Timber-concrete composite structures - an overview

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Table of contents

Why composite structures?

Some favourable properties of timber

- Environmentally friendly
- Specific strength and stiffness
- Low weight- Easy to prefabricate, transport and erect
- Easy (and cheap) to shape
- …and much more (aesthetics, low price, availability, workability, etc.)

However, timber has also some unfovourable properties…

Some **unfavourable** properties of timber

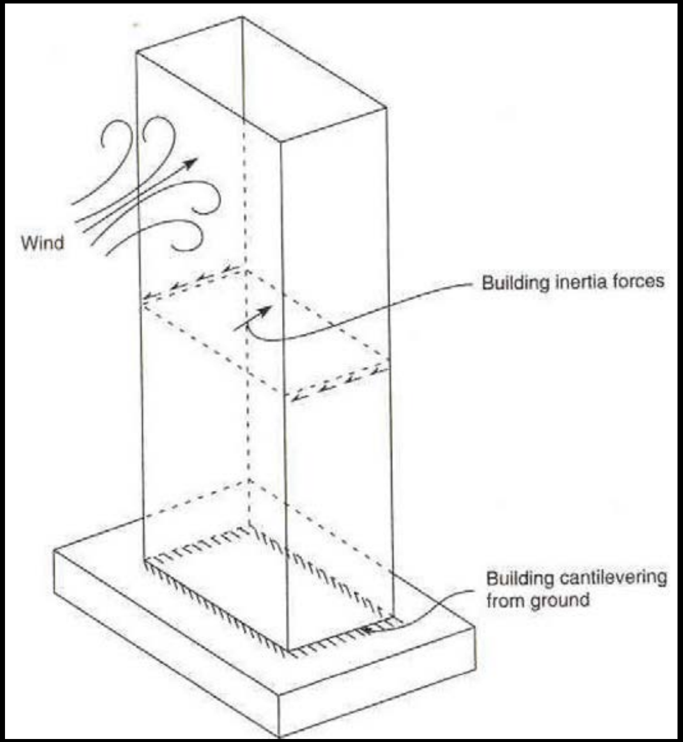
1. Low mass

2. Low Young's modulus

3. High variability of mechanical properties

4. etc

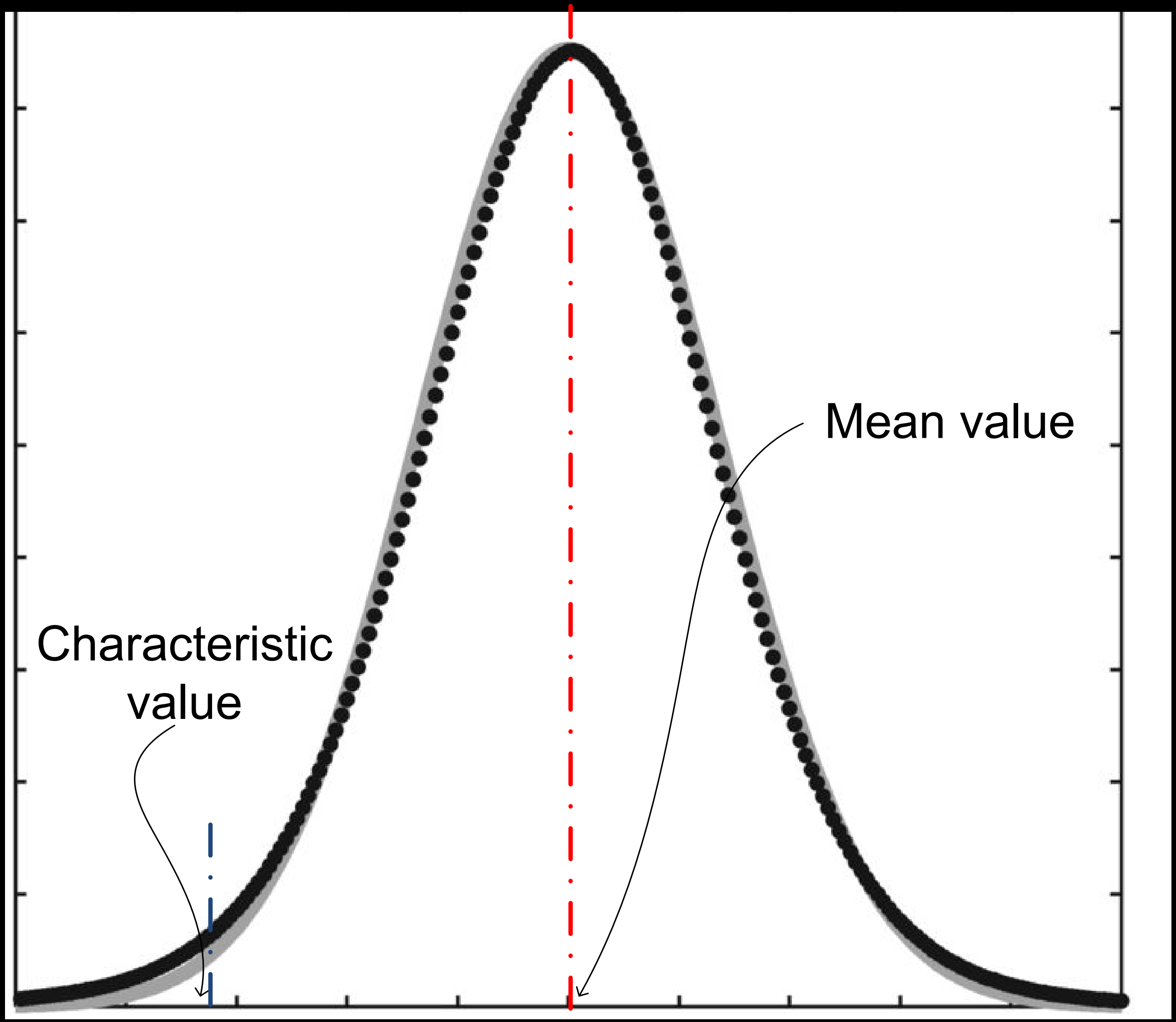
Low mass
Low Young's modulus



- Tilting
- Wind-induced vibration

- Acoustics and vibrations
- Deep floor structure

High variability of mechanical properties



Large scatter → low charactiristic strength

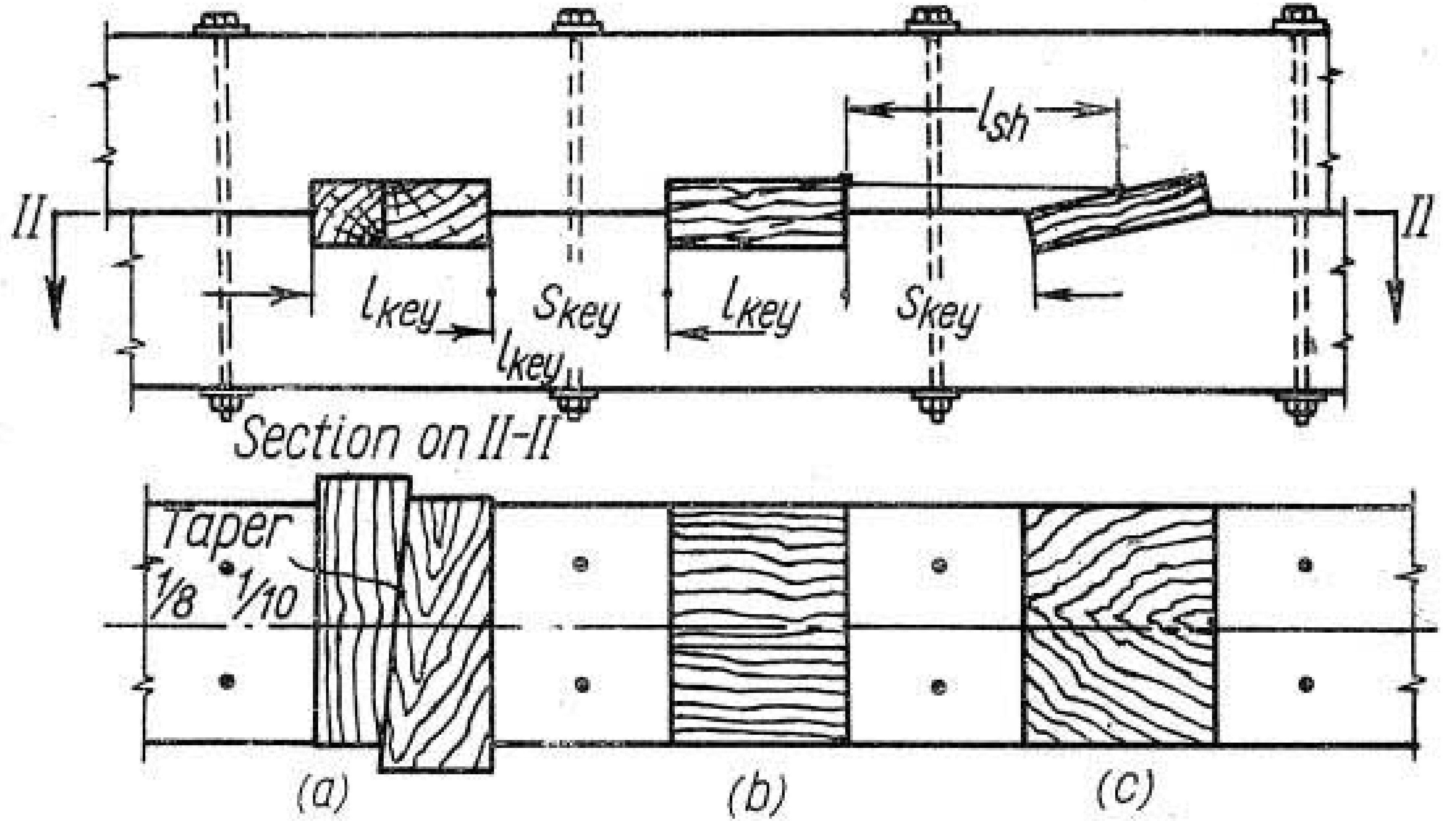
So, what is the solution?

Timber- concrete composite structures

Prefabricated concrete floor, span 8 m, Lund University, 2015

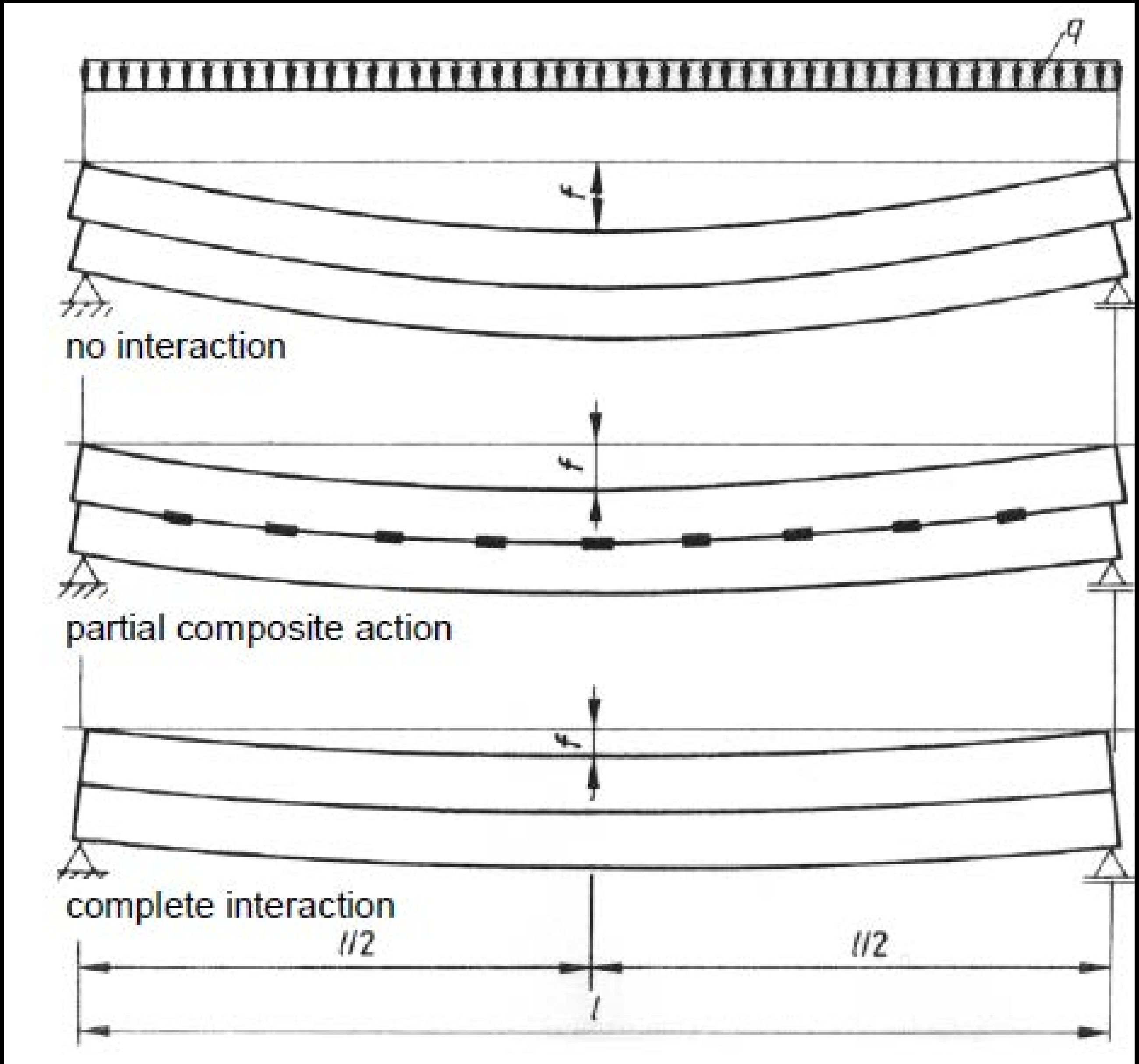
- Significant increase of stiffness (not least in the transversal direction) → reduced vibrations
- Increase of mass → better stability against overturning/tilting, and better acoustic performance
- Reduced depth of floor → better economy

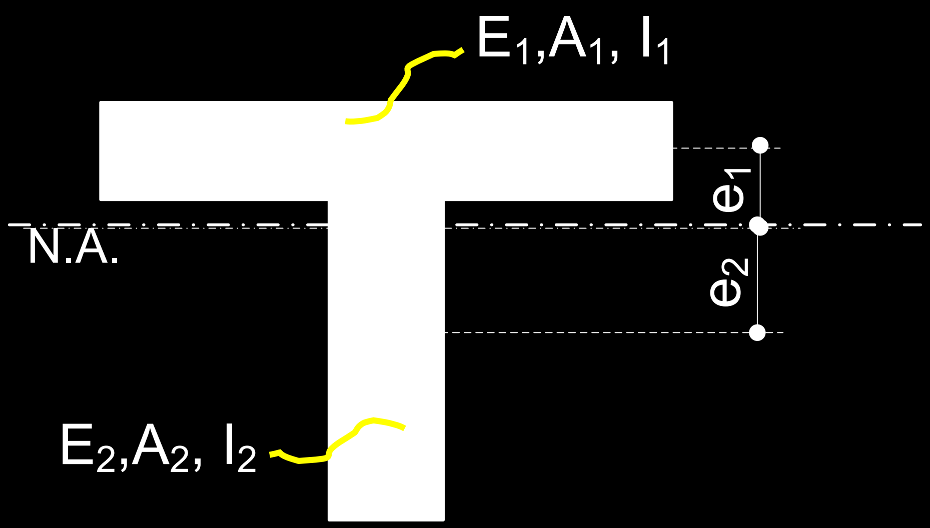
The importance of the shear connectors



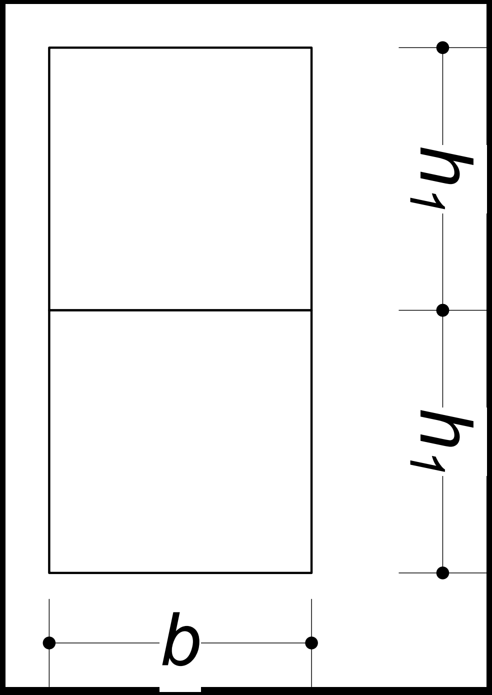
II
II
l_{sh}
l_{key}
S_{key}
l_{key}
S_{key}
l_{key}
Section on II-II
Taper
1/8
1/10
(a)
(b)
(c)

Behaviour of beams with varying composite action





A simple example



No composite action (separated elements)

BENDING STRENGTH : $W_S = \frac{b \cdot h_1^2}{6} \cdot 2 = \frac{b h_1^2}{3}$

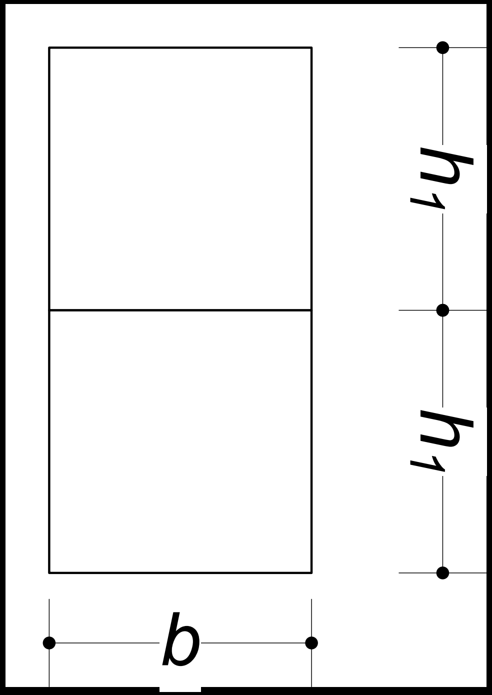
" STIFFNESS : $I_S = \frac{b h_1^3}{12} \cdot 2 = \frac{b h_1^2}{6}$

Full-composite action (separated elements)

BENDING STRENGTH : $W_G = \frac{b \cdot (2 h_1)^2}{6} = \frac{b \cdot 4 h_1^2}{6} = 2 \frac{b h_1^2}{3}$

" STIFFNESS : $I_G = \frac{b (2 h_1)^3}{12} = \frac{b \cdot 8 h_1^3}{12} = 4 \frac{b h_1^3}{12}$

A simple example

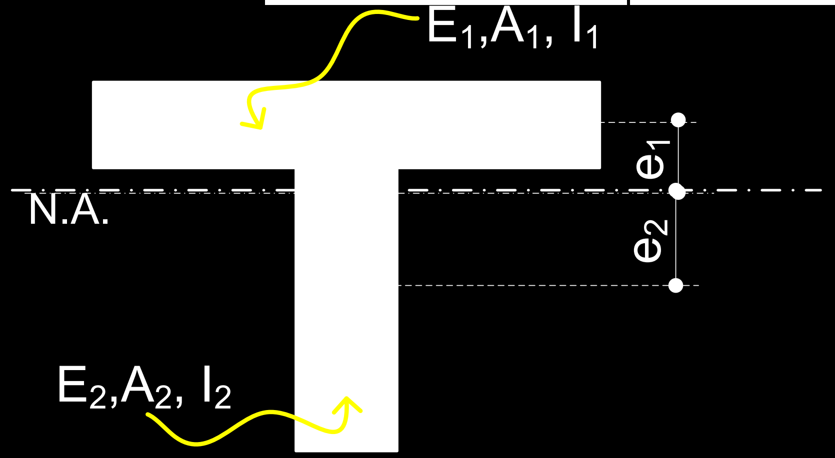


$$Strength \Rightarrow \frac{W_{full-composite}}{W_{non-composite}} = 2$$

$$Stiffness \Rightarrow \frac{I_{full-composite}}{I_{non-composite}} = 4$$

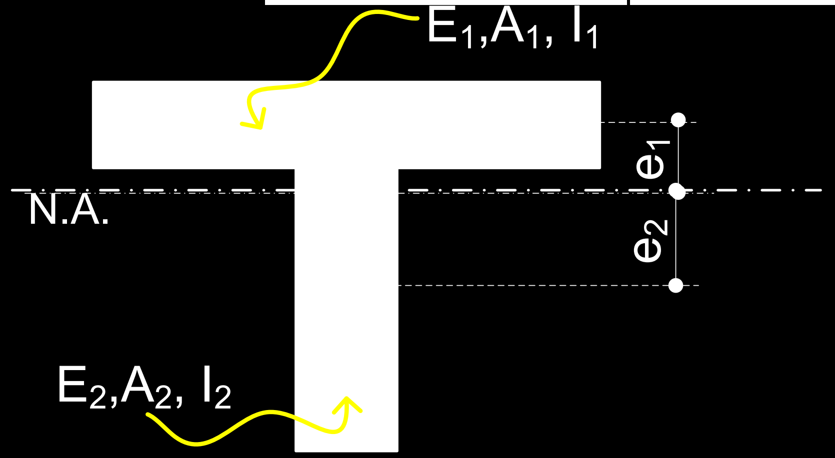
Timber-concrete beams with incomplete composite action

Composite action	Axial stiffness	Bending stiffness
None	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$E_1 \cdot I_1 + E_2 \cdot I_2 = (E \cdot I)_0$
Full	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$(E \cdot I)_0 + E_1 \cdot A_1 \cdot e_1^2 + E_2 \cdot A_2 \cdot e_2^2$
Incomplete	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$(E \cdot I)_0 + \gamma_1 \cdot E_1 \cdot A_1 \cdot e_1^2 + E_2 \cdot A_2 \cdot e_2^2$



Timber-concrete beams with incomplete composite action

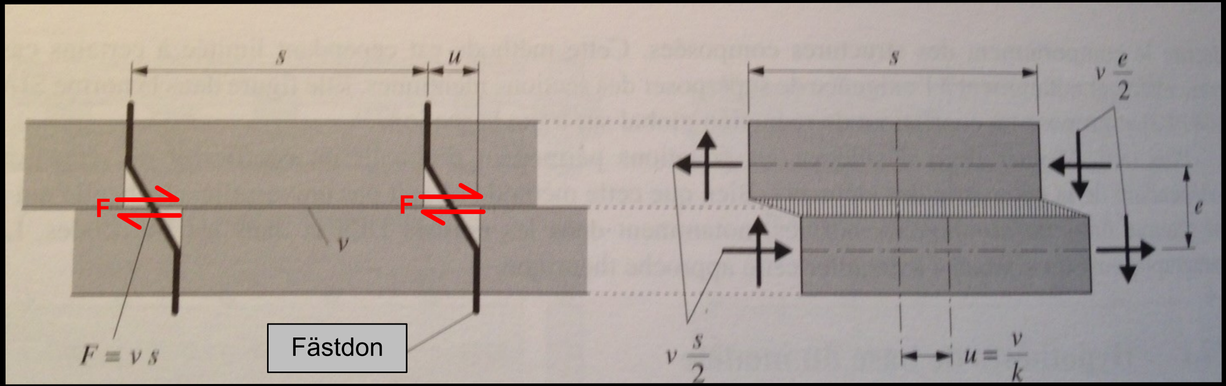
Composite action	Axial stiffness	Bending stiffness
None	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$E_1 \cdot I_1 + E_2 \cdot I_2 = (E \cdot I)_0$
Full	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$(E \cdot I)_0 + E_1 \cdot A_1 \cdot e_1^2 + E_2 \cdot A_2 \cdot e_2^2$
Incomplete	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$(E \cdot I)_0 + \gamma_1 \cdot E_1 \cdot A_1 \cdot e_1^2 + E_2 \cdot A_2 \cdot e_2^2$



$$0 \leq \gamma_1 \leq 1$$

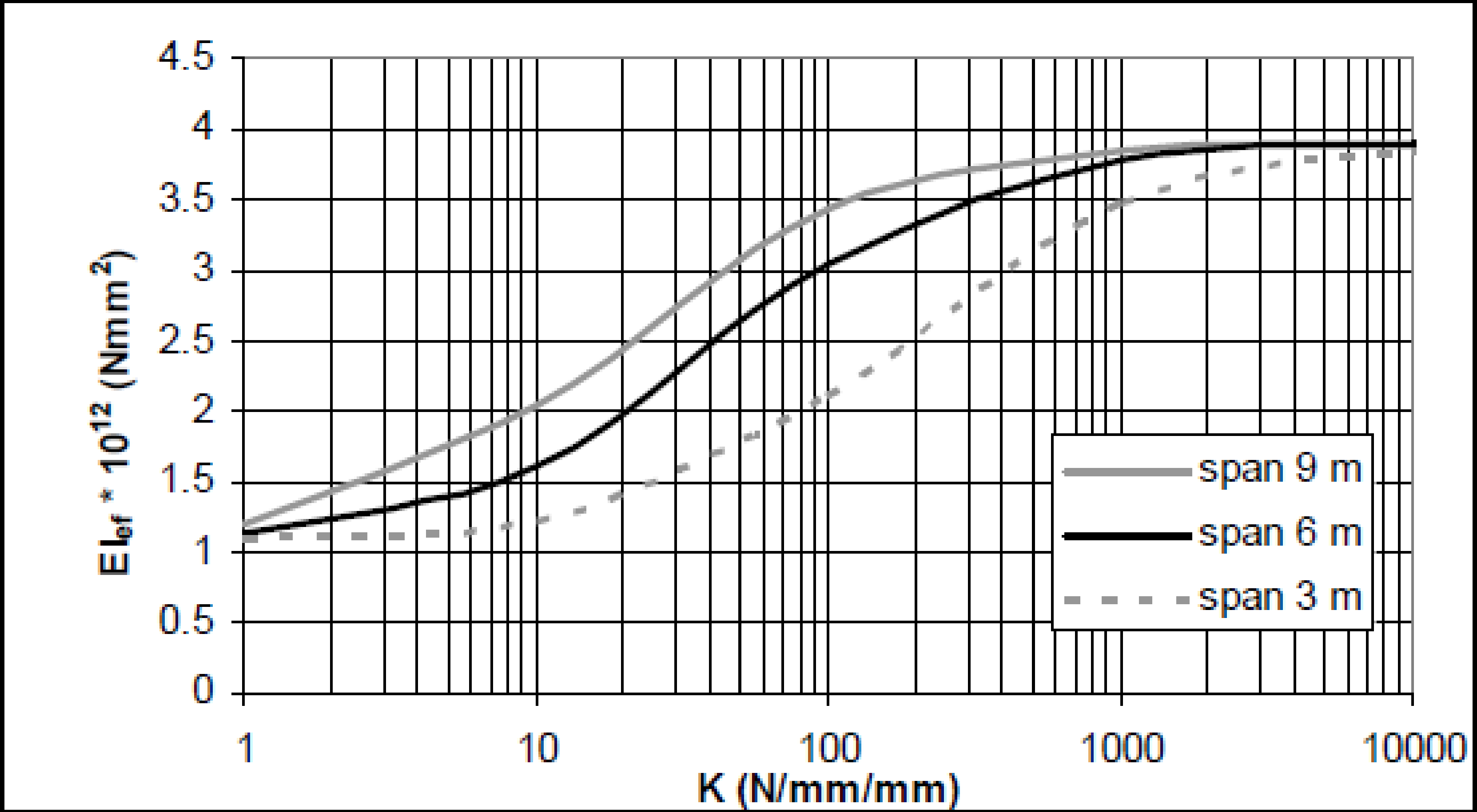
Timber-concrete beams with incomplete composite action

Incomplete	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$(E \cdot I)_0 + \gamma_1 \cdot E_1 \cdot A_1 \cdot e_1^2 + E_2 \cdot A_2 \cdot e_2^2$



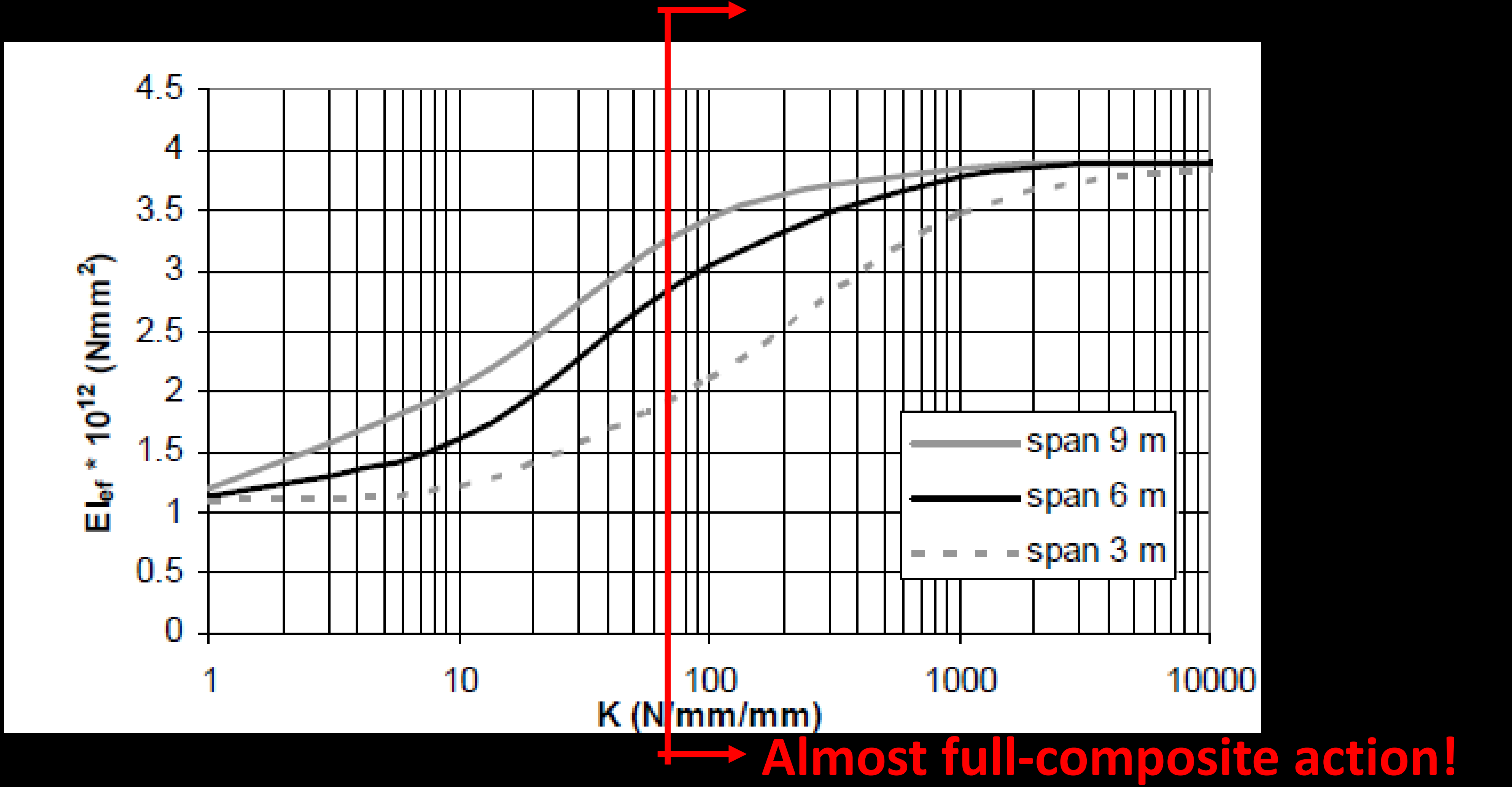
$$\gamma_1 = \frac{1}{1 + \frac{\pi^2 \cdot E_1 \cdot A_1}{k \cdot L^2}}$$

How important is “k”



Relationship between the bending stiffness of the composite structure and the slip modulus of the joint on a logarithmic scale (Van der Linden, 1999)

How important is the shear stiffness of the connector (K)?



Relationship between the bending stiffness of the composite structure and the slip modulus of the joint on a logarithmic scale (Van der Linden, 1999)

Type of shear connectors

Typical connectors

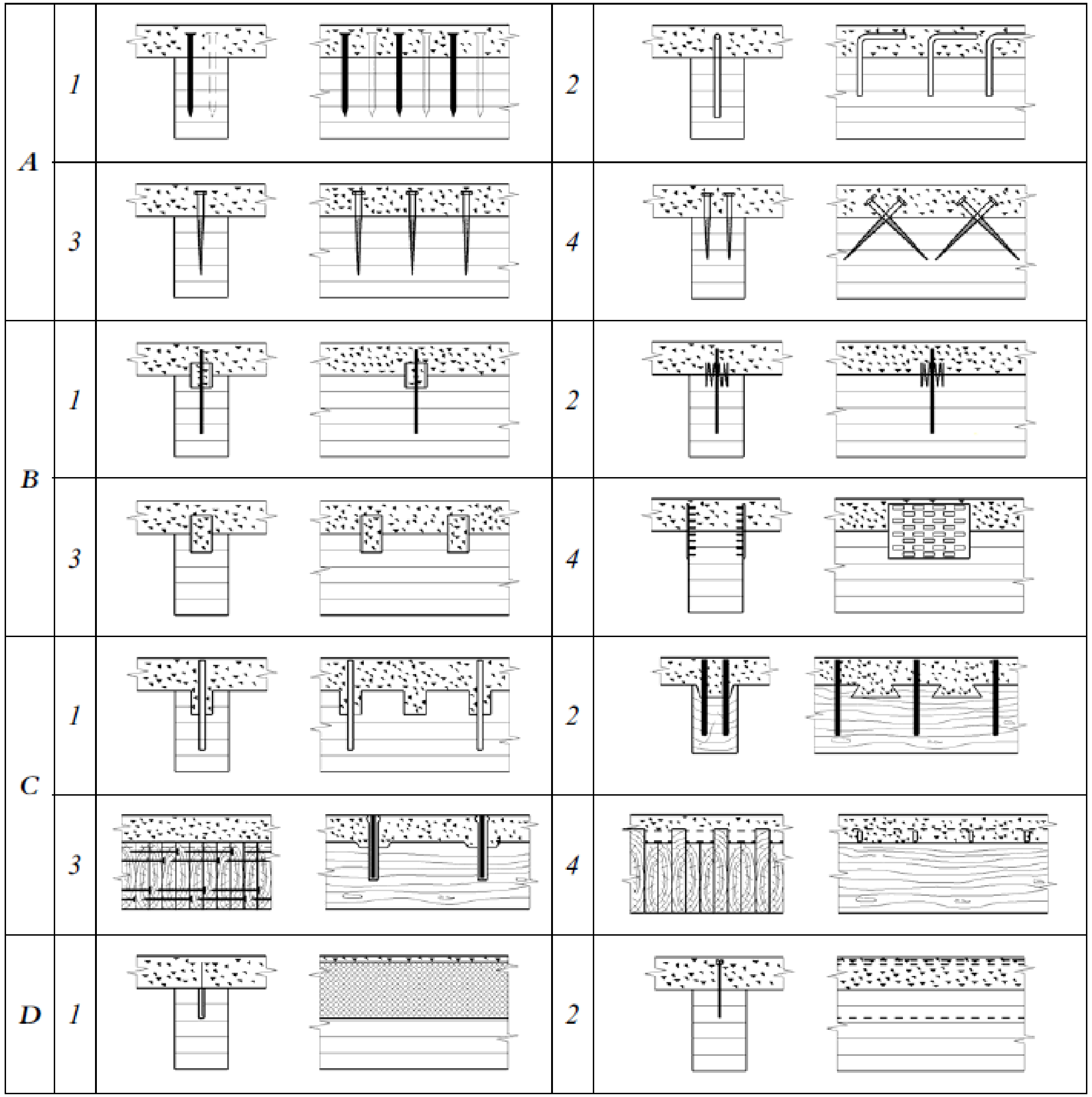
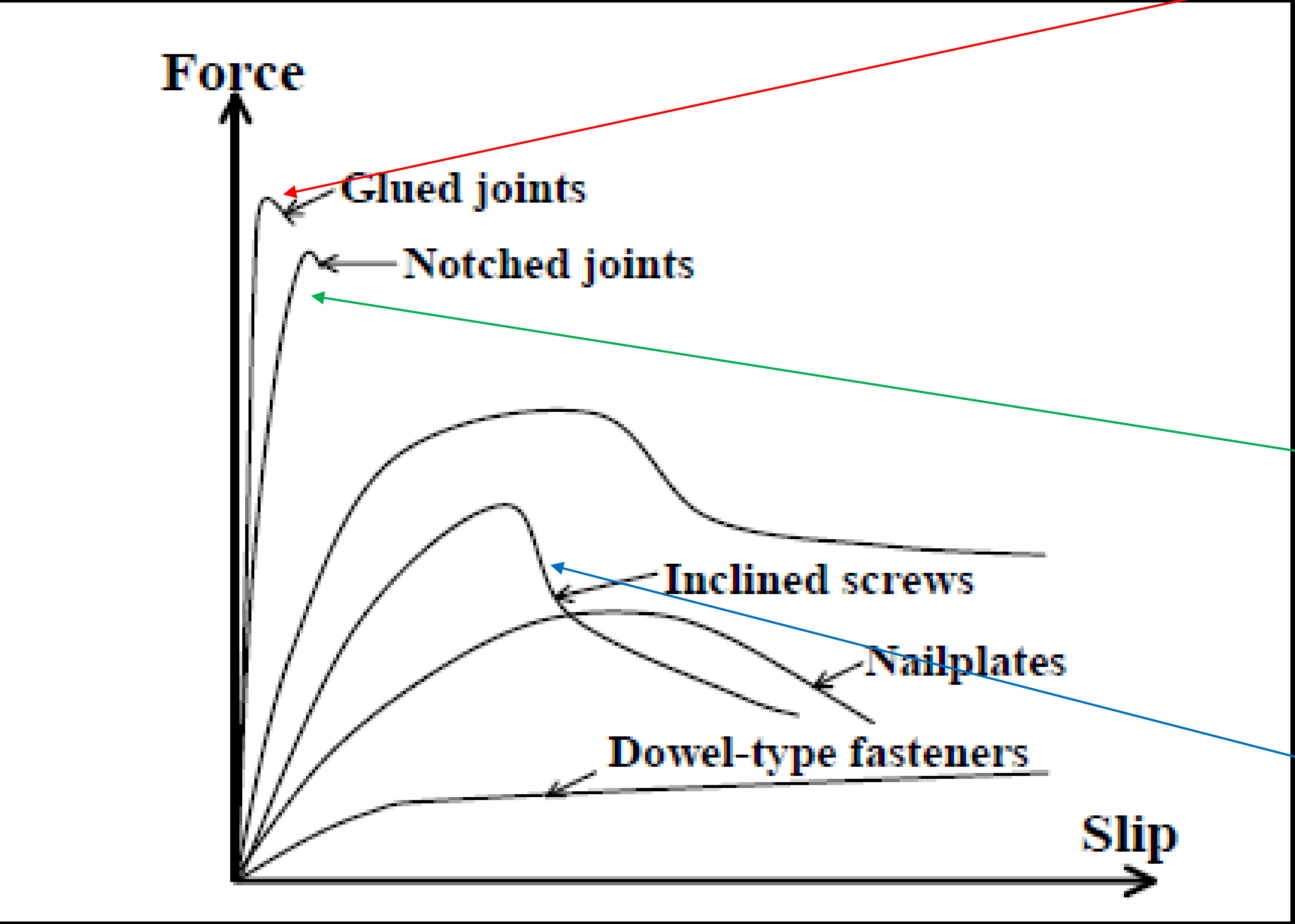
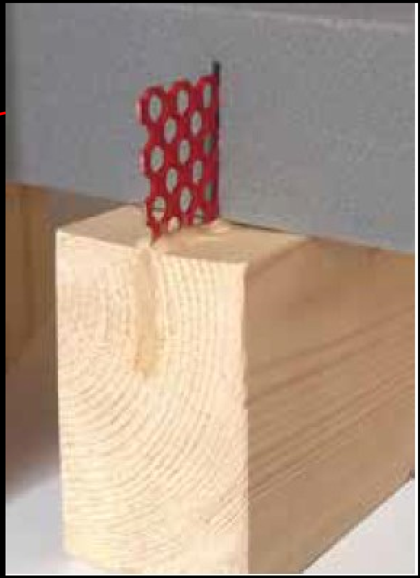
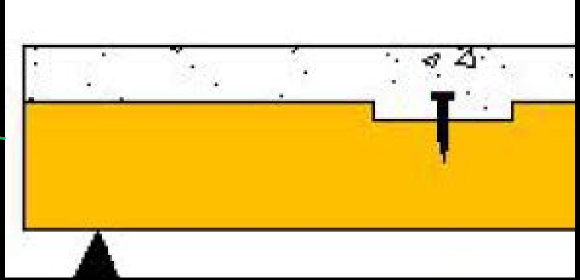


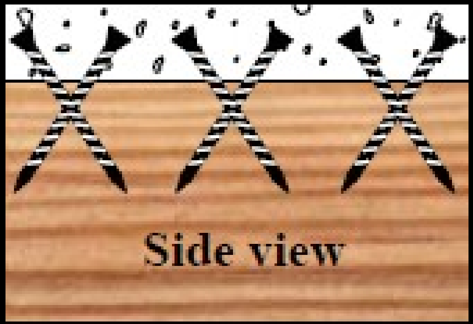
Figure 2.3 Examples of timber-concrete connections with: nails (**A1**); glued reinforced concrete steel bars (**A2**); screws (**A3**); inclined screws (**A4**); split rings (**B1**); toothed plates (**B2**); steel tubes (**B3**); steel punched metal plates (**B4**); round indentations in timber, with fasteners preventing uplift (**C1**); square indentations, ditto (**C2**); cup indentations and prestressed steel bars (**C3**), nailed timber planks deck and steel shear plates slotted through the deeper planks (**C4**), steel lattice glued to timber (**D1**); and steel plate glued to timber (**D2**).

Typical connectors – shear stiffness (qualitative)



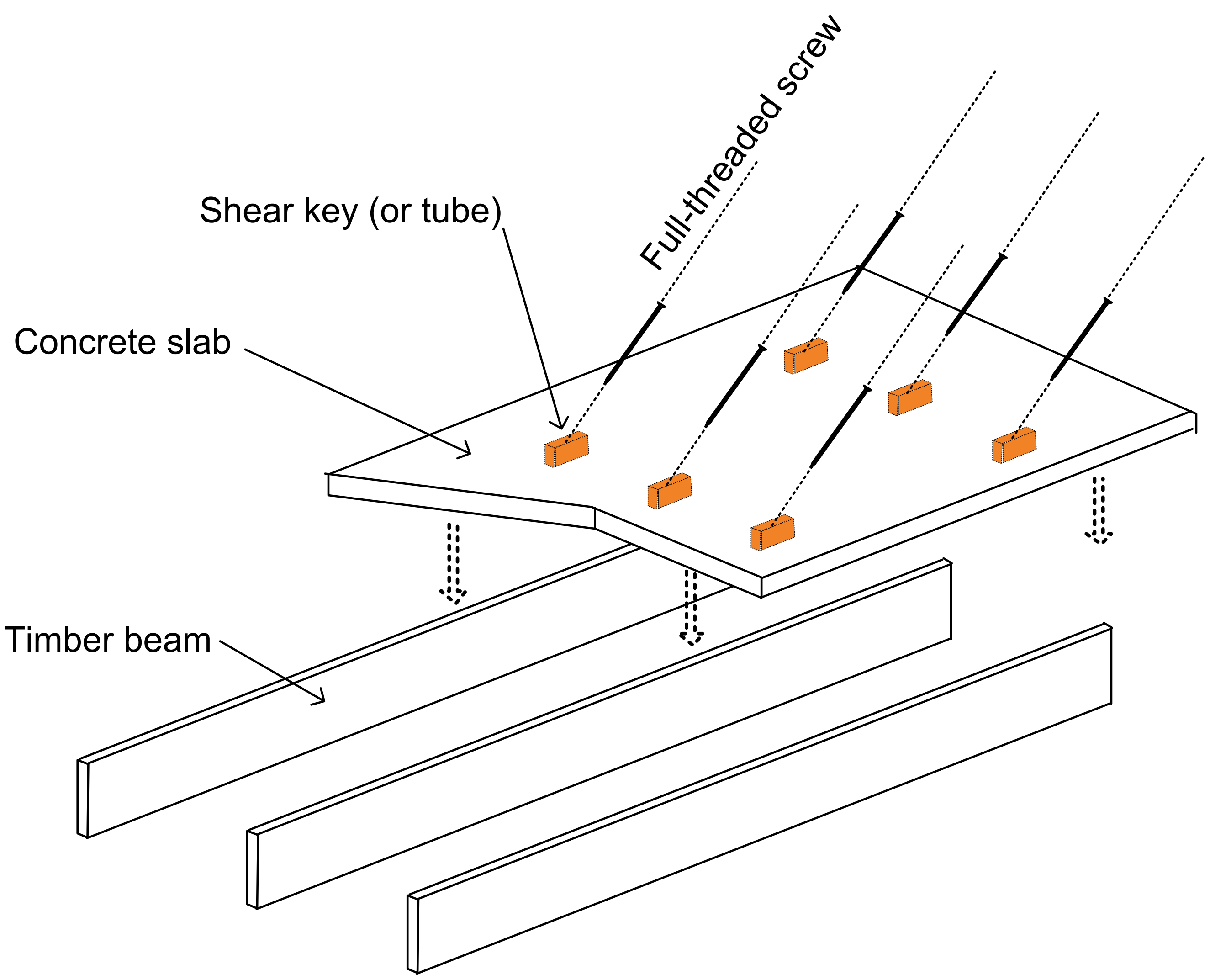






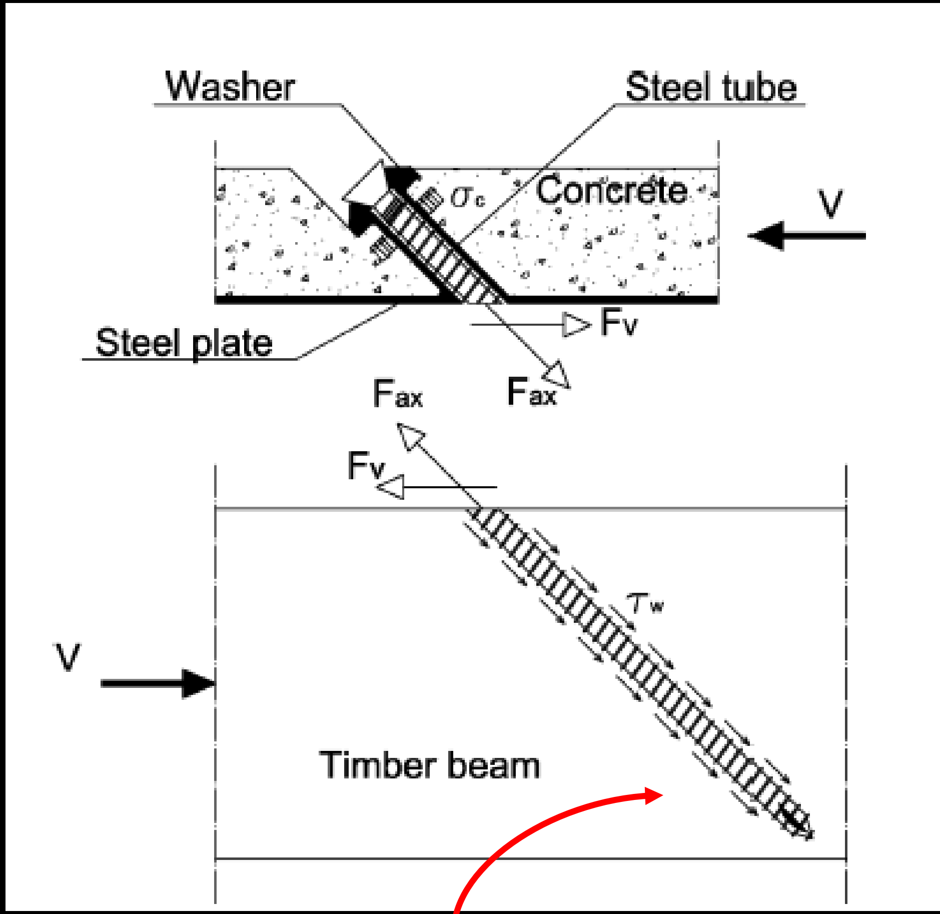
Research at Lund University

Research at Lund University: the first concept (2009)



T-connector

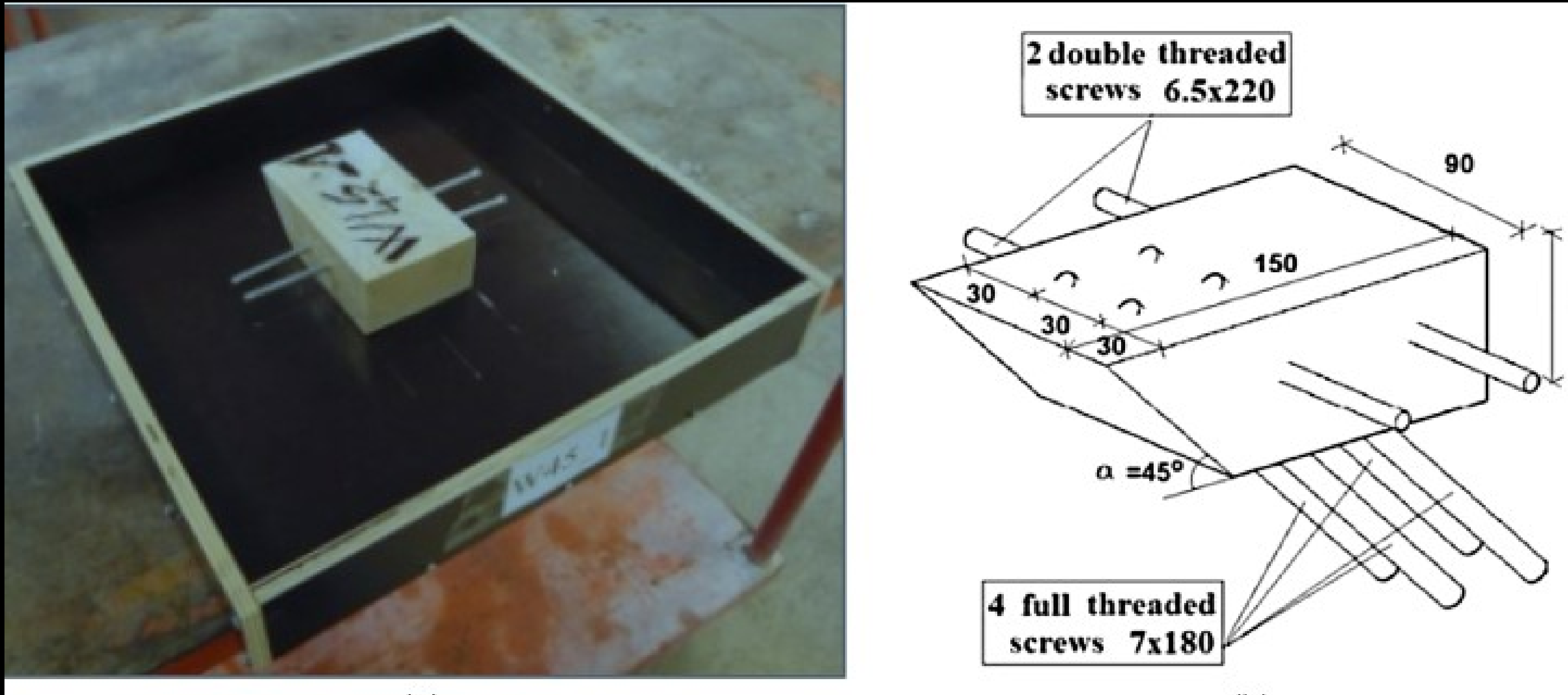
Steel tube d=12 mm, t=2mm



Self-tapping screw: 11x250

T-connector in a “real floor”

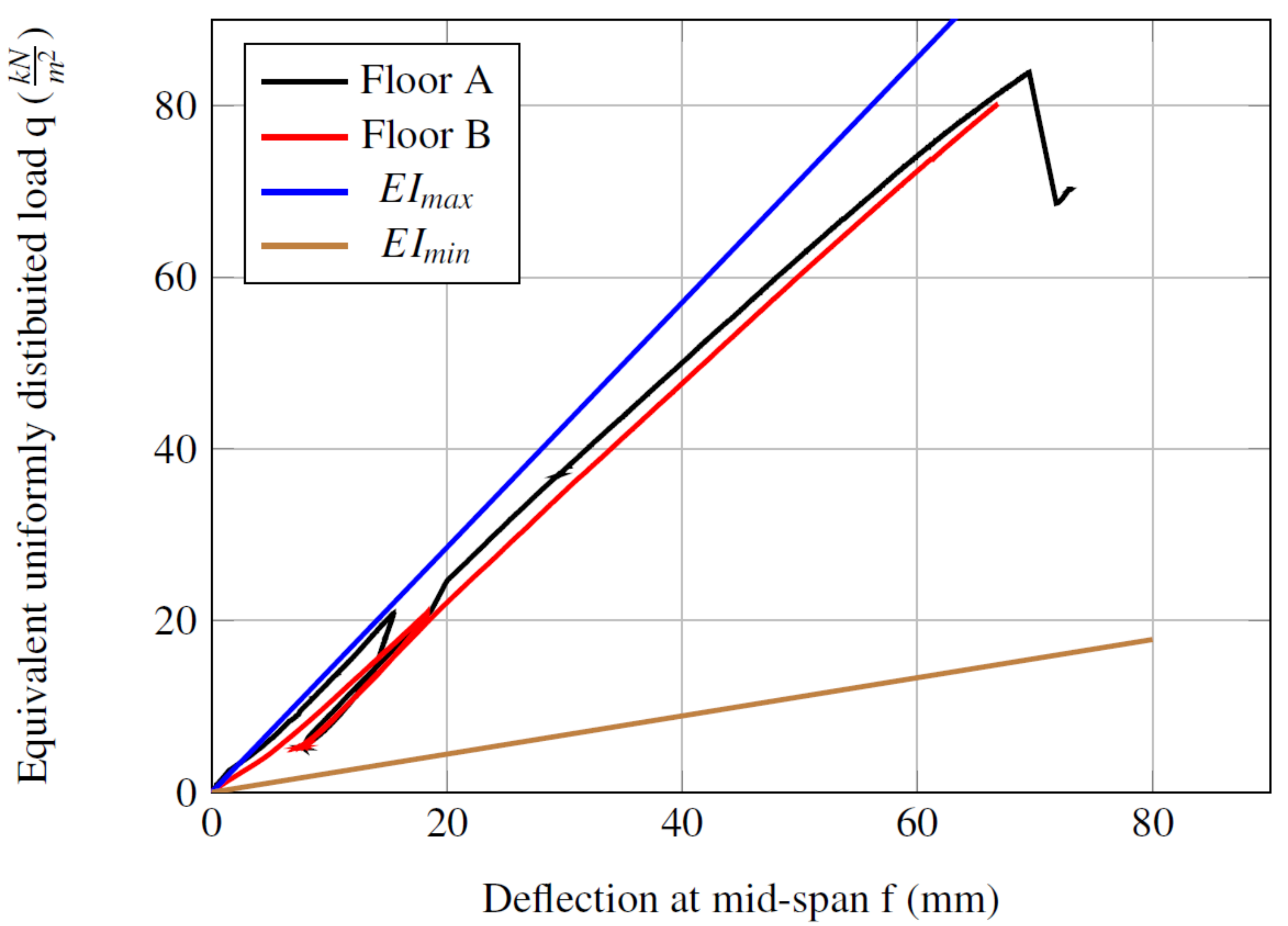
W-connector



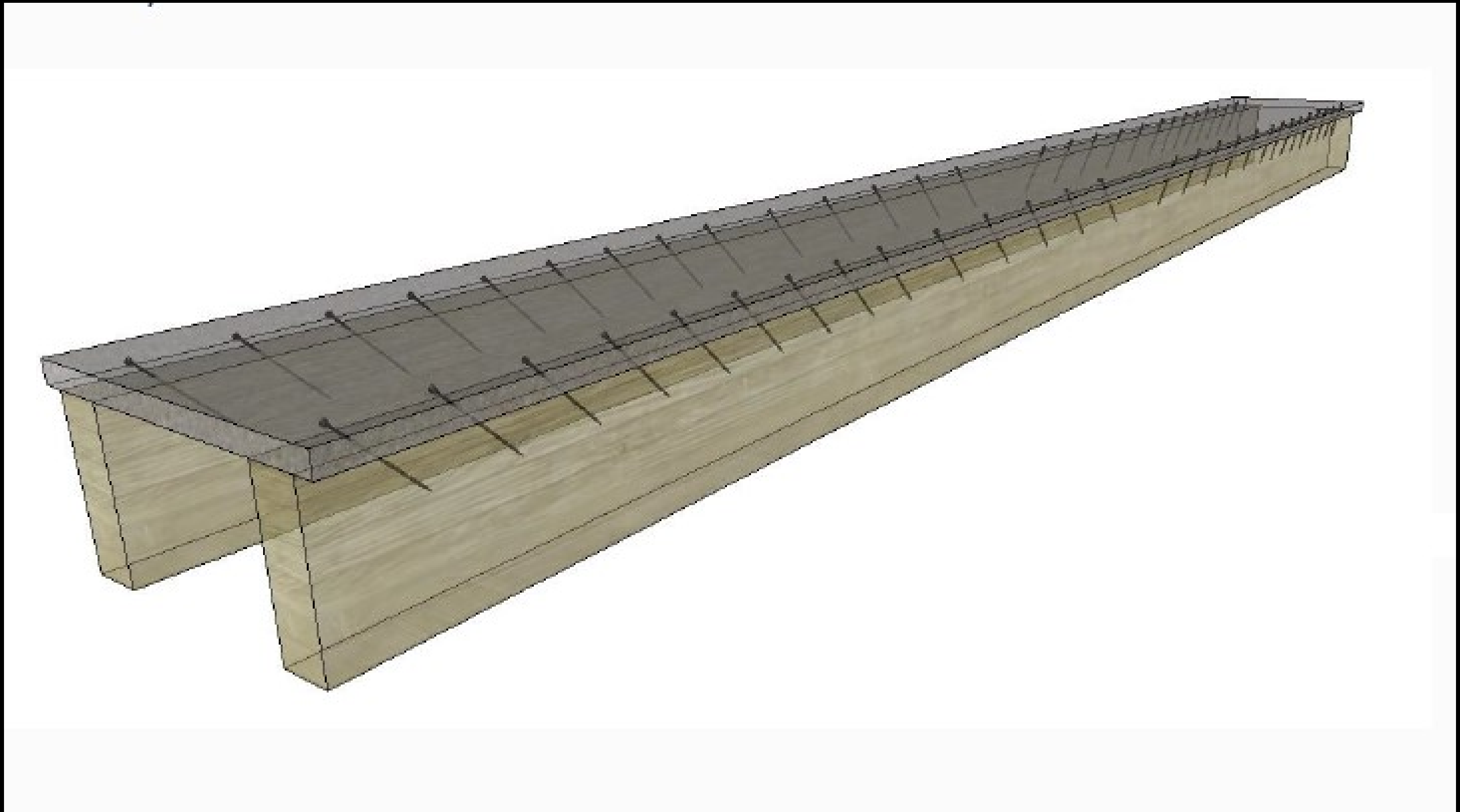
(a) (b)

W-connector in a "real floor"

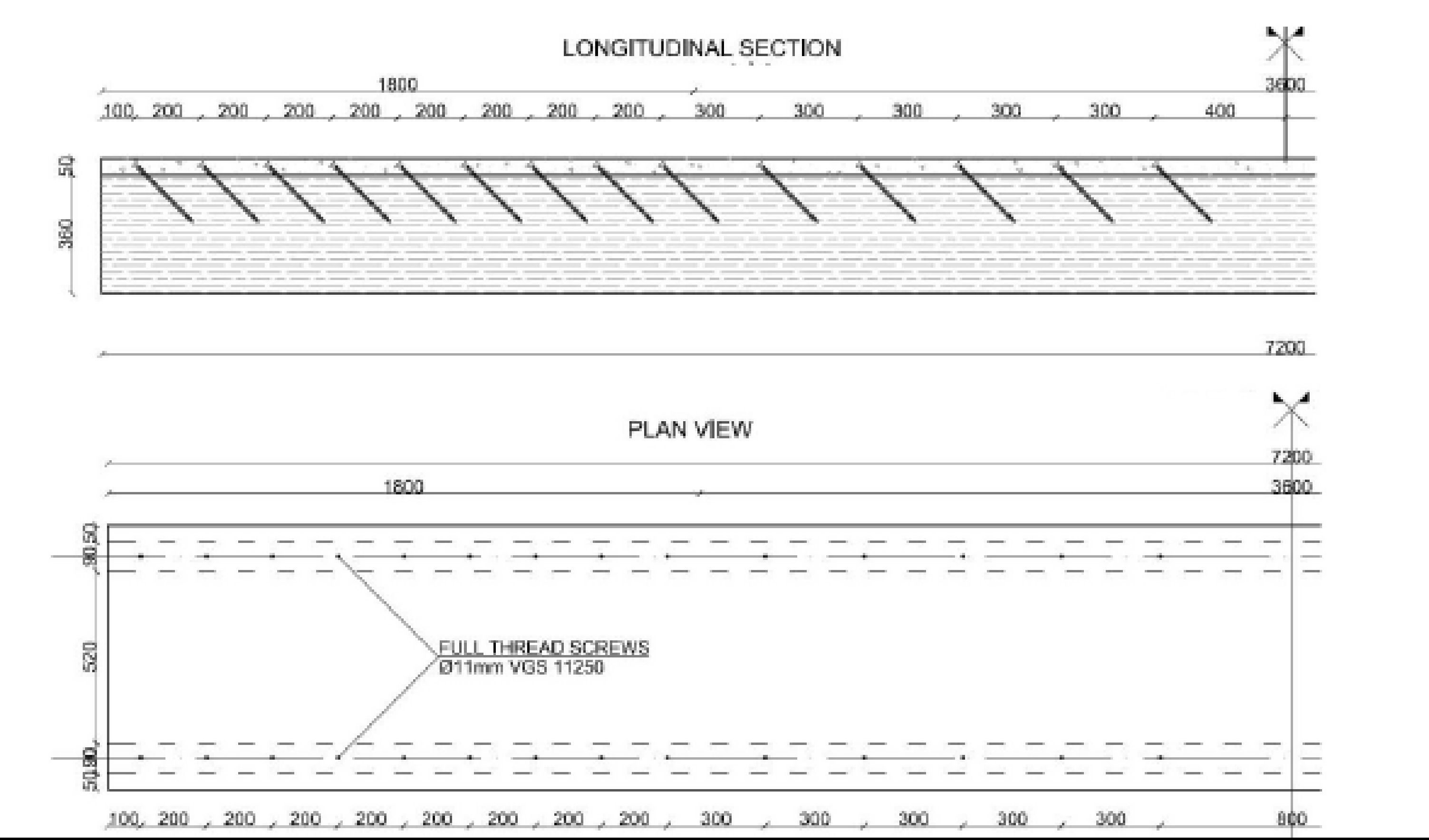
Bending stiffness of the floors

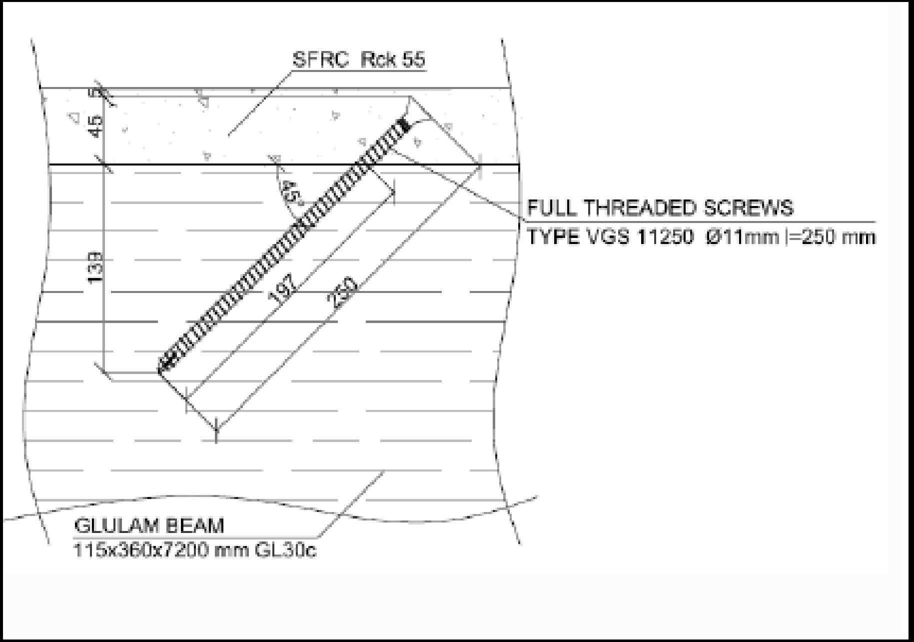


Research at Lund University: the second concept (2012-2013)



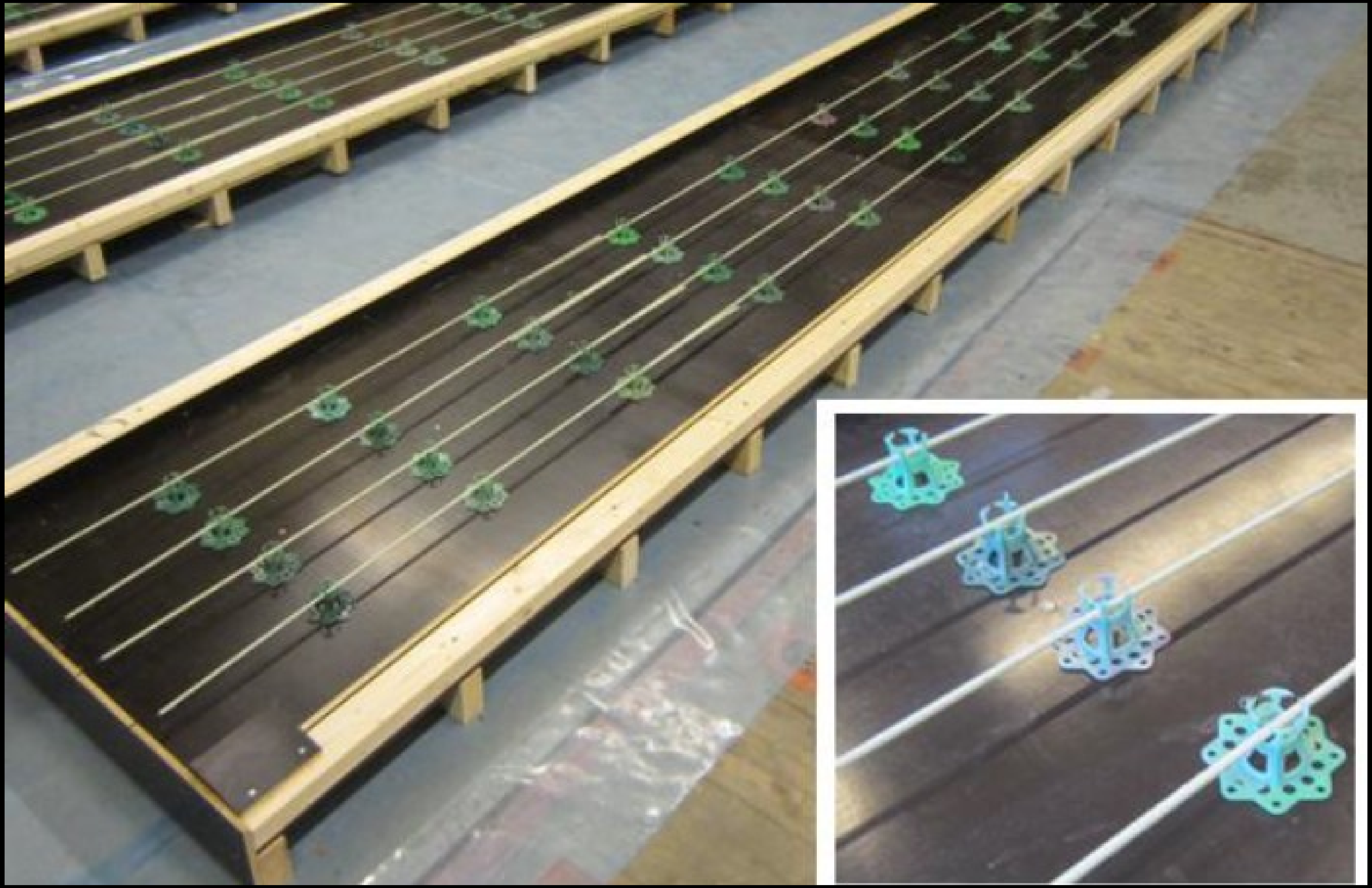
Geometry


LONGITUDINAL SECTION
1800
3600
100 200 200 200 200 200 200 200 200 300 300 300 300 300 400
50
360
7200
PLAN VIEW
7200
1800
3600
FULL THREAD SCREWS
Ø11mm VGS 11250
520
100 200 200 200 200 200 200 200 200 300 300 300 300 300 800


SFRC Rck 55
5
45
45°
139
197
250
FULL THREADED SCREWS
TYPE VGS 11250 Ø11mm l=250 mm
GLULAM BEAM
115x360x7200 mm GL30c

1. Insert full-threaded screws

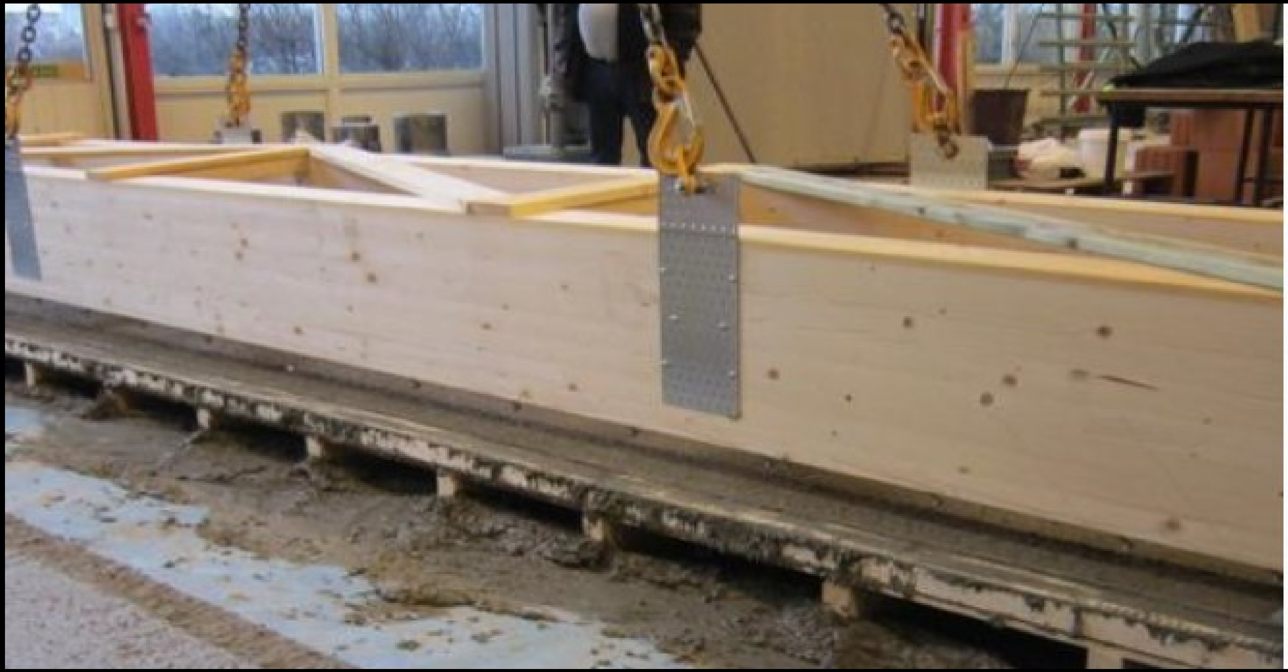
2. Prepare the formworks



3. a) Cast the concrete

b) Turn the beams upside down

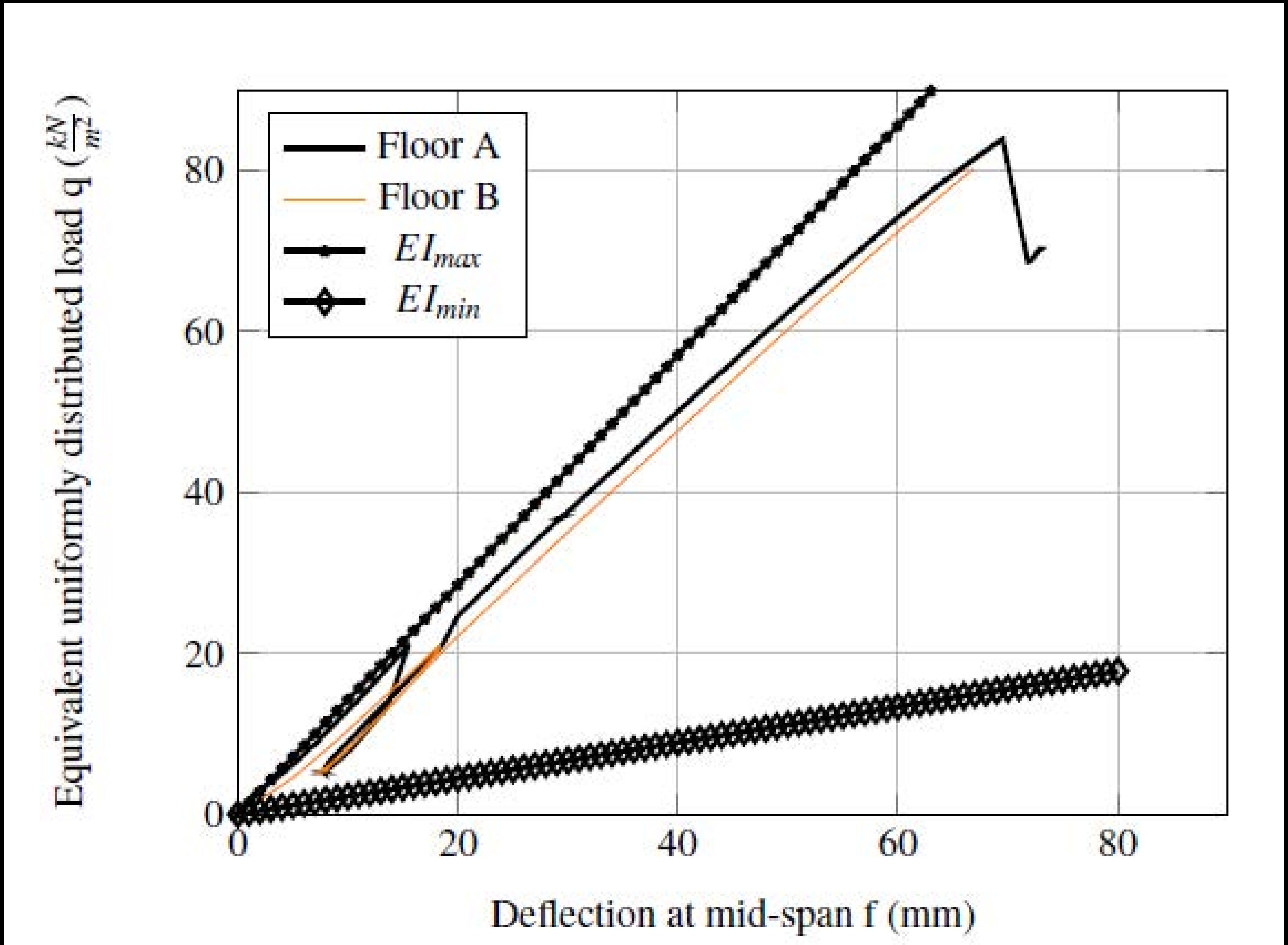
c) Put the beam in the formwork



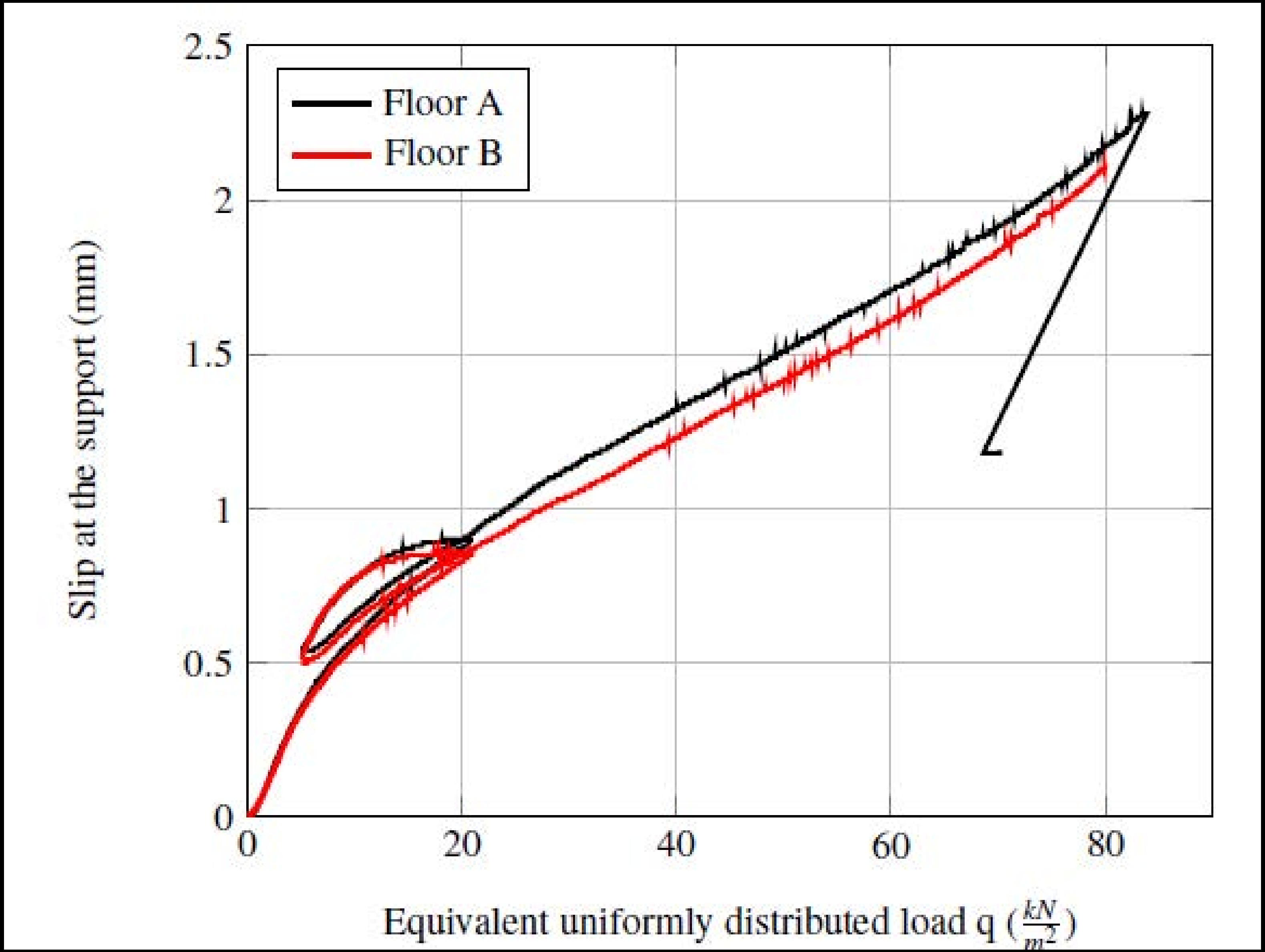
4. After concrete has cured, turn the floor upside down to "right" position

5. Done!

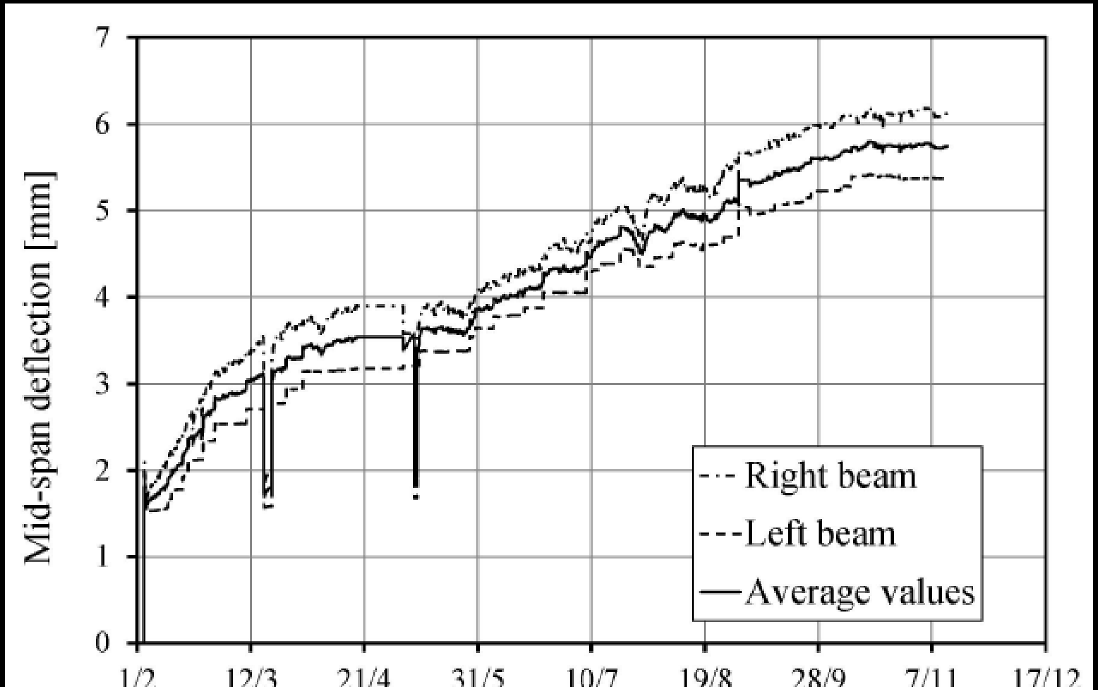
Load vs. mid-span deflection – 2 tests

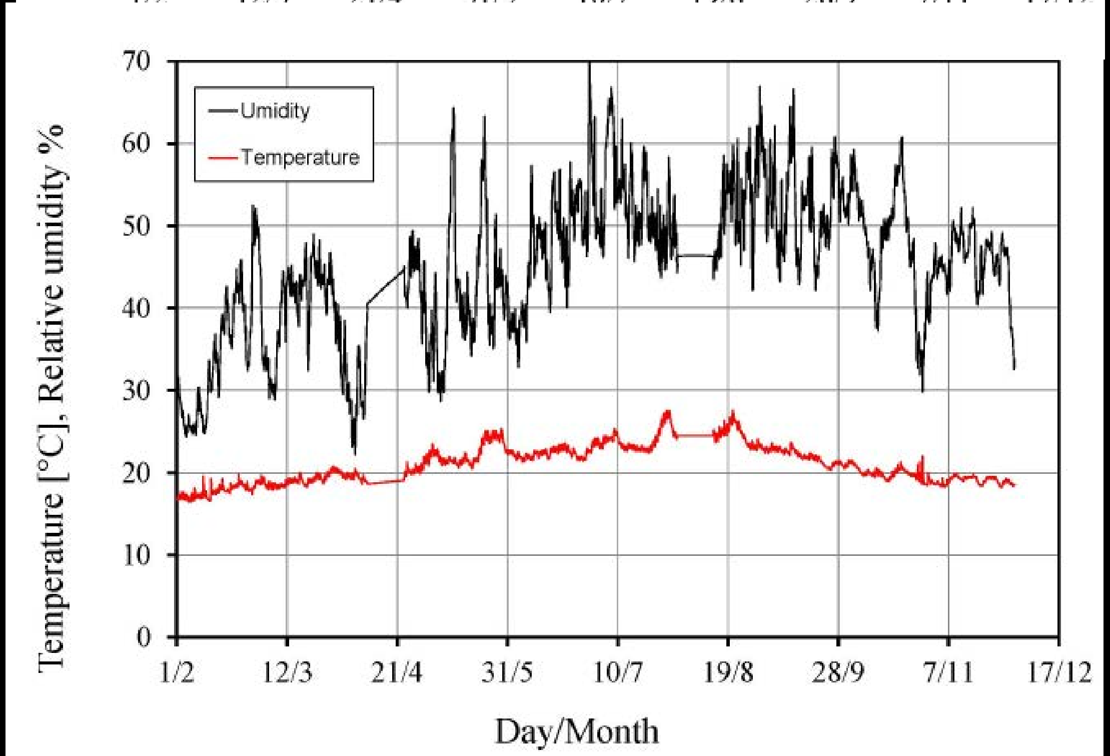


Load vs. end-slip – 2 tests



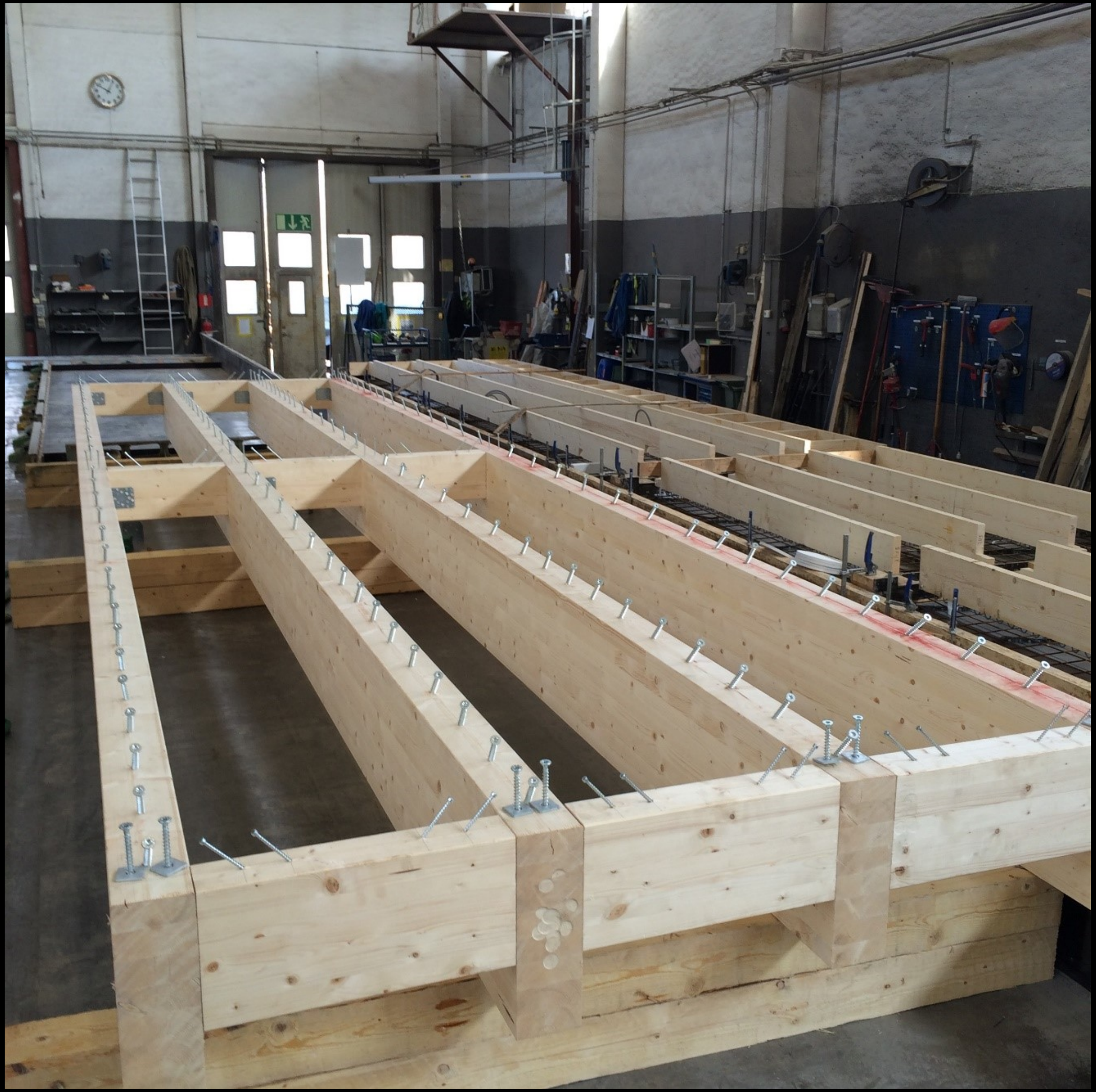
Long-term behaviour





Another type of prefabricated floor

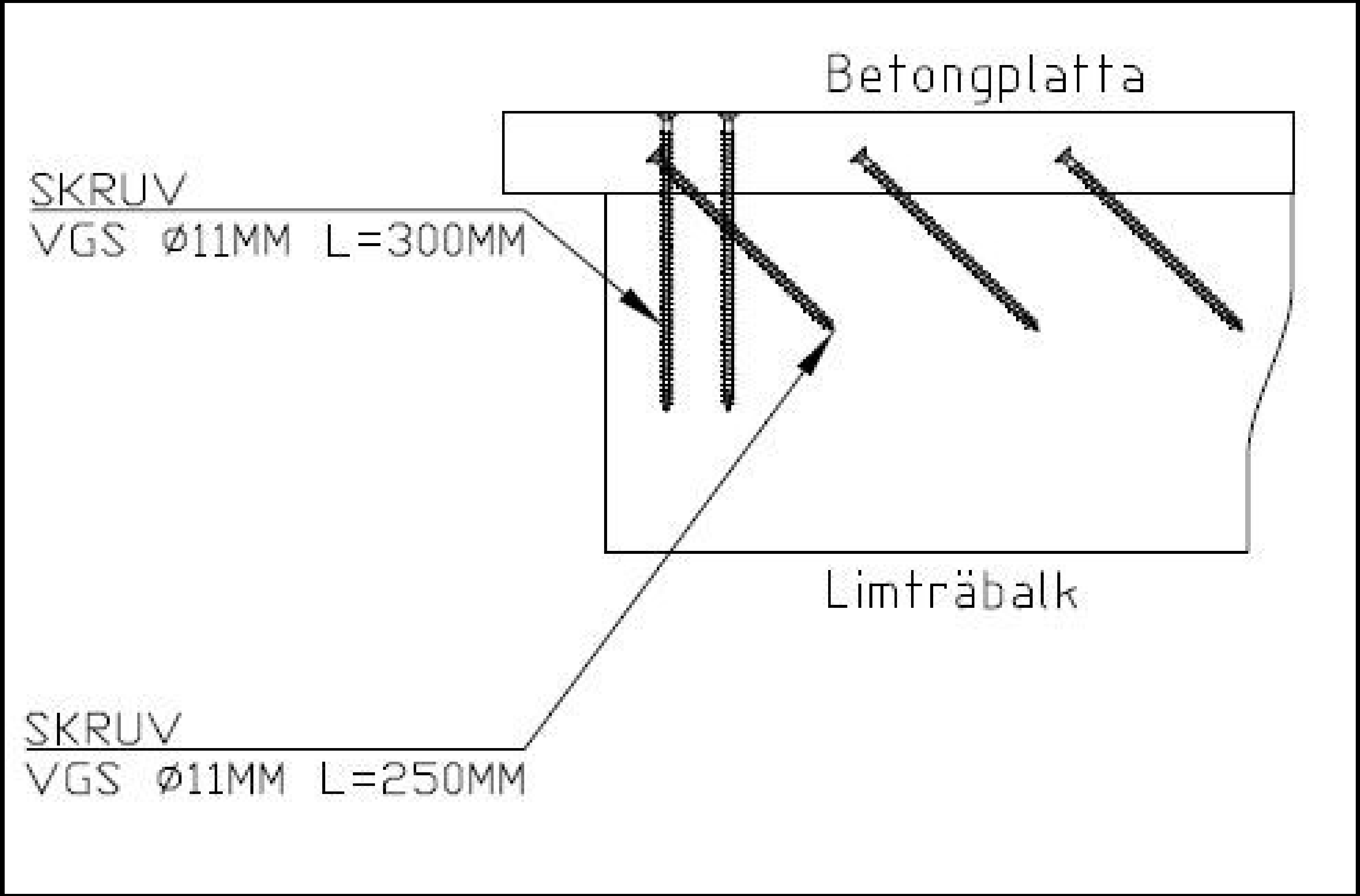
1: Insert screws



2: Twist upside down and cast concrete

3: Let cure and twist upside down again

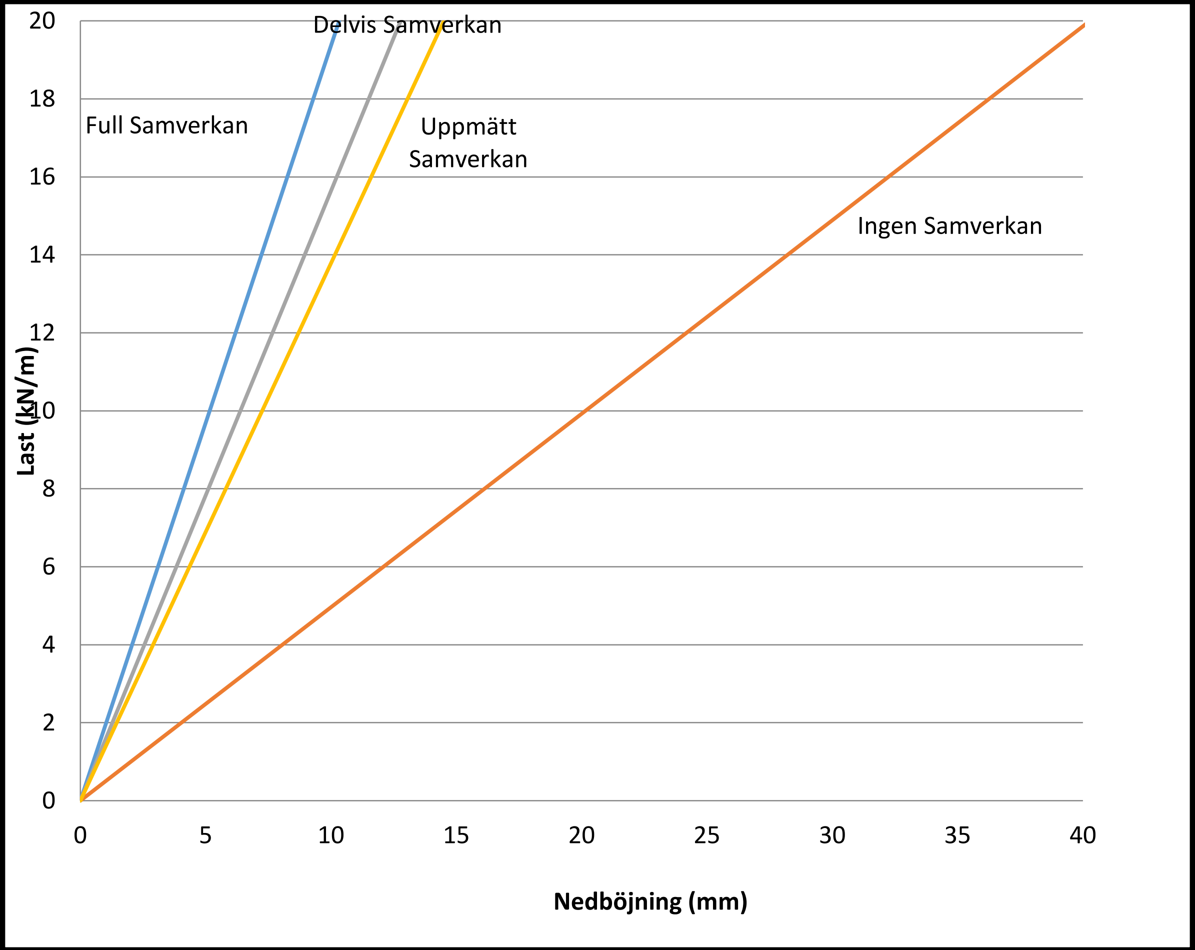
Detail of the support



Concrete C40/50

t = 80mm

Tests



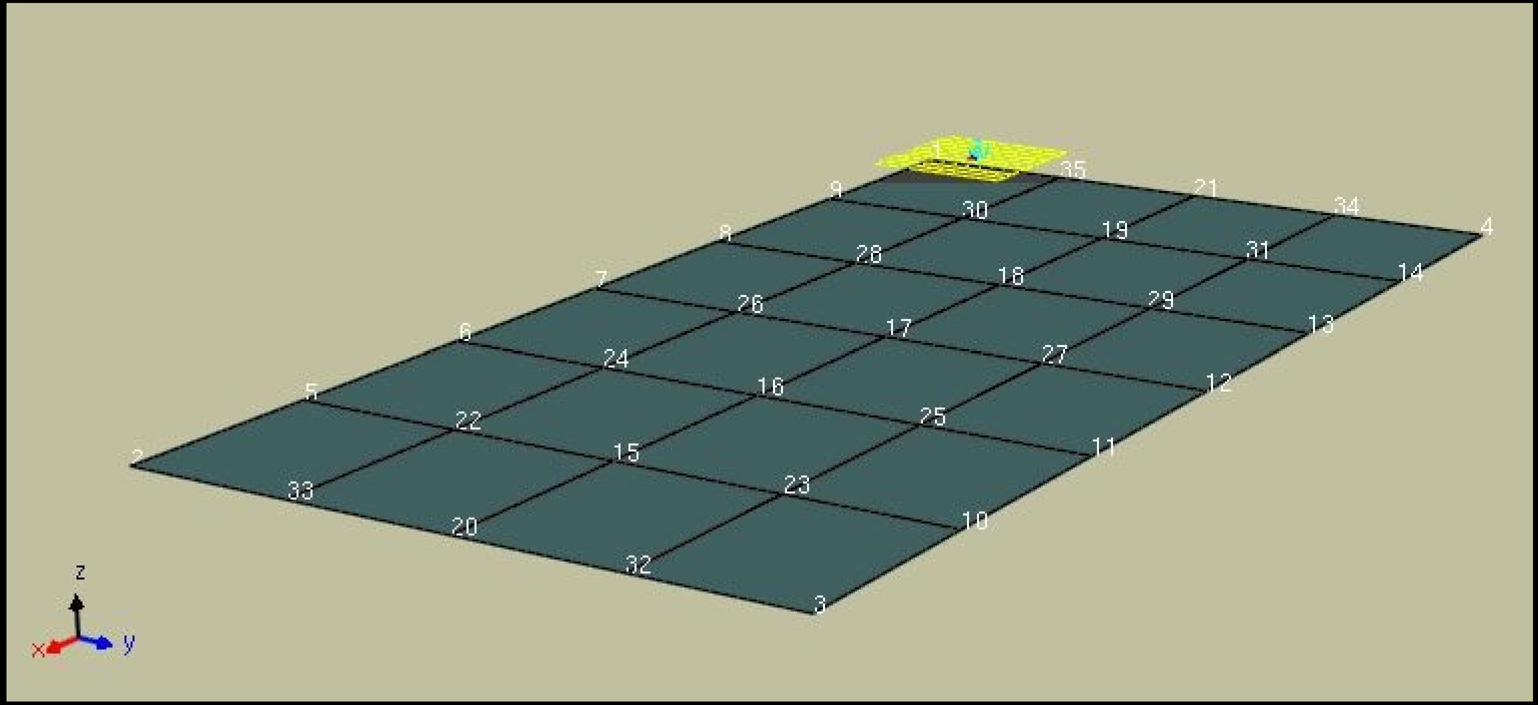
Full Samverkan
Delvis Samverkan
Uppmätt Samverkan
Ingen Samverkan
Last (kN/m)
Nedböjning (mm)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
40

Dynamic tests

Impulse hammer

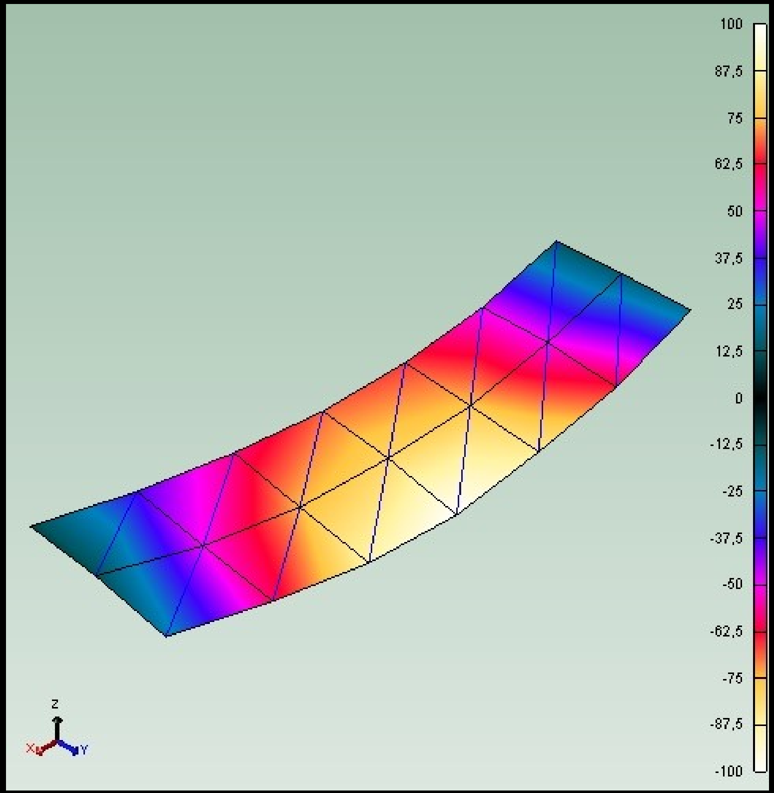
Accelerometre

Measuring points in the floor

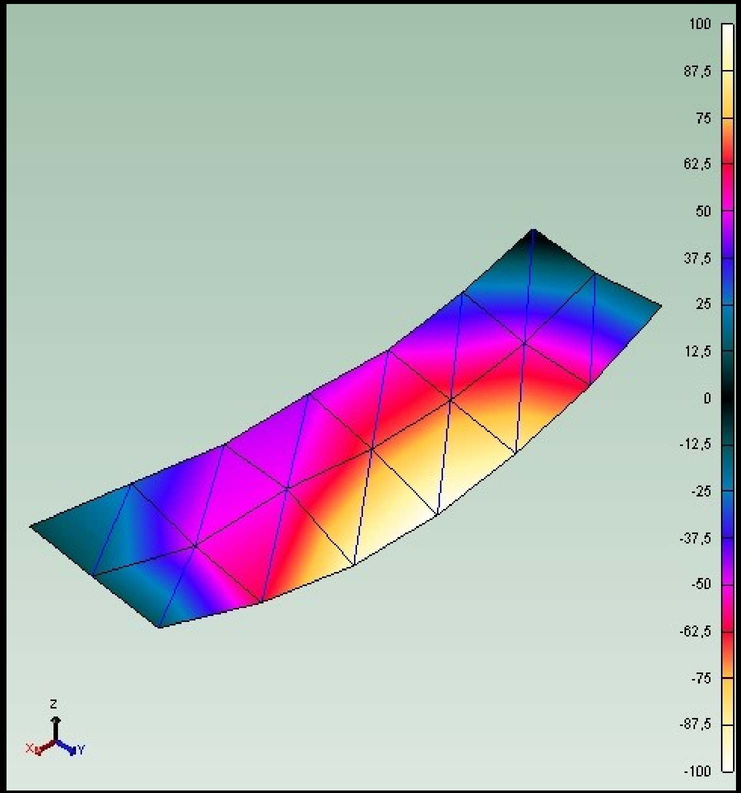


Results

w/o load, f1=9,23 Hz

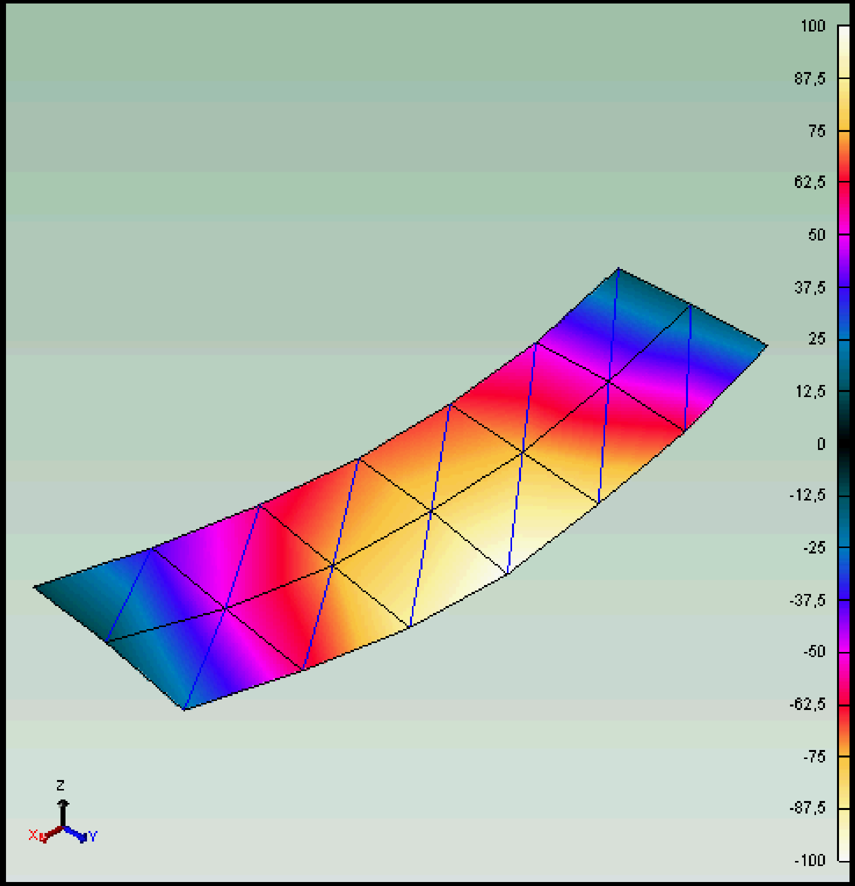


with load, f1=6,27 Hz

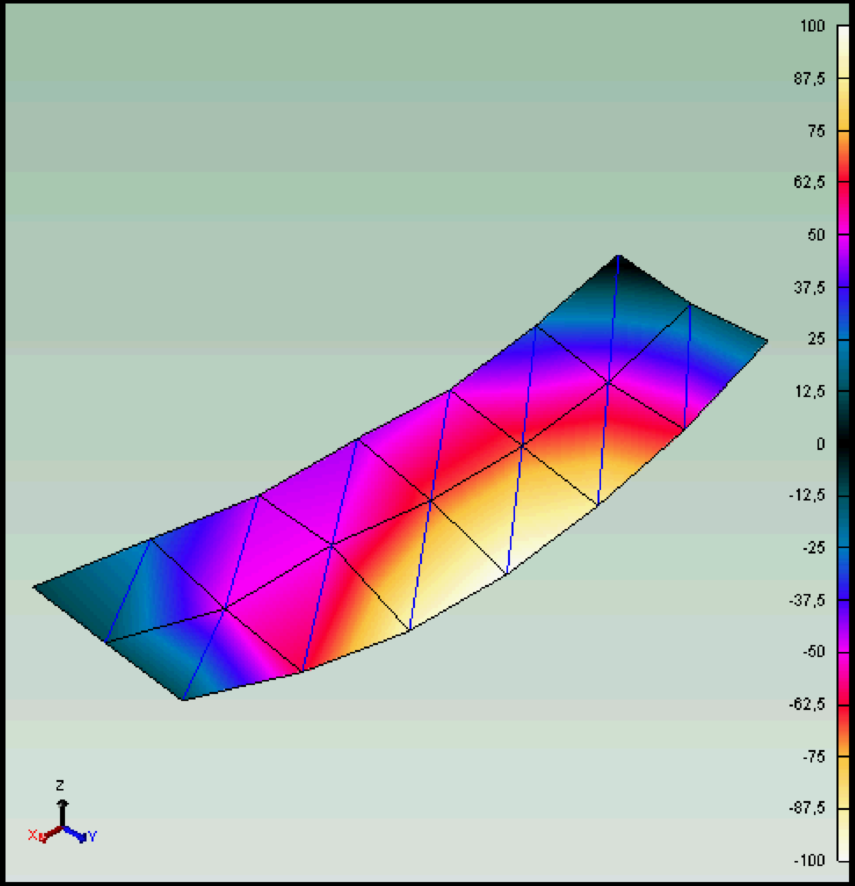


Results

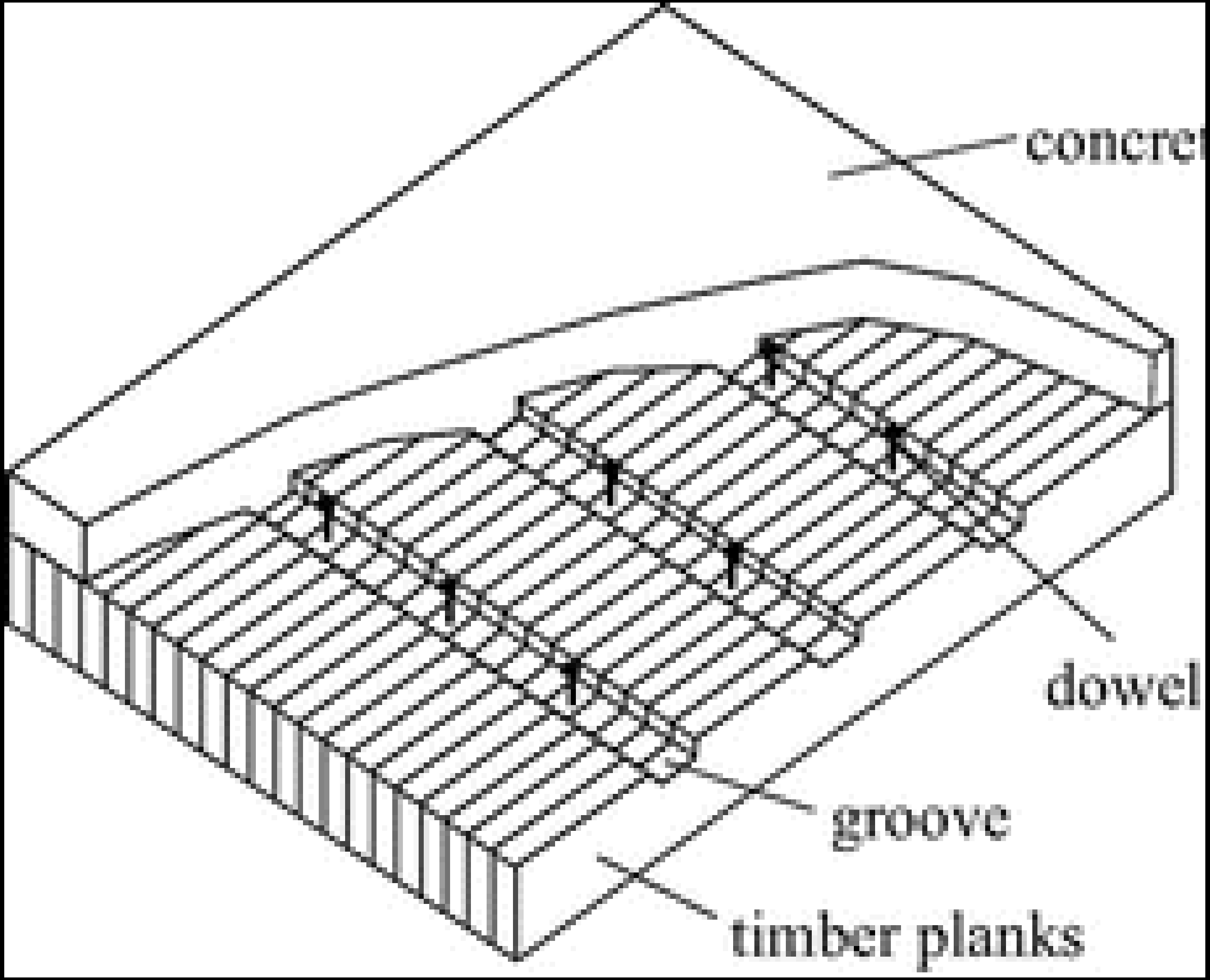
w/o load, f1=9,23 Hz



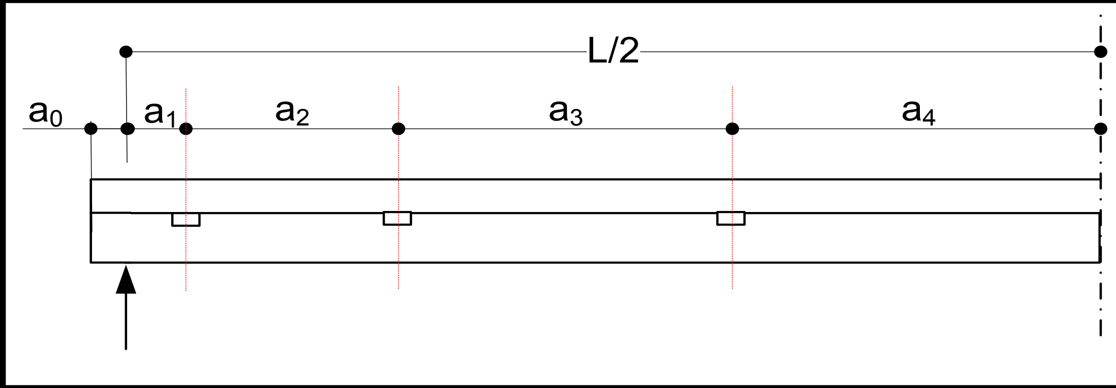
with load, f1=6,27 Hz



The notched connection

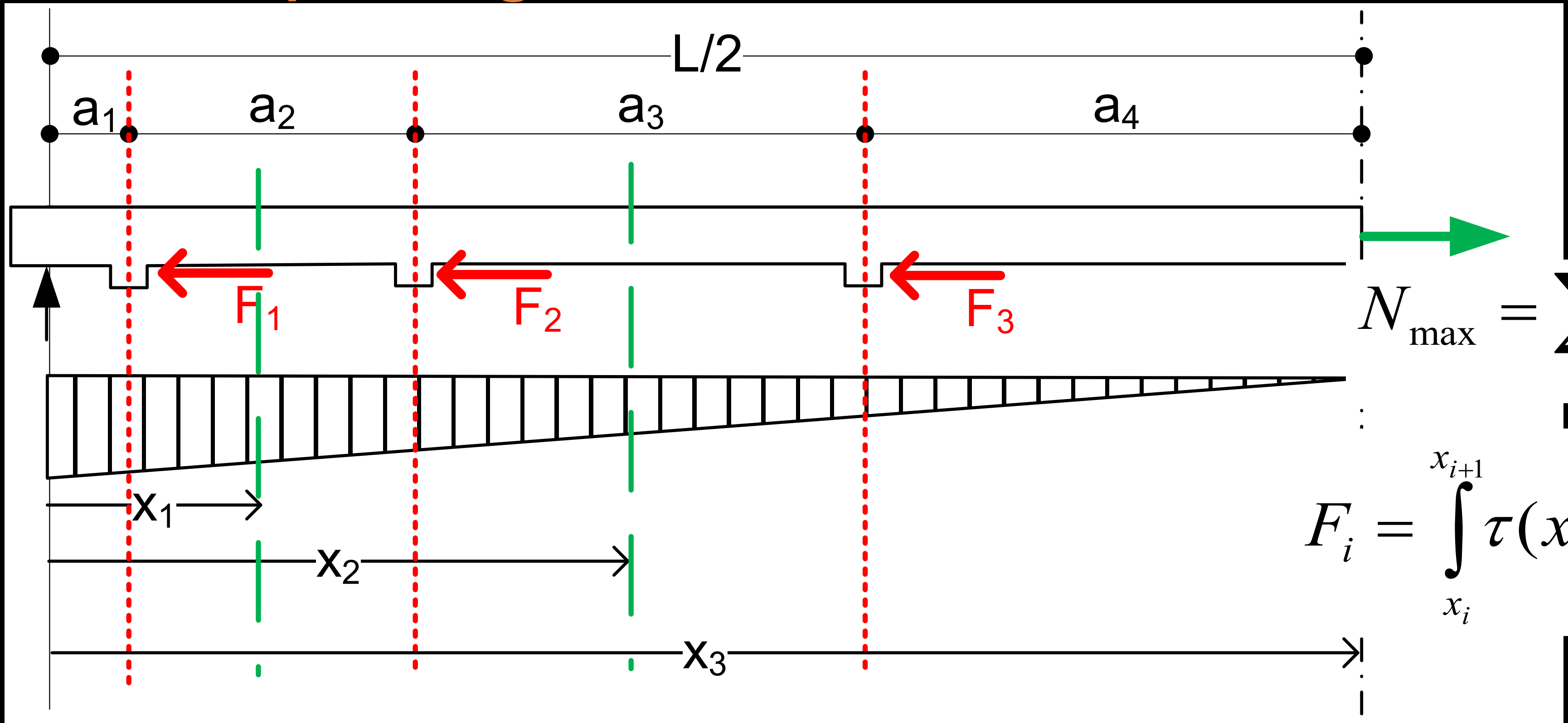


General design rules



- Total depth: h_{tot} ~ L/25
- Concrete depth : h_{conc} ~ 0.3 h_{tot} (avoid tension in concrete)
- Number of notches:
    - L<6m → 2 notches/half-span
    - 6m <L< 10m → 3 notches/half-span
- Notch depth: 20 – 30 mm
- Notch length: 150 – 200 mm

Notch spacing

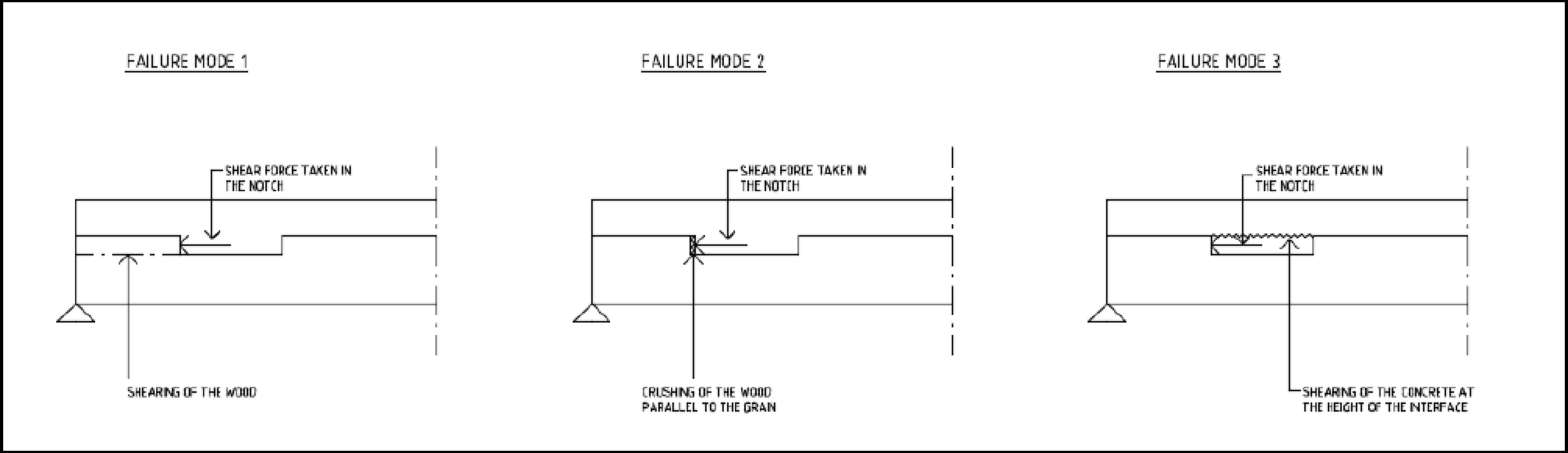


$$N_{\max} = \sum_i F_i$$

$$F_i = \int_{x_i}^{x_{i+1}} \tau(x) \cdot b \cdot dx = \frac{S_{ef}}{I_{ef}} \cdot \int_{x_i}^{x_{i+1}} V(x) \cdot dx$$

- Suggested distance from end grain: > 200 mm
- Place notches so that $F_1 \approx F_2 \approx F_3$

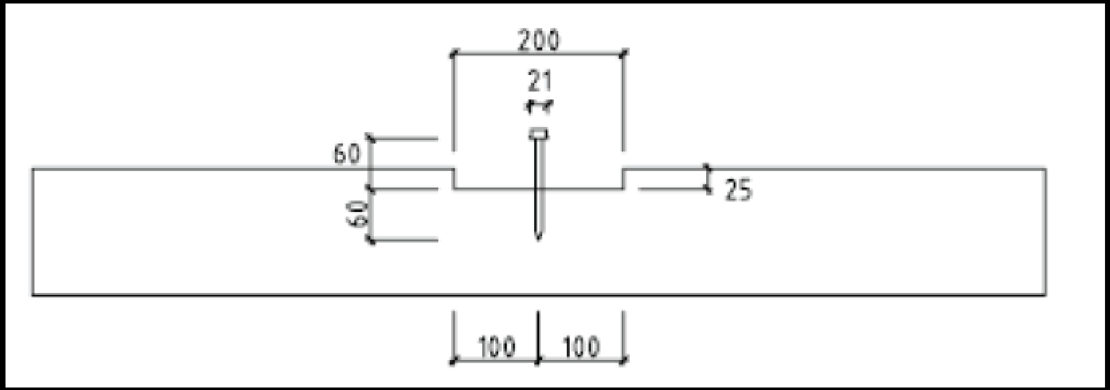
Notched connections: possible failure modes



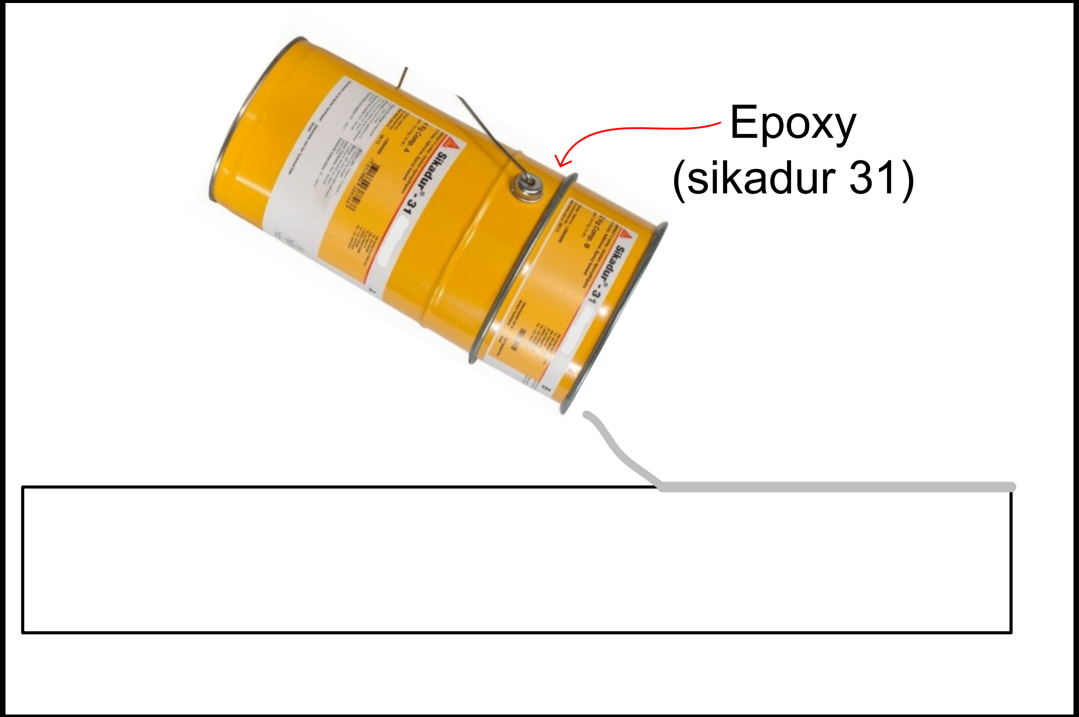
Notched connections tests at Lund University

a) four plates, length approx. 6,5 m and
b) a number of small pieces for shear test specimens

The shear connections



The notched connection

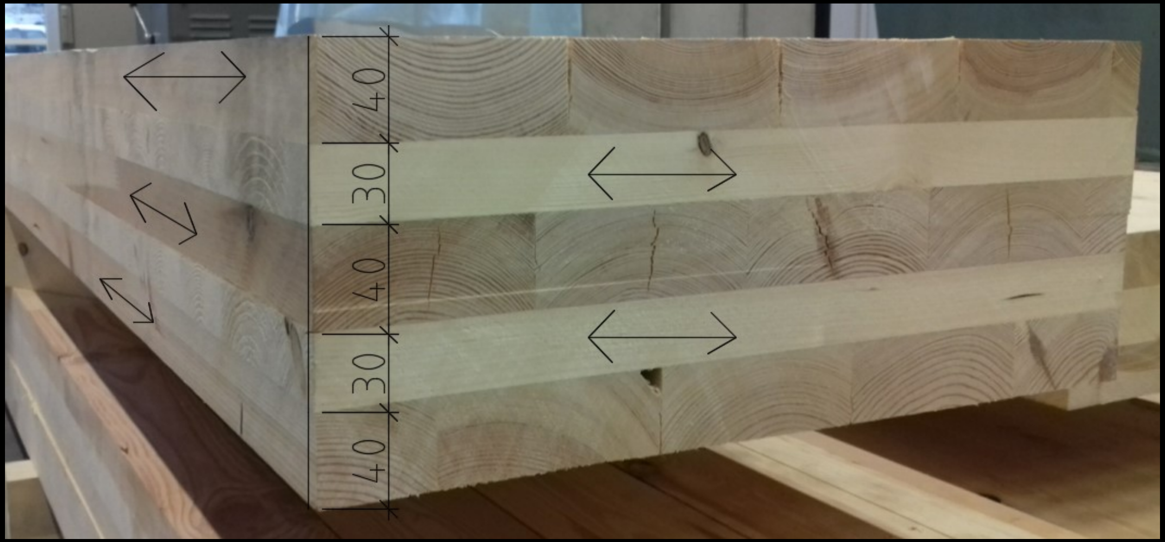


The glued connection

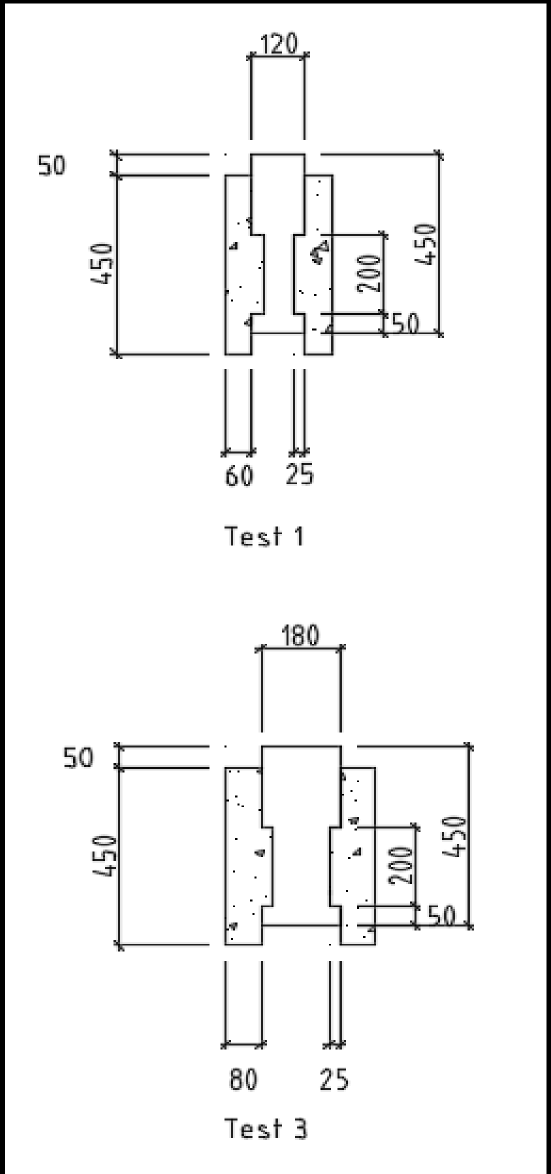
The two CLT plates

Plate 1: 450 x 120, span 6300

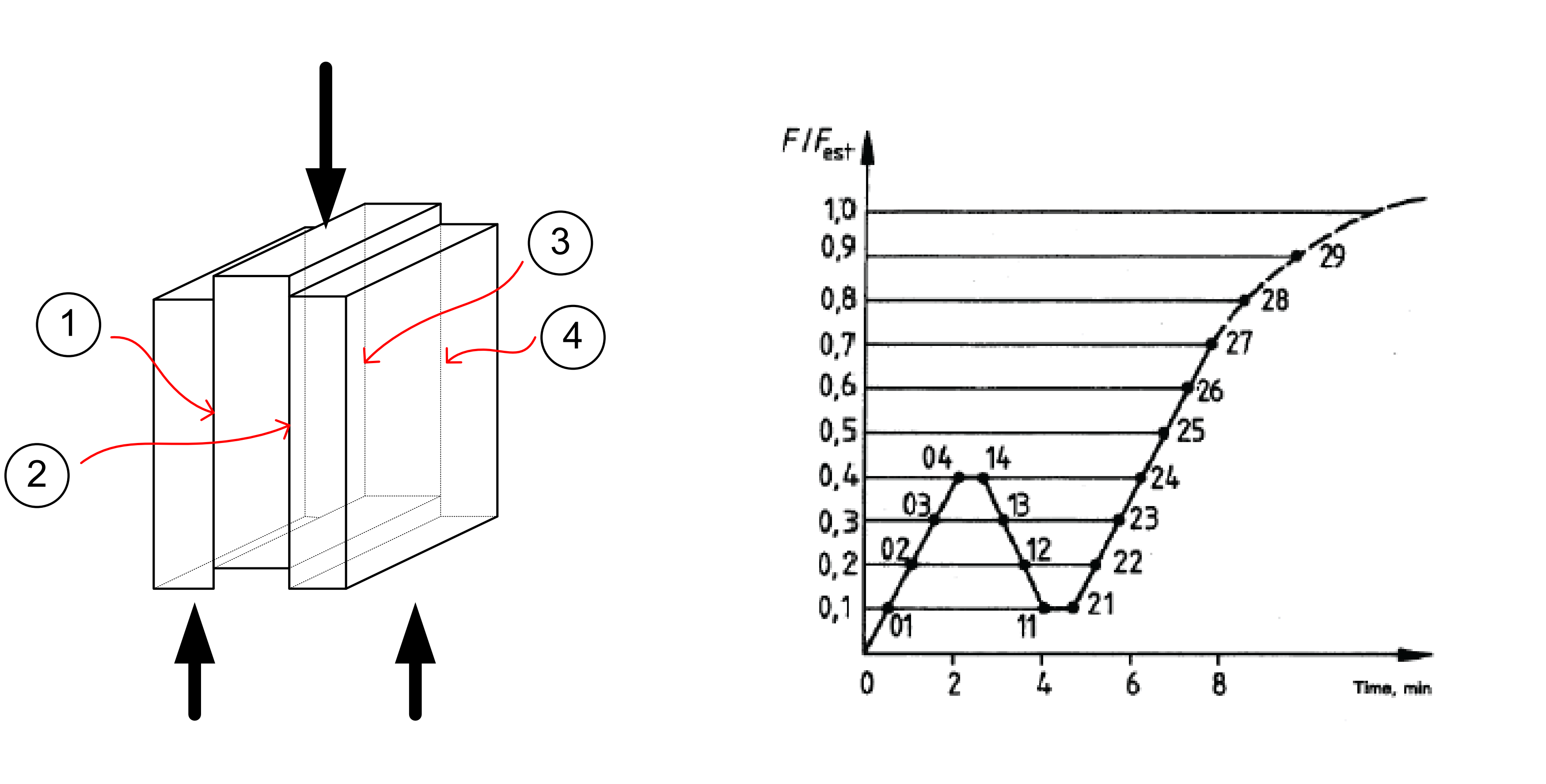
Plate 2: 450 x 180, span 6300



The shear connections

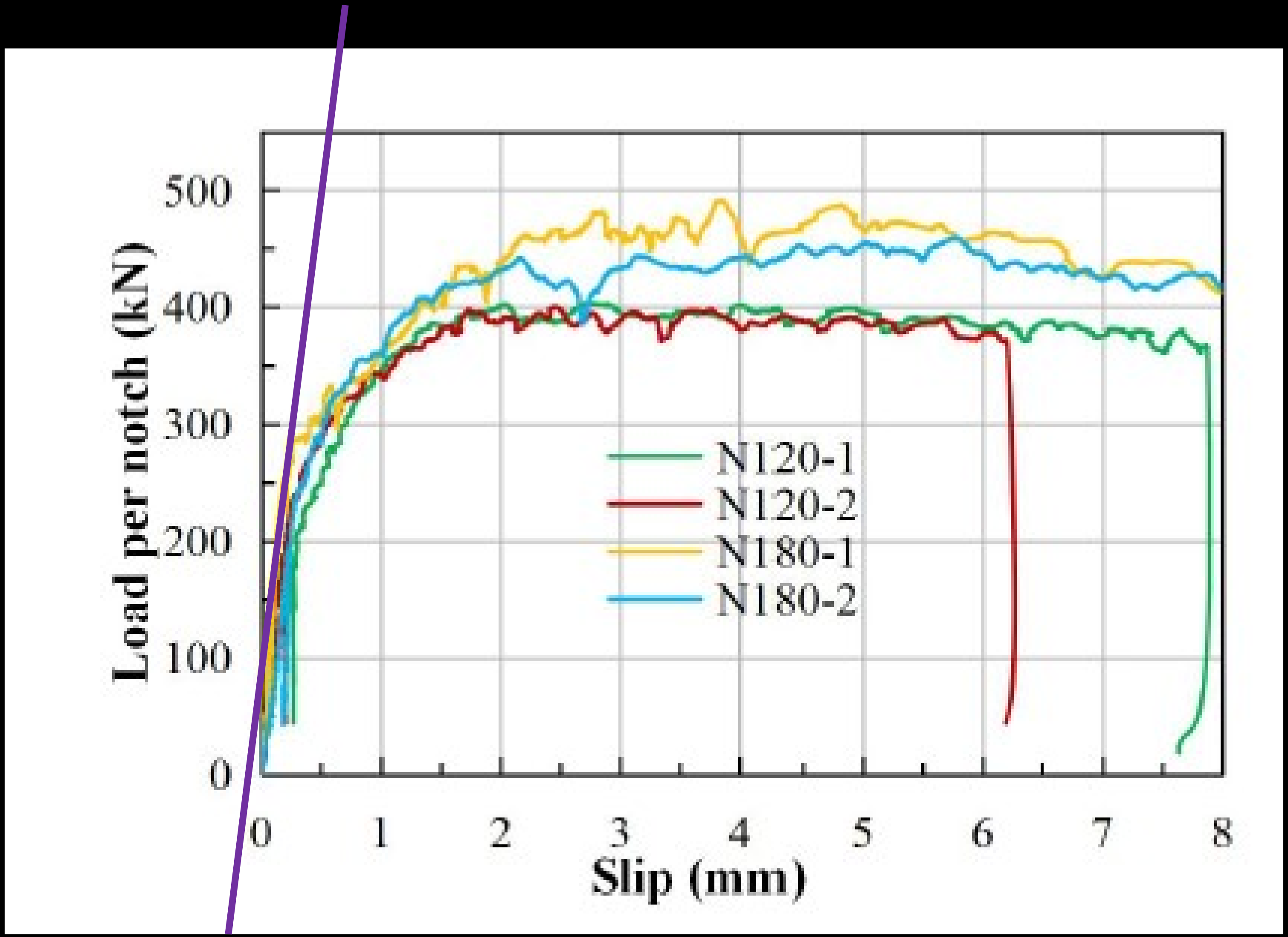


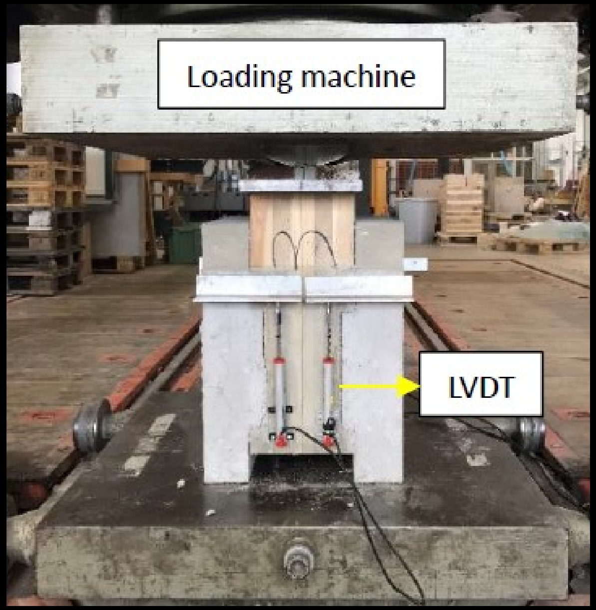
The shear connections



load procedure according to EN 26891

The shear connections





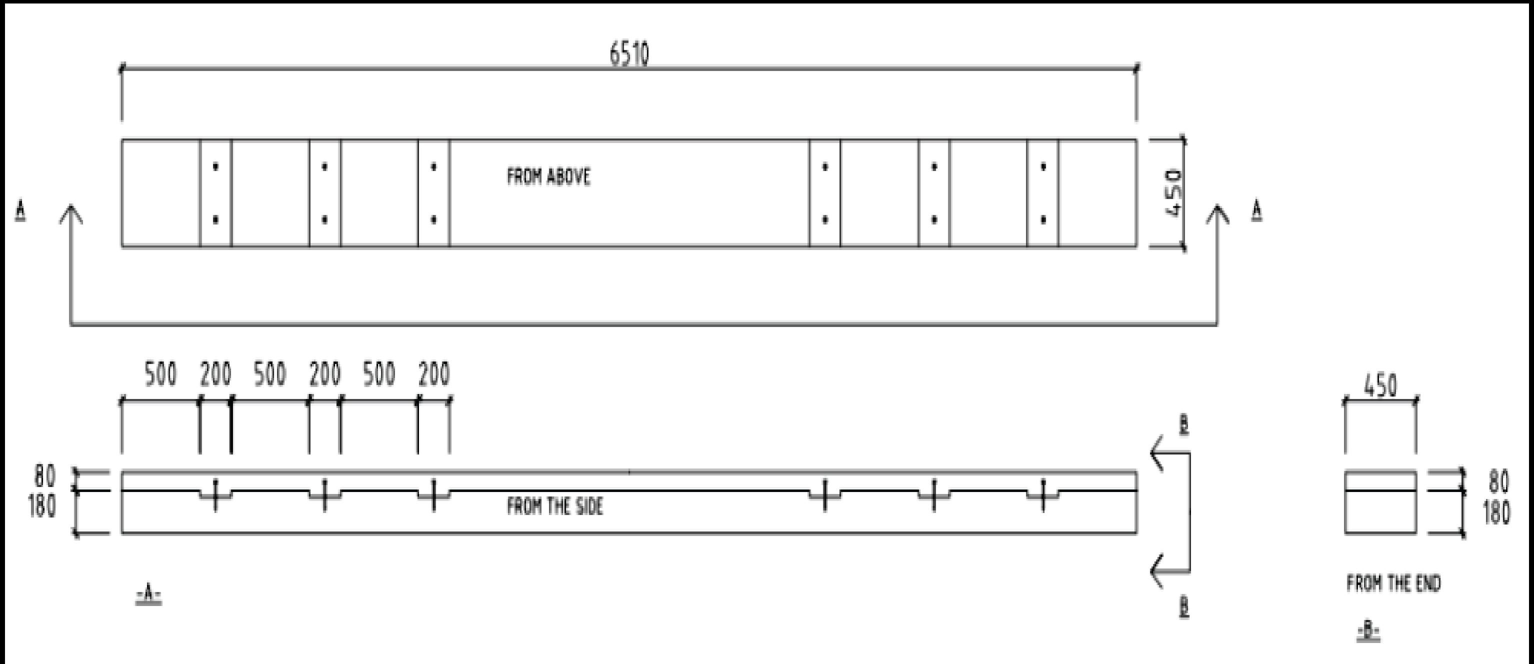
Notch: 200x450x25

Stiffness k_{04}≈1000 kN/mm

Failure modes

Notched specimens

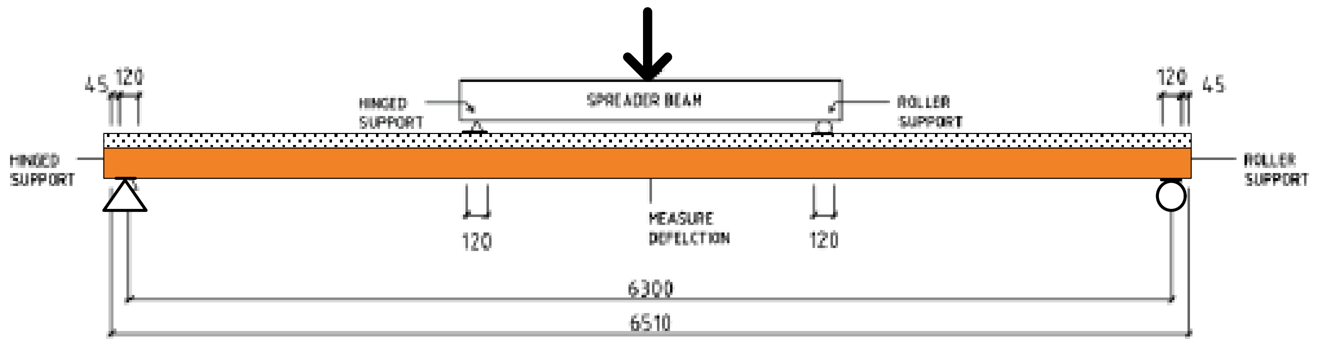
The full-scale tests

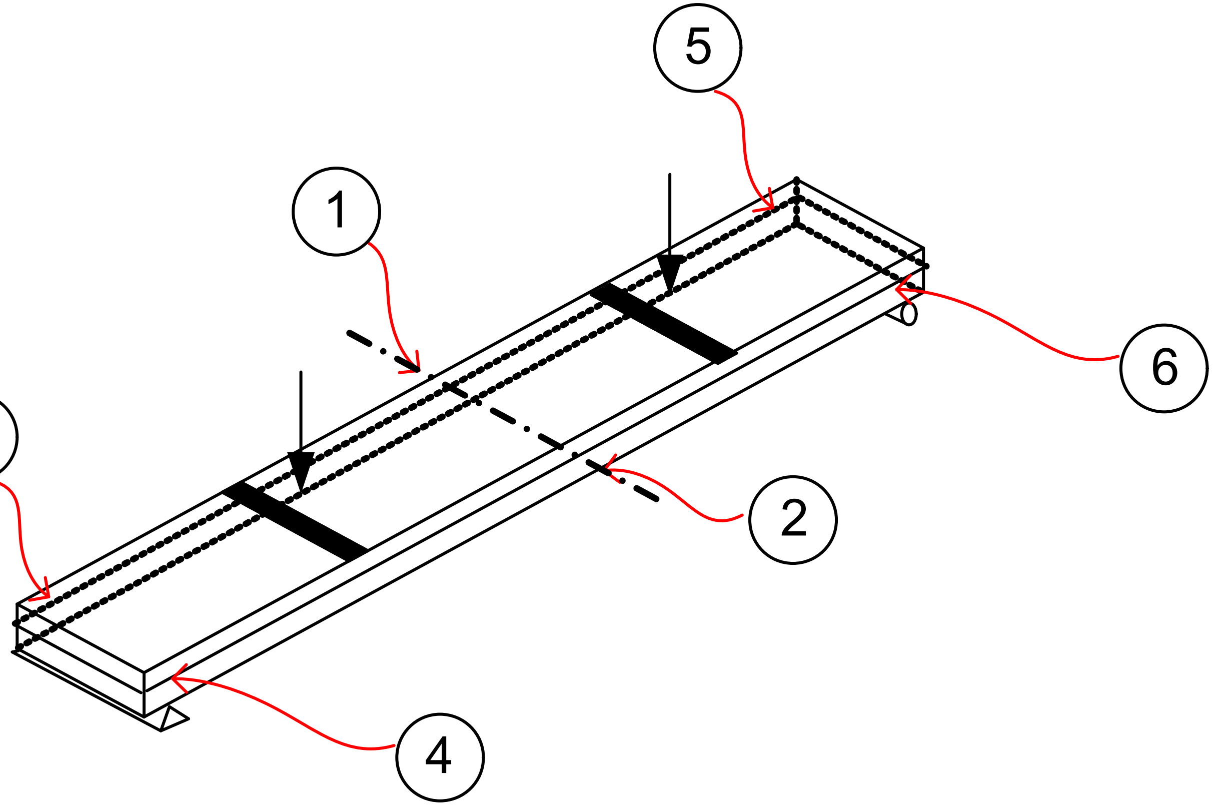


Dimension	type 1 [mm]	type 2 [mm]
Span	6300	6300
Width	450	450
Thickness of CLT	120	180
Thickness of concrete	60	80
Overall depth of beam	180	260

The manufacturing of full-scale specimens

The full-scale tests

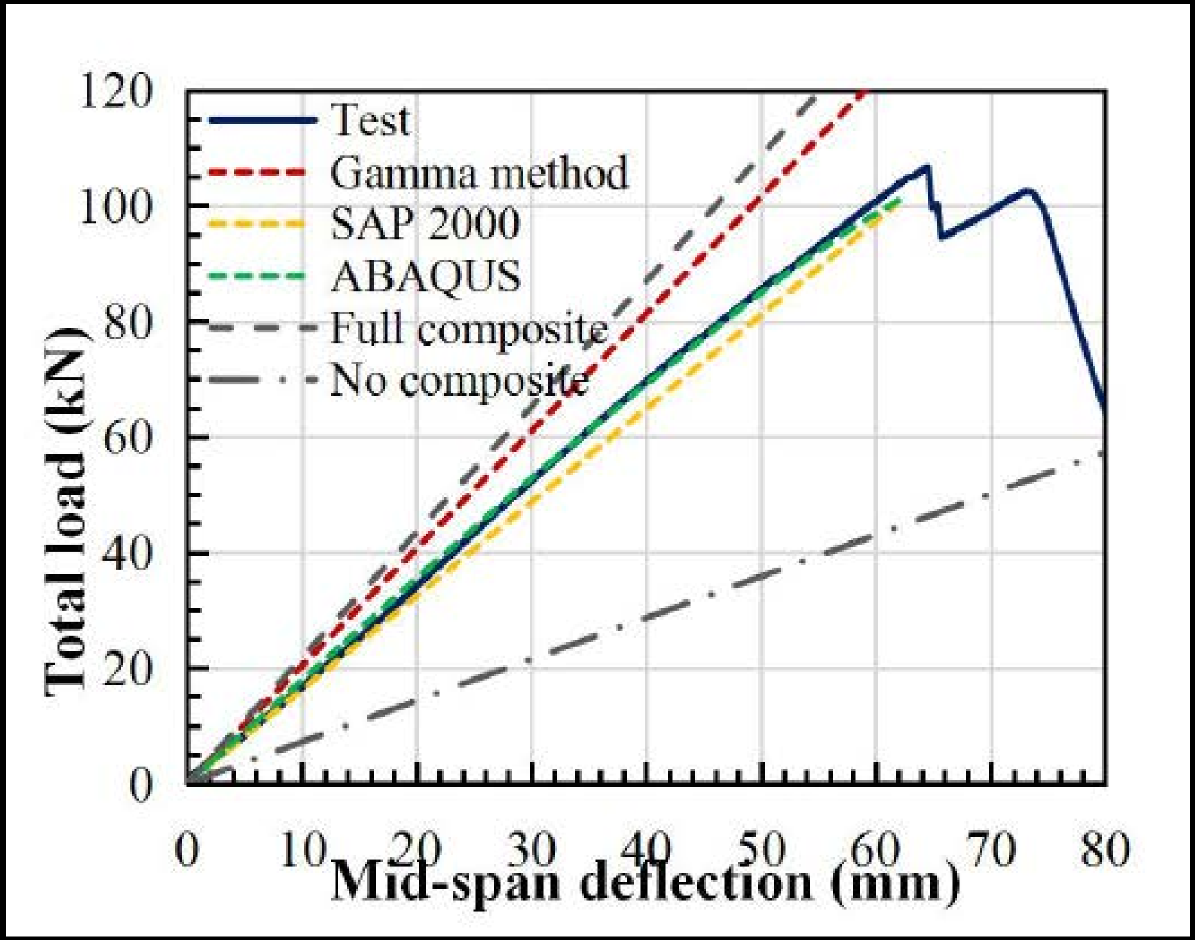


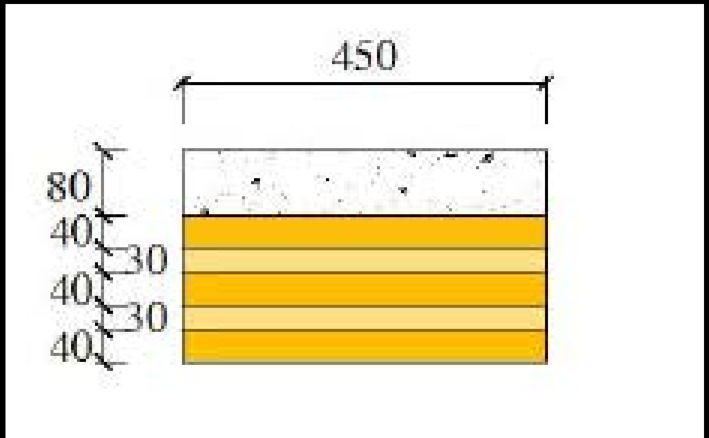


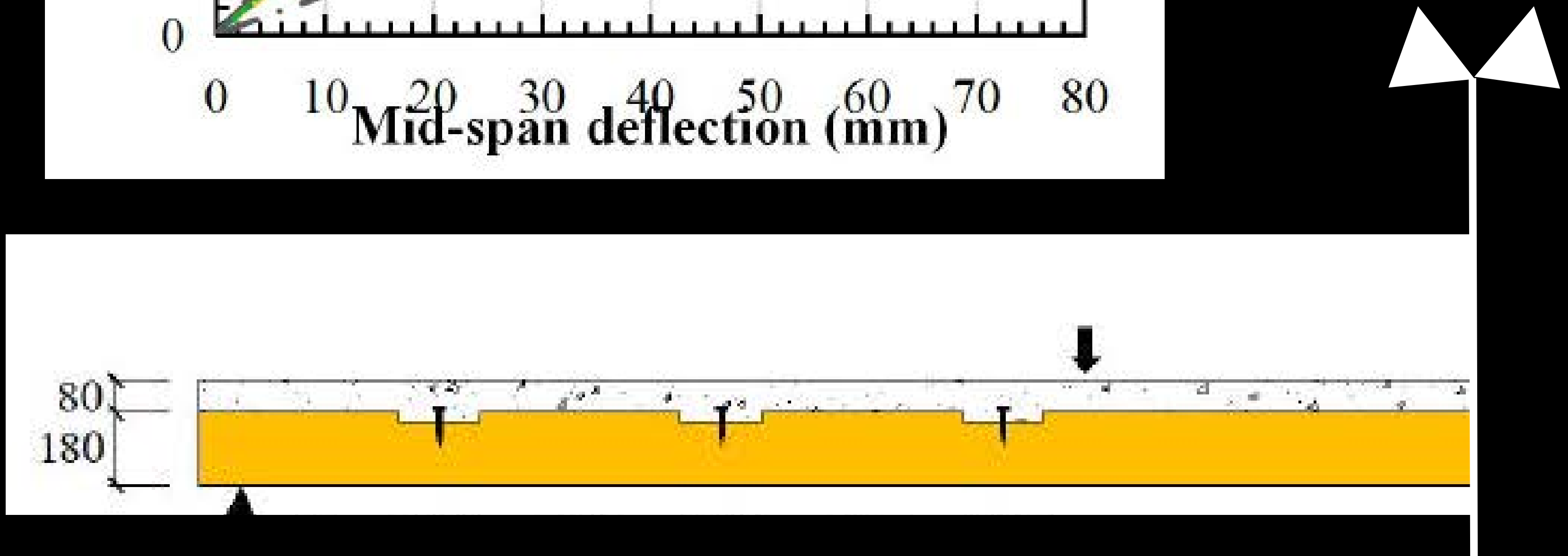
The full-scale tests

Failure modes

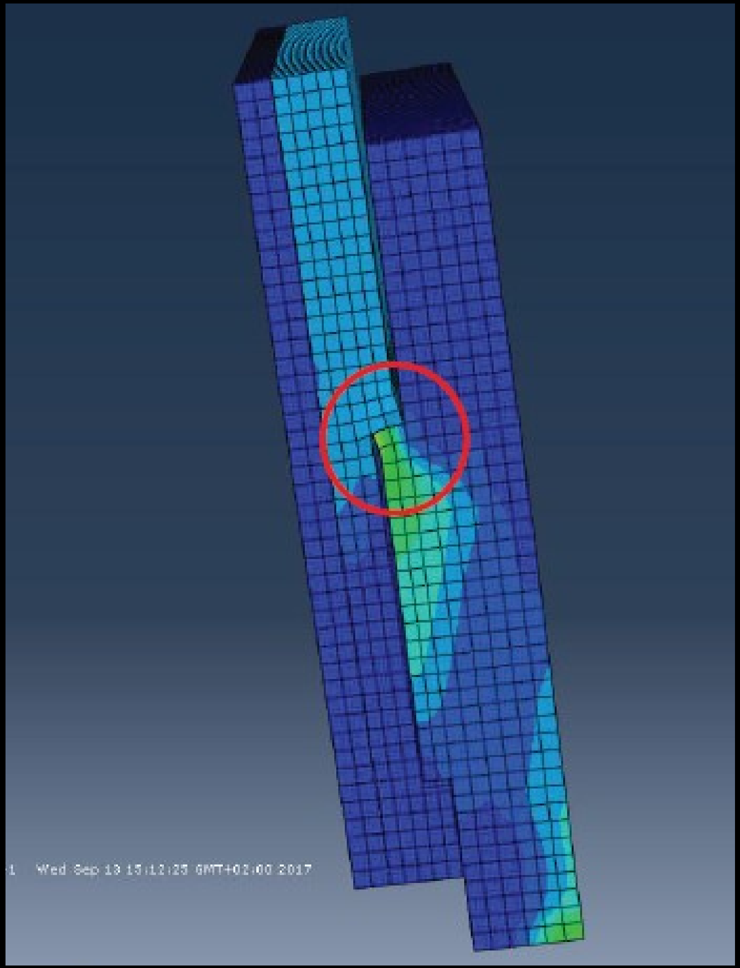
Some test results

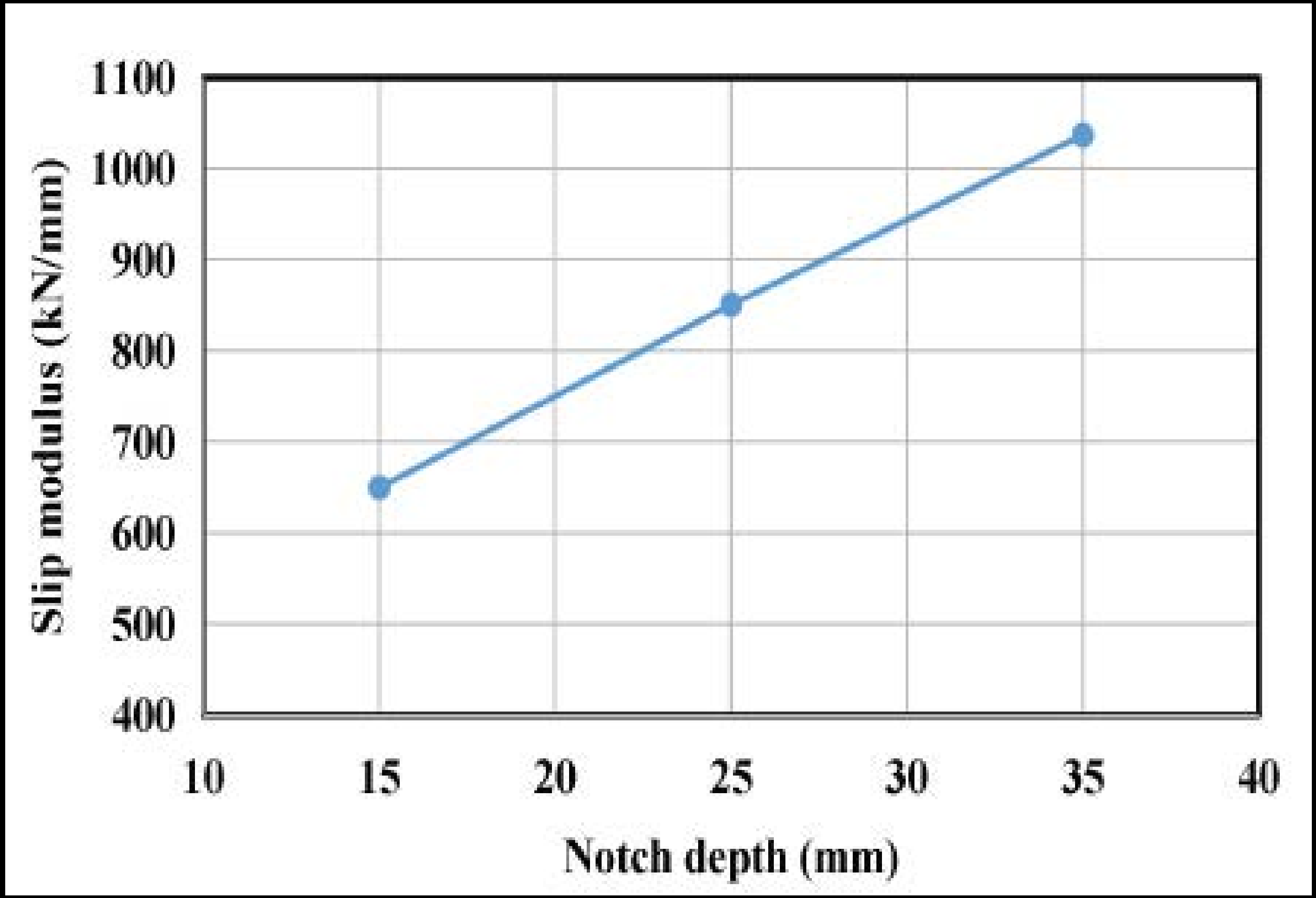






Parametric study





Further research

- Develop prefabricate systems for both floors and bridges with:
  - CLT + concrete
  - nail laminated deck + concrete
  - Stress laminated + concrete
  - Glulam + concrete

- Monitor moisture content in timber at the interlayer between timber and concrete, both in service class 1, 2 and 3 → when do we need to protect the wood

- Study the compatibility between wood and new (more environmentally friendly) concrete types, e.g. *fly ash concrete*

- *…and much more*

Takk for din oppmerksomhet