

Timber-concrete composite structures - an overview

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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.)

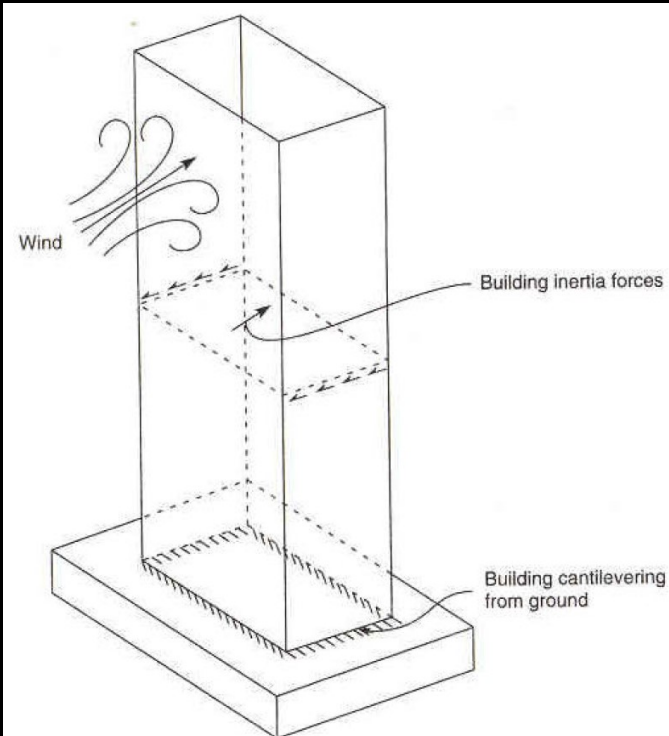
However, timber has also some unfavourable properties...

Some unfavourable properties of timber

1. Low mass
2. Low Young's modulus
3. High variability of mechanical properties
4. etc

Low mass

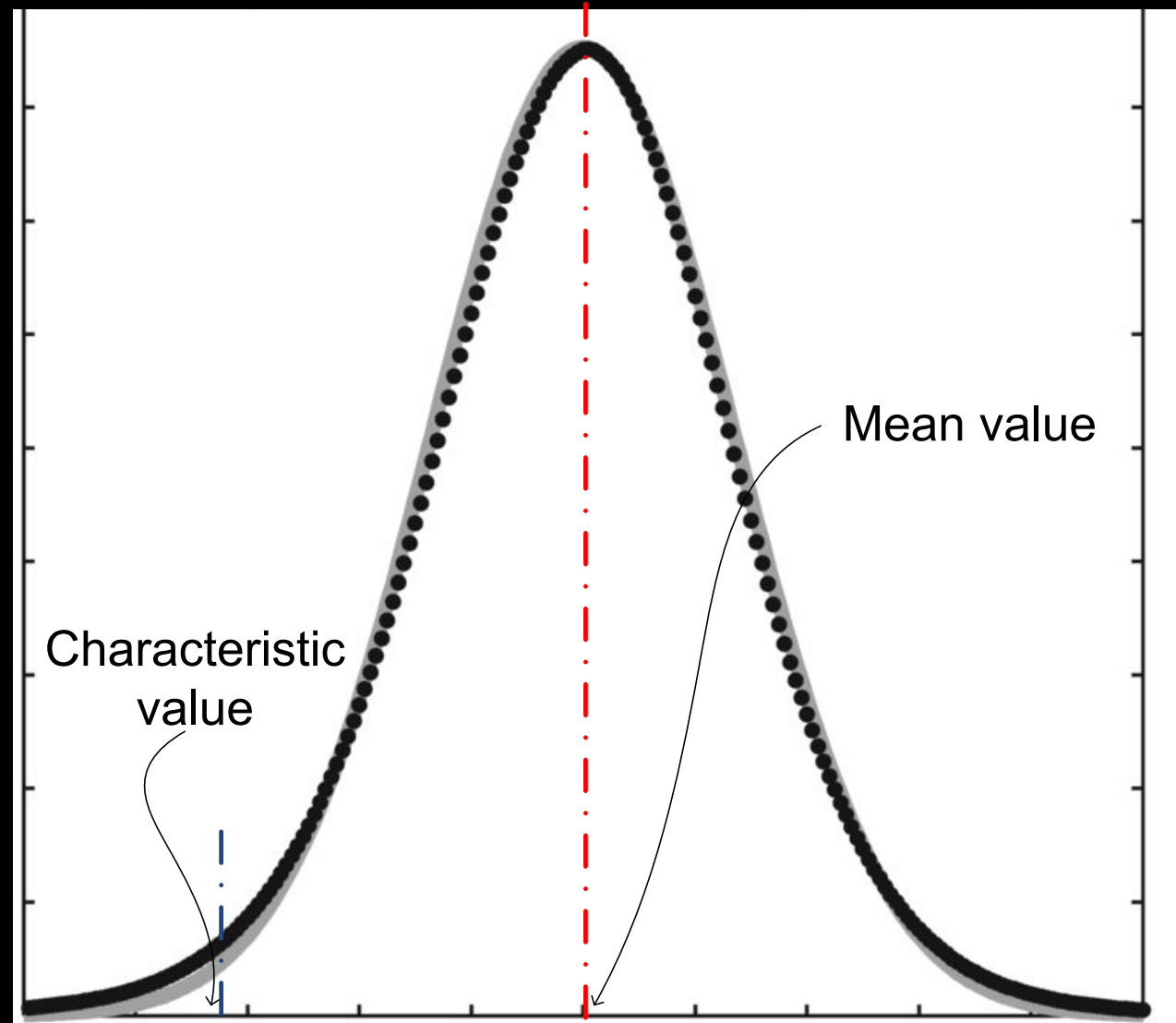
Low Young's modulus



- Acoustics and vibrations
- Deep floor structure

- Tilting
- Wind-induced vibration

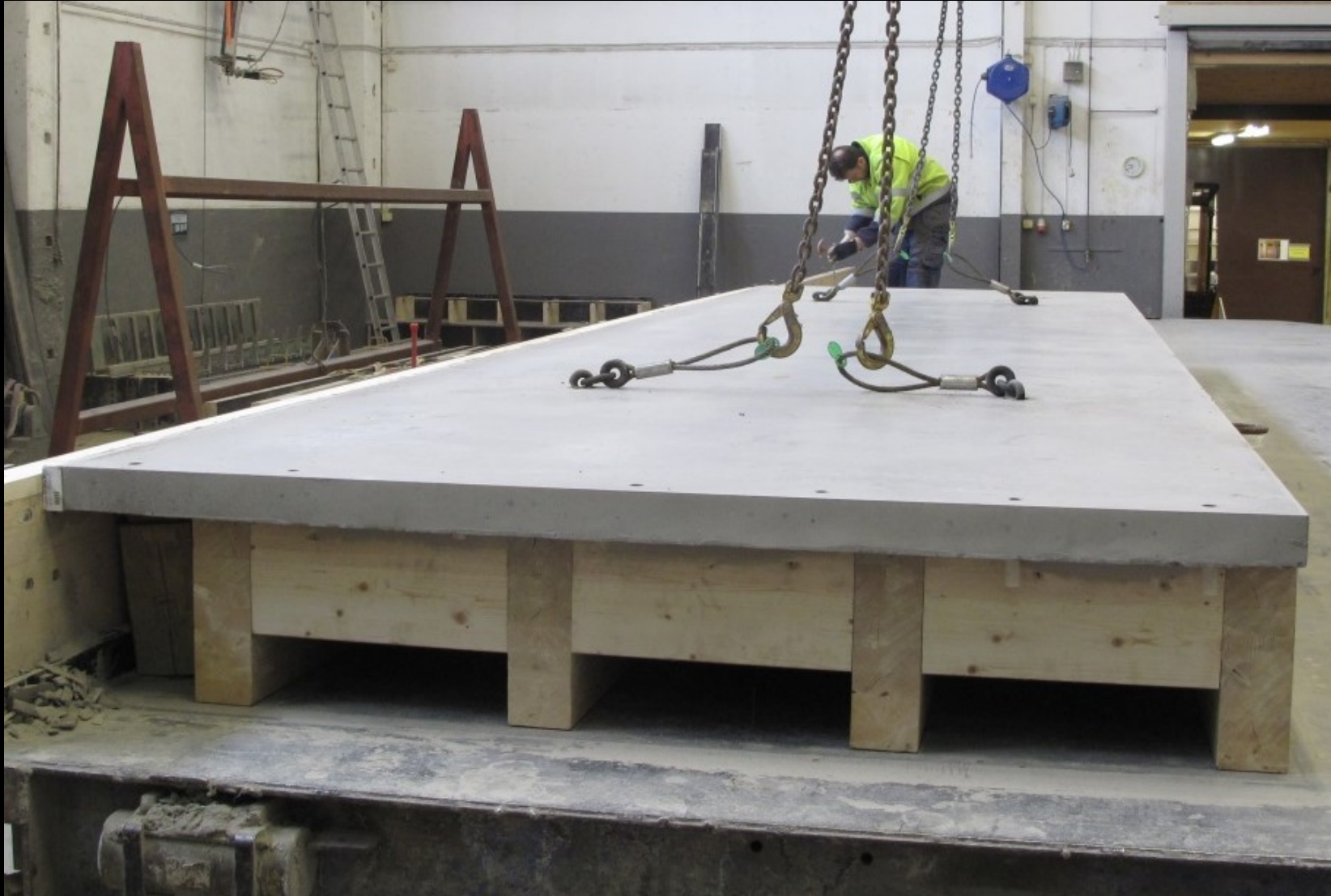
High variability of mechanical properties



Large scatter → low characteristic strength

So, what is the solution?

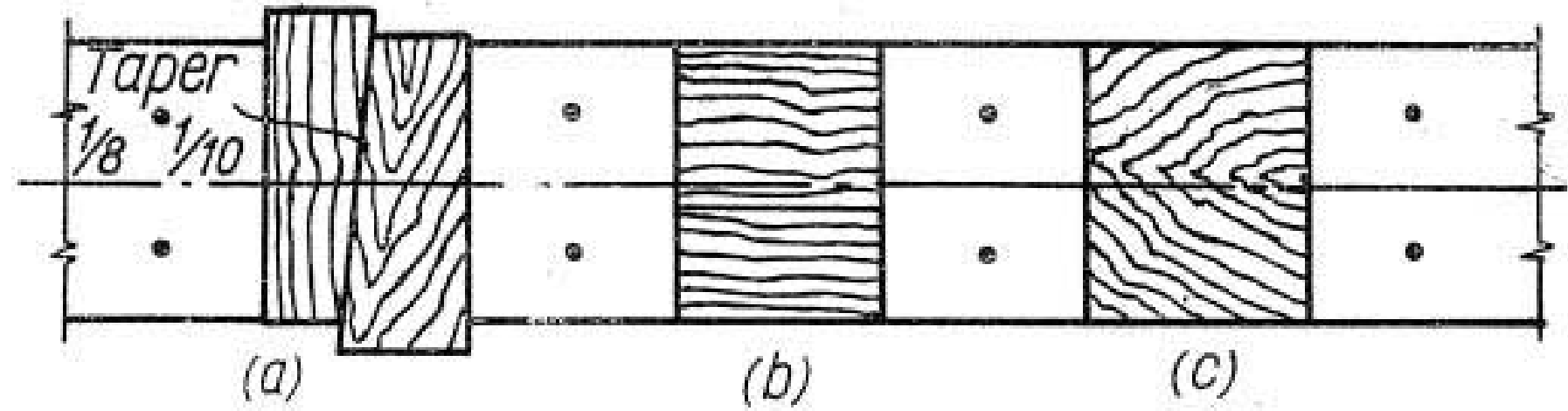
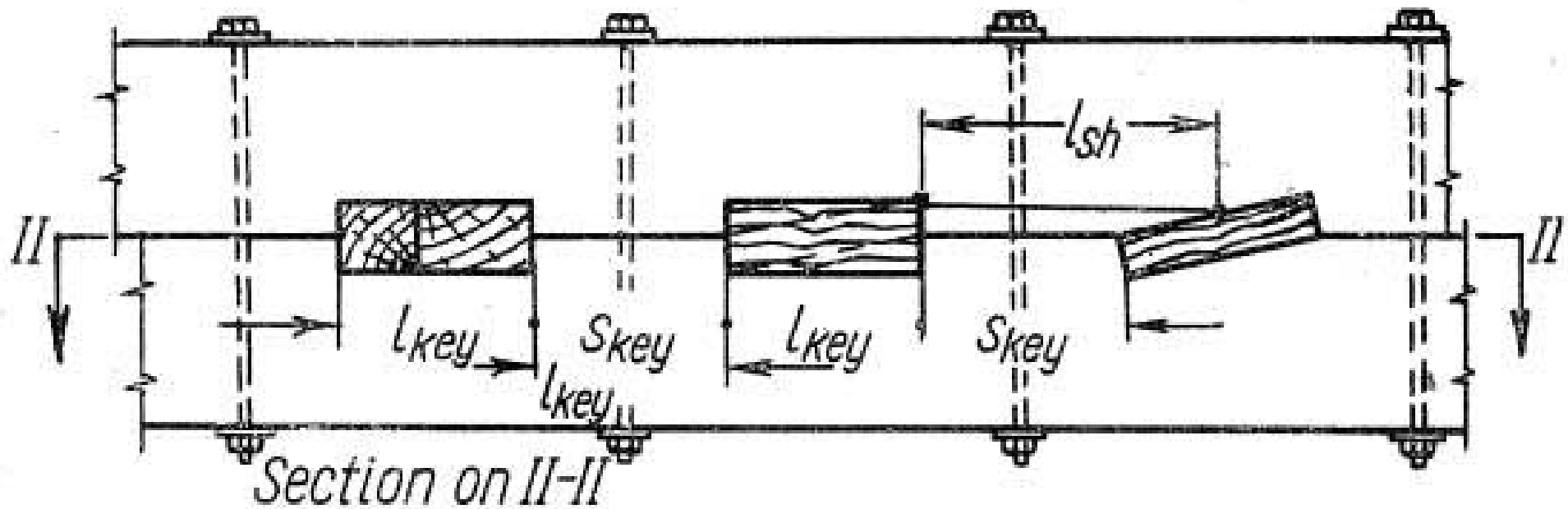
Timber- concrete composite structures



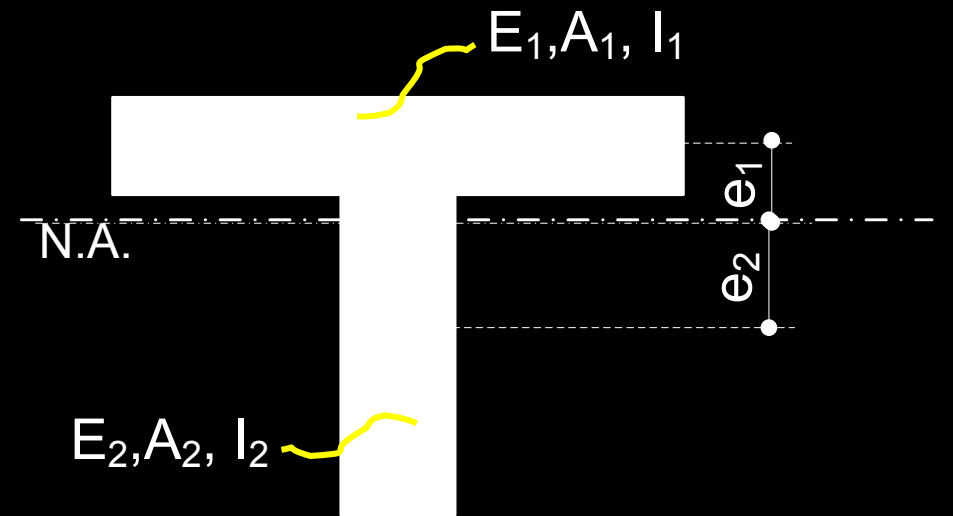
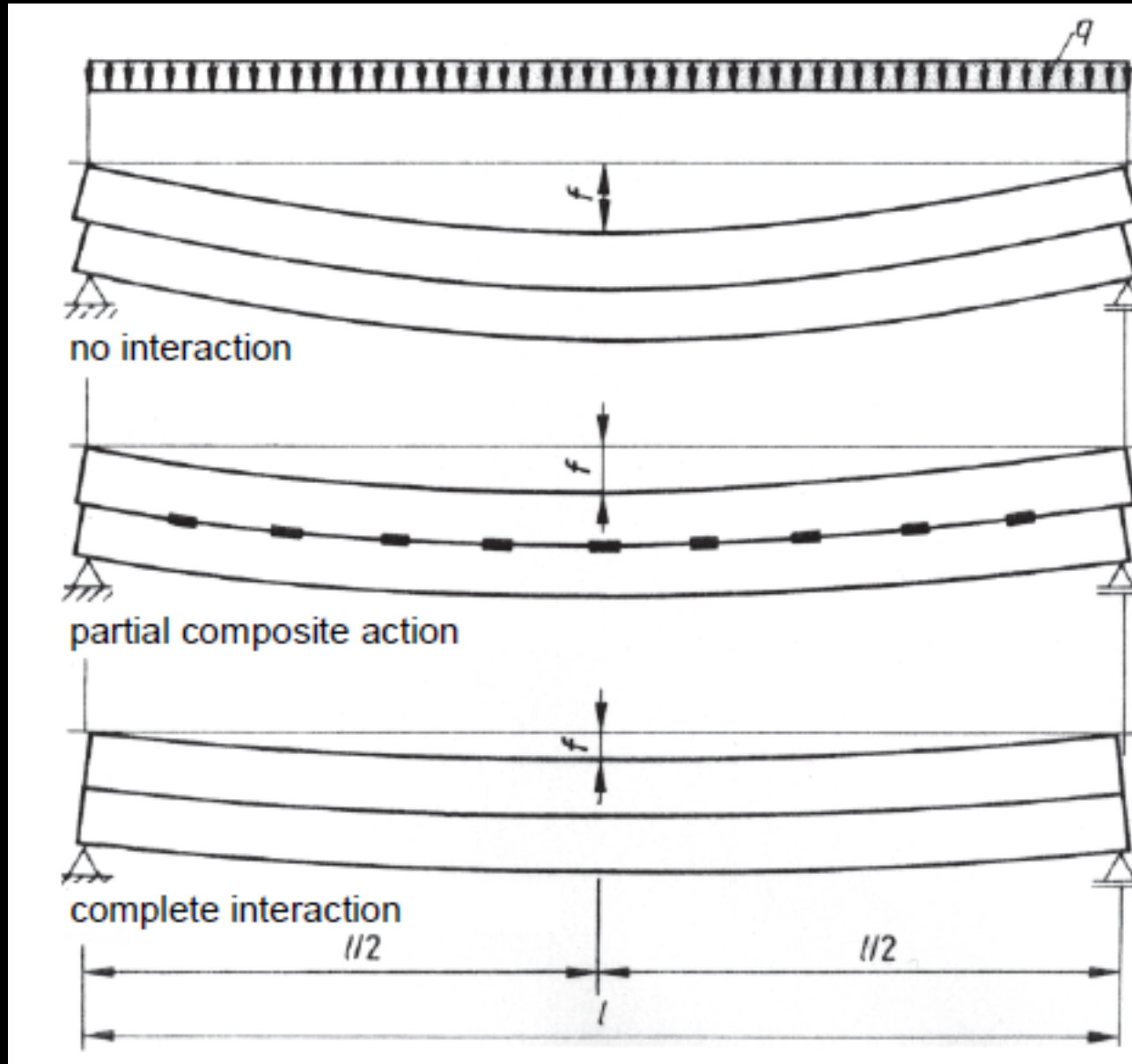
- Significant increase of stiffness (not least in the transversal direction) → reduced vibrations
- Increase of mass → better stability against overturning/tilting, and better acoustic performance
- Reduced depth of floor → better economy

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

The importance of the shear connectors

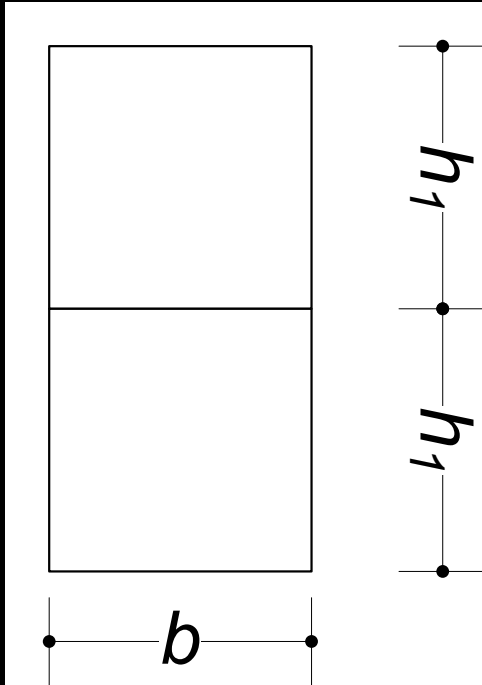


Behaviour of beams with varying composite action



A simple example

No composite action (separated elements)

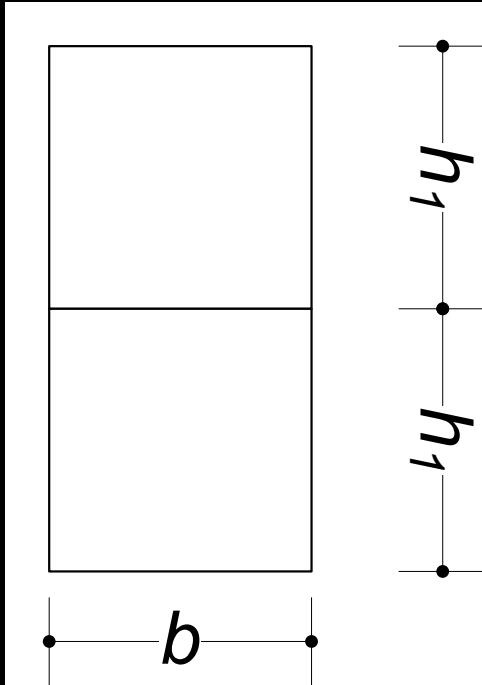


$$\text{BENDING STRENGTH} = W_s = \frac{b \cdot h_1^2}{6} \cdot 2 = \frac{b h_1^2}{3}$$
$$\text{// STIFFNESS: } I_s = \frac{b h_1^3}{12} \cdot 2 = \frac{b h_1^3}{6}$$

Full-composite action (separated elements)

$$\text{BENDING STRENGTH: } W_G = \frac{b \cdot (2h_1)^2}{6} = \frac{b \cdot 4h_1^2}{6} = 2 \frac{b h_1^2}{3}$$
$$\text{// STIFFNESS: } I_G = \frac{b (2h_1)^3}{12} = \frac{b \cdot 8h_1^3}{12} = 4 \frac{b h_1^3}{12}$$

A simple example

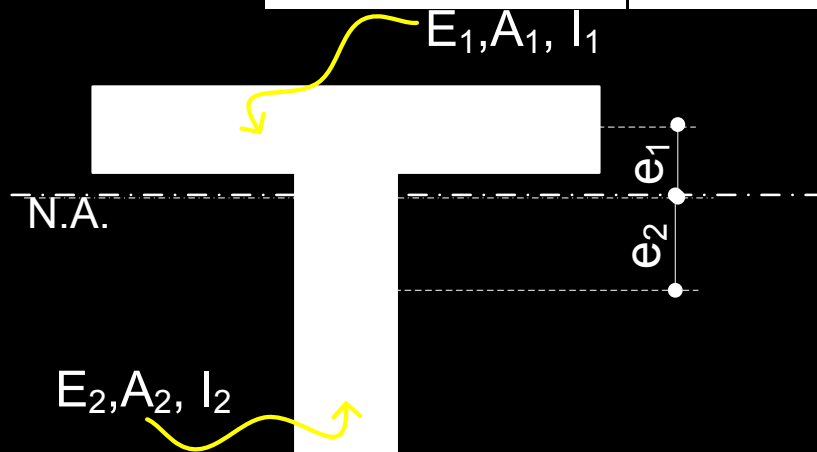


$$\text{Strength} \Rightarrow \frac{W_{full-composite}}{W_{non-composite}} = 2$$

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

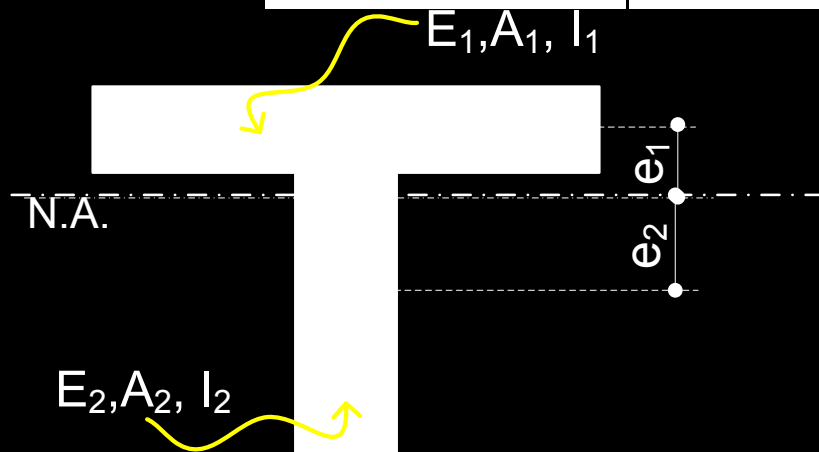
Timber-concrete beams with incomplete composite action

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



Timber-concrete beams with incomplete composite action

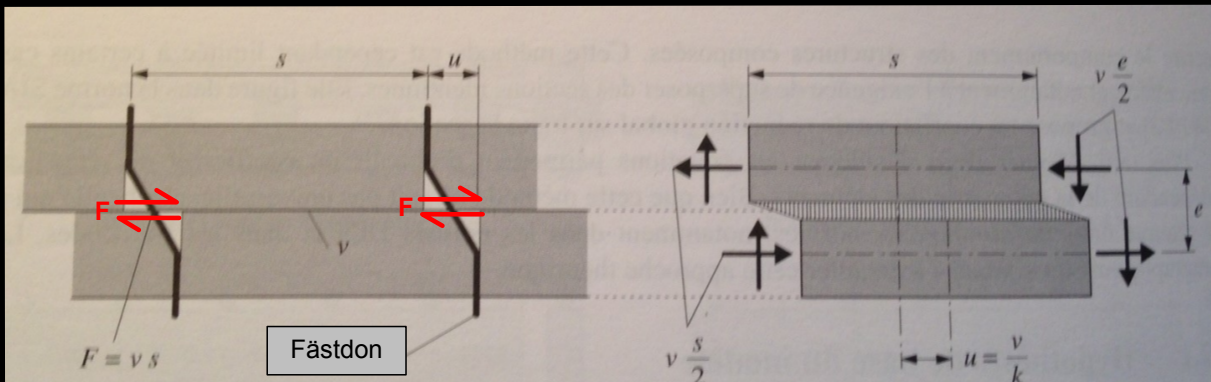
Composite action	Axial stiffness	Bending stiffness
<i>None</i>	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$E_1 \cdot I_1 + E_2 \cdot I_2 = (E \cdot I)_0$
<i>Full</i>	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$(E \cdot I)_0 + E_1 \cdot A_1 \cdot e_1^2 + E_2 \cdot A_2 \cdot e_2^2$
<i>Incomplete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



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

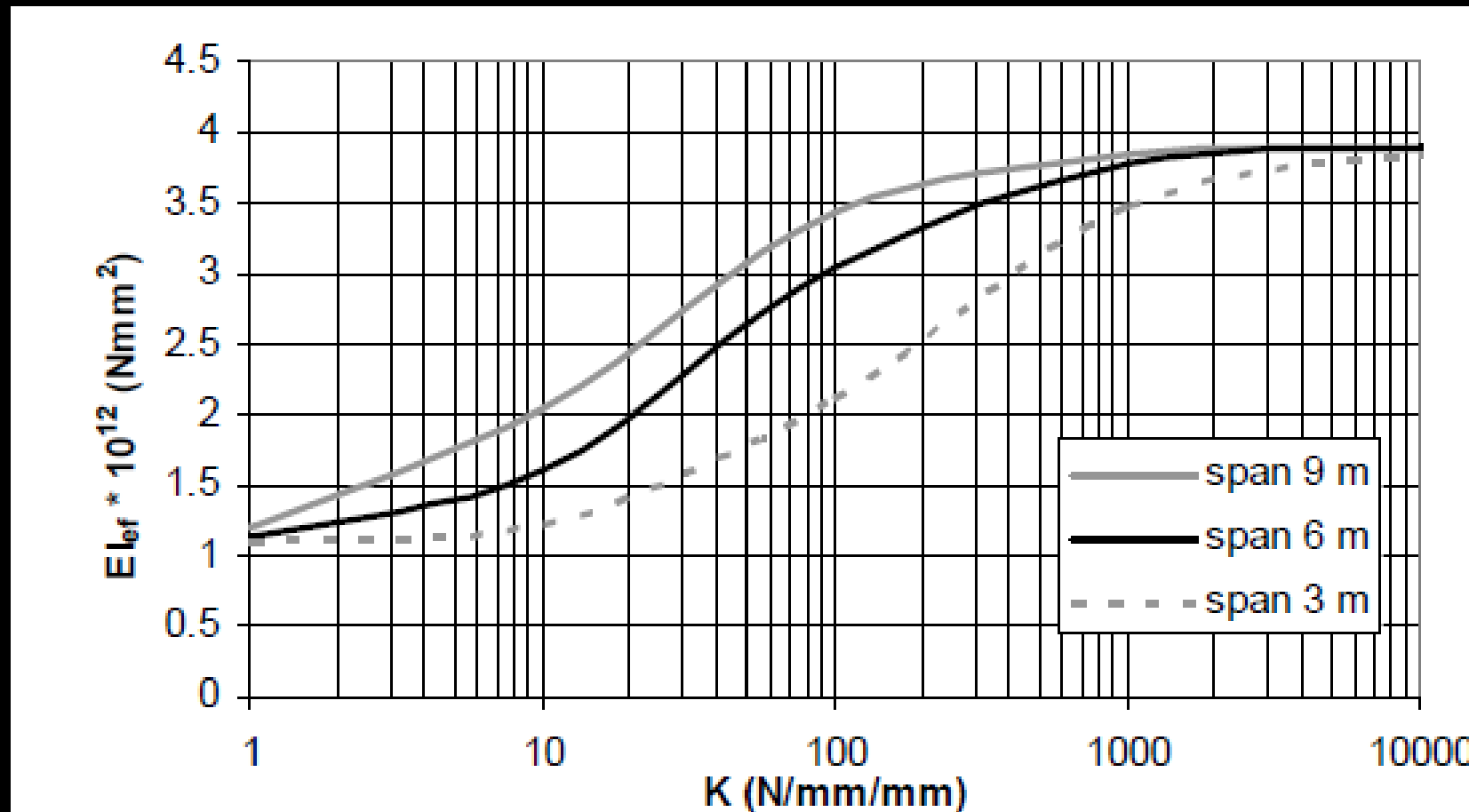
Timber-concrete beams with incomplete composite action

<i>Incomplete</i>	$E_1 \cdot A_1 + E_2 \cdot A_2 = (E \cdot A)_0$	$(E \cdot I)_0 + \gamma_1 \cdot E_1 \cdot A_1 \cdot e_1^2 + E_2 \cdot A_2 \cdot e_2^2$
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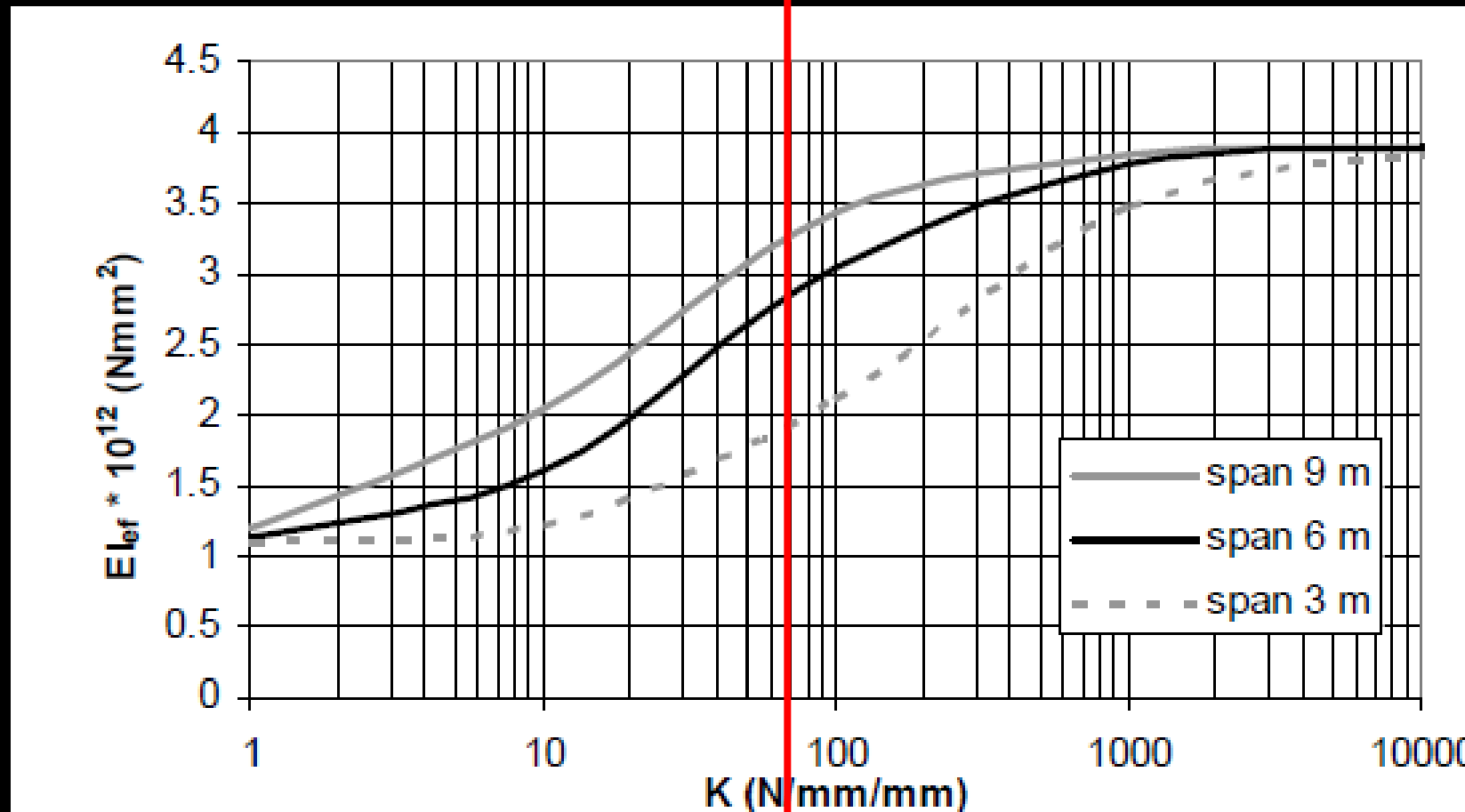
$$\gamma_1 = \frac{1}{1 + \frac{\pi^2 \cdot E_1 \cdot A_1}{k \cdot L^2}}$$

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)?



→ **Almost full-composite action!**

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

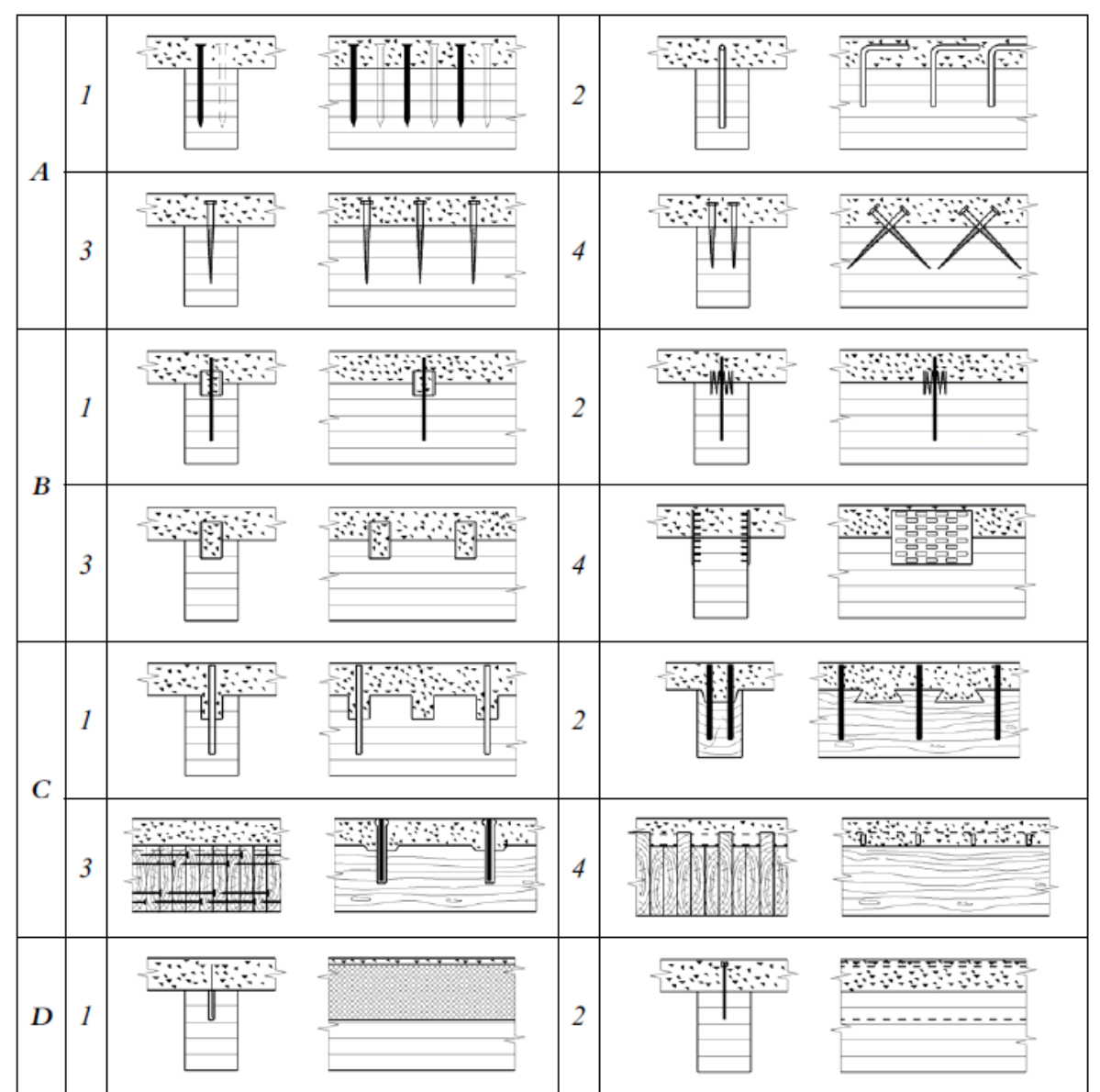
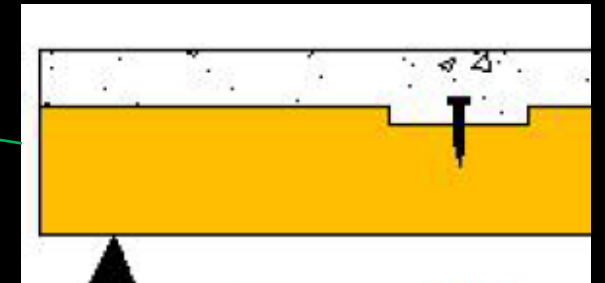
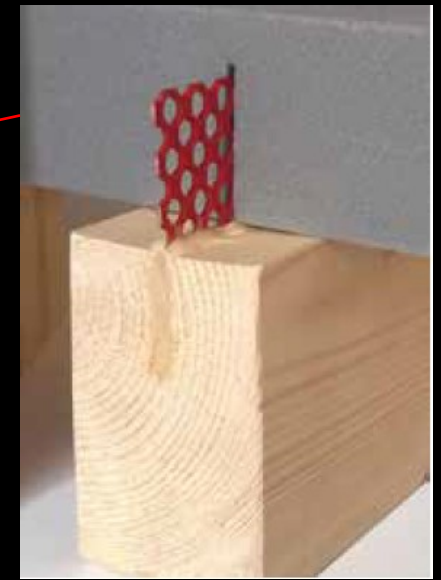
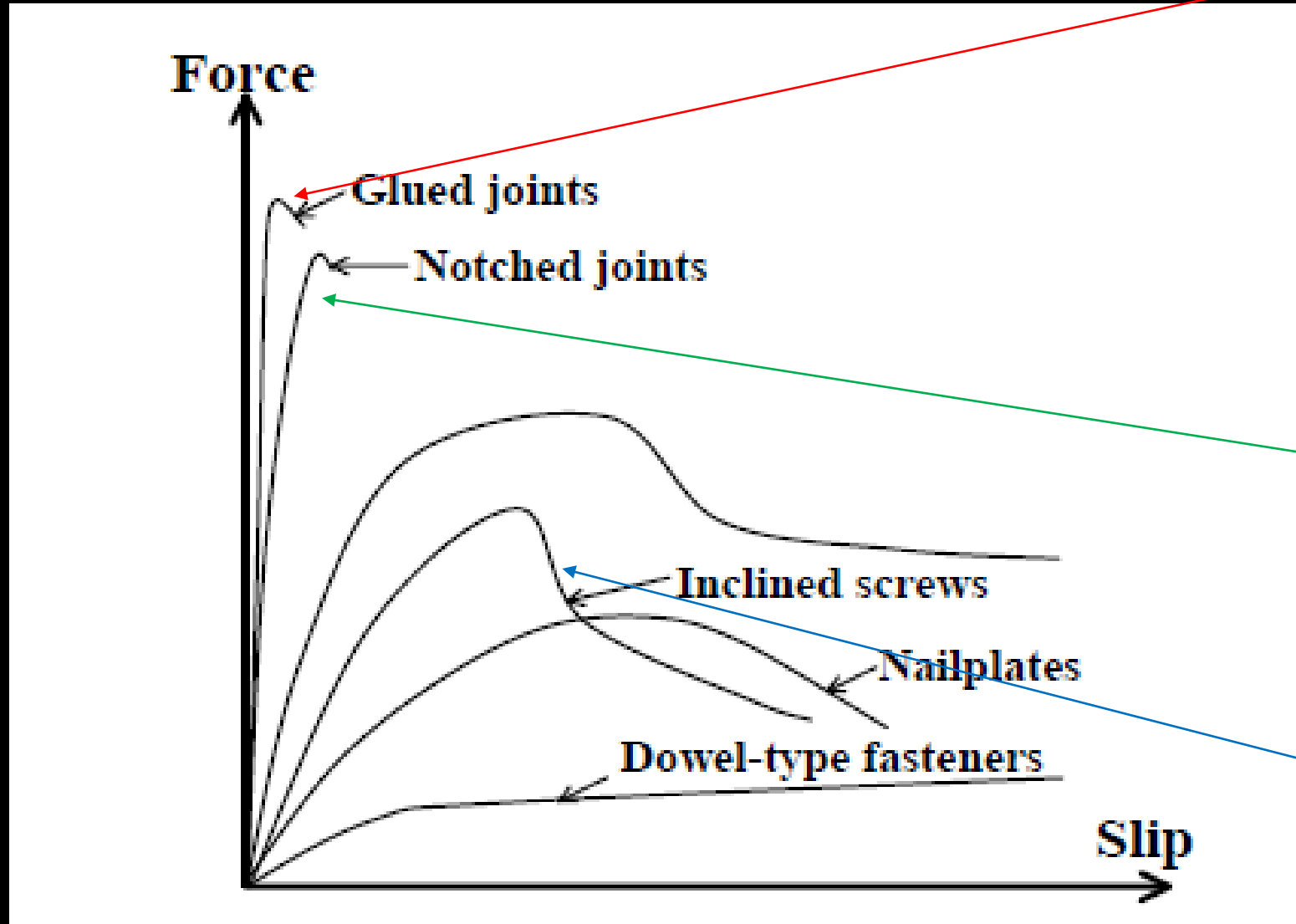


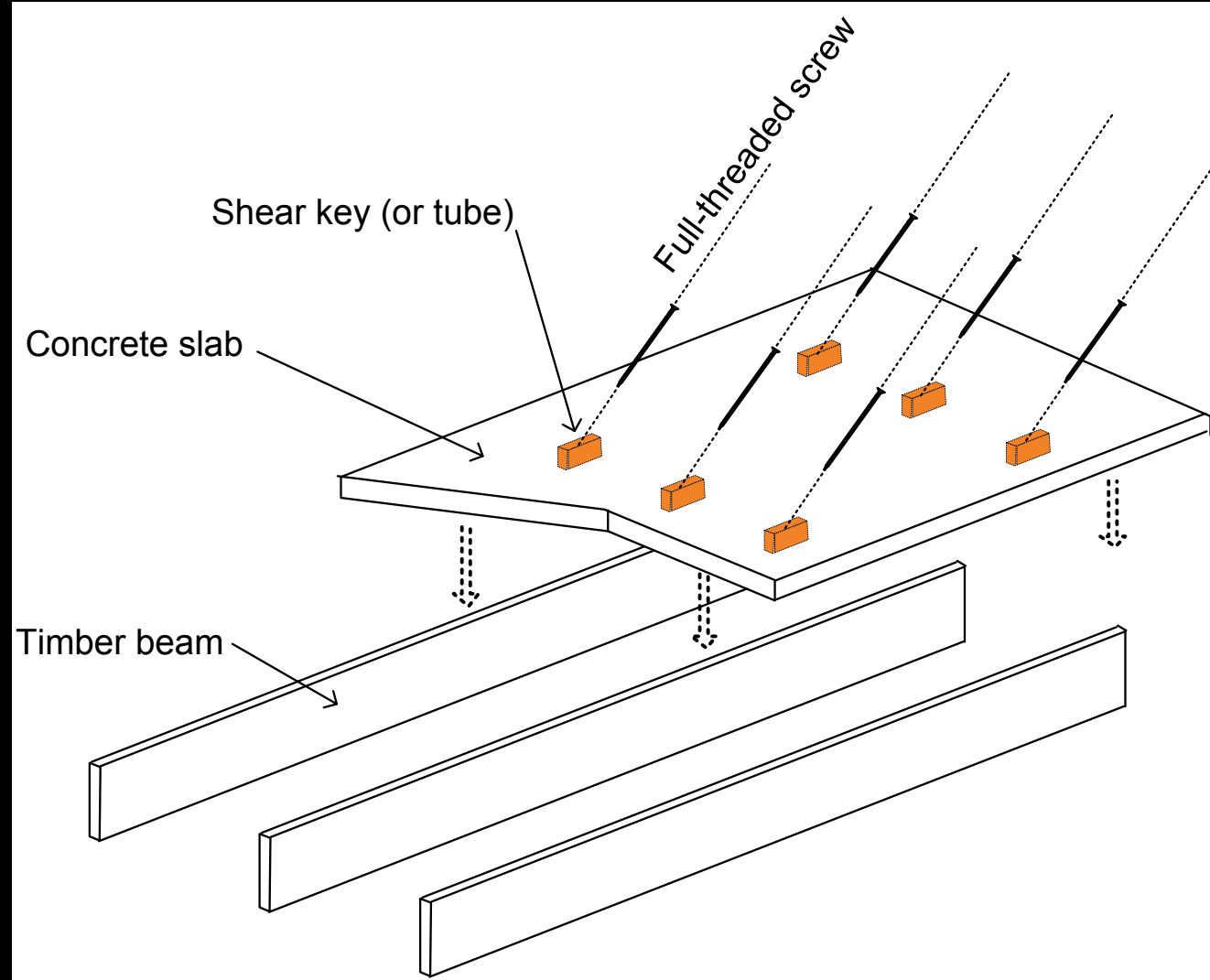
Figure 2.3 Examples of timber-concrete connections with: nails (A1); glued reinforced concrete steel bars (A2); screws (A3); inclined screws (A4); split rings (B1); toothed plates (B2); steel tubes (B3); steel punched metal plates (B4); round indentations in timber, with fasteners preventing uplift (C1); 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)



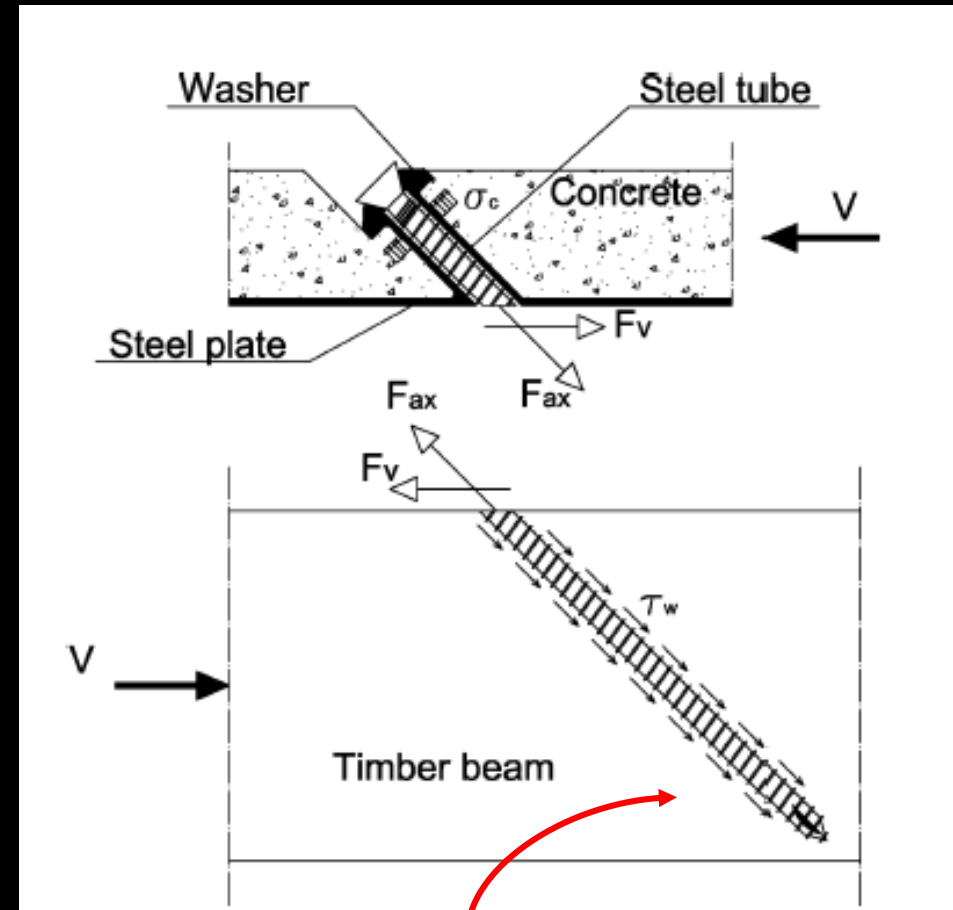
Research at Lund University

Research at Lund University: the first concept (2009)



T-connector

Steel tube $d=12$ mm, $t=2$ mm



Self-tapping screw: 11x250

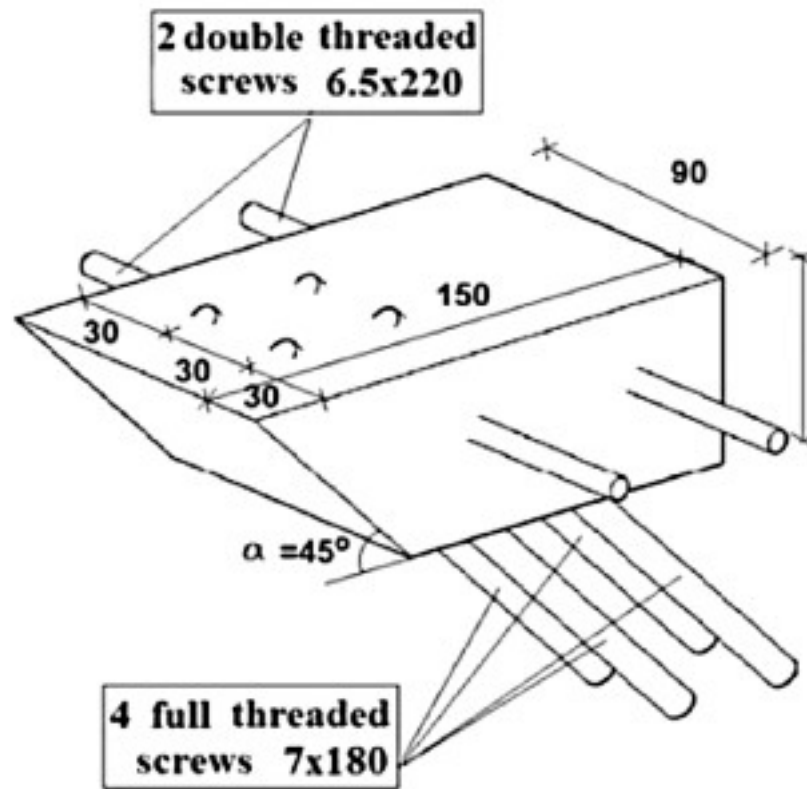
T-connector in a "real floor"



W-connector



(a)

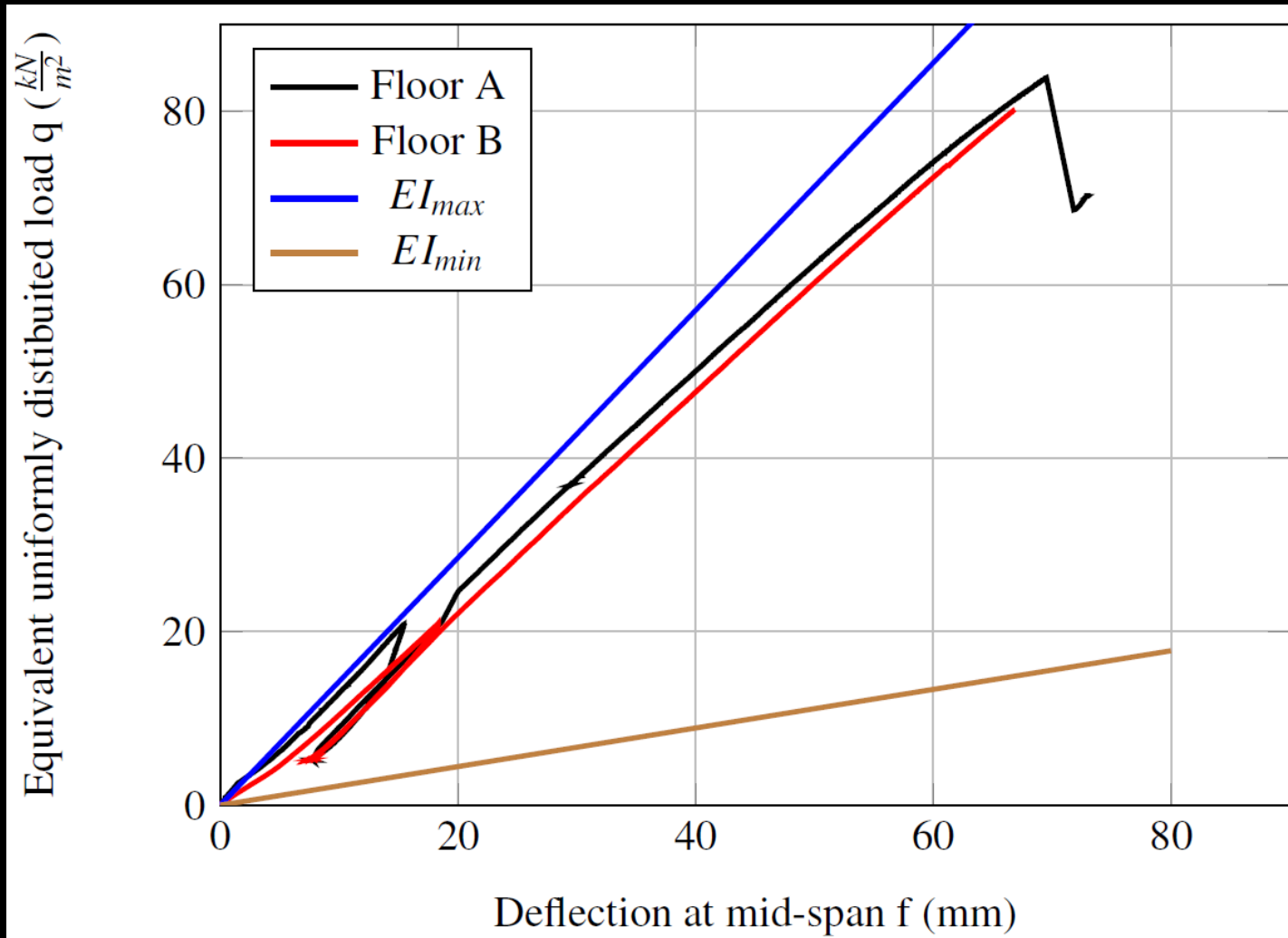


(b)

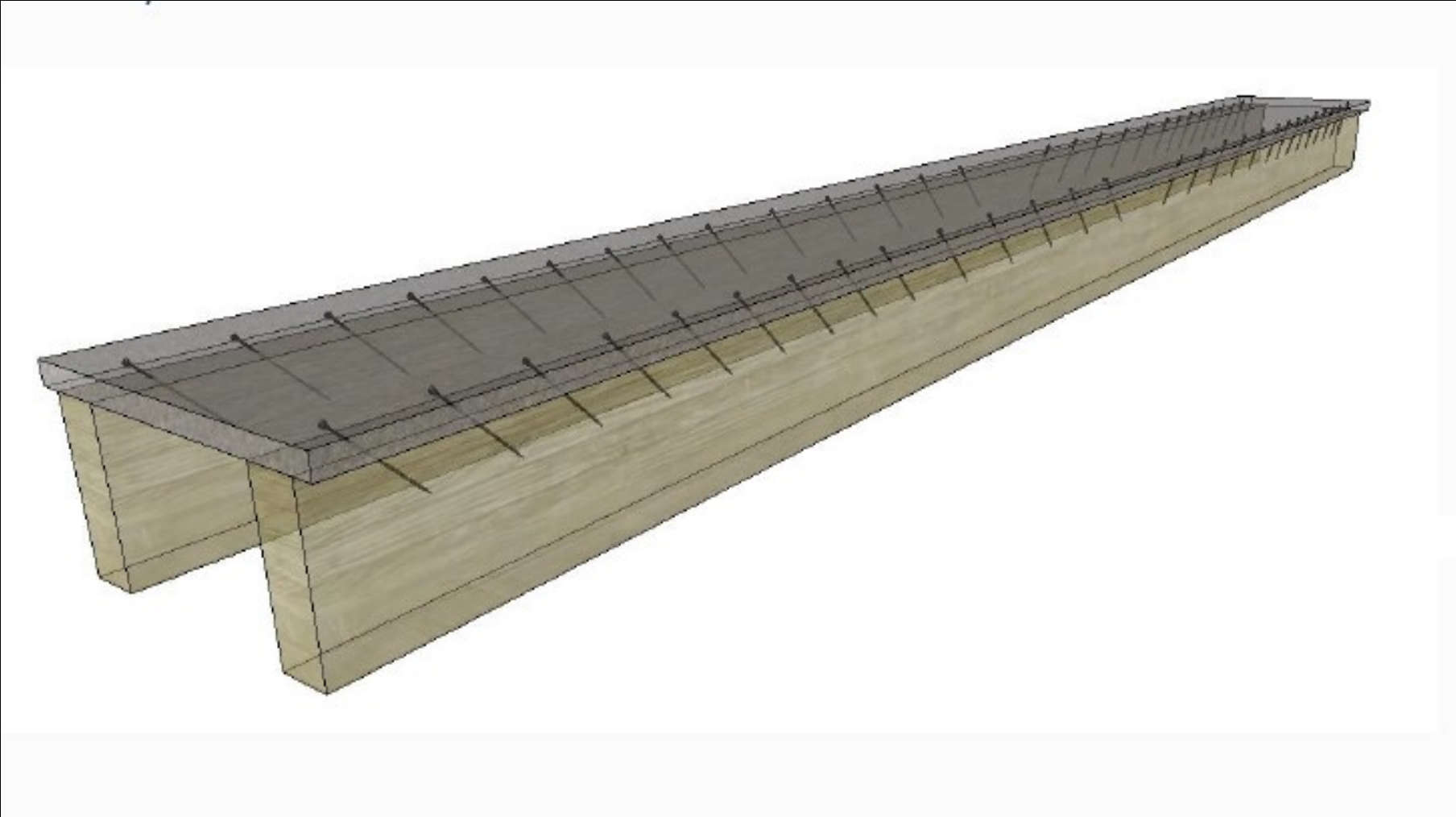
W-connector in a “real floor”



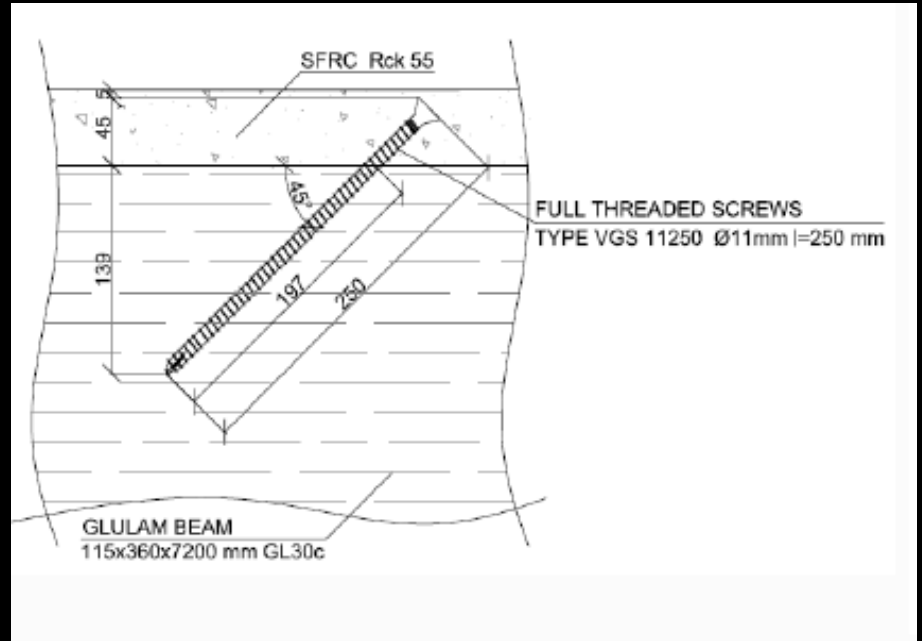
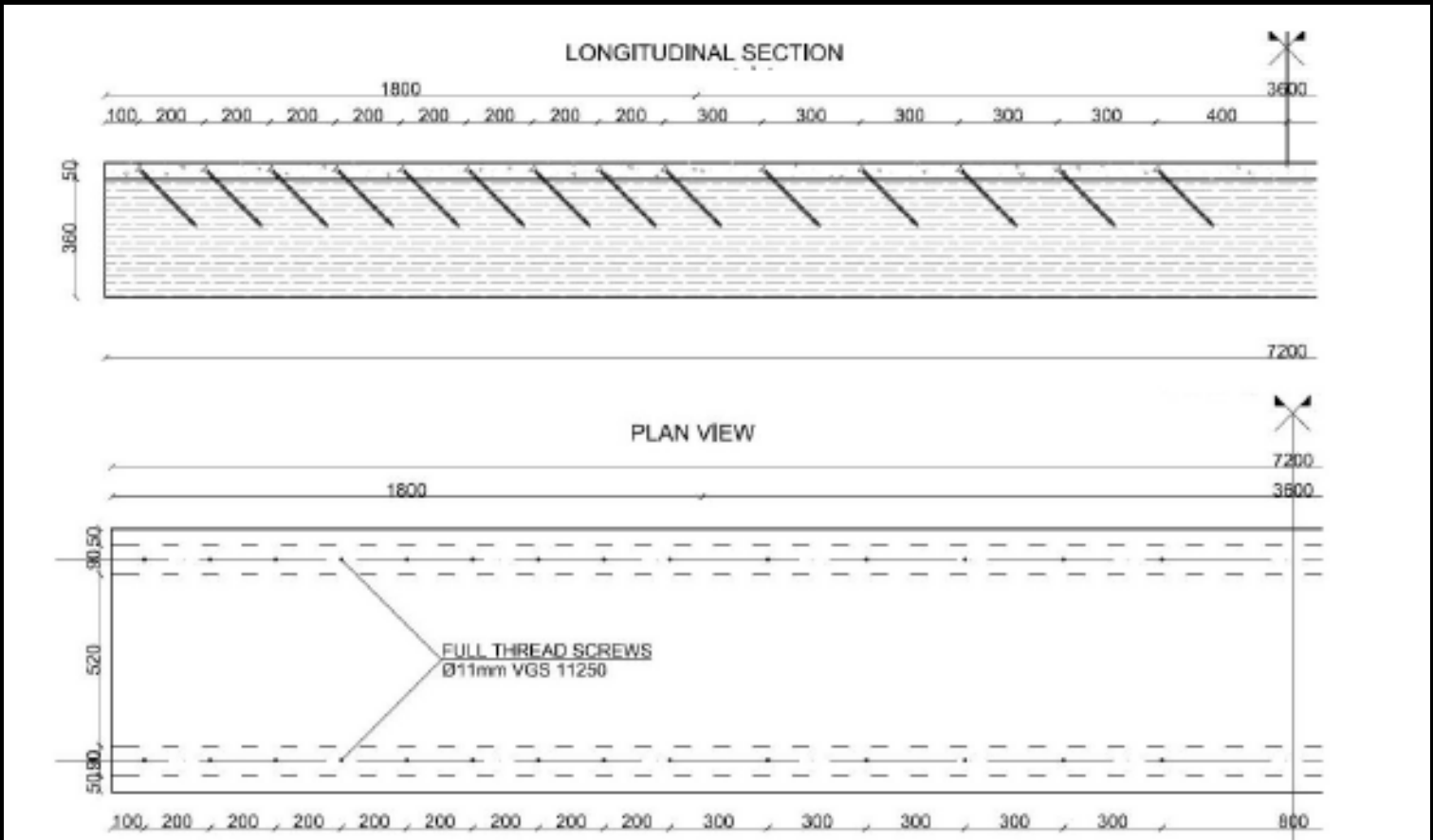
Bending stiffness of the floors



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



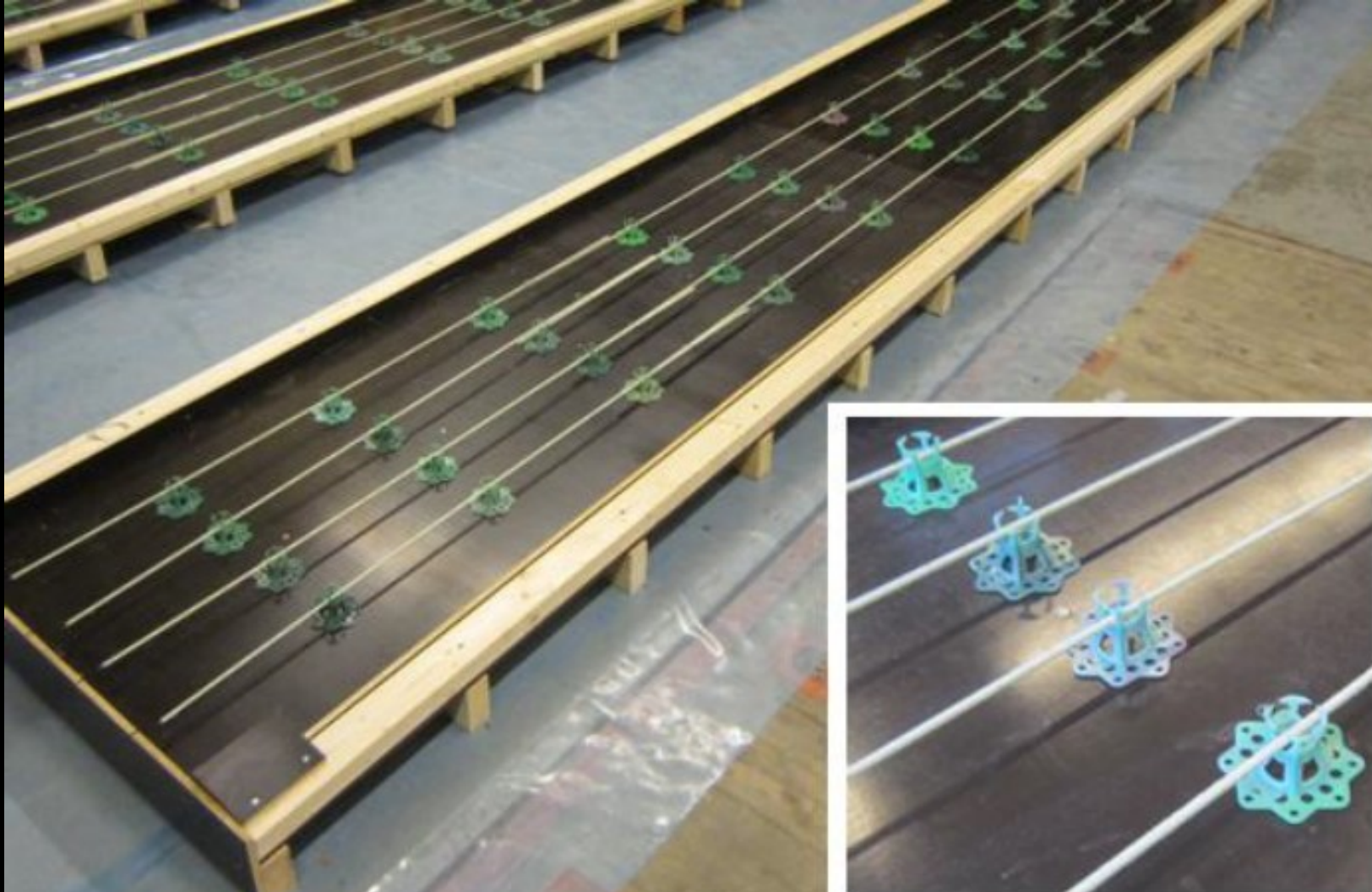
Geometry



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



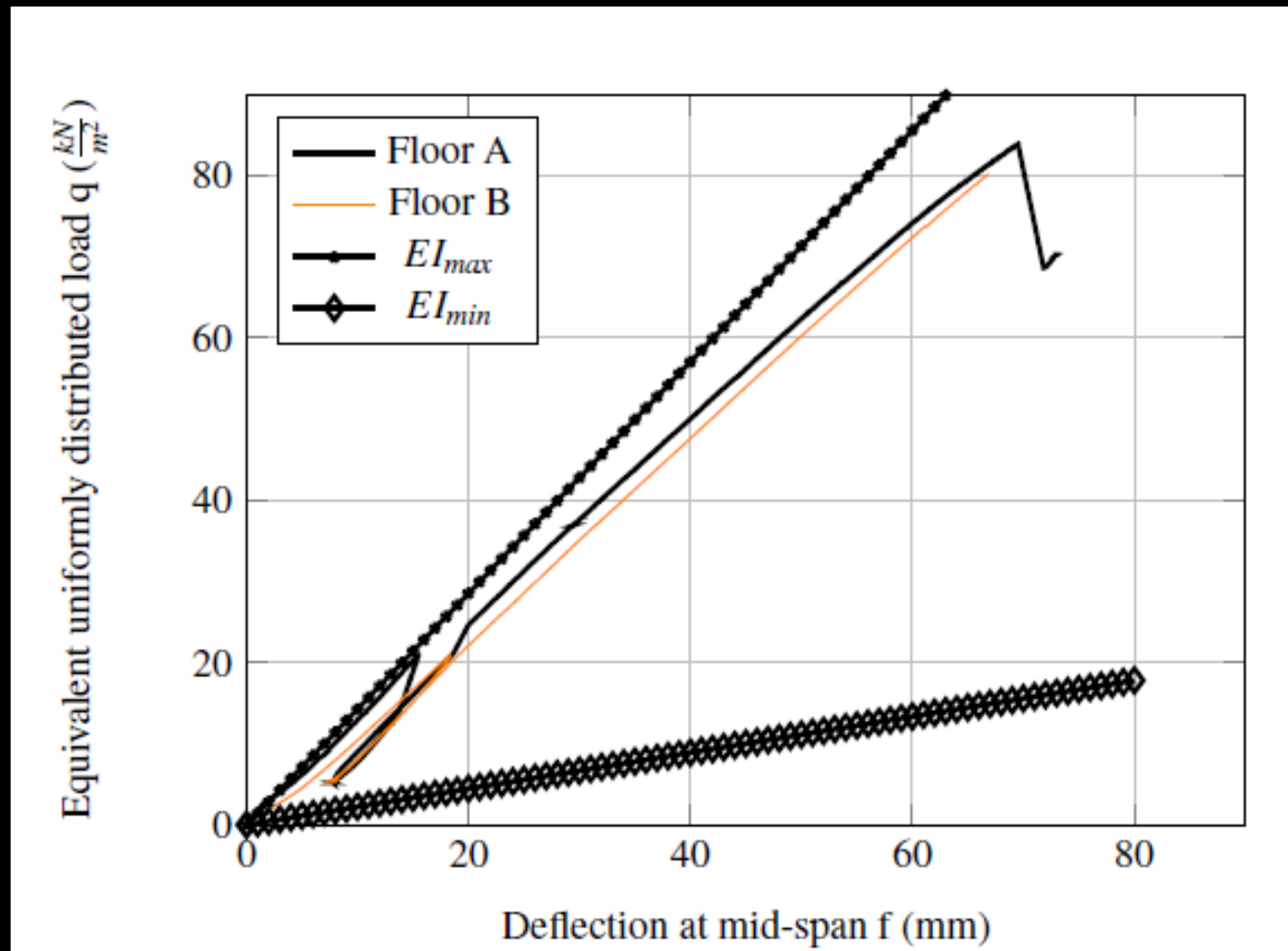
4. After concrete has cured, turn the floor upside down to “right” position



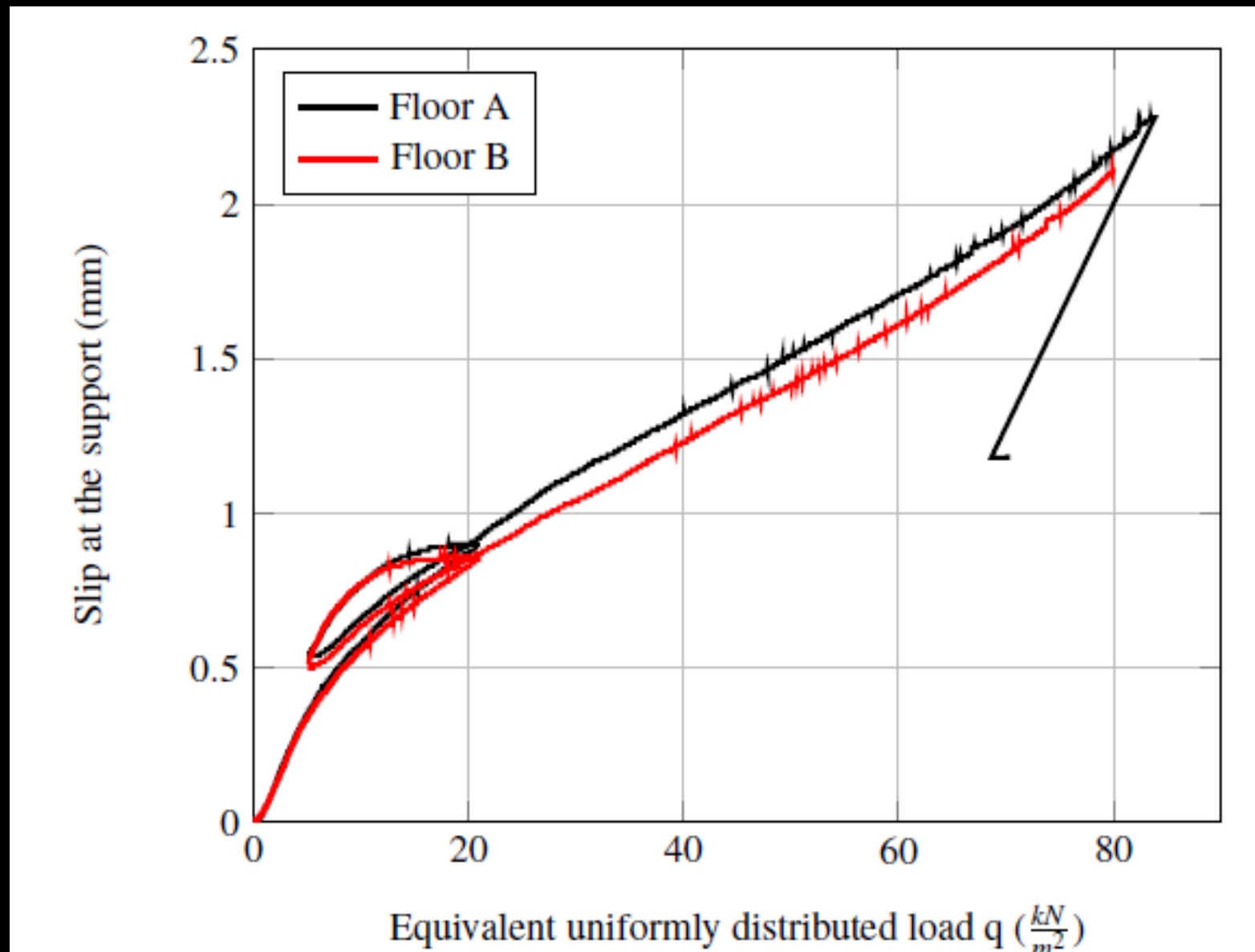
5. Done!



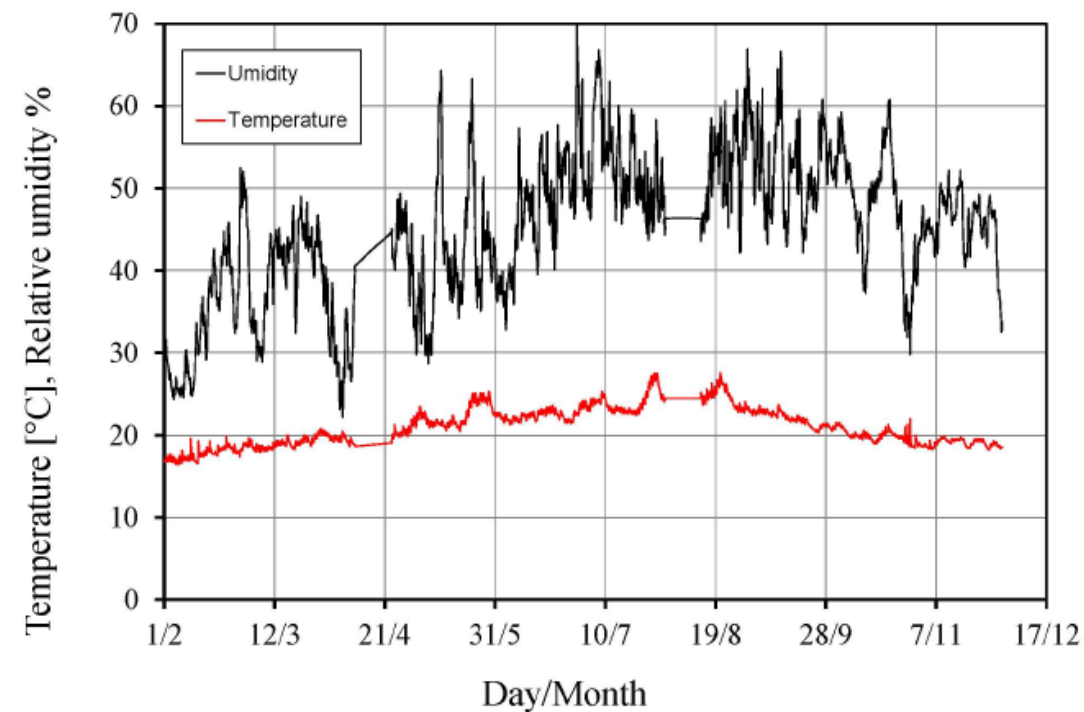
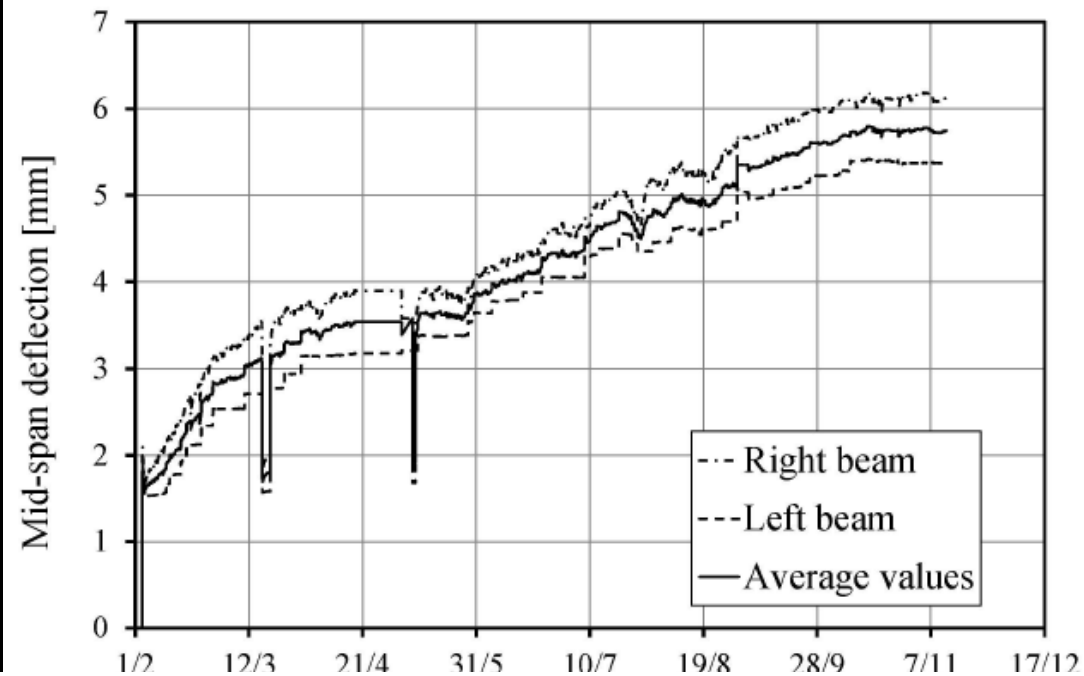
Load vs. mid-span deflection – 2 tests



Load vs. end-slip – 2 tests



Long-term behaviour



Another type of prefabricated floor

1: Insert screws



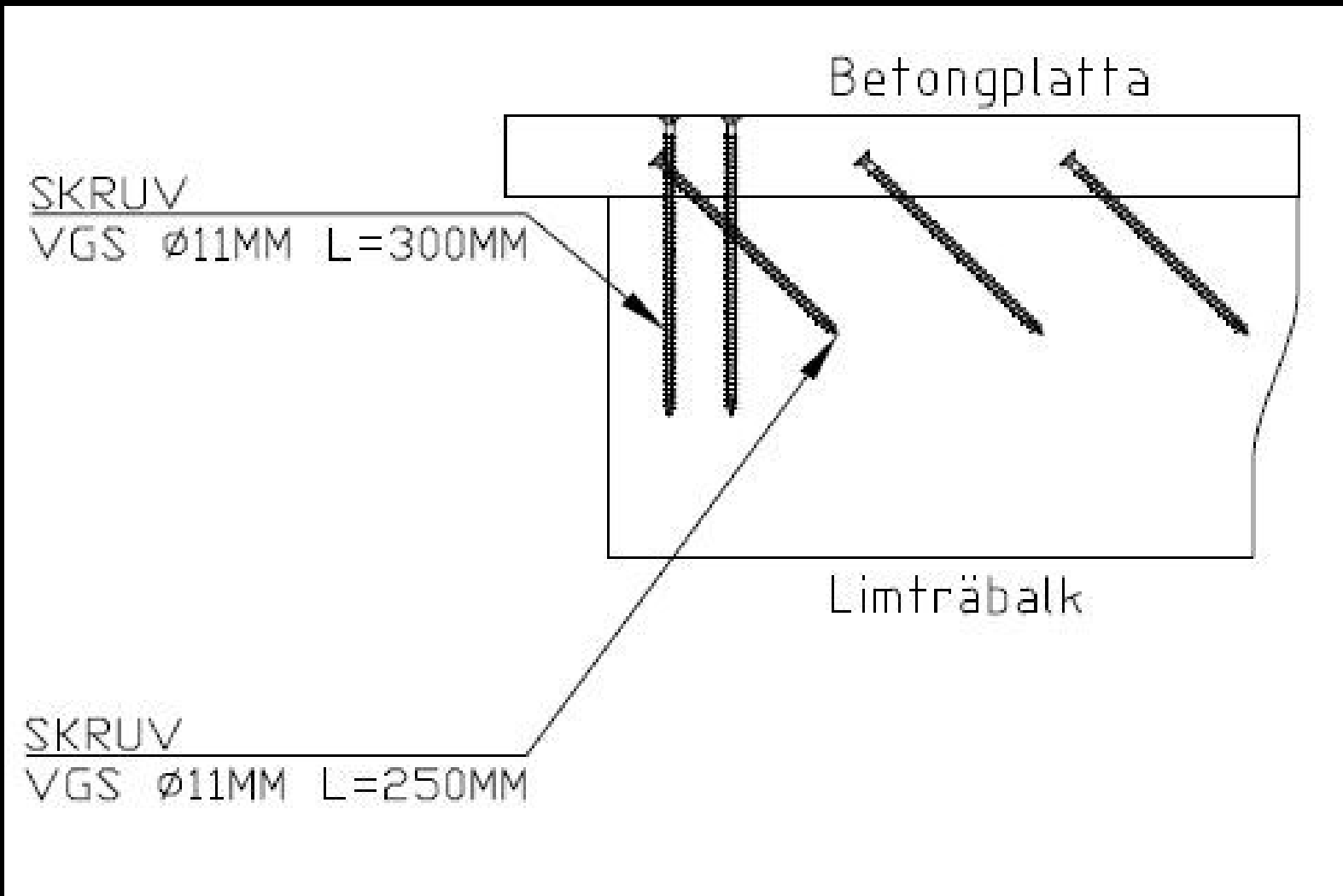
2: Twist upside down and cast concrete



3: Let cure and twist upside down again

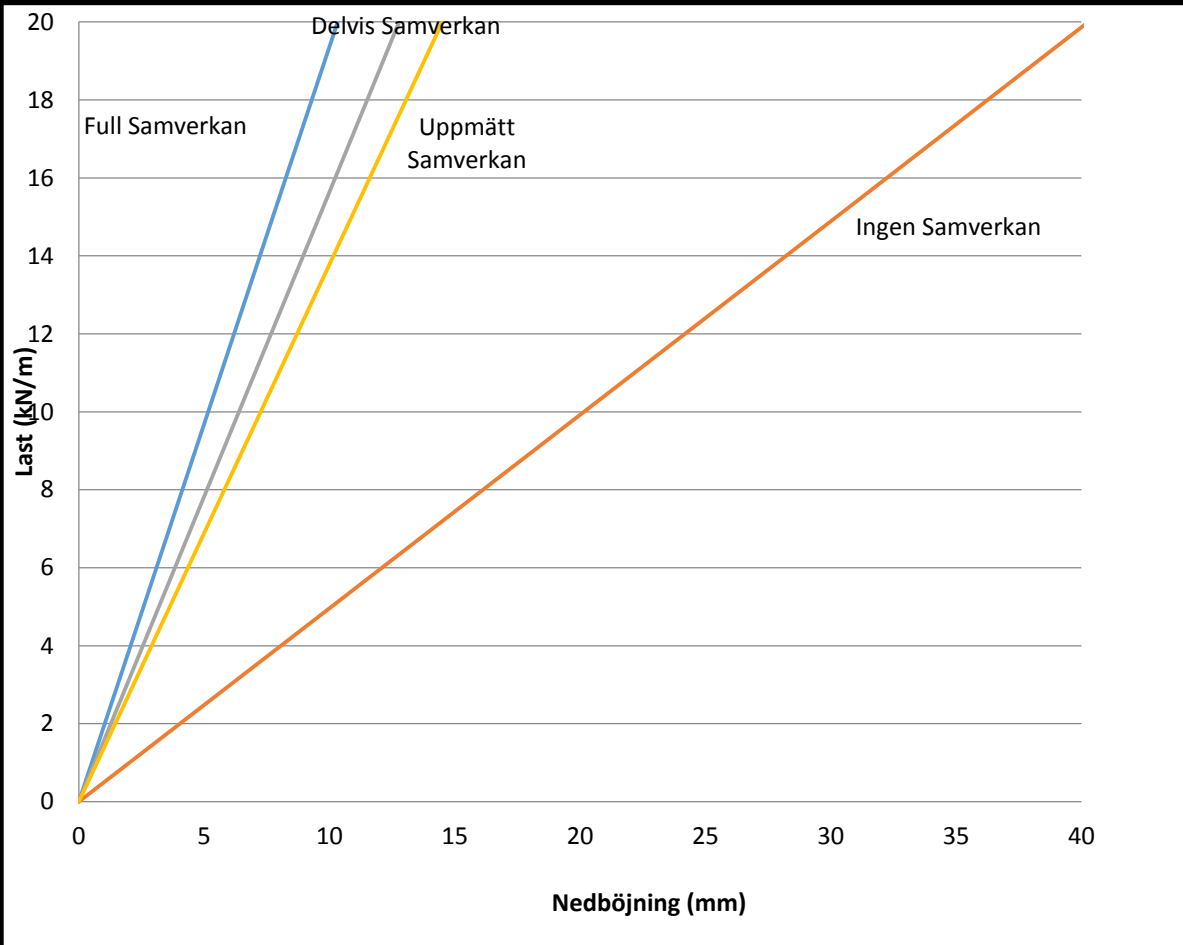


Detail of the support



Concrete C40/50
t = 80mm

Tests



Dynamic tests

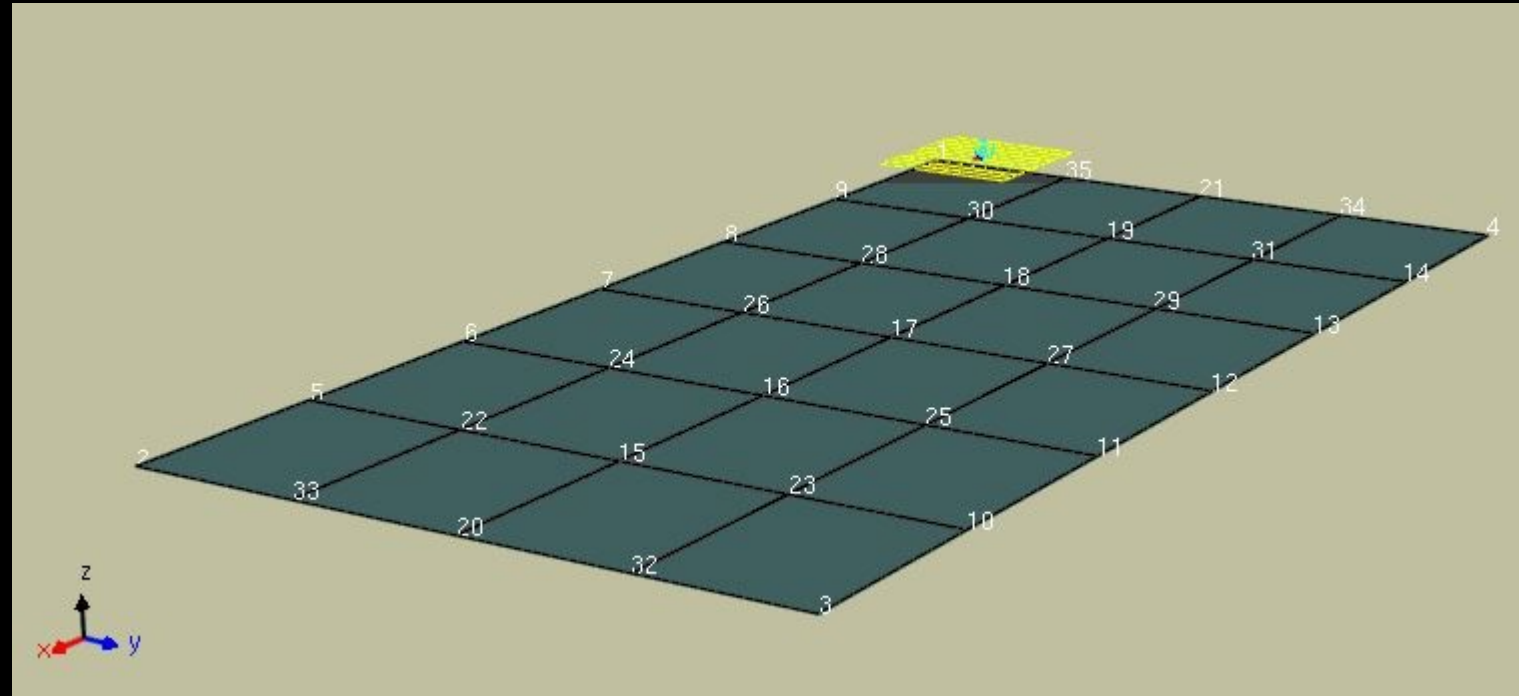
Impulse hammer



Accelerometre

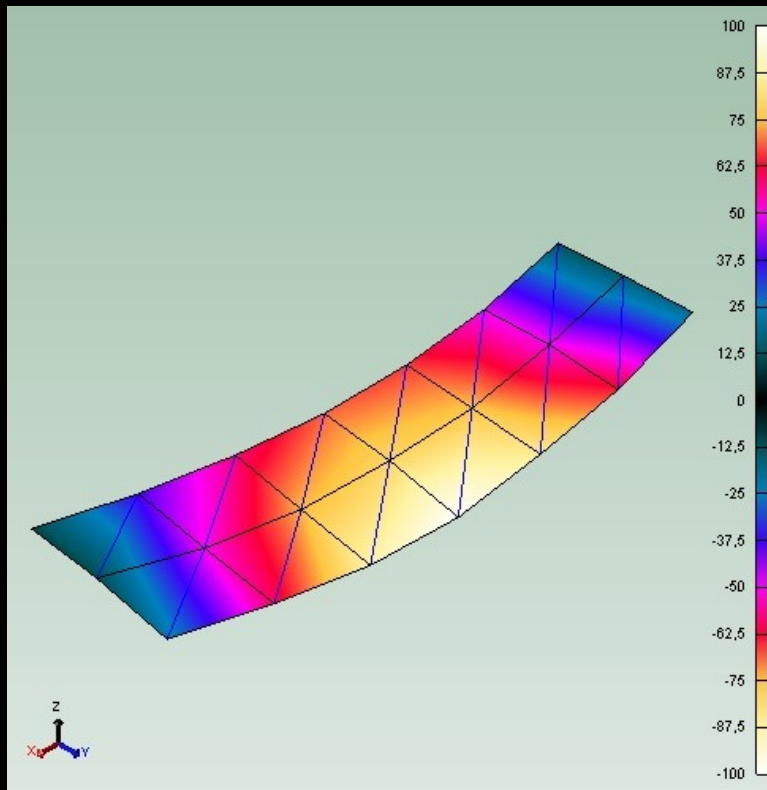


Measuring points in the floor

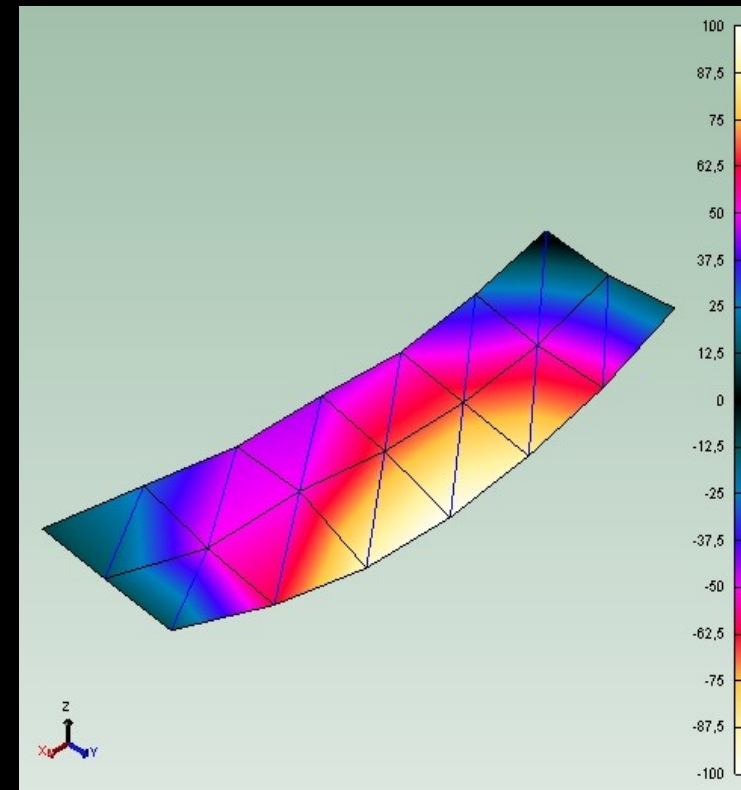


Results

w/o load, $f_1=9,23$ Hz

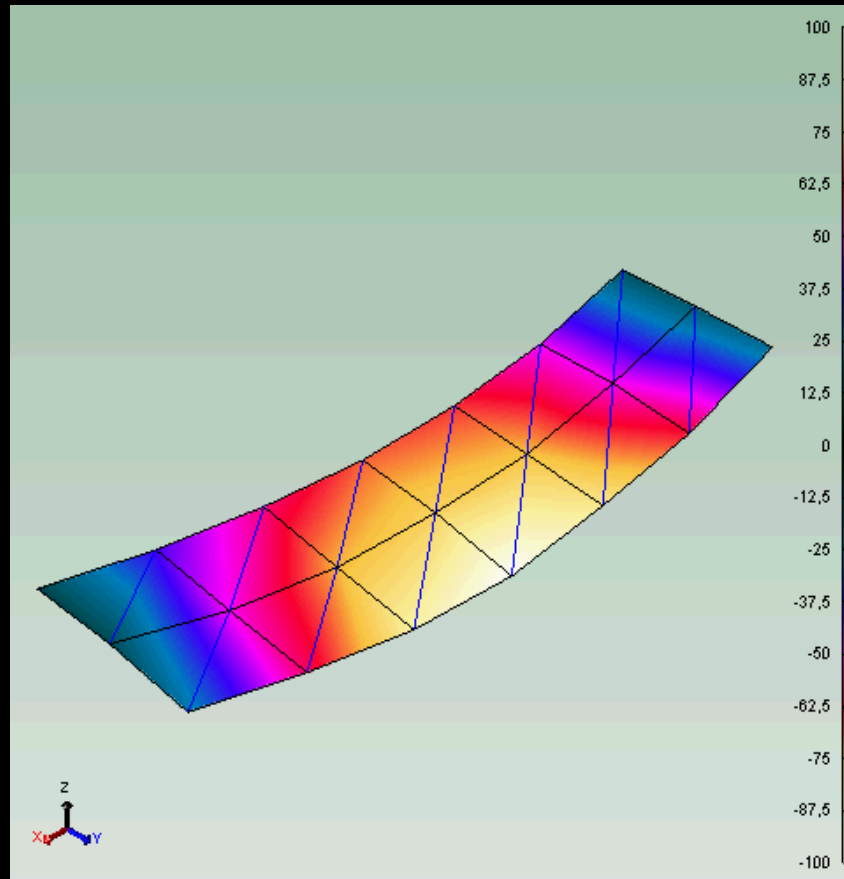


with load, $f_1=6,27$ Hz

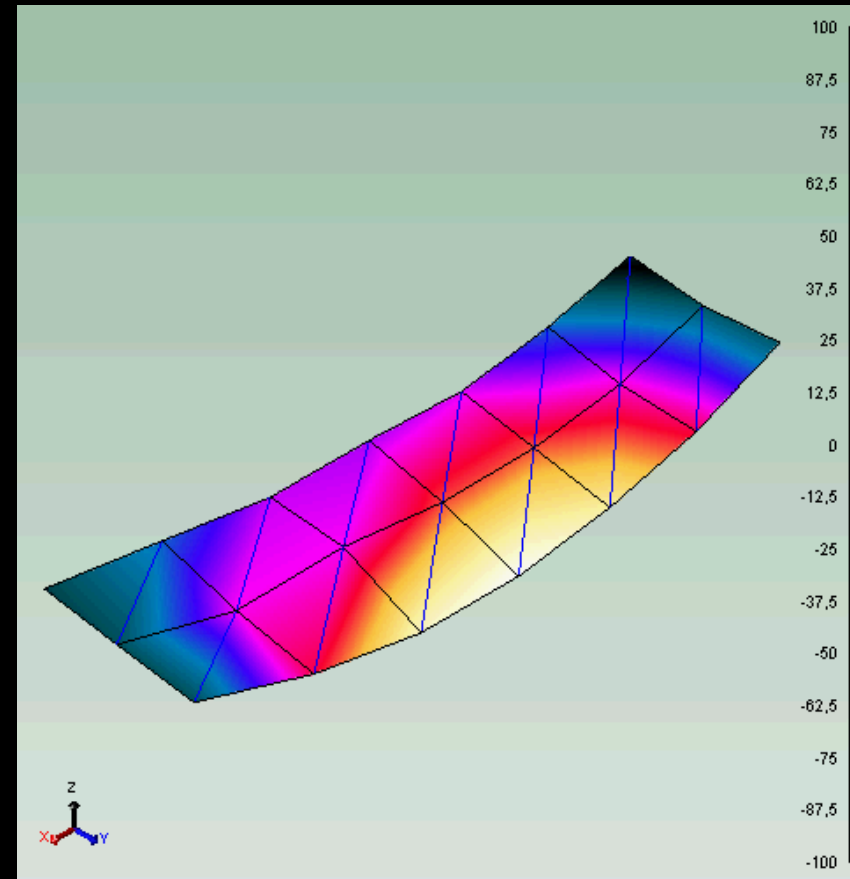


Results

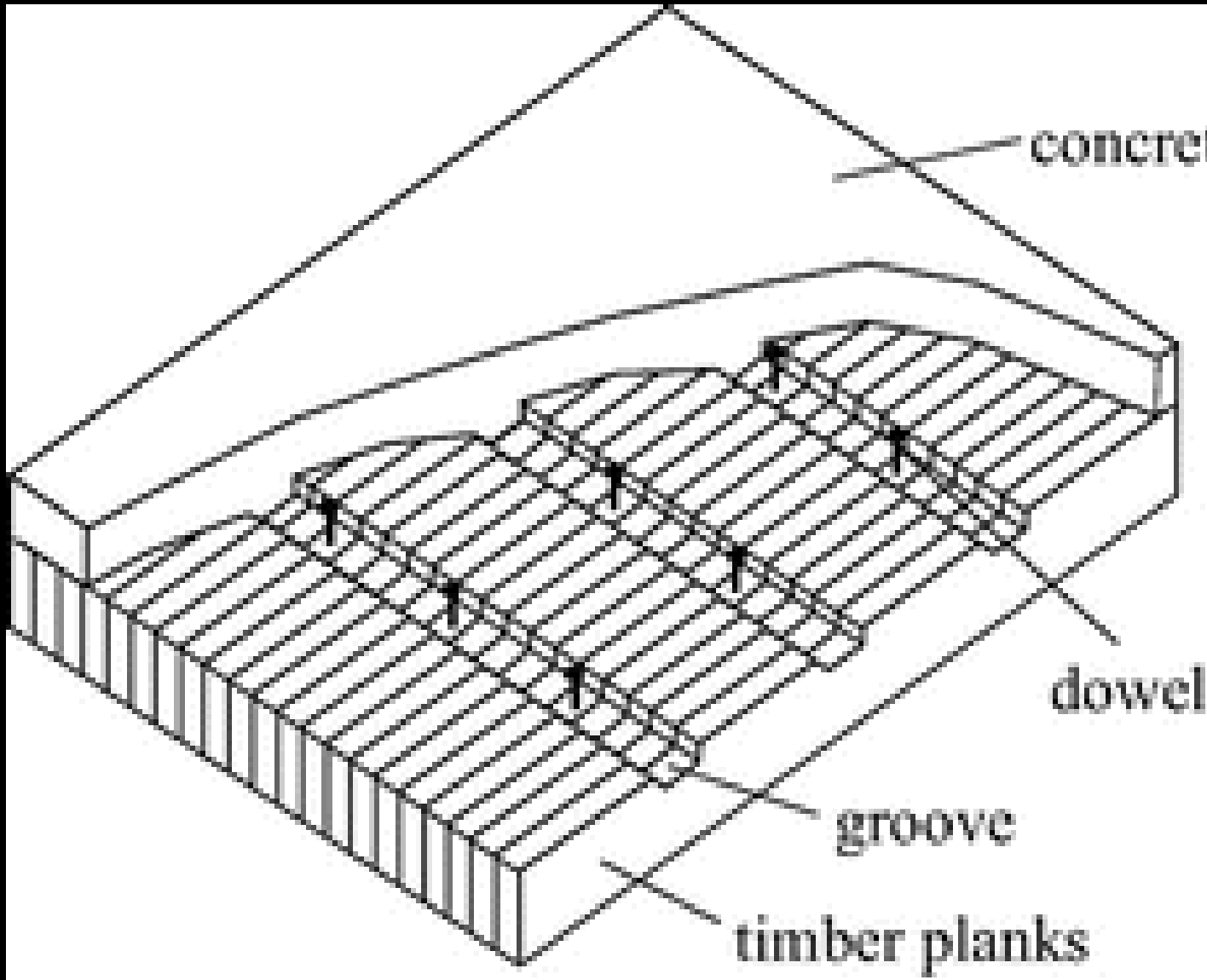
w/o load, $f_1=9,23$ Hz



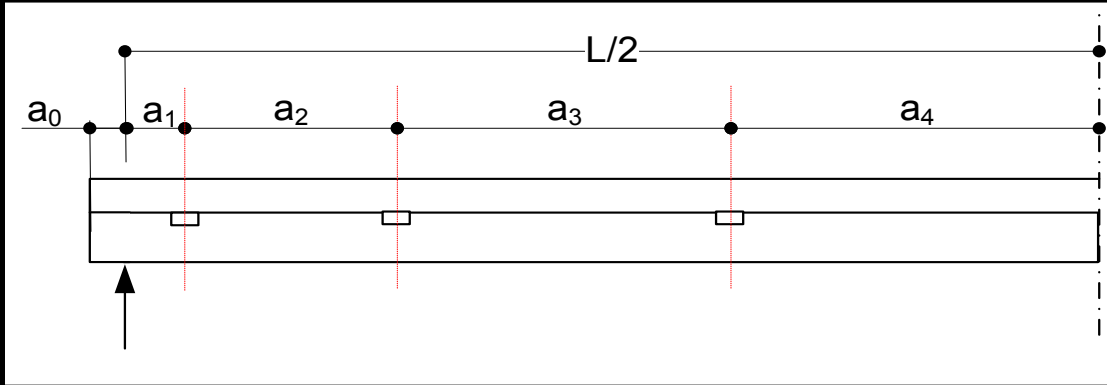
with load, $f_1=6,27$ Hz



The notched connection

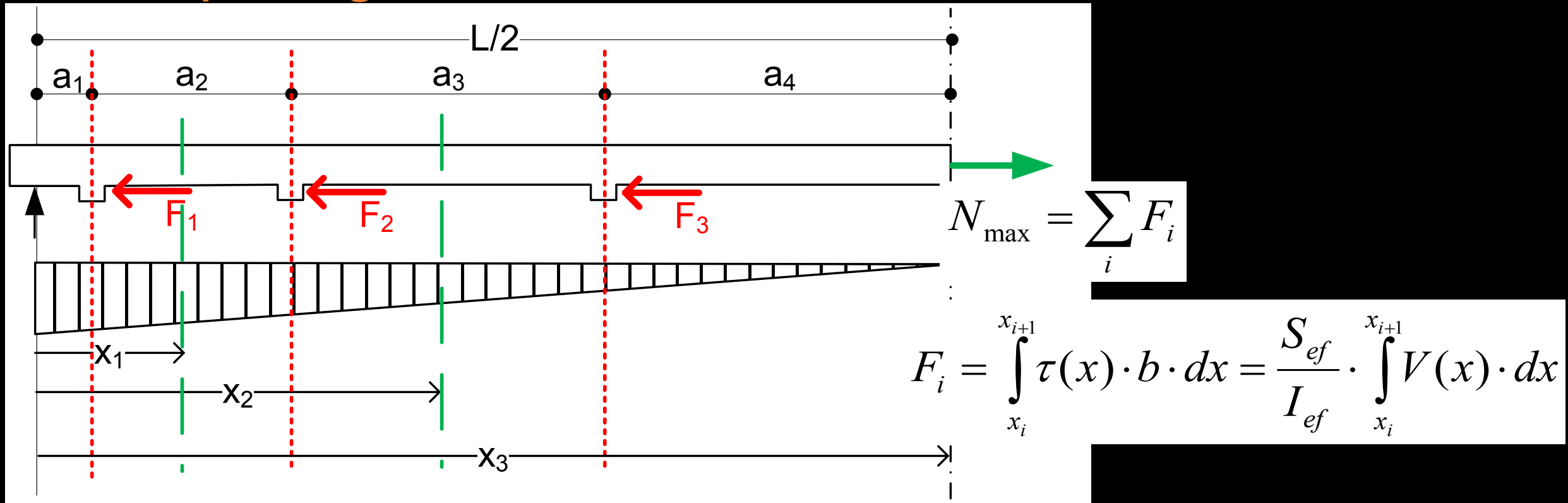


General design rules



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

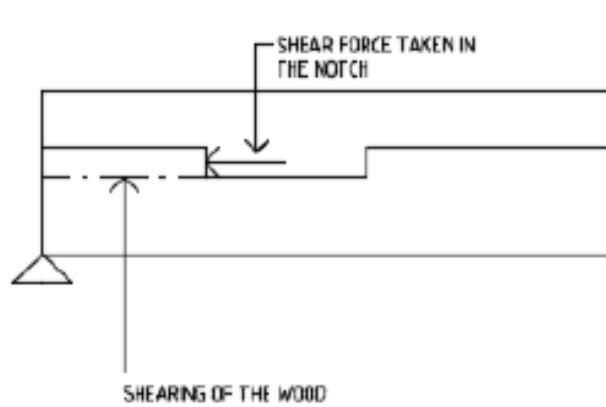
Notch spacing



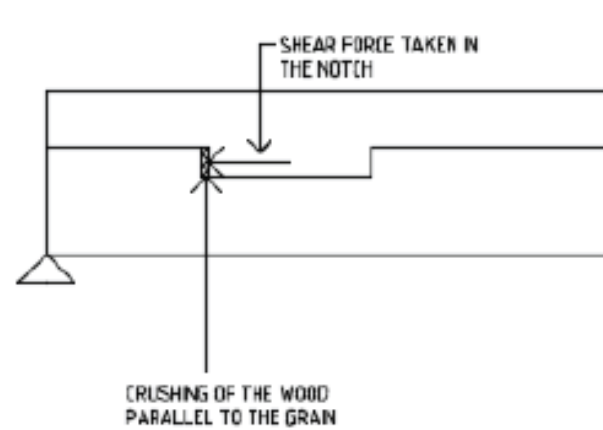
- Suggested distance from end grain: > 200 mm
- Place notches so that $F_1 \approx F_2 \approx F_3$

Notched connections: possible failure modes

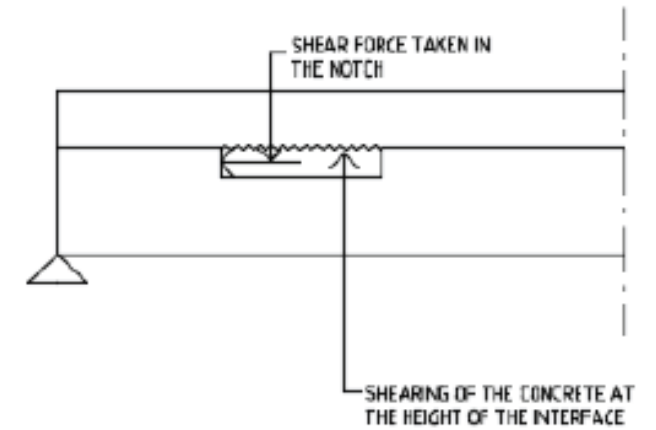
FAILURE MODE 1



FAILURE MODE 2



FAILURE MODE 3

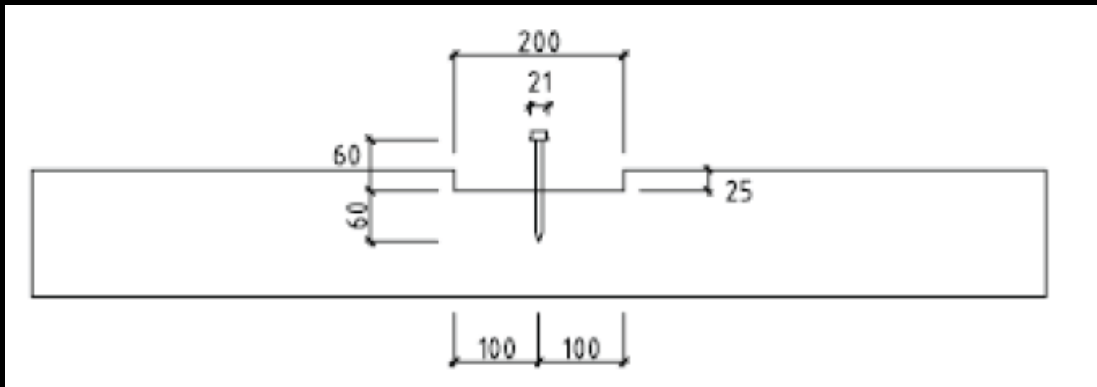


Notched connections tests at Lund University

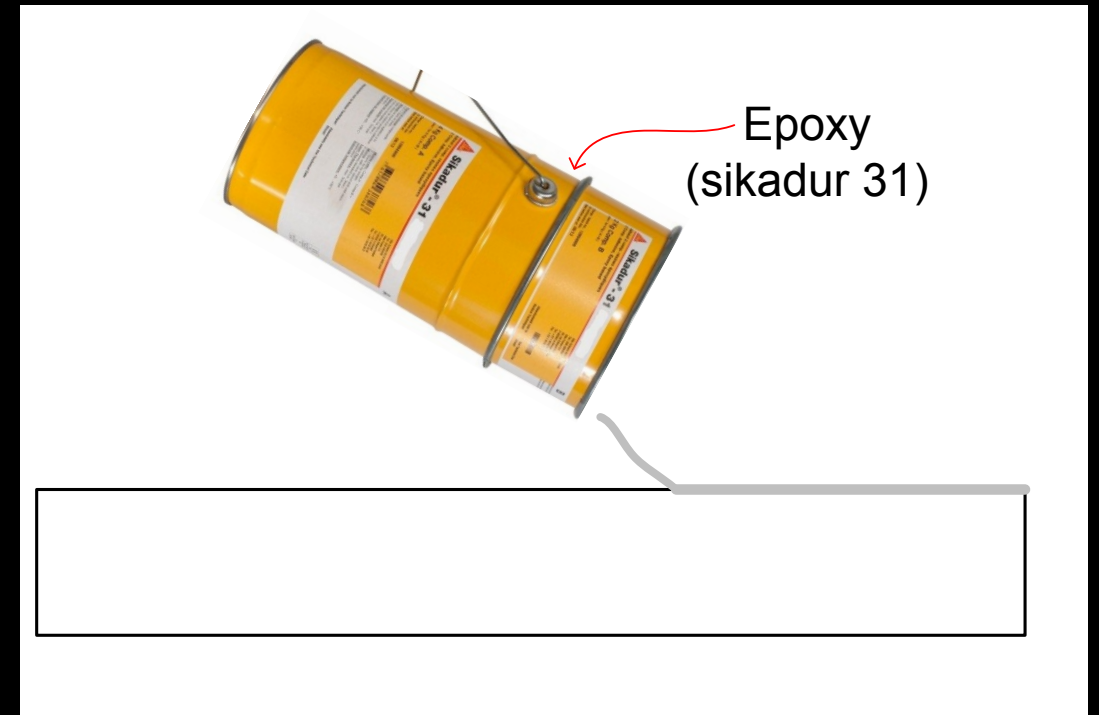


- a) four plates, length approx. 6,5 m and
- b) a number of small pieces for shear test specimens

The shear connections



The notched connection



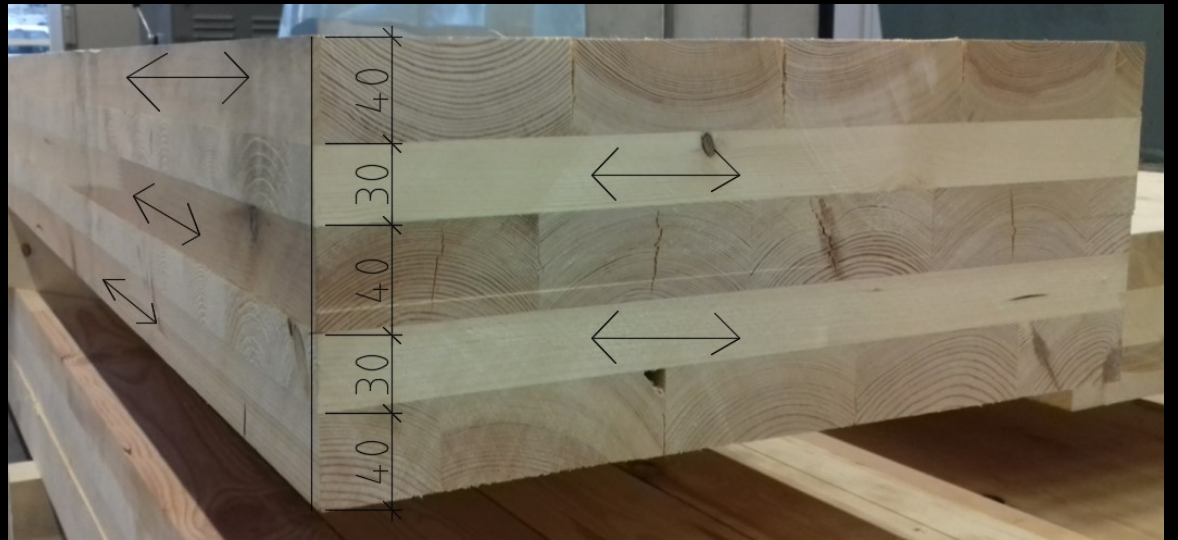
The glued connection

The two CLT plates

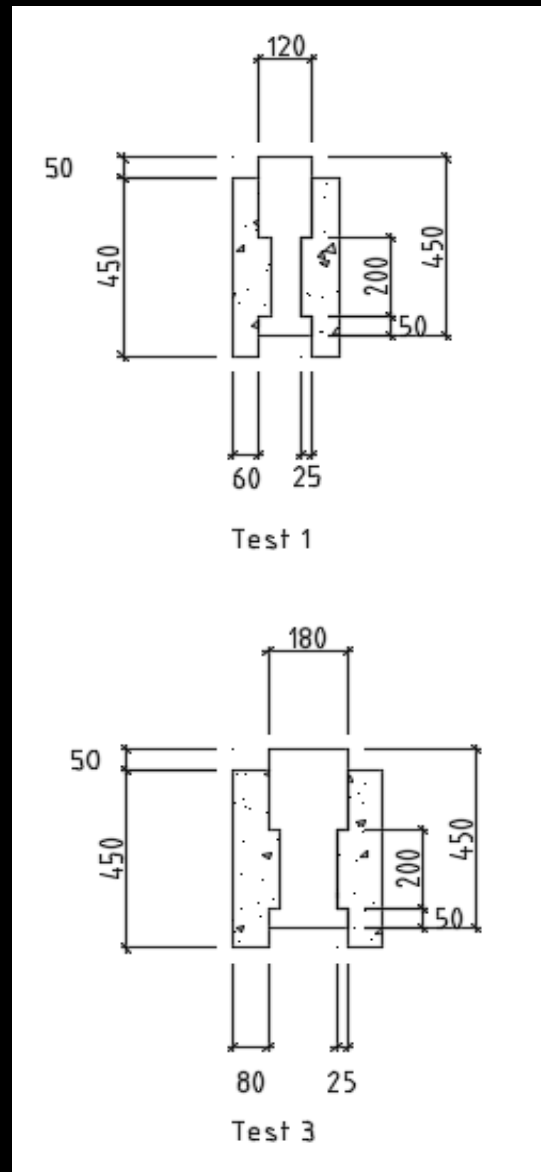
Plate 1: 450 x 120, span 6300



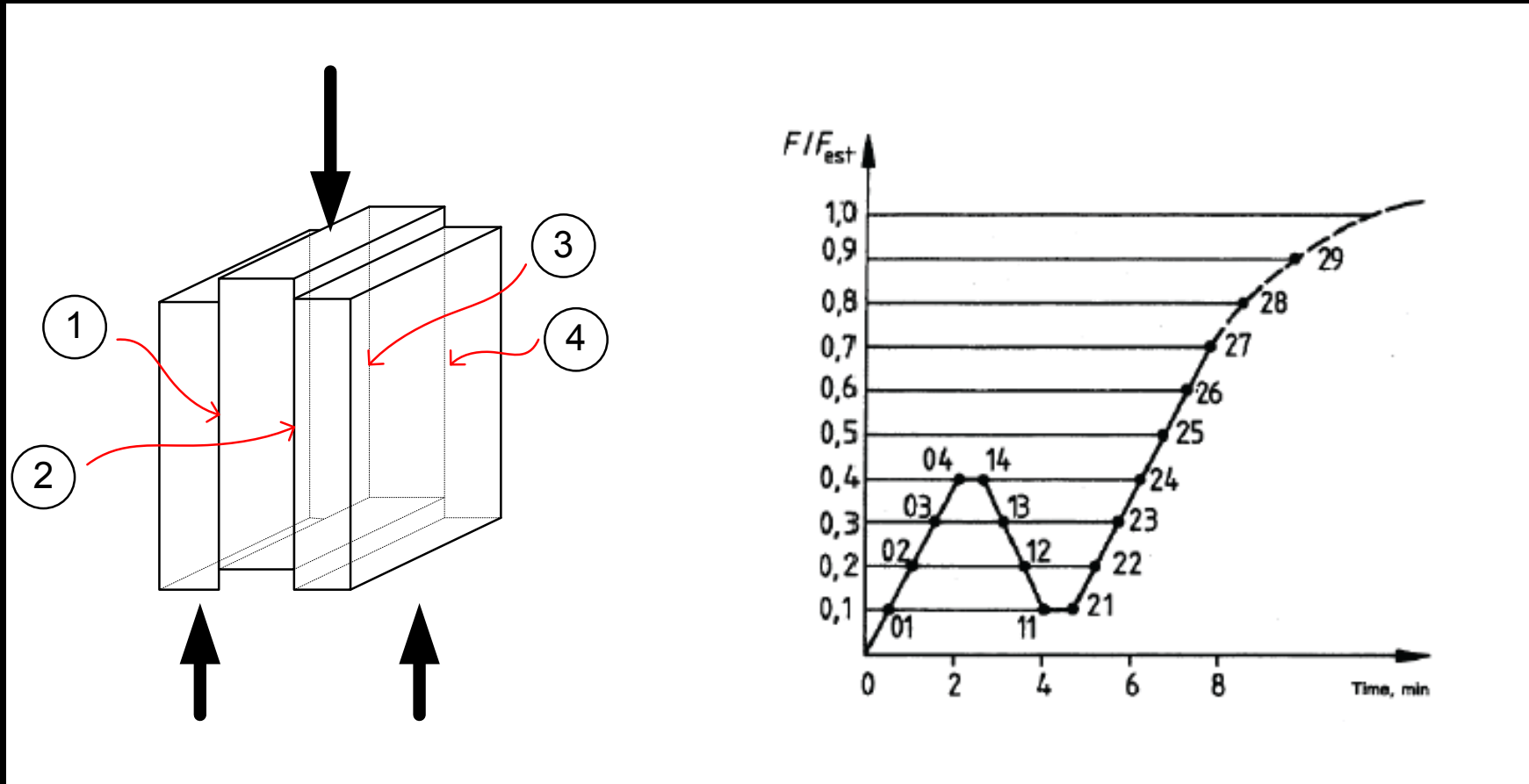
Plate 2: 450 x 180, span 6300



The shear connections

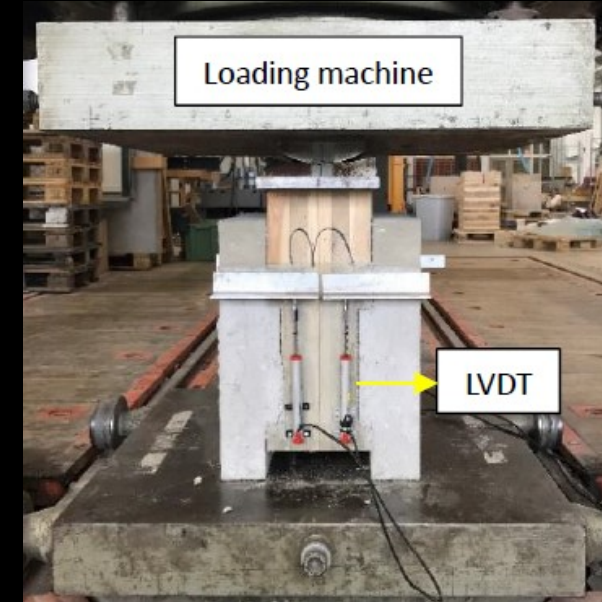
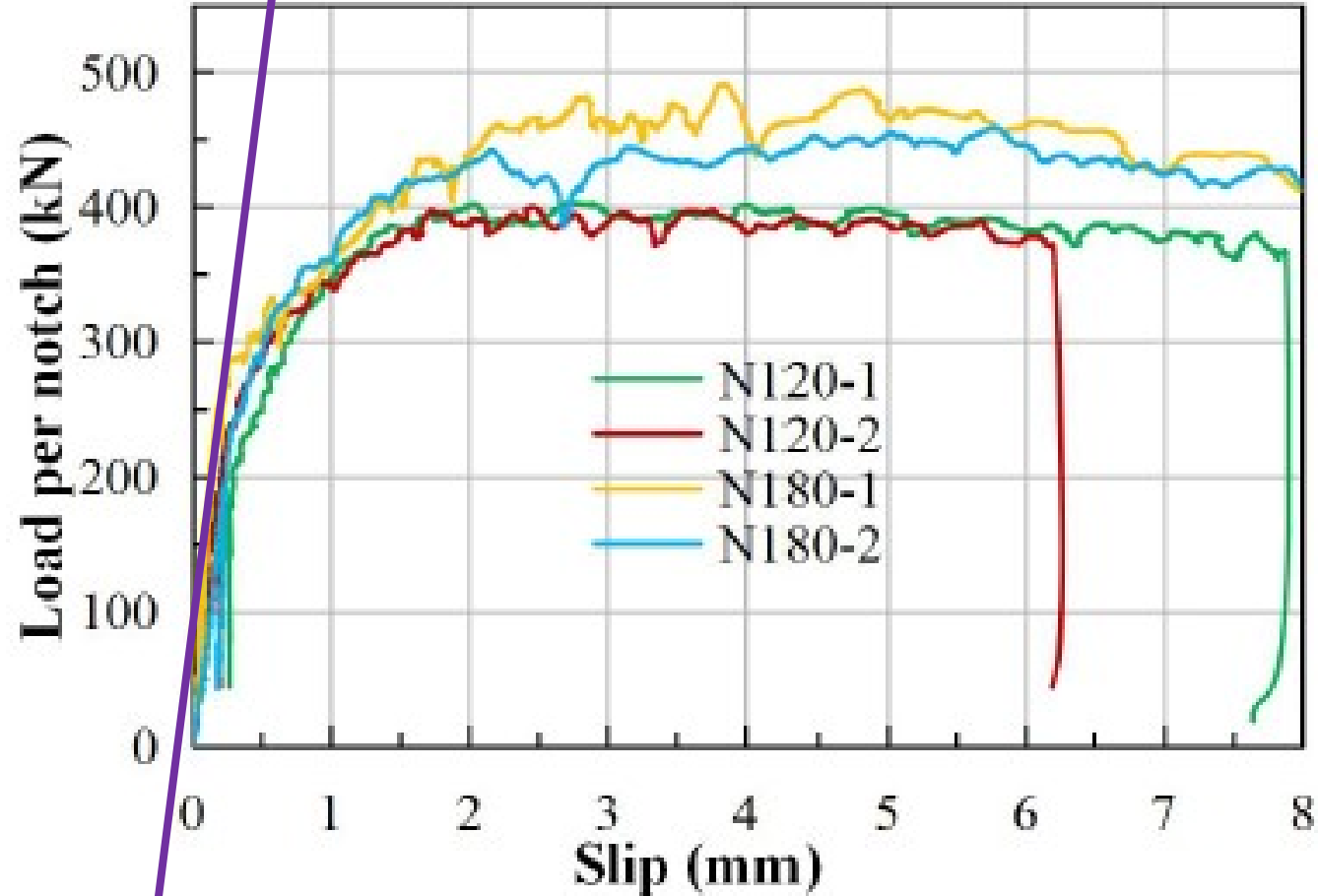


The shear connections



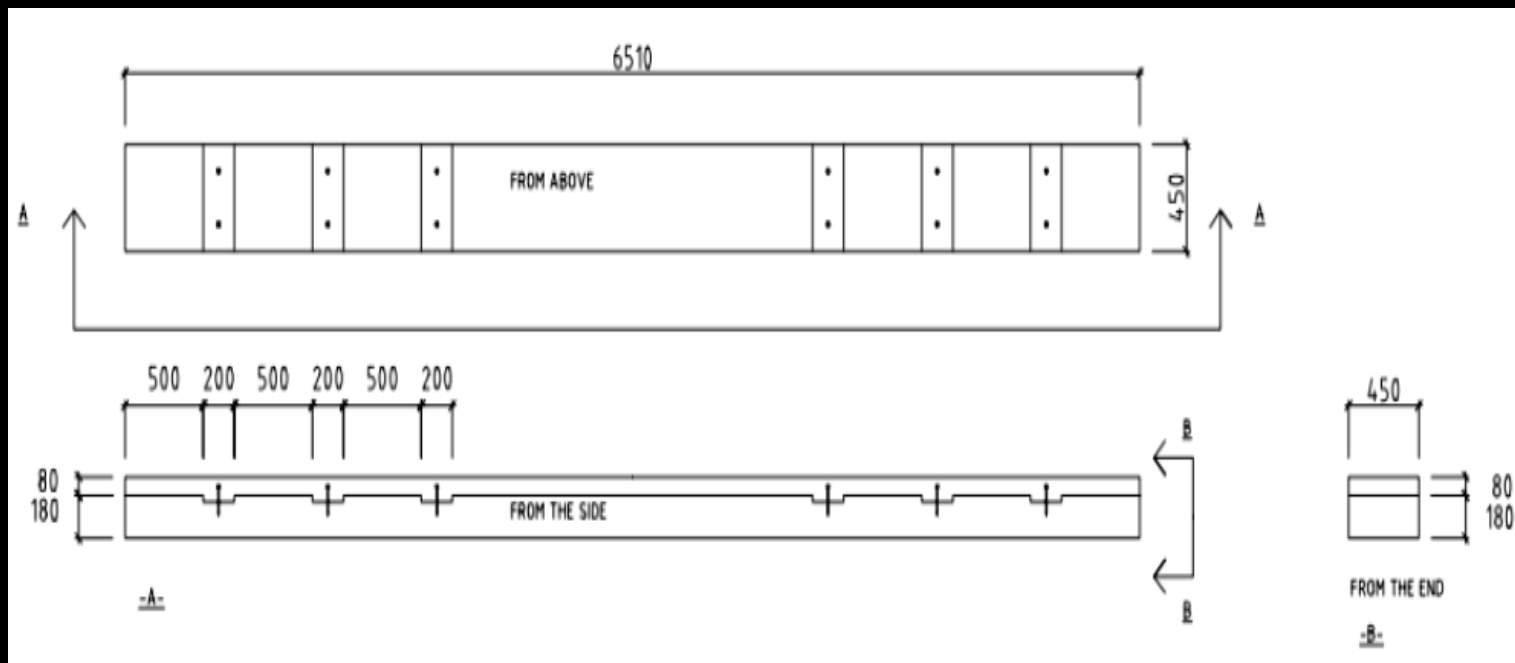
load procedure according to EN 26891

The shear connections



Notch: 200x450x25
Stiffness $k_{04} \approx 1000$ kN/mm

The full-scale tests

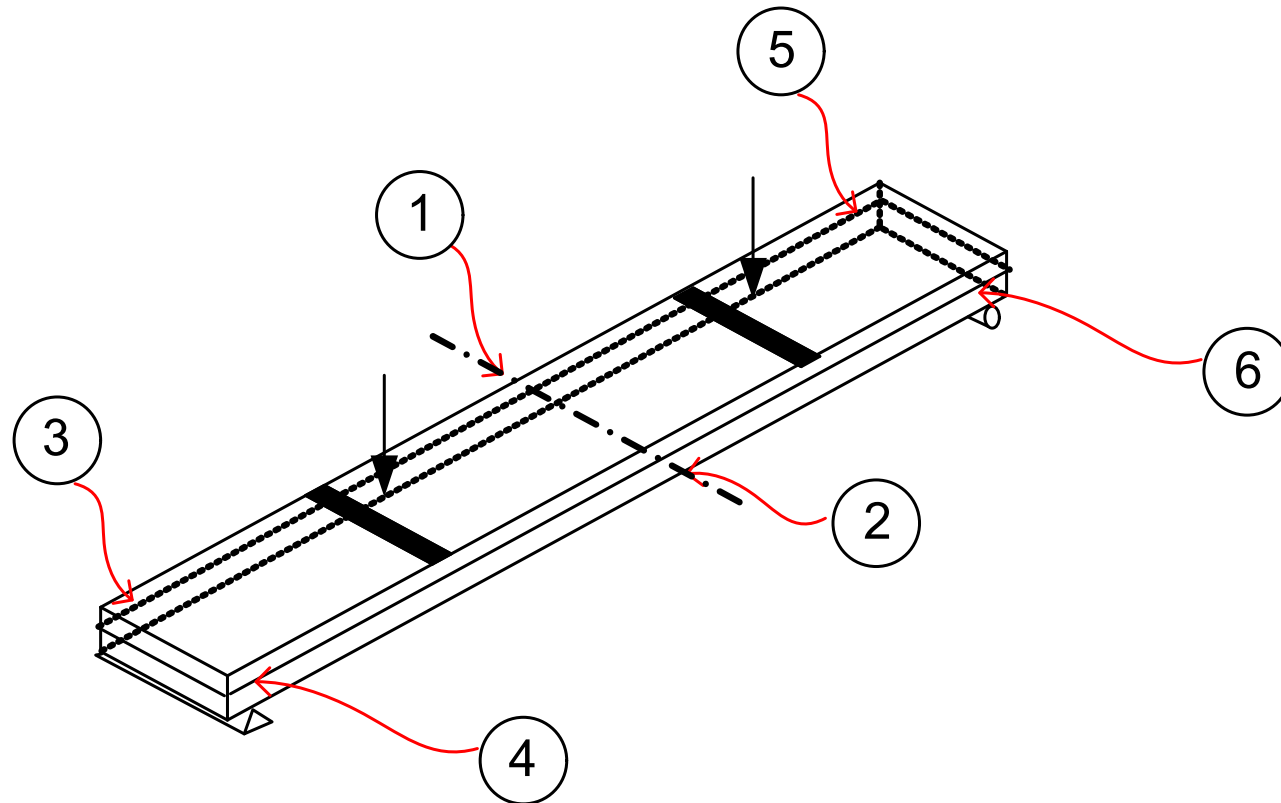
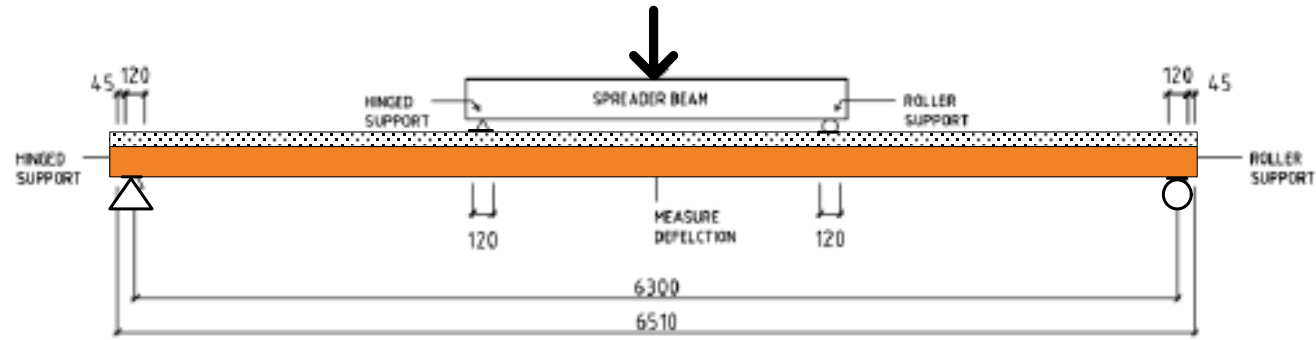


Dimension	type 1 [mm]	type 2 [mm]
Span	6300	6300
Width	450	450
Thickness of CLT	120	180
Thickness of concrete	60	80
Overall depth of beam	180	260

The manufacturing of full-scale specimens



The full-scale tests



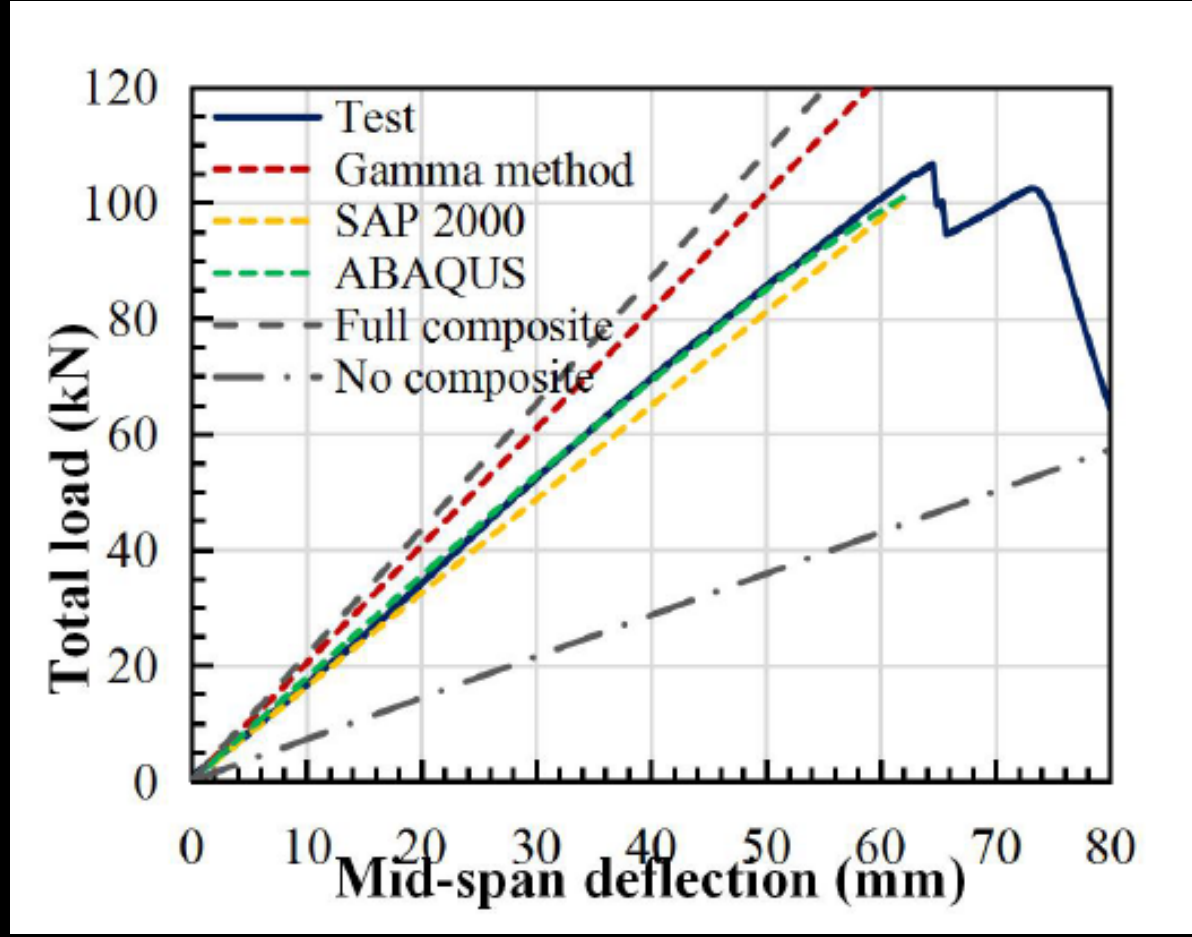
The full-scale tests



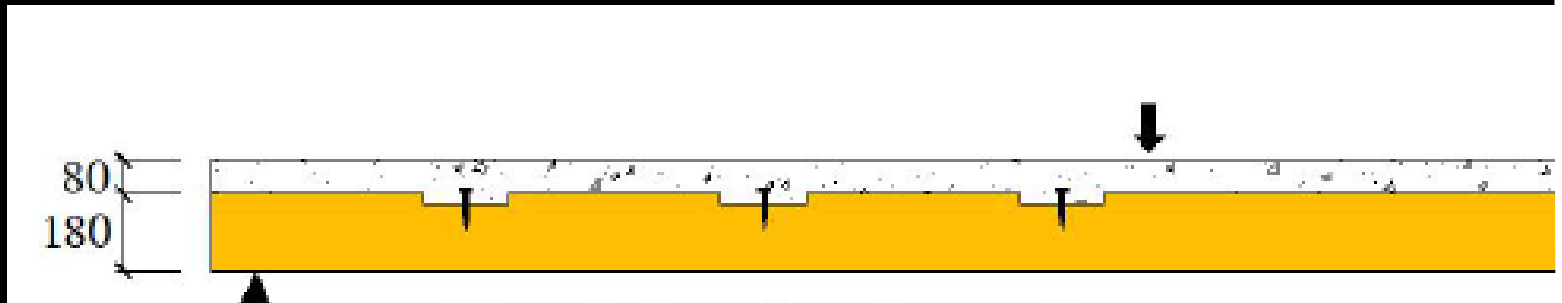
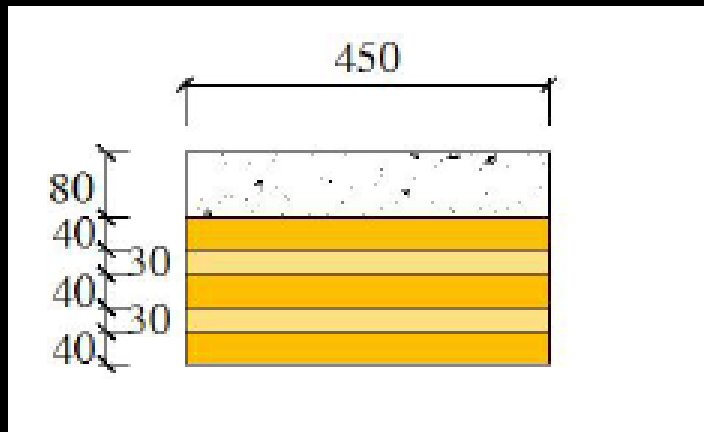
Failure modes



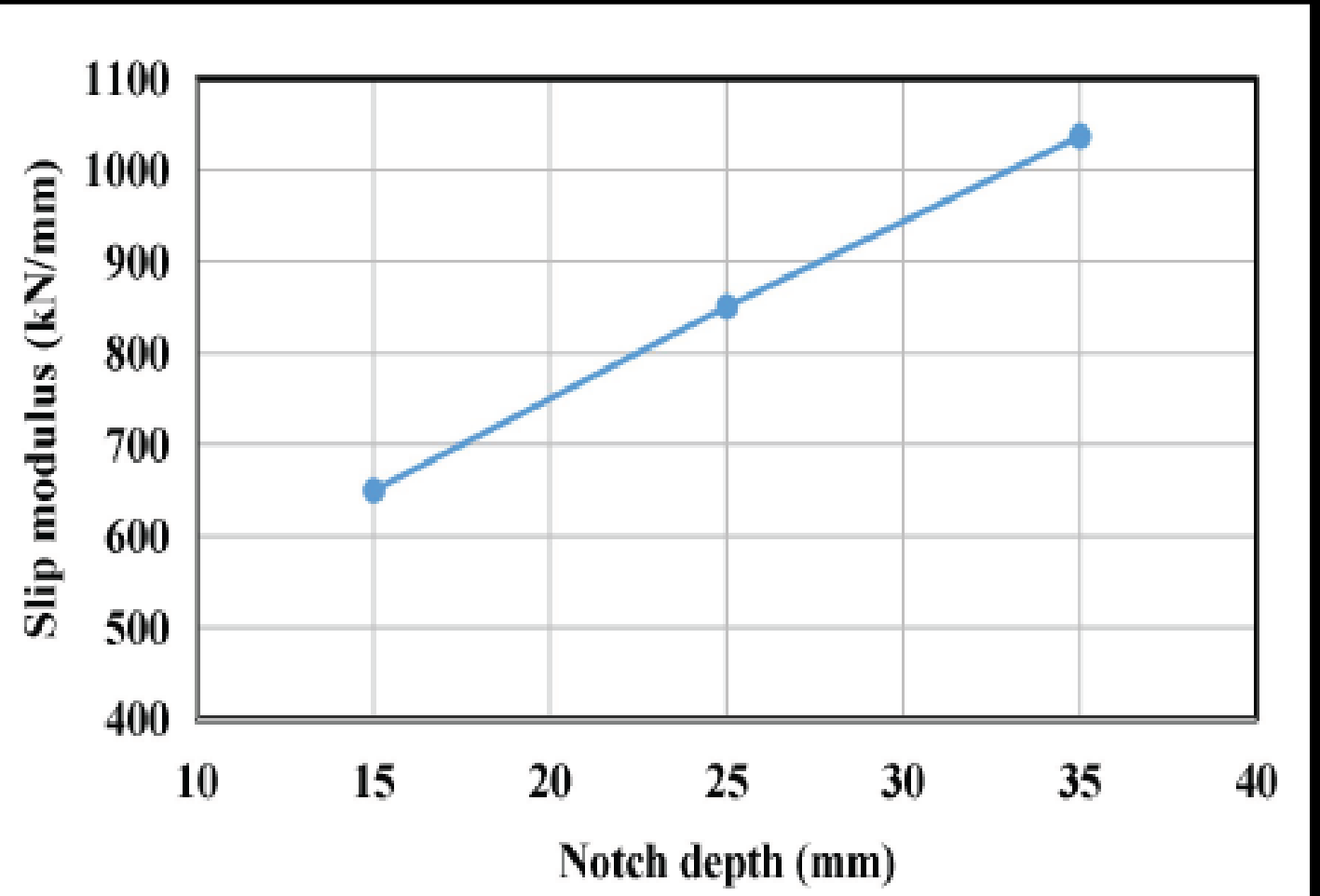
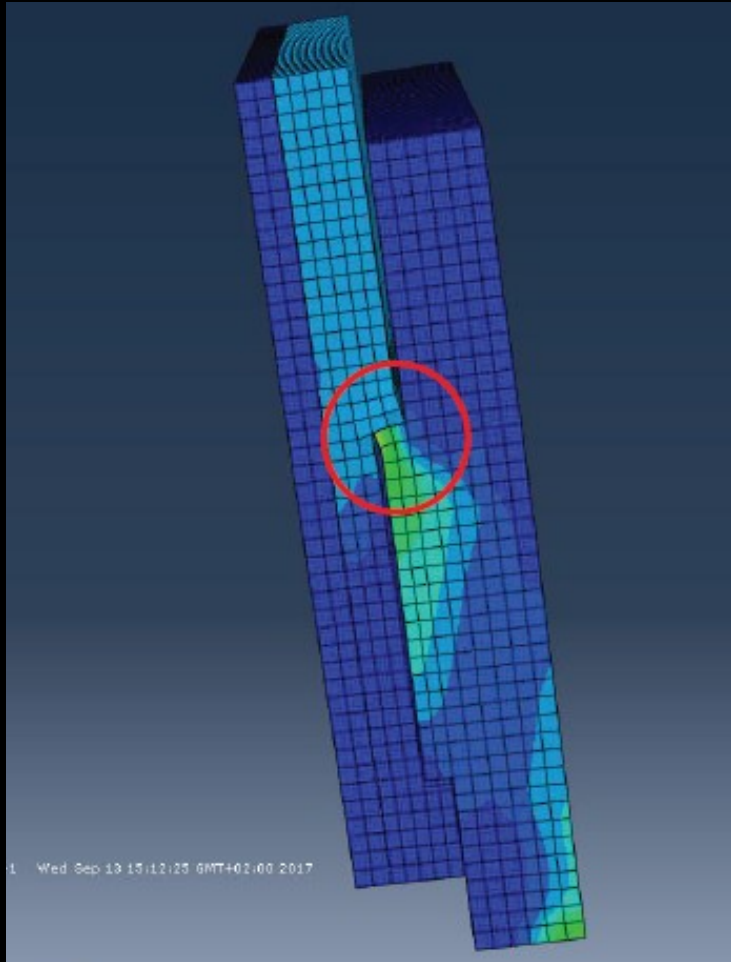
Some test results



Symm,



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