



BSI Standards Publication

Eurocode 4 — Design of composite steel and concrete structures

Part 1-101: Double and single skin steel concrete composite (SC) structures

National foreword

This Published Document is the UK implementation of CEN/TS 1994-1-101:2025.

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

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Date	Text affected

English Version

**Eurocode 4 - Design of composite steel and concrete
structures - Part 1-101: Double and single skin steel
concrete composite (SC) structures**

Eurocode 4 - Calcul des structures mixtes acier-béton -
Partie 1 101 : Structures mixtes acier-béton (SC)
simple ou double peau

Eurocode 4 - Bemessung und Konstruktion von
Verbundtragwerken aus Stahl und Beton - Teil 1 101:
Bemessung von wandartigen Verbundkonstruktionen
mit ein- oder beidseitig außenliegenden Stahlblechen

This Technical Specification (CEN/TS) was approved by CEN on 27 January 2025 for provisional application.

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European foreword

This document (CEN/TS 1994-1-101:2025) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN.

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This document has been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by this document.

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0 Introduction

0.1 Introduction to the Eurocodes

The Structural Eurocodes comprise the following standards generally consisting of a number of Parts:

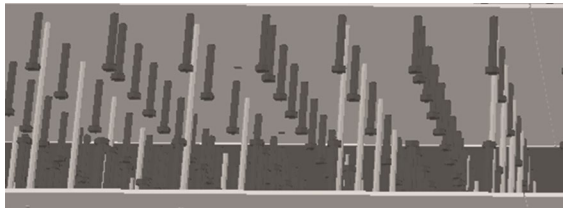
- EN 1990 Eurocode — Basis of structural and geotechnical design
- EN 1991 Eurocode 1 — Actions on structures
- EN 1992 Eurocode 2 — Design of concrete structures
- EN 1993 Eurocode 3 — Design of steel structures
- EN 1994 Eurocode 4 — Design of composite steel and concrete structures
- EN 1995 Eurocode 5 — Design of timber structures
- EN 1996 Eurocode 6 — Design of masonry structures
- EN 1997 Eurocode 7 — Geotechnical design
- EN 1998 Eurocode 8 — Design of structures for earthquake resistance
- EN 1999 Eurocode 9 — Design of aluminium structures
- New parts are under development, e.g. Eurocode for design of structural glass

NOTE Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

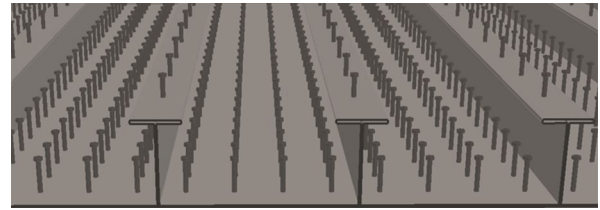
0.2 Introduction to CEN/TS 1994-1-101

Double skin steel concrete composite (DSC) structures comprise two steel plates connected by a grid of tie bars. The void between the plates is filled with concrete. The plates act as load bearing formwork during the placement of the concrete (core) eliminating the need for temporary formwork. In the permanent condition, the plates act as reinforcement to the concrete and therefore are fundamental to the structural performance of the panels. The tie bars in DSC (which may be welded or bolted to the steel plates) hold the two steel plates together at the construction stage allowing them to act as load bearing formwork and resist fresh concrete pressures during concreting. Once the concrete has set, they act as shear reinforcement, thus contributing to the transverse (out-of-plane) shear resistance of the structure. Alternatives to tie bars may be used (e.g. ribs or stiffeners). Composite action between the steel plates and the concrete is provided by shear connectors welded to the steel plates. DSC structures are commonly used in a vertical orientation as wall structural components but may also be used in a horizontal orientation as floor structural components.

Single skin steel concrete composite (SSC) structures comprise a single steel plate reinforced by steel sections (typically T-stiffeners) which provide stiffness during construction and shear resistance to the section against out of plane loading in the permanent condition. Shear stud connectors are welded to both the plate and the flange of the T-stiffeners to achieve composite action with the concrete which is placed on the plate. SSC structures are commonly used in a horizontal orientation as floor structural components.



a) DSC structure (typically used for walls)



b) SSC structure (used for floors)

Figure 1 — SC structures

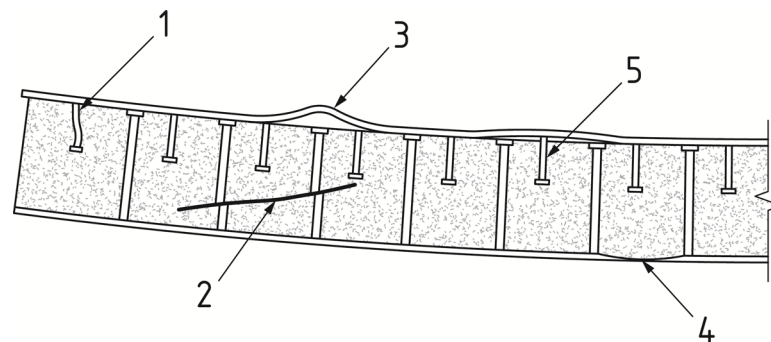
DSC and SSC structures are collectively referred to as SC structures, see Figure 1. SC structures are suitable for use in buildings and other structures whose structural system comprises shear walls or floor slabs (or decks) or a combination of shear walls and slabs/decks.

Depending on the number of shear stud connectors used, full or partial shear connection between the plates and the concrete can be achieved. Partial shear connection results in greater relative movement (slip) between the plate(s) and the concrete such that force transfer will be limited by the capacity of the shear stud connectors. Where the number of shear stud connectors is such that full shear connection is provided, the structural resistance will be limited by the strength of either the concrete or the steel plates.

The strength of a steel plate in compression in a DSC structure can either be governed by outward buckling, before yield stress is reached, or by yielding and plastic deformation.

Concrete can fail in one of two modes in SC structures. The first is a compressive failure by crushing of the concrete. The second is shear failure, which is characterised by blocks of concrete sliding relative to each other.

Figure 2 illustrates the main failure modes of a DSC member.



Key

- 1 failure of connectors
- 2 shear failure
- 3 buckling of compression plate
- 4 yield of tension plate
- 5 stud pull-out due to locally applied tension (e.g. from attachments to the steel plate of the DSC member)

Figure 2 — Failure modes of a DSC member

Concrete shrinkage occurs with time and is evidenced by shortening of the concrete even when a member is not externally loaded. It occurs due to water/cement hydration and escape of water from the concrete mix. This effect is normally mitigated by suitable concrete mix design and controlled concreting operations. Creep occurs when concrete is subject to relatively high stress for a sustained period of time. The magnitude of the action, the time of application of the action and the age of the concrete influence the amount of creep. Creep can also occur when actions are not applied continuously over a long period

of time but in regular cycles. For SC construction the effects of creep can be accounted for by using in design an appropriate effective value of the concrete modulus. This results in the use of a higher effective modular ratio (ratio of steel to concrete modulus) for long term loads than for short term loads.

At present, there are no harmonized or national European standards covering the design of SC structures. This document fills this gap by providing rules for SC structures and has been developed as a first step towards defining requirements for a European Standard for SC structures (as a Part of EN 1994).

0.3 Verbal forms used in the Eurocodes

The verb “shall” expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may” expresses a course of action permissible within the limits of the Eurocodes.

The verb “can” expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.4 National Annex for CEN/TS 1994-1-101

This document gives values within notes indicating where national choices can be made. Therefore, a national document implementing CEN/TS 1994-1-101 can have a National Annex containing all Nationally Determined Parameters to be used for the assessment of buildings and civil engineering works in the relevant country.

When not given in the National Annex, the national choice will be the default choice specified in the relevant Technical Specification.

The national choice can be specified by a relevant authority.

When no choice is given in the Technical Specification, in the National Annex, or by a relevant authority, the national choice can be agreed for a specific project by appropriate parties.

National choice is allowed in CEN/TS 1994-1-101 through notes to the following clauses:

8.1(3) – 2 choices	8.2.2(2)	8.2.3(1)	8.3.2(1)
8.4.2(2)	8.5.1(2)	8.5.1(7)	8.5.1(8)
8.5.1(9)	8.6(1)	8.6(3)	8.8(2)
10.2.3(2)	10.4(3)	11.2.1(2)	12.3.2.2(4)
12.3.4(2)	12.3.4(3)		

The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.

1 Scope

1.1 Scope of CEN/TS 1994-1-101

- (1) This document deals with the design of steel-concrete composite (SC) structures comprising either:
- two steel plates with shear stud connectors connected by a grid of tie bars and having structural concrete between the plates (referred to as DSC), typically used for walls; or
 - a steel plate with shear stud connectors and T-stiffeners welded to the plate (referred to as SSC), typically used for floors.
- (2) This document gives basic rules for design, design for the construction stage and design for the accidental situation of fire exposure.

1.2 Assumptions

- (1) The assumptions of EN 1990 apply to this document.

2 Normative references

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

NOTE See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. in 'should' clauses), permissions ('may' clauses), possibilities ('can' clauses), and in notes.

EN 1990, *Eurocode — Basis of structural and geotechnical design*

EN 1992-1-1:2023, *Eurocode 2 — Design of concrete structures — Part 1.1: General rules and rules for buildings, bridges and civil engineering structures*

EN 1992-4:2018, *Eurocode 2 — Design of concrete structures — Part 4: Design of fastenings for use in concrete*

EN 1993-1-1:2022, *Eurocode 3 — Design of steel structures — Part 1-1: General rules and rules for buildings*

EN 1994-1-1:—,¹ *Eurocode 4 — Design of composite steel and concrete structures — Part 1-1: General rules and rules for buildings*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1992-1-1, EN 1993-1-1 and EN 1994-1-1 apply.

3.2 Symbols

For the purposes of this document, the following symbols apply.

¹ Under preparation. Stage at the time of publication: prEN 1994-1-1:2024.

Latin uppercase letters

A_a	Cross-sectional area of both steel plates in a DSC member
A_b	Cross-sectional area of a dowel bar
A_c	Cross-sectional area of the concrete
A_f	Area of the flange of a T-stiffener in a SSC member
A_{net}	Net cross-sectional area of both steel plates in a DSC member
A_p	Area of a steel plate in a SC member
A_{pc}	Area of the steel plate in compression in a DSC member
$A_{pc,eff}$	Effective area of steel plate in compression in a DSC member
A_{pt}	Area of the steel plate in tension in a SC member
A_r	Cross-sectional area of reinforcement
A_s	Cross-sectional area of the T-stiffener and plate of width b_e of a SSC section
A_{sw}	Cross-sectional area of shear reinforcement in DSC member in the form of tie bars
A_v	Shear area of a structural steel section
A_w	Area of the web of a T-stiffener
B_{eff}^+	Effective width of plate for positive (sagging) bending under fresh concrete pressure in a DSC member
B_{eff}^-	Effective width of plate for negative (hogging) bending under fresh concrete pressure in a DSC member
B	Term used for the calculation of the cracked section properties
C	Axial rigidity of the section (6); term used for the calculation of the cracked section properties
D	Thermal Bending rigidity of the section (6)
D_{th}	Thermal bowing displacement in a DSC member when the design value of the applied normal force in the fire situation is $\leq 0,15N_{fi,pl,Rd}$, the design plastic resistance of the cross-section in the fire situation
E_{cm}	Secant modulus of elasticity of concrete
$E_{c,eff}$	Effective modulus of elasticity for concrete accounting for long-term effects
$E_{c,fi}$	Modulus of concrete in the fire situation
E_e	Effective modulus of elasticity for analysis of the sections (6)
E_s	Modulus of elasticity of structural steel
$(EI)_{eff}$	Effective flexural stiffness of section
$(EI)_{eff,fi}$	Effective flexural stiffness of section in the fire situation
F_g	Resultant design shear force per headed stud connector due to global actions
F_l	Design longitudinal force per headed stud connector

F_s	Resultant design shear force per headed stud connector due to the combined effects of global and local actions
F_{strut}	Force in diagonal concrete strut in a strut-and-tie model
F_t	Design tension force per headed stud connector
G	Shear rigidity of the section (6)
G_c	Shear modulus of concrete
$G_{\text{eff,ts}}$	Shear modulus of DSC section at the temporary stage (before concreting)
G_s	Shear modulus of structural steel
I	Second moment of area of section
I_a	Second moment of area of both steel plates in a DSC section
$I_{a,\text{fi}}$	Second moment of area of the steel plates in a DSC section in the fire situation
I_b	Second moment of area of a tie bar
I_c	Second moment of area of the un-cracked concrete section
$I_{c,\text{fi}}$	Second moment of area of the concrete section in the fire situation
I_{cr}	Second moment of area of the cracked concrete section
I_p	Second moment of area of one steel plate
I_{eff}	Effective second moment of area of section
$I_{\text{eff,ts}}$	Effective second moment of area of DSC section at the temporary stage (before concreting)
I_s	Second moment of area of the T-stiffener and plate of width b_e of a SSC section
K_e	Correction factor to be used for adjusting the contribution of concrete to the stiffness of composite sections for buckling calculations
K_{ps}	Concentration factor applied to the plate stress at a junction with a bar (temporary stage)
K_s	Contribution of the steel plates in a DSC section to in-plane shear stiffness
K_{sc}	Contribution of cracked concrete in a DSC section to in-plane shear stiffness
L	Span; length
M	Moment acting at a junction between a plate and a tie bar
M_{Ed}	Design value of the applied bending moment
M_{Ed}^I	Design value of the applied first order bending moment
$M_{\text{fi,Ed}}$	Design value of the applied bending moment in the fire situation
$M_{\text{fi,pl,Rd}}$	Design value of the plastic resistance moment of the section in the fire situation
$M_{\text{fi,Rd}}$	Design value of the resistance of the section to bending in the fire situation
$M_{\text{pl,Rd}}$	Design value of the plastic resistance moment of the section
M_{Rd}	Design value of the resistance of the section to bending
M_{th}	Thermal bending moment

N_c	Resistance of the concrete in compression
N_{cc}	Resistance of the concrete above the T-stiffener in a SSC section
$N_{c,Rd}$	Design value of the resistance of the section to compression
N_{cr}	Elastic critical normal force
$N_{cr,fi}$	Elastic critical normal force in the fire situation
N_{Ed}	Design value of the applied normal force (tension or compression)
N_f	Axial resistance of the flange of a T-stiffener in a SSC section
$N_{fi,Ed}$	Design value of the applied normal force in the fire situation
$N_{fi,pl,Rd}$	Design plastic resistance of DSC cross-section in the fire situation
$N_{fi,Rd}$	Design value of the resistance of the section to normal force in the fire situation
$N_{G,Ed}$	Design value of the part of the compressive normal force that is permanent
N_p	Axial resistance of a plate
N_{pc}	Axial resistance of the compression plate in a DSC member
$N_{pl,c,Rd}$	Design value of the plastic resistance of the section to compressive normal force
$N_{pl,t,Rd}$	Design value of the plastic resistance of the section to tensile normal force
$N_{pl,Rk}$	Characteristic value of the plastic resistance of the section to compressive normal force
N_{pt}	Axial resistance of the tension plate
N_{Rd}	Design value of the resistance of the section to normal force (tension or compression)
$N_{r,Rd}$	Design value of the resistance of a reinforcing bar to tension
$N_{t,Rd}$	Design value of the resistance of the section to tension
$N_{u,Rd}$	Design ultimate resistance to normal forces of the net cross-section at holes for fasteners
N_w	Axial resistance of the web of a T-stiffener
P_{Rd}	Design value of the shear resistance of a single connector
Q_p	First moment of area of the steel plate under consideration about the neutral axis of the cracked section
V_{Ed}	Design value of the applied out-of-plane shear force
$V_{i,Ed}$	Design value of the applied in-plane shear force
$V_{i,Rd}$	Design value of the resistance of the section to in-plane shear
$V_{L,Ed}$	Design value of the longitudinal shear force per unit length to be used to determine the spacing between headed stud connectors
V_{Rd}	Design value of the resistance of the section to out-of-plane shear
$V_{Rd,c}$	Design value of the resistance to out-of-plane shear of a DSC section with no shear reinforcement (tie bars)
$V_{Rd,max}$	Maximum value of the resistance to out-of-plane shear of a DSC section with shear reinforcement (tie bars)

V_{Rn}	Nominal value of the resistance of the section to out-of-plane shear
$V_{Rd,s}$	Design value of the resistance to out-of-plane shear of a DSC section with shear reinforcement (tie bars)
$V_{Rd,a}$	Design value of the resistance of the T-stiffener to out-of-plane shear
$V_{Rd,a,fi}$	Design value of the resistance of the T-stiffener to out-of-plane shear in the fire situation
W	Width of a DSC member

Latin lower case letters

a	Exponent
b	Width of section; exponent
b_e	Effective width of SSC composite member for calculation of deflection
c	Depth of linear stress block for concrete in a strut-and-tie model; exponent
c_2	Calibration constant for concrete contribution (6)
c_r	Concrete cover to reinforcement of SSC member
d	Diameter of the shank of a headed stud connector; effective depth of SC section for determination of out-of-plane shear resistance; effective depth of SC section for calculation of tensile reinforcement ratio
d_c	Effective depth of the continuous DSC member in a T-connection of DSC members
d_e	Effective depth of end DSC member in a corner L-connection of DSC members
d_r	Distance between the centre of the bolts and the top face of the bottom steel plate
d_s	Effective depth of section of a DSC member used in analysis
d_{th}	Thermal bowing displacement in a DSC member when the design value of the applied normal force in the fire situation $N_{fi,Ed} = N_{fi,pl,Rd}$, the design plastic resistance of the cross-section in the fire situation
e_0	maximum amplitude of imperfection of a DSC member at the construction stage
f_a	Stress in the plate
f_{bd}	Ultimate bond stress for anchorage of reinforcement bars
f_{ck}	Characteristic value of the cylinder compressive strength of concrete at 28 days
f_{cd}	Design value of the cylinder compressive strength of concrete (as defined in EN 1992-1-1 unless specified otherwise)
$f_{cd,fi}$	Design value of the compressive strength of concrete in the fire situation
f_{ctd}	Design value of the tensile strength of concrete
f_{sd}	Design value of the yield strength of reinforcing steel
f_{sk}	Characteristic value of the yield strength of reinforcing steel
f_y	Nominal value of the yield strength of structural steel
f_{yc}	Nominal value of the yield strength of compression plate

f_{yd}	Design value of the yield strength of structural steel
$f_{yd,fi}$	Design value of the yield strength of structural steel in the fire situation
f_{yt}	Nominal value of the yield strength of tension plate
f_{ywk}	Characteristic yield strength of shear reinforcement (tie bars)
f_u	Specified ultimate tensile strength
f_{ub}	Specified ultimate tensile strength of a dowel bar
h	Overall depth of section; thickness
h_c	Thickness of concrete
h_{cc}	Depth of concrete above the flange of the T-stiffener in a SSC section
h_{ccomp}	Depth of concrete in compression in a SSC member
h_e	Effective thickness of shell element for analysis of DSC sections (6)
$h_{c,eff}$	Effective thickness of concrete in the fire situation
h_{sc}	Overall nominal height of a headed stud connector
h_w	Depth of the web of a T-stiffener in a SSC member
$h_{0,fi}$	Thickness of concrete neglected in the fire situation
k	Factor relevant to out-of-plane shear; limiting value of the thermal bending moment reduction factor
k_1	Constant
$k_{b,\theta}$	Reduction factor for bolt bearing resistance in the fire situation
k_c	Factor to be used in calculating the shear resistance of a single connector to account of the state of concrete (cracked or uncracked)
k_{cc}	Reduction factor to account for the effect of concrete relaxation under sustained load
$k_{E,\theta}$	Reduction factor for the elastic modulus of structural steel giving the slope of the linear elastic range at elevated temperature, $E_{a,\theta}$
$k_{y,\theta}$	Reduction factor for the yield strength of structural steel giving the maximum stress level at elevated temperature, $f_{ay,\theta}$
k_{sc}	Stiffness of a shear connector
k_v	Shear stiffness of DSC section before concreting (temporary stage)
$k_{v,\theta}$	Reduction factor for bolt shear resistance in the fire situation
l_{bd}	Design bar anchorage length
$l_{b,rqd}$	Basic required bar anchorage length
l_θ	Global buckling length of DSC member in the fire situation
m	Modular ratio
n_c	Number of connectors attached to the compression plate of a DSC member between positions of maximum and zero bending moment

n_f	Number of connectors attached to the flange of the T-stiffener in a SSC members between positions of maximum and zero bending moment
n_p	Number of connectors attached to the plate of a SSC members between positions of maximum and zero bending moment
n_t	Number of connectors attached to the tension plate of a DSC member between positions of maximum and zero bending moment
q_p	Fresh concrete pressure
$q_{p,max}$	Limiting value of fresh concrete pressure
s	Distance between points of out-of-plane restraint to the plate provided by a headed stud connector or a tie bar; headed stud connector spacing when $s_l = s_t$
s_l	Headed stud connector spacing measured along the longitudinal axis
s_t	Headed stud connector spacing measured along the transverse axis
$s_{l,tie}$	Tie bar spacing in a DSC member measured along the longitudinal axis
$s_{t,tie}$	Tie bar spacing in a DSC member measured along the transverse axis
$s_{tie,min}$	Minimum tie bar spacing in a DSC member
$t_{c,\theta}$	The thickness of the concrete neglected in the fire situation
t_f	Thickness of flange of T-stiffener
t_p	Plate thickness when $t_{pc} = t_{pt}$ in a DSC member; bottom plate thickness in a SSC member
t_{pc}	Thickness of the compression plate in a DSC member
t_{pe}	Thickness of plate exposed to fire
t_{pt}	Thickness of the tension plate
t_{pu}	Thickness of the unexposed plate (fire situation)
t_w	Thickness of web of T-stiffener
x	Distance between the plastic neutral axis and extreme fibre of concrete in compression
x_c	Dimension related to continuous wall for definition of node geometry in a strut-and-tie model; effective depth of concrete in compression
x_e	Dimension related to end wall for definition of node geometry in a strut-and-tie model
x_{fi}	Distance of elastic neutral axis from inner face of the unexposed plate in the fire situation
$x_{p,fi}$	Distance of plastic neutral axis from inner face of the unexposed plate in the fire situation
$\bar{y}$	Distance of the centroid of steel plate from the neutral axis of the cracked section
y_{cr}	Distance of the neutral axis of the cracked section measured from the top of the section
y_s	Elastic neutral axis depth of the built-up steel section measured from the top of the T-stiffener
$y_{p,fi}$	Distance between the plastic neutral axis and the extreme fibre of concrete in compression in the fire situation
w	Uniform transverse loading applied to a member
z	Lever arm

Greek upper case letters

Δ_H	Out-of-plane deflection due to shear for the single bar/plate model used to determine the shear stiffness of a DSC section before concreting (temporary stage)
ΔM	Equivalent applied bending moment considering second order effects
ΔV	Shear force due to application of ΔM

Greek lower case letters

α	Imperfection factor; geometric parameter affecting shear resistance of headed stud connectors
α_v	Shear span
β	Reduction factor
γ_C	Partial factor for concrete
$\gamma_{C,fi}$	Partial factor for concrete in the fire situation
γ_{M0}	Partial factor for structural steel applied to resistance of cross-sections
γ_{M2}	Partial factor for resistance of cross-sections in tension to fracture
$\gamma_{M,fi}$	Partial factor for structural steel in the fire situation
γ_M^*	Partial factor for resistance of cross-sections
γ_V	Partial factor for design shear resistance of connectors (headed studs and tie bars)
γ_S	Partial factor for resistance of reinforcing steel
γ_f	Partial factor for fresh concrete pressure
ε_{cu}	Ultimate compressive strain in the concrete
ε_s	Strain in the steel plate
δ	Total deflection of an unfilled panel (temporary stage)
δ_b	Deflection of a SC member before concreting (temporary stage) due to bending
δ_p	Bending deflection of plate due to fresh concrete pressure
δ_{th}	Design value of the thermal bowing displacement
δ_v	Deflection of a DSC member before concreting (temporary stage) due to shear
$\delta_{v,end}$	Shear deflection midway between the first and second bars from the end of a DSC member (simply supported, uniformly loaded member)
$\delta_{v,max}$	Maximum mid-span deflection due to shear effects in a simply supported and uniformly loaded SC member before concreting (temporary stage)
η	Factor applied to concrete stress
η_{fi}	Factor applied to concrete stress in the fire situation
η_1	is a coefficient related to the quality of the bond condition and the position of the bar during concreting;
η_2	Factor related to reinforcement bar diameter used to determine the ultimate bond stress for anchorage

θ	Effective truss angle (between the concrete compression strut and the member axis perpendicular to the shear force); angle of inclination of diagonal strut in a strut-and-tie model
κ	Factor
λ	Factor for the effective zone of concrete in compression
$\bar{\lambda}$	Non dimensional slenderness
$\bar{\lambda}_{fi}$	Non-dimensional slenderness in the fire situation
μ	Factor
ν	Effective Poisson's ratio for analysis of SC sections (6); strength reduction factor for concrete cracked in shear
ν_c	Poisson's ratio for concrete
ν_s	Poisson's ratio for structural steel
ρ	Reinforcement ratio
ρ_l	Tensile reinforcement ratio
ρ_w	Shear reinforcement ratio
σ_{ac}	Total stress in the compression plate
$\sigma_{ac,a}$	Component of stress in the plate due to axial compression
$\sigma_{ac,b}$	Component of stress in the plate due to global bending
σ_{cp}	Compressive stress in the concrete from axial load
$\sigma_{Rd,max}$	Design strength (maximum allowable stress) for a concrete strut in a cracked compression zone
$\sigma_{Rd,node_max}$	Design value for the compressive stress within a node
σ_{strut}	Design stress in a concrete strut
σ_{sd}	Design stress of the bar at the position from where the anchorage is measured from
σ_{tpb}	Tensile stress in tie bars due to fresh concrete pressure
$\sigma_{v,bar}$	Maximum stress in a tie bar due to shear effects before concreting (temporary stage)
$\sigma_{v,pl}$	Local bending stress in a plate at the connection with the outermost tie bar (simply supported, uniformly loaded member)
φ	Diameter of tie bars
φ_t	Creep coefficient
ϕ	Diameter of reinforcing bars
χ	Reduction factor for flexural buckling
χ_{fi}	Reduction factor for flexural buckling in the fire situation

4 Basis of design

4.1 Basic requirements

(1) The following requirements apply to both DSC and SSC members (as appropriate):

- The thickness of a structural steel plate should be at least 6 mm (unless a smaller thickness, not less than 4 mm, can be justified) and not greater than 40 mm.

NOTE It is difficult to maintain the flatness of large plates of SC members where the plate thickness is less than 6 mm. It will also often be found that smaller thicknesses will not be sufficient to resist the hydrostatic pressure of fresh concrete at the construction stage.

- The ratio of the maximum plate thickness (t_p) to the overall thickness of the section (h) should be in accordance with the following requirements:
 - When the concrete grade is $< C40/50$, $t_p/h \leq 0,033$;
 - When the concrete grade is $\geq C40/50$ and the steel grade is $\leq S355$, $t_p/h \leq 0,05$;
 - When the concrete grade is $\geq C50/60$ and the steel grade is $\leq S355$, $t_p/h \leq 0,075$;
 - When the concrete grade is between $C25/30$ and $C60/75$ and the steel grade is $S460$, $t_p/h \leq 0,033$;
 - $t_p/h \geq 0,0075$ due to considerations at the construction stage.

(2) The slenderness of a plate in compression should be determined using the limits given in 8.2.2(3).

(3) Headed shear stud connectors should conform to the requirements of EN 1994-1-1:—, 8.6.10.7.

(4) The method of attaching the tie bars to the plates in DSC members should be by arc welding conforming to the relevant standards. Alternatively, threaded bars bolted through holes in the plates (with a nut on either side of the plate) may be used. The use of a single nut per plate (placed on the outside face of the plate) may be used provided that the performance of the connection detail can be demonstrated.

(5) The diameter of a welded tie bar should not be greater than 2,5 times the thickness of the plate to which it is welded.

(6) Plates of different thickness may be used for DSC members, provided that any resulting eccentricities are accounted for in design.

(7) In hybrid DSC members, where one plate is from one grade of steel and the other from a different grade (including stainless steel), differences in the yield strength of the two plates should be accounted for in the design.

(8) The minimum depth of concrete in a SSC member above the T-stiffener should satisfy the following criterion:

$$h_{cc} \geq h_{sc} + c_{nom} \quad (4.1)$$

where

h_{sc} is the nominal shear connector height, in mm.

(9) The concrete cover to reinforcement, c_{nom} , should be in accordance with EN 1992-1-1:2023, Clause 6 and Tables 6.3 and 6.4 but not less than 20 mm.

5 Materials

5.1 Concrete

- (1) Concrete used in SC structures should be of a strength class between C25/30 and C60/75. The use of lightweight concrete is permitted, provided that the design is backed up by experimental evidence and the strength class is between LC30/33 and LC55/60.
- (2) Properties should be obtained by reference to EN 1992-1-1:2023, 5.1 and Annex M for normal weight concrete and lightweight concrete, respectively.
- (3) For DSC members, where the concrete is placed between two plates, only autogenous shrinkage should be considered. Drying shrinkage, which relates to the evaporation of water from the concrete, may be neglected. However, for SSC members both autogenous and drying shrinkage should be considered.
- (4) Shrinkage of concrete should be accounted for considering the ambient humidity, the dimensions of the element and the composition of the concrete. Reference should be made to EN 1992-1-1:2023, 5.1.5 and Table M.2 for normal weight concrete and lightweight concrete, respectively.

5.2 Structural steel plates and sections

- (1) Structural steel plates and sections should be of grades not lower than S235 or higher than S460.
- (2) Properties should be obtained by reference to EN 1993-1-1:2022, 5.1 and 5.2.
- (3) Where stainless steel plate is used, properties should be obtained by reference to FprEN 1993-1-4:2024, 5.1.
- (4) For plate thickness between 15 mm and 20 mm, the plate should be class Z35. As an alternative to specifying a class Z35 plate in this thickness range, the following criteria should be satisfied:
 - It should be demonstrated that the risk of lamellar tearing is limited by reference to FprEN 1993-1-10:2024, Clause 3.
 - The sulphur content of the plate material should be below 0,01 % (as per the material certificate or chemical analysis of 2 separate plates by lot).
 - Tensile/bending production tests in accordance with EN ISO 14555 to be performed on plate/stud samples and should show that no lamellar tearing occurs.
- (5) For plate thickness greater than 20 mm, the plate should be class Z35.

5.3 Connecting devices

- (1) Reference should be made to EN 1993-1-8 for requirements for fasteners and welding consumables. Supplementary requirements for stainless steel should be in accordance with FprEN 1993-1-4:2024, 5.2.

5.3.1 Headed stud connectors

- (1) Reference should be made to EN ISO 13918.

5.3.2 Tie bars

- (1) Reference should be made to EN 10025-2 (as relevant).

5.4 Reinforcing bars

- (1) Reinforcing bars in the form of ribbed reinforcement should have a specified yield strength between 400 N/mm² and 600 N/mm² inclusive.
- (2) Properties should be obtained by reference to EN 1992-1-1:2023, 5.2.

(3) The reinforcing bars should have Class B ductility with characteristic strain values at maximum force $\geq 5\%$, according to EN 1992-1-1:2023, Clause C.4.

6 Structural analysis

6.1 Global analysis

For the determination of internal forces and displacements:

(1) The general requirements provided in EN 1992-1-1:2023, 7.1 should be applied as amended by (2) of this clause.

(2) The global analysis can be either a linear elastic analysis or a non-linear analysis.

(3) Second order effects should be taken into account if they significantly affect the overall stability of a structure and for the verification of the ultimate limit state at critical sections.

6.2 Structural modelling and basic assumptions

6.2.1 Linear elastic analysis

(1) Linear analysis of elements based on the theory of elasticity may be used for both the serviceability and ultimate limit states.

(2) For the determination of the action effects, linear analysis should be carried out assuming:

- linear stress-strain relationships;
- effective value of the modulus of elasticity for each material;
- the stresses in the plates and the concrete are limited to their design values.

6.2.2 Non-linear analysis

(1) Non-linear analysis should be in accordance with EN 1992-1-1:2023, 7.3.4 and EN 1993-1-1:2022, 7.4.3 or EN 1993-1-14.

(2) The behaviour of the shear connection shall be taken into account.

(3) Effects of the deformed geometry of the structure shall be taken into account.

(4) The following criterion in relation to plate slenderness should be satisfied:

for plates subjected to uniaxial compression:

$$\frac{s}{t_{pc}} \leq \sqrt{E_s/f_y} \quad (6.1)$$

for plates subjected to biaxial compression:

$$\frac{\sqrt{s_l^2 + s_t^2}}{t_{pc}} \leq \sqrt{E_s/f_y} \quad (6.2)$$

where

s is the distance between points of out-of-plane restraint to the plate provided by a headed stud connector or a tie bar;

- s_l and s_t are the distances between points of out-of-plane restraint to the plate provided by a headed stud connector or a tie bar in the longitudinal and transverse directions respectively
- t_{pc} is the thickness of the compression plate in a DSC member;
- f_y is the nominal value of the yield strength of the plate material;
- E_s is the modulus of elasticity of structural steel.

7 Geometric and material properties for elastic analysis

(1) SC members may be modelled using equivalent homogeneous properties (equivalent shell elements in the case of finite element analysis) or by directly using the calculated rigidities of the section.

(2) The analysis should be one that implements the 'Mindlin-Reissner' formulation as SC sections are relatively thick and their out of plane shear deformations cannot be neglected. If the analysis is performed using finite elements, the structure should be modelled using elements with 8 degrees of freedom; 3 translations, 3 rotations and 2 shear deformations.

(3) Properties of equivalent DSC members are given by the following formulae:

Axial rigidity, C :

$$C = \frac{E_e}{1 - \nu^2} h_e \quad (7.1)$$

Bending rigidity, D :

$$D = \frac{E_e h_e^3}{12(1 - \nu^2)} \quad (7.2)$$

Out-of-plane shear rigidity, G :

$$G = \frac{E_e}{2(1 + \nu)} h_e \quad (7.3)$$

Where the section is in compression and the concrete can be considered uncracked, the out-of-plane shear rigidity may instead be taken as:

$$G = \frac{5E_{cm}}{12(1 + \nu)} h_c \quad (7.4)$$

In the above formulae, the effective modulus of elasticity, E_e is given by:

$$E_e = E_s \frac{(h_c/m) + t_{pt} + t_{pc}}{h_e} \quad (7.5)$$

where h_e is the effective thickness of the equivalent section given by:

$$h_e = \frac{\sqrt{m(4t_{pt}^3 - 6t_{pt}^2 d_s + 3t_{pt} d_s^2) + m(4t_{pc}^3 - 6t_{pc}^2 d_s + 3t_{pc} d_s^2) + c_2 h_c^3}}{\sqrt{m(t_{pt} + t_{pc}) + h_c}} \quad (7.6)$$

- ν is the effective Poisson's ratio of the element, taken as 0,2;
 m is the modular ratio E_s/E_{cm} for short term loading;
 E_{cm} is the modulus of elasticity of concrete calculated in accordance with EN 1992-1-1;
 h_c is the thickness of the concrete;
 d_s is the effective thickness (depth) of the section ($= h - t_{pc}/2 - t_{pt}/2$);
 h is the total thickness of the section;
 t_{pc} is the thickness of the compression plate;
 t_{pt} is the thickness of the tension plate;
 c_2 is a calibration constant for the concrete contribution, taken as:
 $c_2 = 0,48\rho m + 0,10$
 ρ is the reinforcement ratio, given by $(t_{pt} + t_{pc})/h$.

(4) The eccentricity in non-symmetric DSC cross-sections is given by $z_0 - z_G$ where z_0 is the geometric centre of the cross-section and z_G is the stiffness centre:

$$z_G = \frac{h_c(0,5h_c + t_{pt}) + 0,5mt_{pt}^2 + mt_{pc}(h - 0,5t_{pc})}{h_c + m(t_{pc} + t_{pt})} \quad (7.7)$$

(5) The density of the equivalent homogeneous material is given by ρ_e where:

$$\rho_e = \frac{\rho_s(t_{pc} + t_{pt}) + \rho_c h_c}{h_e} \quad (7.8)$$

Where ρ_s and ρ_c are the densities of steel and concrete respectively.

(6) For the purposes of a global analysis, the T-stiffeners in SSC members may be neglected and the properties of equivalent SSC members are given by the following formulas:

Axial rigidity, C :

$$C = \frac{E_e}{1 - \nu^2} h_e \quad (7.9)$$

Bending rigidity, D :

$$D = \frac{E_e h_e^3}{12(1 - \nu^2)} \quad (7.10)$$

In the above formulas, the equivalent effective modulus of elasticity, E_e and the effective thickness, h_e are given by:

$$E_e = E_s \sqrt{\frac{(t_p + y/m)^3}{12I_{com}}} \quad (7.11)$$

$$h_e = \sqrt{\frac{12I_{com}}{t_p + y/m}} \quad (7.12)$$

Out-of-plane shear rigidity of the equivalent shell elements, G :

$$G = \frac{5E_{cm}}{12(1 + \nu)} y \quad (7.13)$$

Where y is the depth from the top of concrete to the neutral axis of the section given by:

$$y = -mt_p + \sqrt{m^2 t_p^2 + 2(h_c + \frac{t_p}{2})t_p m} \quad (7.14)$$

and I_{com} is the second moment of area of the cracked composite section per unit width given by:

$$I_{com} = \frac{y^3}{3m} + t_p(h_c + 0,5t_p - y)^2 + \frac{t_p^3}{12} \quad (7.15)$$

(7) The eccentricity in SSC cross-sections is given by $z_0 - z_G$ where z_0 is the geometric centre of the cross-section and z_G is the stiffness centre:

$$z_G = \frac{h_c(0,5h_c + t_p) + 0,5mt_p^2}{h_c + mt_p} \quad (7.16)$$

(8) The forces and moments determined from the global analysis are converted into stresses acting on the steel plates, concrete, shear studs and tie bars to verify that the assumed properties are adequate.

(9) The determination of these stresses may be based on the following assumptions:

- Perfect bond between the steel plates and the concrete (i.e. no strain discontinuity at the steel/concrete interface).
- Stresses/strains vary linearly over the depth of the section.
- Concrete tensile strength is ignored.
- The von Mises criterion is used to calculate the equivalent stresses acting on the section.

(10) In-plane moments may be accounted for by being resolved into a pair of axial forces (tension – compression) applied to the section.

(11) Torsional moments may be accounted for as additional in-plane and out-of-plane moments.

8 Ultimate limit state

8.1 Members in tension

(1) The design value of the tension force N_{Ed} acting at the centroid of the cross-section shall satisfy:

$$\frac{N_{Ed}}{N_{t,Rd}} \leq 1 \quad (8.1)$$

For cases where the tension force is not aligned with the centroid of the cross-section, the associated eccentricities shall be accounted for.

(2) The design tension resistance $N_{t,Rd}$ of SC members should be determined in accordance with EN 1993-1-1.