COST TU0601 Workshop and MC Meeting,
Zurich 4-5 February 2008

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Robustness oriented analysis of structural joints of steel-concrete composite frames

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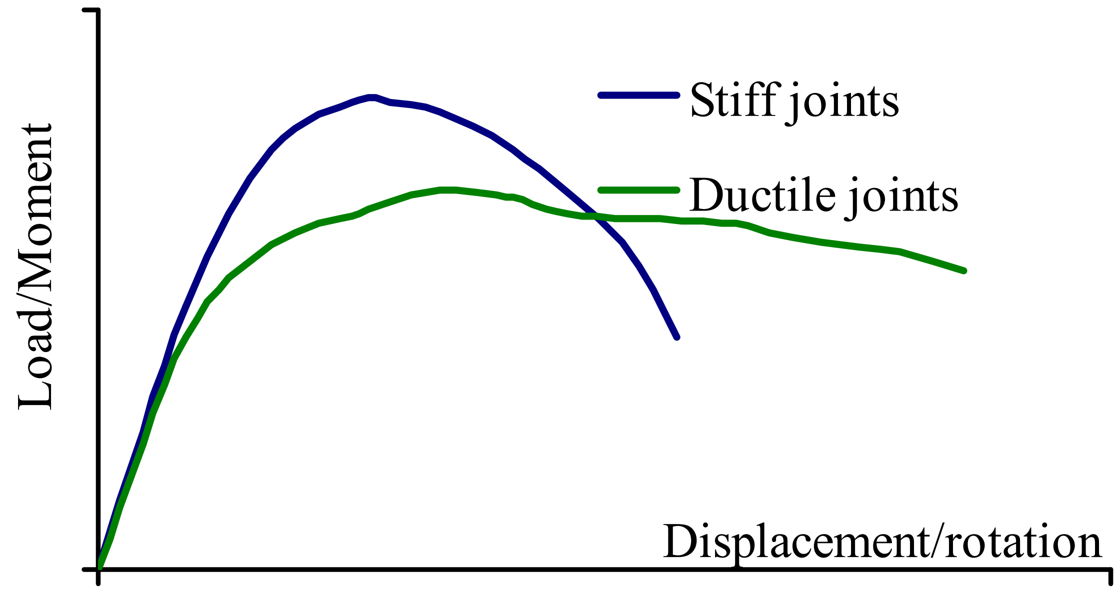
Subject:
structural joints of steel-concrete composite frames

- more frequently applied in commercial buildings, parking areas and bridges
- effective application of steel and concrete
- increased strength and stiffness
- mechanical behavior is more complex comparing to pure steel connections
- deterioration of concrete, interaction between concrete and steel parts, variety of technical solutions
- limited guidance and shortage of experience

Objective:

- balance between required load carrying capacity and stiffness, and sufficient postbuckling ductility



Hypotheses:

- joints with thin end-plates exhibit a better ductility performance than joints shaped in the conventional way
- balance between the concrete slab reinforcement and the steel part of the joint – better ductility

Scope:

- nonlinear analysis reaching up to the failure
- possible modeling approaches
- ties between the experimental and the numerical studies
- road map – discussion
- difficulties encountered in finite element modeling
- future research directions

Robustness:

- infrequent loadings
- prevention against progressive and disproportionate collapse
- proper redundancy and ductility of the main structural elements can limit damage
- force redistribution process
- frame joints need to provide larger rotations

The roof of one of the buildings at Katowice International Fair collapsed leading to 65 deaths and more than 170 injuries. 28 January 2006.

Steel beam-to-column joints -experience:

- structural performance depends on mechanical parameters
- stiff vs. ductile joints

Type of end-plate	End-plate thickness t_p [mm]	Symbol used for joints	
		bare steel	composite steel-concrete
Flush	10	ES1	EZ1
	12	ES4	EZ4
Extended	8	ES3	EZ3
	10	ES2	EZ2

Stiff joints :

- relatively thick end-plates
- rapid reduction of stiffness after reaching the ultimate load
- brittle-like failure mode when their weld or bolt connectors reach the ultimate strength
- equilibrium paths - steep drop in post-limit phase
- dynamic, uncontrolled damage resulting from rupture

Ductile joints:

- thinner end-plates: 40-60% of bolt diameter
- stronger bolts
- better ductility as the result of membrane action activated
- continuous capability of resisting the overloading in a more ductile manner
- equilibrium paths - flat branches of post-elastic deformations
- desired effect of force redistribution in the structure

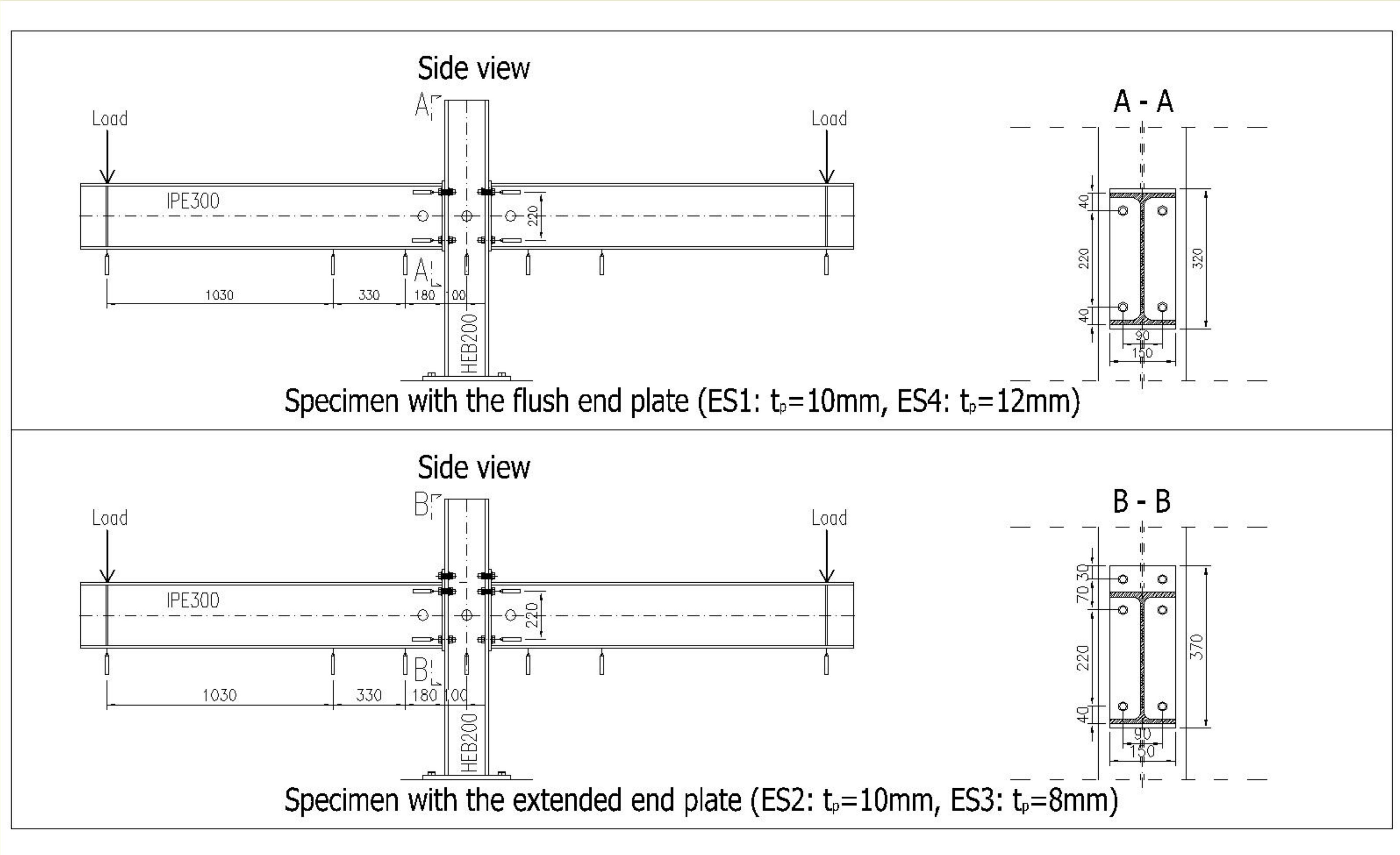
Experimental work – things to consider:

- loading
- specimen configuration, scale and dimensions
- measurements
- additional coupon and core tests

Assumptions:

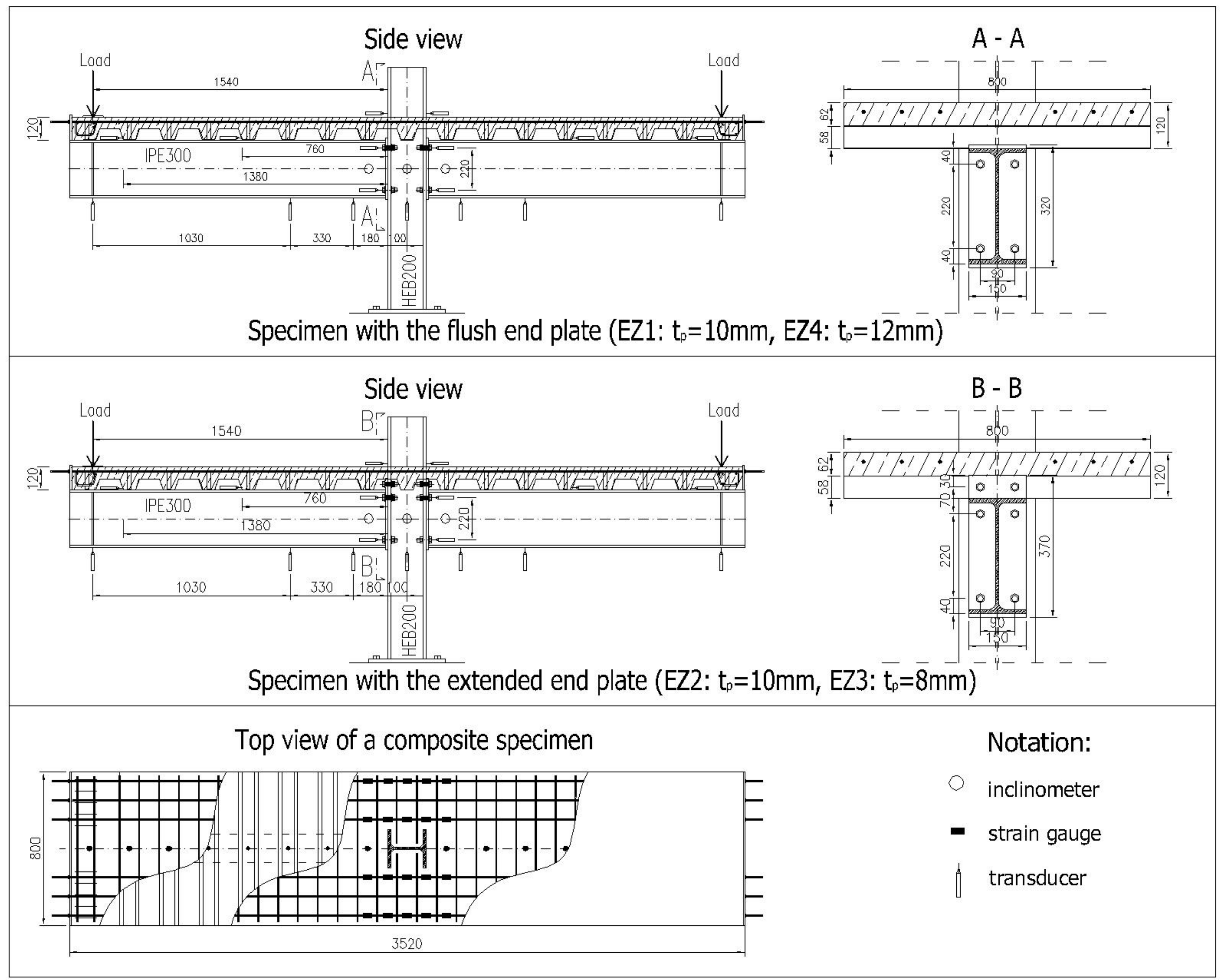
- joints under bending conditions
- flush and extended end-plates relatively thin
- the same arrangement for composite and bare steel joints
- more ductile end-plates and stronger bolts
- bolt distances allowing stressing the end-plate mostly in bending in the zones where the HAZ effect due to welding of the end-plate is minimized
- for composite joints - balance between the concrete slab reinforcement and the steel part of the joint

Experimental work:



steel joint specimens

Experimental work:



composite joint specimens

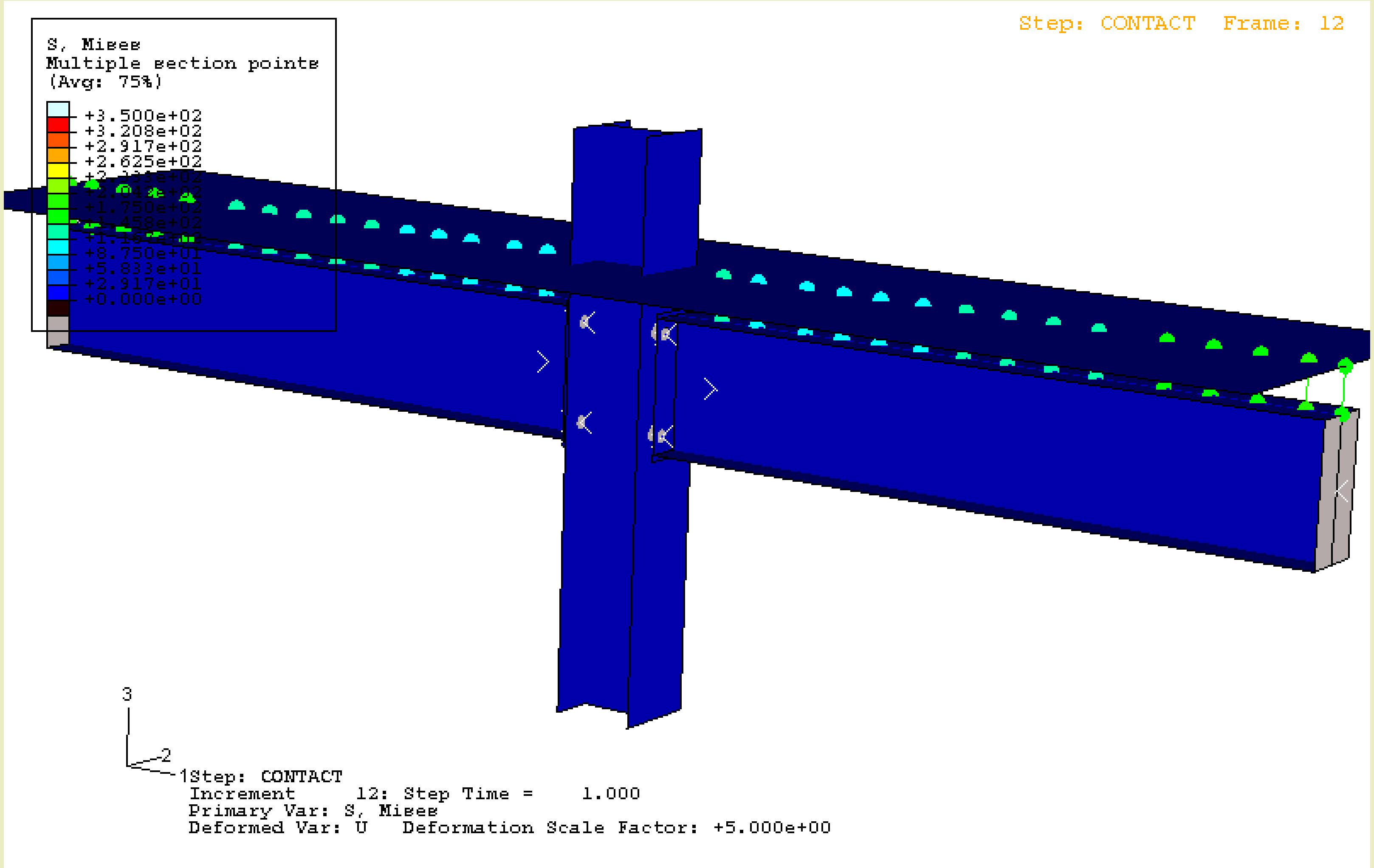
Experimental work- measurements

- rotations of the joints, by electronic inclinometers and furthermore by use of transducers facing the upper and lower bolt rows
- deflections of the cantilevers by means of inductive transducers located at three points of each cantilever
- deflection of the column by means of inductive transducers positioned at two sides of the column web
- strains in the tension bolts by stain gauges fixed on the surface of the bolt shank
- loading control by two 200 kN load cells

Experimental work-
additional measurements for composite specimens

- deflection of the column - inductive transducers positioned at the outsides of the column flanges, above the slab
- strains in the longitudinal reinforcement bars - strain gauges
- slip between the slab and beam - inductive transducers located on the top surface of the beam flange near the ribs of the slab at two points of each cantilever
- strains in the concrete slab - adaptive gauge
- crack width by a microscope

Finite element modeling



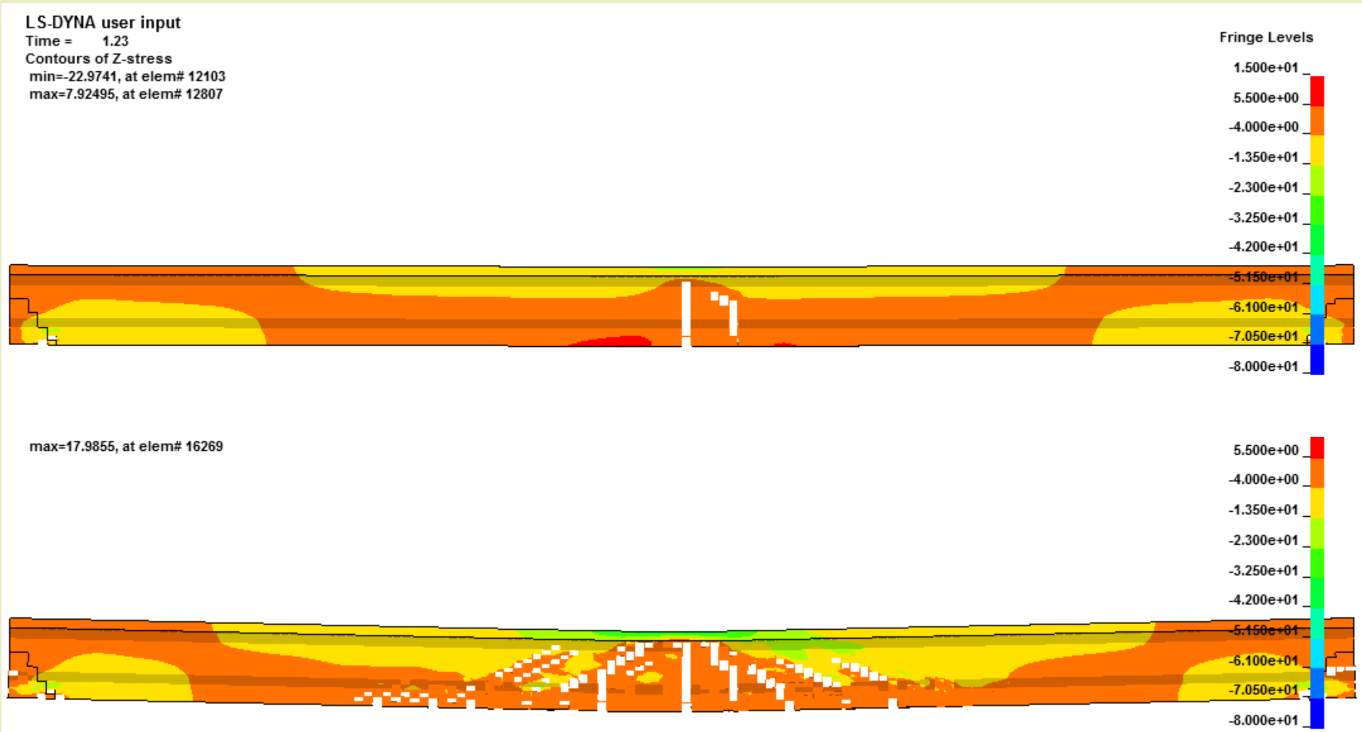
Example FE model for composite concrete – steel joint.

Finite element modeling – problems to solve

- software – general purpose commercial vs. research codes ABAQUS and Ls-Dyna
- type of analysis – static (implicit) vs. dynamic (implicit or explicit)
- modeling of concrete – cracking, tension stiffening, solution convergence
- discretization – mesh density, type of elements
- modeling of composite action
- benchmarks, verification & validation

Finite element modeling – Ls-Dyna capabilities

- dynamic analysis – explicit formulation
- effective contact algorithms-
- new material models for concrete:
  - *MAT_072R3:_CONCRETE_DAMAGE_REL3
  - *MAT_078 _SOIL_CONCRETE
- damage – element erosion
- prestress – special purpose material model – cable with initial elongation



Conclusions and future activities planned

- Better understanding of failure mechanisms with reference to optimally chosen balance between the ductility of thin end-plate and slab reinforcement

- Experimental investigations on the reinforcement with greater diameter but of the same grade - behavior in the wider range of parameters influencing the ductility.

- Shell element based models developed for ABAQUS software are accurate enough for the strength prediction but less accurate for the ductility prediction.

- Need for better modeling of composite action in terms of a “smoothed stiffness” of shear connectors and the bonding effect of concrete.

- Modeling based on crack propagation through element erosion and using LS-Dyna software seems to be promising for prediction of composite joint ductility.