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Slim-floor steel-timber composite beams

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Tampere, Finland

- Tampere University is the second largest university in Finland.
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- Faculty of Management and Business
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- Faculty of Social Sciences

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190	1300	15,5 M€	5 M€

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- Research Centre Terra
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- Transportation Research Centre Verne
- Concrete and Bridge Structures
- **Metal and Lightweight Structures**
- Building Physics
- Construction Management and Economics
- Renovation and service life engineering of structures
- Structural Mechanics
- Water and Sanitation Services CADWES

Metal and lightweight structures

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FIRE RESEARCH
Mikko Malaska D.Sc. (Tech.)
Professor

- Fire safety solutions for smart cities and buildings
- Advanced fire engineering methods
- Fire safety and resistance of timber buildings
- Fire testing laboratory

LIGHTWEIGHT AND SPECIAL STRUCTURES, TIMBER STRUCTURES
Sami Pajunen D.Sc. (Tech.)
Professor

- Industrial timber construction
- Timber and hybrid structures
- Advanced simulation and design methods

KEY RESEARCH TOPICS

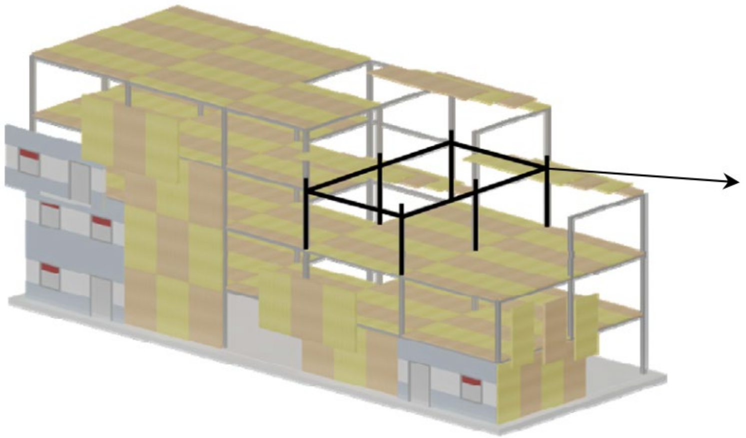
- High strength steels in construction
- **Design automation and structural optimization**
- Sandwich panels and cold-formed steel structures

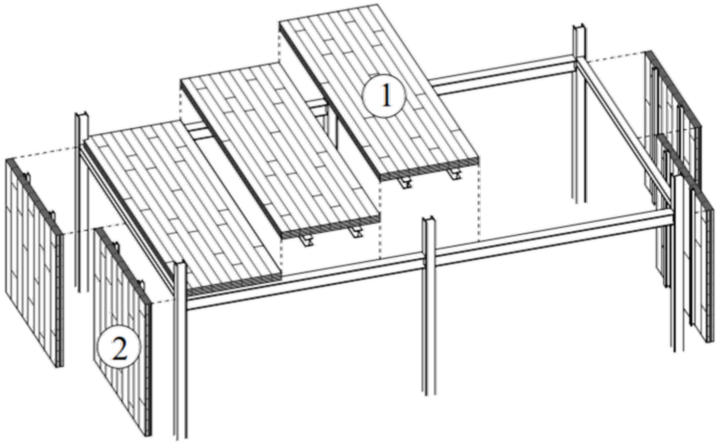
STEEL STRUCTURES
Kristo Mela D.Sc.(Tech.)
Assistant Professor

STEEL-TIMBER COMPOSITE BEAMS

Why steel-timber composite beams?

- Lightweight structures
- High speed installation
- Highly industrialized buildings
- Dry construction
- Reduction of embodied carbon
- Easily replacable and recyclable components



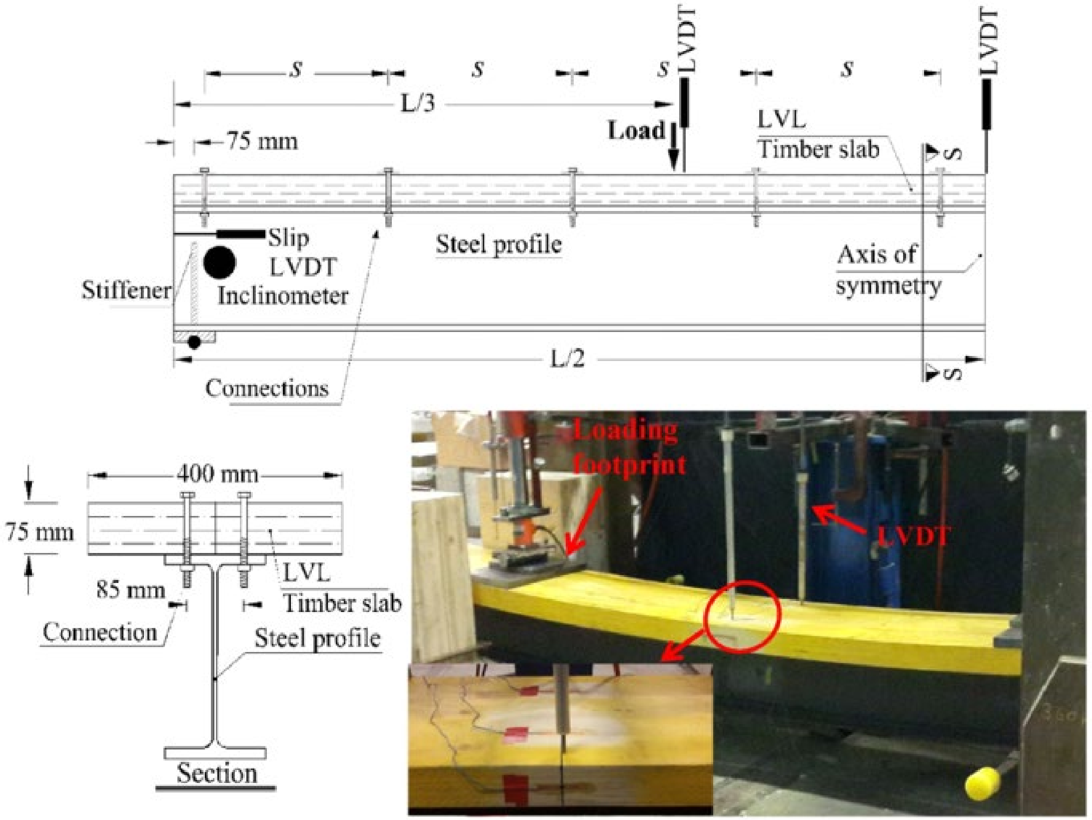


Figures: Loss et al. (2016)

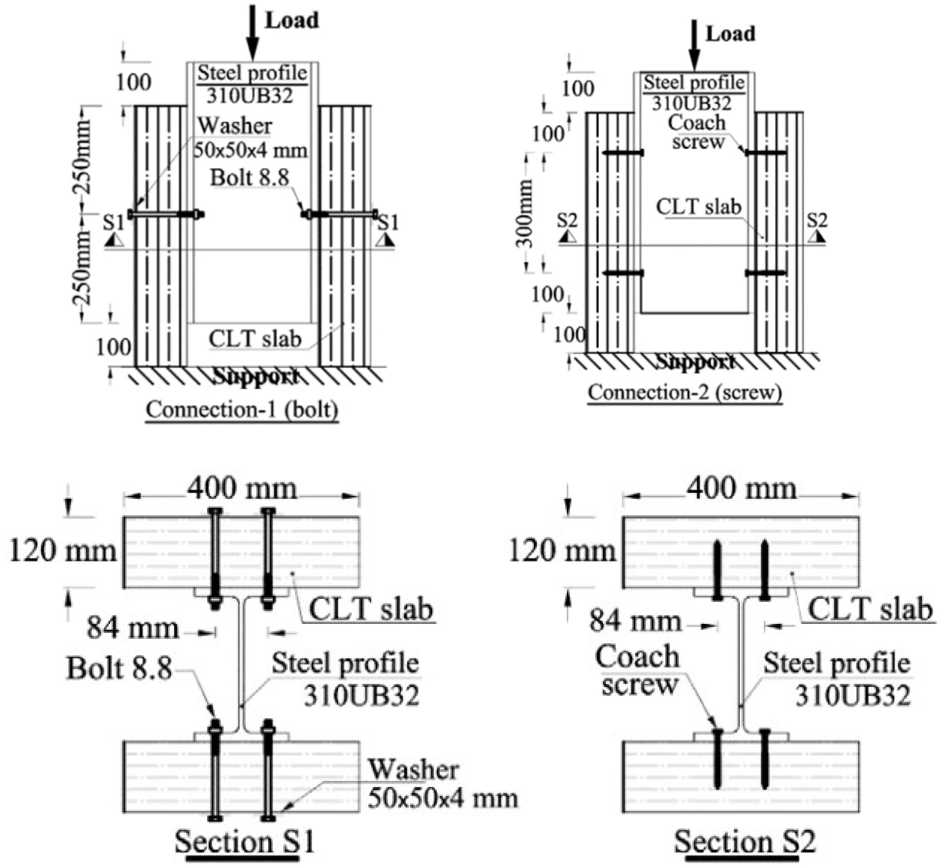
What do we need to know?

- What is the arrangement between steel and timber?
  - Which timber and steel components to use and how?
- How to achieve composite action?
  - Which fasteners to use?
  - What connection elements are required?
  - What degree of composite action can be achieved?
- How to analyse the composite beam?
- Additionally: vibrations/acoustic performance, behaviour in fire, long-term behaviour…

Research on steel-timber composite beams

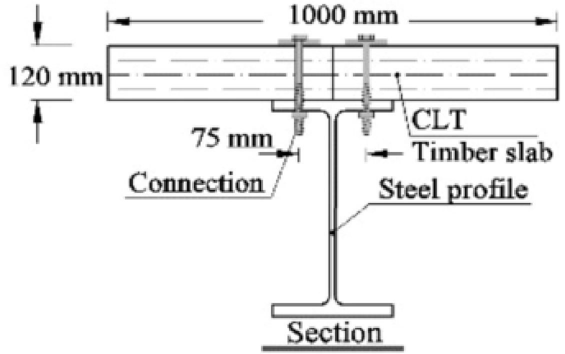


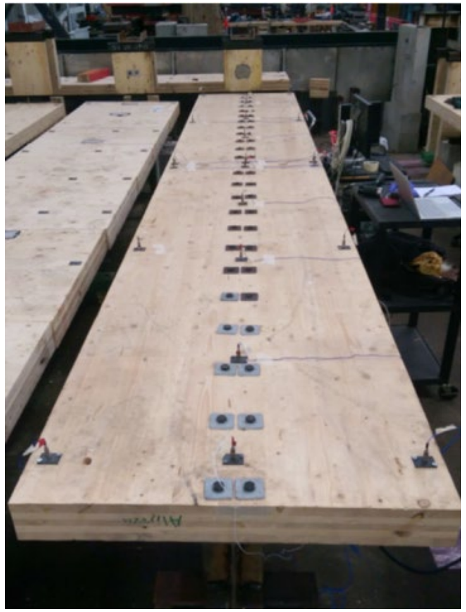
A. Hassanieh, H.R. Valipour, M.A. Bradford, *Experimental and numerical study of steel-timber composite (STC) beams*, Journal of Constructional Steel Research 122 (2016) 367–378.



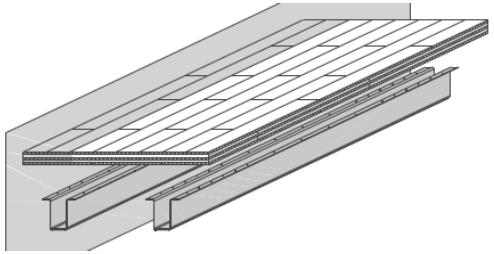
A. Hassanieh, H.R. Valipour, M.A. Bradford, *Load-slip behaviour of steel-cross laminated timber (CLT) composite connections*, Journal of Constructional Steel Research 122 (2016) 110–121.

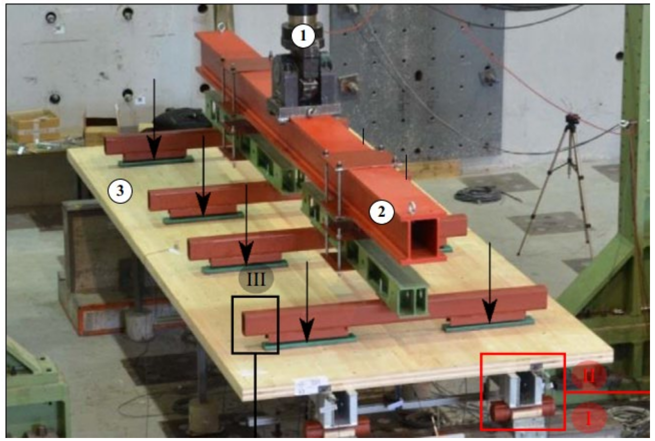
Research on steel-timber composite beams

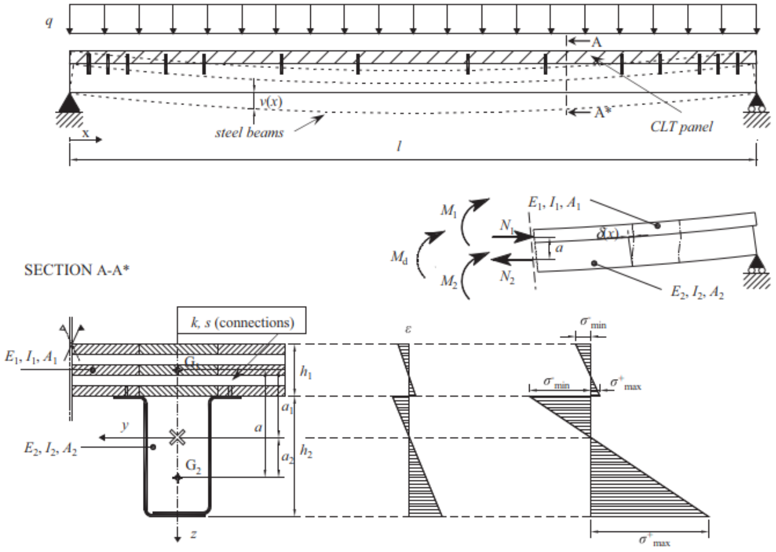




A. A. Chiniforush, M. Makki Alamdari, U. Dackermann, H.R. Valipour, A. Akbarnezhad, *Vibration behaviour of steel-timber composite floors, part (1): Experimental & numerical investigation*, Journal of Constructional Steel Research 161 (2019) 244–257.







C. Loss, B. Davison, *Innovative composite steel-timber floors with prefabricated modular components*, Engineering Structures 132 (2017) 695–713

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STEEL-TIMBER COMPOSITE BEAMS
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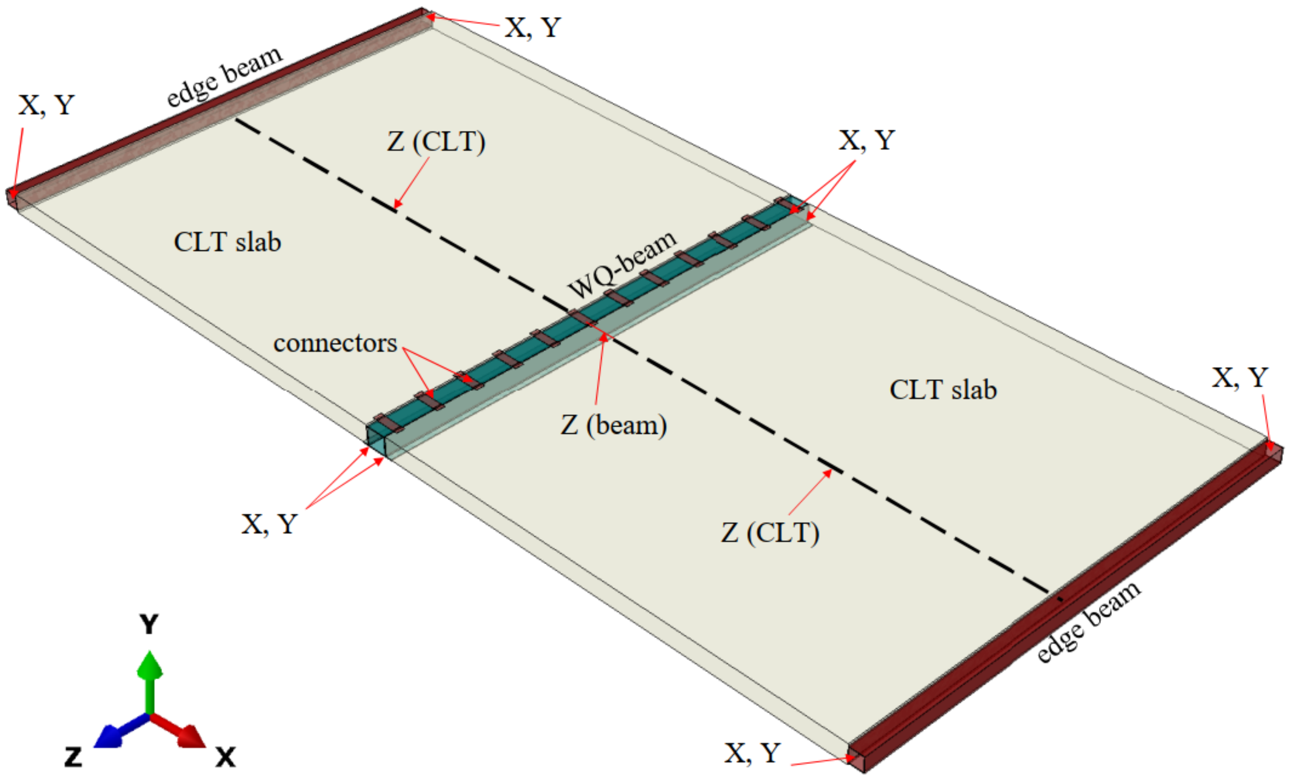
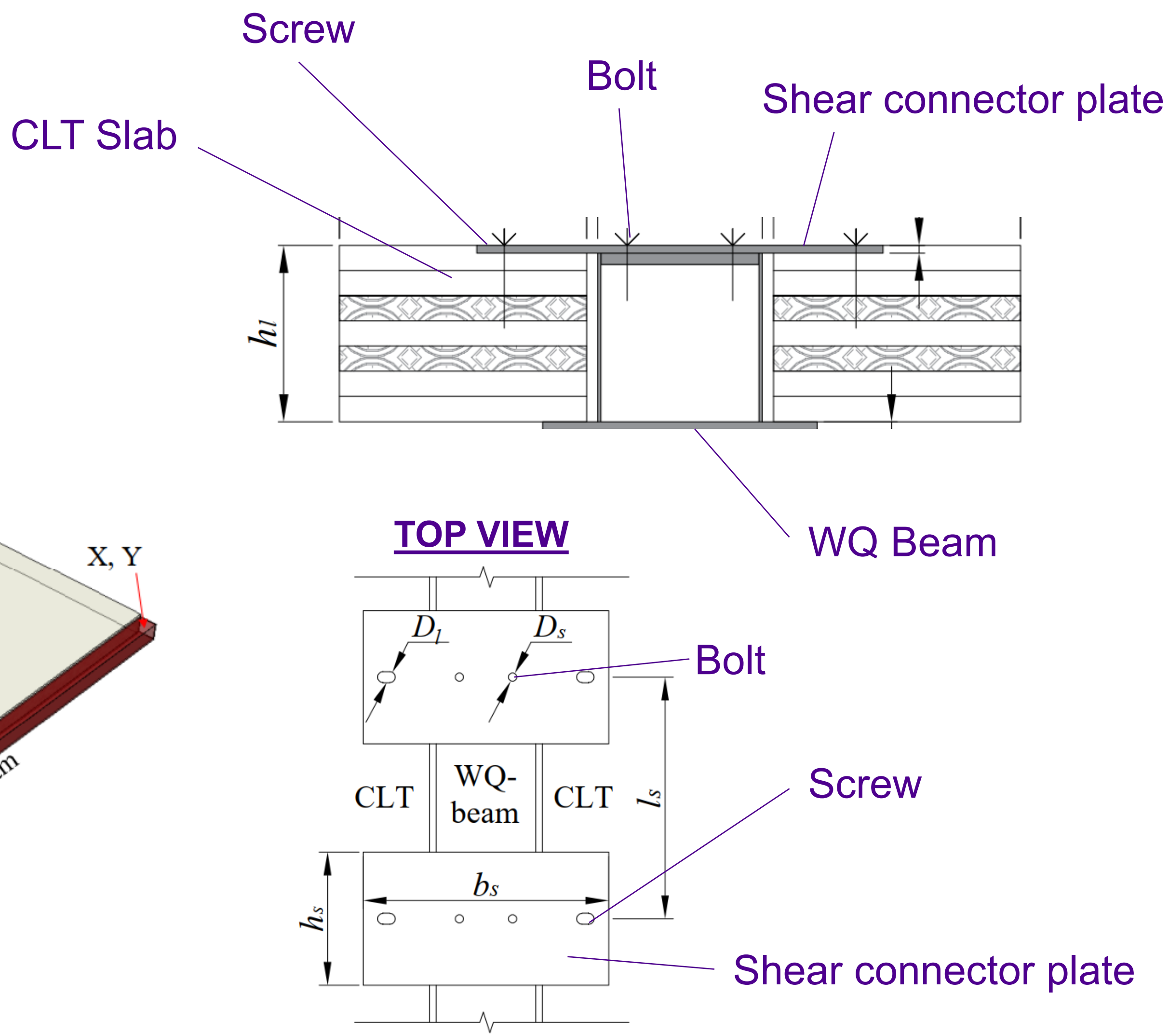
Nordic System

Nordic System



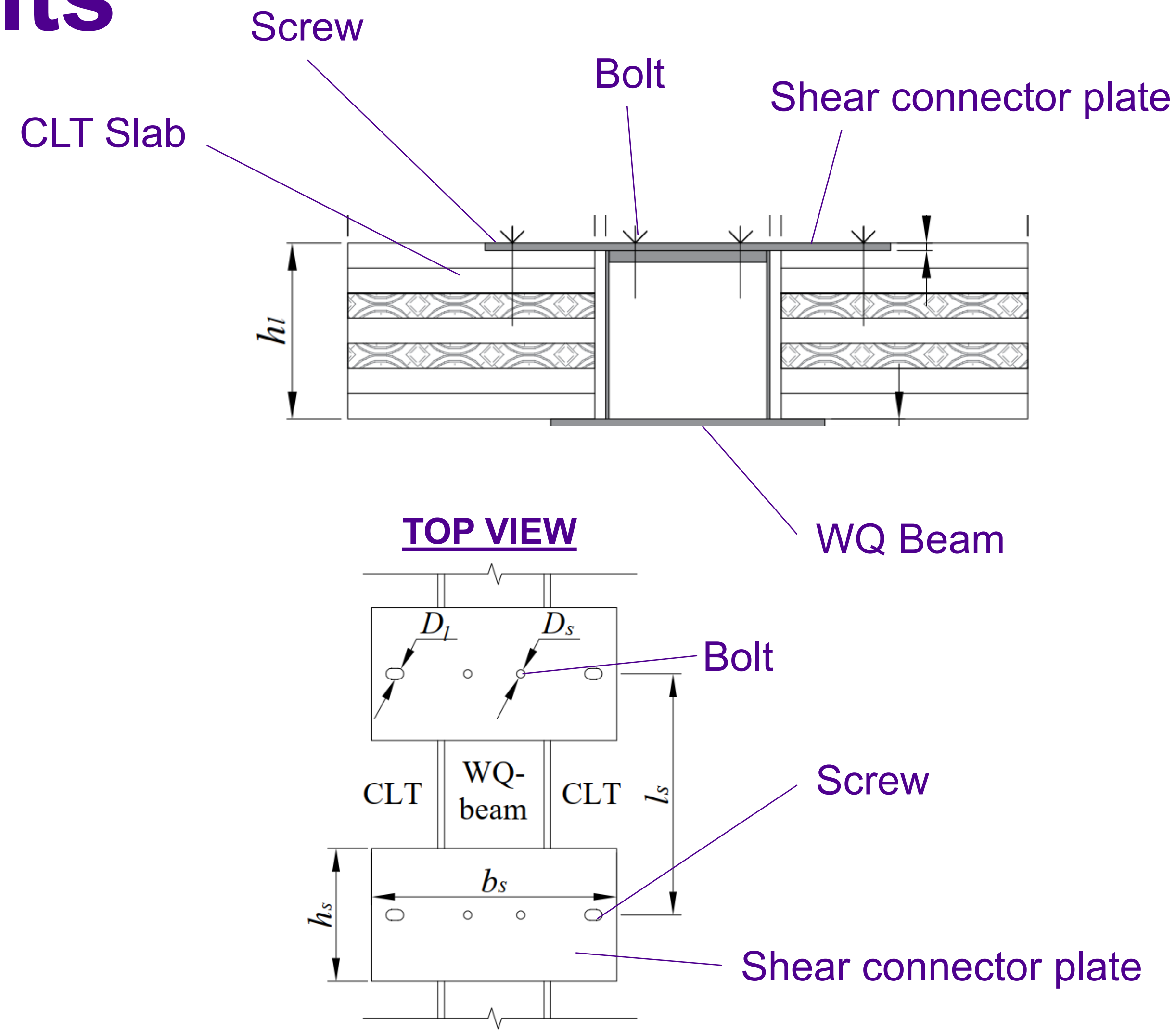


Nordic System – benefits

- Slim-floor construction
- WQ beam has high torsional rigidity
  - No/less need for support during construction
- Slabs provide fire protection for the steel beam.
- Shear connector installation can be carried out from above.

QUESTIONS:

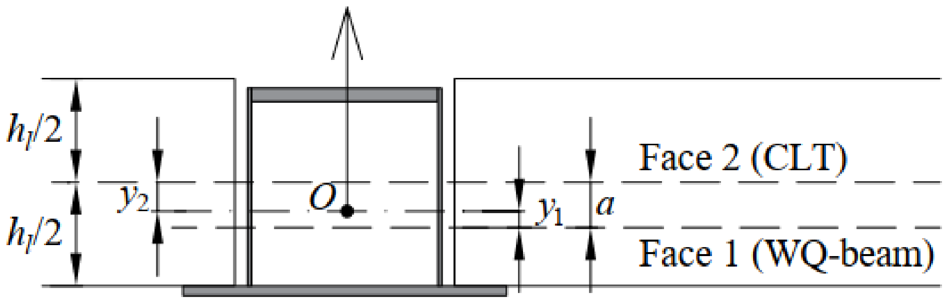
1) What benefits in **design** can be obtained?
2) Does the shear connector provide full composite action?



Research on Nordic System so far…

Theoretical background*

- Theory of *layered beams* is employed (Pleskov (1952), Stamm & Witte (1974)).
  - WQ beam and CLT slabs are the layers/faces, shear connectors are the ”periodic core”.
- Composite action is governed by
  - shear stiffness of the connector plates governs the composite action.
  - distance a between the centroids of the WQ beam CLT slab.
- Bending stiffness of the CLT slab is obtained by homogenization.



Bending stiffness of composite beam

$$EI = (EI)_1 + (EI)_2 + (EI)_s$$

WQ beam

CLT slab

”composite action”

Bending stiffness of CLT slab

$$(EI)_{eff} = \sum_{r=1}^{n} E_r J_r + \sum_{r=1}^{n} \gamma_r \zeta_r^2 E_r A_r$$

$$\gamma_r = \begin{cases} 1, & \text{midlayer} \\ 1, & \text{transverse layer} \\ \dfrac{1}{1 + \dfrac{\pi^2 E_r h_r}{L^2} \dfrac{t_j}{G_{9090,j}}}, & \text{longitudinal layer} \end{cases}$$

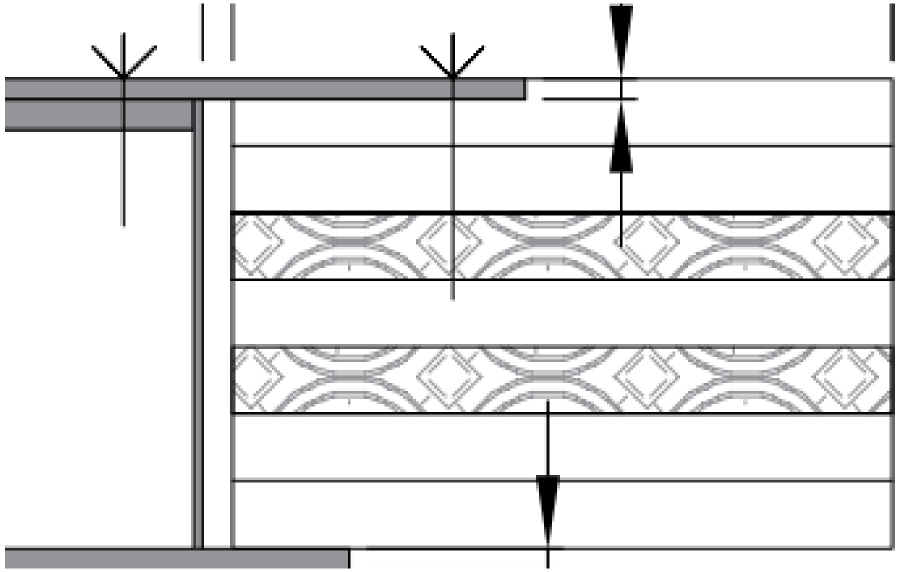
*Heinisuo M., Mela K., Pajunen S., Malaska M., *New steel-timber composite beam, Nordic system*, ce/papers 3 (2019)

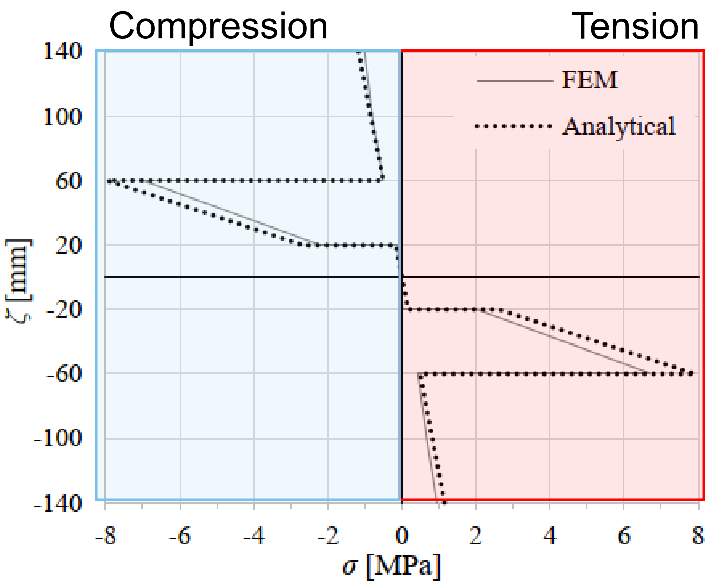
Research on Nordic System so far…

Effective width of CLT slabs

- Bending stresses in CLT slab are more complicated than in steel-concrete composite beams
  - No clear definition for effective width

Axial stresses in CLT slab

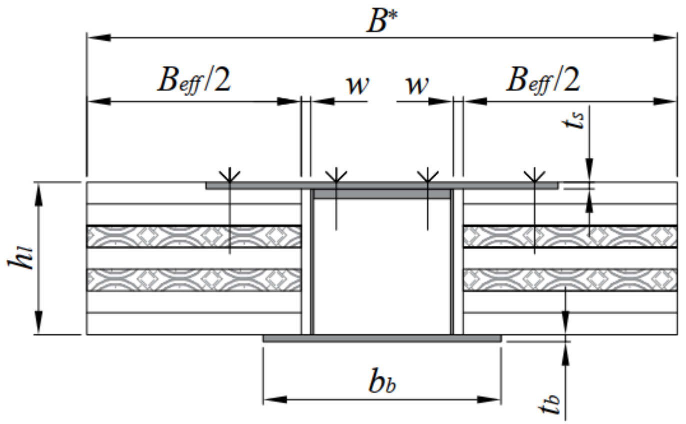




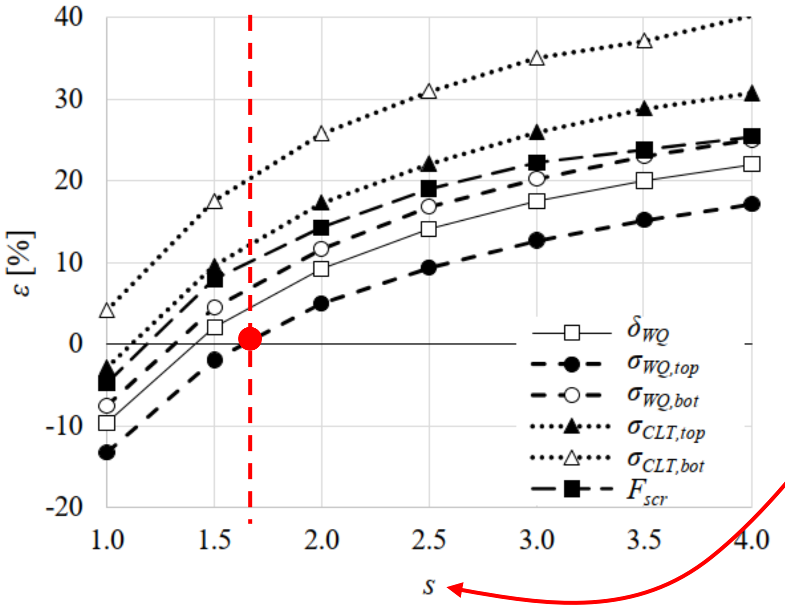
Research on Nordic System so far…

Effective width of CLT slabs

- Approach:
    1. Obtain relevant design quantities (experiments or FEM)
    2. Compare ”real values” with analytically determined values.
    3. Effective width corresponds to case where all design quantities are on the ”safe side”.
- Preliminary results:
    - effective width depends on beam configuration.
    - effective width ***can be*** $L/2$ instead of $L/4$ which is commonly used in steel-concrete beams.



$$B_{eff} = \frac{L_1}{s} - 2w - 2t_w - b_t$$



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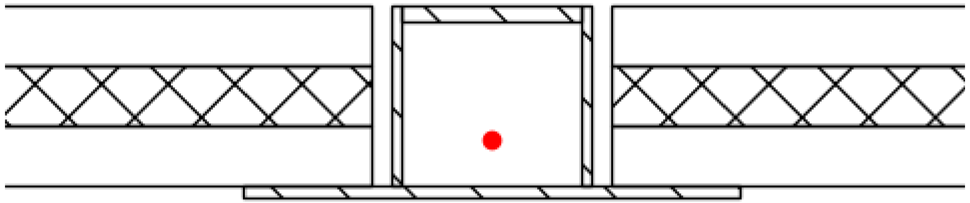
Example – Analysis of Nordic System*

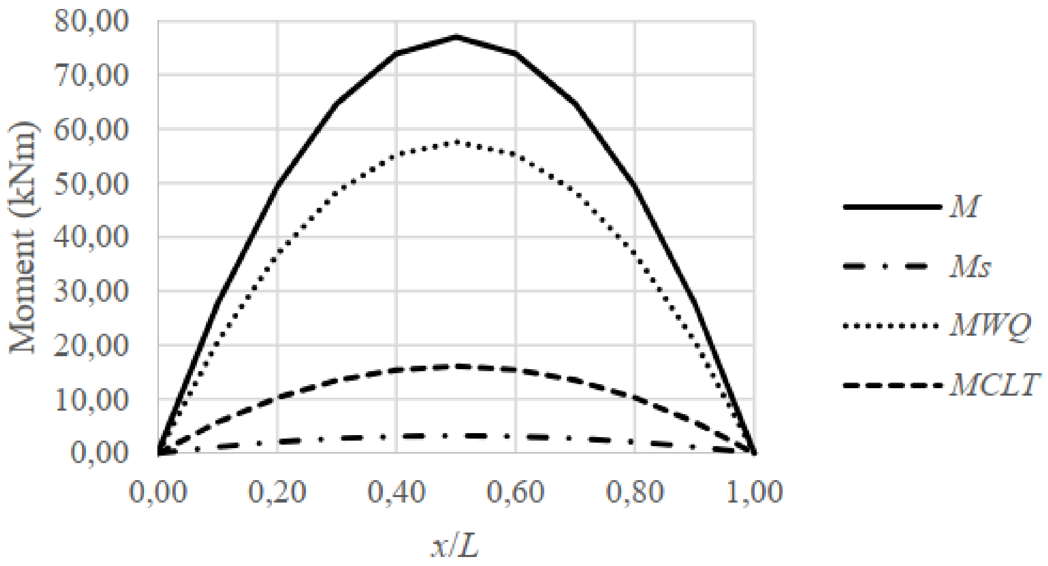
- Beam span 5 m, slab span 5 m.
- Dead load 1kN/m^2, live load 2kN/m^2.
- Slab properties:
  - Thickness 120 mm
  - 3 layers of 40 mm thickness.
- WQ beam: WQ112-5-10x120-8x330 S355
  - Comparison: pure WQ-beam WQ120-6-10x120-8x330
- Connectors:
  - plates: t = 8mm, spacing 600 mm.
  - Timber screws: *D* = 10mm, stiffness 1.33 N/mm, shear resistance 23.1 kN.
  - Bolts: D_s = 20mm



*Heinisuo M., Mela K., Pajunen S., Malaska M., *New steel-timber composite beam, Nordic system*, ce/papers 3 (2019)

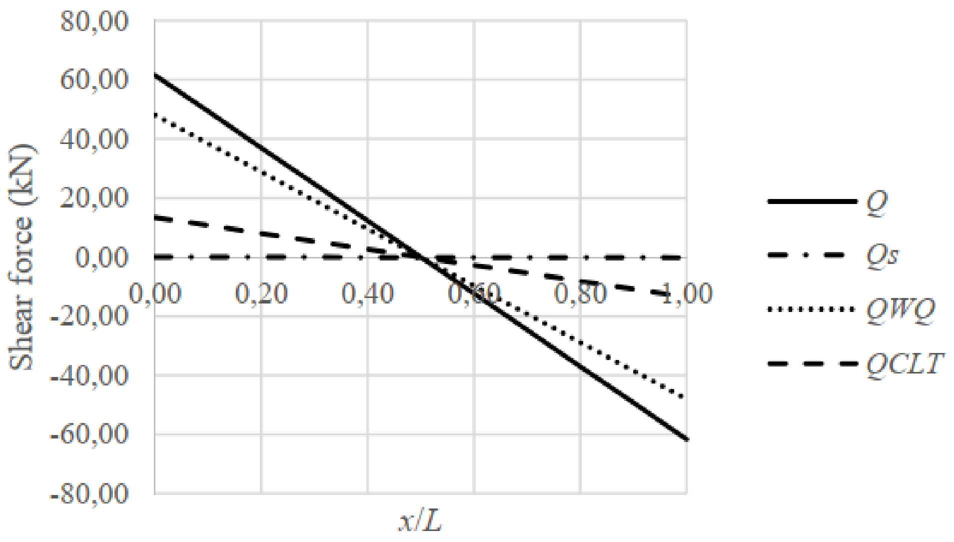
Example

BENDING MOMENT



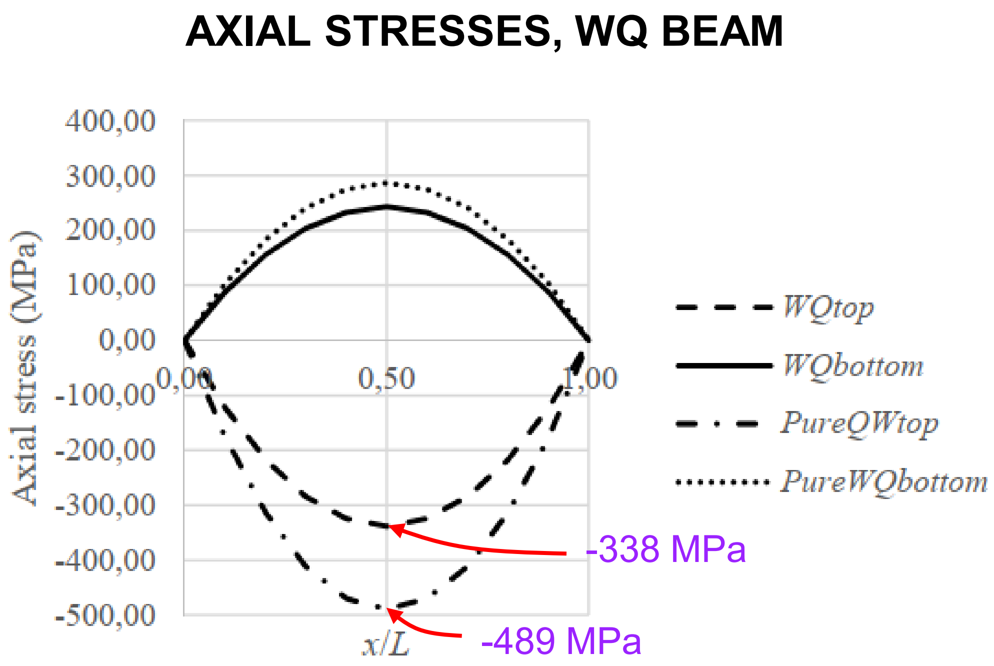
- Steel beam carries most of the bending moment

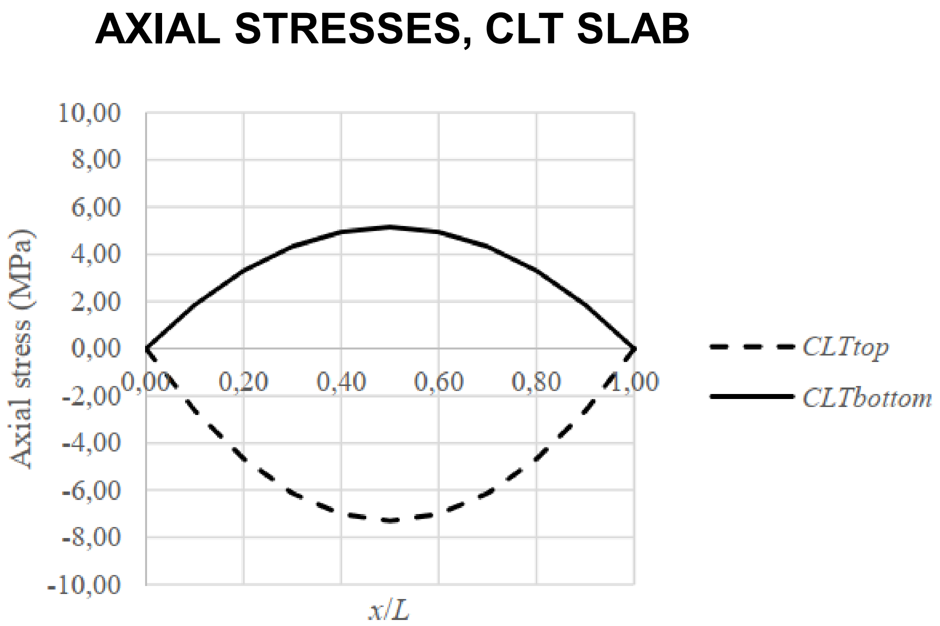
SHEAR FORCE



- Steel beam carries most of the shear force

Example – Axial Stresses

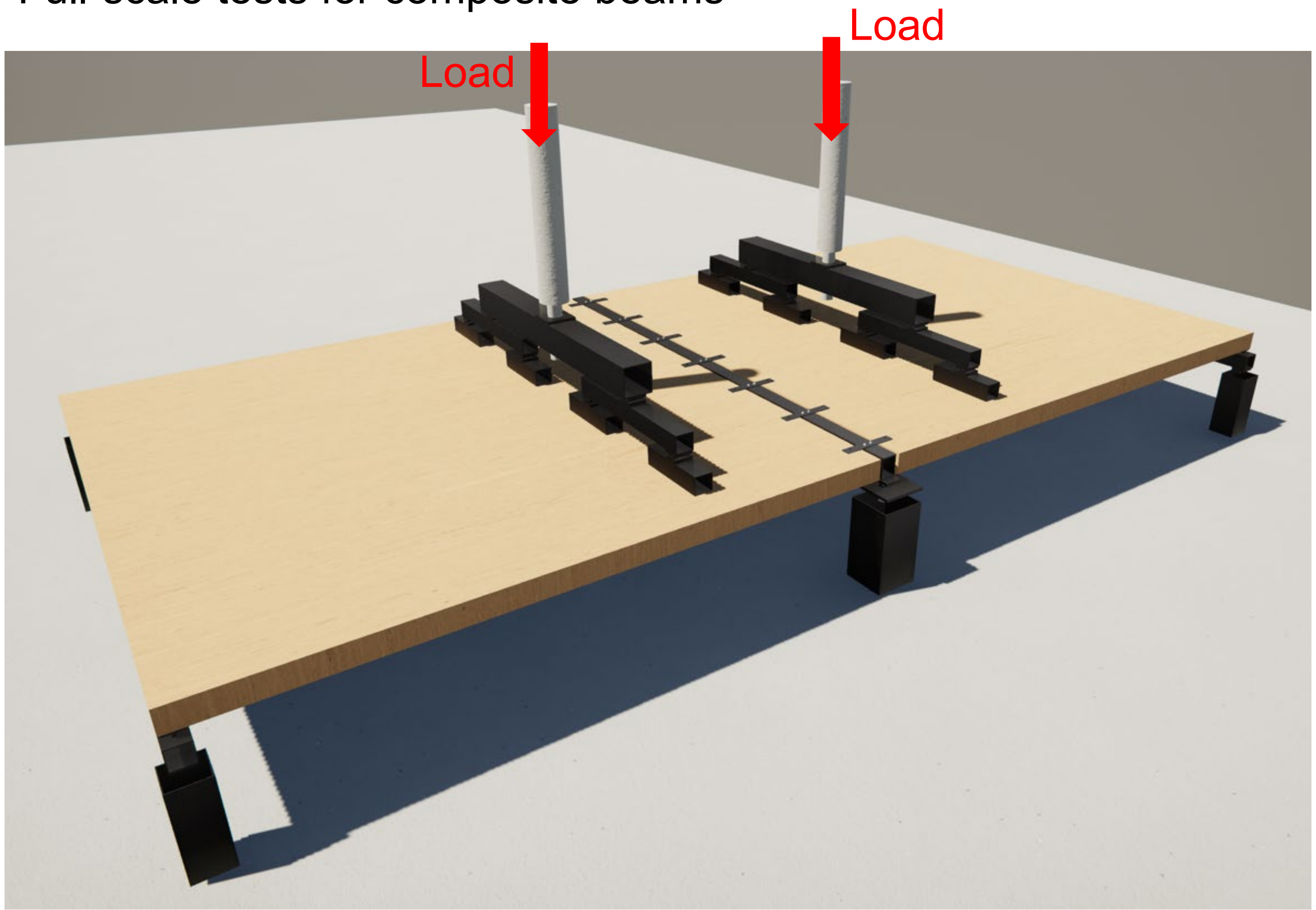




- Composite action *reduces the axial stresses* in the top flange substantially (also in bottom flange) compared with the case of pure WQ beam.
- Stresses in CLT are small

Coming soon…

Full-scale tests for composite beams

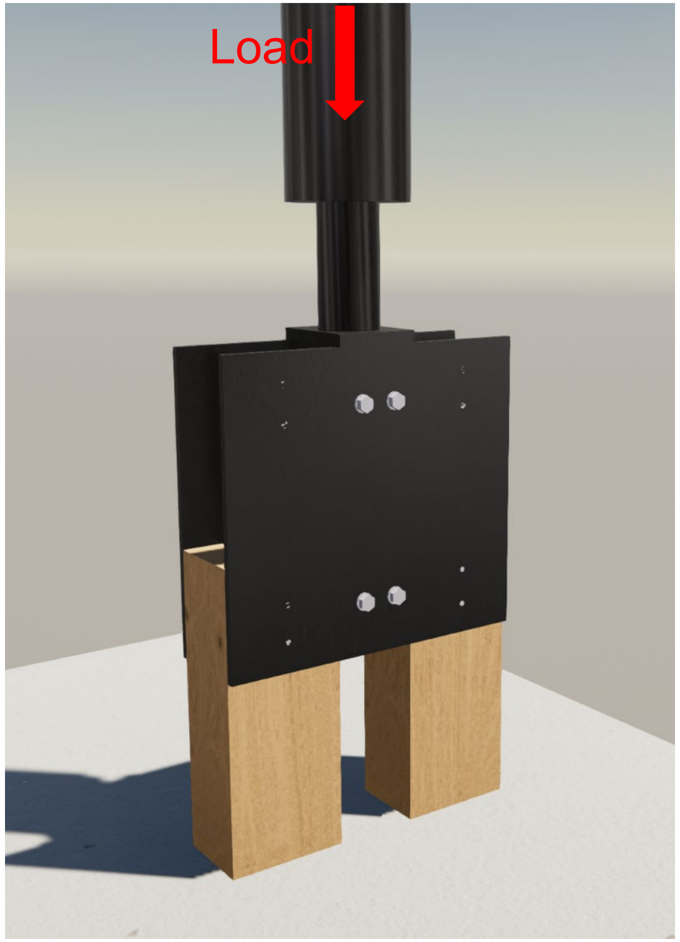


Steel structures sponsored by NORDEC

Coming soon…

- 6 full-scale bending tests, including
  a) Heel-drop tests
  b) Walking tests
  c) Static loading until failure
  - Goal of the tests:
    - Validate theory
    - Obtain data for further analysis (simulations)
- 18 push-out tests
  - Determine shear stiffness and resistance of shear connectors

Push-out tests for shear connectors



Doctoral researcher: **Aku Aspila**

Open questions

1) Long-term behaviour
    - Serviceability limit state design
2) Fire performance
    - Do CLT slabs provide protection for the steel beam?
3) Acoustic performance
4) Range of spans and loads
5) Optimum design
    - Orientation and thickness of CLT layers
    - Size of WQ beam
    - Weight and cost minimization

Summary

- Composite action in slim-floor steel-timber beams can be utilized for *favourable stress distribution* and *increased stiffness*.
  - This can lead to *economical benefits* and *reduction in embodied carbon* in floor constructions
- The arrangement of shear connectors for the Nordic System enables *easy installation and demounting*.
- Research is taking the first steps, many open questions and possible directions remain.

Research Team

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