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Numerical modelling of shear connection between concrete slab and sheeting deck

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Introduction

- Structural arrangement

Steel beam

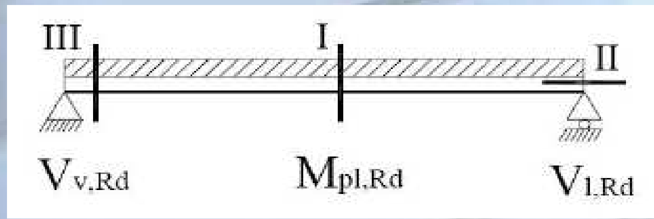
Profile deck

Reinforced concrete slab

} Frictional interlock

Mechanical interlock – rolled embossments

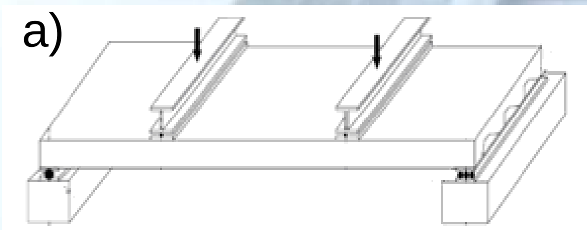
- Failure modes



(I) flexural failure (II) longitudinal shear failure (III) vertical shear failure

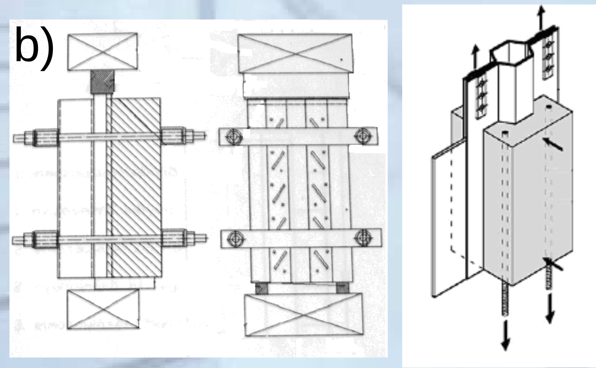
Introduction

- Performance tests



(a) Full – scale test

└ Eurocode 4



(b) Small – scale test

- Scopes

  (i) simplify the experiments

  (ii) develop an advanced numerical model for the simulation

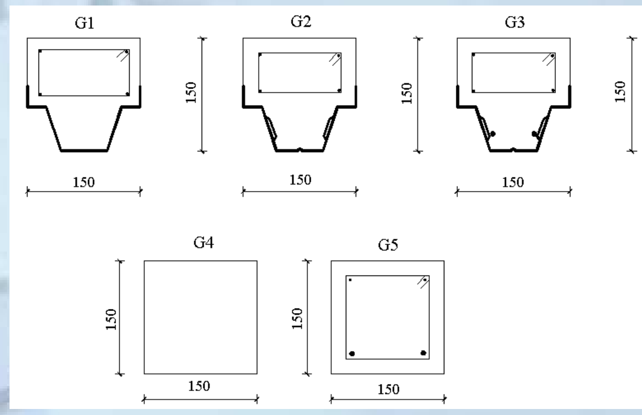
Experimental program

- Short beam specimens

Geometry: 150x150x700

Type:

- Concrete beam
- Reinforced concrete beam
- Composite beam
  - half wave of an open through profile
  - with and without rolled embossments
  - ~3mm of rim



Experimental program

- Short beam specimens

  - Loading → four point bending
  - Measured values → mid-span deflection → on all beams
    - → end-slip } on composite beams
    - → mid-span strains } on composite beams

Verification background for further numerical models

Numerical modelling

- Finite element model development

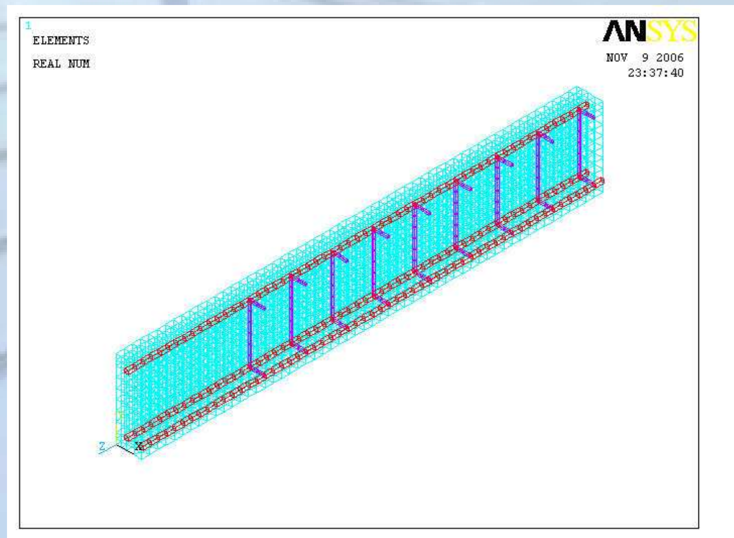
    - 1st concete material model
    - 2nd composite connection model
    - 3rd composite beam model

} ANSYS

Reinforced concrete modelling

- Reinforced concrete beam model test #1
  - Based on published experiment
  - 150x250x2800mm
  - Modelling parameters
    - Concrete:
      - Solid65 solid element
      - 4 required input data
      - 2 kind of failure surface
    - Reinforcement:
      - Link8 spar element if discrete
      - Material property of Solid65 if smeared

Quarter beam model:



Reinforced concrete modelling

- Reinforced concrete beam model test #1

Input data	1/a	1/b	1/c	1/d	1/e	1/f
Concrete compressive strength	-1	69	69	69	69	-1
Concrete tensile strength	5.1	5.1	5.1	5.1	5.1	5.1
Shear transfer coefficient for open crack	-	-	-	0.1	1	1
Shear transfer coefficient for closed crack	-	-	-	0.9	1	1
Failure surface	2D	2D	3D	2D	2D	2D
Reinforcement (d = discrete, s = smeared)	d	d	d	s	d	d

- Loading → four point bending

- Small loadsteps → velocity of crack propagation to be low → numerical stability

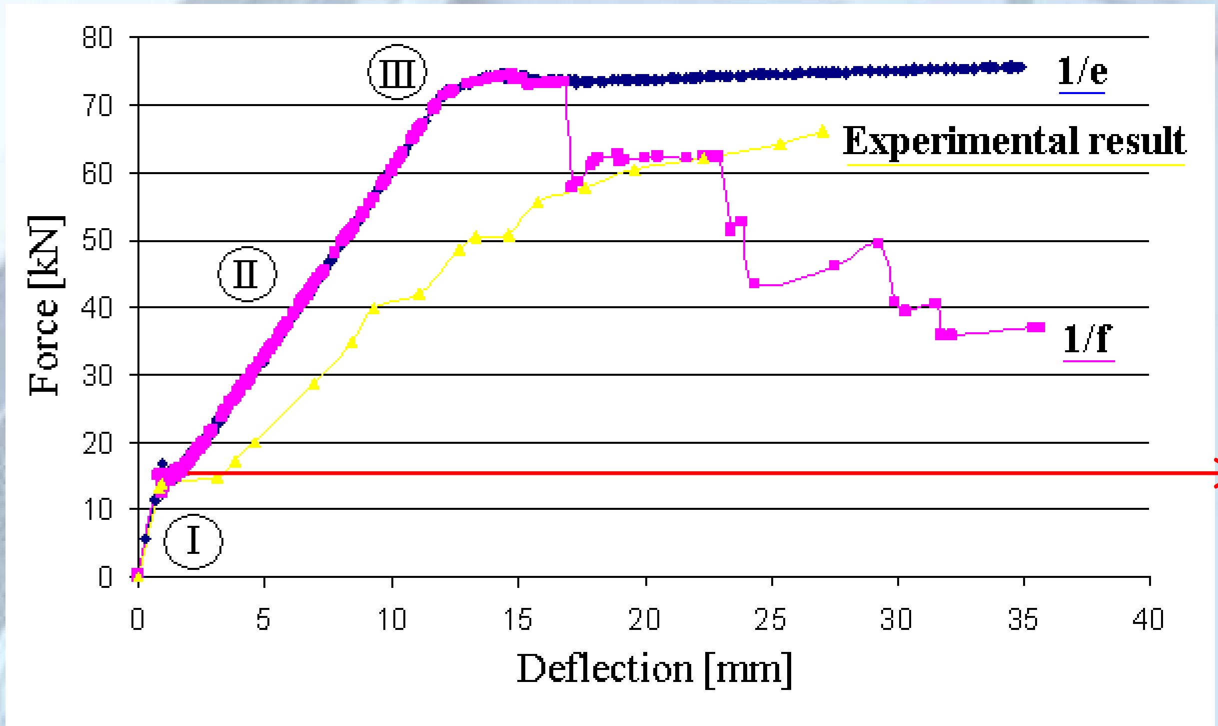
Reinforced concrete modelling

- Reinforced concrete beam model test #1

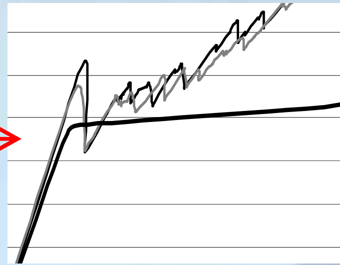
III. stress state:
Yielding of steel

II. stress state:
Cross section
with crack

I. stress state:
Cross section
without crack



Tensile cracks appear:



Reinforced concrete modelling

- Reinforced concrete beam model test #1
  - The numerical model show good accordance with published research
  - Type of failure surface
  - Type of reinforcement

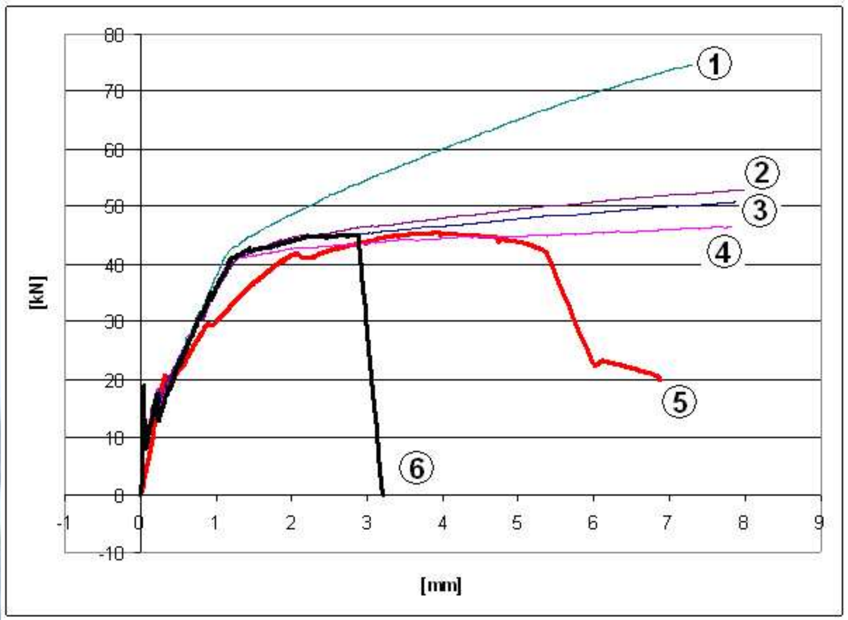
    } No significant effect
  - Numerical stability by small loadsteps (slow crack propagation)

↓ control step ↓

- Reinforced concrete beam model test #2
  - New RC beam model by RC short beam experiment
  - Progressive model calibration

Reinforced concrete modelling

- Reinforced concrete beam model test #2



1) Full reinforcement, non crushing concrete, shear transfer coefficient=1

2) Without stirrups, non crushing concrete, shear transfer coefficient = 1

3) Only tensioned reinforcement, non crushing concrete, shear transfer coefficient = 1

4) Only tensioned reinforcement, non crushing concrete, shear transfer coefficient = 0.3

5) Experimental results

6) Only tensioned reinforcement, crushing concrete, shear transfer coefficient = 0.3

← Crack patterns for first crack and final state

Local models of rolled embossments

- "Fictive" local model

Composite short beam experimental observations

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Major factors in failure

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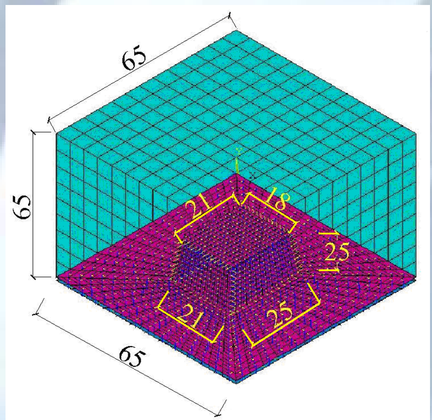
(1) chemical bond,
(2) mechanical bond
- effect of rolled embossments
(3) pull-out of the steel rim.

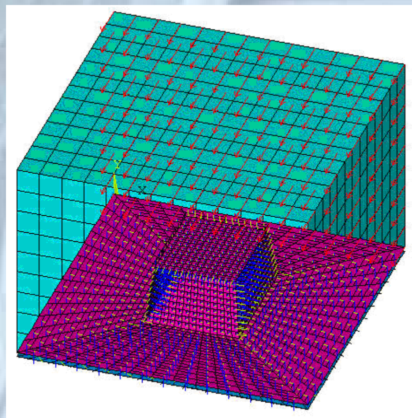
(1)–(2) } General factors → MODELLING

(3) → Short beam's specific factors

Local models of rolled embossments

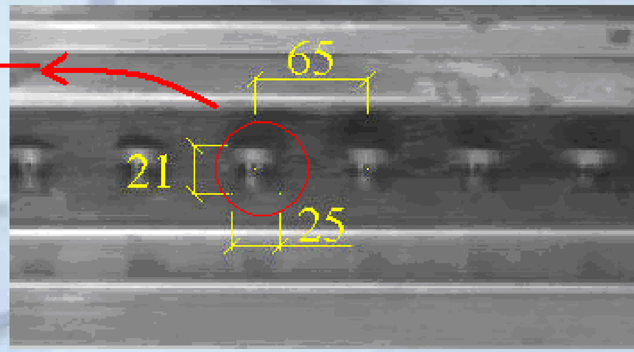
- Local model construction





Simplified geometry

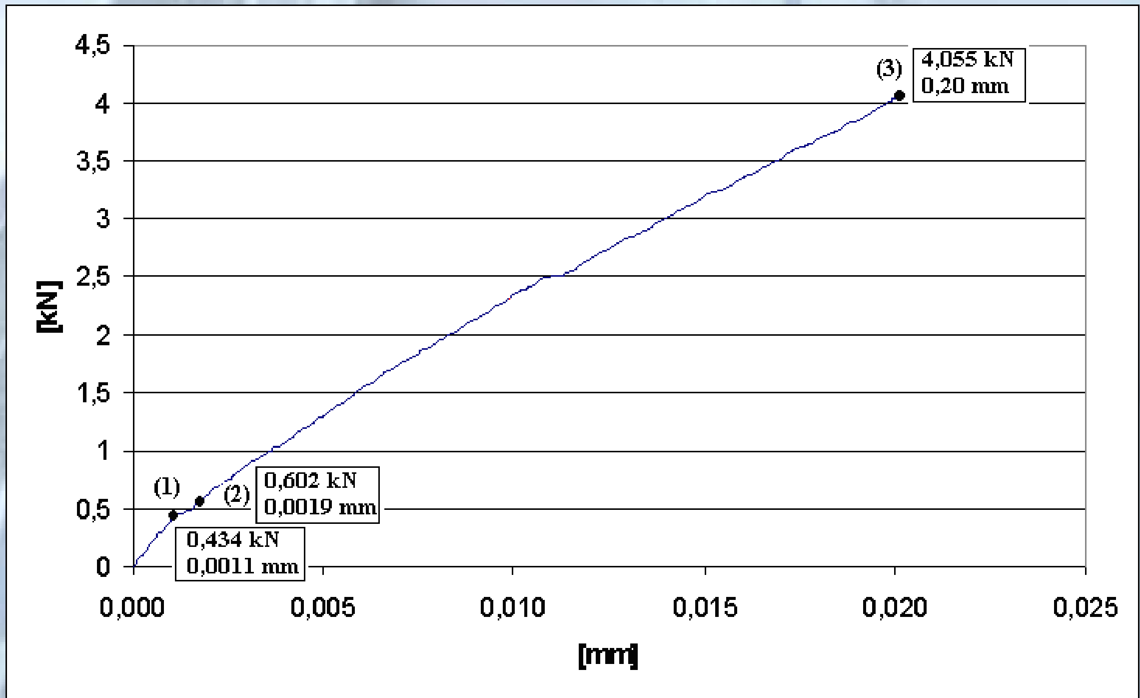
Rectangular dishing type:



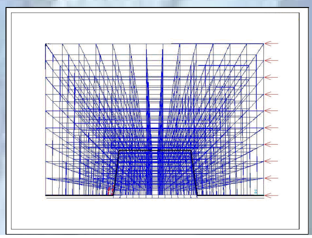
Material	FE in ANSYS
Concrete	Solid65
Steel	Shell181
Frictional interlock	Conta173-Targe170

Local models of rolled embossments

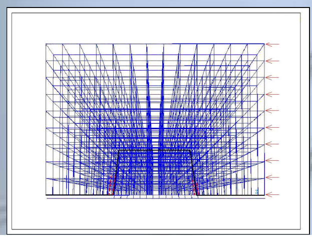
- Results of the local model



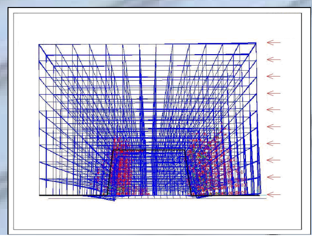
First crack

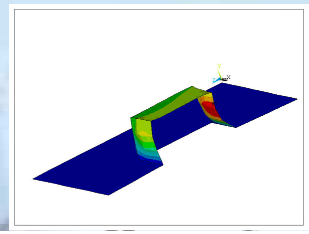


Second crack



Final state: cracks and deformed sheet





Local models of rolled embossments

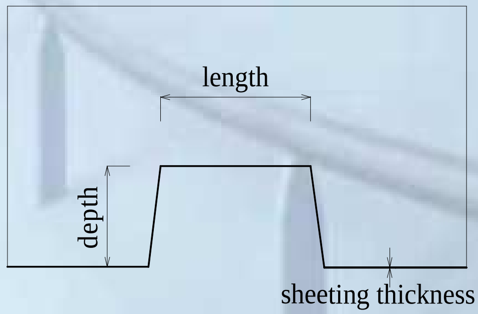
- Results of the local model
  - Runtime ~5 hours
  - Significant increase in runtime when increasing the model size
  - Efficient composite beam model
  - Embossments ⟶ spring
  - Spring constant ⟶ local model analysis

Local models of rolled embossments

- Parametric study by local models

Parameters:

– Embossment’s depth
– Embossment’s length
– Sheeting thickness



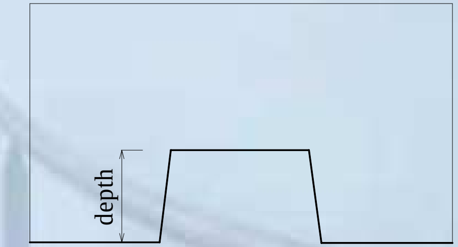
Expected results by experimental observations [1]:

– Deeper embossment → higher shear stress value (most significant)
– Longest length → higher shear resistance (limit!)
– Sheeting thickness → significant effect on stiffness

[1] P. Mäkeläinen, Y. Sun: “The longitudinal shear behaviour of a new steel sheeting profile for composite floor slabs”, Journal of Constructional Steel Research, 49, 117-128, 1999

Parametric study by local models

- Depth analysis

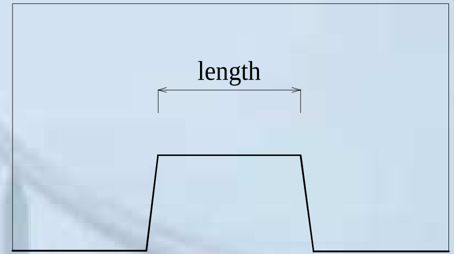


  - Curve’s character remained the same
  - Increase in the load when increasing the depth at the end of linear phase
  - Significant difference in ultimate loads → tendency not obvious

Depth [mm]	Load at the end of the linear phase [kN]	Ultimate load [kN]
10	0.3345	1.304
12.5	0.3588	3.488
15	0.4054	4.055
17.5	0.4095	3.184
22.5	0.4257	3.857
25	0.4340	4.055

Parametric study by local models

- Length analysis



  - Increase in load when increasing the length
  - The difference between the ultimate loads in 10% range

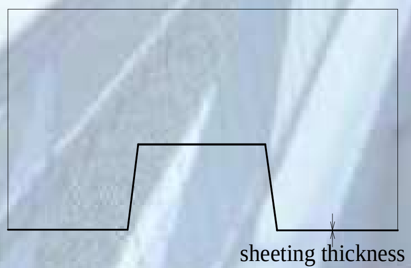
↓

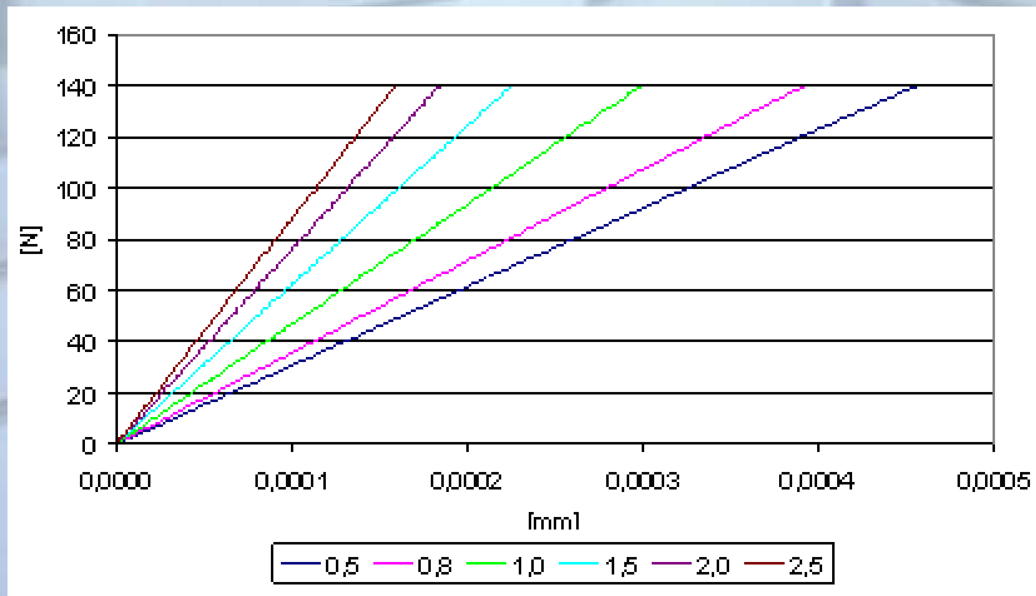
  - The change of length has not significant influence

Length [mm]	Load at the end of the linear phase [kN]	Ultimate load [kN]
15	0.3649	3.604
17.5	0.4054	4.054
20	0.4257	3.812
21	0.4340	4.055
22.5	0.4440	3.925
30	0.5292	3.936

Parametric study by local models

- Effect of sheeting thickness
  - Increase in stiffness when increasing the sheeting thickness





Concluding remarks

- Novel alternative of experimental analysis (short beam) for composite connection.
  - Tendency of the failure modes became traceable → numerical analysis
- Adequate concrete and reinforced concrete model
- Numerical local model for fictive rolled embossments
  - Basic behaviour modes
  - Parametric study ↔ published experiments

Contradiction in the results of the depth and length analysis

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Chosen experiment ↔ traditional push-out tests

Necessity of new laboratory experiments to prove the results

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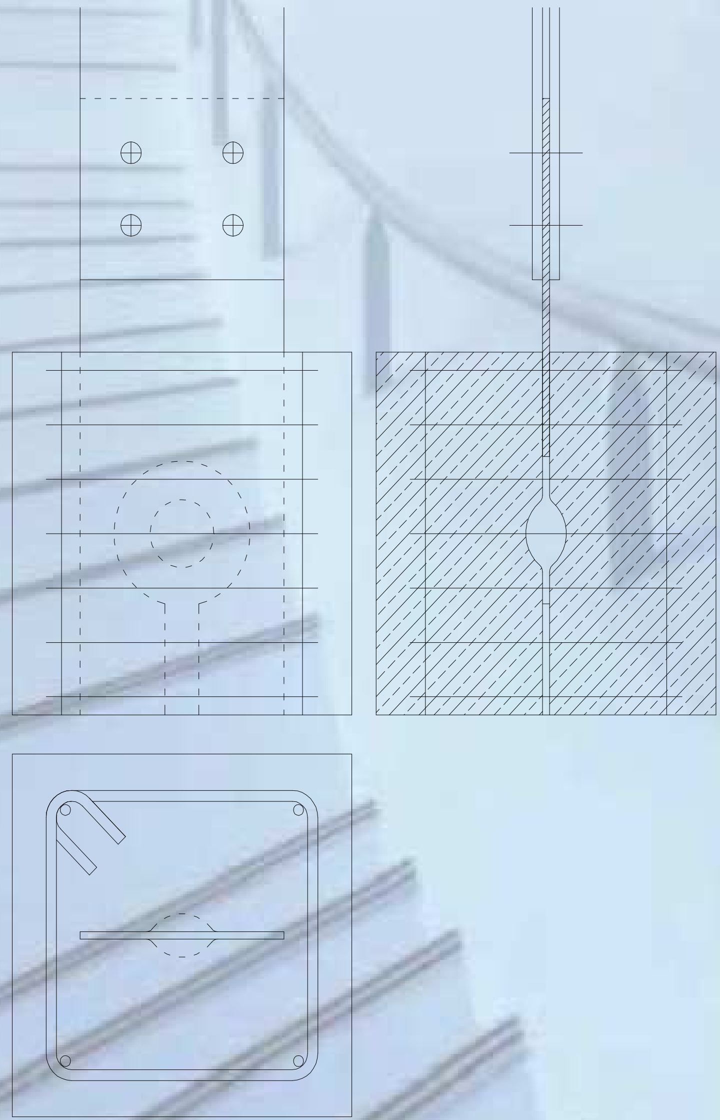
Pilot experimental investigation for local model calibration

Pilot experimental program

- Special pull-out test
  - 20x20x20 RC cube
  - Embedded steel plate with one enlarged embossment



Thank you