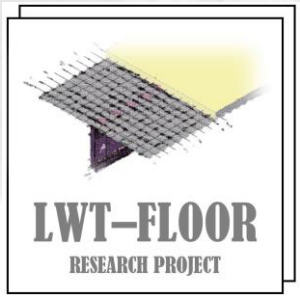
Design and fabrication of material, spot welded and push-out specimens

Ivan Lukačević, **Ivan Ćurković**, Andrea Rajić, Vlaho Žuvelek



University of Zagreb/Faculty of Civil Engineering
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1. Planned programme

- Complete experimental program will consist of the following tests: A) The first step includes tensile and compression tests which will be performed on materials from each set of elements (e.g. web sheeting, slab sheeting, lipped channel sections, shear panel, rebar, and concrete) which will be procured from the same fabricator. 4 thicknesses of trapezoidal sheet x 2 (flat + corner) x 5 tests = 40 specimens, 4 thicknesses for lipped channel x 4 (web, flange, lip, corner) x 5 tests = 80 specimens, 2 thicknesses for flat sheet x 5 tests = 10 specimens, 2 diameters of reinforcing steel x 5 tests = 10 specimens, 2 diameters of bolted shear studs x 5 tests = 10 specimens, 2 concrete types (standard and lightweight) x 5 tests = 10 specimens. A TOTAL of 160 specimens for tensile and compression tests results.

1. Planned programme

- Complete experimental program will consist of the following tests: B) The second step is the sheeting-to-sheeting connections (spot-weld) and sheeting-to-profile connections which will be tested for all sizes and arrangements in which they are applied in the beams' constructions. Spot-Weld connection technologies will be examined and evaluated. The following types of connections will be tested: 4 thicknesses for trapezoidal sheets i.e. 0.8 mm, 1.0 mm, 1.2 mm, 1.5 mm and 3 thicknesses for lipped channel sections for flanges, i.e. 1.5 mm, 2 mm, 2.5 mm and 3 will be investigated. 2 thicknesses for shear panel will be used, i.e. 1 mm and 1.5 mm. Spot-weld fasteners: corrugated sheet-to-corrugated sheet (1 sheet-to-1 sheet), 4 thicknesses for trapezoidal sheets = 10 combination x 5 tests = 50 specimens.

1. Planned programme

- Complete experimental program will consist of the following tests: Spot-weld fasteners: shear plate-to-corrugated sheet (1 sheet-to-1 sheet), 4 thicknesses for trapezoidal sheets and 2 for shear panel = 8 combination x 5 tests = 40 specimens. Shear plate + corrugated sheet-to-flange (2 sheet-to-1 sheet), 8 thicknesses combinations for trapezoidal sheets + shear plate and 4 for shear panel = 32 combination x 5 tests = 160 specimens. Flange-to-corrugated webs (1 sheet-to-1 sheet) 4 thicknesses for flanges and 4 for corrugated webs = 16 combination x 5 tests = 80 specimens. A TOTAL of 330 test specimens for welded connections. It should be mentioned that for each type of weld 2 specimen/combination will be used to calibrate the welding technologies.

1. Planned programme

- Complete experimental program will consist of the following tests: C) The third step is the selection of the optimal shear connection type. In this step, the preparation of experimental tests will start with the selection of shear connection type. Shear connections will be tested using push-out procedure for all types of shear connections and arrangements of shear studs. The shear connection types will be examined and evaluated. A TOTAL of 12 specimens for shear connection results, i.e. six with composite dowel rib connectors and six with demountable headed shear studs connectors.

1. Planned programme

- Complete experimental program will consist of the following tests: D) The fourth step is the selection of full-scale steel girder specimens without and with additional web openings for the integration of installations to be investigated (parallel flange horizontal beam of 6 m span). A TOTAL of 4 full-scale beam specimens results, i.e. two without web openings and two with web openings.

1. Planned programme

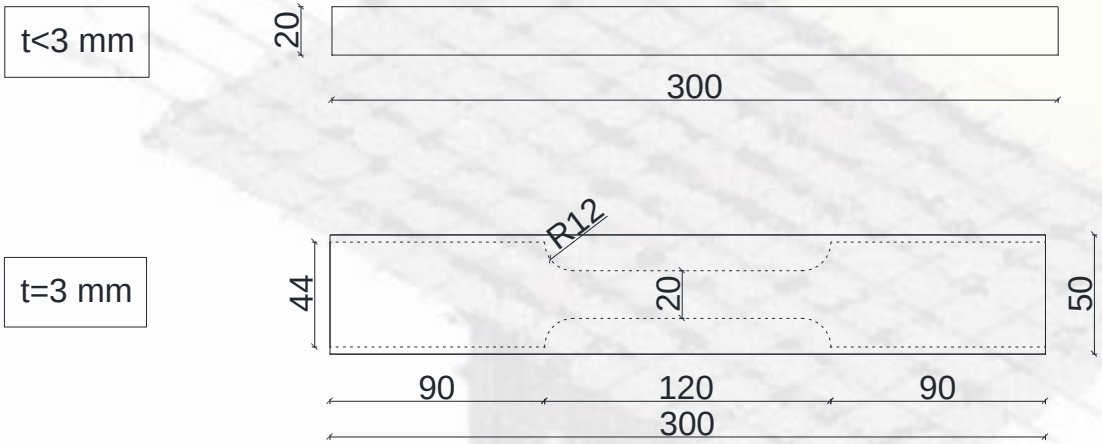
- Complete experimental program will consist of the following tests: E) The fifth step is the selection of full-scale composite floor system specimens with and without additional web openings and optimal configurations of cold-formed sheet thicknesses and shear connection from previous results to be investigated (parallel flange horizontal beam of 6 m span). A TOTAL of 4 full-scale composite specimens results, i.e. two without web openings and two with web openings.

2. Tensile and compresion mat. tests

- Zwick&Roell Z600

2. Tensile and compresion mat. tests

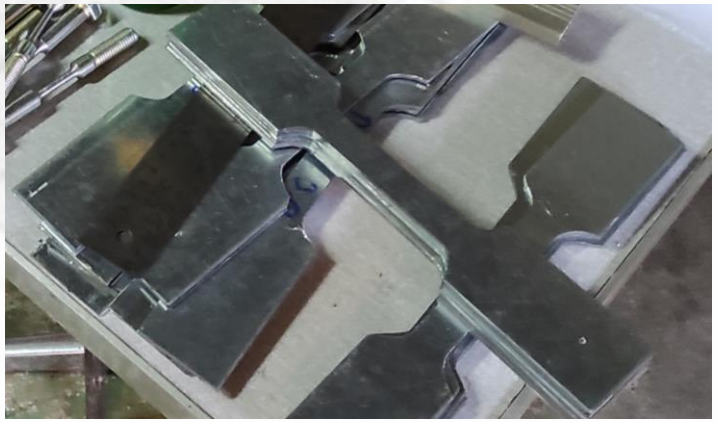
- **Steel sheets**
- HRN EN ISO 6892-1:2019 Metallic materials -- Tensile testing -- Part 1: Method of test at room temperature (ISO 6892-1:2019; EN ISO 6892-1:2019)



- Thicknesses 0,8; 1,0; 1,25; 1,5; 2,0; 2,5; 3,0 mm
- 135 specimens

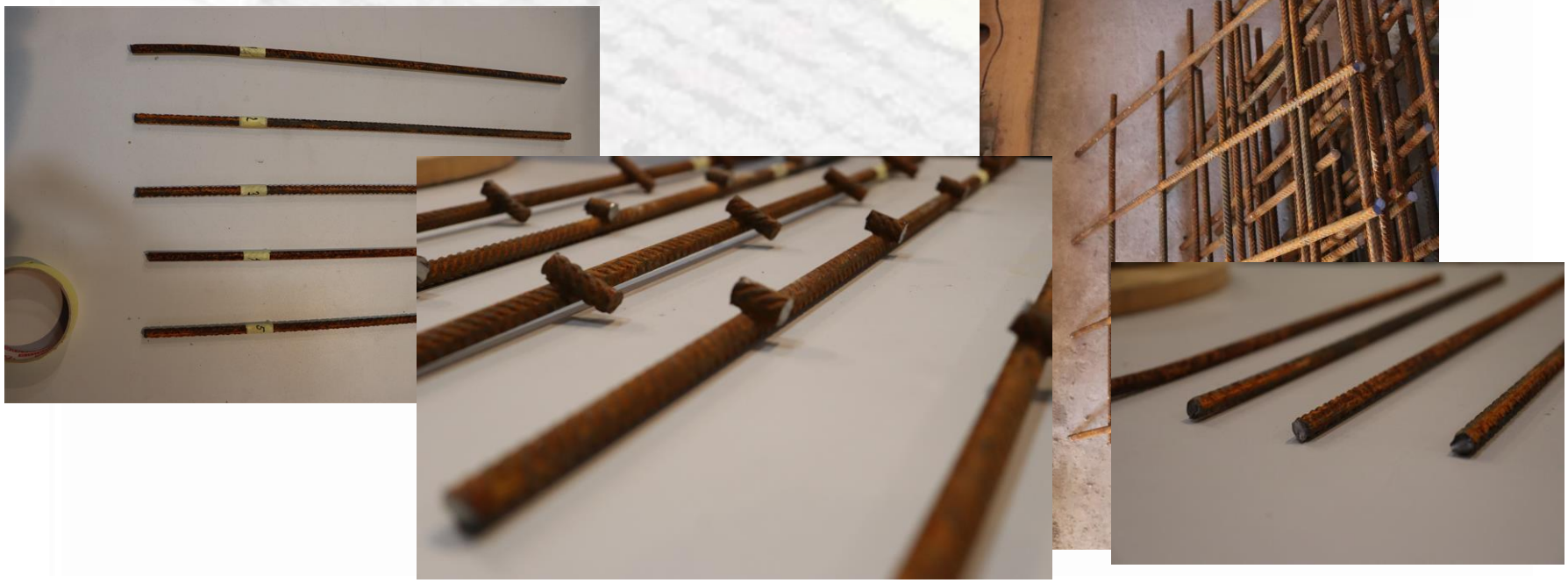
2. Tensile and compresion mat. tests

- **Steel sheets**
- Cutting of steel sheets from C profiles



2. Tensile and compresion mat. tests

- **Steel reinforcement**
- HRN EN ISO 6892-1:2019 Metallic materials -- Tensile testing -- Part 1: Method of test at room temperature (ISO 6892-1:2019; EN ISO 6892-1:2019)
- Diameters 8 mm and 10 mm
- 10 specimens - without machining



2. Tensile and compresion mat. tests

- **Bolts**
- HRN EN ISO 6892-1:2019 Metallic materials -- Tensile testing -- Part 1: Method of test at room temperature (ISO 6892-1:2019; EN ISO 6892-1:2019)
- Diameters 12 mm and 16 mm
- 10 specimens - machining

2. Tensile and compresion mat. tests

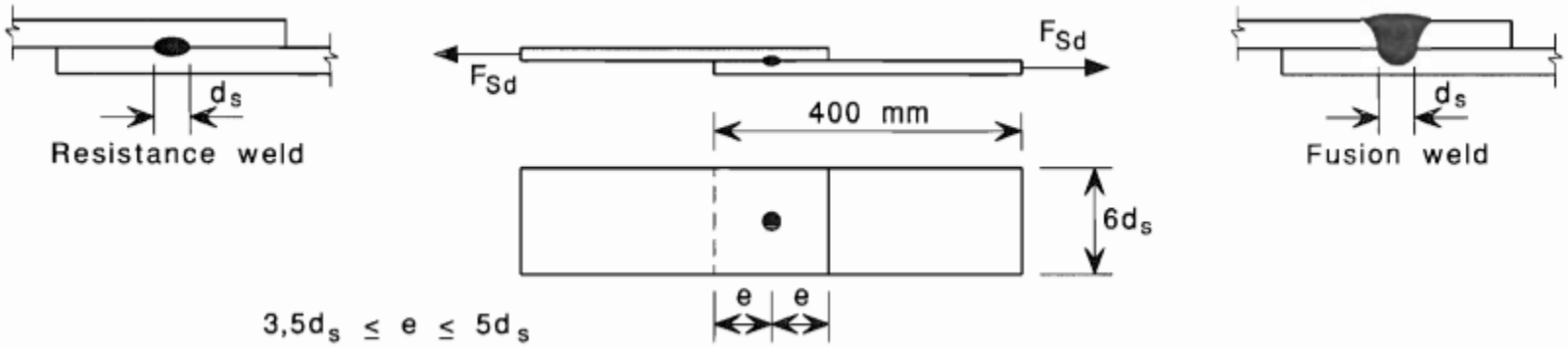
- **Concrete**
- HRN EN 12390-3:2019 Testing hardened concrete -- Part 3: Compressive strength of test specimens (EN 12390-3:2019)
- Cylinders with a diameter of 150 mm
- 25 specimens (10 LC, 15 NC)
- Compressive strength and modulus of elasticity tests

3. Tensile tests of spot welds

- Zwick&Roell Z600

3. Tensile tests of spot welds

- HRN EN 1993-1-3:2014 Eurocode 3: Design of steel structures -- Part 1-3: General rules -- Supplementary rules for cold-formed members and sheeting (EN 1993-1-3:2006+AC:2009)



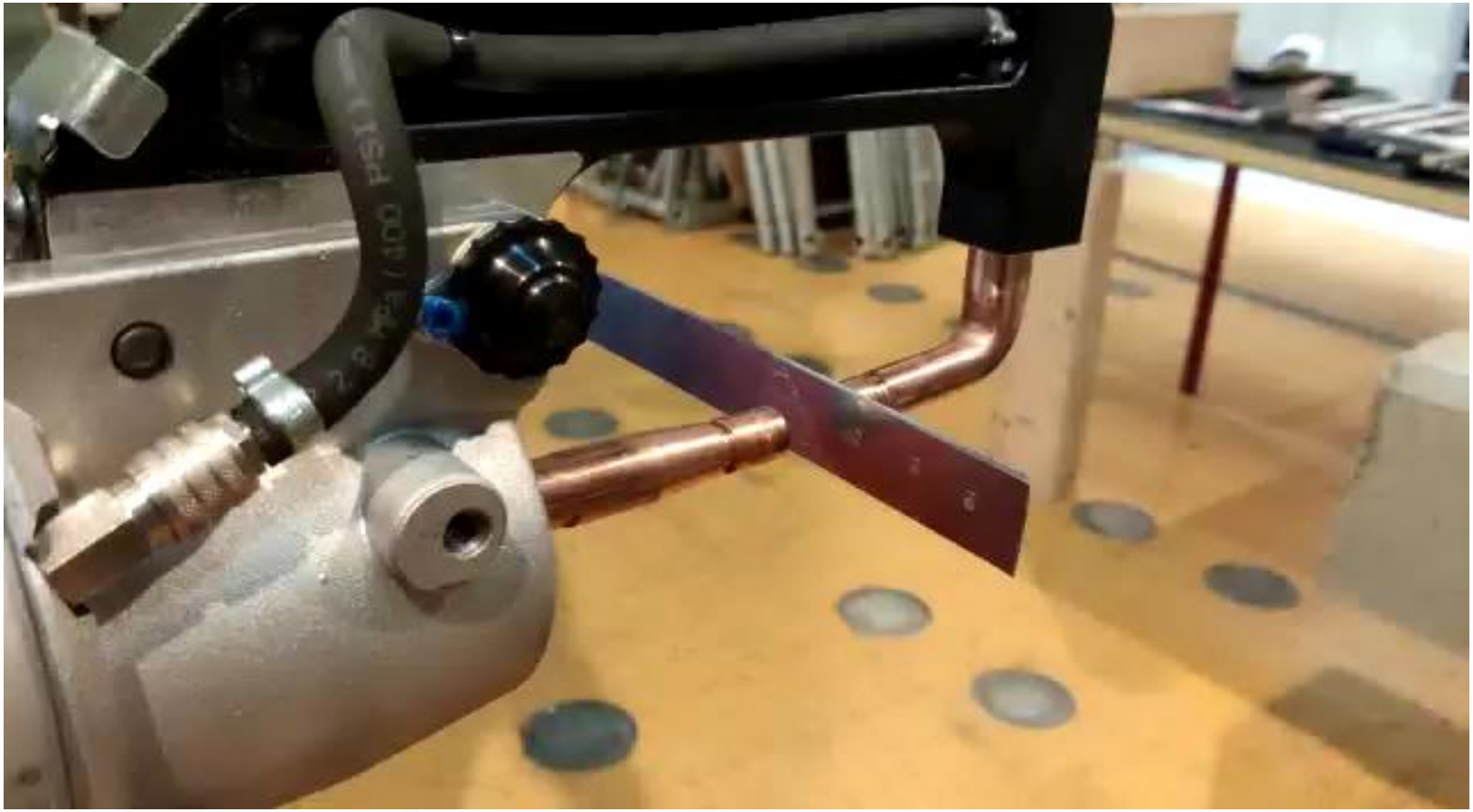
- Thicknesses 0,8; 1,0; 1,25; 1,5; 2,0; 2,5; 3,0 mm
- 570 specimens

3. Tensile tests of spot welds

- Cutting of steel sheets

3. Tensile tests of spot welds

- Demonstration of welding process with spot welding machine



3. Tensile tests of spot welds

- Produced specimens

3. Tensile tests of spot welds

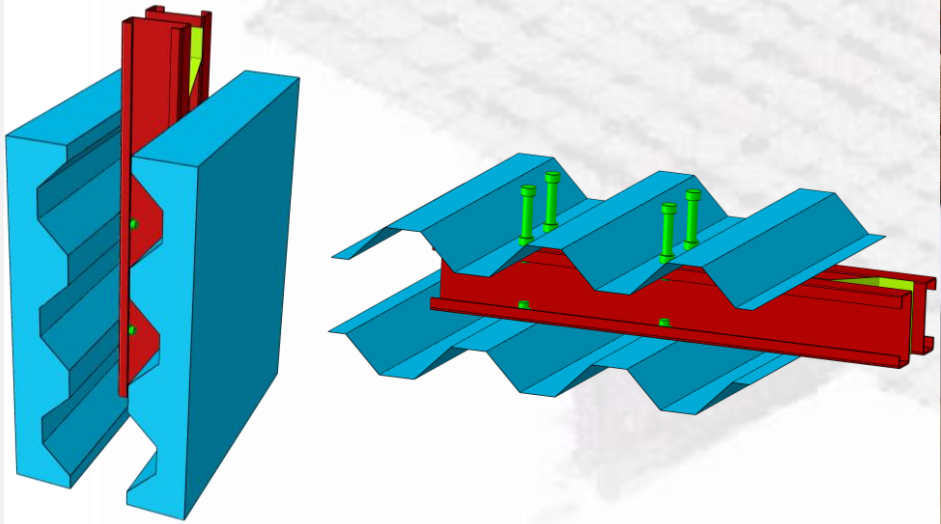
3. Tensile tests of spot welds

4. Push out tests

- Zwick&Roell Z600

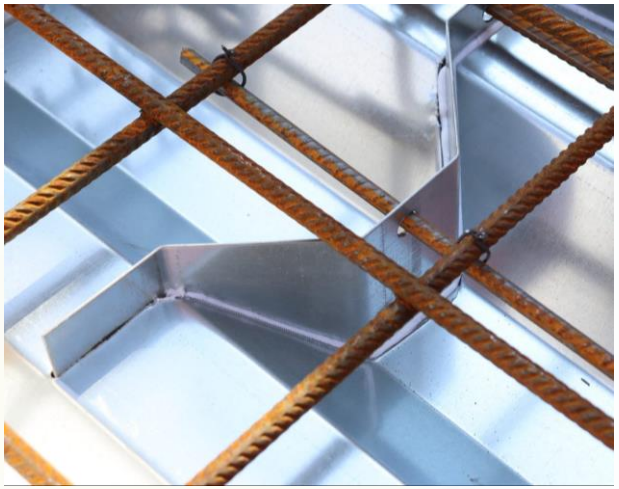
4.1 Shear connection types

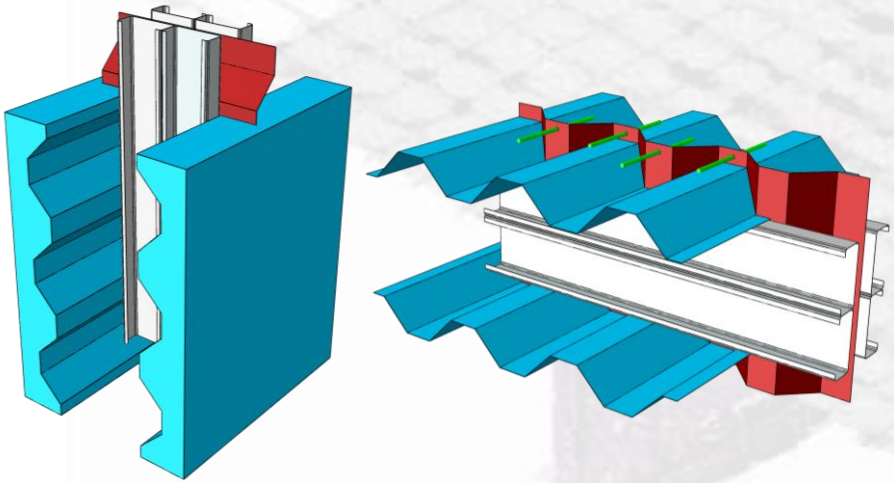
- **Bolted shear connection (embedded nuts)**
  - Embeded nuts
    - Increased stiffness
    - Easier mounting
  - Direct shear force transmission

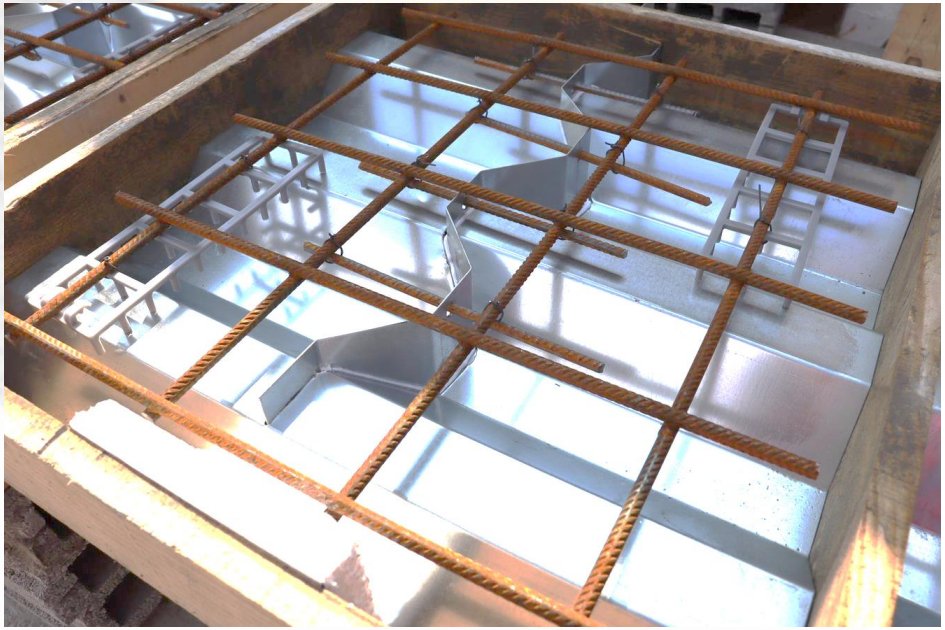


4.1 Shear connection types

- **Composite dowel rib connection**
  - Innovative shear connection
  - Indirect shear force transmission

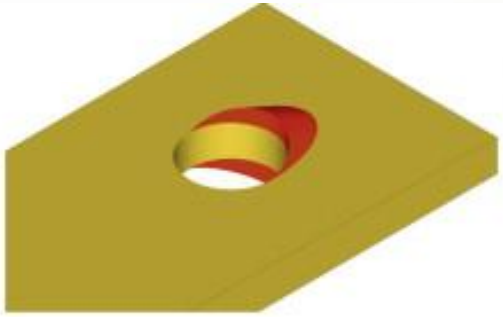




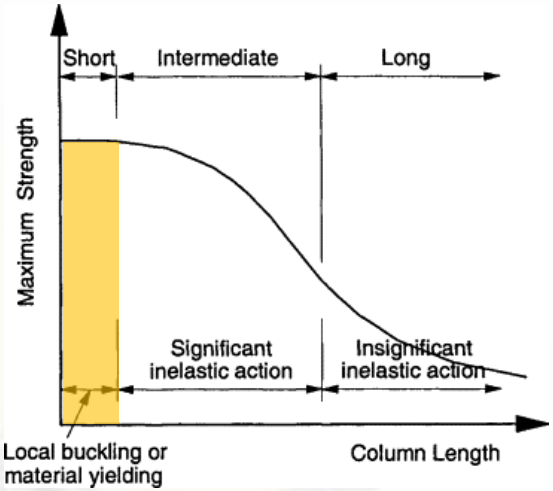


4.2 Specimen design

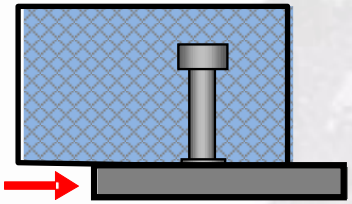
- **Bolted shear connection (embedded nuts)**
  - 4 failure modes were considered



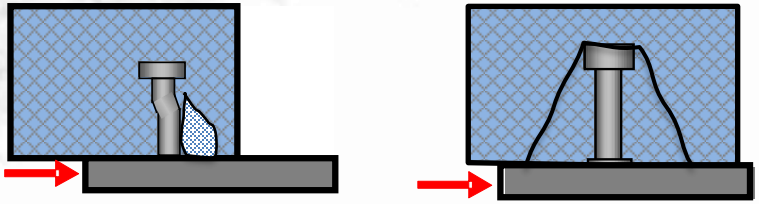
Hole bearing resistance (C profile)



Cross-section resistance



Shear connector failure /
Bolt shear failure



Concrete failure

4.2 Specimen design

- **Bolted shear connection (embedded nuts)**
  - 4 failure modes were considered

Characteristic values									
Name of specimen	Bearing resistance per hole [kN]	Σ Bearing resistance [kN]	Resistance of C profiles [kN]	Concrete resistance per one bolt [kN]	Σ Concrete resistance [kN]	Shear resistance of one headed stud [kN]	Σ Shear resistance of headed studs [kN]	k_t × Σ Concrete resistance [kN]	k_t × Σ Shear resistance of headed studs [kN]
BB_01-03	25,4	203	363	32,3	259	54,4	435	150	252
BB_03-06	34,4	275	363	57,5	460	99,9	799	267	464
BCWB_01-03	34,4	275	363	57,5	460	100	799	267	464
BCWB_03-06	25,4	203	363	32,3	259	54	435	150	252
BCWB_S350GD_01-03	44,4	355	470	57,5	460	99,9	799	267	464
BCWB_25_01-03	21,1	169	287	32,3	259	54,4	435	150	252

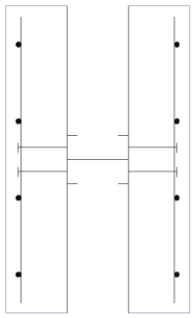
Properities of push-out specimens										
Name of specimen	f_y [N/mm^2]	f_u [N/mm^2]	A_{eff} [mm^2]	t [mm]	E_{cm} [Mpa]	f_{ck} [N/mm^2]	α	d_{bolt} [mm]	$f_{u,bolt}$ [N/mm^2]	d_{bc} [mm]
BB_01-03	270	325	672	3	30000	20	1	10,4	800	12
BB_03-06	270	325	672	3	30000	20	1	14,1	800	16
BCWB_01-03	270	325	672	3	30000	20	1	14,1	800	16
BCWB_03-06	270	325	672	3	30000	20	1	10,4	800	12
BCWB_S350GD_01-03	350	420	672	3	30000	20	1	14,1	800	16
BCWB_25_01-03	270	325	532	2,5	30000	20	1	10,4	800	12

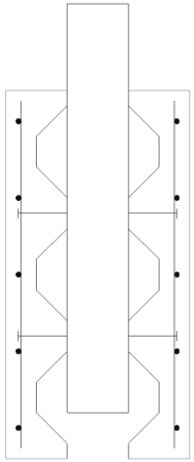
DX51d / S350GD

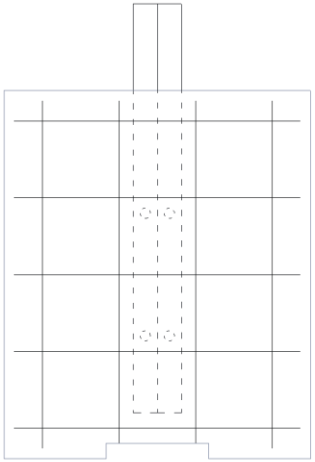
4.2 Specimen design

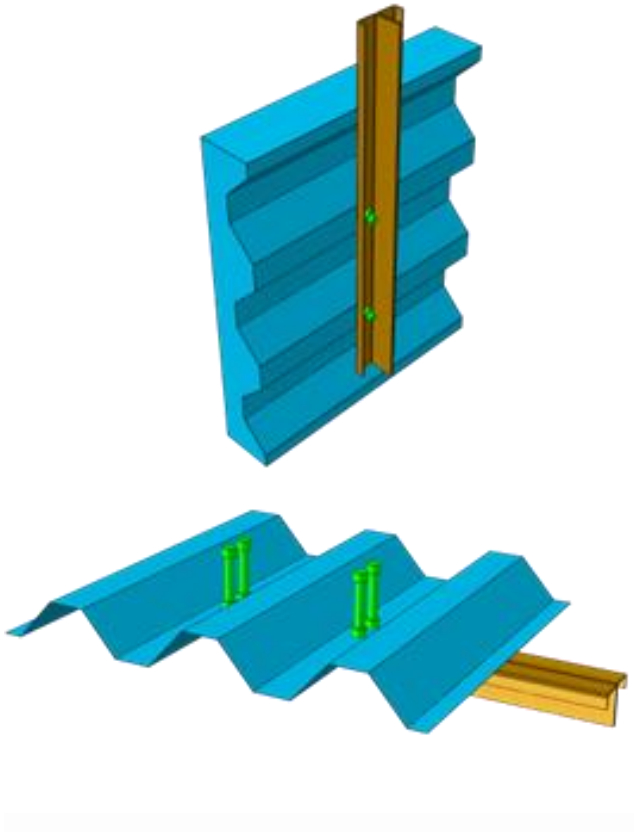
- **Bolted shear connection (embedded nuts)**
  - 18 specimens in total

6 specimens (back-to-back)





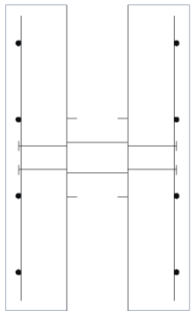


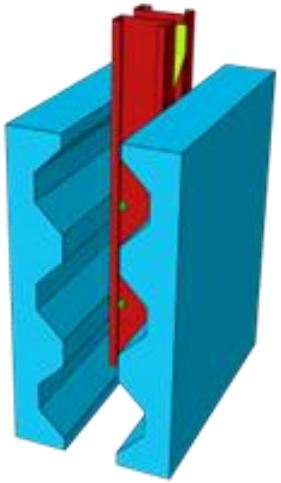


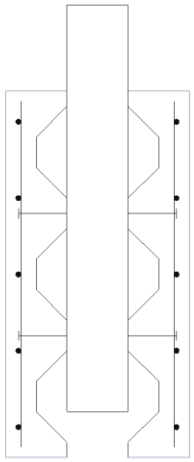
4.2 Specimen design

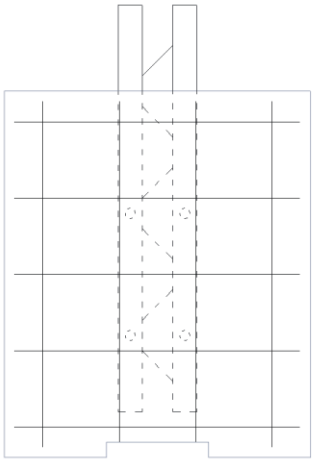
- **Bolted shear connection (embedded nuts)**
  - 18 specimens in total

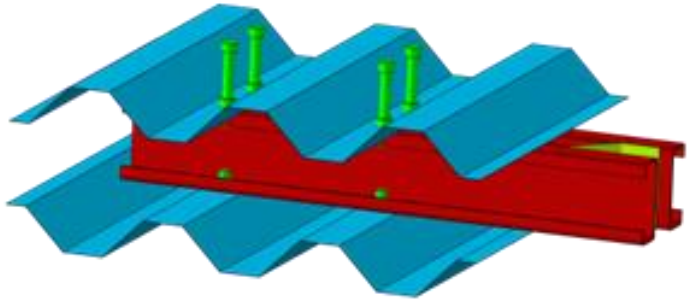
12 specimens (with corrugated web)







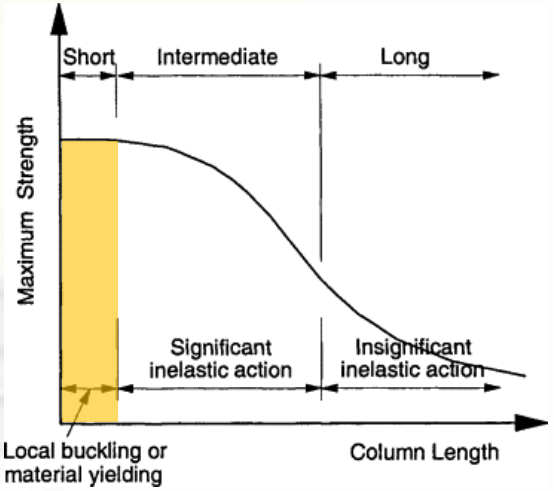




4.2 Specimen design

- **Composite dowel rib connection**
  - 2 failure modes were considered

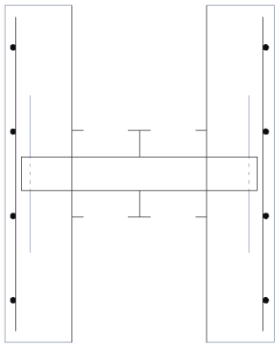
Spot welds loaded in shear

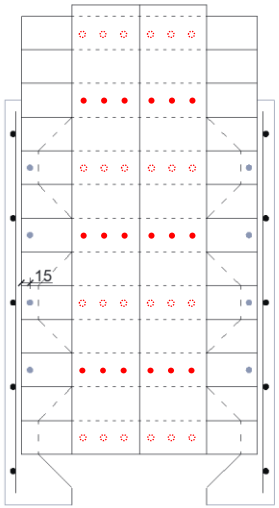


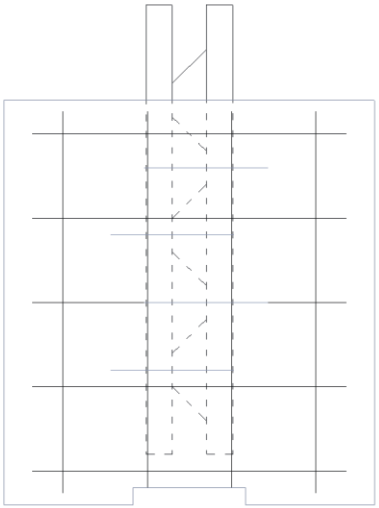
Cross-section resistance

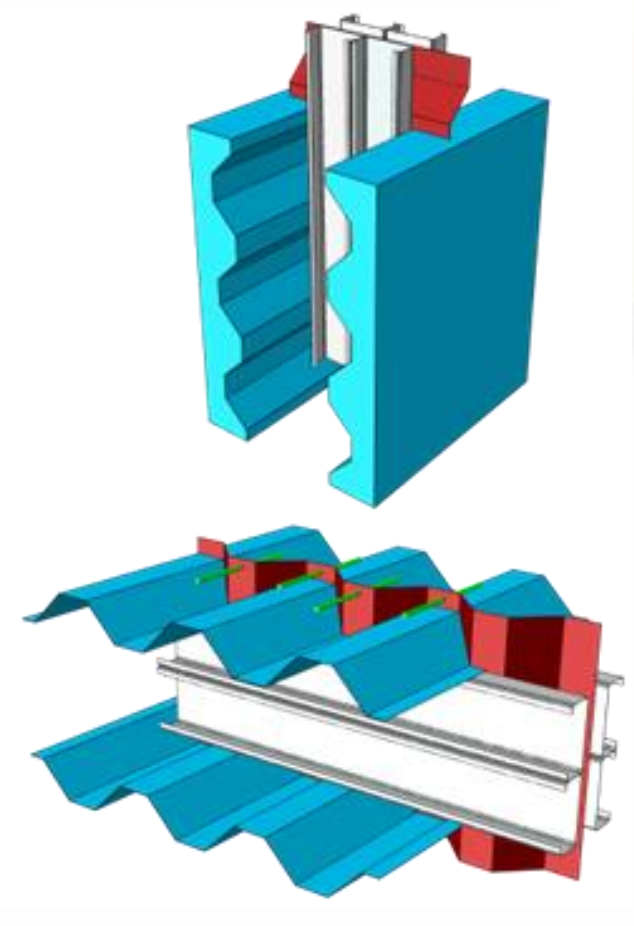
4.2 Specimen design

- **Composite dowel rib connection**
  - 12 specimens in total – CW 0.8/1.5 mm + concrete NC/LC



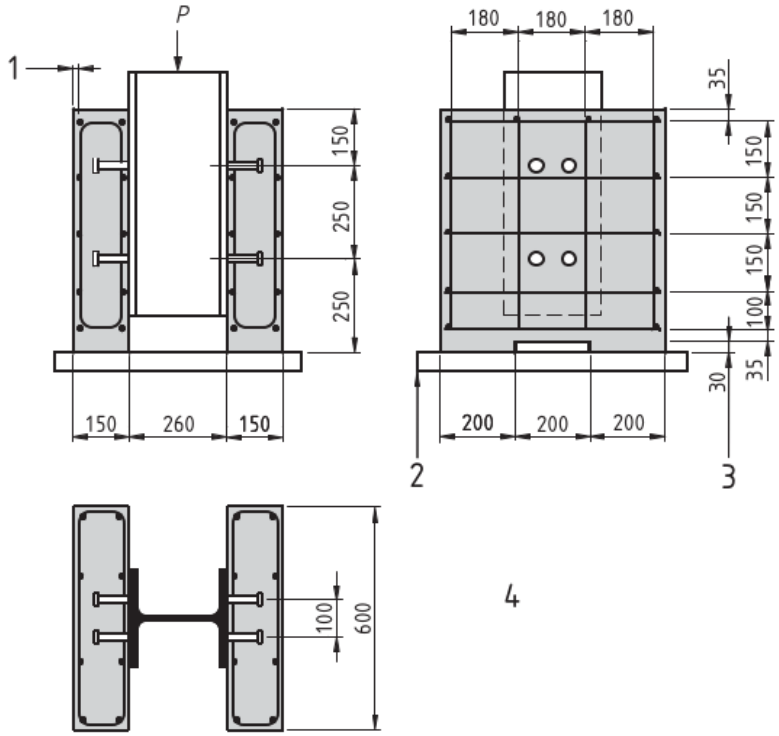






4.2 Specimen design

- **EN 1994-1-1 - Annex B – B.2 Test on shear connectors**



Key

1 cover 15 mm

2 bedded in mortar or gypsum

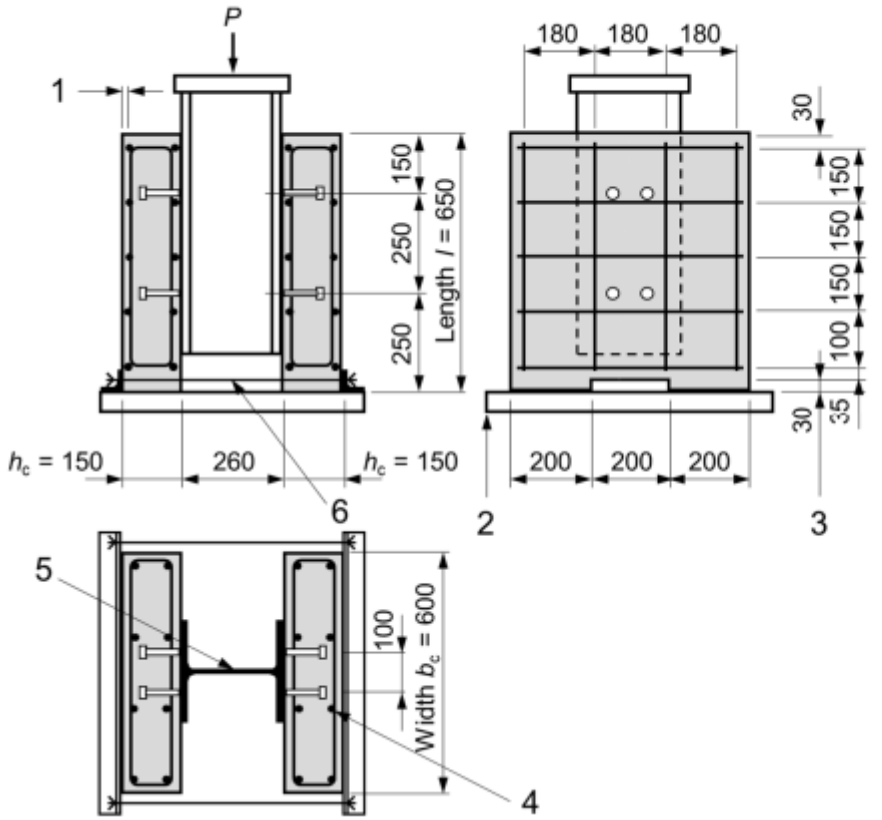
3 recess optional

4 reinforcement: ribbed bars ϕ 10 mm resulting in a high bond with $450 \leq f_{sk} \leq 550$ N/mm^2

steel section: HE 260 B or 254 x 254 x 89 kg. UC

4.2 Specimen design

- **Final draft prEN 1994-1-1 (2021) - Annex B – B.2 Test on shear connectors**



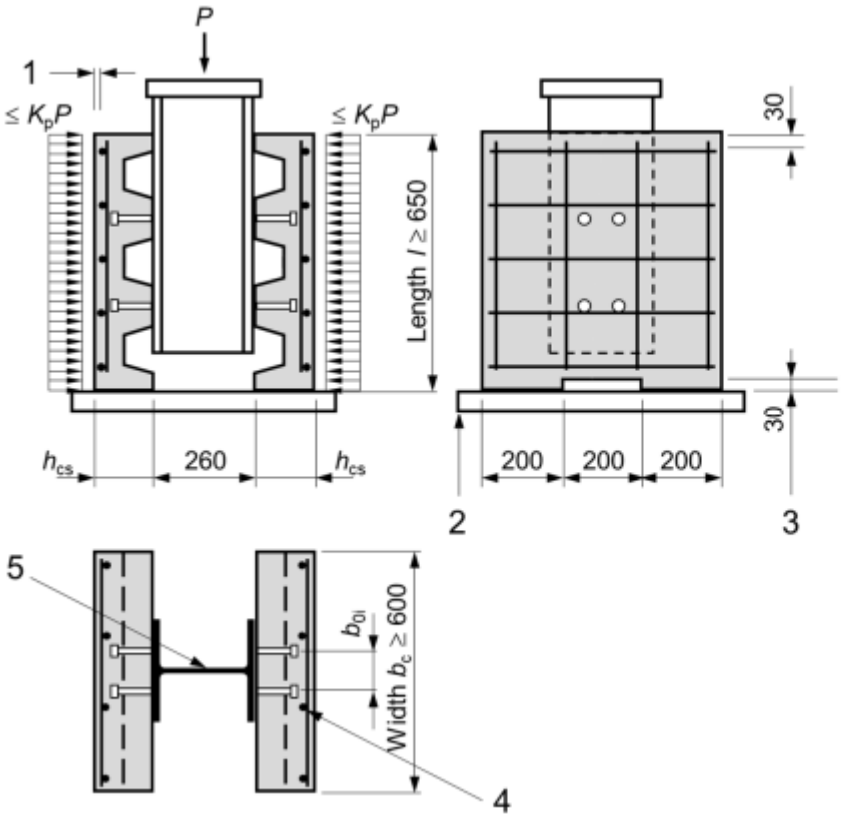
Key

(1) cover 15 mm
(2) bedded in mortar, gypsum or similar
(3) recess
(4) reinforcement: ribbed bars
∅ 10 mm resulting in a high bond with 450 ≤ f_{sk} ≤ 550 N/mm^2
(5) steel section: HE260B or 254 x 254 x 89 kg. UC
(6) L-Profile with external tension ties

Standard push-out test

4.2 Specimen design

- **Final draft prEN 1994-1-1 (2021) - Annex B – B.2 Test on shear connectors**



Key

(1) cover 15 mm

(2) bedded in mortar, gypsum or similar

(3) recess

(4) reinforcement: ribbed bars
∅ 10 mm resulting in a high bond with :
$450 \leq f_{sk} \leq 550$ N/mm²

(5) steel section: HE260B or 254 x 254 x 89 kg. UC

Specific push-out test

4.3 Specimen fabrication

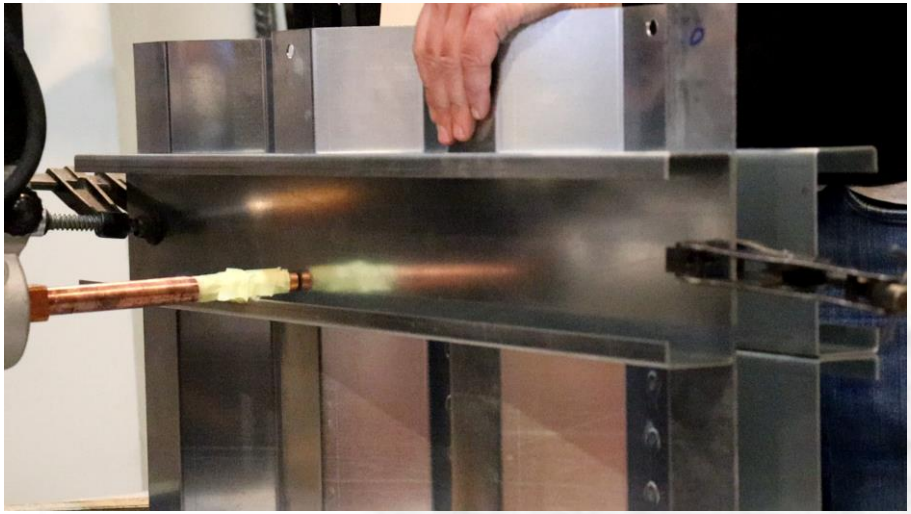
- **Bolted shear connection (embedded nuts)**

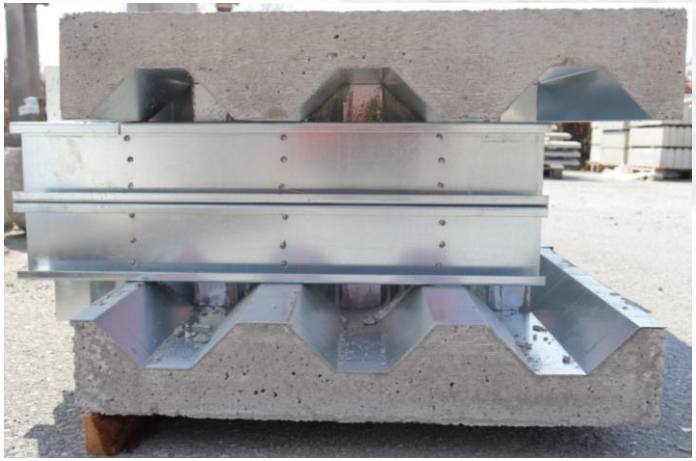
4.3 Specimen fabrication

- **Bolted shear connection (embedded nuts)**

4.3 Specimen fabrication

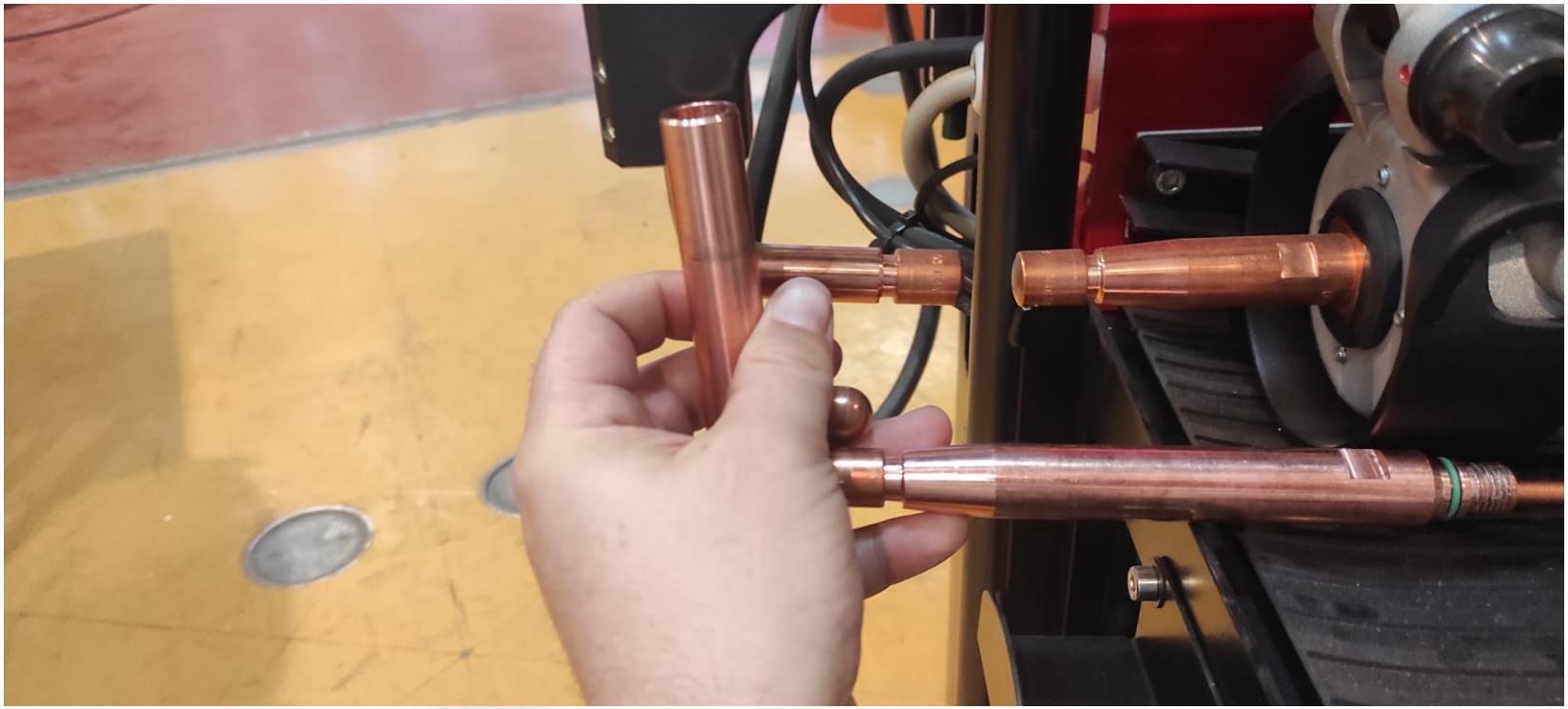
- **Composite dowel rib connection**





4.3 Specimen fabrication

- Fabrication and adjustment of new electrodes for spot welding machine in order to shorten fixed electrode



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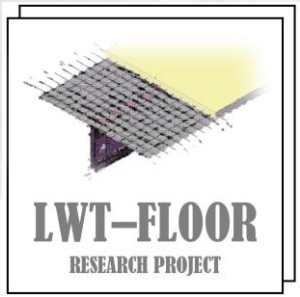

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