Composite Steel and Concrete Structures

Innovative Solutions for Outstanding Buildings
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Part I-1

Introduction
Typical composite members

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<tr>
<th>composite members</th>
<th>![Image of composite beams]</th>
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<td>composite slim floor systems</td>
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Typical application of composite structures for buildings

- High rise buildings
- Hotels, Hospitals, Office buildings, Museums
- Industrial buildings
- Multi storey car park
Typical application of composite structures for bridges

- Box girder
- Composite bow string arch
- Composite bridge with rolled steel sections
- Composite truss with double composite action
- Box girder with double composite action
Advantages for the client and the building contractor

- High degree of industrial prefabrication
- Independence from exposure
- Low area requirement for construction equipment and erection
- Low construction time and reduction of building costs
- High bearing capacity of beams and columns
- Simple solutions for strengthening in case of later requirements for the use of the building
- High flexibility for the user due to longer span length of beams and small dimension of members
- High fire resistance
- High dimensional accuracy for finish and service work
## Historical overview

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Part I-2

Composite slabs and composite slim floor systems
Composite slabs

- Steel sheeting can be assembled by hand.
- Steel sheeting can be used as work platform.
- Steel sheeting acts as formwork for casting of concrete.
- Steel sheeting acts together with concrete as a composite member in the final stage.
- Sheeting can be used to prevent lateral torsional buckling of the composite beam during erection.
- Steel sheeting allows simple solutions for fixing of service equipment
- High fire resistance
Composite slabs consist of thin profiled steel sheeting with zinc coating. For casting the sheeting is acting as formwork and after hardening of concrete the sheeting and the concrete act together as a composite member.

- In-situ concrete
- Open profile
- Re-entrant profile
- Headed studs for end anchorage of the slab and shear connection for the composite beams
- Welded mesh for transverse load distribution and fire resistance
Composite slabs
Longitudinal shear resistance

**Mechanical interlock** provided by deformations in the profile (indentations or embossments)

**Frictional interlock** for profiles shaped in a re-entrant form

**End anchorage** provided by welded studs or by deformation of the ribs at the end of the sheeting or by another type of local connection between the concrete and the steel sheet
Composite action due to mechanical interlock and friction

- **Mechanical interlock**
- **Frictional interlock**

Indentations or embossments cause friction in the interface between steel and concrete in addition to the mechanical interlock.

- Friction due to vertical deformation of the top flange of the sheeting
- Friction due to lateral strain of the sheeting (effect of Poisson's ratio)
Temperature distribution in composite slabs in case of fire
Composite slim floor systems

- small depth of the cross-section
- high bending resistance
- high fire resistance
- no danger of punching shear
- no formwork
- high degree of industrial prefabrication
Composite slim floor systems

- in-situ concrete
- in-situ concrete in combination with partially prefabricated concrete elements
- in-situ concrete in combination with profiled steel sheeting
Composite slim floor systems

DELTA-system

partially prefabricated slabs

prestressed hollow core slabs
Composite slabs with high steel profiles

Hoesch - Additiv - System

COMFLOOR-System
Systems to increase the punching shear resistance of concrete slim floors

- System „Geilinger Europilz“
- Shear head system „stahl+verbundbau“
Shear head system “Geilinger Europilz”
Shear head system “stahl+verbundbau”
Part I-3

Composite beams
Typical composite beams

- Composite beam with solid slab
- Partially concrete encased beams
- Composite beam with composite slab
- Structural steel sections are rolled or welded
Typical composite beams in buildings

- partially concrete encased beams
- beams without concrete encasement
Composite beams with web openings

Web openings with stiffeners

Web openings without stiffeners
Partially concrete encased beams

- Casting of concrete
- Bolted anchor plate for installation
- Triangular infill
Advantages of partially concrete encased beams

- Structural steel section with headed studs
- Longitudinal reinforcement for normal temperature situations and for increasing fire resistance
- Welded mesh

**Advantages:**
- High flexural stiffness
- High fire resistance (classes R30 – R120)
- Longitudinal reinforcement can be used instead of additional flange plates or altering flange thickness
Prefabricated slabs

- hoops

- Elastomer strips

- partially prefabricated slabs

- $e \geq 25\text{mm} + \frac{d}{2}$
Different types of shear connection

- Nails
- Angle connectors
- Perfobond
- Friction grip bolts
- Block-connectors
- Headed studs
Headed stud shear connectors
Headed studs in combination with profiled steel sheeting
Fire resistance – Design concept

thermical analysis

gas temperature $\theta_g$

temperature of the structure

mechanical analysis

resistance $R_{fi,d,t}$

Action effects $E_{fi,d,t}$

Verification $E_{fi,d,t} \leq R_{fi,d,t}$

$\theta$, $\theta_g$

t – time of fire

$E_{fi,d,t}$, $R_{fi,d,t}$

$t_{fi,req}$, $t_{fi,d}$

time
Strength and modulus of elasticity of structural steel due to high temperatures

- Yield strength
  \[ k_{ay,\theta} = \frac{f_{ay,\theta}}{f_{ay}} \]

- Modulus of elasticity
  \[ k_{a,E,\theta} = \frac{E_{a,\theta}}{E_a} \]

- Proportional limit
  \[ k_{ap,\theta} = \frac{f_{ap,\theta}}{f_{ay}} \]

Temperature \( \theta = \theta_a \) [°C]
Fire resistance of composite beams

- Fire protection plates
- Partially concrete encased section
- Fireproofing applied plaster
Fire resistance of partially concrete encased beams

temperature distribution

100°C

300°C

500°C

700°C

900°C

effective cross section and reduced strength of steel and concrete

Design strength for fire resistance

\[ f_{c,fi,d} = \frac{f_{ck}}{\gamma_{c,fi}} \]

\[ f_{ay,fi,d} = \frac{f_{yk}}{\gamma_{a,fi}} \]

\[ f_{s,fi,d} = \frac{f_{sk}}{\gamma_{s,fi}} \]
Part I-4

Composite columns
Composite columns

- Concrete encased sections
- Concrete filled hollow sections
- Partially concrete encased sections
Special cross-sections

- Hollow sections with additional inner profiles
- Partially concrete encased sections
Composite columns with hollow sections and additional inner profiles

Post-Tower Bonn

Commerzbank Frankfurt
Concrete encased sections

**advantages:**
- high bearing resistance
- high fire resistance
- economical solution with regard to material costs

**disadvantages:**
- high costs for formwork
- difficult solutions for connections with beams
- difficulties in case of later strengthening of the column
- in special case edge protection is necessary
Partially concrete encased sections

advantages:
- high bearing resistance, especially in case of welded steel sections
- no formwork
- simple solution for joints and load introduction
- easy solution for later strengthening and additional later joints
- no edge protection

disadvantages:
- lower fire resistance in comparison with concrete encased sections.
Casting of partially concrete encased sections

- Reinforcing pocket 1
- Casting pocket 1
- Turning the steel profile
- Reinforcing pocket 2
- Casting pocket 2
Concrete filled hollow sections

**Advantages:**
- high resistance and slender columns
- advantages in case of biaxial bending
- no edge protection

**Disadvantages:**
- high material costs for profiles
- difficult casting
- additional reinforcement is needed for fire resistance
Casting of concrete in case of concrete filled hollow sections

Casting from the top

Pumping in vertical direction

hole for vent

Opening for casting

Outside compactor

e \leq 5m

hole for vent

pumping in inclined position

H \approx 0.2L
Concrete filled hollow sections with additional inner profiles

**Advantages:**
- Extreme high bearing resistance in combination with slender columns
- Constant cross section for all stories is possible in high rise buildings
- High fire resistance and no additional reinforcement
- No edge protection

**Disadvantages:**
- High material costs
- Difficult casting
HILTI – shear connection with nails

\[ \varnothing 10 \]

\[ \varnothing 4.5 \]

\[ l_s \]

\[ l_s + 2 \]
Part I-5

Connections for composite structures
Classification of joints

- **Full strength connection**
  - \( M_{pl, beam} \) - Plastic bending resistance of the beam

- **Partial strength connection**
  - \( 0.25 M_{pl} \)

- **Simple connection**

Graph showing the relationship between moment (M) and rotation (\( \phi \)).
Simple joints for composite beams with concrete encasement

beam to column connection

beam to beam connection
Rigid connections

beam to column connection

splice plate

contact plate

beam to beam connection
Joints with half end plates
Joint with endplates and cleats
Joint with solid core profiles
Joint with solid core profile for continuous beams

splice plate

contact plate
Load introduction with gusset plates
Load introduction with partially loaded end plates
Load introduction with distance plates for columns with inner core profiles
Part I-6

Examples of composite buildings
High-rise building in Düsseldorf "Stadttor Düsseldorf"

Bracing systems with composite columns

Composite columns, composite beams and composite floors
Commerzbank Tower in Frankfurt
Commerzbank Tower in Frankfurt

Composite beams

Composite slabs

Composite columns
Composite columns with inner core profiles
Highlight Munich Business Towers

- 126 m, 33 levels
- 106 m, 27 levels
Highlight Munich Business Towers

grid: longitudinal: 8,10m
transverse: 5+7m

flat slabs
\( d = 28 \, \text{cm} \)

\( L \times B = \sim 80 \times 13,50 \)
Highlight Munich Business Towers
Highlight Munich Business Towers
Highlight Munich Business Towers
Office buildings

Sony-Center Berlin
Office building and production unit of Siemens in Berlin
Body unit of Porsche in Stuttgart
Body unit of Porsche in Stuttgart
Paint unit of Opel in Eisenach
Paint unit of Opel in Eisenach
Paint unit of Opel in Eisenach
Paint unit of Opel in Eisenach

Full strength and rigid frame joint
Paint unit of Opel in Eisenach

Connection of the trusses with the composite columns
Airport Hannover
Composite Steel and Concrete Structures
Innovative Solutions for Outstanding Buildings

Thank you very much for your kind attention!