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Robustness of steel composite open car parks under localised fire

Numerical evaluation of the effect of axial restraints

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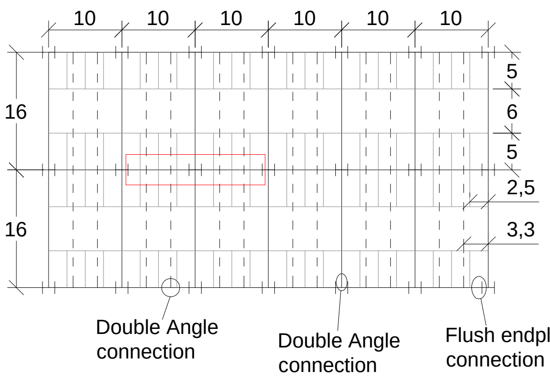
INTRODUCTION

- **EUROPEAN RFCS ROBUSTFIRE PROJECT**
  - **NEW DESIGN CRITERIA** of car parks WITH SUFFICIENT ROBUSTNESS UNDER LOCALISED FIRE
  - **PRACTICAL DESIGN GUIDELINES**

→ Behaviour study of the frame elements directly affected by the localised fire (Experimental tests and numerical models)

TESTED SUB-FRAME

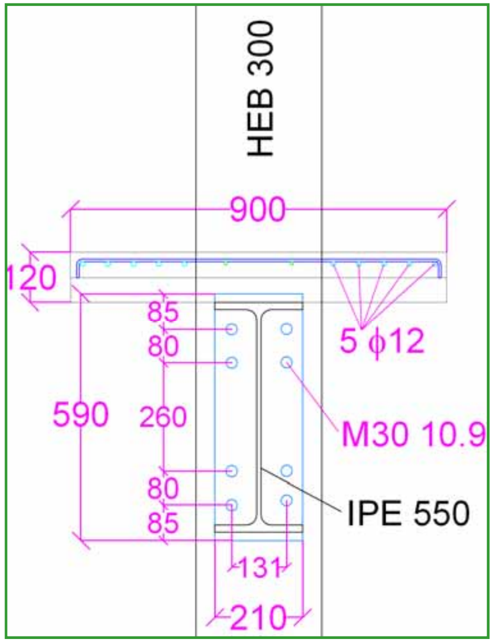
- From the open car park building

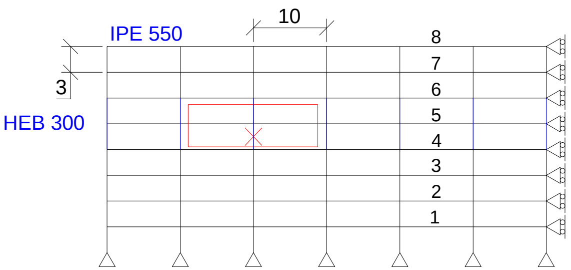


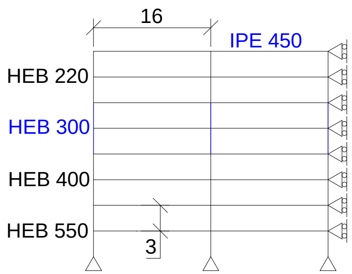
Steel column: S460
Steel beam: S355

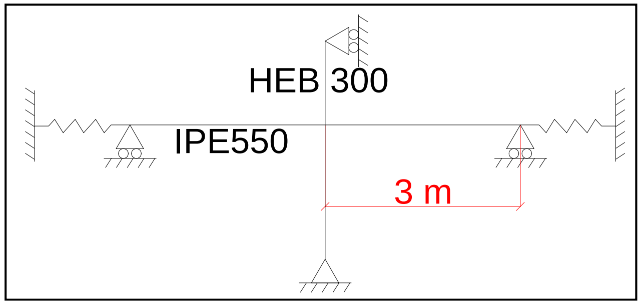
Concrete: C25/30
Slab thickness = 0.12

Car Load: 2.5kN/m2

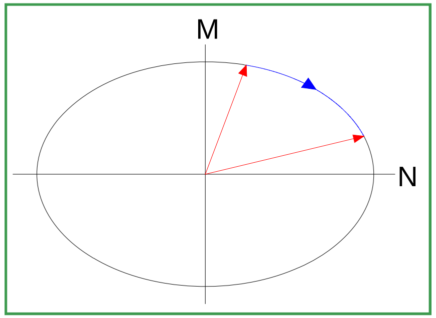






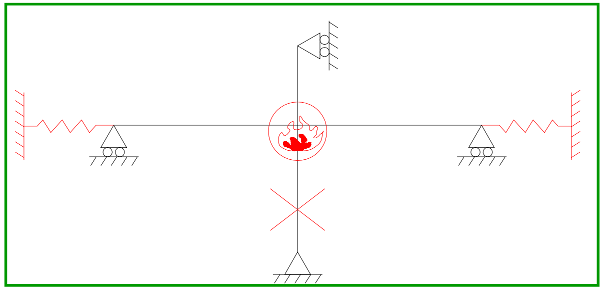


OVERVIEW OF THE 7 EXPERIMENTAL TESTS ON JOINTS



❑ OBJECTIVE

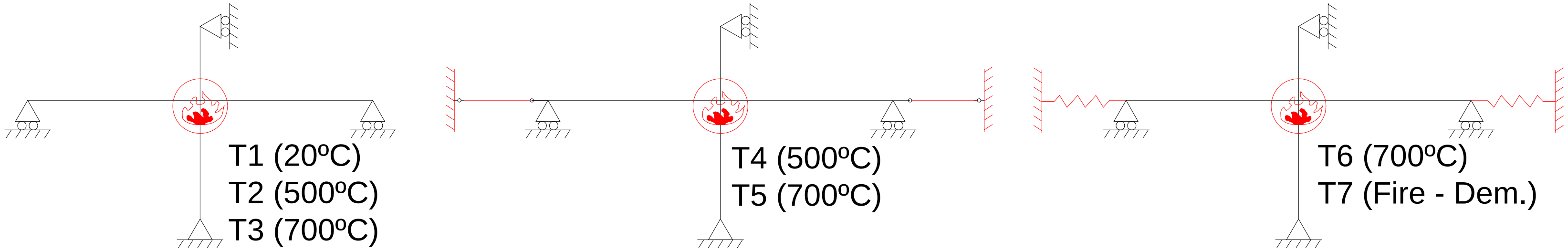
To observe the **COMBINED BENDING MOMENT and AXIAL LOADS** in the heated joint after the loss of the column due to a localised fire



❑ 7 EXPERIMENTAL TESTS

- **1 REFERENCE TEST** at ambient temperature
- **5 TESTS** at elevated temperatures (500ºC and 700ºC)
- **1 DEMONSTRATION TEST** under fire (increase of temp. up to the failure of the joint)

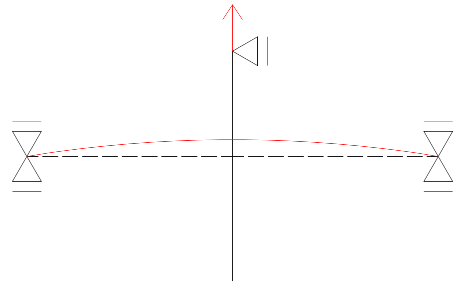
❑ INFLUENCE OF THE LATERAL RESTRAINTS



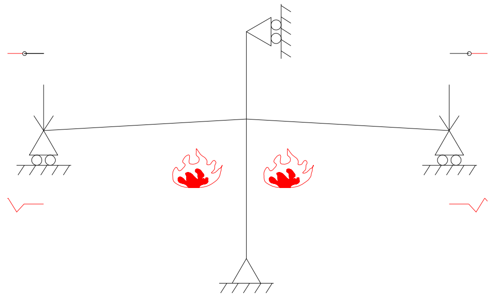
MECHANICAL AND THERMAL LOADINGS OF TESTS 1 to 6

3 LOADING STEPS

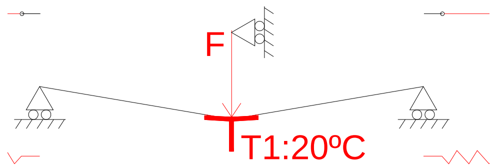
- **1: INITIAL HOGGING BENDING MOMENT IN THE JOINT**
  → as in the real car park building



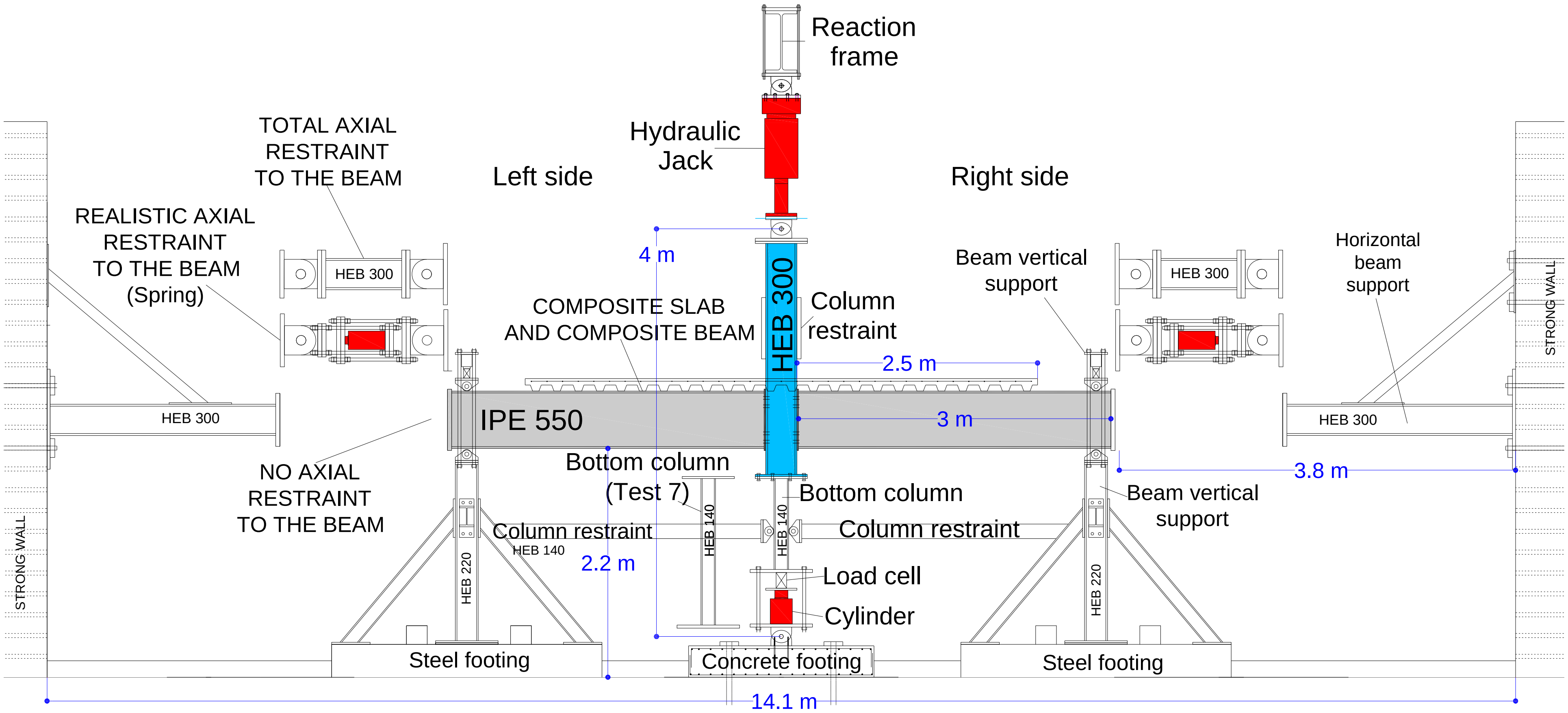
- **2: LOCALISED FIRE**
  → heating of the joint zone up to reach 500ºC or 700ºC in beams bottom flanges



- **3: LOSS OF THE COLUMN AND INCREASE OF THE SAGGING BENDING MOMENT**
  → increasing the vertical load at the column top up to the failure of the joint (constant temperature)

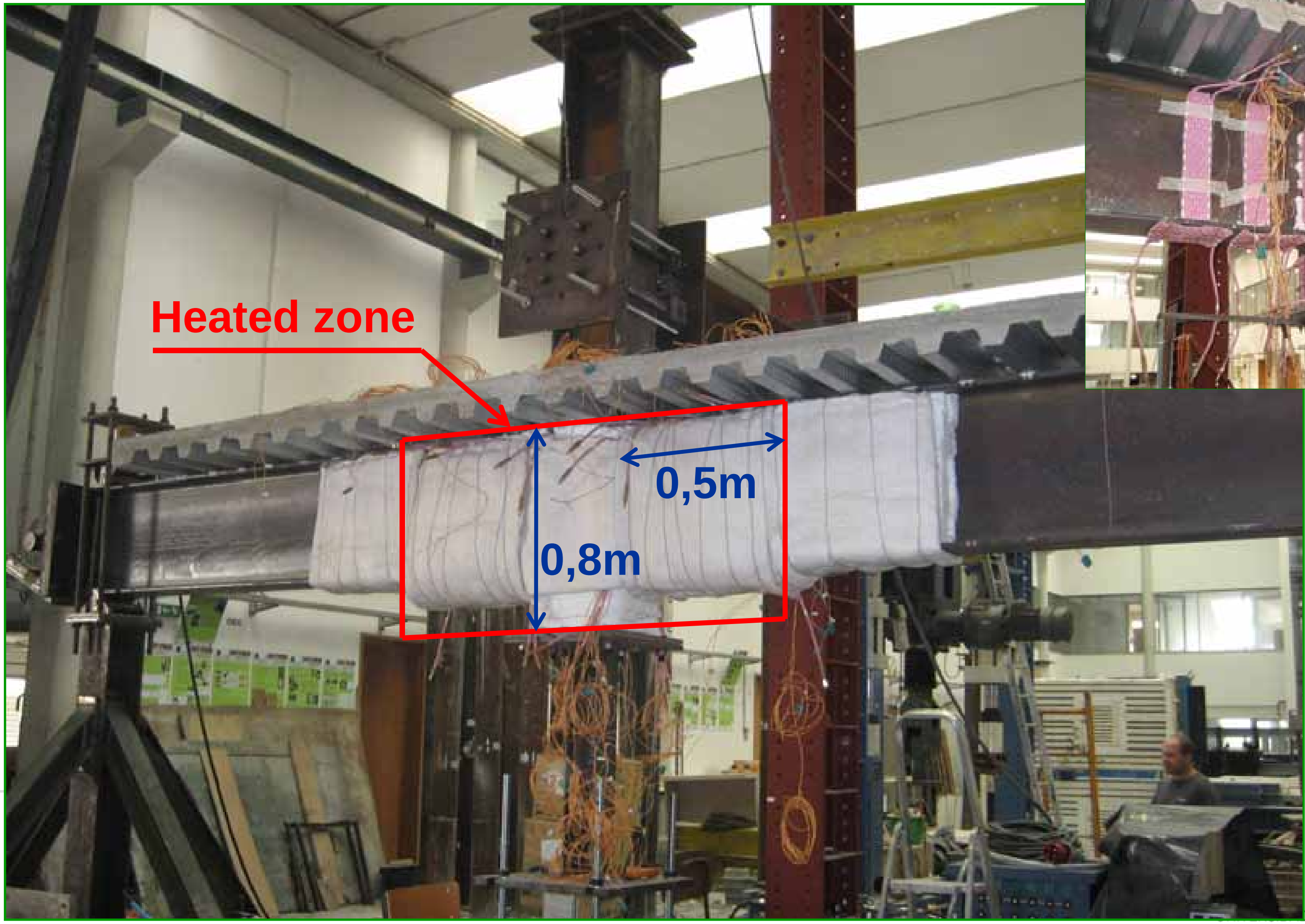


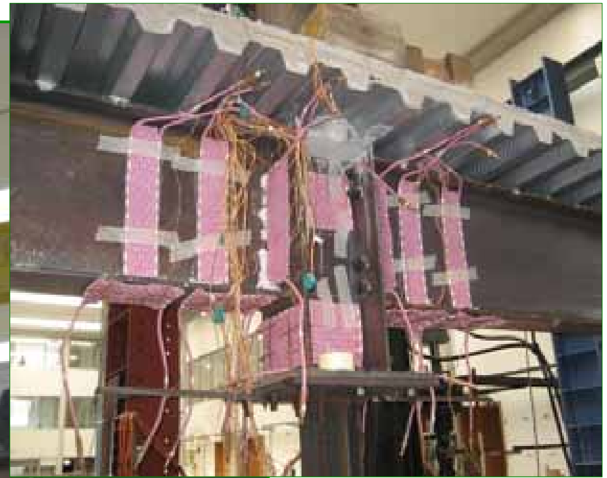
TESTING ARRANGEMENT



STEP 2: Localised Fire

- **Tests at high temperatures – Ceramic pad heating elements**





MECHANICAL RESULTS AND FAILURE MODES

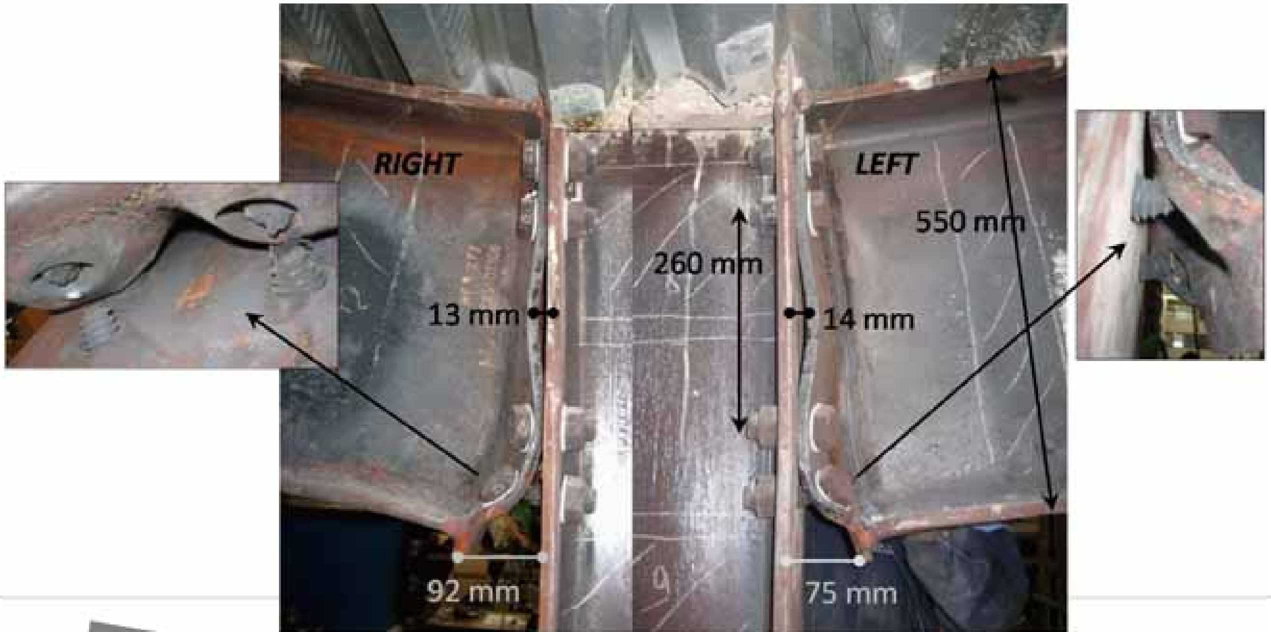
- CONCRETE CRUSHING IN COMPRESSION
- SOME BOLTS FAILURES IN TENSION (BOTTOM ROW)

MECHANICAL RESULTS AND FAILURE MODES

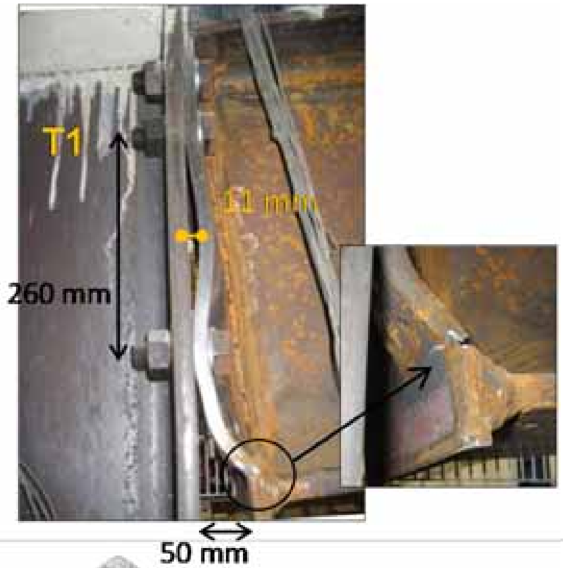
❑ Deformation of the steel end-plate (centre and bottom part)

- **Because of the JOINT CONFIGURATION** (260 mm, end-plate (15 mm) thinner than column flange (19 mm), and an initial gap (0.6 mm));
- **Because of the SAGGING BENDING** (tensile loads at the bottom part)

TEST 6: 700ºC/SPRING RESTRAINT

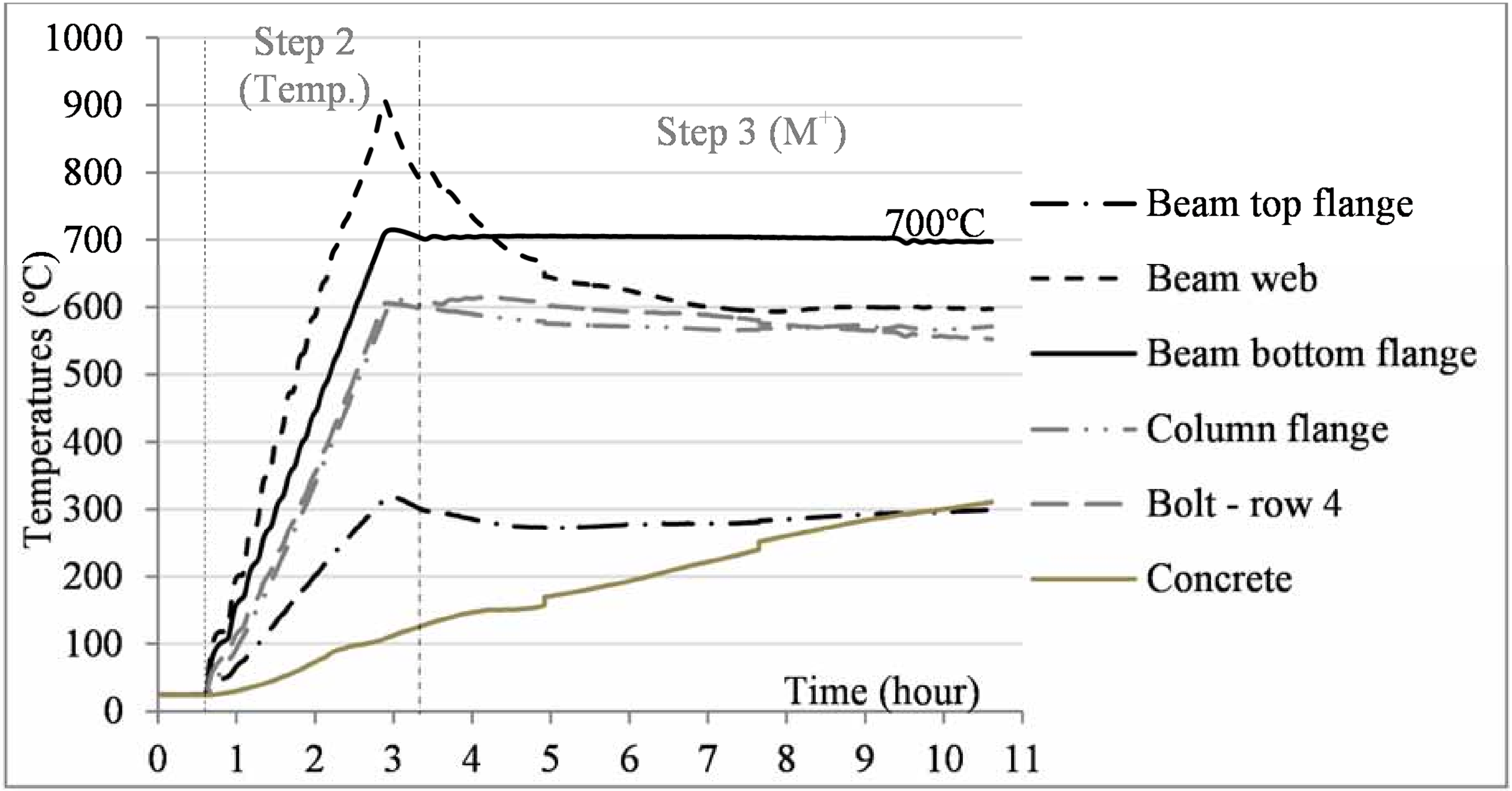


TEST 1: 20ºC/NO RESTRAINT



TEMPERATURES RESULTS

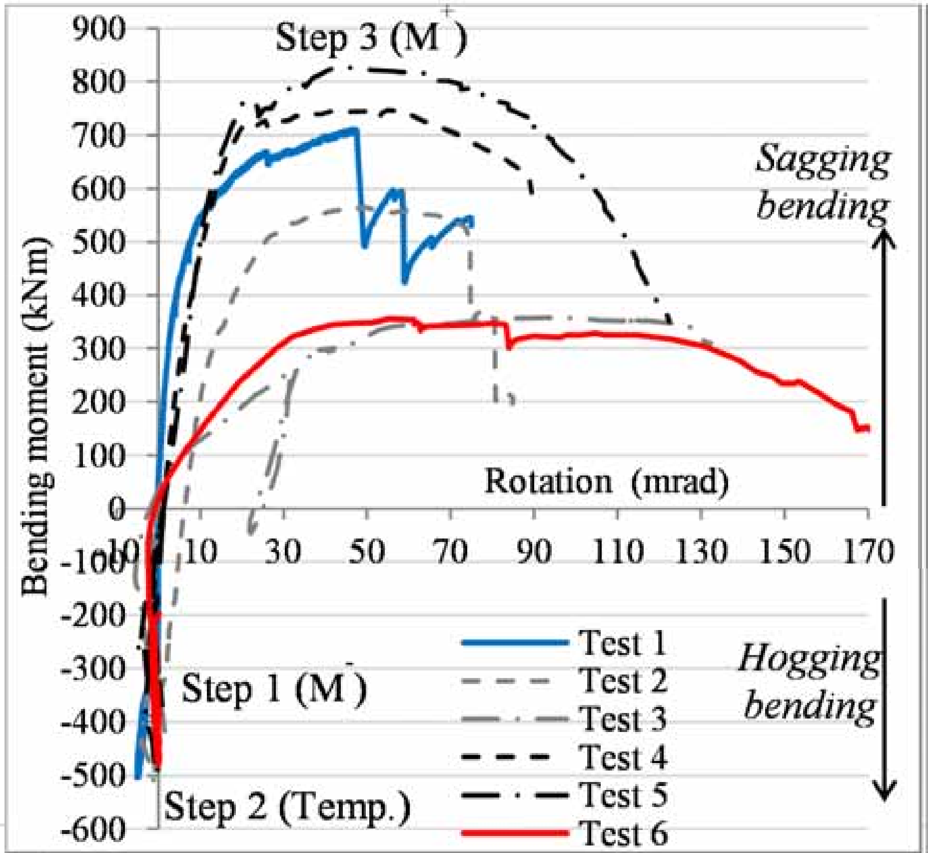
- **TEST 6 (700ºC)**

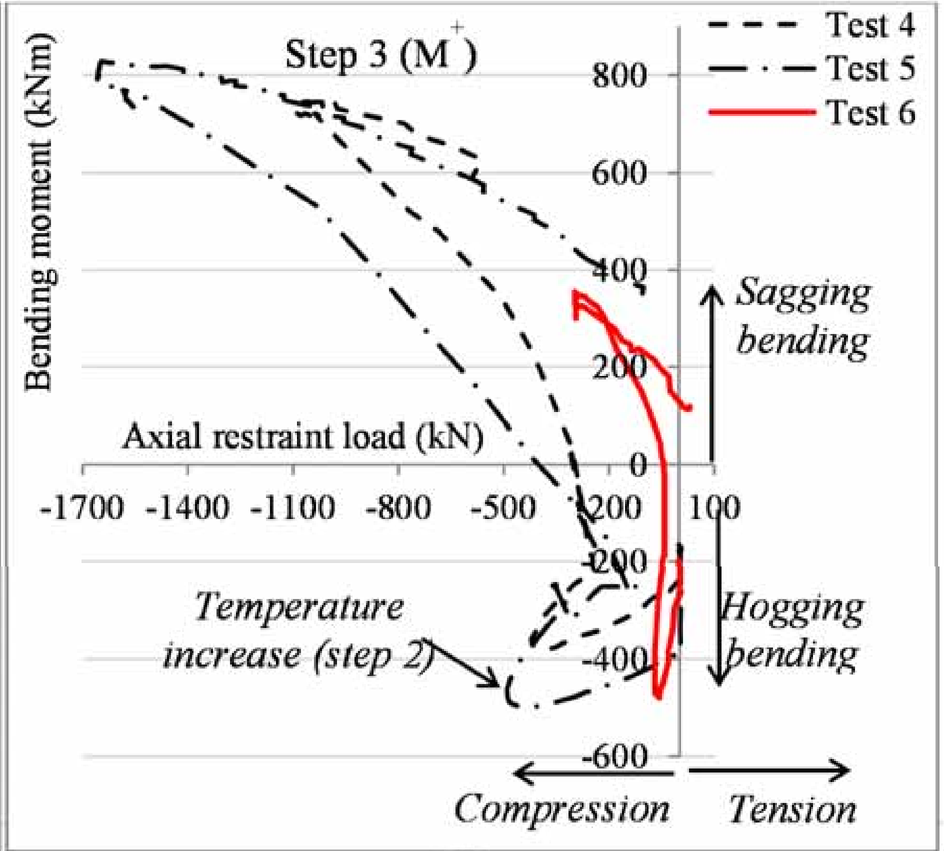


MECHANICAL RESULTS AND FAILURE MODES

❑ MOMENT/ROTATION and MOMENT/AXIAL LOAD

- **Joint rotation + ductility** increased by temperature and compression axial loads
- **Maximum sagging bending moment** decreased by temp. / increased by axial loads





NUMERICAL MODELS

- ❑ **ABAQUS**

- ❑ **OBJECTIVES**

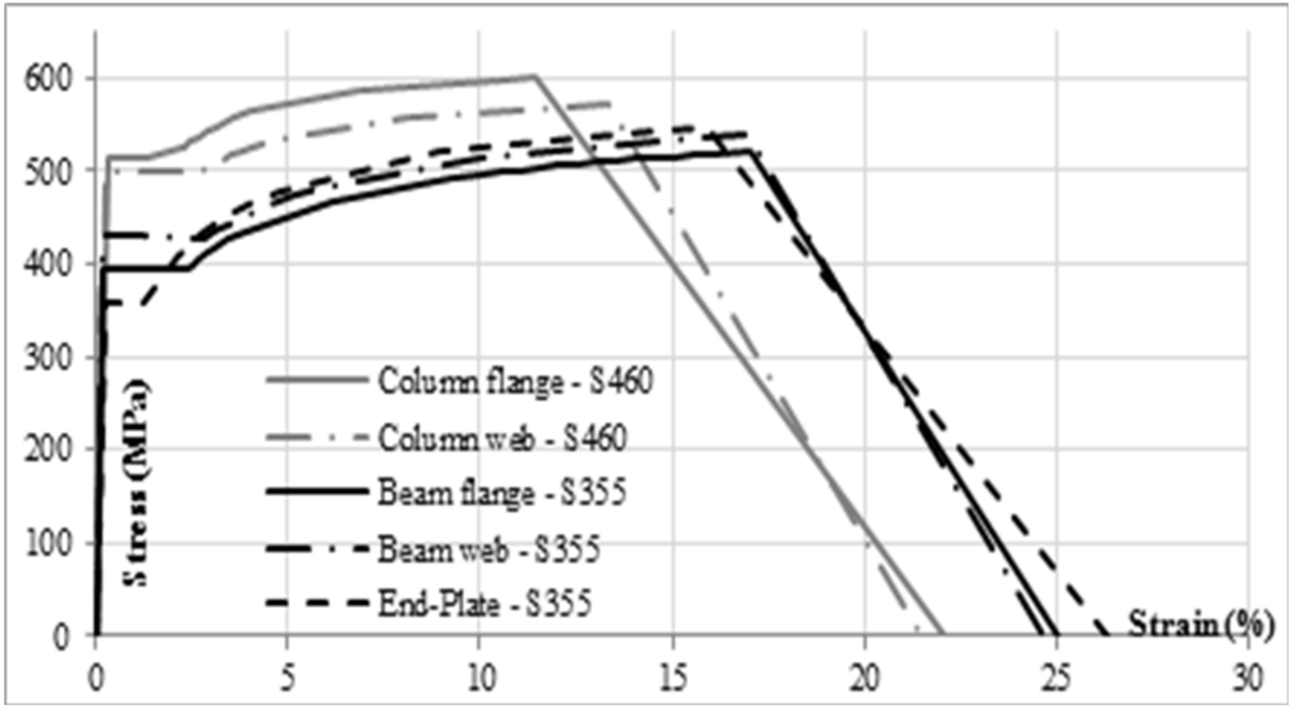
  - **Calibration** of two/three models under 20ºC (test 1) and 700ºC (test 5), also with spring restraint (test 6)
  - Study of the **influence of the axial restraint** to beam;
  - Study of the joint behaviour under **catenary actions**

    → More realistic situation, with beam span of 10 m

NUMERICAL MODEL (TEST 1 – 20ºC)

STEEL MECHANICAL PROPERTIES (IPE550, HEB300, End-plate)

- Tensile coupon tests (20ºC, 500ºC and 700ºC)
- Standardized curves defined using the Menegotto-Pinto model (for materials of sharp-knee type)



- To be converted to the true stress-strain measures ($\sigma_{tru}, \varepsilon_{tru}$)

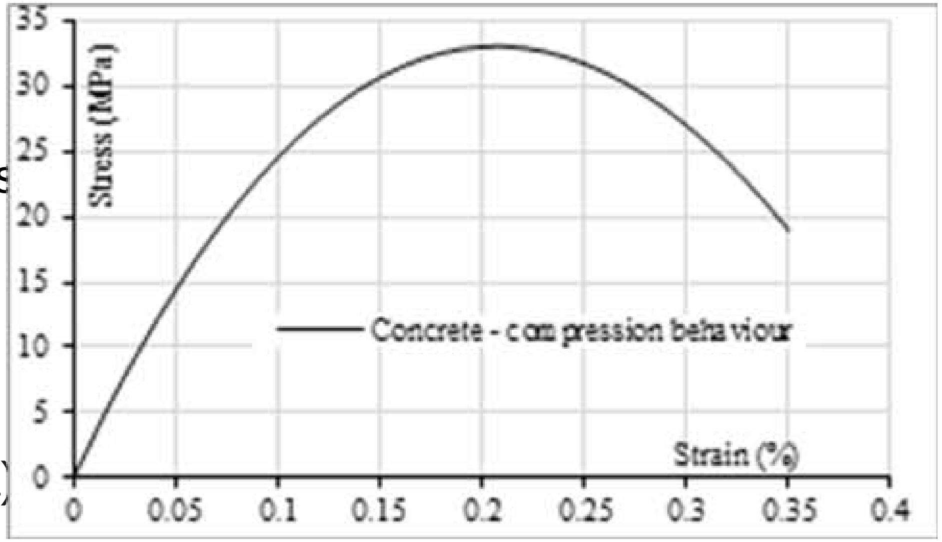
NUMERICAL MODEL (TEST 1 – 20ºC)

❑ PROPERTIES OF M30 GRADE 10.9 BOLTS

- Tensile coupon tests (20ºC, 200ºC, 400ºC, 500ºC, 600ºC, 700ºC and 800ºC)
- At 20ºC: idealized by a **bi-linear curve:** yield strength = 932 MPa (ε_{nom} = 0.45 %) and ultimate strength = 1044 MPa (ε_{nom} = 5 %)

❑ CONCRETE PROPERTIES

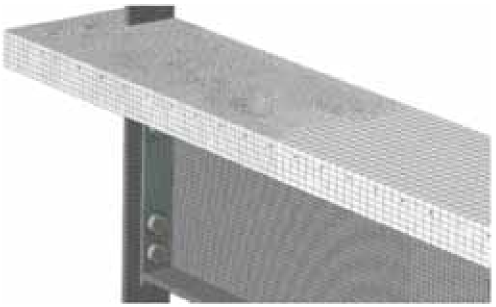
- Compression tests on concrete blocks
- C25/30 after 28 days *confirmed*
- in tension:
  - maximum tensile stress (2.6 MPa)
  - fracture energy G_F (93.4 N/m) (energy required to propagate a tensile crack of unit area)

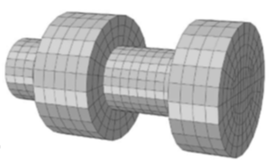


NUMERICAL MODEL (TEST 1 – 20ºC)

GENERAL MODELLING ASSUMPTIONS

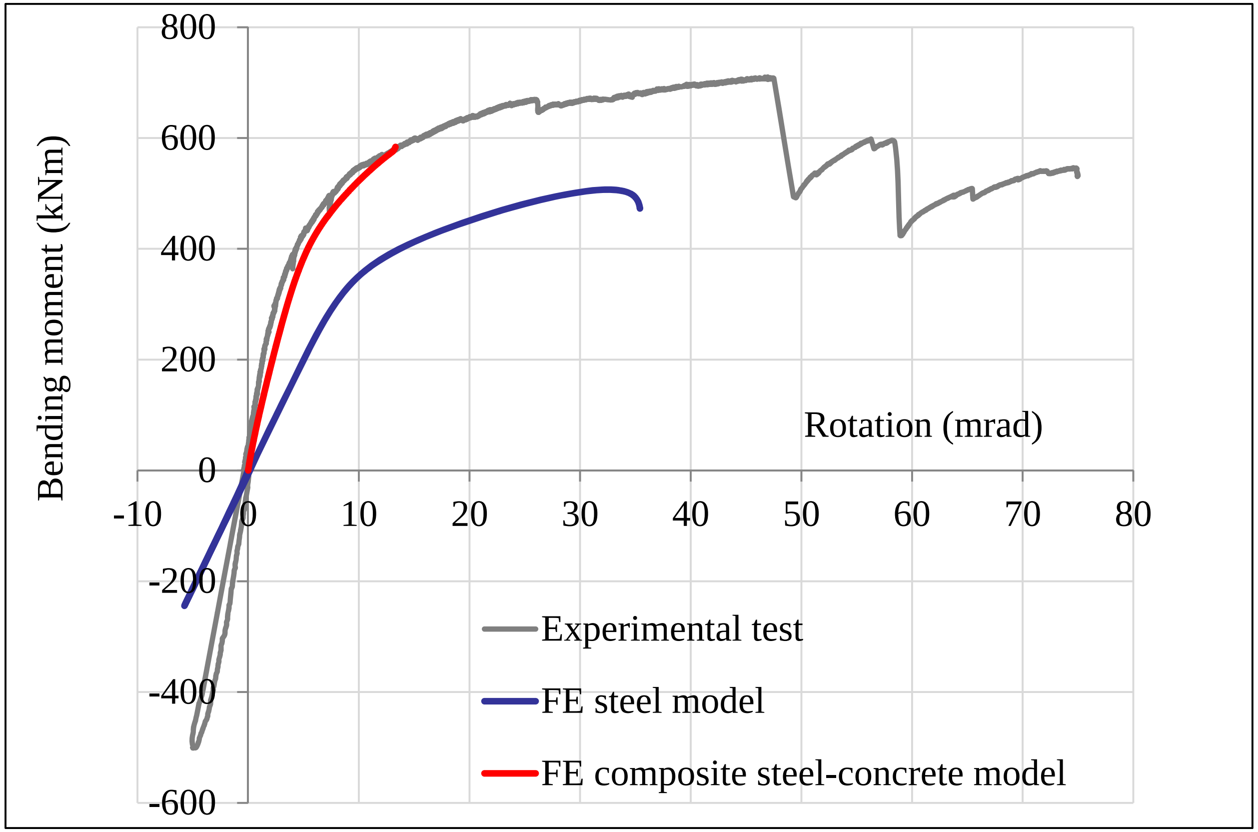
- **Symmetry** of the joint (no local buckling of webs)
- Boundary conditions
- C3D8R **solid elements** (B31 for upper part of the column)
- **Concrete slab**: TIE to the steel beam
- **Contact** interactions (surface to surface/small sliding)
- **Initial deformation** of end-plate (0.6 mm)
- General static analysis
  - Step 1: bolts pre-loading (adjusting length)
  - Step 2: self-weight
  - Step 3: hogging bending moment
  - Step 4: sagging bending moment





NUMERICAL RESULTS (TEST 1 – 20ºC)

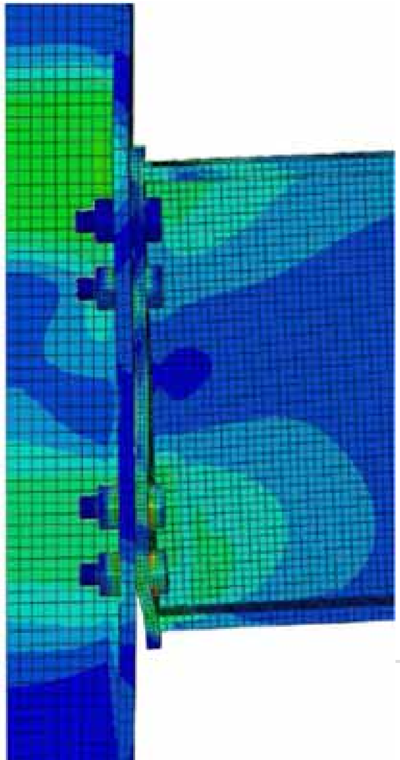
- **STEEL AND COMPOSITE MODELS**

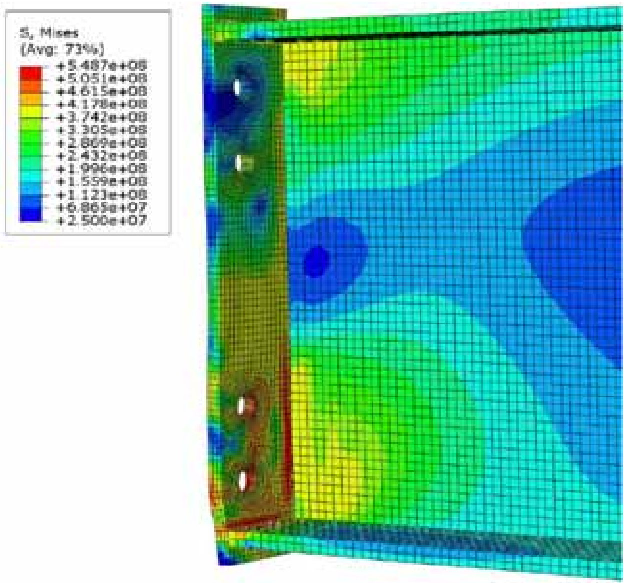


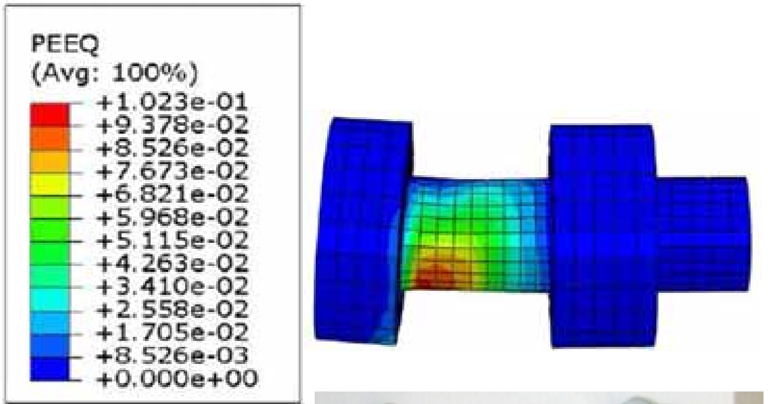
NUMERICAL RESULTS (TEST 1 – 20ºC)

❑ STEEL MODEL

- **Plastic deformations of the end-plate** evidenced in the tensile zone
- **Ultimate stress-strain** is reached in the bottom bolt (row 4)
- **Similar bolt failure** test/model



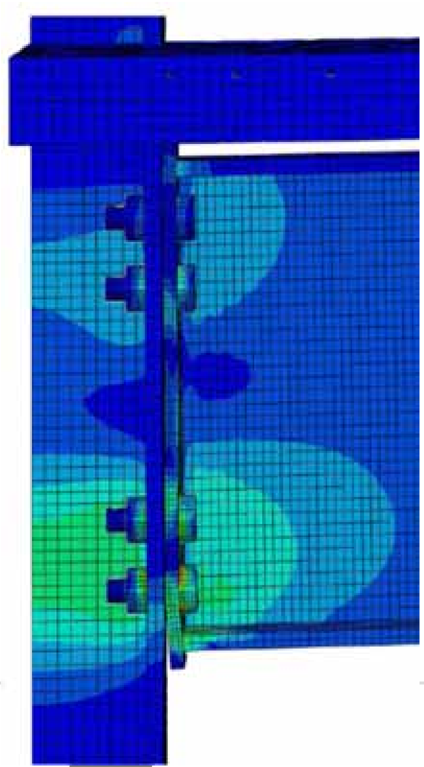


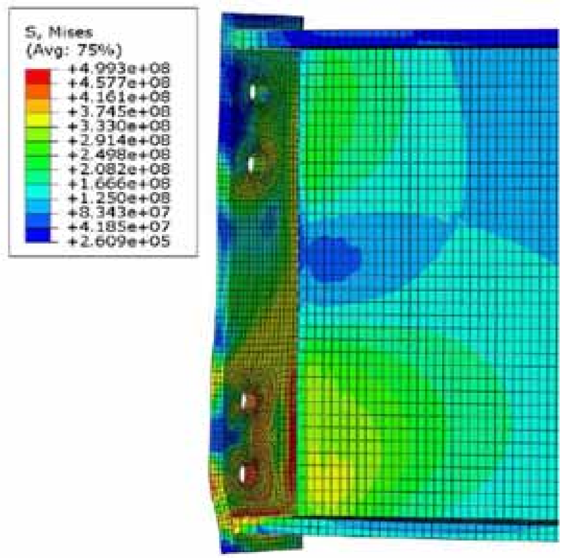


NUMERICAL RESULTS (TEST 1 – 20ºC)

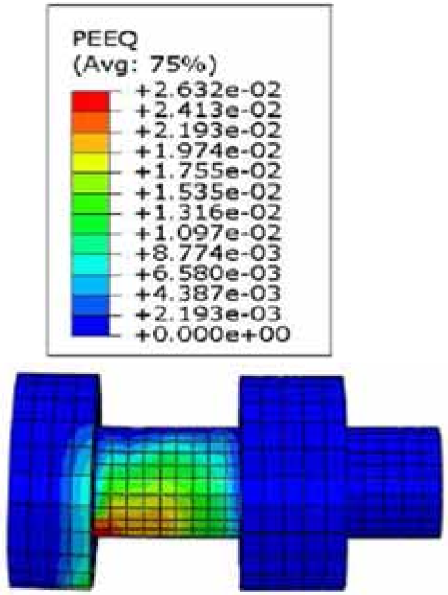
❑ COMPOSITE MODEL

- Num. model stopped before reaching ultimate stress-strain in bolt
- At this point (13 mrad rotation): **concrete not yet crushed**





(Scale 3)



FUTURE DEVELOPMENTS

- **TO SOLVE THE COMPOSITE BEHAVIOUR PROBLEM**
  - Modelling the **shear connectors** (springs or solid elements?)
  - Real shape of the composite slab?
- **THE TEMPERATURES**
  - **Directly applied** using predefined temperatures
  - Expansion coefficient and material properties degradation
- **THE AXIAL RESTRAINT TO THE BEAM**
- **THE REAL BEAM LENGTH DIMENSION**

Thank you

for your attention!

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