$c'' = \frac{A_S}{I_K} \quad (16)$$

$$S_{1S} = -2 \cdot \sin\frac{\alpha}{2}; \quad (17)$$

$$S_{1K} = +1 \quad (18)$$

$$\max M_{1K} = R \cdot \left(1 - \cos\frac{\alpha}{2}\right); \quad (19)$$

For polygonally arranged rim bars, we have
$M_{1K} = 0$.
For the wheel with n sectors, we obtain the following relationships for the condition $X_1 = 1$:

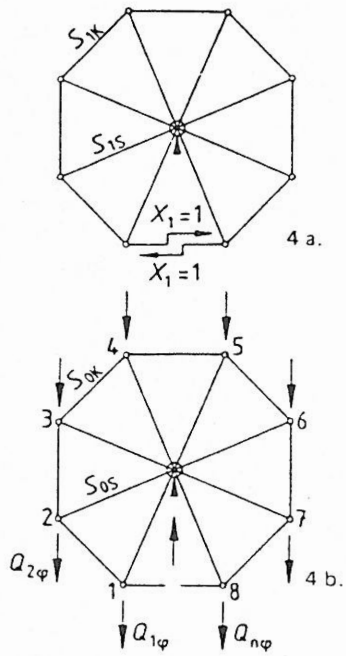


Figure 4. Statically determinate basic system of a Ferris wheel with $n = 8$ sectors (polygonally arranged)

From the normal force

$$\frac{E \cdot A_S}{R} \cdot \delta_{11}^{N} = n \cdot 2 \cdot \left(\sin \frac{\alpha}{2}\right) \cdot \left(2 \cdot \sin \frac{\alpha}{2} + c'\right) \tag{20}$$

and from the moment

$$\frac{E \cdot A_S}{R} \cdot \delta_{11}^{M} = n \cdot c'' \cdot R^2 \cdot \left(\frac{\alpha}{2} + \alpha \cos^2 \frac{\alpha}{2} - 3 \cdot \sin \frac{\alpha}{2} \cdot \cos \frac{\alpha}{2}\right) \tag{21}$$

for polygonally arranged rim bars we have

$$\frac{E \cdot A_S}{R} \cdot \delta_{11}^{M} = 0 \tag{22}$$

$$\frac{E \cdot A_S}{R} \cdot \delta_{10} = 2 \cdot \left(\sin \frac{\alpha}{2}\right) \cdot \left(c' \cdot \sum_{1}^{n} S_{OK} - \sum_{1}^{n} S_{OS}\right) \tag{23}$$

The statically indeterminate quantity then becomes
X_1 from $Q_1 = 1, Q_2 = 1 \ldots Q_n = 1$

$$X_1 = - \frac{\dfrac{E \cdot A_S}{R} \cdot \delta_{10}}{\dfrac{E \cdot A_S}{R} \cdot \delta_{11}^{N} + \dfrac{E \cdot A_S}{R} \cdot \delta_{11}^{M}} \tag{24}$$

Final stress resultants on the statically indeterminate system for a Ferris wheel with n sectors, with two wheel centre webs from loading $Q\varphi$:

spokes: $$S_S = \frac{Q_\varphi}{2} \cdot \left(S_{OS} + X_1 \cdot S_{1S}\right) \tag{25}$$

rim bars: $$S_K = \frac{Q_\varphi}{2} \cdot \left(S_{OK} + X_1 \cdot S_{1K}\right) \tag{26}$$

$$\max M_{1K} = S_K \cdot R \left(1 - \cos \frac{\alpha}{2}\right) \tag{27}$$

$M_K = 0$ in the case of polygonally arranged rim bars. The maximum bar forces are featured in the table below for polygonally arranged Ferris wheels, for $c' = 0{,}2$ to 3,0, for loading case $Q_n = 1$ and $n = 6$ to 16. The bar forces in a wheel centre web shall be calculated by multiplying the values of the table by $\dfrac{Q\varphi}{2}$.

Table 2.

Number of sectors n	6	8	10	12	14	16
Spokes	± 2,00	± 2,00	± 2,00	± 2,00	± 2,00	± 2,00
Rim bars	+ 1,16	+ 1,43	+ 1,68	+ 2,00	+ 2,30	+ 2,64
	−1,50	−1,60	−1,68	−2,00	−2,30	−2,64
In the above table + signifies tension and − signifies compression.						

The influence on the spokes and rim bars of wind acting at right angles to the wheel centre web shall be verified by calculation (proportion of wind load per spoke arising from the gondolas, spoke, rim bars and any fairings which may be fitted). In the case of the spokes and rim bars, the bending influence from the self weight and from any other loads which may be present shall also be taken into account. If the drive and braking are effected on one wheel centre web only, the effect on the wheel resulting from such an arrangement shall be checked.

5.3.4 Erection

The erection procedure of the wheel shall be verified by calculation. If for example the wheel is erected in such a way that the last rim bar is inserted at the bottom, then the ring of rim bars shall be pushed apart in such a way that it will be subjected to the compressive force which results from the statically indeterminate calculation with the existing loads.

5.3.5 General indications

The sum of all the externally acting forces shall be led off via the support structure, and the verification of safety against overturning and of resistance to sliding shall be carried out, firstly under operating conditions with a wind load in accordance with subclause 4.5.3 acting on the wind application area which may in some cases have been enlarged by the imposed load, and secondly in the inoperative condition (condition at rest, without imposed load), with a wind load in accordance with subclause 4.5.1 and subclause 4.5.2. The wind shall be assumed to act parallel to the wheel centre web in a first loading case calculation, and at right angles to the wheel centre web in a second calculation. The safety against overturning and resistance to sliding of the structure shall be verified for both the above loading cases. If necessary, the safety against overturning and resistance to sliding shall also be verified for the erection condition. Because the spokes cannot, as a general rule, be attached to the centre point of the shaft (which is the assumption in the calculation), the wheel centre web represents an unstable system, i.e. the hub is capable of accomplishing a finite twisting motion against a wheel held stationary, until a stable position has been attained. In order to prevent this kind of wear, the spokes should be attached to the hub in such a way (e.g. by clamping) that any relative twisting of the hub is prevented. If tension members are used as spokes, the influence of the tension member sag on the wheel shall be assessed.

When calculating the effect of the wind at right angles to the wheel centre web, it shall be borne in mind that the total wind load of the wheel acts on one single bearing only, unless a load distribution onto both bearings is ensured beyond any doubt by virtue of the axle and bearing design.

As regards the verification of safety against overturning, the overturning of the complete structure shall only be calculated if there is a possibility of the complete structure tilting about one arris or one fulcrum. If for example support trestles are likely to tilt individually, the verification of safety against overturning shall be carried out for each support trestle on its own.

In the case of slanting supports subjected to compression, the moment arising from the compression force multiplied by the sag shall be taken into account.

The influence on the gondola suspension of a gondola occupied by passengers on one side only, coupled with a wind load, shall be taken into consideration.

5.4 Roundabouts

5.4.1 General

Roundabouts shall be calculated both in the inoperative condition and in the operating condition, fully loaded, and also on the assumption that only a portion of the slewing gear is loaded.

One-sided loading shall be assumed as meaning that at least those seats which are situated on 1/4 or 3/4 of the periphery are occupied. The general stress analysis shall be carried out for this one-sided loading.

The overturning moment caused by one-sided loading when seats on at least 1/6th of the periphery are occupied shall not exceed the stability moment in existence at the same time, not taking the anchor ties into consideration. For this one-sided loading the operational strength shall be verified. This shall be done also for a one-sided loading on 5/6th of the periphery. 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-seat gondolas in lieu of single seats.

If there are 18 or more seats uniformly distributed around the periphery, a higher one-sided loading may be the determining factor in respect of an adequate safety against overturning in certain cases. In this connection please refer to the relationship between M_{St} and M_{K_v} dealt with in subclause 5.4.2.

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

Wheel treads, tracks, tread rollers, retaining rollers and the like are all subject to wear. The permissible wear rates shall be specified.

The adequate safety of the hydraulic and pneumatic equipment shall be demonstrated by means of construction drawings, calculations and the relevant circuit diagrams.

The seats and gondolas shall be sized on the basis of the forces resulting from dead loads, imposed load 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 the 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 motions of the roundabout shall be designed in such a way, or the seats shall be designed and secured in such a way that the passengers are safely accommodated in their seats in relation to the motions of the roundabout. Safety belts for the passengers shall be required in cases where the passenger is pressed onto his seat with less than $0{,}2 \cdot g$ due to the resultant acceleration.

The substructure shall be sized and designed in such a way that the forces arising (such as start-up and braking forces for example, also impact forces, out-of-balance forces) are safely transmitted to the foundation soil.

5.4.2 Flyer roundabouts and suspension roundabouts

The centrifugal forces on flyer and suspension roundabouts with a vertical rotational axis are to be calculated as follows:

$$H_{FL} = \frac{m \cdot v^2}{R + a} = Q' \cdot \tan\alpha; \qquad (28)$$

$$m = \frac{Q'}{g} \quad (29); \qquad v = \frac{\pi \cdot n \cdot (R + a)}{30} \qquad (30)$$

where $a = l \cdot \sin\,\alpha$ (31) as a function of v is an unknown quantity for the present. Equation (32) below shall be used to determine α (see figure 5):

$$q = \cos\alpha + \frac{R}{l} \cdot \cot\alpha \qquad (32)$$

where

$$q = \frac{894}{l \cdot n^2}, \text{ with } l \text{ in m and } n \text{ in U/min.} \qquad (33)$$

In formulae (28) to (33)

Q' is the dead load of gondola including imposed load;
l is the length of rope or thread;
R is the radius as shown in figure 6;
n is the rotational speed;
a is the excursion amplitude of the gondola;
α is the excursion angle in relation to the vertical;
v is the peripheral speed of the gondola;
m is the mass of gondola including imposed load;
H_{FL} is the centrifugal force produced in a gondola;
g is the gravitational constant.

Instead of solving the above equation, the excursion angle can be determined as a function of the rotational speed with the aid of figure 5.

Suspension components (e.g. four chains, four ropes, four rods) for the seats or gondolas and the fasteners associated therewith shall be sized in such a way that each suspension component is capable of absorbing half the resultant force from H_{FL} and Q'.

The locking devices (rope) shall also be calculated in respect of the resultant from H_{FL} and Q'; in the case of chains, the force from the chain pull shall be taken into account.

The locking device shall not be fastened to the suspension components.

In the case of smaller chain flyer roundabouts it will suffice to assume an excursion angle $\alpha = 45°$ ($H_{FL} = Q'$), in so far as no more accurate assessment is made.

If two seats are attached next to one another on one and the same outrigger, an excursion angle $\alpha = 45°$ may be assumed by way of simplification for both seats.

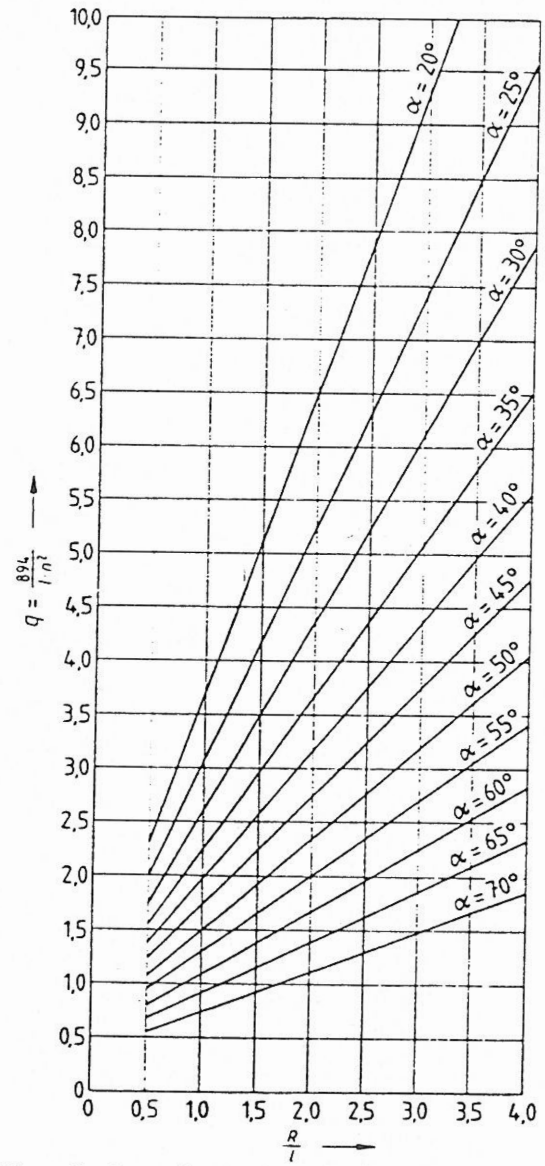


Figure 5. Graph for the determination of the excursion angle α

For children's roundabouts with suspended figures of animals and the like, it will suffice to assume an excursion angle $\alpha = 30°$ ($H_{FL} = 0{,}5\,Q'$) if a more accurate assessment is not made.

The moment of the vertical and horizontal loads about point A (foot of the mast) is:

$$M_A = c_1 \cdot P \cdot (R + h \cdot \tan\alpha) + (H_w \cdot h_w - V_w \cdot x) \quad (34)$$

A one-sided imposed load at maximum rotational speed is the determining value for the determination of the safety against overturning in the operating condition.

The wind load shall be assumed as acting in the most unfavourable direction.

The moments about the tilting arris $k - k$ or $k' - k'$ are as follows

Overturning moment:

$$M_{K\nu} = 1{,}3 \cdot [P \cdot c_1 (R + h \cdot \tan\alpha) - P \cdot c_2 \cdot e] + 1{,}2 \cdot [H_w \cdot h_w - V_w (x + e)] \quad (35)$$

$$M_{K'\nu} = 1{,}3 \cdot \left[P \cdot c_1 (R + h \cdot \tan\alpha) - P \cdot c_2 \cdot \frac{e}{\sqrt{2}}\right] + 1{,}2 \cdot \left[H_w \cdot h_w - V_w \left(x + \frac{e}{\sqrt{2}}\right)\right] \quad (36)$$

Stability moment

$$M_{St} = \Sigma \bar{G} \cdot e \quad (37)$$

$$M_{St'} = \Sigma \bar{G} \cdot \frac{e}{\sqrt{2}} \quad (38)$$

As far as $\bar{G}$ is concerned, only the minimum mass which can be assumed safely to exist at all times shall be entered in the equation (woods in the fully dried out state).

The relationships $M_{St} \geq M_{K\nu}$ and $M_{St'} \geq M_{K'\nu}$ shall be attained.

If there are 18 or more seats uniformly arranged around the periphery, an adequate safety against overturning may be a determinant factor under certain conditions. In such cases, a further verification shall be carried out with

$$\max M_{K\nu} = [P \cdot c_3 (R + h \cdot \tan\alpha) - P \cdot c_4 \cdot e] + 1{,}2 [H_w \cdot h_w - V_w (x + e)] \quad (39)$$

$$\max M_{K'\nu} = \left[P \cdot c_3 (R + h \cdot \tan\alpha) - P \cdot c_4 \cdot \frac{e}{\sqrt{2}}\right] + 1{,}2 \left[H_w \cdot h_w - V_w \left(x + \frac{e}{\sqrt{2}}\right)\right] \quad (40)$$

c_3 and c_4 are coefficients analogous to c_1 and c_2 (not featured in tabulated form in this standard), but relating to a one-sided loading on one half of the periphery, and any seats which may be situated at the edge of the sector shall be assumed to be empty in this context.

The relationships $M_{St} \geq \max M_{K\nu}$ and $M_{St'} \geq \max M_{K'\nu}$ shall be attained.

If $\frac{M_{St}}{M_{K\nu}}$ or $\frac{M_{St'}}{M_{K'\nu}} < 1$, for one-sided 1/4 occupation at the periphery, then additional precautions shall be taken, e.g. counterweights shall be fitted or anchorages provided.

If ground anchors are fitted at the ends of the base cross, the tensile force Z to be absorbed will be (see figure 6):

$$\text{erf } Z_\nu = \frac{M_{K\nu} - M_{St}}{z} \quad (41)$$

or

$$\text{erf } Z_\nu = \frac{M_{K'\nu} - M_{St'}}{2 \cdot z'} \quad (42)$$

The relationship $Z \geq \text{erf}\ Z_\nu$ shall be attained.

In figure 6 and table 3

Z see subclause 6.2.1;

G' is the dead load of one gondola including suspension;

ΣG is the dead load of all the permanently present individual components acting on the supports;

P is the imposed load of one gondola;

$Q' = G' + P$;

h is the distance of suspension point C of the gondola from floor level;

c_1 is the coefficient which takes the position of the occupied gondola into account, for 1/4 or 1/6th of the periphery;

c_2 is the coefficient which takes the number of occupied gondolas into account (in the case of one-sided loading of 1/4 or 1/6th of the periphery);

H_w is the sum of the horizontal wind loads;

h_w is the distance of H_w from floor level;

V_w is the sum of the vertical wind loads;

x is the distance of V_w from mast centreline;

$\text{erf}\ Z_\nu$ is the effective anchor tensile force under ν-fold overturning loading, at the most highly stressed anchorage point;

e is the distance of tilting axis from mast centreline.

5.4.3 Floor roundabouts (suspended floor and turntable roundabouts)

These roundabouts have a floor which rotates together with the superstructures. The rotating floor (turntable) may either be suspended from outriggers or be mounted on a slewing gear.

The loading in accordance with subclause 4.2.1.4 shall also be entered in the calculation for a one-sided floor sector with a central angle $\alpha = 90°$ or $270°$.

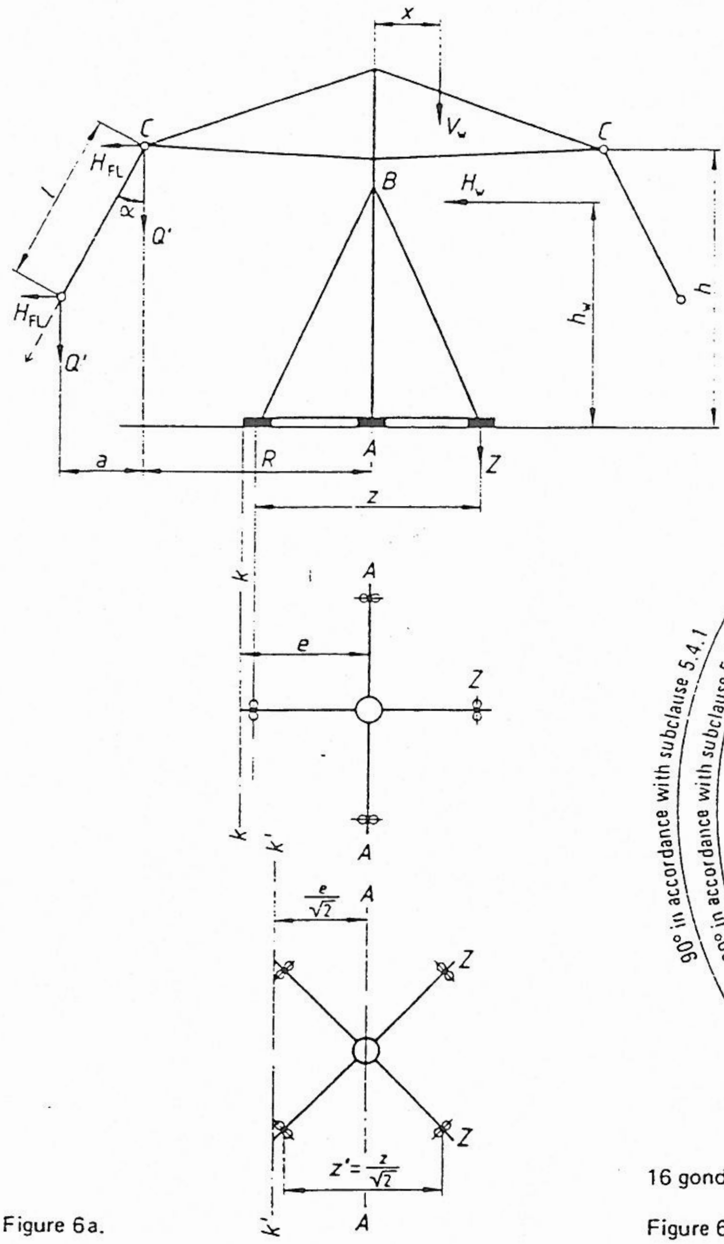
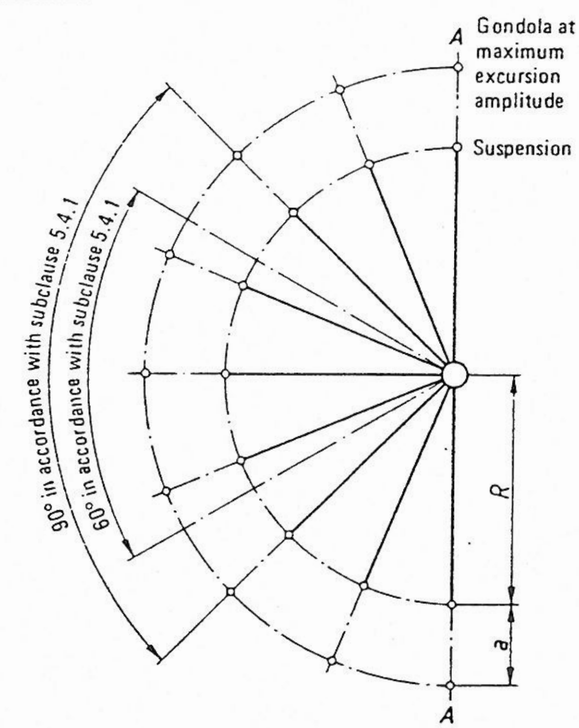


Figure 6a.



16 gondolas uniformly arranged around the periphery

Figure 6b.

Figure 6. Flyer roundabout

Table 3. **Coefficients c_1 and c_2 in the case of non-sided loading**

Total number of gondolas		4	6	8	10	12	14	16	18	20	22	24
1/4 or 3/4 of periphery	c_1	1,414	1,732	2,414	2,618	3,346	3,514	4,262	4,412	5,172	5,310	6,078
	c_2	2	2	3	3	4	4	5	5	6	6	7
1/6 of periphery	c_1	1,0	1,732	1,848	1,902	2,732	2,802	2,848	3,702	3,757	3,799	4,664
	c_2	1	2	2	2	3	3	3	4	4	4	5

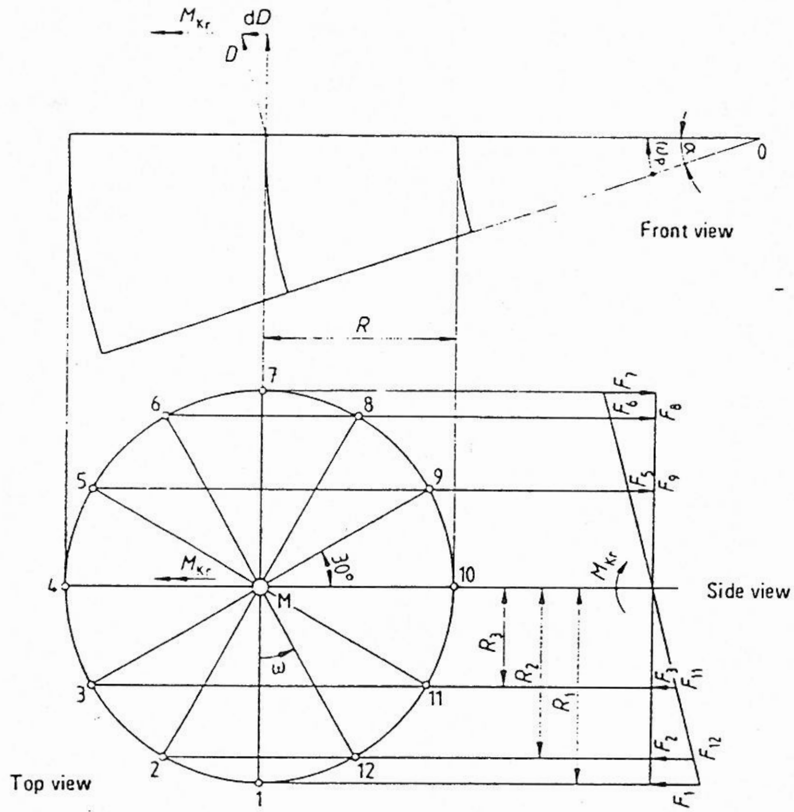


Figure 7. Example for the determination of the gyroscopic moment and for the follow-up of its influence, for a slewing gear with 12 outriggers, rotating at an angular velocity ω, which is slewed by an angle α.

The distance of the centre of gravity from the vertical rotational axis, for a central angle of 90° is

$$a_s = 0{,}60 \cdot \frac{R_a^3 - R_i^3}{R_a^2 - R_i^2} \tag{43}$$

R_a and R_i are the outer and inner radii of the rotating floor.

For roundabouts, the seats of which are supported on outriggers located at the bottom, the bending moments generated by eccentrically acting centrifugal forces shall be taken into account not only in the mast itself but also in these outriggers.

5.4.4 Roundabouts with several motions

5.4.4.1 General

For roundabouts, the moving parts of which are rotated about several axes in different planes, all the forces which arise shall be determined for the chosen angular velocities. Apart from the centrifugal forces which arise, and the starting and braking forces and any impact forces which may arise, the Coriolis forces which arise when the direction of one or more rotational axes is changed, or the forces which are generated by the precession of the gyroscope, shall be taken into account.

In figure 7

D is the twist;

dD is the rate of change of twist;

M_{Kr} is the gyroscopic moment,

R is the radius;

ω is the angular velocity about the gyroscope axis;

ω_P is the angular velocity of precession;

$\Theta = \int R^2\,dm$, is the mass moment of inertia of the slewing gear.

Gyroscopic moment $M_{Kr} = \Theta \cdot \omega \cdot \omega_P$ (44)

Substitute load per outrigger

$$F = M_{Kr}\,\frac{R}{\Sigma R^2} \tag{45}$$

Arising velocities and accelerations, taking into account the relative motions and Coriolis accelerations

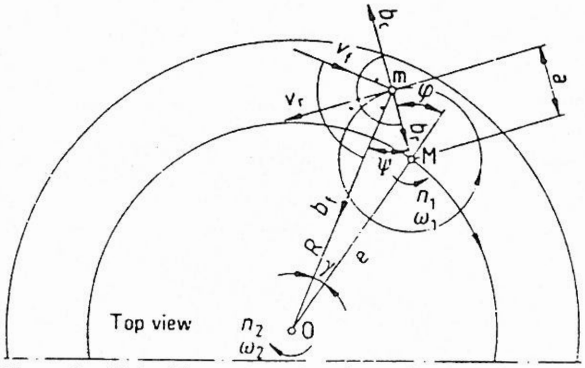


Figure 8. Velocities and accelerations of mass point m

In figure 8

M is the centre point of rotation revolving in a circle;

0 is the stationary centre point of rotation.

Meaning of subscripts:

f guided

r relative

c Coriolis acceleration

without subscript – absolute value

Velocities:

$$\bar{v} = \bar{v}_f + \bar{v}_r \tag{46}$$

$$\bar{v}_f = \bar{R} \cdot \omega_2 \tag{47}$$

$$\bar{v}_r = \bar{a} \cdot \omega_1 \tag{48}$$

$$\bar{R} = \bar{e} + \bar{a} \tag{49}$$

$$R = \sqrt{[e + a - (a - a \cdot \cos\varphi)]^2 + [a \cdot \sin\varphi]^2} = \sqrt{e^2 + 2 \cdot e \cdot a \cdot \cos\varphi + a^2} \tag{50}$$

$$v_{r\parallel\varphi_0} = -v_r \cdot \sin\varphi \tag{51}$$

$$v_{r\perp\varphi_0} = +v_r \cdot \cos\varphi \tag{52}$$

$$v_{f\parallel\varphi_0} = +v_f \cdot \sin\gamma \tag{53}$$

$$v_{f\perp\varphi_0} = -v_f \cdot \cos\gamma \tag{54}$$

$$\sin\gamma = \frac{a \cdot \sin\varphi}{\sqrt{e^2 + 2 \cdot e \cdot a \cdot \cos\varphi + a^2}} \tag{55}$$

$$\cos\gamma = \frac{e + a \cdot \cos\varphi}{\sqrt{e^2 + 2 \cdot e \cdot a \cdot \cos\varphi + a^2}} \tag{56}$$

$$v = \sqrt{(\Sigma v_{\parallel\varphi_0})^2 + (\Sigma v_{\perp\varphi_0})^2} \tag{57}$$

Direction of v:

$$\cot\delta = \frac{v_{\parallel\varphi 0}}{v_{\perp\varphi 0}} \tag{58}$$

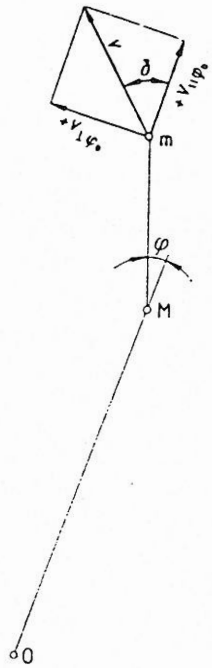


Figure 9. Resolution of velocity v

Accelerations:

$$\bar{b} = \bar{b}_f + \bar{b}_r + \bar{b}_c \tag{59}$$

$$b_f = R \cdot \omega_2^2 \tag{60}$$

$$b_r = a \cdot \omega_1^2 \tag{61}$$

$$b_c = 2 \cdot \omega_2 \cdot v_r \tag{62}$$

$$b_n = b_r - b_c + b_f \cos\psi \quad \text{(normal)} \tag{63}$$

$$b_t = b_f \cdot \sin\psi \quad \text{(tangential)} \tag{64}$$

$$R \cdot \sin\psi = e \cdot \sin\varphi$$

$$\sin\psi = \frac{e}{R} \cdot \sin\varphi \tag{65}$$

$$R \cdot \cos\psi = e \cdot \cos\varphi + a$$

$$\cos\psi = \frac{e \cdot \cos\varphi + a}{R} \tag{66}$$

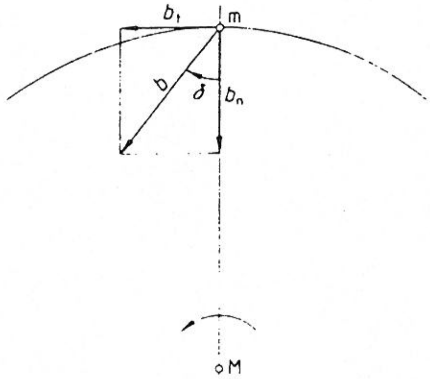
$$b = \sqrt{b_n^2 + b_t^2} \tag{67}$$

The above derivations are only valid for n_1 in the opposite direction to n_2.

If n_1 has the same direction of rotation as n_2, the direction of b_c will be reversed.

5.4.4.2 Roundabouts running on rail track

5.4.4.2.1 with central outrigger guide, with internal or external drive (e.g. rocket railways)



$$\tan \delta = \frac{b_t}{b_n} \tag{68}$$

Figure 10. Direction of acceleration b

On such roundabouts, due attention shall be paid to possible constraints and to the bending and torsional moments in the outriggers 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 sag due to wheel load does not exceed l/500.

5.4.4.2.2 without central guide (e.g. Bavarian curve)

Safety against overturning of the cars shall be ensured by superelevation of the rails or by safety rollers and the like, or if necessary by both these precautions. If the 1,0-fold safety against overturning of the substructure can be demonstrated, the anchorage with the foundation soil need not be taken into consideration in the calculation. In order to attain a ν-fold safety against overturning, the anchorage may be taken into consideration in the calculation.

5.4.4.3 Roundabouts with wavy track (e.g. switchback railways)

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

5.4.4.4 Roundabouts with several rotation gears (e.g. calypsos)

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, the effects of the rotation of the individual rotation gears shall be investigated.

For outrigger flyer roundabouts (e.g. round-ups, ski lifts, twisters, hully-gullies), the gondolas of which may be hoisted, the effects of the forces arising during hoisting and lowering, 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 the individual 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. The telescopic jacks shall be supported without constraint and shall be sized adequately to withstand buckling.

The same applies, as 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 by the provision of damping elements.

The velocity of the lowering motion shall not exceed 1,0 m/s or twice the value of the normal operational velocity in the event of a rupture of the hydraulic pressure lines of the lifting cylinders.

5.5 Roller coasters with rail track bound vehicles

5.5.1 Rail

The longitudinal gradient of the rail shall be limited in such a way that the contact pressure component at right angles to it does not fall below 0,2 g in the most unfavourable case. This value applies also for the car with the highest speed in the case of trains. If the contact pressure component should fall below the above value, the passengers shall be secured against lift-off.

The transverse inclination α of the rail shall be selected in such a way that the forces at right angles to the car remain small. This is the case if α is selected according to the formula below:

$$\tan \alpha = \frac{v^2 \cdot \cos^2 \gamma}{R_h \left(g \cdot \cos \gamma + \frac{v^2}{R_v} \right)} \tag{69}$$

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

In formula (69)

v is the velocity of car;

γ is the longitudinal gradient of rail;

R_h is the horizontal radius;

R_v is the vertical radius;

+ ≙ trough;

− ≙ dome.

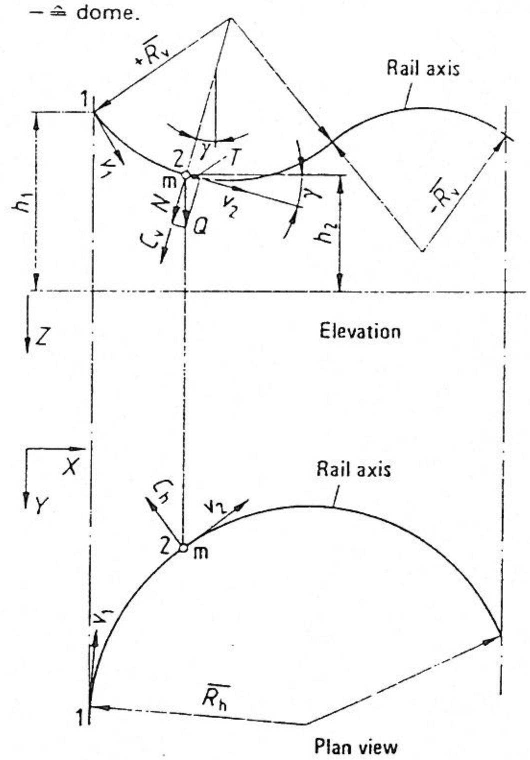


Figure 11. Rail track of a switchback railway