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ELASTIC DESIGN OF STEEL-TIMBER COMPOSITE BEAMS

Wood Material Science and Engineering

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The subject of the thesis:
Calculation method for slim-floor steel-timber composite structures
- Developing the Nordic system

Related publications:

- Aku Aspila*, Markku Heinisuo, Kristo Mela, Mikko Malaska, Sami Pajunen, *Elastic design of steel-timber composite beam*. Wood Material Science and Engineering
- Markku Heinisuo, Sami Pajunen, Aku Aspila. *Analysis of cross-laminated timber (CLT) panels loaded with out-of-plane bending and compression using the classical theory of layered beams.* Waiting for comments
- Aku Aspila*, Sami Pajunen, Markku Heinisuo, Kristo Mela, Mikko Malaska. *Mechanical behaviour of steel-CLT composite shear connection(work topic)*. Working on it
- Aku Aspila*, Lauri Lepikonmäki, Sami Pajunen. *Study of the suitability of steel-timber composites as intermediate floor constructions – a case study based on projects in Finland*. World Conference on Timber Engineering 2023. Waiting for approval

Topic of the day:

ELASTIC DESIGN OF STEEL-TIMBER COMPOSITE BEAMS

- Why steel-timber composite (STC) structures
- What are STC structures
- Open research questions regarding STC structures
- Key takeaways of the paper

Why steel-timber composite structure

Why composite structures

A composite structure is a union of two or more parts of different materials acting together to improve structural performance like:

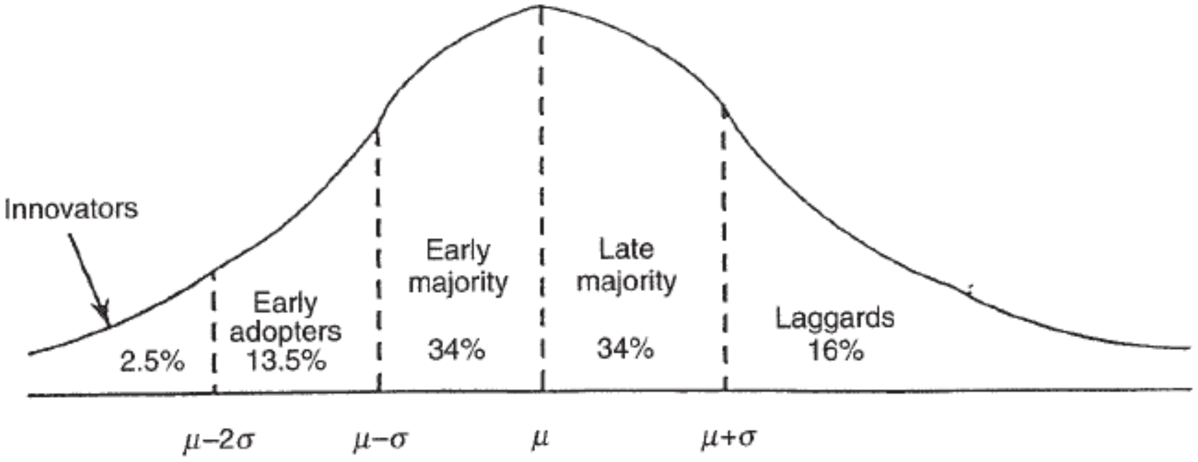
- Reduced self-weight
- Better material efficiency → lower material costs
- Increased load-bearing capacity
- Reduce environmental impact

Why steel-timber composite structure

Multistorey buildings

3-4% of wooden

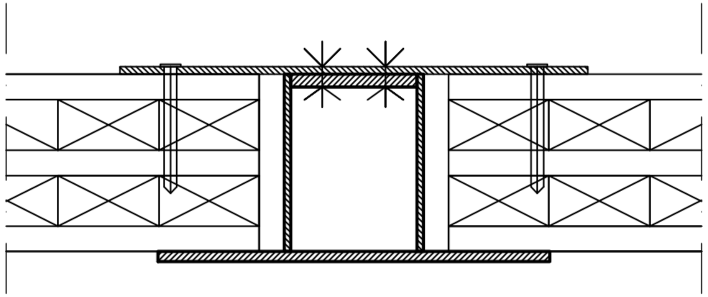
By combining new and traditional ways to build, we can lower the resistance created by the “new” products. This shortens the time it would otherwise take for new products to become dominant in the market.



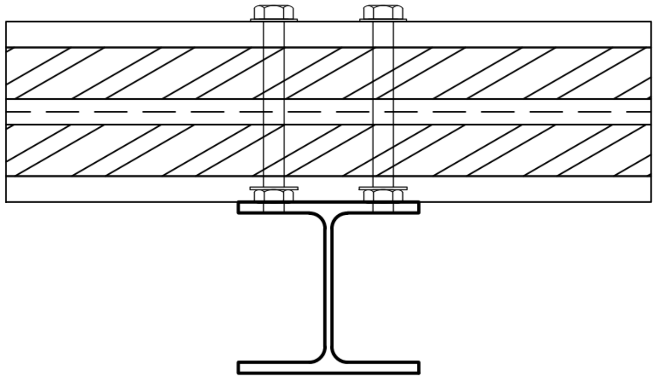
Diffusion of the innovations

What are steel-timber composite structures

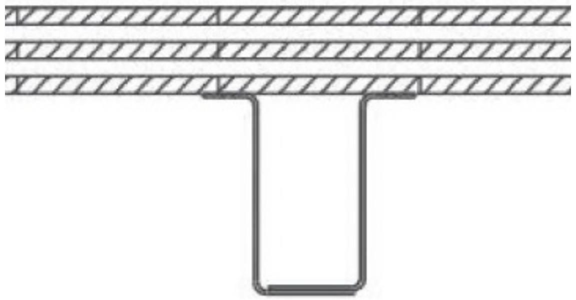
Steel-timber composite cross-sections



Slim-floor variation, Nordic system



More traditional way



Innovative solution from Loss et al. 2017

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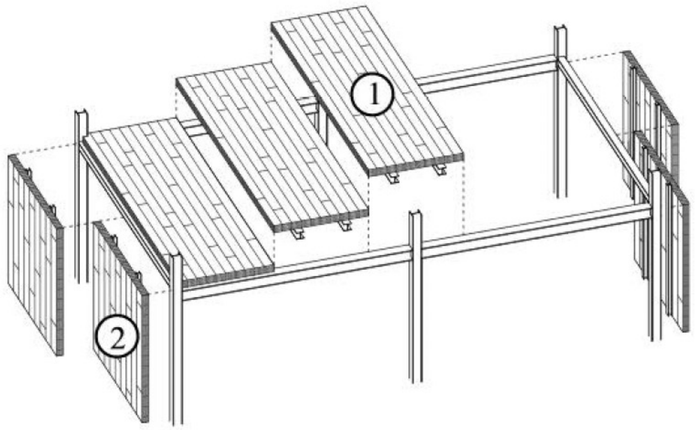
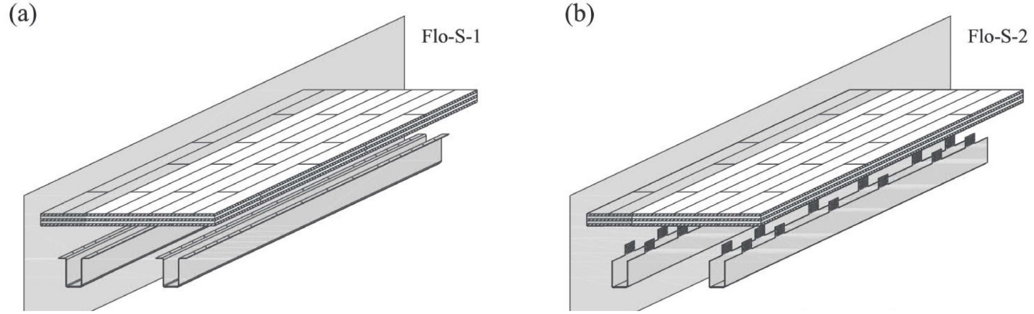
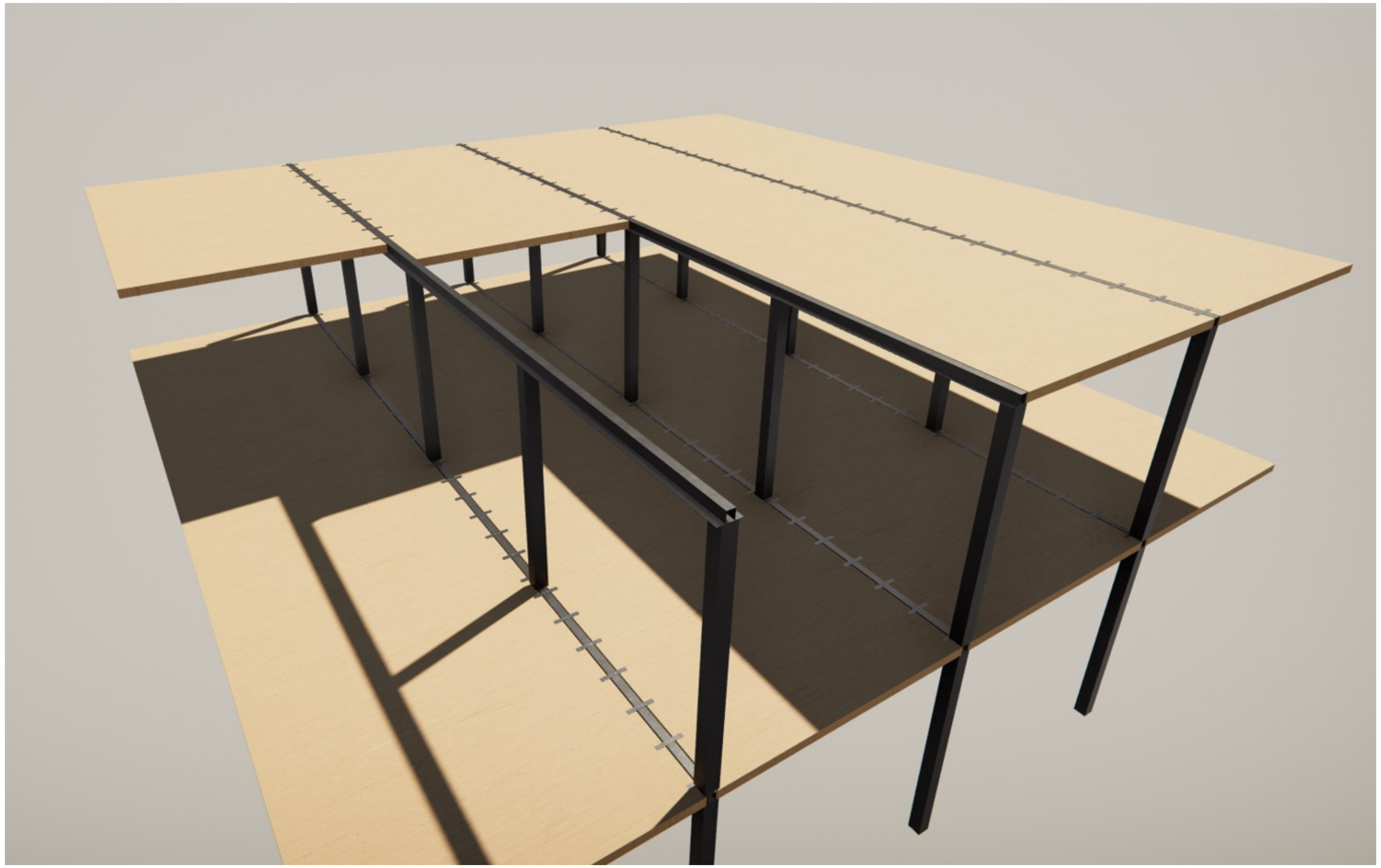
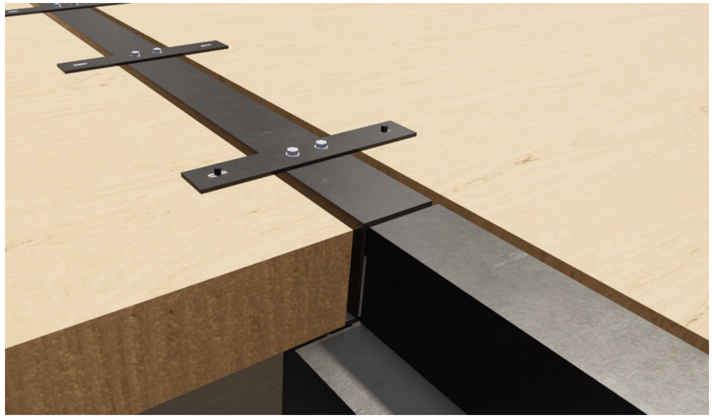
Midfloor solutions









Open research questions regarding STC structures

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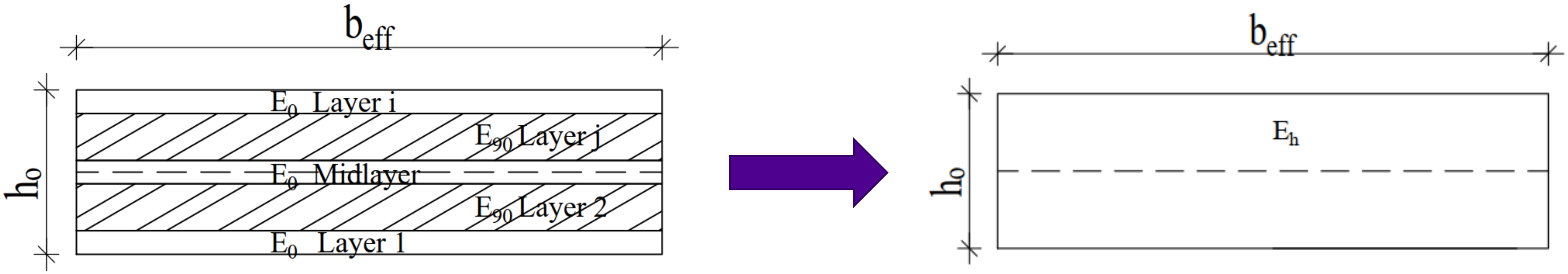
Open research questions regarding STC structures

1. How to calculate the effective width of the slab
2. How to homogenize the layered CLT-cross section computationally simple yet accurate way?
3. What calculation method should be used for the steel-timber structure when analysing the structural behaviour like bending capacity or stress distribution in composite cross-section

2. How to homogenize the layered CLT-cross section computationally simple yet accurate way?

Methods to use when homogenizing CLT cross-section

- Gamma method → most used in North
- Timoshenko´s beam theory
- Shear analogy aka Ratzinger's method
- Layered beam theory

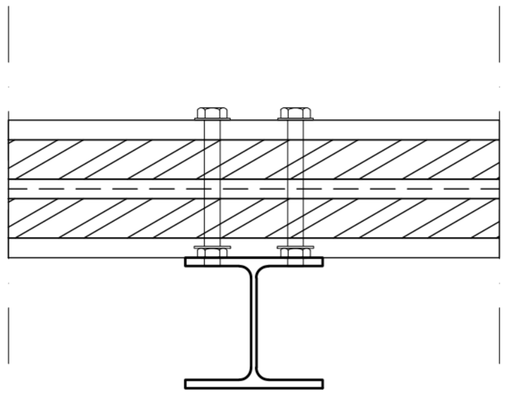


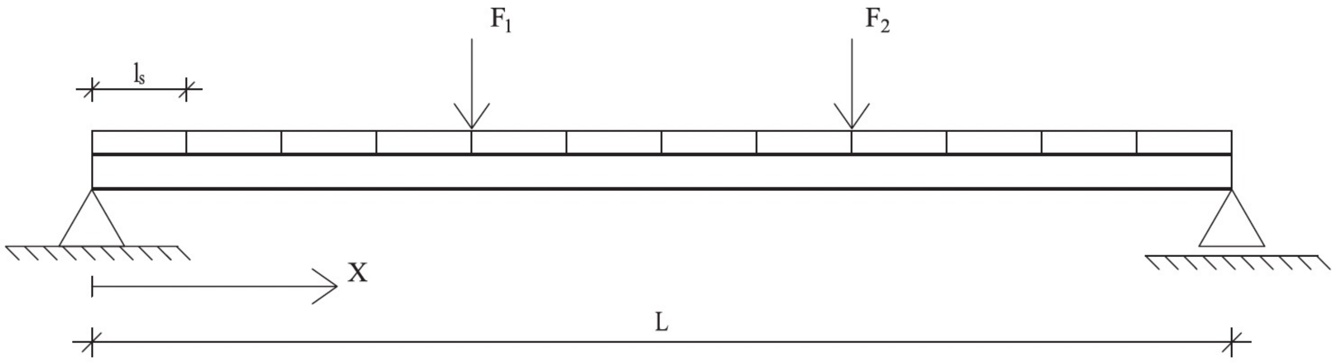
Original cross-sectionaa

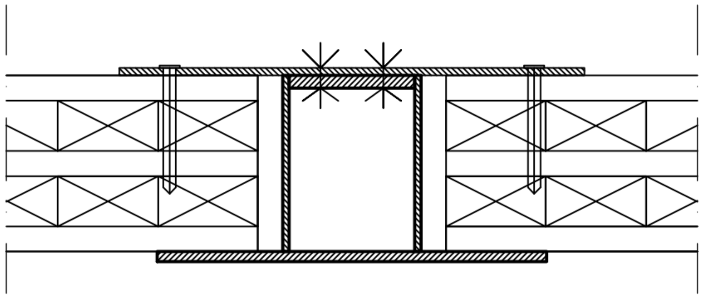
Homogenized cross-section

3. What calculation method should be used for the steel-timber structural

- At the moment Eurocode 5 does not provide design guidelines for STC structures
- Different methods have been presented in the literature over the last 10-5 years







Key takeaways of the paper

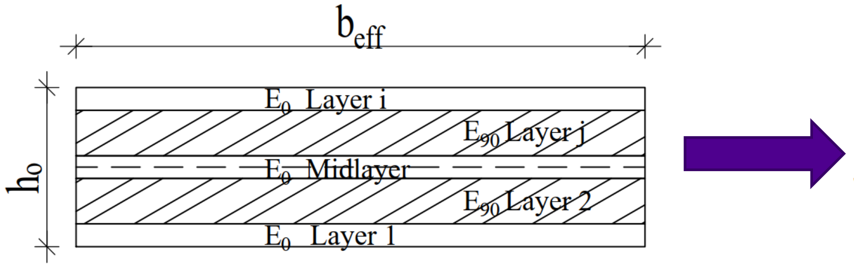
Authors’ approach to the problems

- Propose a new method to homogenize the CLT cross-section
  - EA-equivalent method
- Propose new analytical calculation methods for STC structures
  - Elastic theory of layered beams (ETLB)

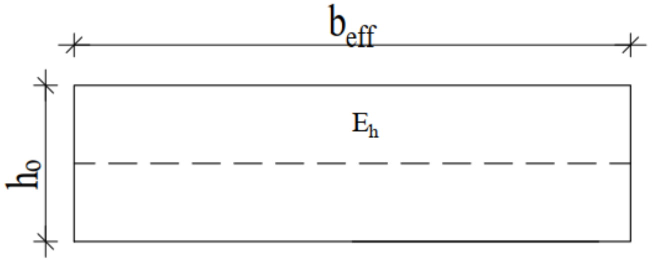
→ Validate these by using existing experimental data

2. Homogenising CLT cross-section

- Proposed method to homogenise CLT cross-section
  - EA-equivalent method that uses the axial stiffness of the cross-sections
- Refecense method used
  - EI-equivalent method that uses the bending stiffness of the cross-sections. Here the gamma method was used (EC5)



Original cross-section



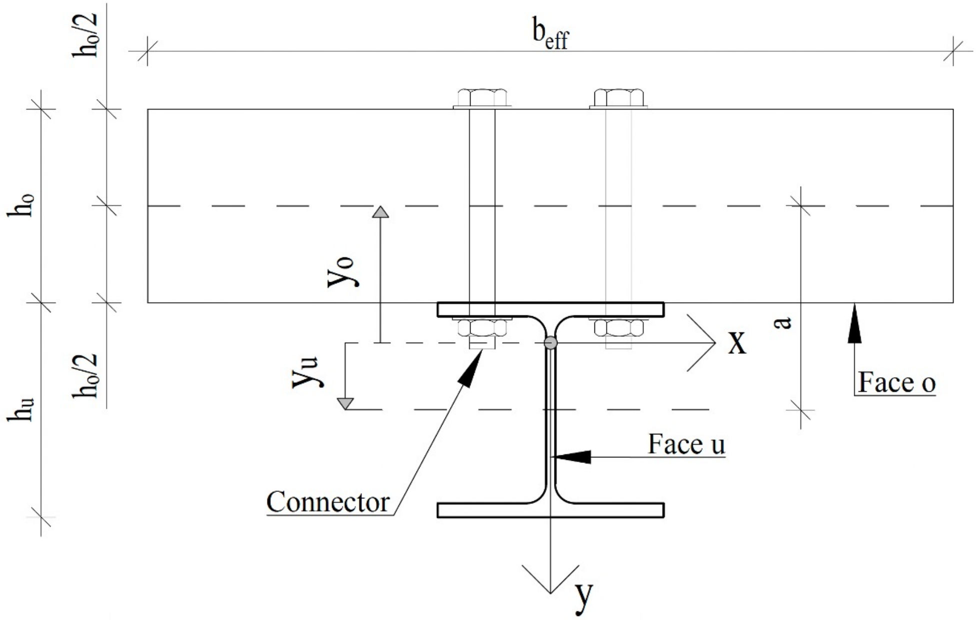
Homogenized cross-section

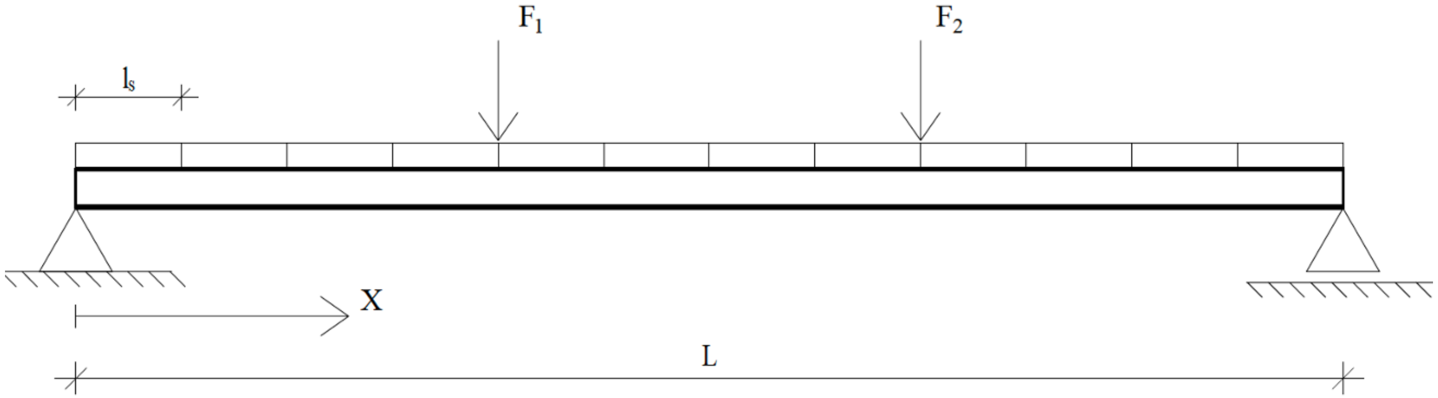
$$(EA)_{eff} = \sum_{i=1}^{n} E_i A_i \rightarrow E_{h.EA} = \frac{\sum_{i=1}^{n} E_i A_i}{A_h}$$

$$(EI)_{eff} = \sum_{i=1}^{n} E_i I_i + \sum_{i=1}^{n} \gamma_i a_i^2 E_i A_i \rightarrow E_{h.EI} = \frac{\sum_{i=1}^{n} E_i I_i + \sum_{i=1}^{n} \gamma_i a_i^2 E_i A_i}{I_h}$$

3. Analytical calculation method

- The study examined the use of Elastic theory of the layered beams (ETLB) for STC structures
- Theory consist of three main components
  - Face o = Timber
  - Face u = Steel
  - Core = connetion
- ETLB has been widely used for sandwich structures
- Was first considered by Heinisuo et al. 2019 for steel-timber composite structures





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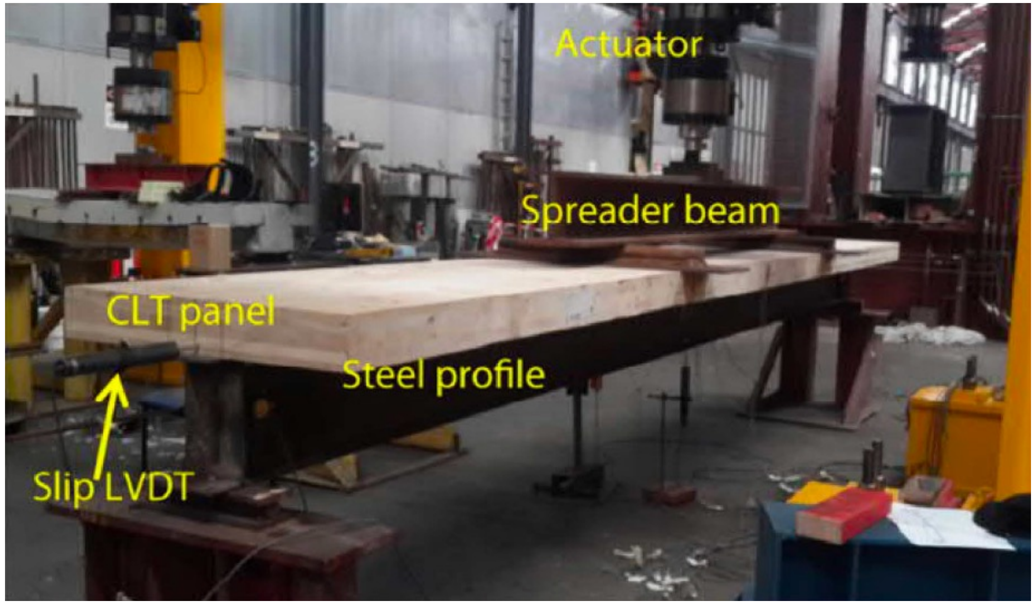
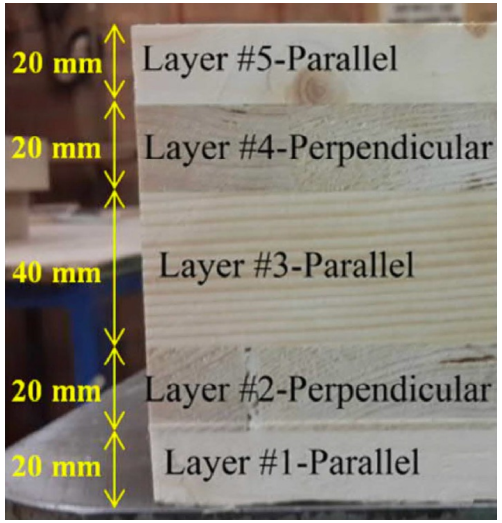
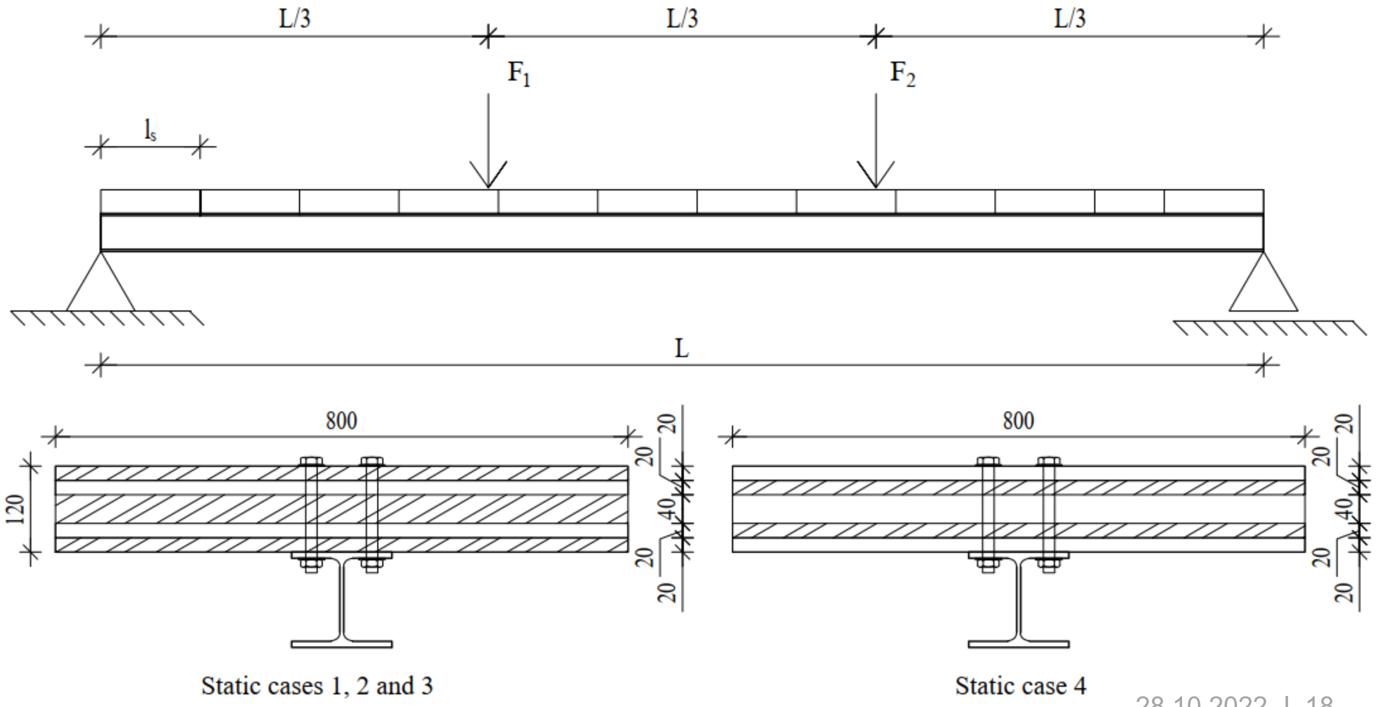
Existing experimental data

- Experimental data was taken from studies conducted by Hassanieh et al. 2017 (statical load tests) and Chiniforush et al. 2019 (vibration tests)
- Studies varied:
  - The connection between CLT and timber
  - Steel profile
  - CLT rotation

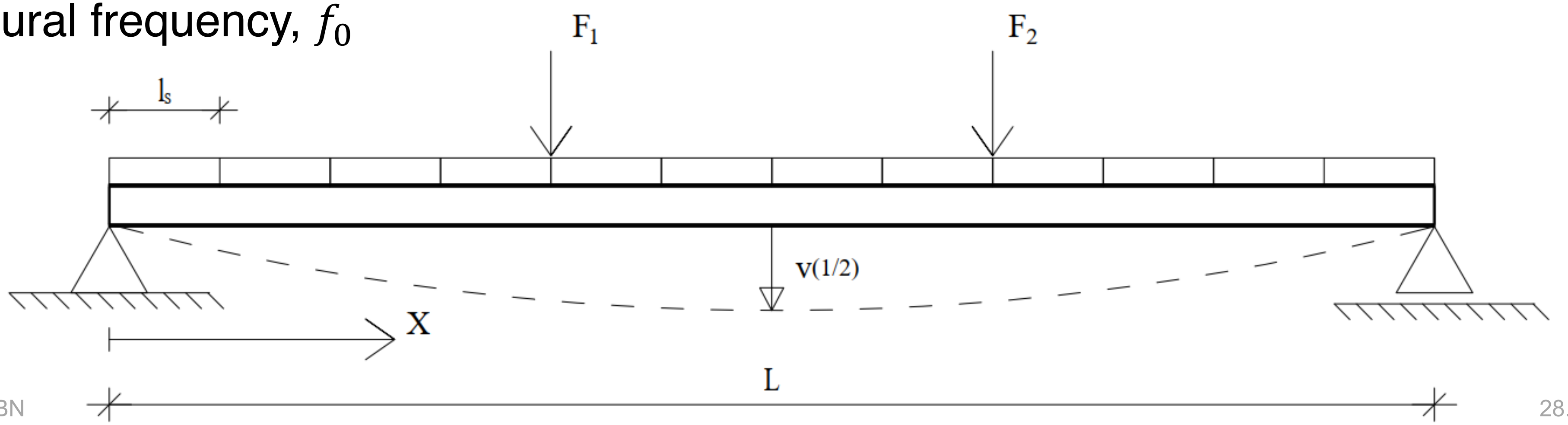






Results

- Three key structural responses were calculated by using ELTB with both EA- and EI-equivalent methods and compared to the *Test* values found in studies
  - Total load value when steel beam starts to yield $F^* = F_1 + F_2$
  - Deflection, $v(1/2\xi)$, at the mid-span of the beam at the load level F^*
  - The lowest natural frequency, f_0



Results, key responses

Table 3. Comparison of selected key responses in the static analysis cases 1-4, where *EA* and *EI* refer to the proposed CLT homogenization methods and *Test* to the obtained values from studies.

	Case 1			Case 2			Case 3			Case 4		
Method	*Test*	*EA*	*EI*	*Test*	*EA*	*EI*	*Test*	*EA*	*EI*	*Test*	*EA*	*EI*
Yield load F^* (kN)	208	201.2	202.3	241	248.7	249.7	214	194.3	195.3	202	184.2	180.9
Mid-span deflection $v(1/2\xi)$ (mm)	31.8	33.4	33.3	30.9	35.6	35.5	32.3	35.3	35.2	21.4	21.4	21.4
Difference F^* (%)		−3.3	−2.7		3.2	3.6		−9.2	−8.7		−8.8	−10.4
Difference $v(1/2\xi)$ (%)		5.0	4.7		15.2	14.9		9.3	9.0		0	0

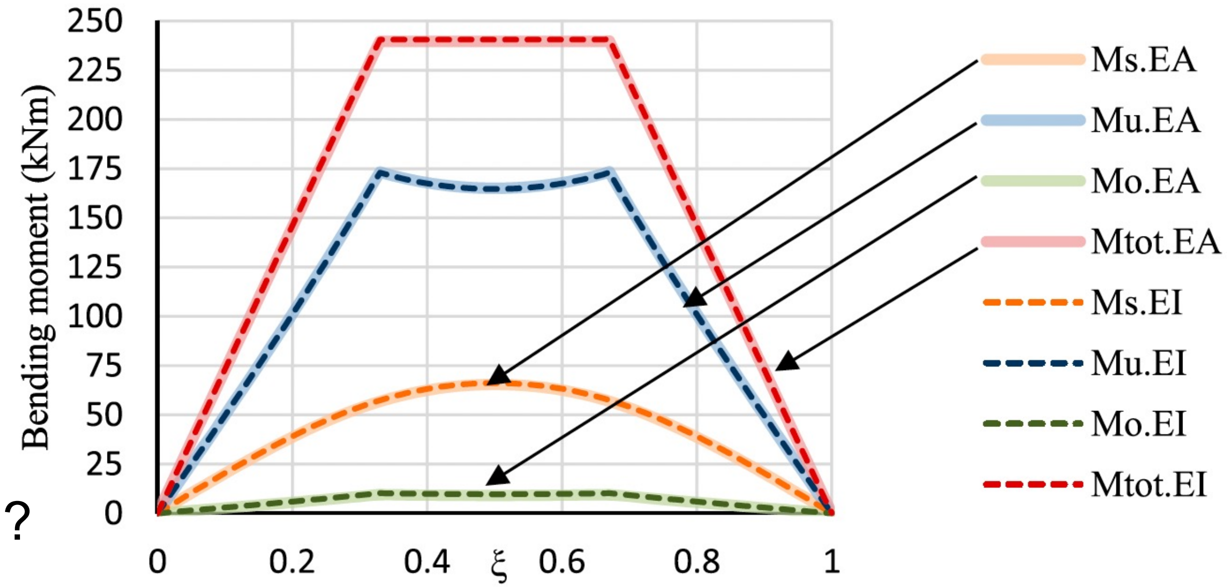
- Both methods provided yield load values that are within 10% of the *Test* values
- All cases but Case 2 provided load values that are underestimating the yield load → calculation is on the safer side

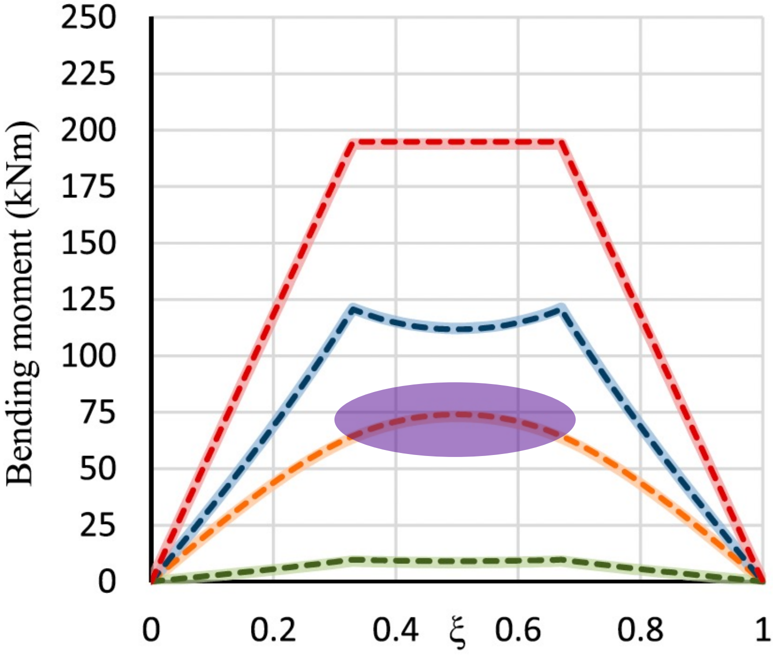
- In the vibration analysis, both methods provided virtually identical results that were within 6% of *Test* values

- Calculated deflections are within 15% of the *Test* values
- All cases provided deflection values that are greater than *Test* values → calculation is on the safer side
- "It is interesting to note that the deviation of the calculated deflection from the *Test* value increases with decreasing shear connection stiffness: the largest stiffness is in case 1, followed be case 3 and case 2"

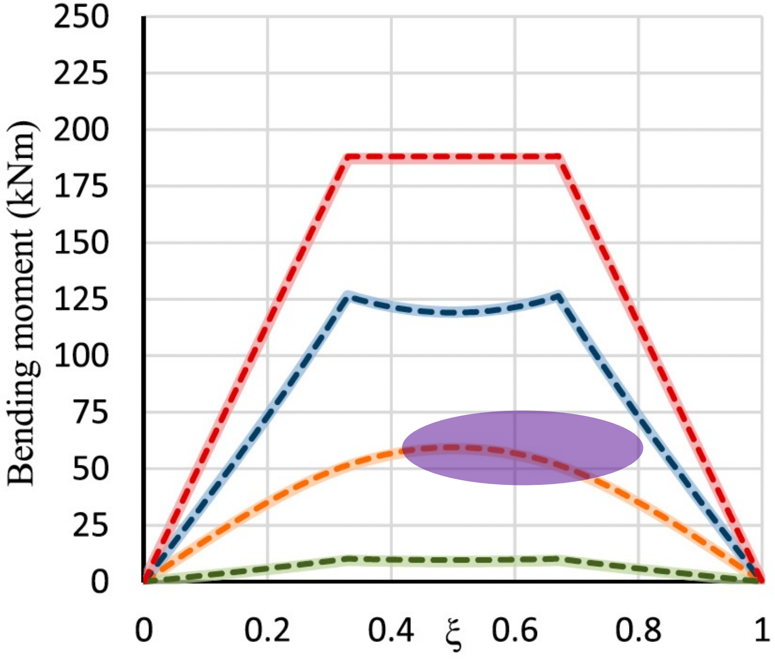
Results, bending moments

- Case 1 has a 29,5% stiffer connection than case 3 and likewise, the composite action (Ms) is 24,5% larger other parameters are the same
  → Better loadbearing capacity
- What this does to stresses in the STC cross-section?





a) Case 1



c) Case 3

Ms=composite action
Mu=bending moment taken by steel
Mo=bending moment taken by CLT

Mtot=Ms+Mu+Mo

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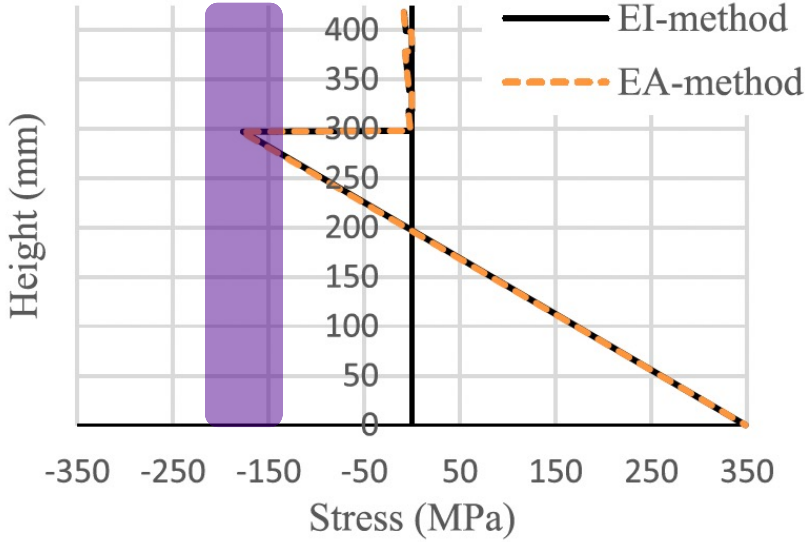
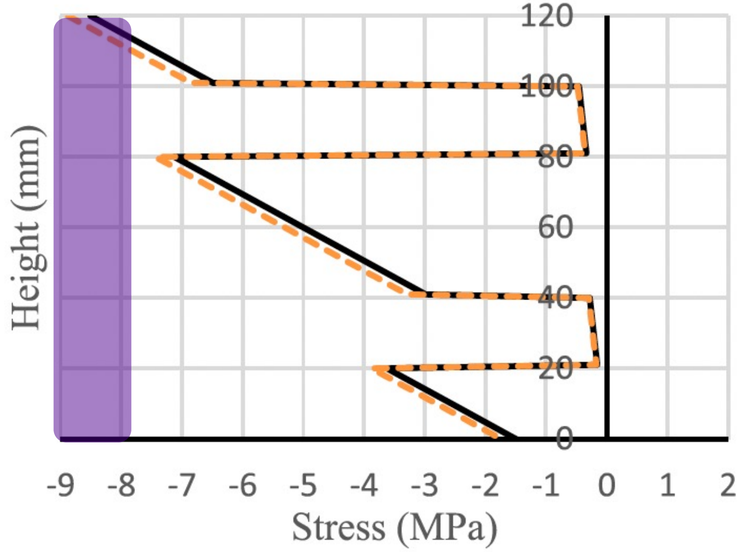
Results, stress distribution

- Stresses in the STC cross-section for Case 1 are lower than in Case 3

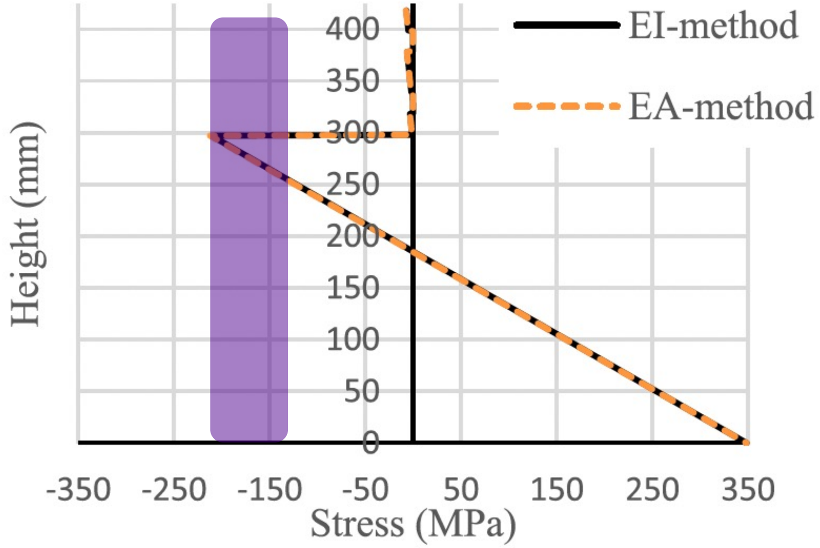
- We could design more material-efficient steel beams when the composite action between steel and timber is stronger



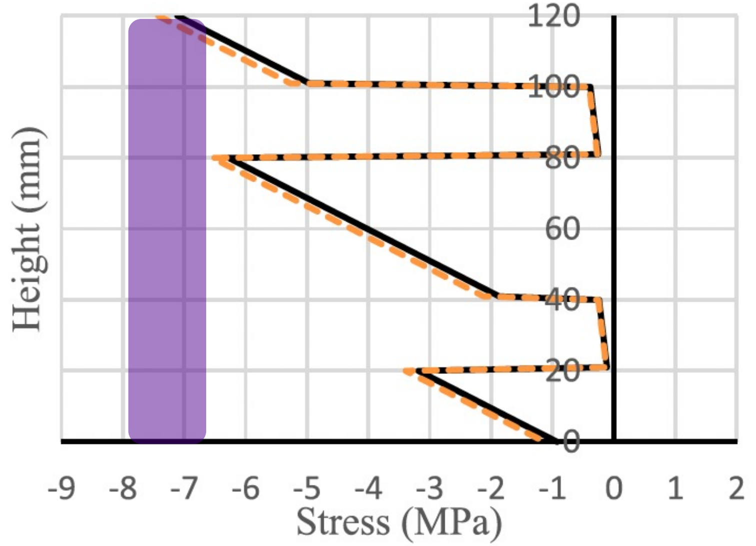
a) STC cross-section from Case 1



b) CLT cross-section from Case 1



e) STC cross-section from Case 3

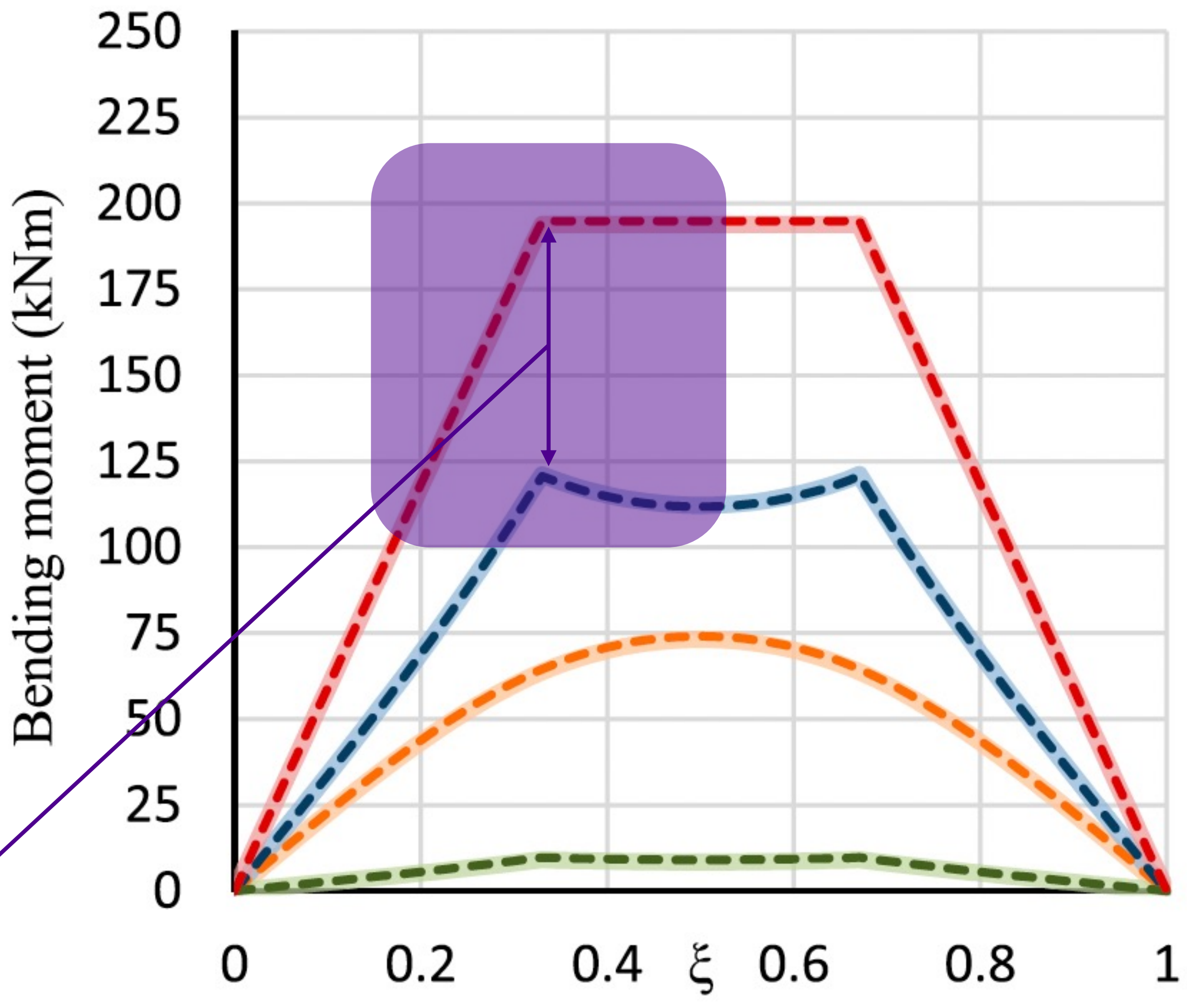


f) CLT cross-section from Case 3

Conclusion

- Composite action between steel and timber leads to better material efficiency → reduse cost → reduce environmental impact

Bending moment capacity is 60% times bigger when composite action is formed between steel and timber when compared to only steel beam



a) Case 1