Finite Element Approach On The Behaviour Of The Demountable Shear Connection In Cold-Formed Steel-Concrete Composite Beams

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LWT–FLOOR
RESEARCH PROJECT

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Agenda

- Introduction
- Finite element (FE) approach
    - Finite element model
    - Characterisation of the constitutive models
    - Validation of finite element model
- Parametric analysis of shear connection
- Conclusion

1. Introduction

Composite steel-concrete structural systems

Cost Effectiveness	Efficiency & Speed	Steel	Concrete
Most cost-effective construction systems	Structural efficiency Accelerated construction speed	High tensile strength and ductility	High stiffness and compressive strength

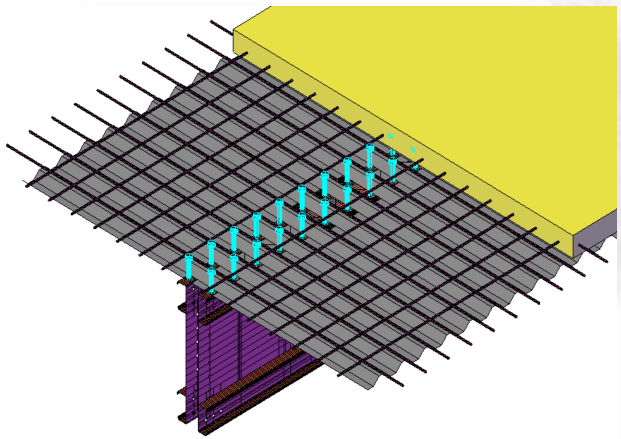
1. Introduction

Continuous Development

Composite steel-concrete systems remain a field of continuous development.

Material Efficiency

Growing tendency to reduce material usage while enhancing performance



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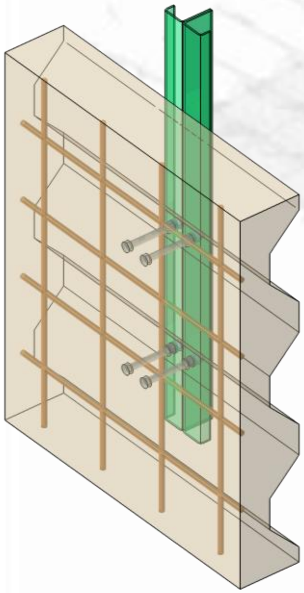
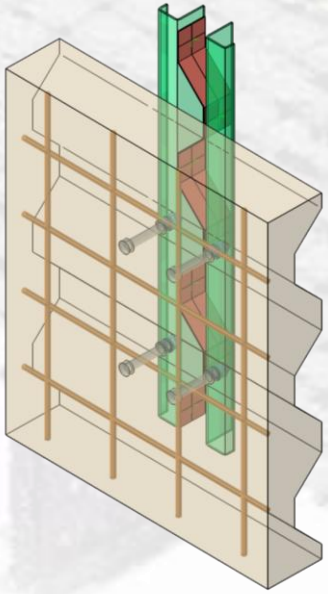
Composite built-up cold-formed steel girders (CFS) with a corrugated web and concrete slab

2. Finite element approach

- Abaqus Explicit solver (quasi – static analysis)
  - To address geometrical and material nonlinearities
- Two configurations:

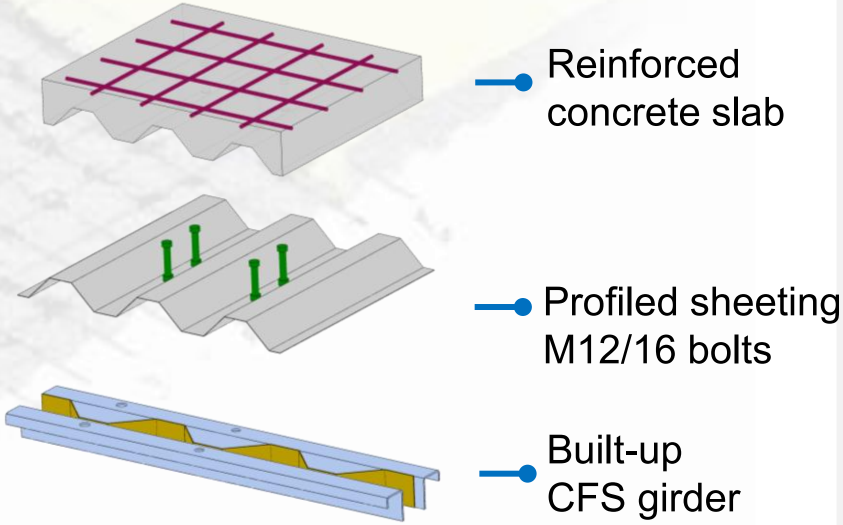


BB series



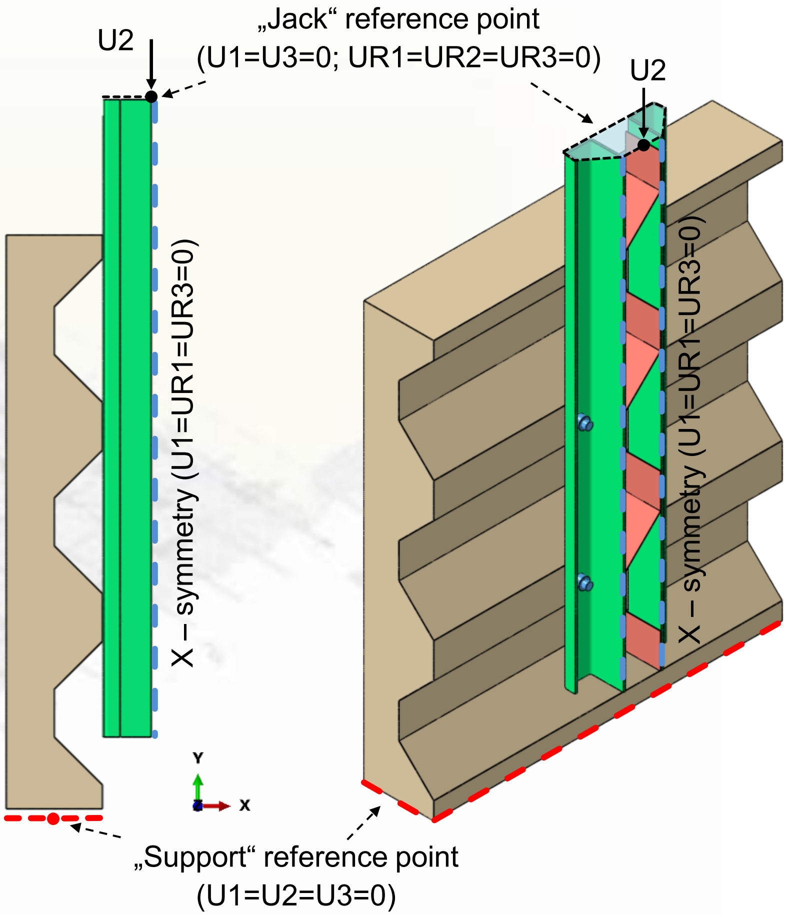
BCWB series

- Bolted shear connection (embedded nuts)
  - Increased stiffness
  - Easier mounting



2. Finite element approach

- Mesh elements:
  - C3D8R, S4R and T3D2
- Boundary Conditions
  - Symmetric boundary conditions
    - Plane orthogonal to the X-axis
  - Bottom concrete plane
    - All directions
  - CFS top
    - Horizontal directions and rotations
- Load
  - Uniform vertical displacement at the CFS top

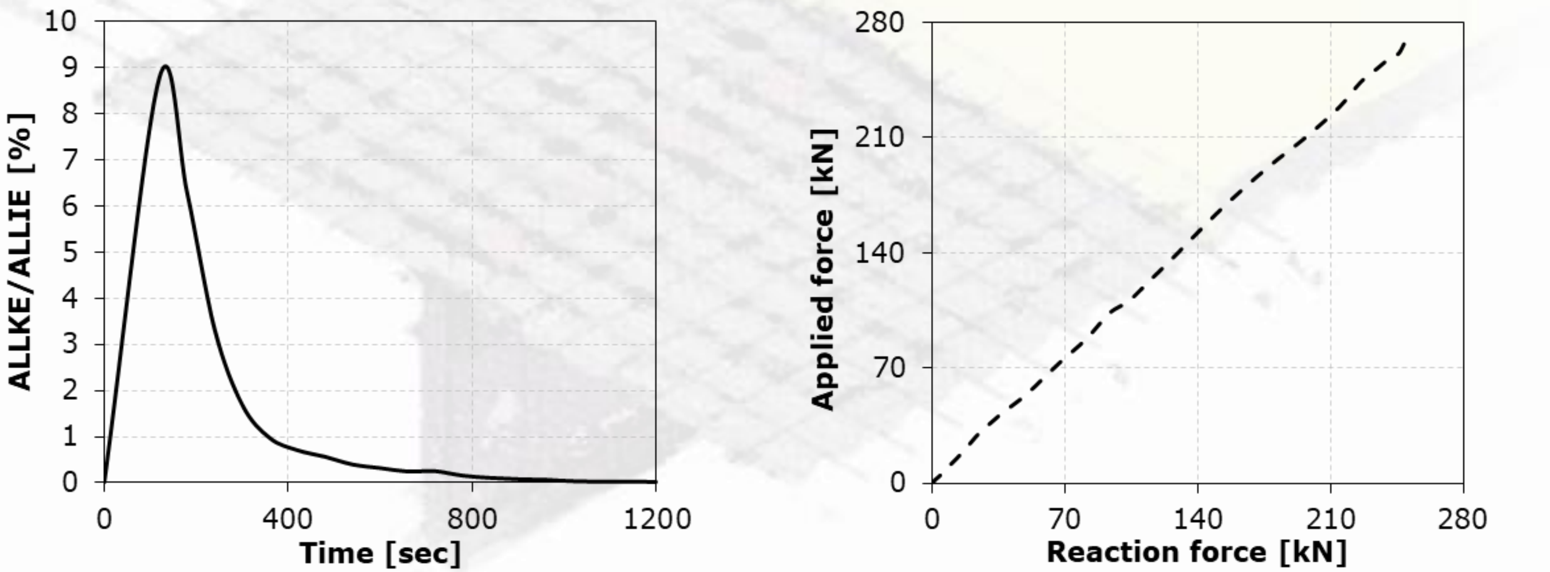


2. Finite element approach

- Interaction
  - Normal behaviour
    - Hard contact
  - Tangential behaviour
    - Penalty friction (0.1, 0.2, 0.3 and 0.7 frictional coefficient)
  - Embedment method
    - For reinforcement
  - Spot welds
    - Bushing type connectors
    - Elasticity, Plasticity, Damage and Failure characteristics

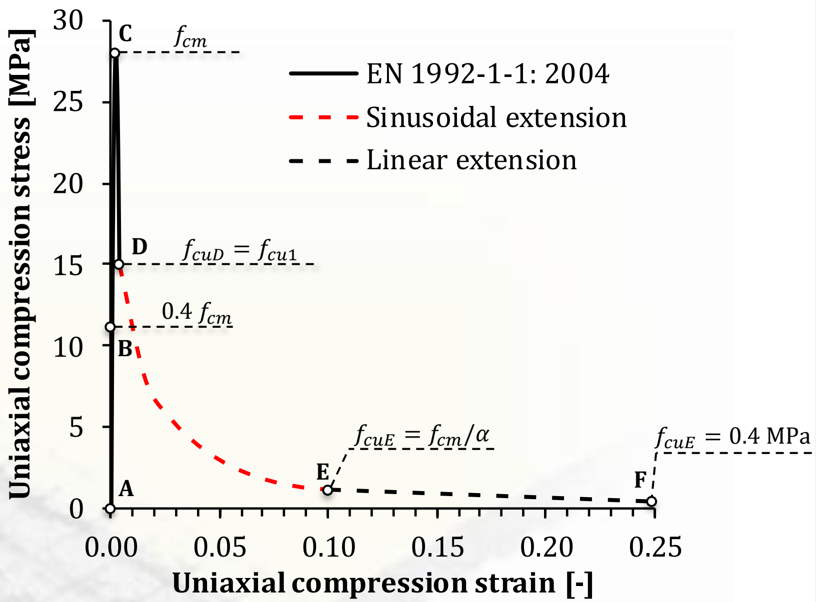
2. Finite element approach

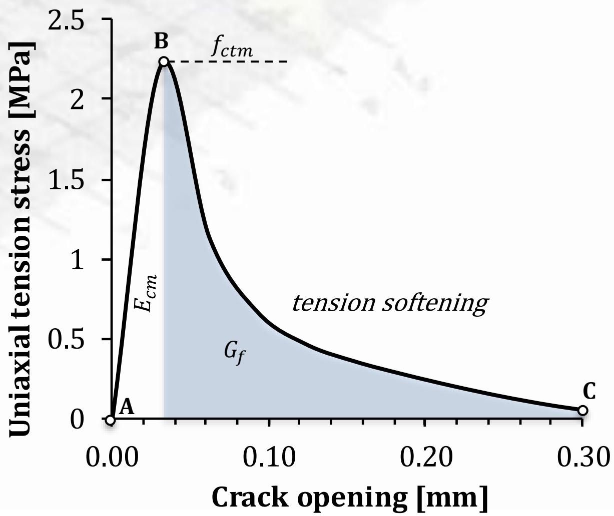
- Sensitivity analysis
  - Mass scaling, time increment 0.006 s
  - Kinetic energy < 10% of internal energy
  - Good correlation between input and reaction forces



2. Finite element approach

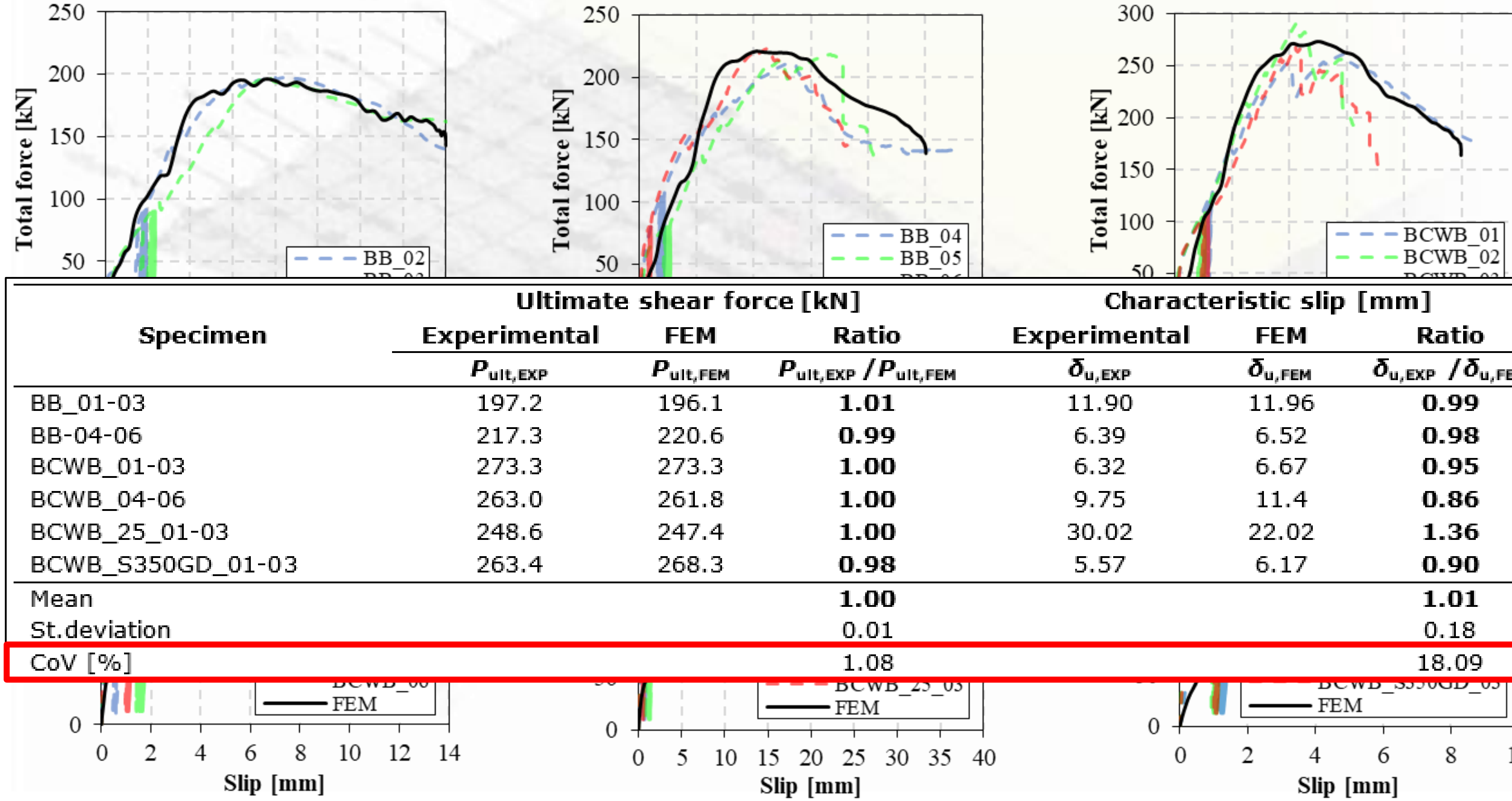
- Constitutive models
  - Steel
    - True stress-strain curve adopted based on experimental results
  - Concrete
    - Concrete Damage Plasticity (CDP) model
      - Compression failure
      - Tension failure





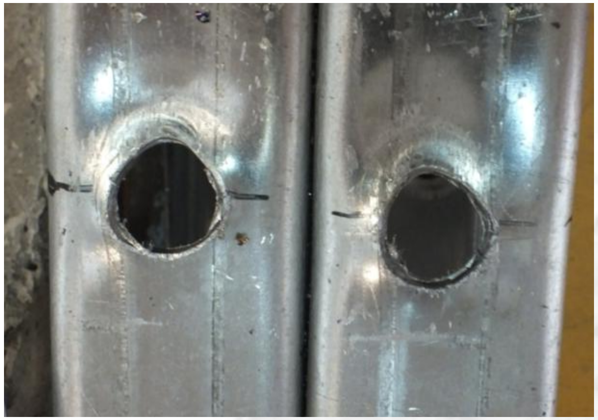
2. Finite element approach

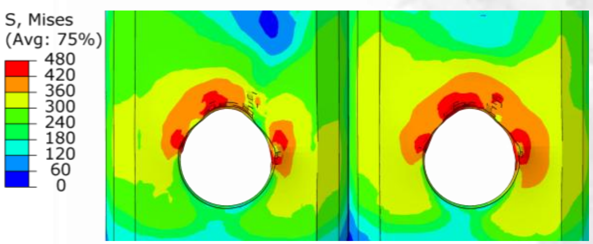
- Validation of numerical models
  - Good agreement between experimental and numerical simulation
  - Benchmark model for parametric analyses

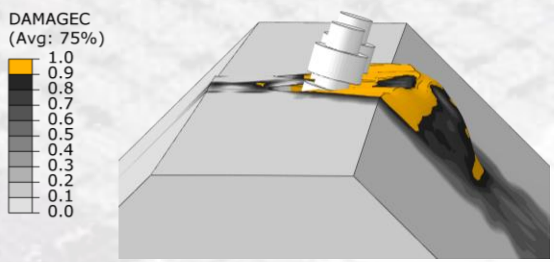


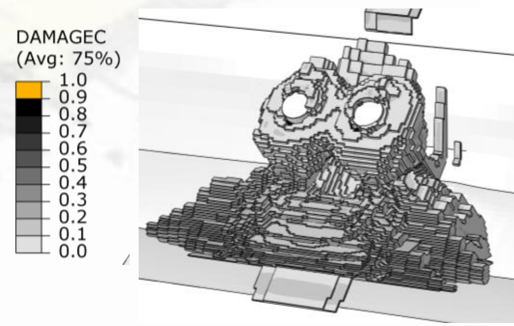
Specimen	Ultimate shear force [kN] Experimental $P_{ult,EXP}$	FEM $P_{ult,FEM}$	Ratio $P_{ult,EXP}/P_{ult,FEM}$	Characteristic slip [mm] Experimental $\delta_{u,EXP}$	FEM $\delta_{u,FEM}$	Ratio $\delta_{u,EXP}/\delta_{u,FEM}$
BB_01-03	197.2	196.1	**1.01**	11.90	11.96	**0.99**
BB-04-06	217.3	220.6	**0.99**	6.39	6.52	**0.98**
BCWB_01-03	273.3	273.3	**1.00**	6.32	6.67	**0.95**
BCWB_04-06	263.0	261.8	**1.00**	9.75	11.4	**0.86**
BCWB_25_01-03	248.6	247.4	**1.00**	30.02	22.02	**1.36**
BCWB_S350GD_01-03	263.4	268.3	**0.98**	5.57	6.17	**0.90**
Mean			**1.00**			**1.01**
St.deviation			0.01			0.18
CoV [%]			1.08			18.09

2. Finite element approach









Validation of failure mechanism between experimental and FE analysis results

- Objective: Investigate factors affecting resistance and ductility of bolted shear connections

- Main parameters:
  - CFS section thickness
  - Bolt diameter
  - Concrete strength
  - Bolt embedment depth

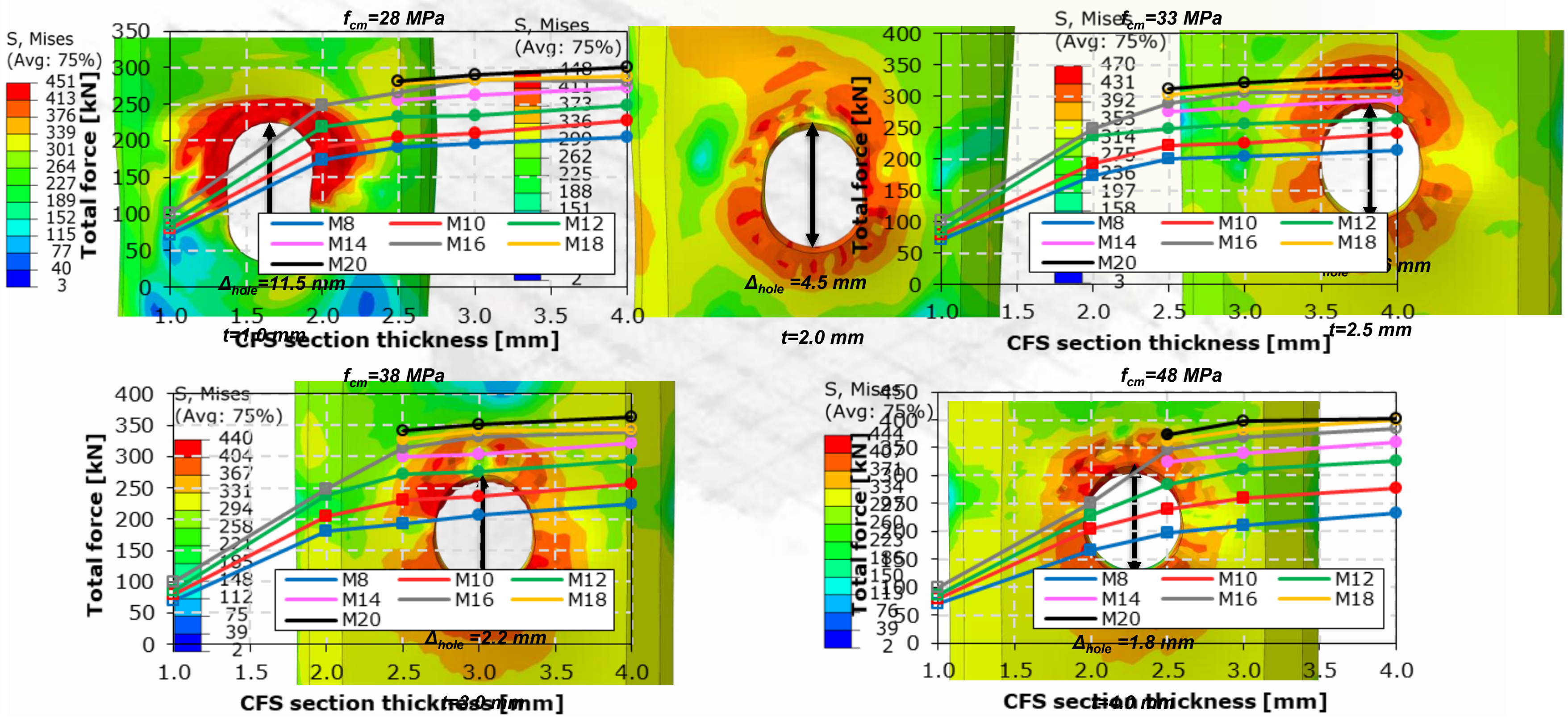
- Scope: 228 numerical models analysed

t [mm]	d [mm]	f_{cm} [MPa]	h_{sc} [mm]
1, 2, 2.5, 3, 4	**8, 10, 12, 14, 16, 18, 20**	**28, 33, 38, 48**	95
3	**12, 14, 16,18**	**28, 33, 38, 48**	**75-105**

Note: **Bold** values represent the parameters that are varied throughout the parametric study

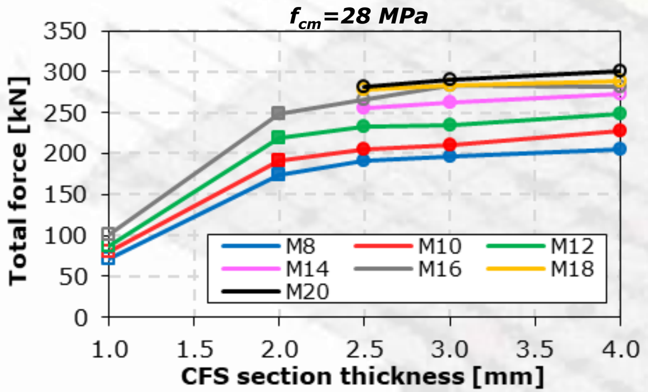
3. Parametric analysis – shear conn.

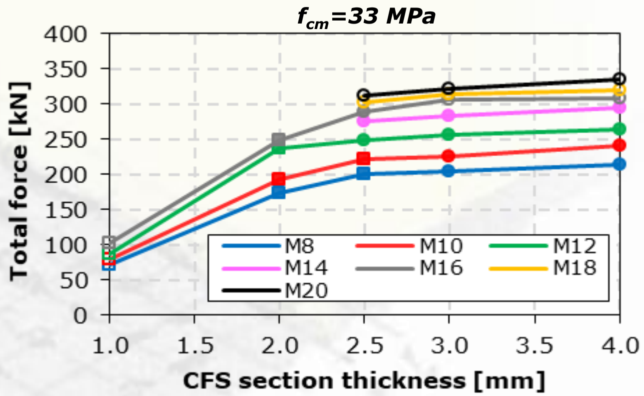
- **CFS thickness:**
  - ↑ thickness → ↑ shear capacity, but effect reduces beyond 3 mm
  - Thin sections → brittle, bearing failure dominant
  - Medium thickness (2 mm) → ductile, good stress redistribution
  - Thick sections (≥ 2.5 mm) → concrete failure dominates, slip decreases

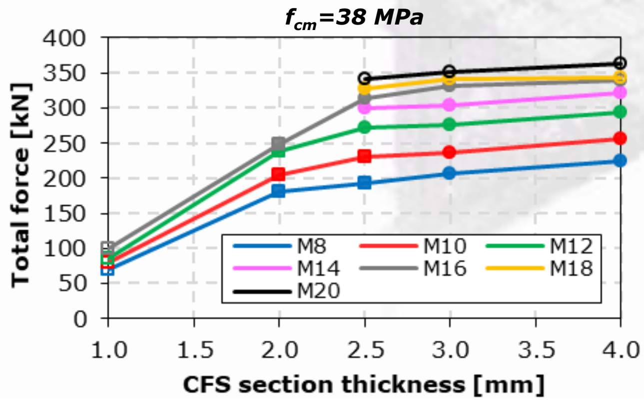


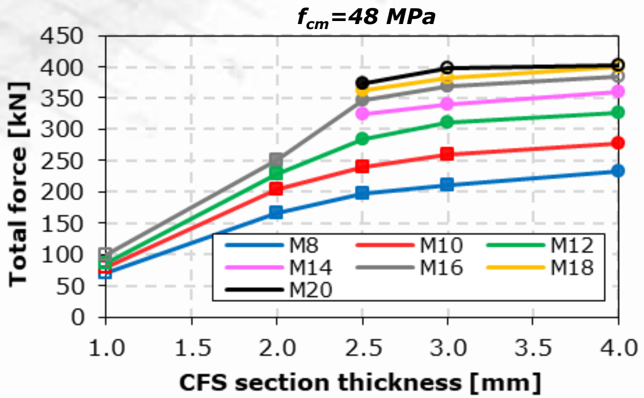
3. Parametric analysis – shear conn.

- **Bolt diameter:**
  - Larger bolts → ↑ shear strength, ↓ ductility
- **Concrete strength:**
  - Limited effect on small diameter bolts
  - ↑ slip capacity for M14 and larger diameter bolts





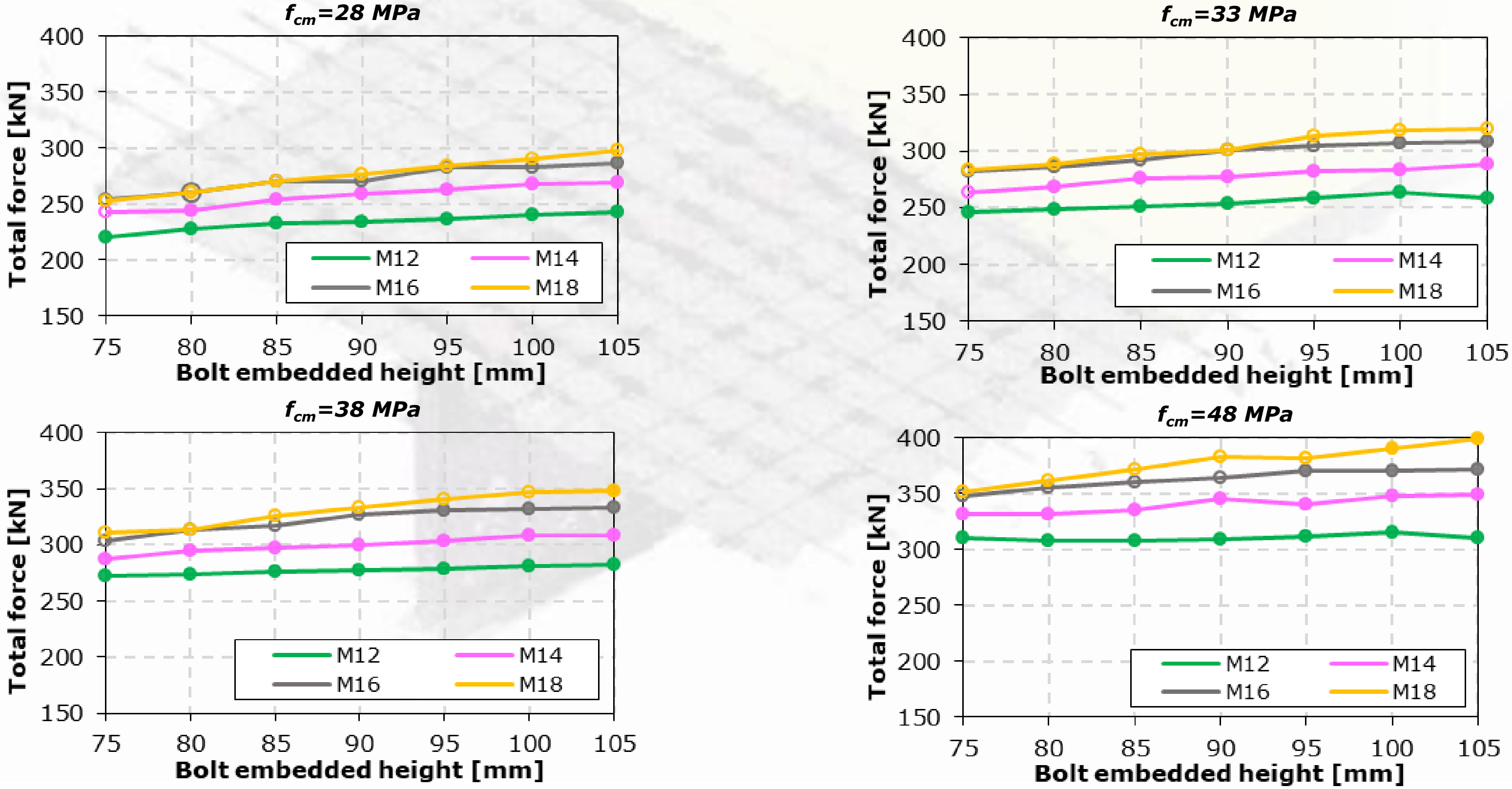




3. Parametric analysis – shear conn.

- **General trend:**
  - ↑ embedded height → ↑ shear resistance → more pronounced for larger bolts

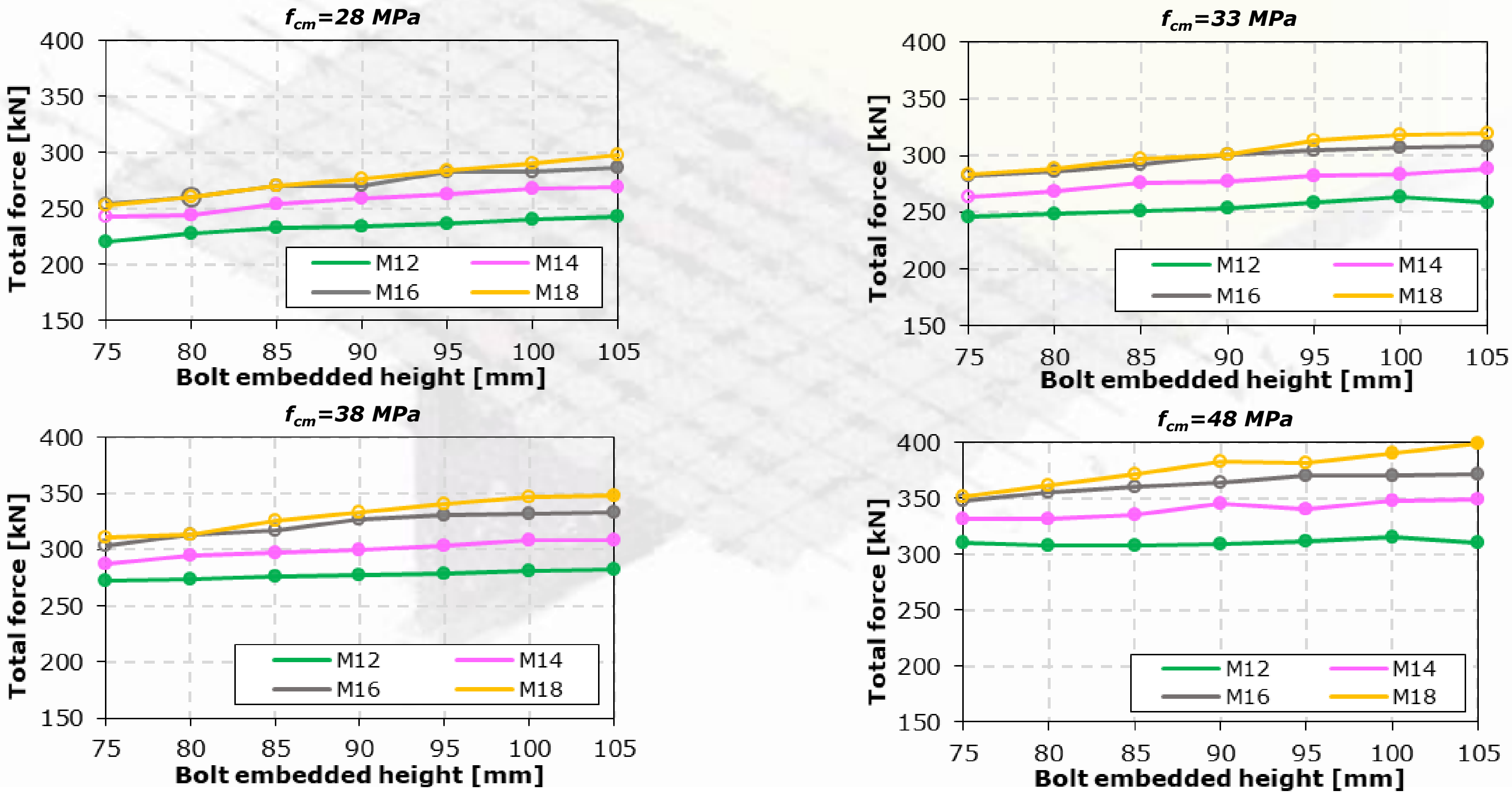
- **M12 and M14 bolts:**
  - Low height (≤ 85 mm) → concrete pry-out dominant
  - High height (≥ 90 mm) → interaction of pry-out and bolt bending



3. Parametric analysis – shear conn.

- **Larger bolts at same height:**
  - Reduced slip capacity
  - Less bolt deformation → lower interaction with concrete
  - M18 example: minimal deformation, lowest ductility

- **Higher embedded heights:** ↑ slip capacity due to bolt bending



4. Conclusion

- The FE analysis has revealed the complex behaviour of the shear connection, highlighting the interaction of several failure modes that influence the ultimate resistance of the connection.

- Selecting the appropriate section thickness, bolt diameter and concrete strength is crucial to achieve an optimal balance between shear resistance and ductility in bolted shear connections.

- The influence of embedded bolt height should be included in the analytical methods to determine the shear resistance and ductility of bolted connections accurately.

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