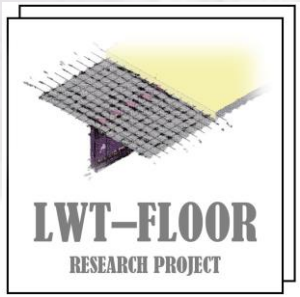
Project title: **Innovative lightweight cold-formed steel-concrete composite floor system**
Acronym: **LWT-FLOOR** Project ID: **UIP-2020-02-2964**
3rd LWT-FLOOR Project Workshop

Finite Element Analyses of Demountable Shear Connection in Cold-Formed Steel-Concrete Composite Beam Based on Experimental Data

Vlaho Žuvelek | Ivan Ćurković | Ivan Lukačević | Andrea Rajić



University of Zagreb/Faculty of Civil Engineering
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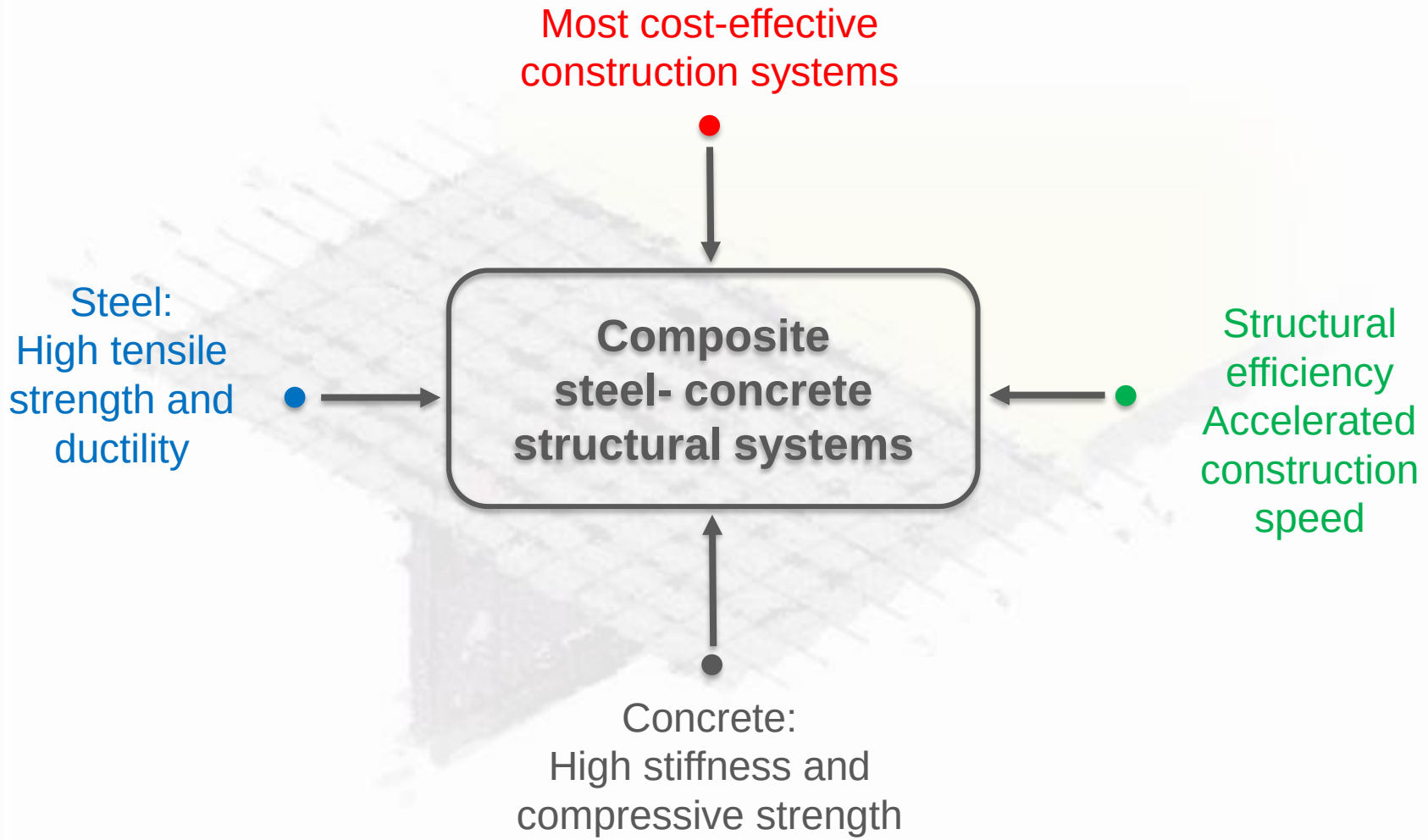
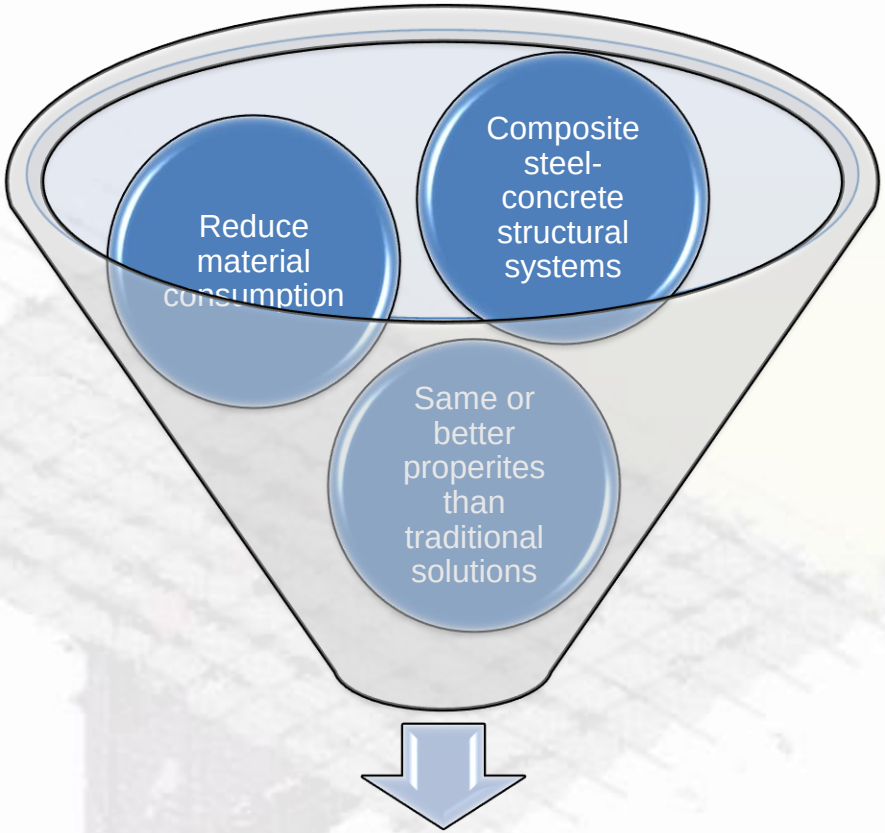
Agenda

- Introduction
- Experimental programme
- Finite element (FE) model
  - Geometry, boundary conditions and loading
  - Mesh, interactions and analysis method
  - Constitutive models
  - Validation of numerical models
- Parametric study
- Results and discussion
- Conclusions

1. Introduction

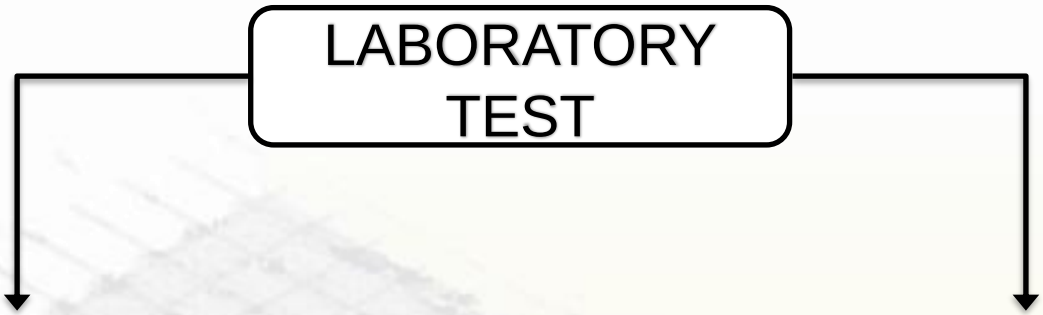


1. Introduction



Composite built-up cold-formed steel girders (CFS) with a corrugated web and concrete slab

2. Experimental programme



- ❑ Base material
  - steel sheets
  - concrete
  - reinforcement bars
  - reinforcemenet mesh
  - bolts
- ❑ Spot welds

- ❑ Push-out specimens

2. Experimental programme

- Thickness of tested steel sheets:
  - ❑0.8 mm
  - ❑1.0 mm
  - ❑1.25 mm
  - ❑1.5 mm
  - ❑2.0 mm
  - ❑2.5 mm
  - ❑3.0 mm

2. Experimental programme

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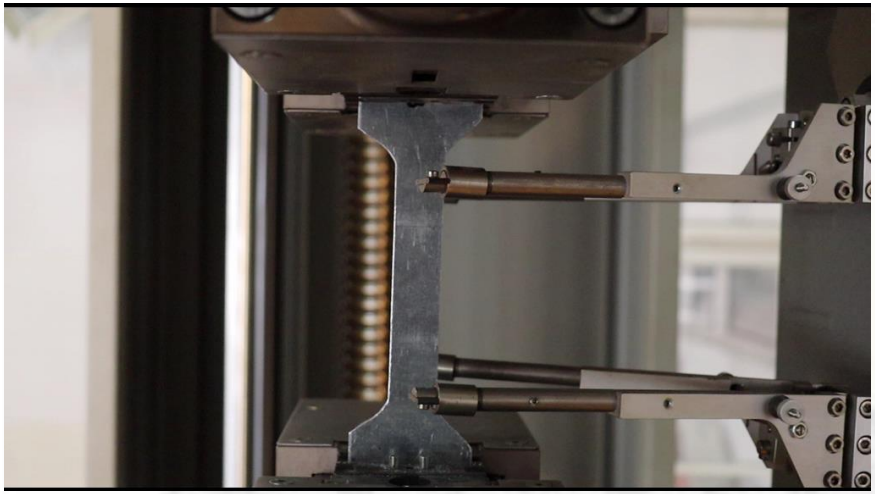
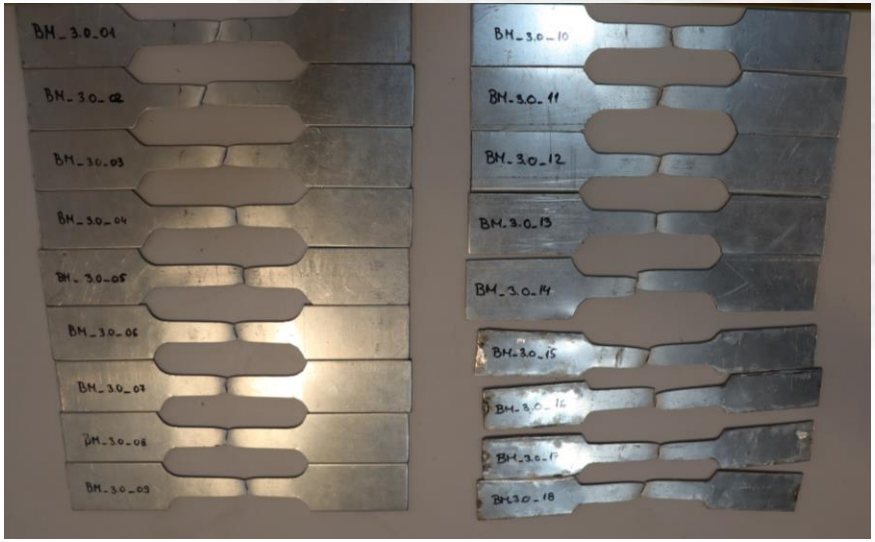
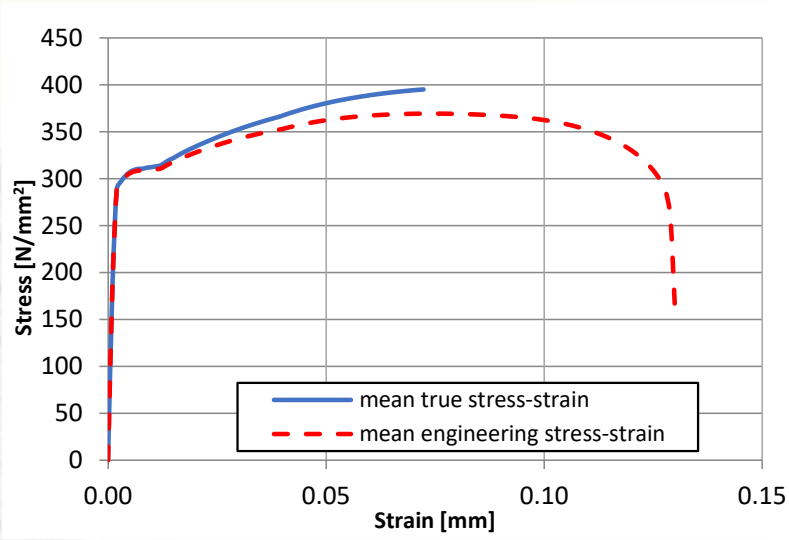
2. Experimental programme







2. Experimental programme

- Concrete:
  - Normal weight concrete (NC)
  - 15 concrete cylinders
- Crushing and modulus elasticity

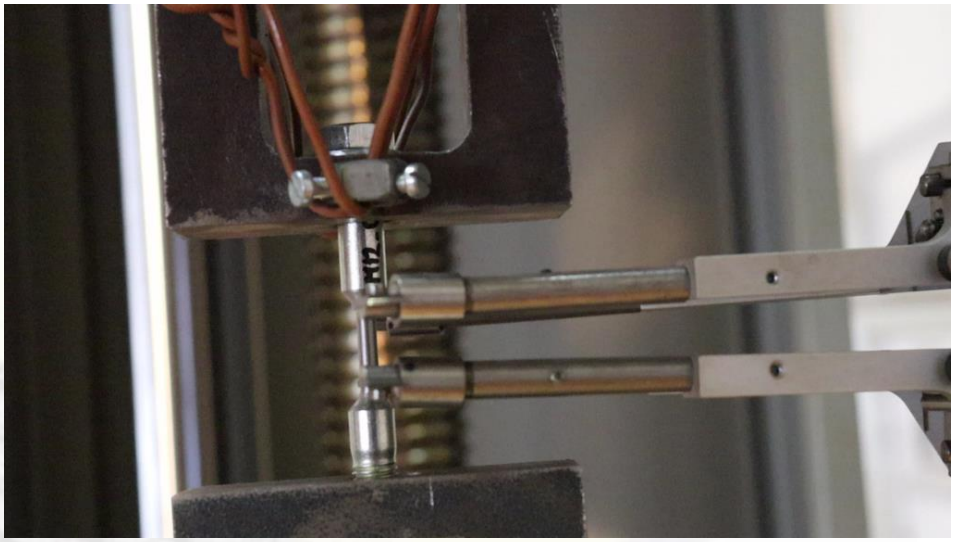
	Compressive strength [MPa]	Modulus of elasticity [MPa]
Mean value	28.09	29526
St. dev. [%]	2.429	0.281
Coefficient of variation [%]	8.64	0.95

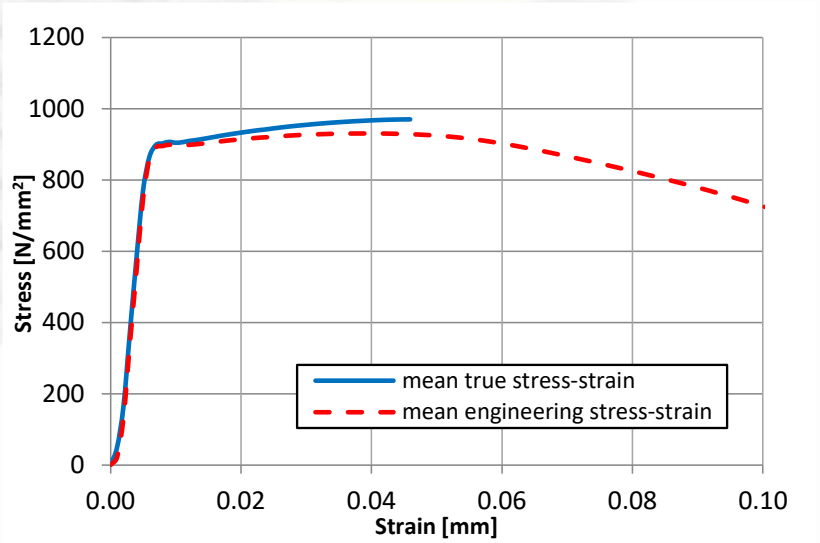
2. Experimental programme

- Reinforcement mesh and bars

2. Experimental programme

- Bolts:
  - M12
  - M16





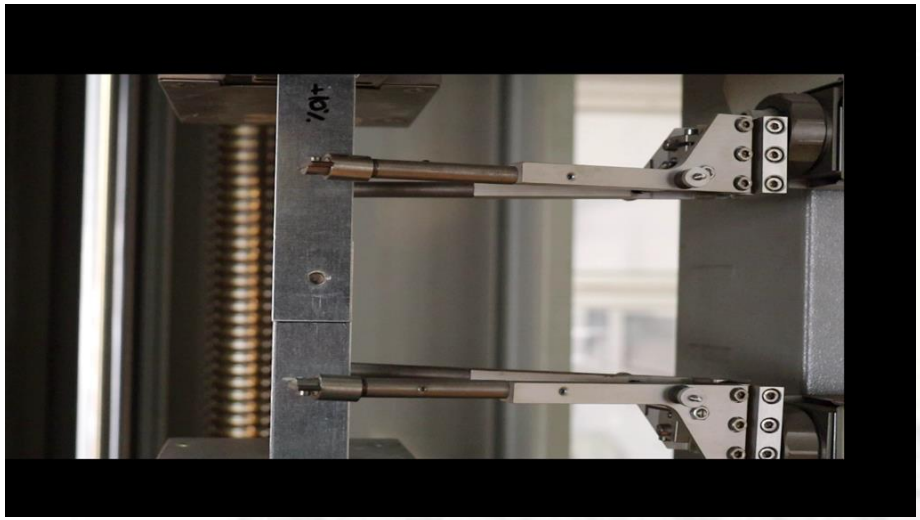
2. Experimental programme

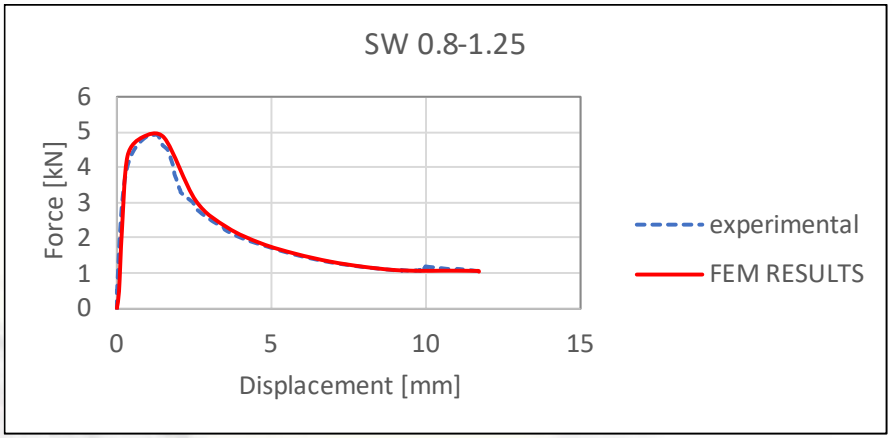
Combination of sheet thicknesses for spot welds:

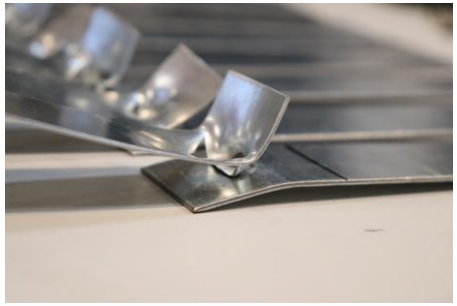
- 0.8 mm – 0.8 mm
- 0.8 mm – 1.0 mm
- 0.8 mm – 1.25 mm
- 0.8 mm – 1.5 mm
- 0.8 mm – 2.0 mm
- 0.8 mm – 2.5 mm
- 0.8 mm – 3.0 mm
- 1.0 mm – 1.0 mm
- 1.0 mm – 1.25 mm
- 1.0 mm – 1.5 mm
- 1.0 mm – 2.0 mm
- 1.0 mm – 2.5 mm
- 1.0 mm – 3.0 mm
- 1.25 mm – 1.25 mm
- 1.25 mm – 1.5 mm
- 1.25 mm – 2.0 mm
- 1.25 mm – 2.5 mm
- 1.25 mm – 3.0 mm
- 1.5 mm – 1.5 mm
- 1.5 mm – 2.0 mm
- 1.5 mm – 2.5 mm
- 1.5 mm – 3.0 mm
- 2.0 mm – 2.0 mm
- 2.0 mm – 2.5 mm
- 2.0 mm – 3.0 mm
- 2.5 mm – 2.5 mm
- 2.5 mm – 3.0 mm
- 3.0 mm – 3.0 mm

- **Total: 558 specimens**

2. Experimental programme

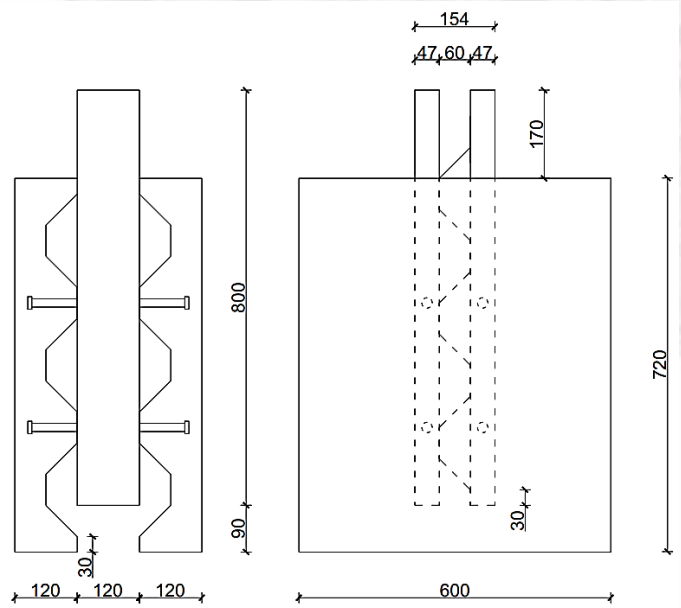






2. Experimental programme

- Idea and design of push-out specimens:
  - CFS 120x47x3 mm
  - Concrete slab 720x600x120 mm
  - Profiled steel sheeting 720x600x1.0 mm
  - Corrugated web 780x120x1.25 mm
  - Bolts M12 & M16, steel grade 8.8

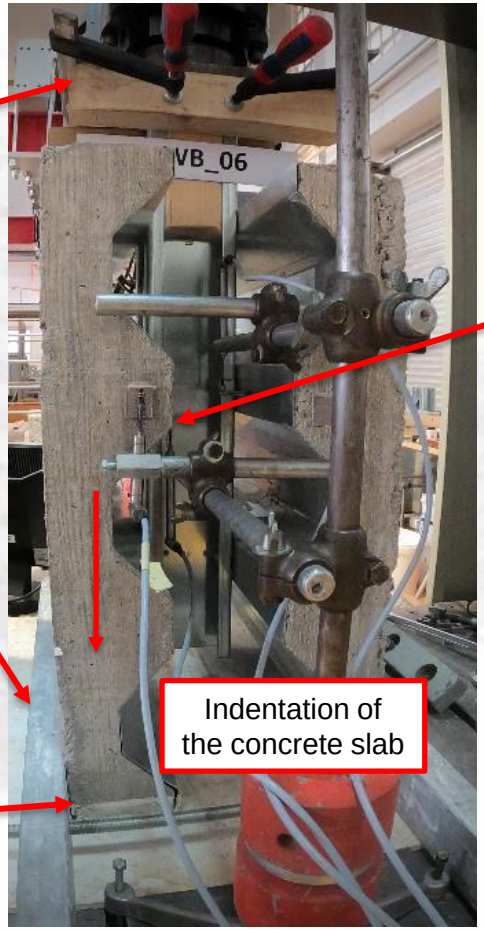


2. Experimental programme

- Fabrication process of bolted shear connection specimens

2. Experimental programme

- Implementation of testing of push-out samples
  - ✓ Loading program was considered based on Eurocode 4-Annex B



Stiffeners

LVDT sensors (8 pieces)

Gypsum base

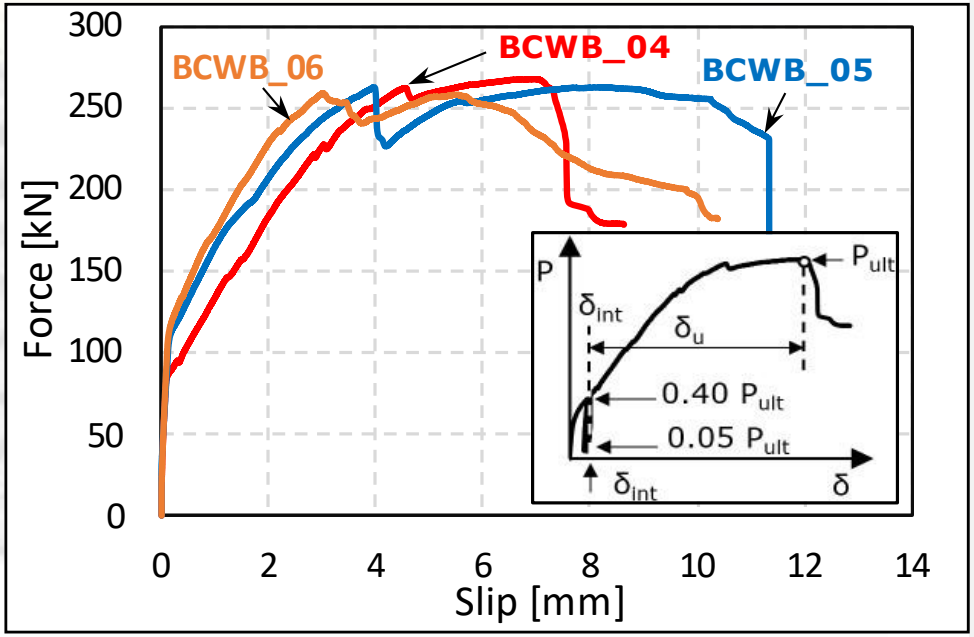
2. Experimental programme

- Implementation of testing of push-out samples

2. Experimental programme

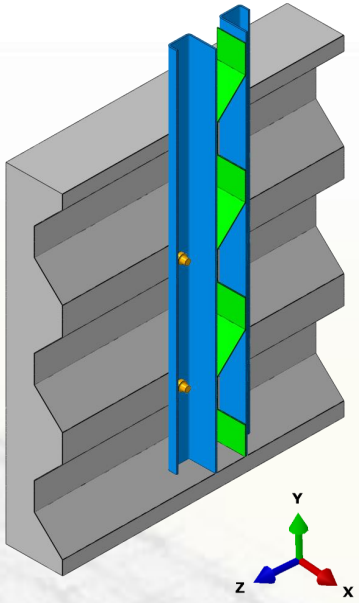
- Analysis and processing of results
  - The statistical evaluation of experimental results according to EN1990 - Annex D

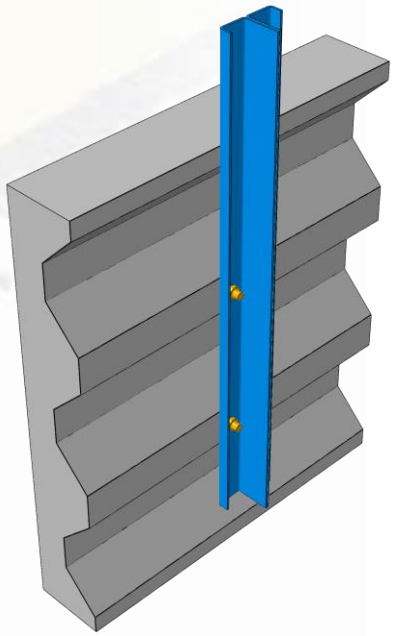
Specimen	Force [kN]	Slip [mm]	
	Ultimate P_{ult}	Initial δ_{int}	Failure δ_u
BCWB_04	267	0.59	6.82
BCWB_05	263	1.66	8.27
BCWB_06	259	1.09	5.67
Mean	263	-	6.92
Coefficient of variation [%]	1.52	-	18.82
Characteristic	250	-	2.53



3. Finite element (FE) model

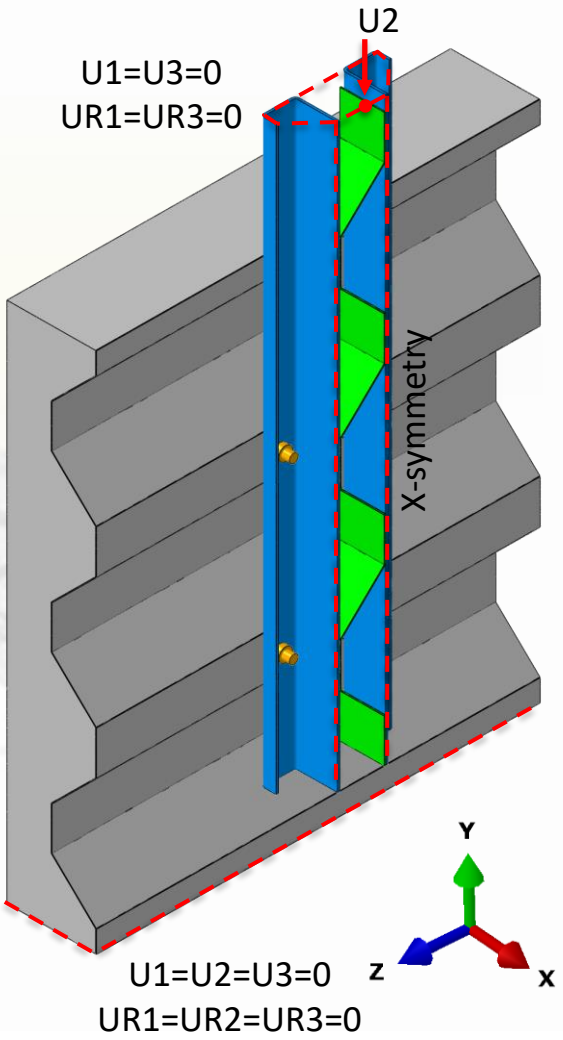
- Bolted shear connection (embedded nuts)
  - Increased stiffness
  - Easier mounting
- Direct shear force transmission
- Two systems configuration:
  - Built-up CFS girder
  - Back-to-back CFS girder





3. Finite element (FE) model

- Boundary Conditions
  - Symmetric boundary conditions
    - Plane orthogonal to the X-axis
  - Bottom concrete plane
    - All directions
  - CFS top
    - Horizontal directions
- Load
  - Uniform vertical displacement at the CFS top

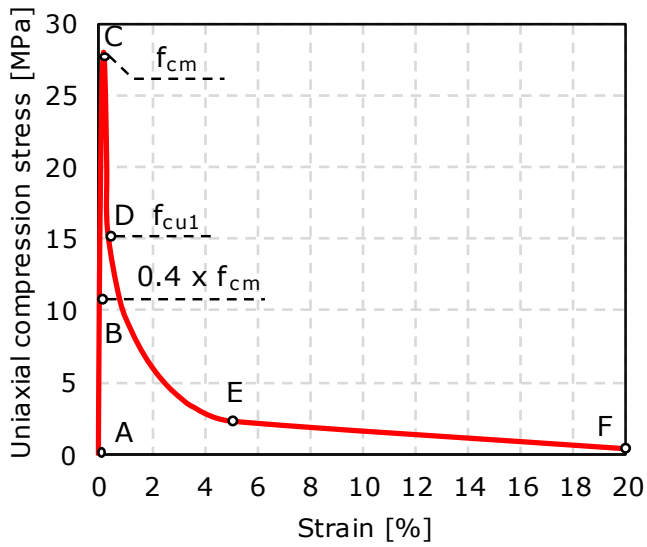


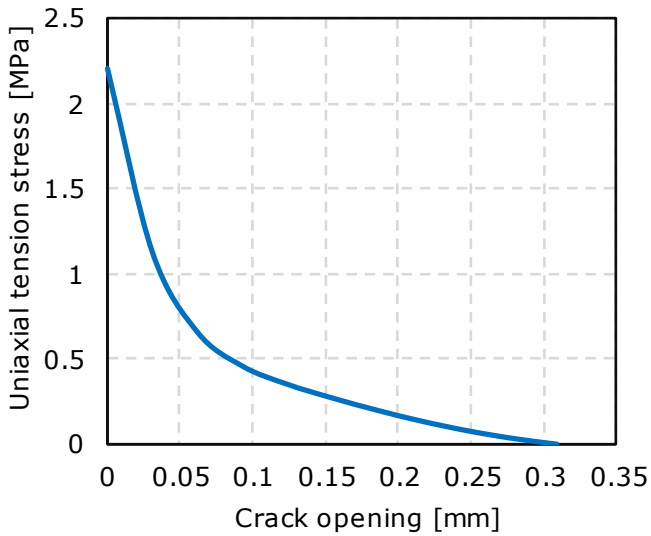
3. Finite element (FE) model

- Interaction
  - Normal behaviour
    - Hard contact
  - Tangential behaviour
    - Penalty friction (0.1, 0.3 and 0.5 frictional coefficient)
  - Spot welds
    - Bushing type connectors
    - Elasticity, Plasticity, Damage and Failure characteristics

3. Finite element (FE) model

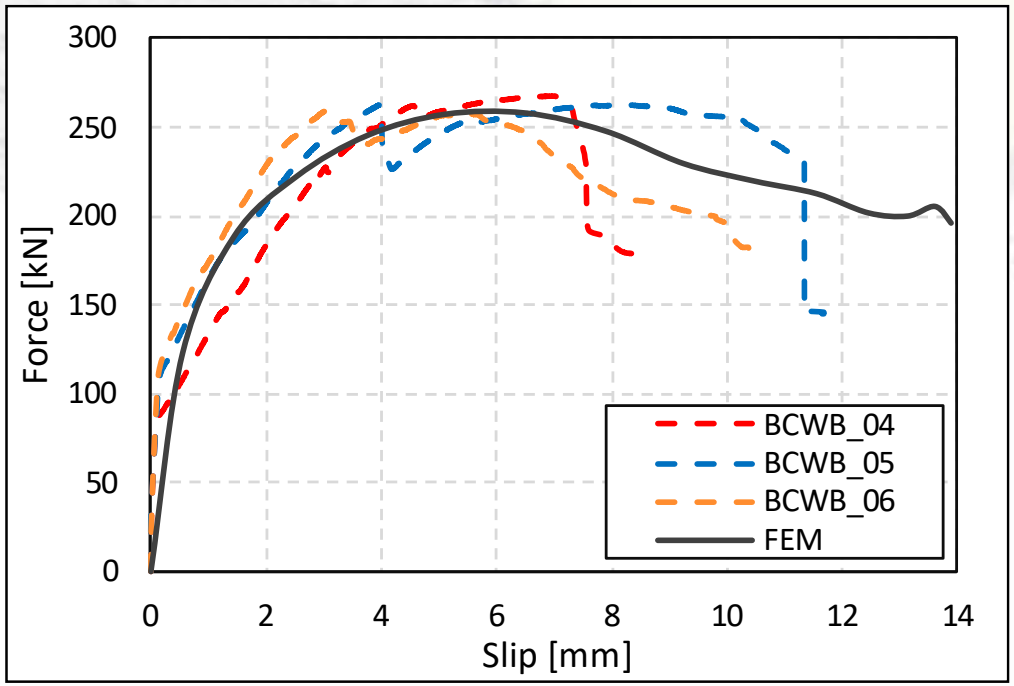
- Constitutive models
  - Steel
    - True stress-strain curve adopted based on experimental results
  - Concrete
    - Concrete Damage Plasticity (CDP) model
      - Compression failure
      - Tension failure





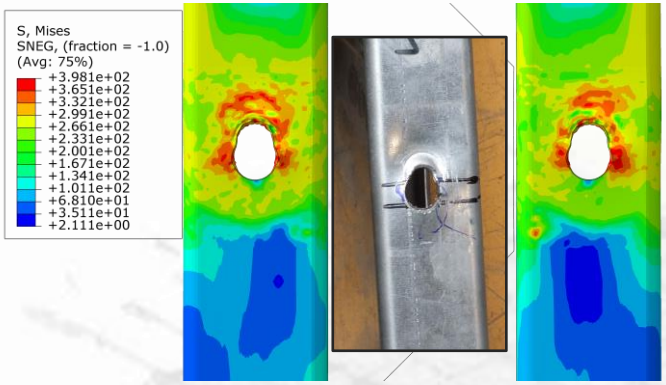
3. Finite element (FE) model

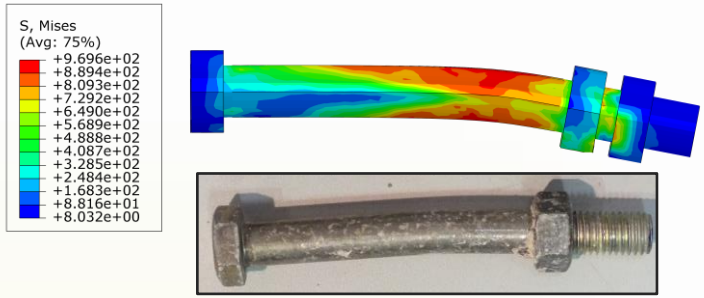
- Validation of numerical models
  - Good agreement between experimental and numerical results
  - Benchmark model for parametric analyses

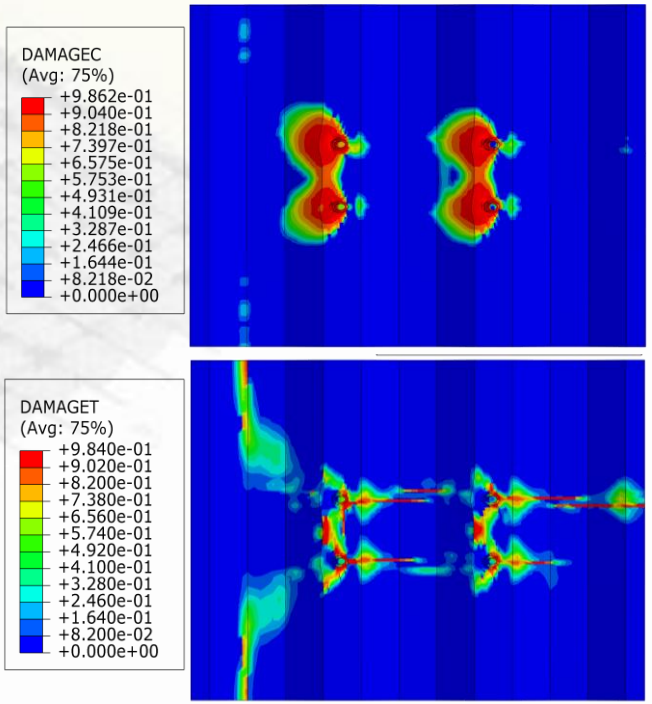


3. Finite element (FE) model

- Validation of numerical models







4. Parametric study

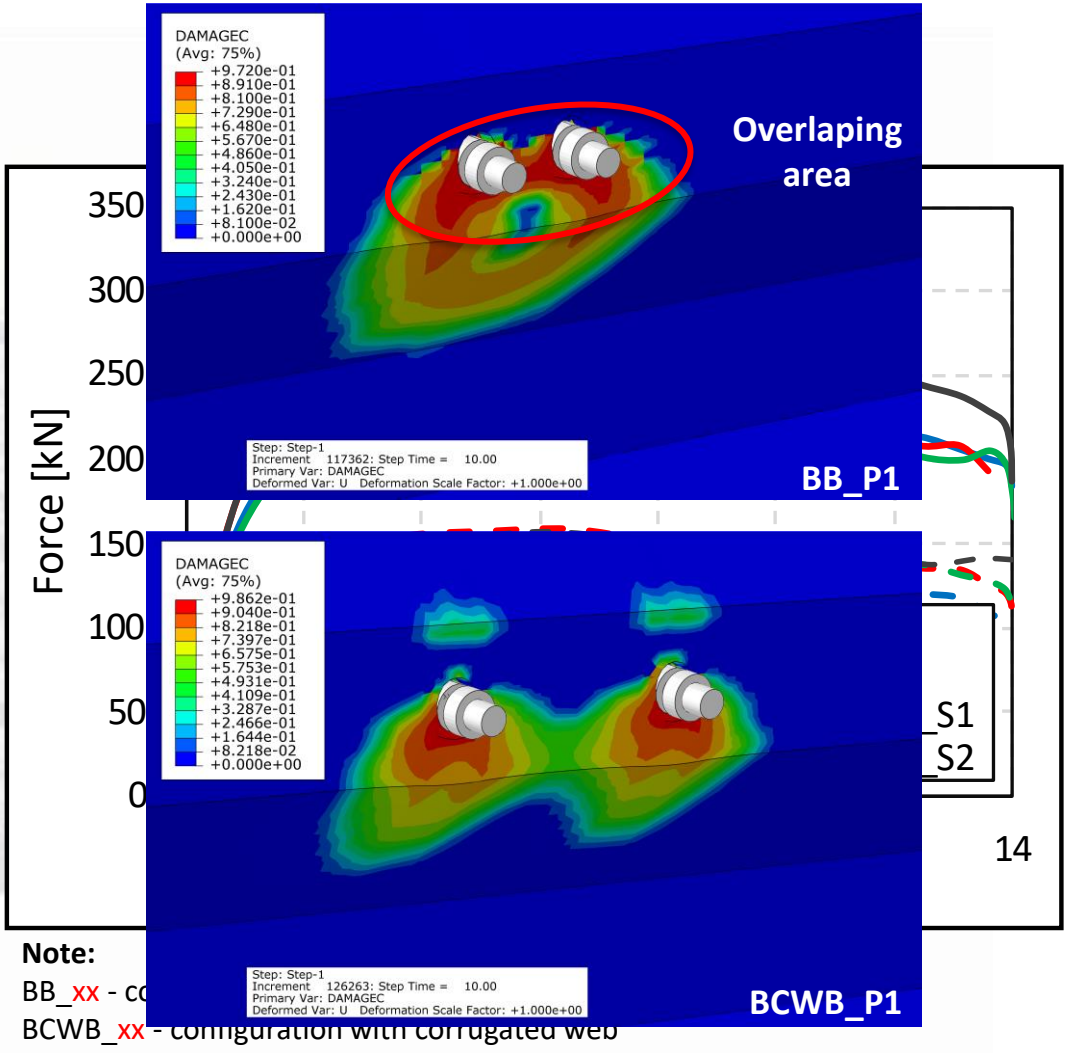
- Two configurations of CFS-concrete composite systems were analysed.

Model name	Bolt	Bolt position	Corrugated web
BB_P1	M12	Pairs	✕
BB_S1	M12	Staggered	✕
BB_P2	M16	Pairs	✕
BB_S2	M16	Staggered	✕
BCWB_P1	M12	Pairs	✓
BCWB_S1	M12	Staggered	✓
BCWB_P2	M16	Pairs	✓
BCWB_S2	M16	Staggered	✓

Note:
BB_xx - configuration without corrugated web
BCWB_xx - configuration with corrugated web

5. Results and discussion

- Several failure modes can occur together
- BB_Px models with two bolts per rib- Lower resistance = concrete failure (overlaping area)
- Models with one bolt per rib
  - Development of the full bearing capacity of shear connection.



Note:
BB_xx - co
BCWB_xx - configuration with corrugated web

6. Conclusions

- Using the FE model, it was confirmed that bolted shear connections in concrete CFS beams mostly exhibit multiple failure modes and that the interaction between these modes has an influence on the behaviour and resistance of the specimen.
- Placing two bolts per rib at a close transverse spacing (BB models), early concrete failure occurs due to the overlap of the failure areas. Therefore, the system configuration with a corrugated web (BCWB models) achieves a more favourable behaviour in terms of resistance and ductility when two bolts per rib are installed.
- Models with one bolt per rib placed in a staggered position allowed the development of the full bearing capacity of the shear connection, regardless of whether the system configuration including a corrugated web or not.

Thank you for attention!

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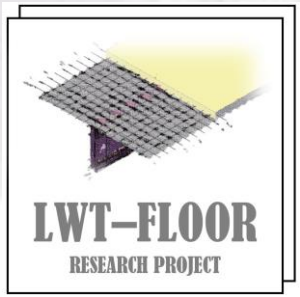

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