BS EN 16481:2014

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Timber stairs — Structural design — Calculation methods

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee B/543, Round and sawn timber.

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

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Timber stairs - Structural design - Calculation methods

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Holztreppen - Bauplanung - Berechnungsmethoden

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Foreword

This document (EN 16481:2014) has been prepared by Technical Committee CEN/TC 175 “Round and sawn timber”, the secretariat of which is held by AFNOR.

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of an identical text or by endorsement, at the latest by December 2014, and conflicting national standards shall be withdrawn at the latest by December 2014.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document takes into account the following standards:

— EN 1990;

— EN 1991-1-1;

— EN 1995-1-1.

This document is addressed for structural designers to design timber stairs from a common European method; it should be useful for SMEs as an alternative to testing where applicable.

This European Standard takes into account the current state of the art regarding safety concept, loading assumptions, determination of stress resultants, as well as dimensioning in the field of wood engineering.

The requirements and verification procedures essential for the verification of mechanical performance characteristics, serviceability and load-bearing capacity of stairs and their components are compiled and described in the following clauses.

The mechanical performance characteristics of stairs may be verified by using the following methods:

— testing of stairs as a whole or in part;

— mathematical verification on the basis of structural analysis following the principles of this European Standard;

— assessment based on experience: conventionally accepted performance (CAP) which should be defined in national documents.

All methods are equally valid.

This document needs to be read in conjunction with EN 15644.

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

1 Scope

This European Standard constitutes a frame standard for the design of timber stairs as well as wood and wood-based components used in stairs by calculation methods. Some calculation methods can be derived from testing results, for example CEN/TS 15680. This document specifies the design and the requirements for materials and components to be used in these calculation methods. It may be complemented by national application documents based on this European Standard.

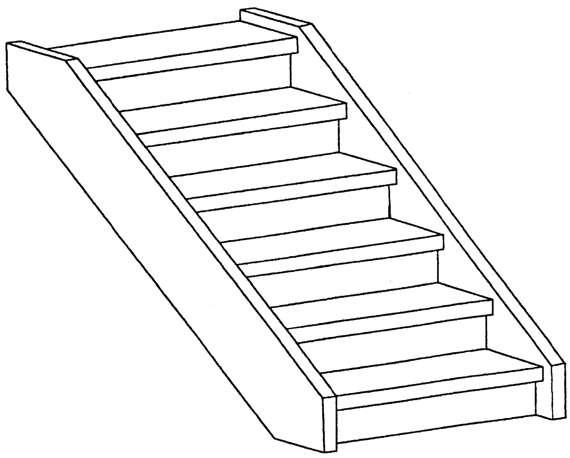
This European Standard applies to coated and uncoated components. This document covers load-bearing components such as strings, treads, risers, posts and guardrails. Requirements for a timber stair are defined in the product standard, EN 15644. This document does not cover stairs that contribute to the overall stability of the works or the strength of the structure.

This European Standard is valid for the verification of mechanical performance characteristics, usability and load-bearing capacity and their related durability. Other requirements, e.g. requirements for acoustic properties, are not covered by this European Standard.

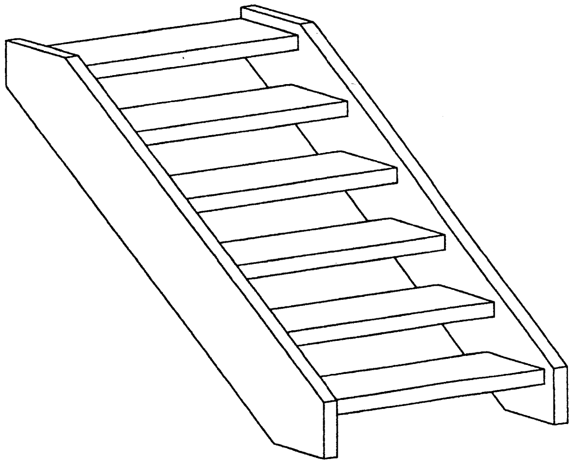
For the design, calculation and determination of not solely resting actions, additional requirements need to be taken into account (to be checked).

For the dimensioning with special reference to resistance to fire and earthquake/seismic action, additional requirements may be taken into account.

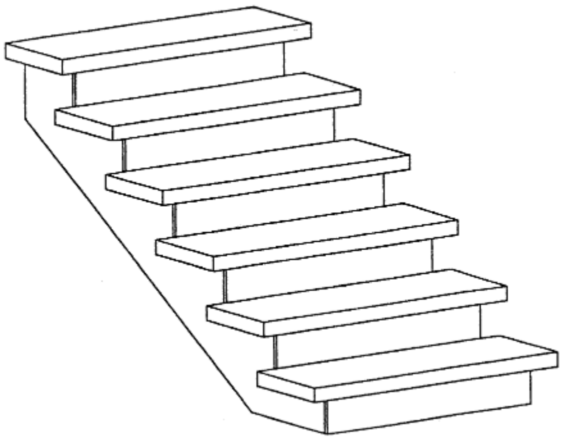
Without further verification, the methods in this European Standard are valid for different types of stair structures and their components, as illustrated in Figure 1:



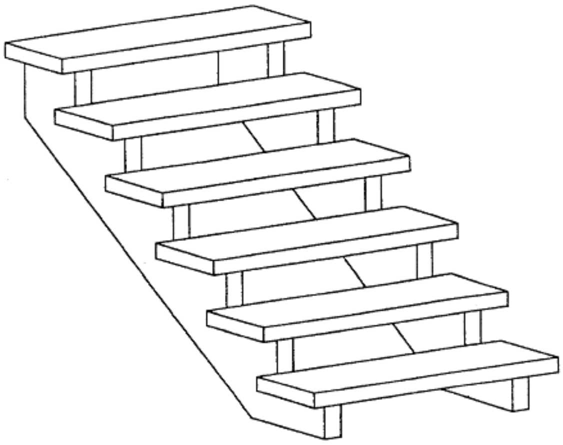
a) Stair with closed string and riser



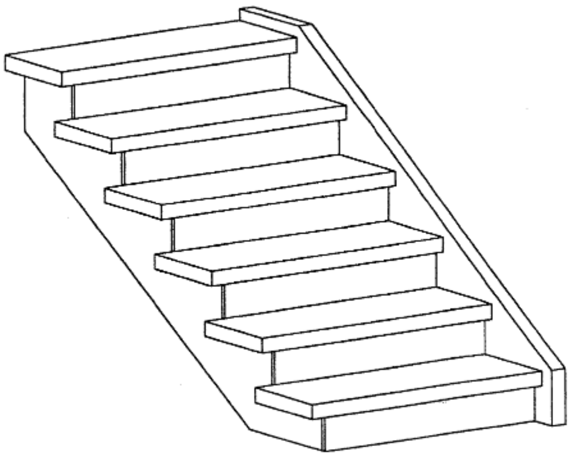
b) Stair with closed string without riser



c) Stair with cut strings and riser



d) Stair with cut strings without riser



e) Combination of stairs with closed string and cut string with or without riser

Figure 1 — Types of stair structures and their components

2 Normative references

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

EN 338, *Structural timber — Strength classes*

EN 1990, *Eurocode — Basis of structural design*

EN 1991-1-1:2002, *Eurocode 1: Actions on structures — Part 1-1: General actions — Densities, self-weight, imposed loads for buildings*

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

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

NOTE Eurocode includes its National Application Documents (NAD).

EN 14076, *Timber stairs — Terminology*

EN 15644, *Traditionally designed prefabricated stairs made of solid wood — Specifications and requirements*

EN ISO 80000-1, *Quantities and units — Part 1: General (ISO 80000-1)*

3 Terms and definitions, formula symbols and SI-units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1990, EN 1995-1-1 and EN 14076 and the following apply.

NOTE The general terms used in the context of actions and resistance as well as terms referring to the safety concept are given in EN 1990.

The specific valid terms used in the field of wood construction are found in EN 1995-1–1.

Specific terms regarding stair construction are given in EN 14076.

3.1.1
cross-bracing
tie-bars
system designed to provide torsional restraint to strings

EXAMPLE Screws, nails, glues.

3.2 Notation of formula symbols

In most cases, the notation of formula symbols consists of a main symbol (main indicator) and one or more subscript indicators. The following list defines the most common notations. Explanations of further notations either follow immediately the formula in which they appear or are described in the accompanying text.

α	pitch
γ	partial safety factor for loads
φ_x	torsional angle around the x-axis
φ_y	torsional angle around the y-axis
φ_z	torsional angle around the z-axis
γ_M	partial safety factor for a material property
Ψ_0	combination coefficient
A	cross-sectional area
A_y	cross-sectional shear area in the direction of the y-axis
A_z	cross-sectional shear area in the direction of the z-axis
$A_{cross\text{-}bracing}$	cross-sectional area of the cross-bracing
A_{string}	calculated cross-sectional area of the string

$A_{string,I-I}$	real cross-sectional area of the string in section I-I
$A_{string,III-III}$	real cross-sectional area of the string in section III-III
$A_{y,string}$	calculated shear area of the string in the direction of the y-axis
$A_{z,string}$	calculated shear area of the string in the direction of the z-axis
corner_i	connecting rod, bottom string-corner section
corner_i+1	connecting rod, top string-corner section
D_{max}	maximum distance between lower edge of string and lower edge of housing
D_{medium}	average value of D_{max} und D_{min}
D_{min}	smallest distance between upper edge of string and upper edge of housing
d	cross-sectional thickness, subscript for rated value
$d_{housing}$	depth of housing
d_{tread}	thickness of the tread
d_{string}	thickness of the string
E	modulus of elasticity
e	eccentricity
EA	stretch stiffness of a component
E_d	value of influence regarding the verification
EI_y	bending stiffness around the y-axis
EI_z	bending stiffness around the z-axis
$EI_{y,tread}$	bending stiffness of the tread around the y-axis
$EI_{z,tread}$	bending stiffness of the tread around the z-axis
e_{tread}	distance of the plumb line of tread and the idealized plumb line of the cut string
F	force, point load
f_1	fundamental frequency
G	rigidity modulus
GA_y	rigidity stiffness of a component in the direction of the y-axis
GA_z	rigidity stiffness of a component in the direction of the z-axis
GI_t	torsional stiffness of a component
G_k	permanent action of construction including all fasteners
g	going
H	acting horizontally live load
h	height of cross-section
$h_{balustrade}$	distance between horizontal rail load and tread
h_{max}	real maximum section height of the cut sting
h_{min}	real minimum section height of the cut sting
$h_{c,string,max}$	real maximum distance between the plumb line of a cut string to lowest edge of the string
$h_{c,string,min}$	real minimum distance between the plumb line of a cut string to lowest edge of string
h_{cut}	maximum height of the cut string area ($h_{cut} = h_{max} – h_{min}$)
h_{string}	height of the string

$h_{housing}$	height of the housing
$h^*_{c,string}$	calculated distance of the plumb line of a cut string to lowest edge of string
h^*_{string}	calculated height of the cut string
H^*_{string}	orthogonal projection of the calculated height of the cut string
$H^*_{c,string}$	orthogonal projection of the calculated distance of the plumb line of a cut string to lowest edge of string
I	moment of inertia
$I_{cross\text{-}bracing}$	calculated moment of inertia of the cross-bracing by stairs with cut strings
I_t	torsional moment of inertia
$I_{t,string}$	calculated torsional moment of inertia from the string
I_y	moment of inertia around the y-axis
$I_{y,string}$	calculated moment of inertia of the string around the y-axis
$I_{y,string, I\text{-}I}$	real moment of inertia of the string around the y-axis in section I-I
$I_{y,string,III\text{-}III}$	real moment of inertia of the string around the y-axis in section III-III
I_z	moment of inertia around the z-axis
$I_{z,string}$	calculated moment of inertia of the string around the z-axis
k	spring stiffness
k^D	torsion spring stiffness
k^D_y	torsion spring stiffness in bending around the y-axis
k^D_z	torsion spring stiffness in bending around the z-axis
k^F	stretch spring stiffness
k_m	coefficient
k_{mod}	modifications coefficient that takes into account the impact of the service class and load duration on the strength properties
K_{shape}	coefficient according to the cross-sectional shape
L	length of cross-section or length of system
L_a	calculated support length at the wall side of a kite winder before the corner
L_b	calculated support length at the wall side of a kite winder after the corner
L_c	calculated support length at the outer side of a kite winder before the corner
L_d	calculated support length at the outer side of a kite winder after the corner
$L_{cantilever}$	calculated length of the overhang of a cut tread
L_{cut}	maximum length of cut string area
L_{load}	length of the actual line load
L_{stair}	length stair
L_{tread}	calculated span of tread
M	moment, bending moment, point load
$M_{k,1}$	net mass of the structure, including all fasteners
$M_{k,2}$	single mass
$M_{rail,k}$	bending moment for the computational modelling of the rail load

$M_{x,d,corner\ i}$	governing torsional moment around the x-axis before the corner due to the load combinations
$M_{x,d,corner\_i+1}$	governing torsional moment around the x-axis after the corner due to the load combinations
$M_{x,Rd,corner\_i}$	determined by tests in the link design value of the torsional recordable
$M_{x,d,tread}$	governing torsional moment at the beginning of the tread or end result of the load combination
$M_{x,Rd,tread}$	by test or calculation determined design value of recordable torsion in the tread
$M_{y,d,corner\_i}$	governing bending moment around the y-axis before the corner due to the load combinations
$M_{y,corner\_i+1}$	governing bending moment around the y-axis after the corner due to the load combinations
$M_{y,Rd,corner\_i}$	rated value of the absorbable bending moment in the connection around the y-axis, determined by tests (corner)
$M_{y,d,tread}$	governing bending moment around the y-axis at the beginning of the tread or end due to the load combinations
$M_{y,Rd,tread}$	rated value of the absorbable bending moment in the connection around the y-axis, determined by tests (tread)
$M_{z,d,corner\_i}$	governing bending moment around the z-axis before the corner due to the load combinations
$M_{z,corner\_i+1}$	governing bending moment around the z-axis after the corner due to the load combinations
$M_{z,Rd,corner\_i}$	rated value of the absorbable bending moment in the connection around the z-axis, determined by tests (corner)
$M_{z,d,tread}$	governing bending moment around the z-axis at the beginning of the tread or end due to the load combinations
$M_{z,Rd,tread}$	rated value of the absorbable bending moment in the connection around the z-axis, determined by tests (tread)
m_{lower}	lower margins
m_{upper}	upper margins
o	overlap
Q	variable action, point load
$Q_{k,1}$	concentrated point load
q	variable action, uniformly distributed load
$q_{k,1}$	equally distributed vertical load
$q_{k,2}$	equally distributed horizontal load
$q_{k,left}$	maximum value of variable line load to be applied on a winder tread
$q_{k,right}$	minimum value of variable line load to be applied on a winder tread
r	rise
$T_{d,cross-bracing}$	governing tension force in the cross-bracing as a result of load combinations
$T_{Rd,cross-bracing}$	rated value of the tension force absorbable in the cross-bracing traction, determined by tests or calculation
u, v, w	deformation, deflexion
w	width section,

w_1	outer side real tread width
$w_{1,id}$	idealized outer side step width
w_2	wall side real tread width
$w_{2,id}$	wall side idealized tread width
w_{i_stair}	internal width of the stair
$w_{av,id}$	average value of idealized tread widths
w_{stair}	width of flight
w_{tread}	tread depth
w_G	vertical deformation due to permanent action
$w_{q,k1}$	vertical deformation due to variable uniformly distributed vertical load
$w_{Q,k1}$	vertical deformation due to vertical point load of size 2 kN in an unfavourable position
X	property of building material
X_k	characteristic value of a material property
X_{Rd}	design value of material property
x, y, z	coordinates
$x_{cross\text{-}bracing}$	local x-axis of the cross-bracing
$y_{cross\text{-}bracing}$	local y-axis of the cross-bracing
$z_{cross\text{-}bracing}$	local z-axis of the cross-bracing
x_{string}	local x-axis of the string
y_{string}	local y-axis of the string
z_{string}	local z-axis of the string
x_{tread}	local x-axis of the tread
y_{tread}	local y-axis of the tread
z_{tread}	local z-axis of the tread

3.3 SI-units

SI-units shall be applied in accordance with EN ISO 80000-1.

For calculations, the following units shall be applied:

— forces and loads:	kN, kN/m, kN/m^2;
— bulk density:	kN/m^3;
— density:	kg/m^3;
— tension, stress and stability:	N/mm^2 (=MN/m^2 or MPa);
— elasticity and rigidity modulus:	N/mm^2 (= MN/m^2 or MPa);
— moments (bending moment):	kNm.

4 Principles for verification of mechanical performance characteristics

4.1 Performance characteristics to be verified

The fulfilment of the following mechanical performance characteristics shall be verified.

a) **Serviceability** – a stair is deemed to satisfy this requirement when:

1) under the actions applied, the deformation of the stair as a whole and/or its parts (e.g. steps and strings) shall not at any point exceed the preset maximum deformation values defined in EN 1995-1-1 (Eurocode 5) and National Application Document (NAD) when applicable,

2) under the action applied, the fundamental frequency of the stair as a whole shall fulfil the value defined in EN 1995-1-1 (Eurocode 5) and National Application Document (NAD) where applicable.

b) **Load-bearing capacity** - a stair is deemed to satisfy this requirement when

1) the existing use of the stair as a whole or of one of its single parts under the applied actions shall not exceed at any point the nationally set maximum values with regard to admissible use.

The fulfilment of both performance characteristics shall be verified. For the purpose of evaluating the results, the most unfavourable case is significant.

Stairs assessed based on experience, e.g. conventionally accepted performance (CAP) may be accepted according to national decisions.

4.2 Typical actions

Types and sizes of actions to be applied follow indications found in EN 1991-1-1 and are combined with relevant national regulations. In order to verify the mechanical performance characteristics of stairs, the following action types shall be considered:

— G_k Dead load of construction including all fasteners according to EN 1991–1–1:2002, Clause 5.

— $q_{k,1}$ Equally distributed vertical load [kN/m^2] according to EN 1991–1–1:2002, 6.3.

Without a further national value, the default value should be applied as, $\boldsymbol{q_{k,1}}$ **= 3 kN/m^2**.

— $Q_{k,1}$ Concentrated single load [kN] according to EN 1991–1–1:2002, 6.3.

Without a further national value, the default value should be applied as, $\boldsymbol{Q_{k,1}}$ **= 2 kN**.

— $q_{k,2}$ Equally distributed horizontal load [kN/m] according to EN 1991–1–1:2002, 6.4.

Without a further national value, the default value should be applied as $\boldsymbol{q_{k,2}}$ **= 0,5 kN/m**.

— $M_{k,1}$ Permanent mass of construction including the mass of all fasteners.

— $M_{k,2}$ Single mass for fundamental frequency.

Without a further national value, the default value should be applied as $\boldsymbol{M_{k,2}}$ **= 1 kN** .

4.3 Significant action combinations

4.3.1 General

Types and sizes of applied action combinations are chosen on the basis EN 1991-1-1 in combination with relevant national regulations. In order to verify the mechanical performance characteristics of a prefabricated stair or of one of its parts, the following typical action combinations shall be examined.

Without national values, the default values should be applied as given below.

4.3.2 Action combinations relevant for verification of usability/serviceability

The verification of usability/serviceability shall be carried out by using three action combinations.

1) Action combination "**Deformation_$q_{k,1}$**"

   The significant actions E_d consist of:

$$E_d = E\{1,0 \cdot G_k + 1,0 \cdot q_{k,1}\} \tag{1}$$

2) Action combination "**Deformation_$Q_{k,1}$**"

   The significant actions E_d consist of:

$$E_d = E\{1,0 \cdot G_k + 1,0 \cdot Q_{k,1}\} \tag{2}$$

3) Action combination "**Fundamental frequency_$M_{k,2}$**"

   The significant actions E_d consist of:

$$E_d = E\{1,0 \cdot M_{k,1} + 1,0 \cdot M_{k,2}\} \tag{3}$$

4.3.3 Action combination for verification of the load-bearing capacity

The verification of the load-bearing capacity shall be carried out by using two action combinations.

1) Action combination "**Rupture Load_$q_{k,1}$**"

   The significant actions E_d consist of:

$$\begin{aligned} E_d &= E\{1,35 \cdot G_k + 1,5 \cdot q_{k,1} + 1,5 \cdot \psi_0 \cdot q_{k,2}\} \\ &= E\{1,35 \cdot G_k + 1,5 \cdot q_{k,1} + 1,05 \cdot q_{k,2}\} \end{aligned} \tag{4}$$

2) Action combination "**Rupture Load_$Q_{k,1}$**"

   The significant actions E_d consist of:

$$E_d = E\{1,35 \cdot G_k + 1,5 \cdot Q_{k,1}\} \tag{5}$$

4.4 Bearing resistance within the verification of the load-bearing capacity

The properties of building materials are indicated by characteristic values, X_k.

For wood and wood-based materials, and in the absence of relevant national directives, the assessment values X_{Rd} used within the limit state of the load-bearing capacity result from:

$$X_{Rd} = \frac{k_{mod} \cdot X_k}{\gamma_m} \tag{6}$$

For example using solid timber in service class 2 or 1, use $k_{mod} =$ 0,9 and γ_m = 1,3.

For steel parts, the assessment values X_{Rd} used within the limit state of the load-bearing capacity shall be taken from EN 1993-1-1 in the absence of relevant national directives.

In the absence of relevant national directives, the characteristic stress, stiffness and bulk density indices shall be taken from EN 1995-1-1.

In the absence of relevant national directives, the characteristic rupture load, $X_{k,}$ is used as the lowest value derived from tests with relevance to components resistance based on three identical component tests.

For rupture loads derived from components tests, and in the absence of relevant national directives, the assessment values X_{Rd} used within the limit state of the load-bearing capacity result from:

$$X_{Rd} = \frac{X_k}{\gamma_m} = \frac{X_k}{1,5} \tag{7}$$

Without a further national value, the default value γ_m shall be applied as 1,5 where a minimum of 3 tests have been conducted and this value can be changed to 1,3 where 10 or more tests have been carried out (see ETAG 008).

5 Determination of mechanical stress (stress resultants and deformations)

5.1 General

a) In principle, this European Standard allows the determination of mechanical stress (stress resultants and deformations) in two different ways, as follows:

   1) separate determination of mechanical stress of treads or strings, respectively, with the help of structural frame analysis, either on plan or spatial, as well as static systems for all single parts independent from each other;

   2) interrelated determination of mechanical stress of treads and strings with the help of spatial structural frame analysis and a spatial static system of the stair as a whole.

b) The separate determination of mechanical stress is valid for:

   1) all forms of single treads,

   2) straight stairs with vertical support in places described in the following manner (see Figure 2),

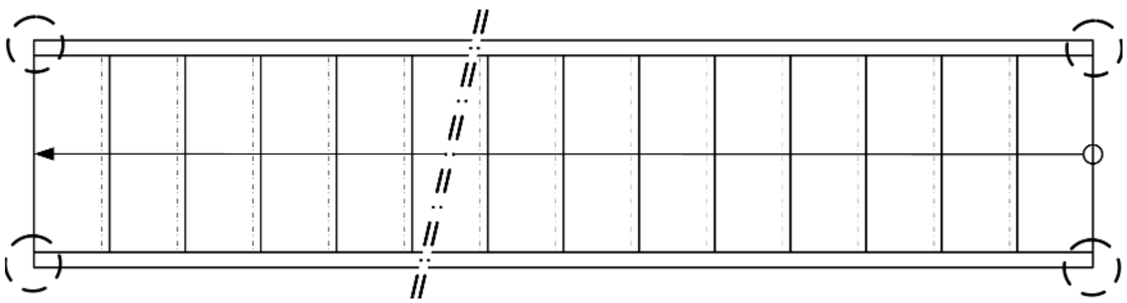


Figure 2 — Ground plan of straight stairs

3) turning stairs (winding stairs) with vertical support in all places in which the string changes direction (see Figure 3).

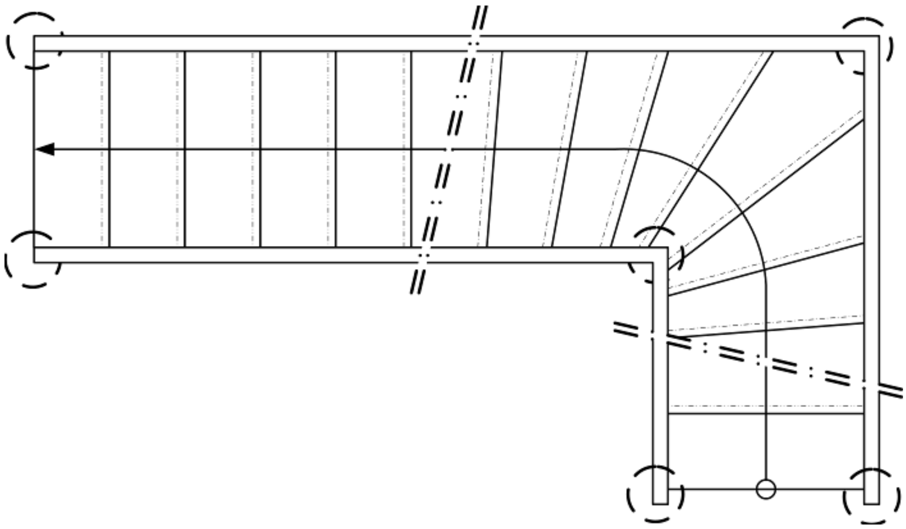


Figure 3 — Ground plan of turning stairs all corners supported

c) The interrelated determination of mechanical stress of steps and strings is needed for all other ground plans of stairs (see Figure 4).

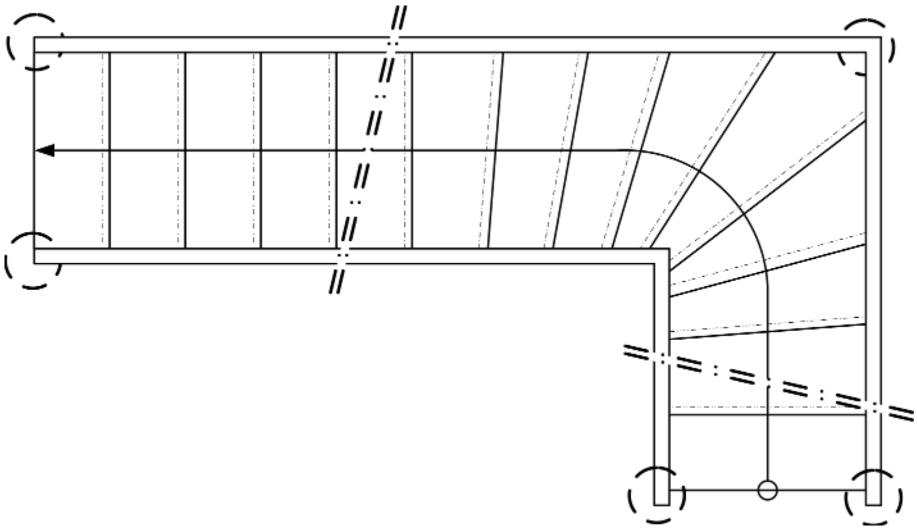


Figure 4 — Ground plan of turning stairs not all corners supported

d) The following calculation methods are admissible:

1) elastic bearing structure calculation;

2) plastic bearing structure calculation.

e) The elastic bearing structure calculation may be used in all cases.

f) The plastic bearing structure calculation may be carried out only if the bearing structure comes with sufficient rotation capacity in those places where plastic joints are formed, be it in components or in joints. The verification of sufficient rotation capacity shall be carried out by the structural designer. Alternatively, the verification may be carried out with component tests.

g) All calculations may be carried out according to the 1st-order-theory.

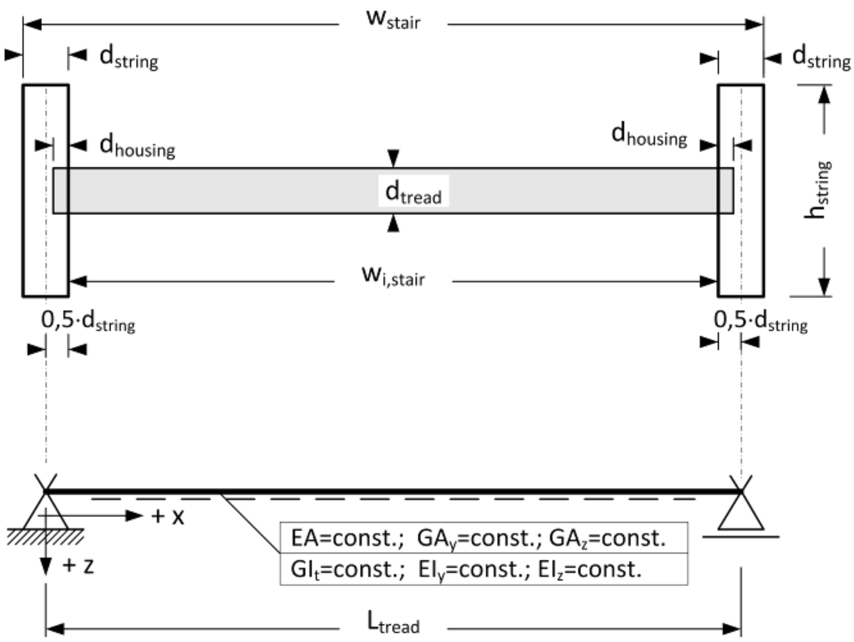
h) The structural analysis model shall be chosen such as to reflect the behaviour within the considered limit state with as much precision as possible in conjunction with the anticipated behaviour of cross-sections, components, joints as well as mountings.

i) Generally, structural frame analysis models are used for the determination of mechanical stress.

5.2 Static systems and cross-section properties for tread of stairs

5.2.1 Parallel treads without riser

— The static system of a parallel treads in a closed string is that of a single-span beam (see Figure 5):

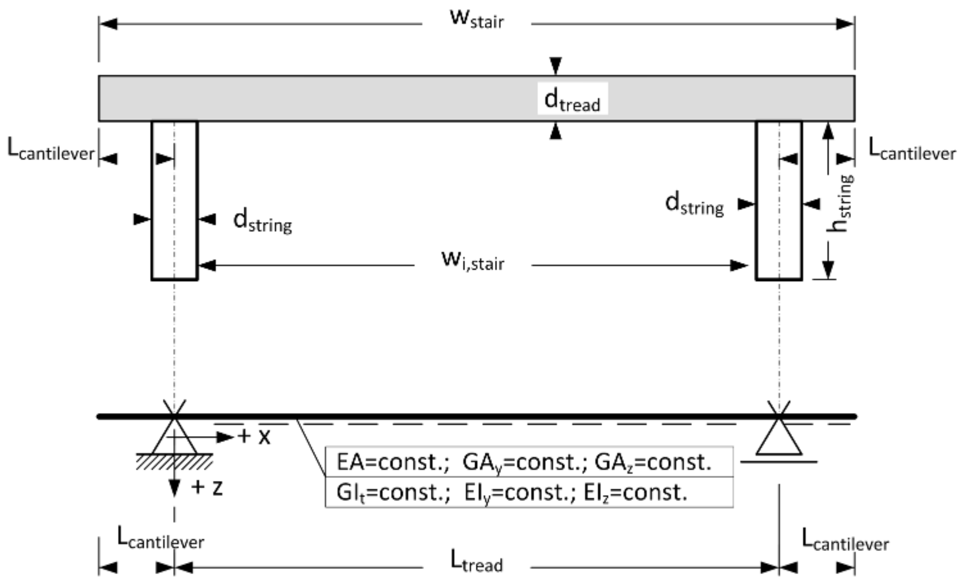


Key

$d_{housing}$	depth of housing
d_{tread}	thickness of the tread
d_{string}	thickness of the string
h_{string}	height of the string
EA	stretch stiffness of a component
EI_y	bending stiffness around the y-axis
EI_z	bending stiffness around the z-axis
GA_y	rigidity stiffness in the direction of the y-axis
GA_z	rigidity stiffness in the direction of the z-axis
GI_t	torsional stiffness
L_{tread}	calculated span of tread
$w_{i,stair}$	internal width of the stair
w_{stair}	width of flight

Figure 5 — Cross-section area of tread with closed strings and static system

— The static system of a parallel tread on cut strings is that of a single-span beam with two cantilever arms (see Figure 6):



Key

d_{string}	thickness of the string
d_{tread}	thickness of the tread
h_{string}	height of the string
$L_{cantilever}$	calculated length of the overhang of a cut tread
L_{tread}	calculated span of tread
$w_{i,stair}$	internal width of the stair
w_{stair}	width of flight

Figure 6 — Cross-section area of tread with cut strings and static system

— The supports are taken as fork bearings and able to absorb torsional moments under eccentric load.

— The calculated support span L_{tread} of a straight tread is the horizontal distance between the centroidal axes of the stair strings.

— The cross-section of a parallel tread without riser is a rectangle. The cross-section height d_{tread} is the thickness of the tread; the cross-section width w_{tread} is the sum of the going and the overlap (g + o). With these measurements, the cross-section values to be applied mathematically (area, shear areas A_y and A_z, torsional moment, I_t, and geometrical moment of inertia, I_y and I_z, respectively) are determined according to the elastic theory.

— Both elasticity modulus, E, and rigidity modulus, G, shall be taken from standards, for example, EN 1995-1-1 or EN 338.

Material properties may also be determined with the help of suitable tests.

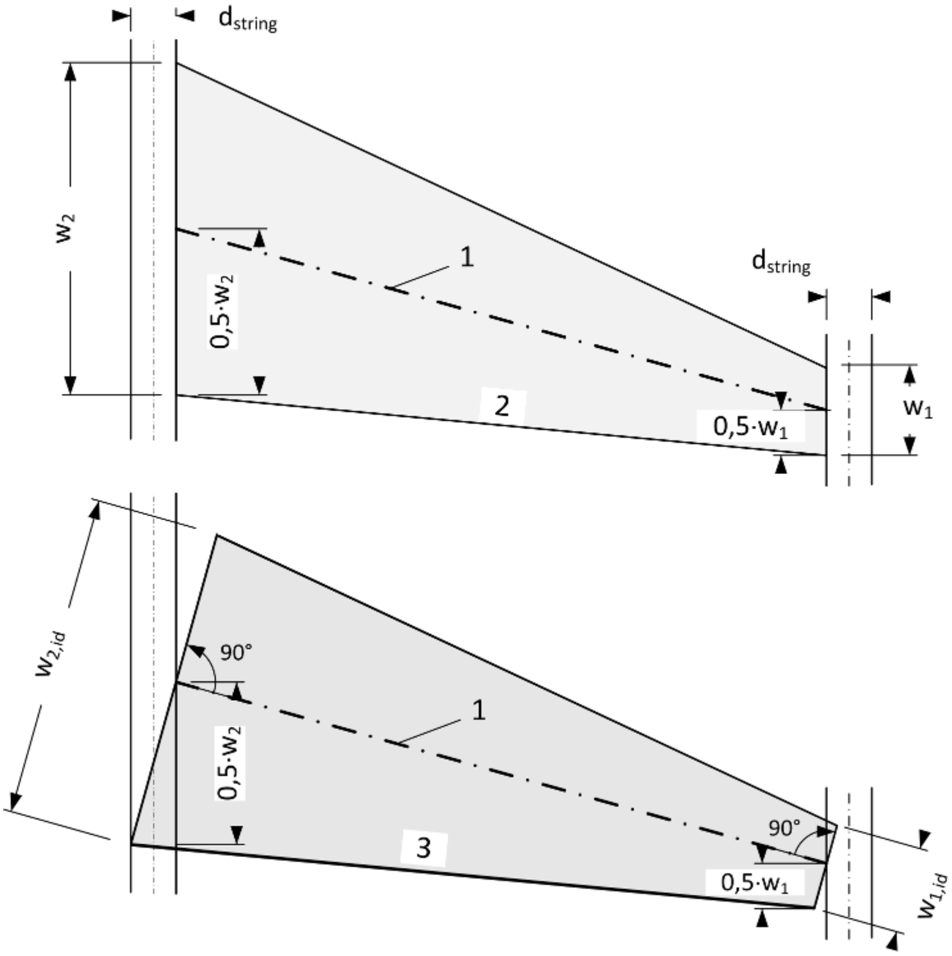
5.2.2 Parallel steps with riser

The span listed under 5.2.1 are also valid for parallel steps with riser.

The cross-section form of a parallel step with riser may be regarded as a t-beam. Required is a friction-locked joint of the riser with the tread. Otherwise, the regulations for steps without riser apply. For the measurements of the t-beam cross-section, the mathematically applied cross-section values (area, shear area A_y and A_z, respectively, torsional moment I_t and moment of inertia, I_y and I_z, respectively) are determined according to the elastic theory.

5.2.3 Tapered treads

1) In the case of tapered treads, the parameters used for the determination of mechanical stress are calculated with the help of an idealized ground plan of the tread as shown in Figure 7.



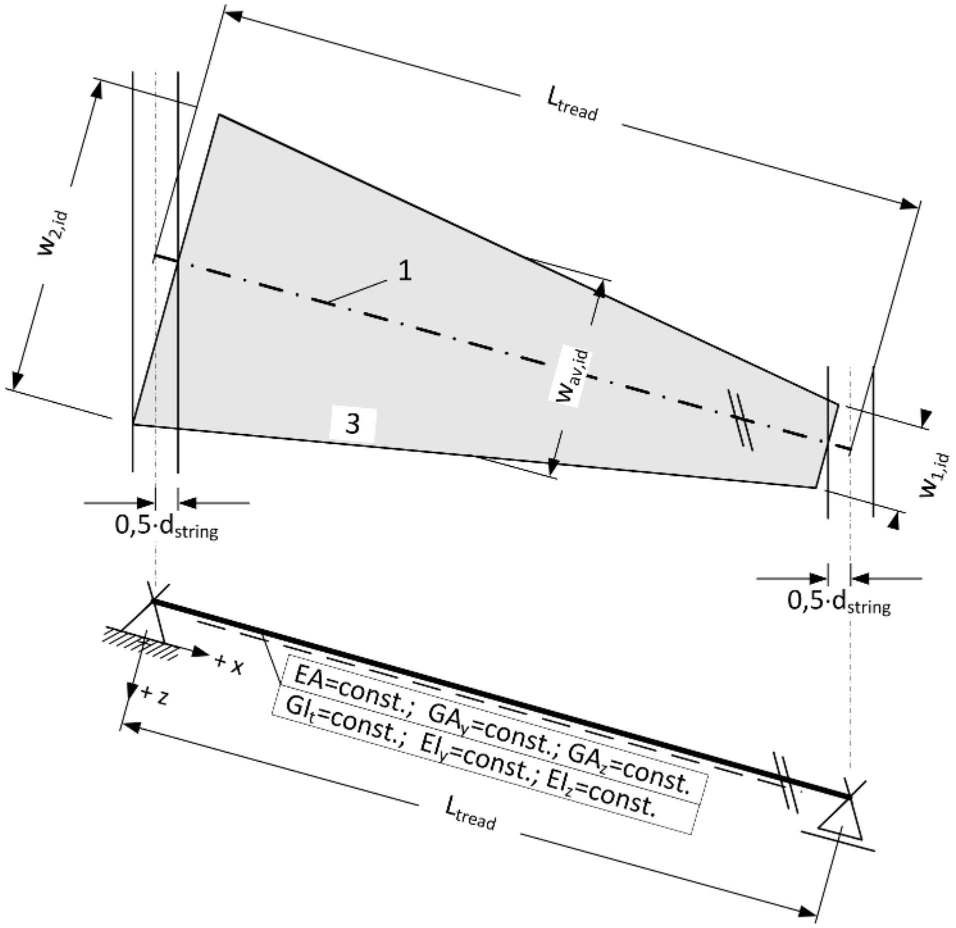
Key

1	tread axis of the real tread
2	real ground plan of tread
3	idealized ground plan of tread
d_{string}	thickness of the string
w_1	outer side real tread width
$w_{1,id}$	idealized outer side tread width
w_2	wall side real tread width
$w_{2,id}$	idealized wall side tread width

Figure 7 — Ground plan and idealized ground plan of tapered treads with closed strings

On the basis of this idealized substitute tread, the static system of a tapered tread is modelled as follows.

2) In the case of closed strings, the static system of a tapered tread is that of a single-span beam (see Figure 8).

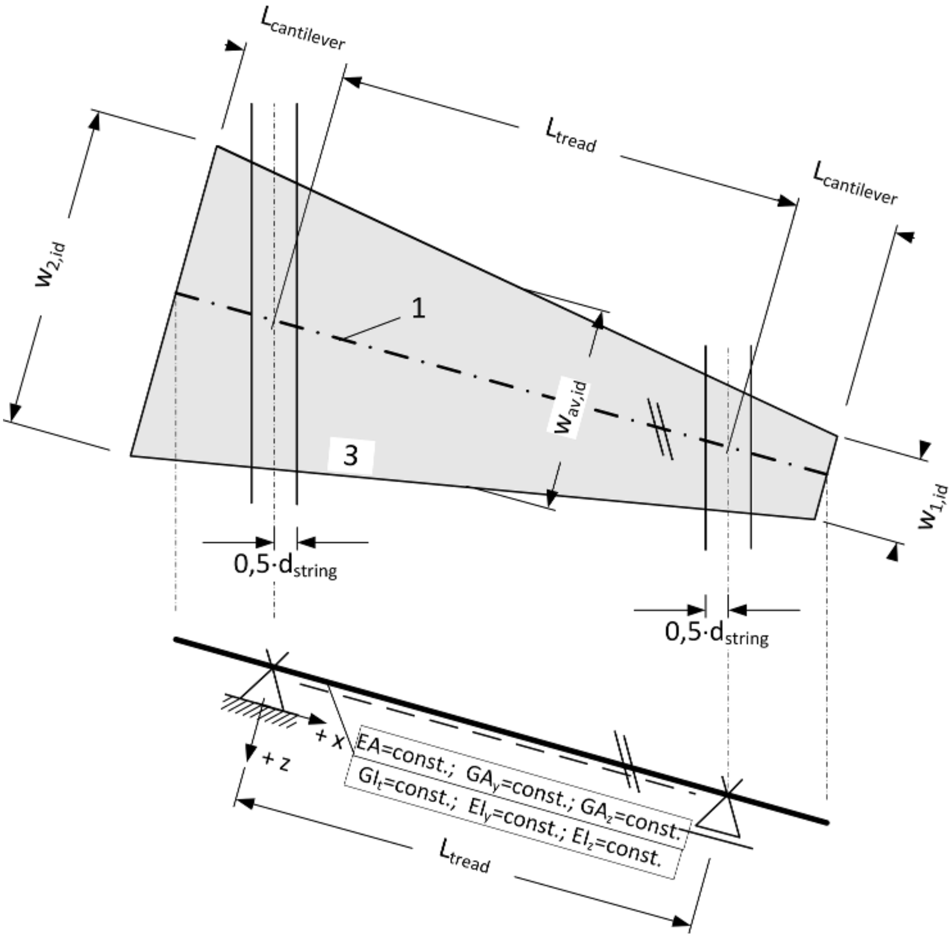


Key

1	tread axis of the real tread
3	idealized ground plan of tread
d_{string}	thickness of the string
L_{tread}	calculated span of tread
w_1	outer side real tread width
$w_{1,\text{id}}$	idealized outer side tread width
w_2	wall side real tread width
$w_{2,\text{id}}$	idealized wall side tread width
$w_{\text{av,id}}$	average value of idealized tread widths

Figure 8 — Idealized ground plan of tapered treads with closed strings and static system

3) In the case of cut strings, the static system of a winding tread is that of a single-span beam with two cantilever arms.



Key

1	tread axis of the real tread
3	idealized ground plan of tread
d_{string}	thickness of the string
L_{tread}	calculated span of tread
w_1	outer side real tread width
$w_{1,id}$	idealized outer side tread width
w_2	wall side real tread width
$w_{2,id}$	idealized wall side tread width
$w_{av,id}$	average value of idealized tread widths

Figure 9 — Idealized ground plan in case of cut strings and static system

4) The calculated span L_{tread} of a tapered tread of a stair is the distance of the centroidal axis of the stair strings measured in the tread axis of the idealized substitute tread.

5) The cross-section height, $d_{tread,}$ is the tread thickness; the cross-section width, $w_{av,id,}$ as the median value is derived from the values of the tread width $w_{1,id}$ and $w_{2,id}$.

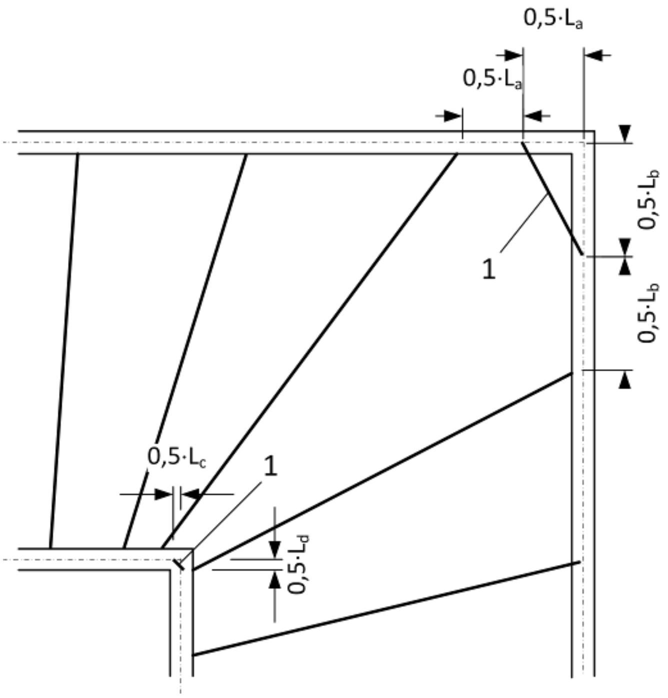
   With the help of these measurements, the mathematically applied cross-section values (area and moment of inertia) are determined according to the rules of the elastic theory.

6) Both elasticity and rigidity modulus shall be taken from EN 1995-1-1.

The material properties may also be determined with the help of suitable experiments.

5.2.4 Kite winders

1) In case of kite winders, the idealized ground plan is related to the bearing line shown in Figure 10. The idealized support line of a kite winder for closed strings is centred on the centroidal axis of the strings. This is dependent on the single lengths of the bearing lines at the corner.

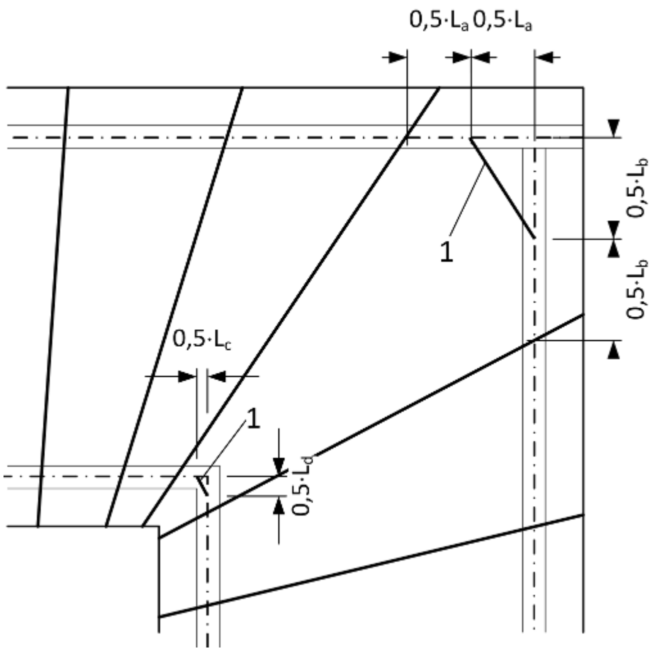


Key

1	idealized support line
L_a	calculated support length at the wall side of a kite winder before the corner
L_b	calculated support length at the wall side of a kite winder after the corner
L_c	calculated support length at the outer side of a kite winder before the corner
L_d	calculated support length at the outer side of a kite winder after the corner

Figure 10 — Ground plan showing idealized support line in case of kite winders with closed strings

2) The idealized support line of a kite winder for cut strings is centred on the centroidal axis of the strings. This is dependent on the single lengths of the support lines at the corner (see Figure 11).



Key

1 idealized support line

L_a calculated support length at the wall side of a kite winder before the corner

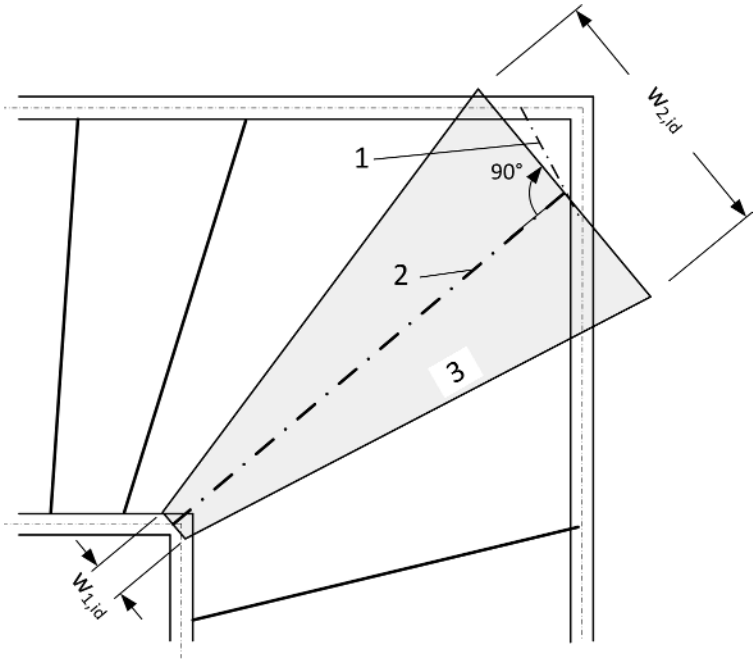
L_b calculated support length at the wall side of a kite winder after the corner

L_c calculated support length at the outer side of a kite winder before the corner

L_d calculated support length at the outer side of a kite winder after the corner

Figure 11 — Ground plan showing idealized support line in case of kite winders with cut strings

3) Analogously, the idealized ground plans of kite winders are determined according to the same procedure as with regard to treads (see Figure 12).



Key

1 idealized support line

2 tread axis of the real tread

3 idealized ground plan of tread

$w_{1,id}$ idealized outer side tread width

$w_{2,id}$ idealized wall side tread width

NOTE The tread axis is not in the orthogonal position to the idealized support line, but is usually the median line between the front and back edges of the idealized tread.

Figure 12 — Idealized ground plan in case of kite winders with closed strings and cut strings

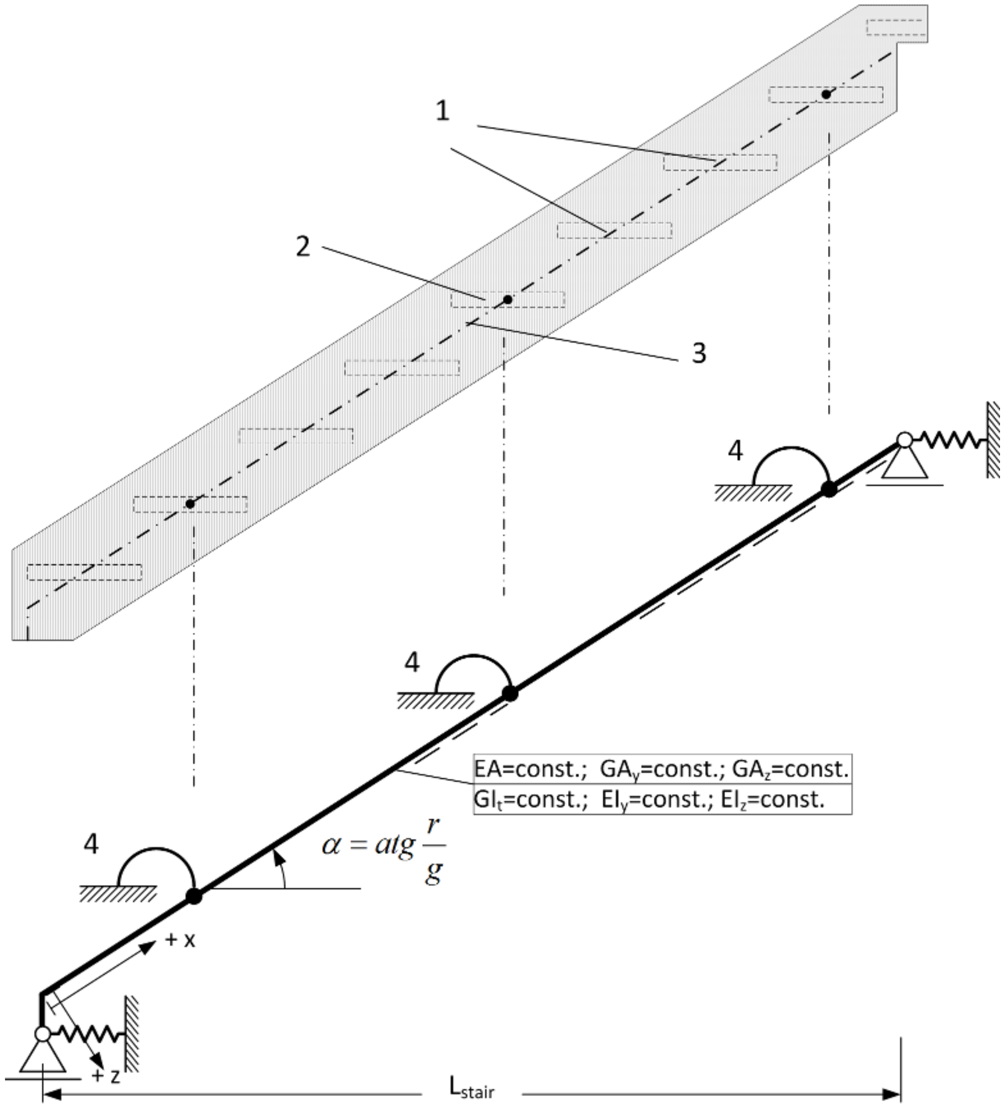
4) The determination of calculated span, cross-section dimensions and material properties of kite winders are carried out on the basis of the idealized ground plan of the tread according to the rules of the elastic theory.

5.3 Static systems for stair strings and their cross-sectional characteristics

5.3.1 Closed strings

1) In the case of stairs with closed strings, the static system of the stair string is that of a straight (single or multiple supported) or a turning span beam (multiple supported) with constant cross-sectional properties.

   In case of a straight stair, the following static system can be used, mountings are suggested as follows in Figure 13.



Key

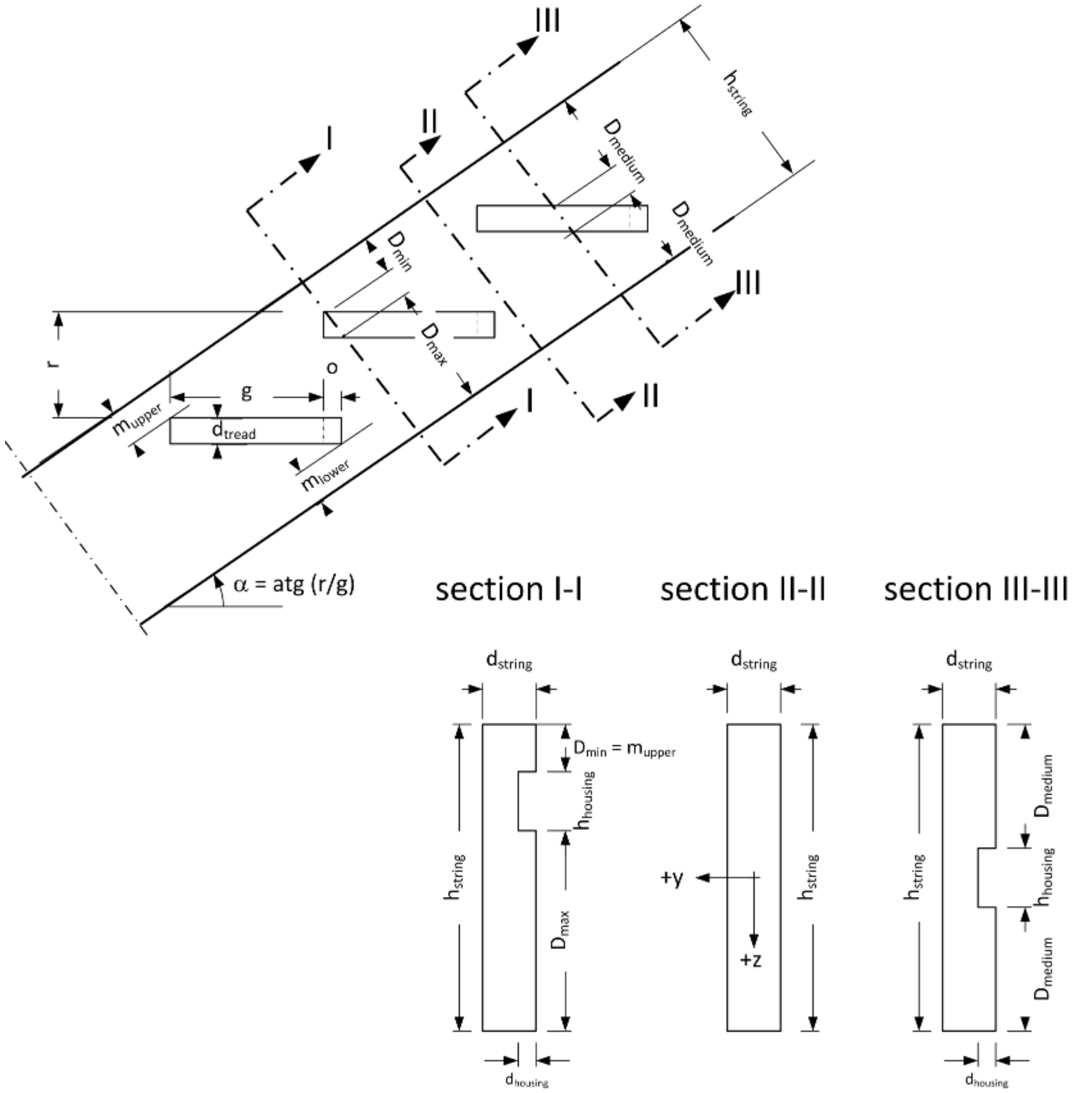
1	tread without cross-bracing
2	tread with cross-bracing
3	idealized system line of the string
4	fixture against torsional movement
EA	stretch stiffness of a component
EI_y	bending stiffness around the y-axis
EI_z	bending stiffness around the z-axis
G	going
GA_y	rigidity stiffness of a component in the direction of the y-axis
GA_z	rigidity stiffness of a component in the direction of the z-axis
GI_t	torsional stiffness of a component
L_{stair}	length stair
r	rise
α	pitch

Figure 13 — Example of static system with cross-bracing

2) The modelling of construction connections at the points of the bottom step and top step are described in 5.4.4.

3) In the case of treads with cross-bracing, the string is clamped/fixed around the x-axis (torsion).

4) The cross-section values (area, torsional moment of inertia and moments of inertia) shall be applied in the structural frame analysis to determine the mechanical stress of the string, which are calculated with the help of the string dimensions shown in Figure 14.



Key

D_{max}	maximum distance between upper edge of string and upper edge of housing in section I-I
D_{medium}	average value of D_{max} and D_{min}
D_{min}	smallest distance between lower edge of string and upper edge of housing
$d_{housing}$	depth of housing
d_{string}	thickness of the string
d_{tread}	thickness of the tread
g	going
$h_{housing}$	height of the housing
h_{string}	height of the string
m_{lower}	lower margin
m_{upper}	upper margin
o	overlap
r	rise
α	pitch

Figure 14 — Cross-sectional dimensions for closed strings

5) The height of the string, $h_{string,}$ is derived from the dimensions of going, g, overlap, o, step thickness, d_{tread}, margin, m_{upper}, margin, m_{lower}, and pitch, α, by:

$$h_{\text{string}} = (g + o) \cdot \sin\alpha + d_{\text{tread}} \cdot \cos\alpha + m_{\text{upper}} + m_{\text{lower}}$$

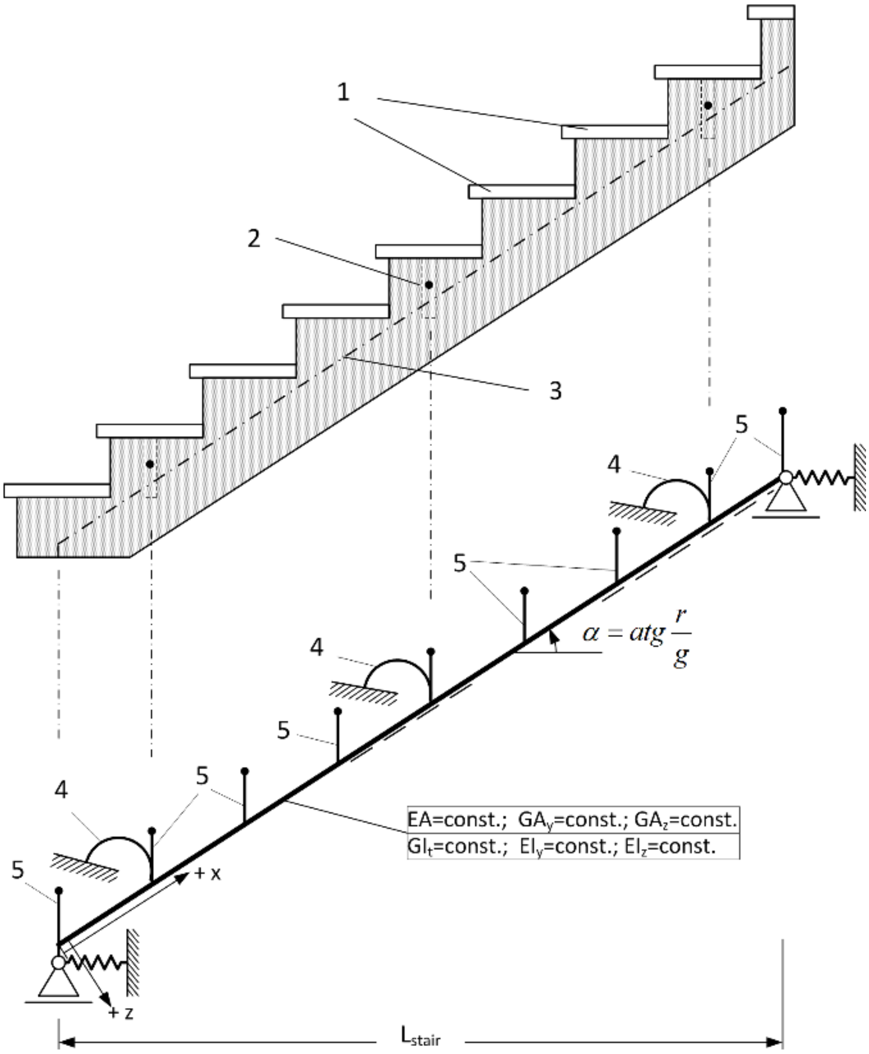
6) The cross-section values A_{string}, $A_{\text{y,string}}$, $A_{\text{z,string}}$, $I_{\text{t,string}}$, $I_{\text{y,string}}$ and $I_{\text{z,string}}$ as median values applied in the structural frame analysis are mathematically derived from sections I-I and III-III. The rule is:

$$A_{\text{string}} = \frac{A_{\text{string,I-I}} + A_{\text{string,III-III}}}{2}; I_{\text{y,string}} = \frac{I_{\text{y,string,I-I}} + I_{\text{y,string,III-III}}}{2}; \text{etc.}$$

5.3.2 Cut string

1) In the case of stairs with cut strings, the static system of the stair string is that of a straight (single or multiple supported) or a turning span beam (multiple supported) with constant cross-sectional properties.

   In case of a straight stair, the following static system can be used, mountings are suggested as follows in Figure 15.

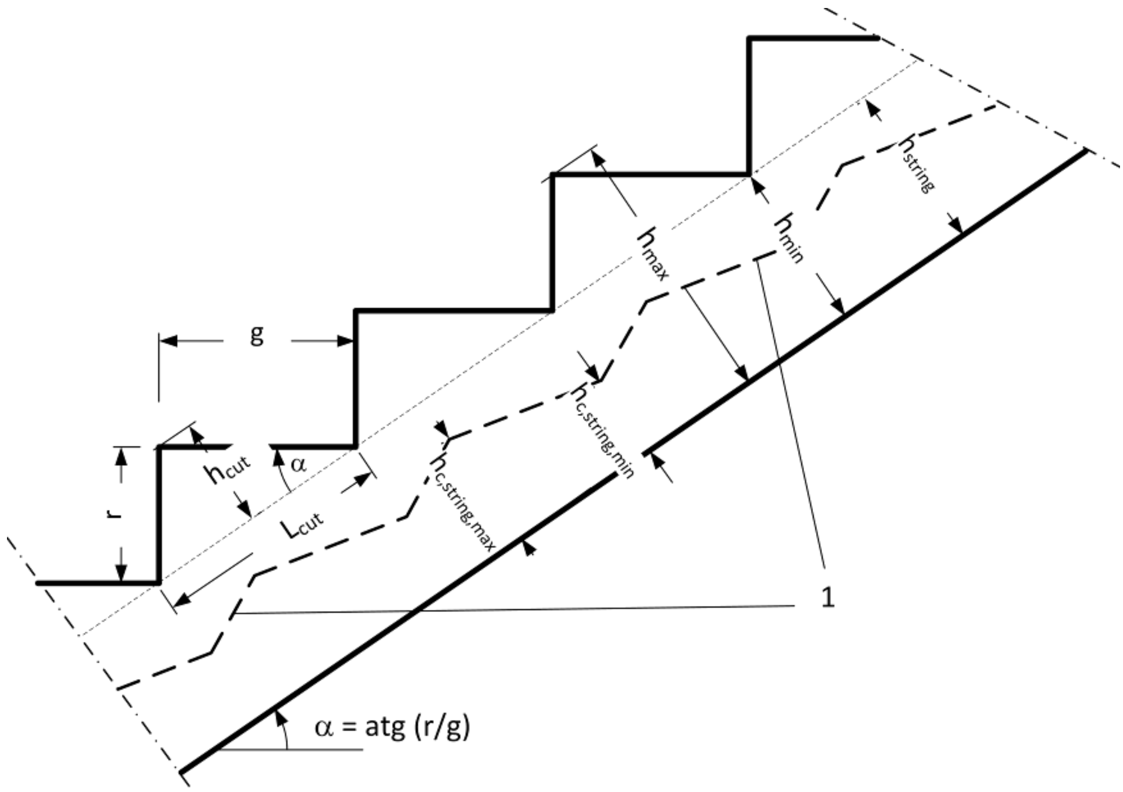


Key

1	tread without cross-bracing
2	tread with cross-bracing
3	idealized system line of the string
4	fixture against torsional movement
5	rigid weightless beam
EA	stretch stiffness of a component
EI_y	bending stiffness around the y-axis
EI_z	bending stiffness around the z-axis
g	going
GA_y	rigidity stiffness of a component in the direction of the y-axis
GA_z	rigidity stiffness of a component in the direction of the z-axis
GI_t	torsional stiffness of a component
L_{stair}	length stair
r	rise
α	pitch

Figure 15 — Static system of cut string for straight stair

2) The cross-section values (area, torsional moment of inertia and moments of inertia) shall be applied in the structural frame analysis to determine the mechanical stress of the string, which are calculated with the help of the string dimensions shown in Figure 16.



Key

1	system line of the real cut string
g	going
$h_{c,string,max}$	real maximum distance between the plumb line of a cut string to lowest edge of string
$h_{c,string,min}$	real minimum distance between the plumb line of a cut string to lowest edge of string
h_{cut}	maximum height of the cut string area
h_{max}	real maximum section height of the cut string
h_{min}	real minimum section height of the cut string
h_{string}	height of the string
L_{cut}	maximum length of the cut string area
r	rise
α	pitch

Figure 16 — Elevational dimensions of the cut string

3) The minimum distance, $h_{c,string,min}$ of the centroidal axis of a real cut string and the lower edge of the string is:

$$h_{c,string,min} = \frac{h_{string}}{2}$$

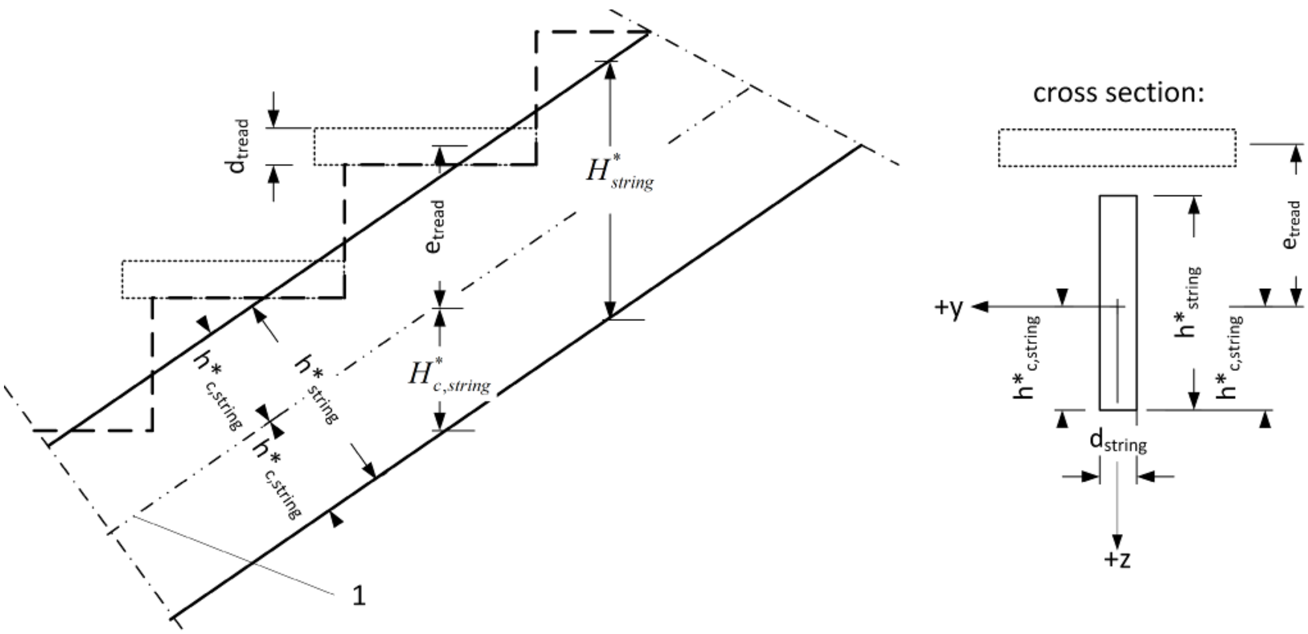
4) The maximum distance, $h_{c,string,max}$ of the centroidal axis of a real cut string and the lower edge of string is:

$$h_{c,string,max} = \frac{\left[h_{string} \cdot \frac{g}{\cos\alpha} \cdot \frac{h_{string}}{2}\right] + \left[\frac{g^2}{2} \cdot \tan\alpha \cdot \left(h_{string} + \frac{g \cdot \sin\alpha}{3}\right)\right]}{\left[h_{string} \cdot \frac{g}{\cos\alpha} + \frac{g^2}{2} \cdot \tan\alpha\right]}$$

5) The distance, $h^*_{c,string}$, of the centroidal axis of an idealized cut string and lower edge of string to be applied in the calculation is:

$$h^*_{c,string} = \frac{h_{c,string,min} + h_{c,string,max}}{2}$$

6) For the purpose of determining the cross-section values of an idealized cut string, the following designations are used as in Figure 17.



Key

1	system line of the idealized cut string
d_{string}	thickness of the string
d_{tread}	thickness of the tread
e_{tread}	distance of the plumb line of tread and cut string
$H^*_{c,string}$	orthogonal projection of the calculated distance of the plumb line of a cut string to lowest edge of string
H^*_{string}	orthogonal projection of the calculated height of the cut string
$h^*_{c,string}$	calculated distance of the plumb line of a cut string to lowest edge of string
h^*_{string}	calculated height of the cut string

Figure 17 — Cross-sectional dimensions for cut strings

7) The calculated height of string h^*_{string} is:

$$h^*_{\text{string}} = 2 \cdot h^*_{\text{c,string}}$$

8) The calculated string thickness d_{string} is identical with the real string thickness d.

9) The calculated distance e_{tread} between system line of step and system line of string is

$$e_{\text{tread}} = H^*_{\text{string}} - H^*_{\text{c,string}} + \frac{d_{\text{tread}}}{2} = \frac{h^*_{\text{string}}}{\cos\alpha} - \frac{h^*_{\text{c,string}}}{\cos\alpha} + \frac{d_{\text{tread}}}{2}$$

NOTE The distance between system line of string and that of the tread in this model is done with the help of a rigid weightless beam.

10) The modelling of connections to the construction at the bottom step and the top step is described in 5.4.4.

11) In the case of treads with cross-bracing, the string is clamped/fixed around the x-axis (i.e. torsion).

5.4 Calculation models for joints

5.4.1 General

When determining the mechanical stress (stress resultants - and deformations) of stairs using structural frame analysis, the following types of connections are admissible:

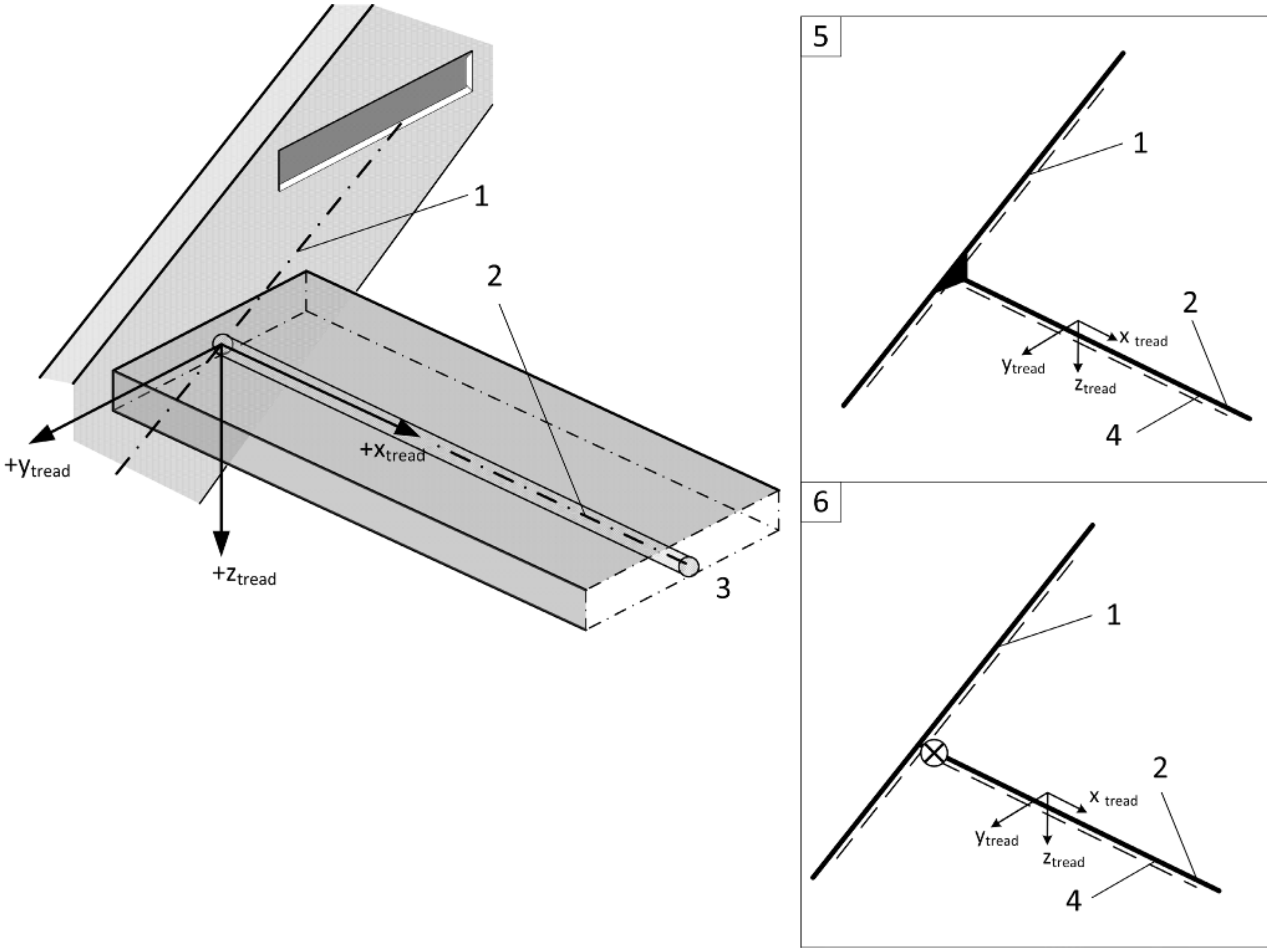
— loose-jointed connections, if it can be assumed that the connection does not transmit any bending moments;

— rigid connections, if the stiffness and/or the load-bearing capacity of the connection allow(s) the adaption of components that are rigidly connected within the calculation;

— deformable connections, if the deformation behaviour of the connection shall be considered with the dimensioning.

5.4.2 Modelling of tread-string connections

5.4.2.1 Connection type 1: treads for stairs with closed strings – cross-bracing without riser



Key

1 system line of the string

2 system line of the tread

3 example demonstration of cross-bracing using tie-bars

4 cross-section values pertaining to rectangular cross-section of tread

5 connection properties verified

6 connection properties not verified

x_{tread} local x-axis of the tread

y_{tread} local y-axis of the tread

z_{tread} local z-axis of the tread

Figure 18 — Connection type 1: treads for stairs with closed strings – cross-bracing without riser

1) The system line of a tread with cross-bracing is fixed to eliminate the horizontal and vertical deformation with the system line of the string.

2) The system line of a tread with cross-bracing is connected with the system line of the string in a rigid manner around the x-axis of the relative rotation between step and string ($\Delta\varphi_x = 0$).

3) The connection properties for mutual rotation around the y-axis between system line of a tread with cross-bracing and the system line of the string shall be verified. Without this verification, the connection shall be modelled as loose-jointed around the y-axis of the tread.

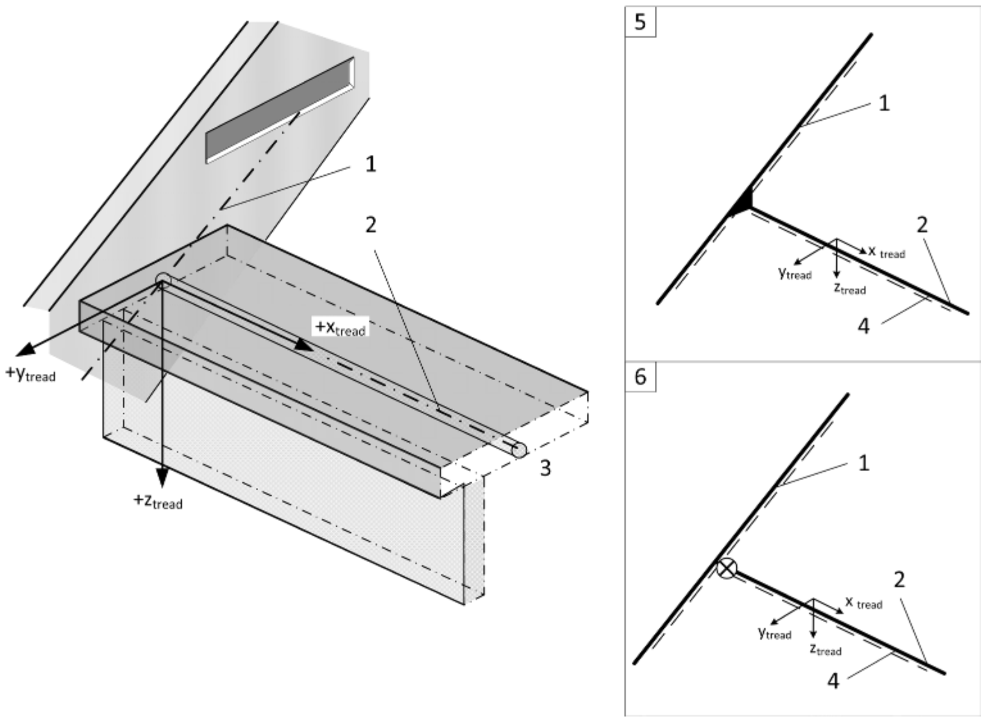
   If the minimum depth of the housing, $d_{housing,}$ measures at least 14 mm, the connection may be modelled as bending resistant around the y-axis of the tread (relative rotation $\Delta\varphi_y = 0$). Other depths of housing may be accepted provided they can be demonstrated to reach the necessary performance.

4) Connection properties for the mutual rotation around the z-axis between the system line of a tread with cross-bracing and the system line of the string shall be verified.

Without this verification, the connection shall be modelled as (loose-) jointed around the z-axis of the tread.

If as a result of the cross-bracing, a couple may be induced between the tread and string around the z-axis, the connection may be modelled rigidly around the z-axis of the tread (relative rotation $\Delta\varphi_Z = 0$).

5.4.2.2 Connection type 2: treads for stairs with closed strings – cross-bracing with riser



Key

1 system line of the string

2 system line of the tread

3 exemplary demonstration of a cross-bracing

4 cross-section values pertaining to cross-section of tread and riser construction

5 connection properties verified

6 connection properties not verified

x_{tread} local x-axis of the tread

y_{tread} local y-axis of the tread

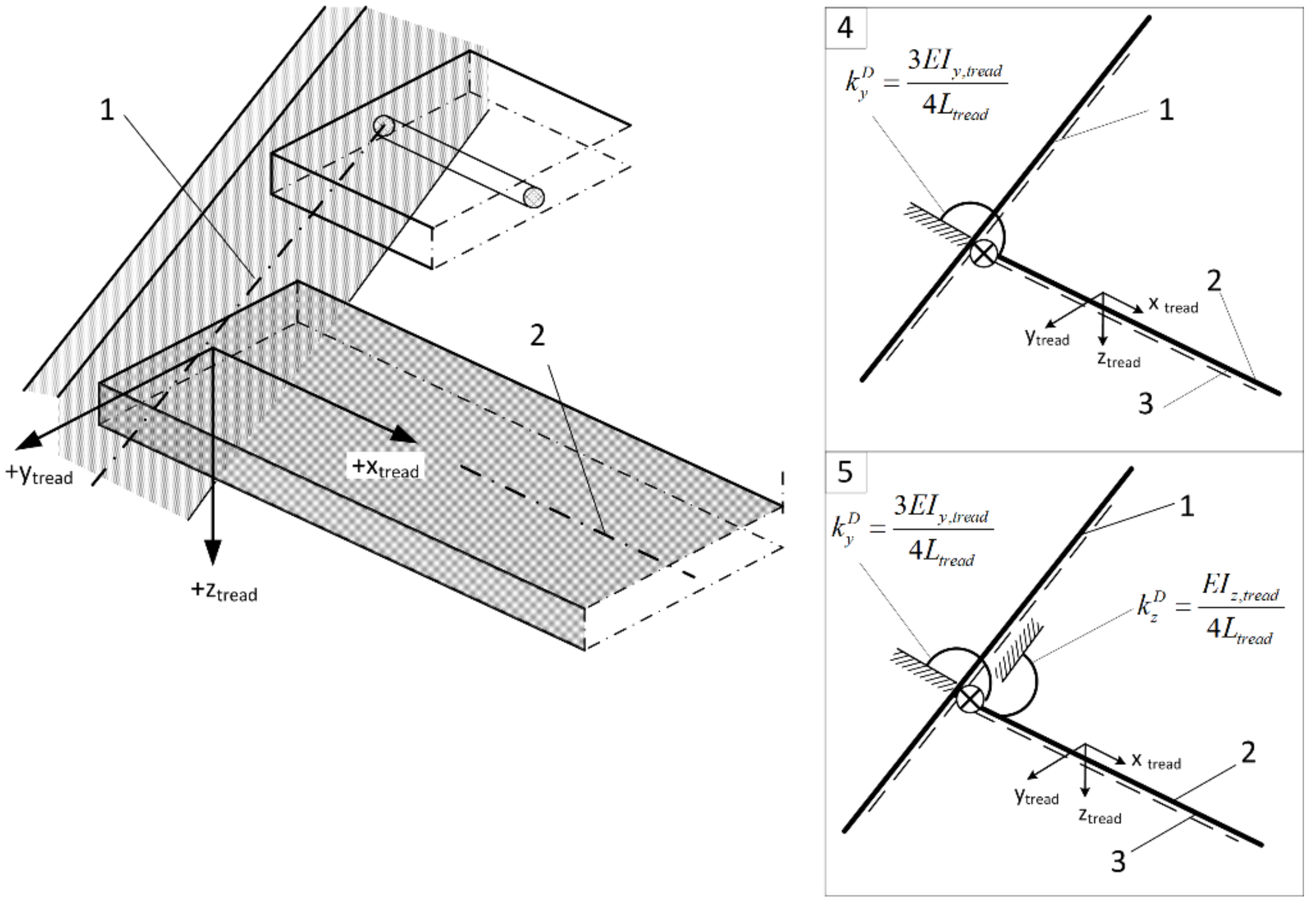
z_{tread} local z-axis of the tread

Figure 19 — Connection type 2: treads for stairs with closed strings – cross-bracing with riser

1) The rules formulated for connection type 1 are also valid for a tread with cross-bracing and riser.

2) When modelling the tread and string connection, the system line of a tread with riser is always applied to the system line of the rectangular cross-section of the tread, independently of the cross-section of the tread.

5.4.2.3 Connection type 3: treads for stairs with closed strings – no cross-bracing, no riser



Key

1	system line of the string
2	system line of the tread
3	cross-section values pertaining to rectangular cross-section of tread
4	connection properties according to 3) below, last paragraph
5	connection properties according to 4) below, last paragraph
$EI_{y,tread}$	bending stiffness of the tread around the y-axis
EI_z	bending stiffness around the z-axis
k^D_y	torsion spring stiffness in bending around the y-axis
L_{tread}	calculated span of tread
x_{tread}	local x-axis of the tread
y_{tread}	local y-axis of the tread
z_{tread}	local z-axis of the tread

Figure 20 — Connection type 3: treads for stairs with closed strings – no cross-bracing, no riser

1) The system line of a tread without cross-bracing is fixed to eliminate the horizontal and vertical deformation with the system line of the string.

2) The system line of a tread without cross-bracing is rigidly connected with the system line of the string around the x-axis of the tread.

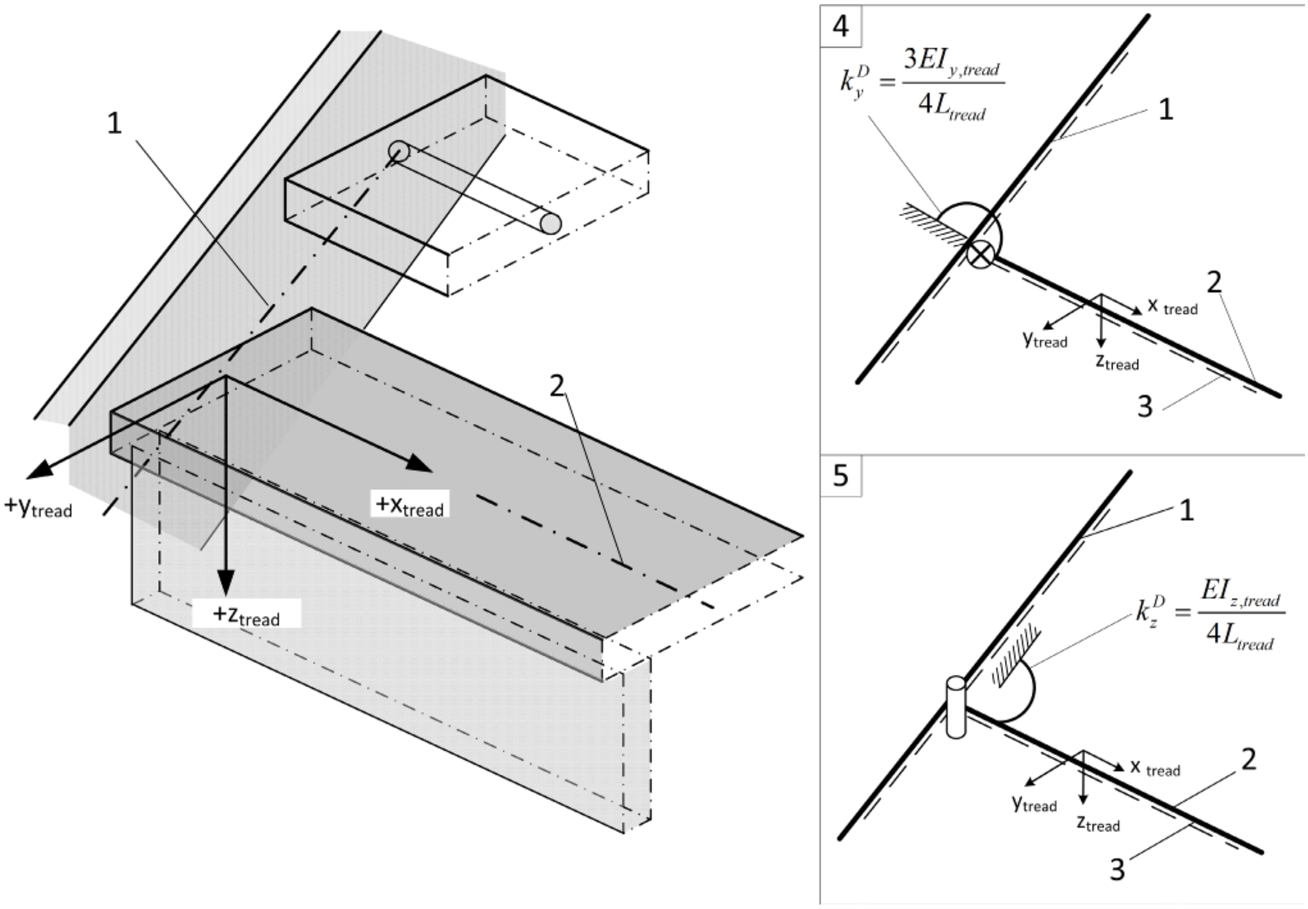
3) The connection properties for mutual rotation around the y-axis between the system line of a tread without cross-bracing and the system line of the string shall be verified. Without this verification, the connection shall be modelled as pin-jointed around the y-axis of the tread.

   If the minimum depth of the housing d_{housing} measures at least 14 mm, the connection may be modelled semi-flexibly with a torsion spring stiffness of $k_y^D = \frac{3EI_{\text{y,tread}}}{4L_{\text{tread}}}$ around the y-axis of the tread. Other depths of housing may be accepted provided they can be demonstrated to reach the necessary performance.

4) The connection properties for mutual rotation around the z-axis between the system line of a tread without cross-bracing and the system line of the string shall be verified. Without this verification, the connection shall be modelled as hinged around the z-axis of the tread.

   For verification purposes under the action combination "fundamental frequency_$M_{k,2}$", the connection may be modelled semi-flexibly with a torsion-spring stiffness of $k_z^D = \frac{EI_{\text{z,tread}}}{4L_{\text{tread}}}$ around the z-axis of the tread, if the depth of the housing d_{housing} measures at least 14 mm. Other depths of housing may be accepted provided they can be demonstrated to reach the necessary performance.

5.4.2.4 Connection type 4: treads for stairs with closed strings – no cross-bracing - with riser



Key

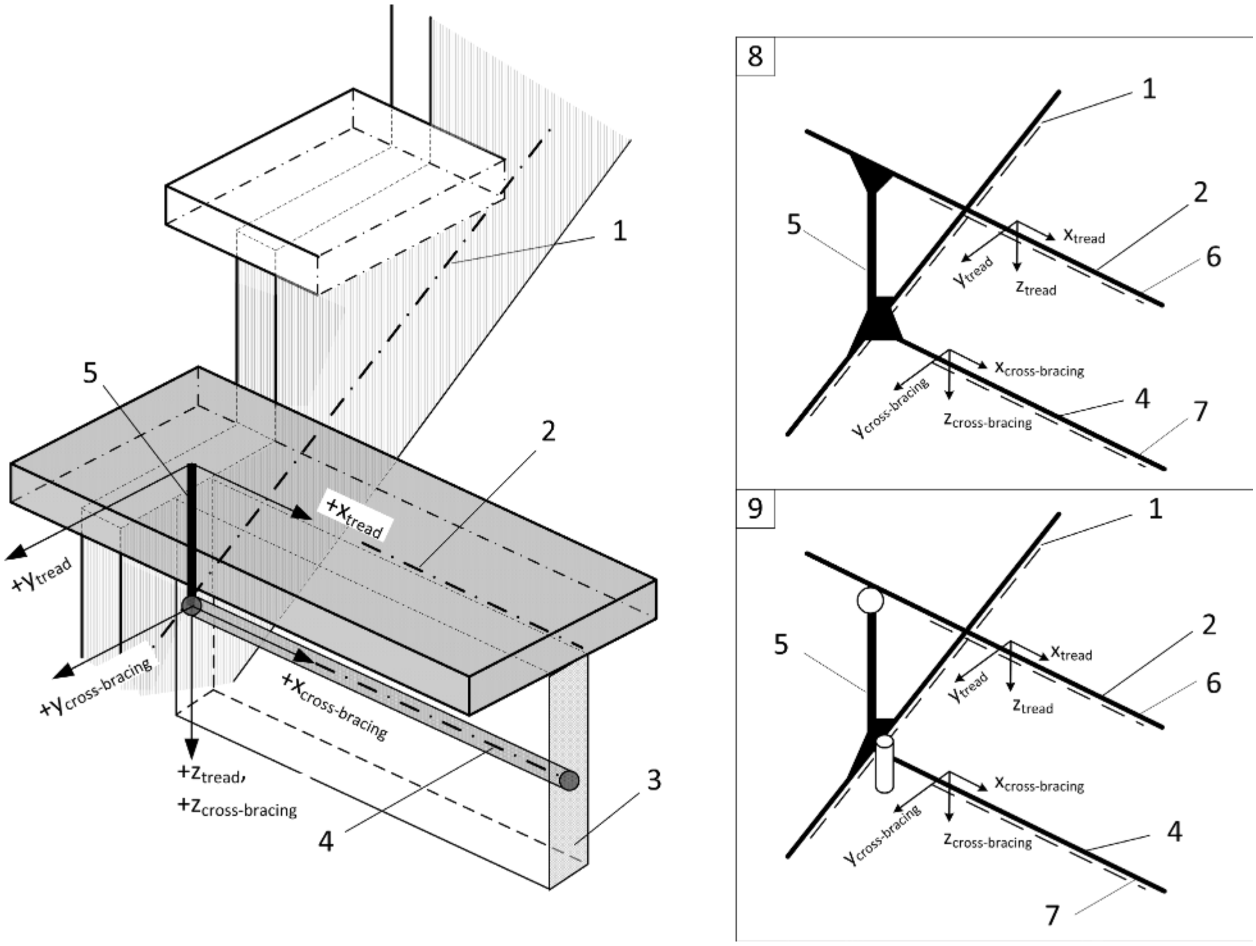
1	system line of the string
2	system line of the tread
3	cross-section values pertaining to cross-section of tread and riser construction
4	connection properties according to 5.4.2.3, 3), last paragraph
5	connection properties according to 5.4.2.3, 4), last paragraph
$EI_{y,tread}$	bending stiffness of the tread around the y-axis
EI_z	bending stiffness around the z-axis
$k^D{}_y$	torsion spring stiffness in bending around the y-axis
L_{tread}	calculated span of tread
x_{tread}	local x-axis of the tread
y_{tread}	local y-axis of the tread
z_{tread}	local z-axis of the tread

Figure 21 — Connection type 4: treads for stairs with closed strings – no cross-bracing - with riser

1) The rules formulated for type 3 with relevance to the modelling of the connection are also valid for a tread with riser without cross-bracing.

2) When modelling the tread-string connection, the system line of a tread with riser is always applied to the system line of the rectangular cross-section of the tread, independently of the cross-section of the tread.

5.4.2.5 Connection type 5: treads for stairs with cut strings–with cross-bracing



Key

1	system line of the string
2	system line of the tread
3	exemplary demonstration of a cross-bracing
4	system line of the cross-bracing
5	system line of the rigid weightless connection beam
6	cross-section values pertaining to rectangular cross-section of tread
7	cross-section values pertaining to the cross-section of cross-bracing
8	connection properties – glued cross-bracing
9	connection properties – not glued cross-bracing
$x_{\text{cross-bracing}}$	local x-axis of cross-bracing
$y_{\text{cross-bracing}}$	local y-axis of cross-bracing
$z_{\text{cross-bracing}}$	local z-axis of cross-bracing
x_{tread}	local x-axis of the tread
y_{tread}	local y-axis of the tread
z_{tread}	local z-axis of the tread

Figure 22 — Connection type 5: treads for stairs with cut strings – with cross-bracing

1) The system line of a tread with cross-bracing eccentrically connects to the system line of the string in distance e_{tread}.

Within the structural frame analysis, this eccentricity is modelled through a rigid and weightless beam with the length e_{tread} which is connected to the string in a rigid manner.

2) The system line of a cut string with cross-bracing is directly connected with the system line of the distance piece.

3) The connection properties for mutual rotation between the system line of a tread with cross-bracing and the system line of the connection beam shall be verified. Without verification, the connection shall be modelled in a loose- jointed manner.

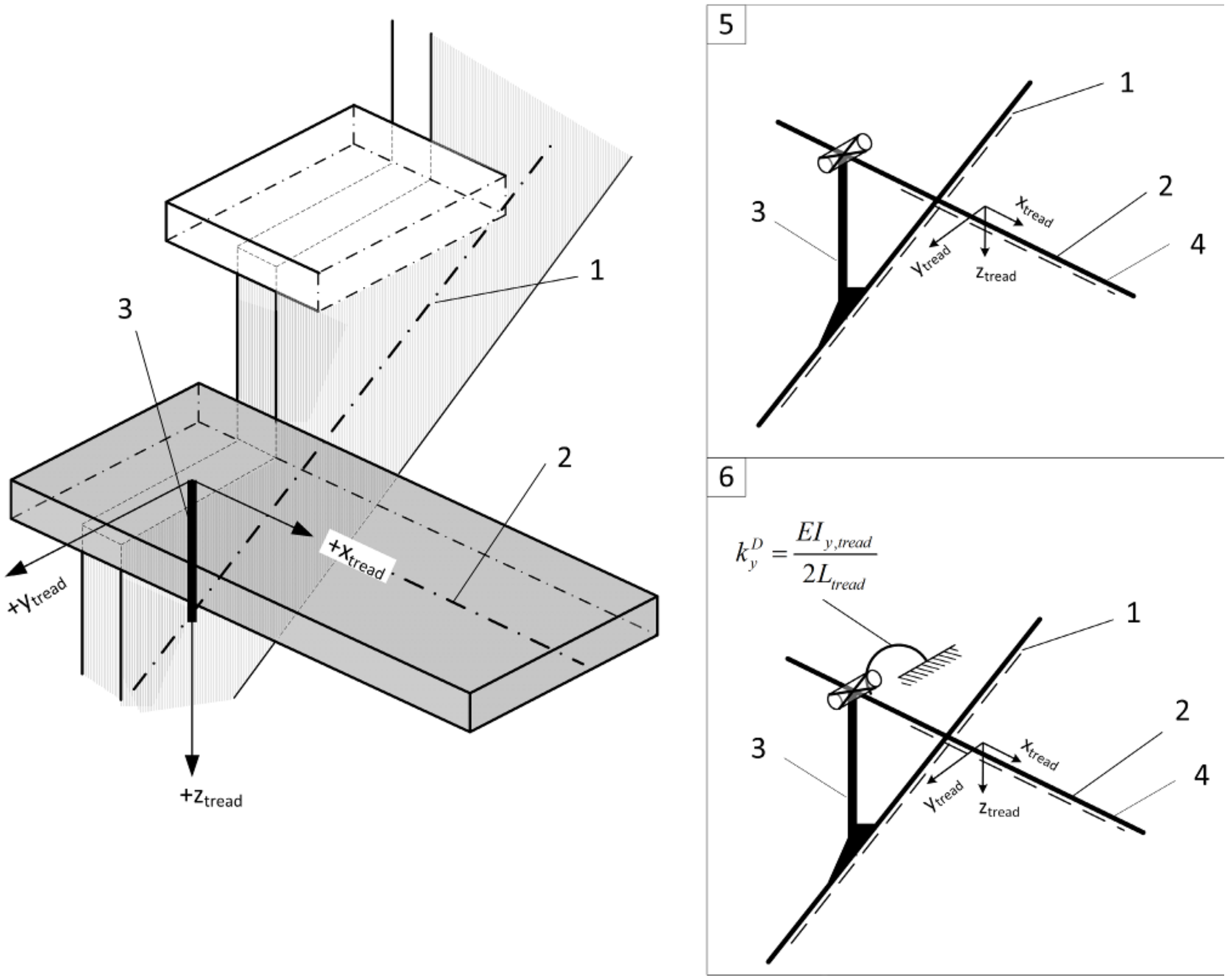
   If the cross-bracing is glued to the tread, the system line of the tread may be connected with the system line of the connection beam in a rigid manner.

4) The system line of the cross-bracing fixed unto a cut string centrically connects to the system line of the string.

5) The properties of the connection between the system line of the cross-bracing and that of the string shall be verified. Without verification, the connection shall be modelled as directly connected, rigidly around the y-axis, and pin-jointed around both the x- and z-axis of the cross-bracing.

If the cross-bracing is glued to the tread, the system line of the cross-bracing may be connected with the system line of the string in a rigid manner.

5.4.2.6 Connection type 6: treads for stairs with cut strings – no cross-bracing – no riser



Key

1 system line of the string

2 system line of the tread

3 system line of the rigid weightless connection beam

4 cross-section values pertaining to rectangular cross-section of tread

5 connection properties according to 3) and 5), last paragraph

6 connection properties according to 4), last paragraph

$EI_{y,tread}$ bending stiffness of the tread around the y-axis

k^D_y torsion spring stiffness in bending around the y-axis

L_{tread} calculated span of tread

x_{tread} local x-axis of the tread

y_{tread} local y-axis of the tread

z_{tread} local z-axis of the tread

Figure 23 — Connection type 6: treads for stairs with cut strings – no cross-bracing – no riser

1) The system line of a tread without cross-bracing eccentrically connects in distance e_{tread} to the system line of the string. Within the structural frame analysis, this eccentricity is modelled through a rigid weightless beam connected to the string, the length of which corresponds with e_{tread}.

2) The system line of a tread without cross-bracing is rigidly connected with the system line of the connection beam.

3) Verification shall be provided for the connection properties of mutual rotation around the x-axis between the system line of a tread without cross-bracing and the system line of the connection beam. Without verification, the connection shall be modelled in a loose-jointed manner around x-axis of the tread.

   If at least two tensile and shear resistant fasteners (glued beam dowel, screws or similar) are built into the structure with sufficient distance apart, the system line of a tread without cross-bracing may, together with the connection beam, be modelled as rigid around the x-axis of the tread.

4) The connection properties for mutual rotation around the y-axis between the system line of a tread without cross-bracing and the system line of the connection beam shall be verified. Without verification, the connection shall be modelled as loose-jointed around the y-axis of the step.

   If the thickness of the string d_{string} measures at least 44 mm and the tread is connected to the string in a tensile resistant manner, the connection may – for the purpose of verification and under the action combination “fundamental frequency_100kg” – be modelled around the y-axis of the tread with a torsion-spring stiffness of $k_{\text{y}}^{\text{D}} = \frac{EI_{\text{y,tread}}}{2L_{\text{tread}}}$. Other thicknesses of strings may be accepted provided they can be demonstrated to reach the necessary performance.

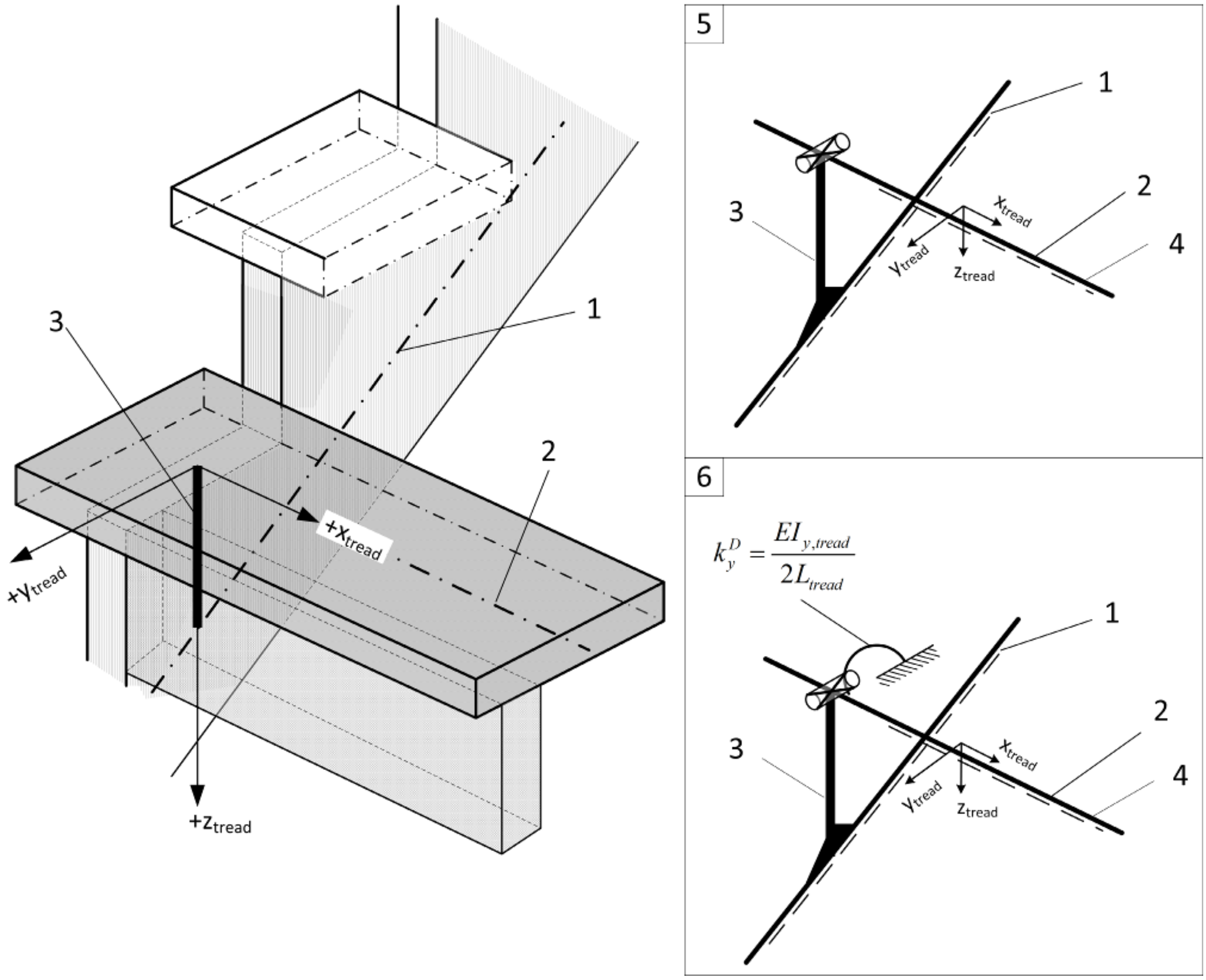
5) The connection properties for mutual rotation around the z-axis between the system line of a tread without cross-bracing and the system line of the connection beam shall be verified. Without verification, the connection shall be modelled as loose-jointed around the z-axis of the tread.

   If at least two tensile- and shear resistant fasteners are built into the (structure) with sufficient distance, the system line of a tread without cross-bracing may, together with the connection beam, be modelled as rigid around the z-axis of the tread.

5.4.2.7 Connection type 7: treads for stairs with cut strings – no cross-bracing – with riser

1) The rules formulated for connection type 6 are also valid for a tread with riser.

2) When modelling the tread and string connection, the system line of a tread with riser is always applied to the system line of the rectangular cross-section of the tread, independently of the cross-section form of the tread.

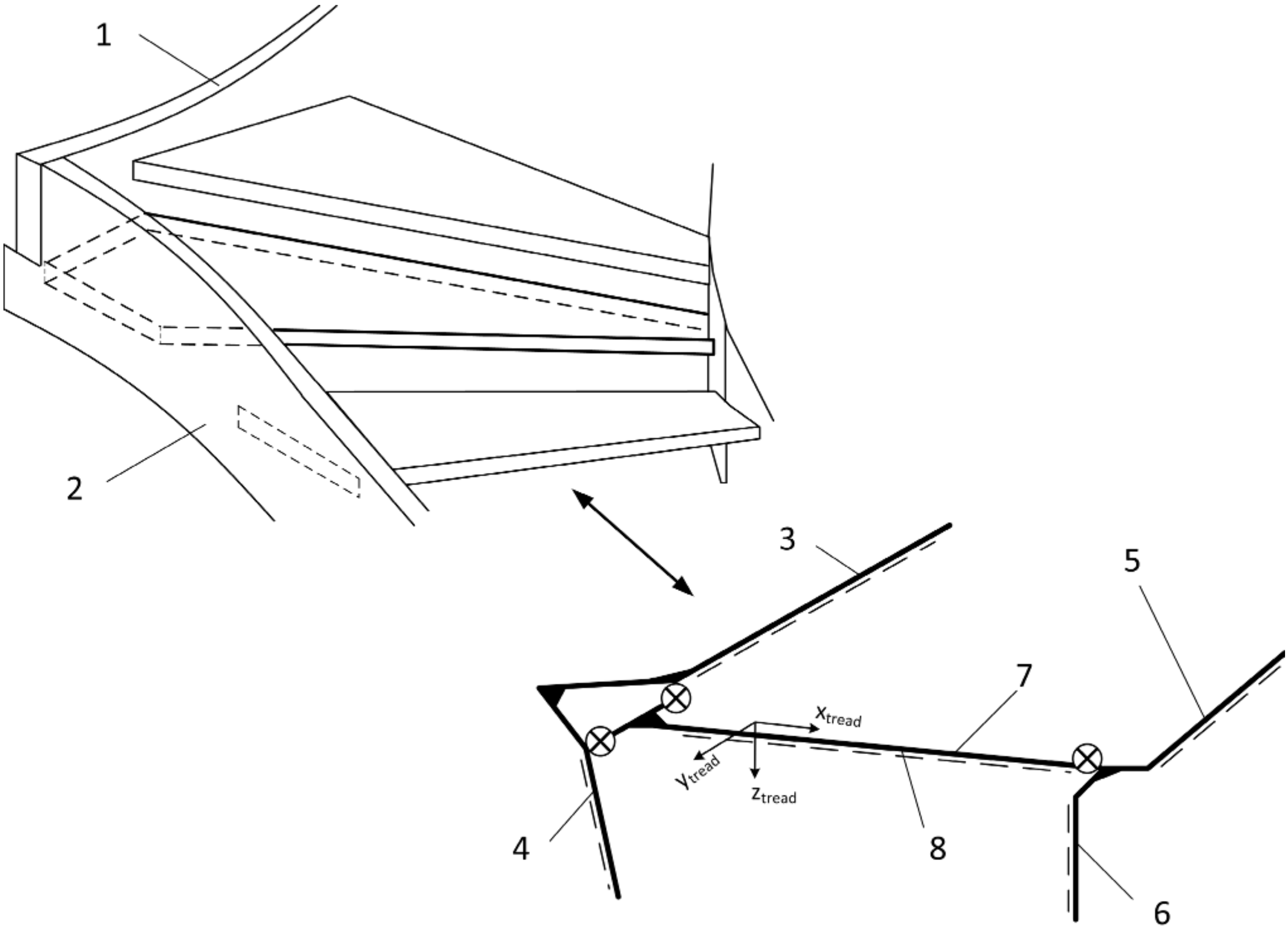


Key

1	system line of the string
2	system line of the tread
3	system line of the rigid weightless connection beam
4	cross-section values pertaining to cross-section of tread and riser construction
5	connection properties according to 5.4.2.6, 3) and 5), last paragraph
6	connection properties according to 5.4.2.6, 4), last paragraph
$EI_{y,tread}$	bending stiffness of the tread around the y-axis
k^D_y	torsion spring stiffness in bending around the y-axis
L_{tread}	calculated span of tread
x_{tread}	local x-axis of the tread
y_{tread}	local y-axis of the tread
z_{tread}	local z-axis of the tread

Figure 24 — Connection type 7: treads for stairs with cut strings – no cross-bracing – with riser

5.4.2.8 Connection type 8: kite winder for stairs with closed strings



Key

1	wall string above
2	wall string below
3	system line of the wall string, above
4	system line of the wall string, below
5	system line of the outer string, above
6	system line of the outer string, below
7	system line of the tread
8	cross-section values due to a rectangle cross-section of tread (see 5.2.4, 4))
x_{tread}	local x-axis of the tread
y_{tread}	local y-axis of the tread
z_{tread}	local z-axis of the tread

Figure 25 — Connection type 8: kite winder for stairs with closed strings

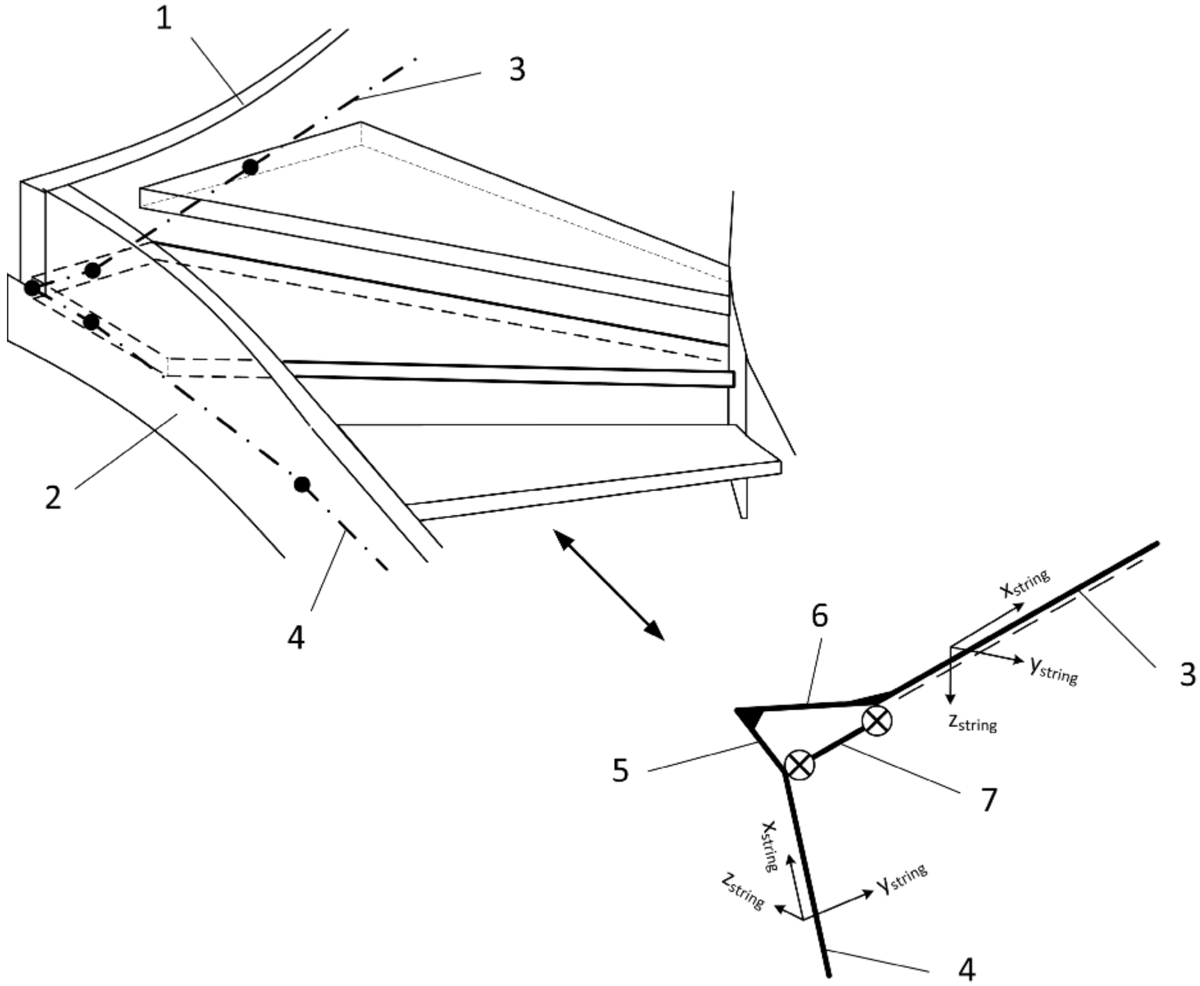
1) At the wall string corner, the system line of a kite winder connects in a rigid manner to the system line of the idealized support line.

2) The system line of an idealized support line connects in a torsional rigid manner around the x-axis, and flexible around the y- and z-axis to the system line of the string.

3) At the outer string corner, the system line of a kite winder connects in a torsional rigid but flexible manner to the system lines of the outer string corner.

5.4.3 Modelling of string-corner connections

5.4.3.1 Connections of wall string corner joints



Key

1	wall string above
2	wall string below
3	system line of the wall string, above
4	system line of the wall string, below
5	system line of the corner_i
6	system line of the corner_i+1
7	system line of the mounting beam of the kite winder
x_{string}	local x-axis of the string
y_{string}	local y-axis of the string
z_{string}	local z-axis of the string

Figure 26 — Connections of wall string corner joints

1) The system lines of the lower- and upper string are connected in a rigid manner with each other throughout.

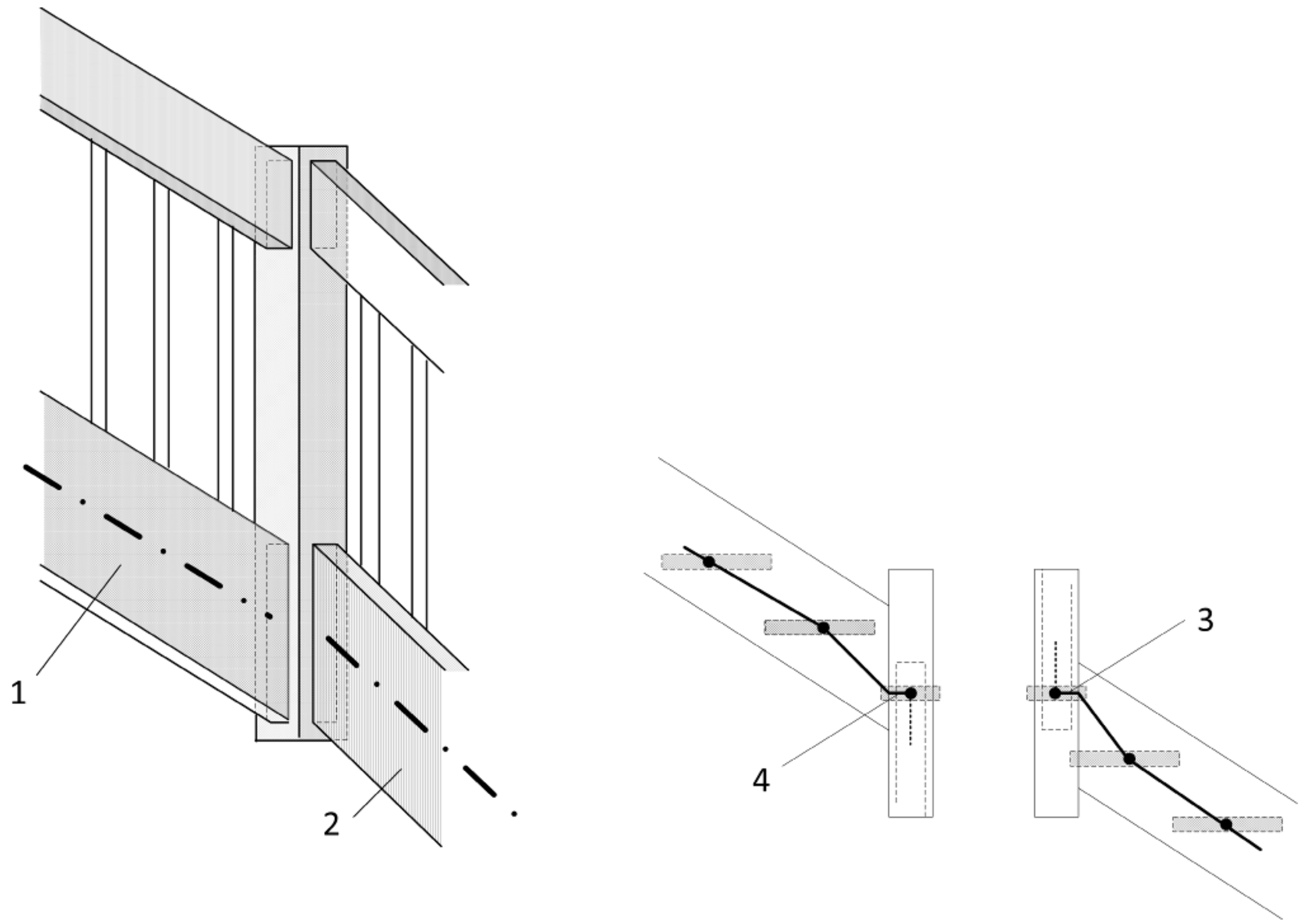
2) The system lines of the corner_i as well as corner_i+1 run horizontally at the level of the kite winder. Each time the length of the beam measures 0,5· support length of the kite winder.

3) The system line of the support beam of the kite winder runs between the beginning of the beam, starting with corner_i and the end of the beam of corner_i+1.

4) The support beam of the kite winder is connected in a torsional rigid manner but flexibly around the y- and z-axis of the wall string.

5) The cross-section of the wall string is applied as the cross-section for all beams.

5.4.3.2 Connection of outer string corner



Key

1 outer string above
2 outer string below
3 system line of the corner_i
4 system line of the corner_i+1

Figure 27 — Connection of outer string corner

1) The system lines of the lower- and upper string are connected with each other in a rigid manner throughout.

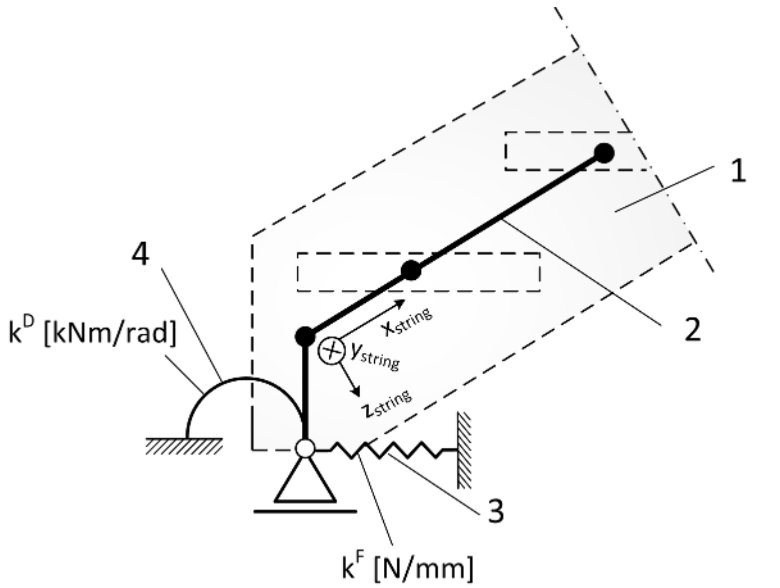
2) The system lines of the corner_i as well as corner_i+1 run horizontally at the level of the kite winder. The length of each system line at the corner measures 1,0 cm.

3) All of the single beams modelled in the connection show the cross-section properties of the outer string.

The corner_i and corner_i+1 may be modelled with rigid cross-sections.

5.4.4 Modelling of connections to the construction

5.4.4.1 Fastening at the bottom step



Key

1	front view of the string
2	system line of the string
3	longitudinal spring in direction of flight
4	torsion spring, vertically fixed in direction of flight
k^D	torsion spring stiffness
k^F	stretch spring stiffness
x_{string}	local x-axis of the string
y_{string}	local y-axis of the string
z_{string}	local z-axis of the string

Figure 28 — Fastening at the bottom step

1) The connection between string and construction at the bottom step shall be modelled rigidly/fixed in vertical direction.

2) The connection between string and construction at the bottom step may be rigidly/fixed modelled to the direction of the local y-axis of the string.

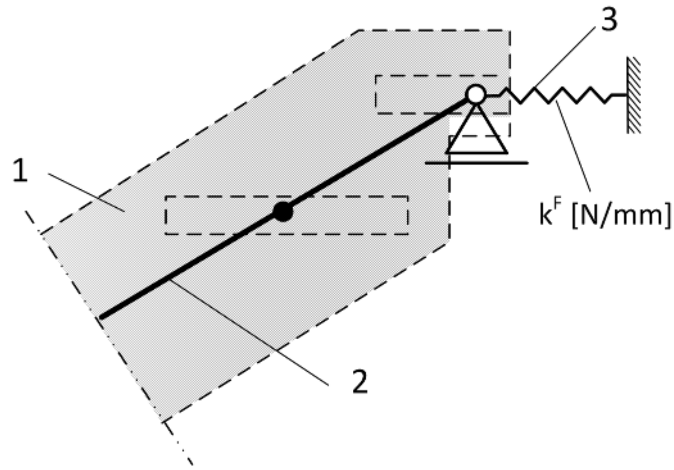
3) The connection of string and construction at the bottom step shall be modelled elastically in the direction of the flight.

Without any further national indications, the spring stiffness of k^F = 3 000 N/mm shall be chosen.

4) The connection between string, wall and construction shall be modelled in a loose-jointed manner.

If a torsion-spring stiffness k^D is chosen in a way that under the effects of load causes the splice between string and unfinished floor to create (at maximum) an extensive separation up to the point of gravity, the mounting at the bottom step may be elastically clamped around the local y-axis of the string.

5.4.4.2 Fastening at the top step



Key

1 front view of the string

2 system line of the string

3 longitudinal spring in direction of flight

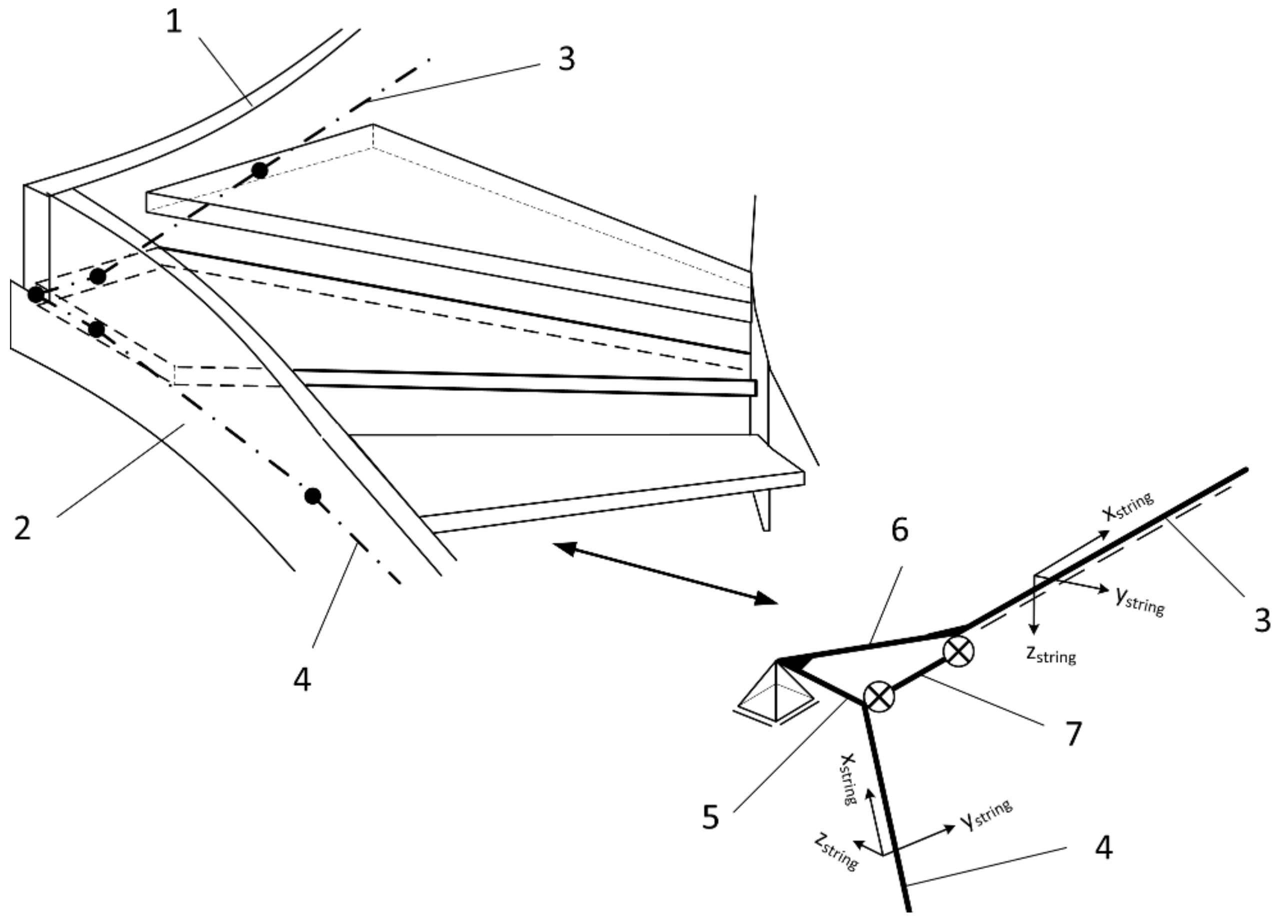
Figure 29 — Fastening at the top step

1) The connection of string and construction at the top step shall be modelled as directly connected in vertical direction and freely rotatable in all directions.

2) The connection of string and construction shall be modelled elastically in the direction of the flight.

   Without any further national indications, the spring stiffness of k^F = 3 000 N/mm shall be chosen.

5.4.4.3 Corner fastening in direction of wall



Key

1 wall string above
2 wall string below
3 system line of the wall string, above
4 system line of the wall string, below
5 system line of the corner_i
6 system line of the corner_i+1
7 system line of the support beam of the kite winder
x_{string} local x-axis of the string
y_{string} local y-axis of the string
z_{string} local z-axis of the string

Figure 30 — Corner fastening in direction of wall

The connection between corner and construction in the direction of the wall shall be modelled unrelocatably in vertical direction, relocatably in the two horizontal directions, and freely rotatable around all axes.

5.5 Modelling of loads

5.5.1 Modelling of permanent loads

Permanent loads are, according to the rules of structural frame analysis, determined via dimensioning of cross-sections as well as the bulk density of construction material and applied to the system lines of single beams. In the case of winders, the dimensioning of an idealized substitute tread is used for the calculation of permanent loads according to 5.2.3.

5.5.2 Modelling of the variable, equally distributed vertical load $q_{k,1}$

1) The variable, equally distributed vertical loads $q_{k,1}$ merely need to be applied to the accessible area of the tread.

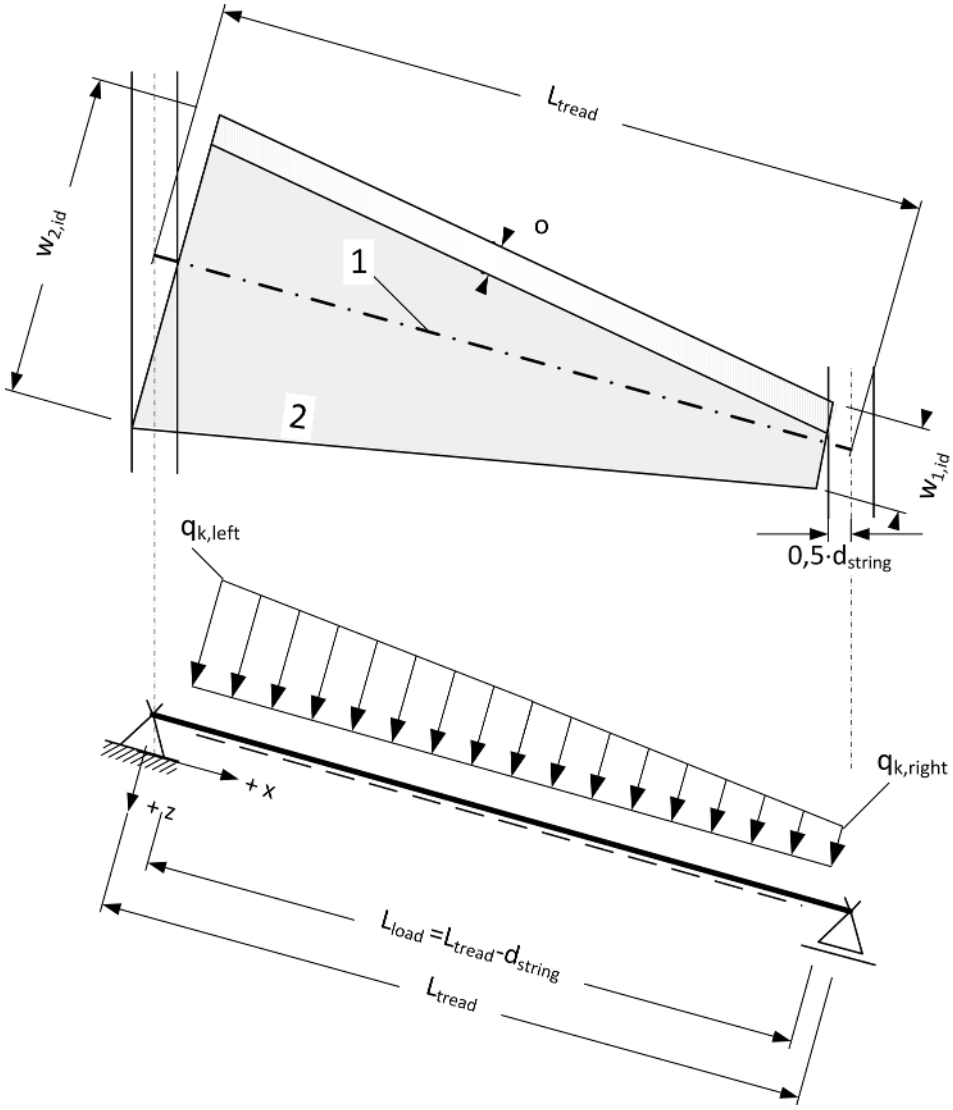
2) In the case of parallel treads, the line load to be applied to the system line of the tread is constant due to the variable vertical load and is calculated as follows:

$$q_{k,left} = q_{k,right} = q_{k,1} * \left(w_{tread} - o\right)$$

3) In the case of tapered treads, the load is applied to the idealized substitute tread (see Figure 31). The line load to be applied to the system line of the tread is linear due to the variable vertical load and is calculated as follows:

$$q_{k,left} = q_{k,1} * \left(w_{2,id} - o\right)$$

$$q_{k,right} = q_{k,1} * \left(w_{1,id} - o\right)$$



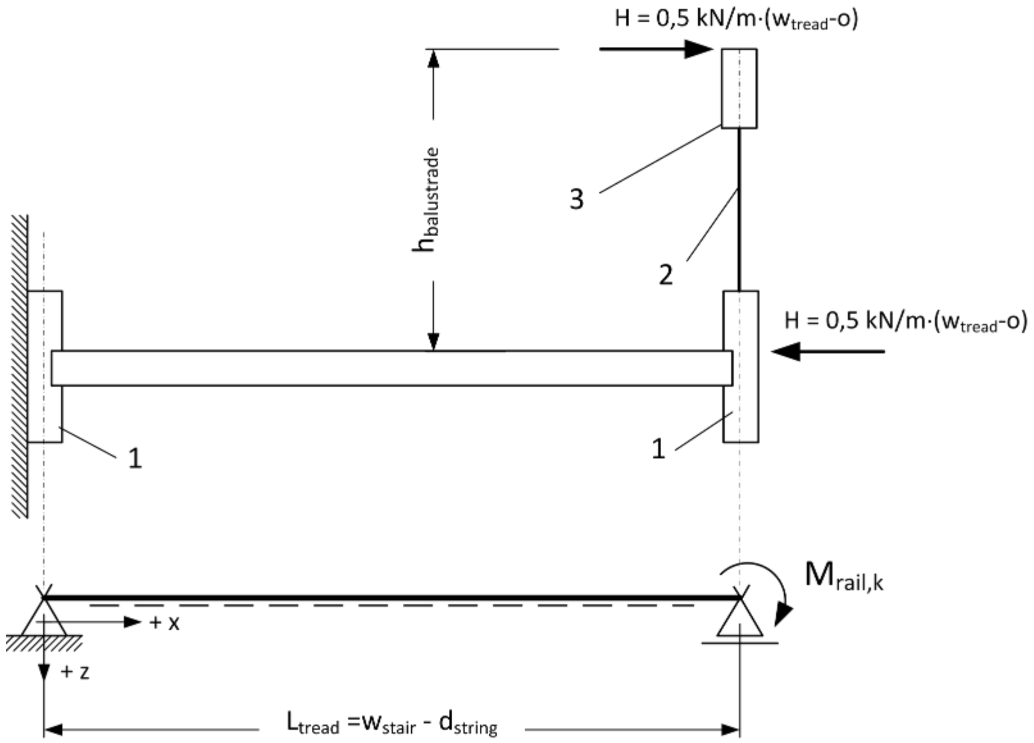
Key

1	tread axis of the real tread
2	idealized ground plan of tread
d_{string}	thickness of the string
L_{load}	length of the actual line load
L_{tread}	calculated span of tread
o	overlap
$q_{k,left}$	minimum value of variable line load to be applied on a winder tread
$q_{k\ right}$	maximum value of variable line load to be applied on a winder tread
$w_{1,id}$	idealized outer side step width
$w_{2,id}$	wall side idealized tread width

Figure 31 — Idealized ground plan of tapered tread and static system

5.5.3 Modelling of the variable and equally distributed horizontal load $q_{k,2}$

1) The variable, equally distributed horizontal loads $q_{k,2}$ merely need to be applied in accessible area of the tread (see Figure 32).



Key

1	cross-section of the string
2	post of guardrail
3	guardrail
d_{string}	thickness of the string
$h_{balustrade}$	distance between horizontal rail load and tread
L_{tread}	calculated span of tread
$M_{rail,k}$	bending moment for the computational modelling of the rail load
o	overlap
w_{stair}	width of flight
w_{tread}	read depth

Figure 32 — Modelling of horizontal loading on guardrail and static system

2) In the case of parallel treads, a single moment shall be applied to the end of the system line of the tread, and is calculated as follows:

$$M_{\text{rail,k}} = 0,5 \cdot \left(w_{\text{tread}} - o \right) \cdot h_{\text{balustrade}} \qquad \left[\frac{kN}{m} \cdot m \cdot m = kNm \right]$$

3) In the case of tapered treads, the load is applied to the idealized substitute treads. The single moment to be applied to the end of the system line of the treads is calculated as follows:

$$M_{\text{rail,k}} = 0,5 \cdot \left(w_{1,\text{id}} - o \right) \cdot h_{\text{balustrade}} \qquad \left[\frac{kN}{m} \cdot m \cdot m = kNm \right]$$

6 Verification within the limit state of serviceability

6.1 General

1) Within the limit states of serviceability, verification is provided firstly through a limiting of admissible vertical deformations, and, secondly through a limiting of the structure's fundamental frequency.

2) Verification of the indicated limit values of deformations shall be provided both for single treads as well as for the stair as a whole.

3) Verification of the indicated limit values of fundamental frequency is only to be provided for the stair as a whole.

4) The limit values for the evaluation of serviceability are established nationally.

   Without any further national directives, the limit values defined in 6.2 are valid with regard to vertical deformation and fundamental frequency (see ETAG 008).

5) The action combination used to provide the verification of limit states of serviceability are indicated in 4.3.1.

6) In order to provide verification of serviceability of a single tread the reference measure L, defined under 5.2, is the support width of a single tread.

7) For the purpose of providing verification of serviceability of a stair as a whole, the reference measure, L, is the length of the whole stair flight and is measured along the median line.

6.2 Limit values of deformations

The verification of serviceability is provided if the following conditions are adhered to.

a) Deflection in conjunction with action combination "Deformation $\mathbf{q}_{\mathbf{k},\mathbf{1}}$":

$$w_{\mathrm{G}} + w_{\mathrm{q,k1}} \leq \frac{L}{200}$$

   Without a further national value, the default value shall be applied length/200 (taken from ETAG 008).

   This shall include:

   1) w_{G} vertical deformation as a result of permanent action,
   2) $w_{\mathrm{q,k1}}$ vertical deformation as a result of a variable uniformly distributed vertical action.

b) Deflection in conjunction with the action combination "**Deformation_ $Q_{\mathbf{k},\mathbf{1}}$**":

$$w_{\mathrm{G}} + w_{\mathrm{Q,k1}} \leq \frac{L}{200}$$

   This shall include:

   1) w_{G} vertical deformation as a result of permanent action,

2) $w_{Q,k1}$ vertical deformation as a result of vertical point load of size.

6.3 Verification of oscillation

The verification of oscillation behaviour is fulfilled if the following prerequisite is adhered to (see EN 15644).

a) Fundamental frequency under action combination "**fundamental frequency_ $M_{k,2}$**":

$$f_1 \geq 5[Hz]$$

This shall include

1) f_1 fundamental frequency as a result of the common effect of constant mass and single mass of 100 kg in most unfavourable position where it is possible to stand.

b) With the verification of oscillation characteristics, the static friction within tread-string connections under insignificant loading of a stair may take into account an increasing of stiffness.

The corresponding directives as to the stiffness to be applied shall be taken from 5.4.2.

7 Verification within the limit state of load bearing capacity

7.1 General

Verification of the load-bearing capacity is carried out at the level of rated values of the component resistance, stress resultants and cross-section values determined according to Clause 5.

7.2 Verification of the load-bearing capacity of cross-sections

a) Verification of the load-bearing capacity of cross-sections of treads and strings shall be conducted according to EN 1995-1-1. Verification is provided if the following conditions are fulfilled.

1) Verification of the normal stress (see Eurocode):

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

and

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

2) Verification of shear stress (see Eurocode):

$$\frac{\tau_{tor,d}}{f_{v,d}} + \left(\frac{\tau_{y,d}}{f_{v,d}}\right)^2 + \left(\frac{\tau_{z,d}}{f_{v,d}}\right)^2 \leq 1$$

b) In the case of stairs with closed strings, verification of shear stress may be carried out involving the full (entire) cross-section, i.e. regardless of housing depth.

c) In the case of stairs with cut strings, the verification of shear stress shall be conducted such as to involve height, $h_{\text{min},}$ for an undisturbed cross-section.

d) A detailed conduct of verification may be waived in case of an obviously sufficient dimensioning of components.

7.3 Verification of load-bearing capacity of the connections

7.3.1 Verification of load-bearing capacity of tread-string connections

— The verification of the torsional load-bearing capacity of a tread-string connection according to 5.4.2 is provided if:

$$M_{\text{x,d,tread}} \leq M_{\text{x,Rd,tread}}$$

where

$M_{\text{x,d,tread}}$ is the governing torsional moment at the beginning of tread or its end, respectively, as a result of action combinations according to 4.3.3;

$M_{\text{x,Rd,tread}}$ is the rated value of the torsional moment absorbable in the connection, derived from tests or calculation.

In case of stairs with closed strings, verification is provided if depth of housing $d_{\text{housing}} \geq 14$ mm. Other depths of housing may be accepted provided they can be demonstrated to reach the necessary performance.

— Evidence of the bending load-bearing capacity around the y-tread axis of a tread-string connection according to 5.4.2 is provided if:

$$M_{\text{y,d,tread}} \leq M_{\text{y,Rd,tread}}$$

where

$M_{\text{y,d,tread}}$ is the governing bending moment around the y-axis at the beginning of tread or its end, respectively, as a result of load combinations according to 4.3.3;

$M_{\text{y,Rd,tread}}$ is the rated value of the bending moment absorbable in the connection around the y-axis, derived from tests or calculation.

— Verification of the bending load-bearing capacity around the z-tread axis of a tread-string connection according to 5.4.2 is provided if:

$$M_{\text{z,d,tread}} \leq M_{\text{z,Rd,tread}}$$

where

$M_{\text{z,d,tread}}$ is the governing bending moment around the z-axis at the beginning of tread or its end, respectively, as a result of load combinations according to 4.3.3;

$M_{\text{z,Rd,tread}}$ is the rated value of the bending moment absorbable in the connection around the z-axis, derived from tests or calculation.

— Verification of the cross-bracing within a tread and string connection is provided if:

$$T_{\text{d,cross bracing}} \leq T_{\text{Rd,cross bracing}}$$

where

$T_{\text{d,cross-bracing}}$	is the governing tension force within the cross-bracing as a result of the action combinations according to 4.3.3;
$T_{\text{Rd,cross-bracing}}$	is the rated value of the tension force absorbable in the cross-bracing, derived from tests or calculation.

— A detailed conduct of verification may be waived in the case of an obviously sufficient dimensioning of connections.

7.3.2 Verification of the load-bearing capacity of string-corner connections

— Evidence of the torsional load-bearing capacity of the string-corner connections according to 5.4.3 is provided if:

$$M_{\text{x,d,corner\_i}} \leq M_{\text{x,Rd,corner\_i}}$$

where

$M_{\text{x,d,corner\_i}}$	is the governing torsional moment at the corner as a result of load combinations according to 4.3.3;
$M_{\text{x,Rd,corner\_i}}$	is the rated value of the torsional moment absorbable within the connection derived from tests.

— Evidence of the bending load-bearing capacity of the string-corner connections around the y-axis of the connection according to 5.4.3 is provided if:

$$M_{\text{y,d,corner\_i}} \leq M_{\text{y,Rd,corner\_i}}$$

where

$M_{\text{y,d,corner\_i}}$	is the governing bending moment around the y-axis at the corner as a result of load combinations according to 4.3.3;
$M_{\text{y,Rd,corner\_i}}$	is the rated value of the bending moment absorbable within the connection around the y-axis, derived from tests or calculation.

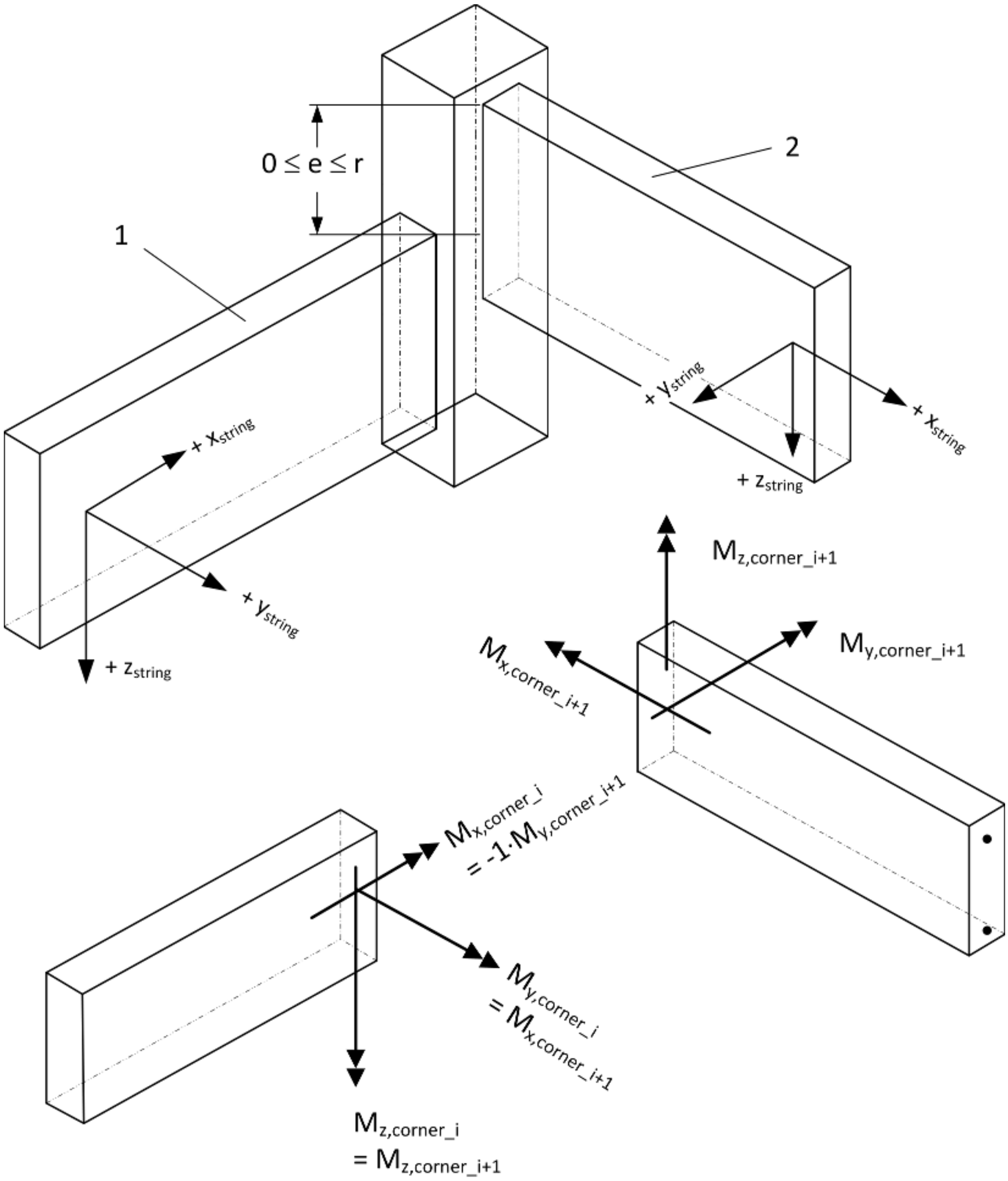
— Evidence of the bending load-bearing capacity of the string-corner-connections around the z-axis of the connection according to 5.4.3 is provided if:

$$M_{\text{z,d,corner\_i}} \leq M_{\text{z,Rd,corner\_i}}$$

where

$M_{\text{z,d,corner\_i}}$	is the governing bending moment around the z-axis at the corner as a result of load combination according to 4.3.3;
$M_{\text{z,Rd,corner\_i}}$	is the rated value of the bending moment absorbable within the connection around the z-axis, derived from tests.

— For verification purposes, the following definitions shall be used (see Figure 33):



Key

1	string below
2	string above
$M_{x,d,corner\_i}$	governing torsional moment before the corner due to the load combination
$M_{y,d,corner\_i}$	governing bending moment around the y-axis before the corner due to the load combinations
$M_{z,d,corner\_i}$	governing bending moment around the z-axis before the corner due to the load combinations
x_{string}	local x-axis of the string
y_{string}	local y-axis of the string
z_{string}	local z-axis of the string

Figure 33 — Definitions for string corner connections

— A detailed verification may be waived in the case of connections described in national application document.

7.4 Verification of the load-bearing capacity of connections to the building

Verification of the load-bearing capacity of the connection between the staircase and the building shall be carried out according to national regulations. The connection capacity should be verified using the relevant properties of the connection type used.

The verification of the load-bearing capacity of component connections may also be provided by carrying out suitable component tests.

Bibliography

[1] CEN/TS 15680, *Prefabricated timber stairs — Mechanical test methods*

[2] ETAG 008, *Prefabricated stairs kits*

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