EUROCODES

EN 1994

Design of composite steel and concrete structures

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2023 EURO CODE DIBt

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Key changes to Eurocode 4

- Correction of errors identified by users during Systematic Review.
- Clarifications requested by users.
- Extensions of scope requested by users, and updates to reflect current practice.
- Improved alignment between parts and with other Eurocodes.
- Reduction in possibilities for national variations (NDPs).

How ease of use has been enhanced

- Better alignment between Parts and with other Eurocodes.
  - Technical provisions.
  - Layout and structure.
  - Wording.
- For technical provisions the hierarchy for ‘harmonisation’ is to:
  - Provide rules that agree with other Eurocodes.
  - Explain why rules that one might imagine should be the same are different (so users appreciate that the differences are not a mistake).
- Generally, trying to avoid changing current, familiar rules unless there is a clear need.

Eurocode 4 Design of composite steel and concrete structures

EN Eurocode 4 (1st generation)

EN 1994-1-1, Part 1-1: General rules and rules for buildings.

EN 1994-1-2, Part 1-2: General rules – Structural fire design.

EN 1994-2, Part 2: General rules and rules for bridges

prEN Eurocode 4 (2nd generation)

prEN 1994-1-1, Part 1-1: General rules and rules for buildings

prEN 1994-1-2, Part 1-2: Structural fire design.

prEN 1994-2, Part 2: Bridges.

prCEN/TS 1994-1-101 Design of double and single skin steel concrete composite (SC) structures

prCEN/TS 1994-1-102 Design rules for the use of Composite Dowels.

prCEN/TS 1994-1-103 Design rules for composite columns comprising high performance materials.

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Composite beams with web-openings

- Many long-span composite systems developed that permit mechanical services to be integrated within the structural depth.
- New Annex in prEN 1994-1-1 supports design of composite beams with web-openings, which compliments new prEN 1993-1-13.
- Supplementary Annex for cases when the flexural stiffness of the concrete slab significant, where tension in the shear connectors and shear in the concrete needs to be considered.

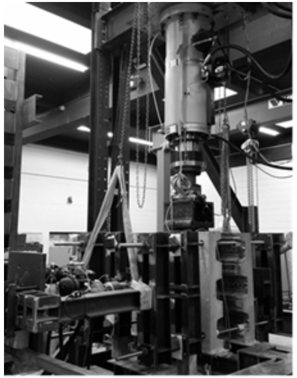
Source: ArcelorMittal

Source: MP Ingénieurs Conseils SA - Suisse

Headed studs used with profiled steel sheeting in buildings with ribs transverse to the supporting beam

- Current design model is to multiply resistance of a stud within a solid slab P_{Rd} by a reduction factor k_t
- Research has shown that the equations for k_t do not perform well for modern open-trough sheets.
- To remedy this situation, new design model given:
  - Existing rules retained within a limited scope (re-entrant and some open-trough sheets).
  - New rules for modern open-trough sheets given within an Annex.

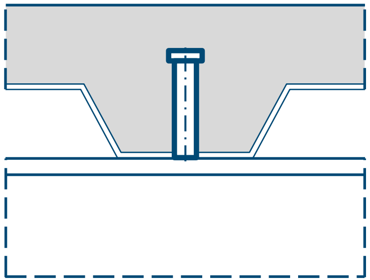
Source: Hicks (2007)

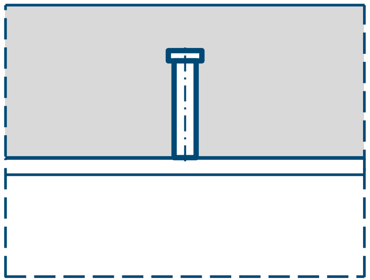


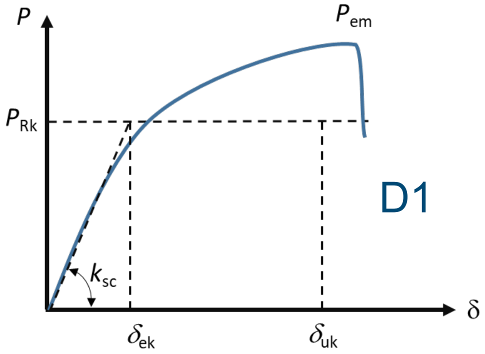
Source: Nellinger *et al.* (2017)

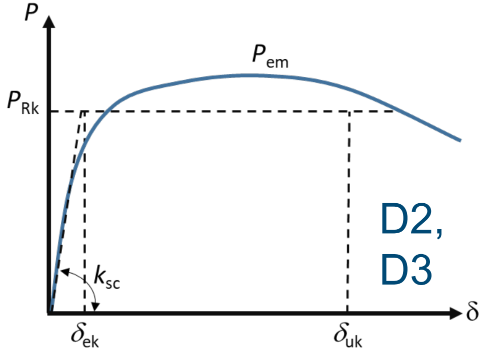
Ductility Categories for shear connectors

Ductility category	Characteristic elastic slip when P_{Rk} is reached δ_{ek} (mm)	Characteristic slip capacity δ_{uk} (mm)
D1	-	-
D2	$\delta_{ek} \leq 2,5$	$6,0 \leq \delta_{uk} < 10,0$
D3		$\delta_{uk} \geq 10,0$





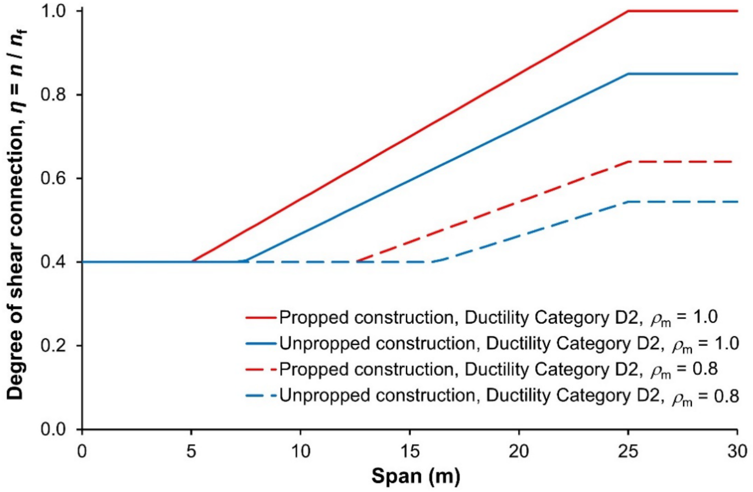




Minimum degree of shear connection in beams for buildings

- Existing rules for partial shear connection based on assumption that:
  - characteristic slip capacity of 19 mm diameter studs in solid and composite slabs was approximately δ_{uk} = 6,0 mm;
  - propped construction conservatively assumed (unusual in current practice);
  - high utilization of design moment resistance $\rho_m = M_{Ed}/M_{Rd}(\eta) \approx 0.95$ (unusual with SLS considerations).
- Recent composite beam tests found that δ_{uk} = 10,0 mm can be achieved for studs in open-trough profiles (i.e. D3)

Minimum degree of shear connection in beams for buildings concluded

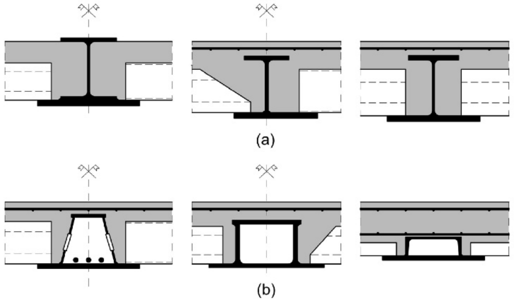


Degree of shear connection η vs. span for S355 symmetric steel sections, D2 shear connectors and utilization of bending resistance of ρ_m = 1,0 or ρ_m = 0,8 (with ρ_{up} = 0,15 for unpropped construction)

- New rules reduce existing conservatism by:
  - considering whether construction is propped (k_{up} = 1) or unpropped (k_{up} = [1- ρ_{up}]);
  - utilization of bending resistance (0,8 ≤ ρ_m ≤ 1,0); and
  - considering shear connector ductility category of D2 or D3.

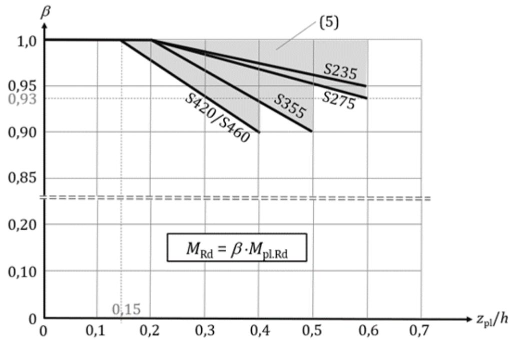
Slim floor beams in buildings

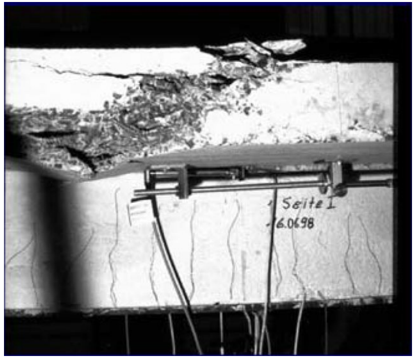
- Shallow floor, or slim-floor construction, has become popular as it provides:
  - a shallow structural zone;
  - a reduced number of beams;
  - flexibility in the layout of mechanical services; and
  - the concrete encasement provides fire protection to the steel beams.
- New Annex within Eurocode 4 provides generic design rules that complement existing proprietary floor systems.



Strain limited design of composite beams in bending

- For composite beams where the plastic neutral axis z_{pl} is deep within the cross-section, the plastic bending resistance $M_{pl,Rd}$ can overestimate design bending resistance M_{Rd}.
- In these cases M_{Rd} should be evaluated from non-linear theory using the stress-strain relationships of the concrete, structural steel and reinforcement.
- Within a defined scope, a simplified method is given in prEN 1994-1-1 where M_{Rd} may be taken as $\beta\, M_{pl,Rd}$ (β is a reduction factor dependent on the steel grade and the ratio $z_{pl}\,/h$)





Source: Use of high-strength steel S460: Final report (2002)

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Fire resistance of composite floors under tensile membrane action

- Tensile membrane action reduces the requirement for applied fire protection to some beams.
- Different design methods have been used by practitioners for over a decade to reduce the applied fire protection on internal (secondary) beams.
- One design method is given in detail within a new Annex to Eurocode 4.

Fire resistance of composite floors under tensile membrane action

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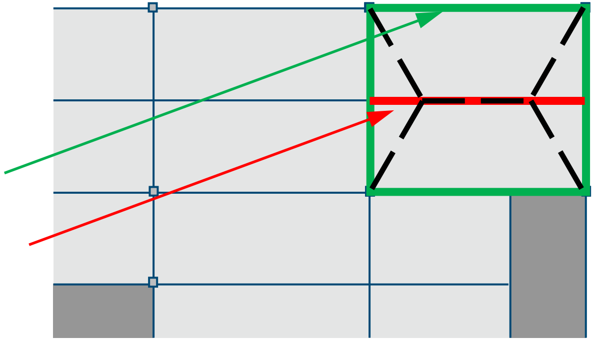
Source: Behaviour of multi-storey, steel framed building subjected to natural fire effects: Final report (2002)

Protected edge and perimeter beams

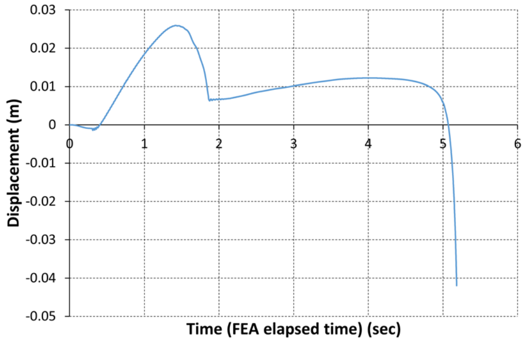
Unprotected internal composite beam



Part floor plan

Composite columns using concrete filled steel tubes

- Improved simple calculation model included within Eurocode 4
  - member slenderness $5 \leq l_{fi} / B \leq 30$;
  - larger eccentricities permitted of $\delta / D \leq 1{,}0$ (cf. $\delta / D \leq 0{,}5$);
  - wider range of fire periods of between 30 and 240 minutes (cf. ≤ 120 mins);
  - full range of hollow sections:
    - circular (CHS) $10 \leq D / e \leq 60$; and
    - square (SHS), rectangular (RHS), and elliptical (EHS) $5 \leq B / e \leq 30$.



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Main changes in prEN 1994-2

- Format completely revised, where all duplicate general rules have been removed and replaced with cross-references to prEN 1994-1-1 (which is reflected by the fact that the title for Part 2 is now ‘Bridges’).
- Rules for composite dowel shear connectors prepared within a draft annex before it was decided to include this within prCEN/TS 1994-1-102 to provide freedom for the provisions to be extended to buildings.

Source: Wojciech Lorenc

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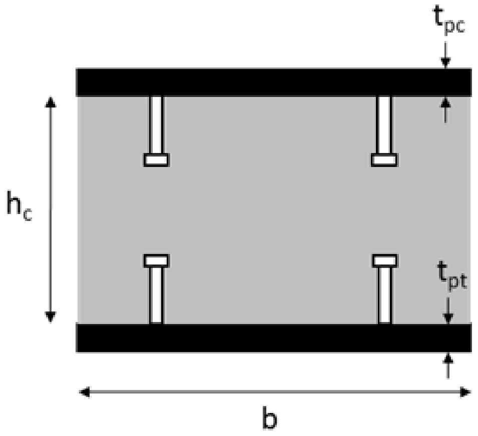
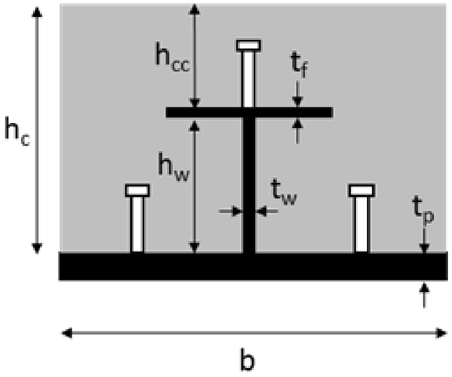
1. Key changes and structure of second generation Eurocode 4
2. prEN 1994-1-1
3. prEN 1994-1-2
4. prEN 1994-2
5. New CEN Technicl Specifications prCEN/TS 1994-1-101 and prCEN/TS 1994-1-102

prCEN/TS 1994-1-101 Design of double and single skin steel concrete composite (SC) structures

- Nuclear power plants using SC construction already built in USA, Japan, South Korea and China.
- SC construction used for core walls in multi-storey steel-framed buildings (e.g. 59-storey Rainier Square building, Seattle, USA).
- Steel plates act as permanent load bearing formwork during the placement of the concrete (core)
- In the permanent condition, the plates act as reinforcement to the concrete and therefore are fundamental to the structural performance of the panels.

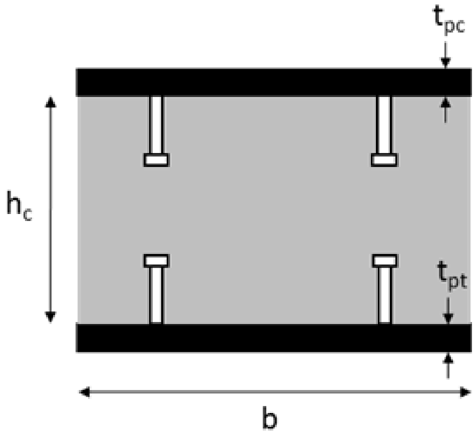


DSC (top) and SSC (bottom) structures



prCEN/TS 1994-1-101 Design of double and single skin steel concrete composite (SC) structures

- prCEN/TS 1994-1-101 gives rules for:
  - double skin (DSC) structures using two steel plates with shear studs connected by a grid of tie bars, typically used for walls; or
  - single skin (SSC) structures using a reinforced steel plate (e.g.T-stiffeners) with shear studs, typically used for floors.
- Includes specific design rules for joints, design for execution, and structural fire design.



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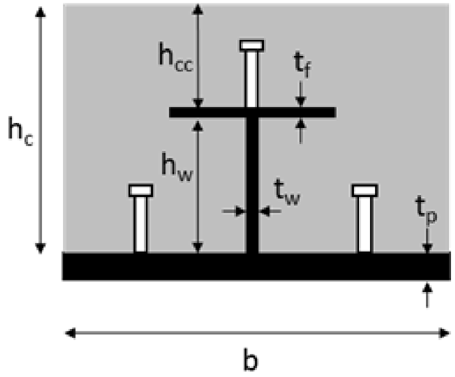
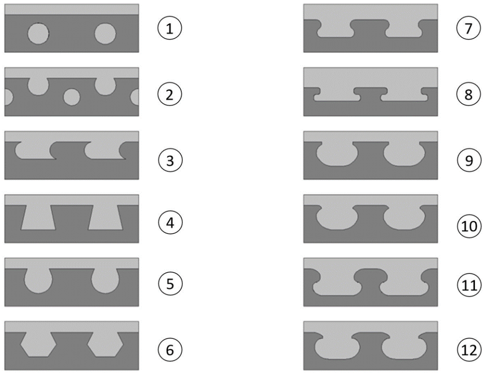
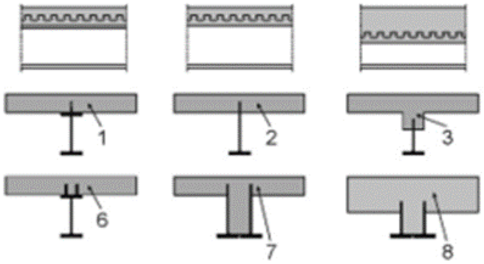


prCEN/TS 1994-1-102 Design rules for the use of Composite Dowels

- Design rules for composite dowels as shear connectors.
- Main part of prCEN/TS 1994-1-102 only provides general rules
- Specific rules are given for particular dowels within the Annexes
- Annex A provides rules for puzzle- and clothoidal-shape dowels
- Annex B provides advanced design rules for shallow floor beams within buildings, complementing the new Annex within prEN 1994-1-1



Typical composite dowel cross-sections



Examples of conventional (1, 2, 6) and hybrid cross-sections (3, 7, 8)

Conclusions

- Project teams commenced work on the second generation of Eurocode 4 in 2015, with the Phase 4 teams concluding in February 2022.
- Although not exhaustive, a selection of the changes within the second generation of Eurocode 4 have been presented (further information on prEN 1994-1-1 given within open access paper by Hicks *et al.* (2023) https://doi.org/10.1002/cepa.1888).
- The current time schedule for prEN 1994-1-1, prEN 1994-1-2 and prEN 1994-2 is as follows:
  - CEN-Enquiry between 1 March 2024 and 22 June 2024.
  - Formal vote between 1 October 2025 and 25 November 2025.
  - DIN/AFNOR ends translation for publication 28 January 2026.

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