Timber-Concrete Composite Technology

Research, Design, and Implementation

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Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board.

Photo courtesy A. Schreyer

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Course Description

Timber-concrete composite floor technology is catching on in North America as a high-performance solution for long spans in commercial and industrial buildings. Comprised of timber beams or panels that are joined to a concrete slab by shear connectors, the resulting composite floor can be stiffer and stronger than non-composite alternatives. This presentation will provide an overview of the evolution of shear connectors for these floor systems, discuss best practices and design guidelines for some of the more prevalent connectors, and present a case study of the new Olver Design Building at the University of Massachusetts Amherst, which features what is currently North America's largest application of this technology.

Learning Objectives

1. Define timber-concrete composite floor systems and highlight their use in modern mass timber buildings.

2. Review the structural design principles and processes associated with timber-concrete composite floor systems.

3. Demonstrate a variety of available composite floor shear connectors and discuss design methods.

4. Highlight the use of timber-concrete composite floors in the University of Massachusetts Design Building, including research done to aid its implementation.

Thompson Community Center, Richmond, British Columbia
Photo courtesy Henriquez Partners Architects

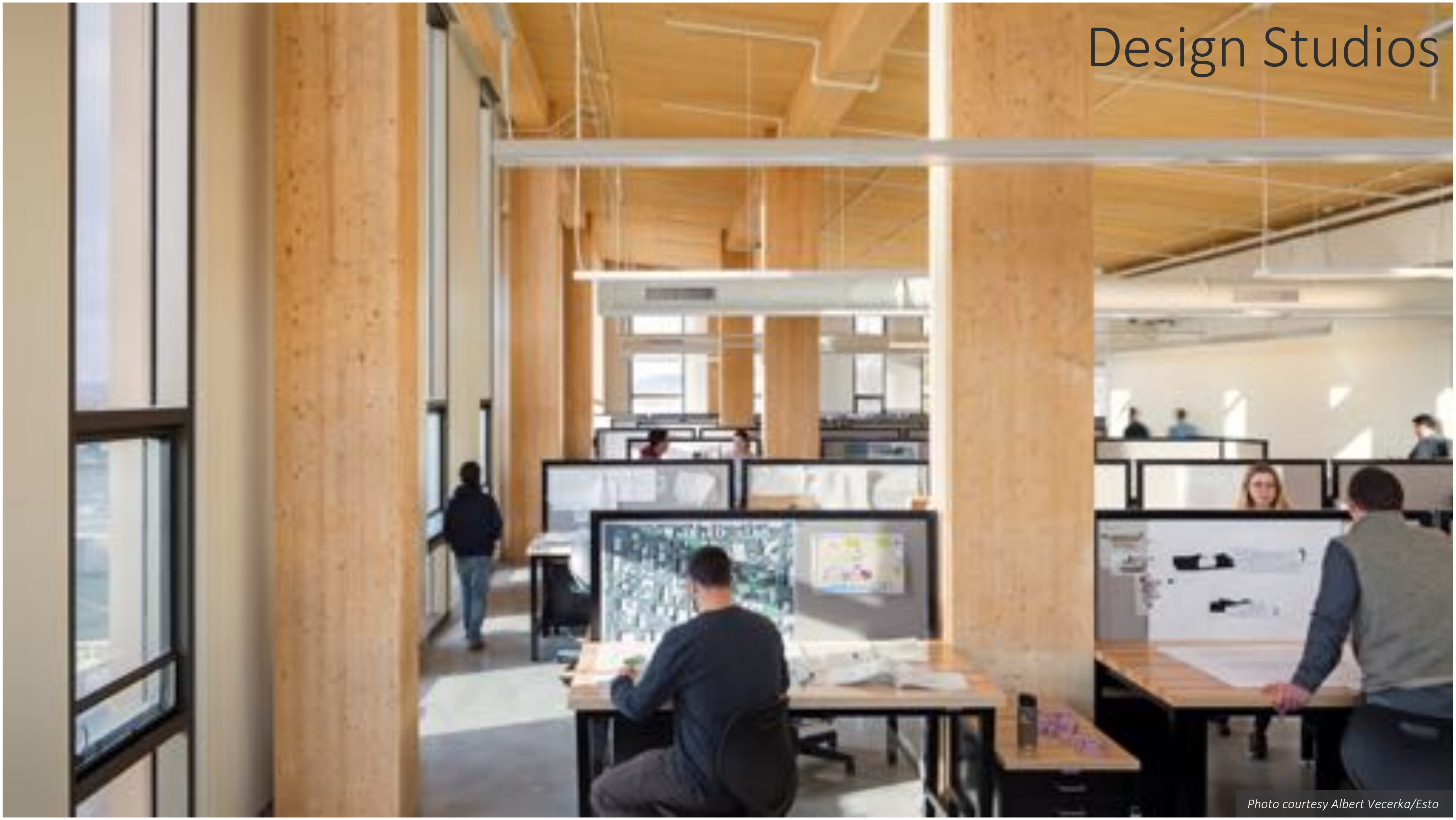

Olver Design Building, UMass Amherst
87,500 ft^2 (8,200 m^2), 4 stories || Project cost: $52M || Construction time: August 2015 – October 2016
Architect: Leers Weinzapfel Associates ||Engineer: Equilibrium / SGH Engineering || Contractor: Suffolk Construction

Awards

- 2018 Wood Design Awards Jury's Choice for Wood Innovation, WoodWorks
- 2017 Building of the Year, world-architects
- 2017 Most Innovative Project Award (less than $100 million), Architectural Engineering Institute
- 2017 Excellence in Structural Engineering Award (New Buildings $20 to $100 Million), National Council of Structural Engineering Associations
- 2017 Awards of Merit for Structural Systems Design and Architectural Engineering Integration, Architectural Engineering Institute
- 2017 Award of Merit, Higher Education/Research Category, ENR New England

+ 6 more!


Photo courtesy A. Schreyer


Design Studios
Photo courtesy Albert Vecerka/Esto


Wood Mechanics Lab
Photo courtesy Albert Vecerka/Esto

Go UMass!

The Design Building is one of the *most technologically advanced* CLT structures in the US

Glulam- and CLT-Concrete Composite Floors

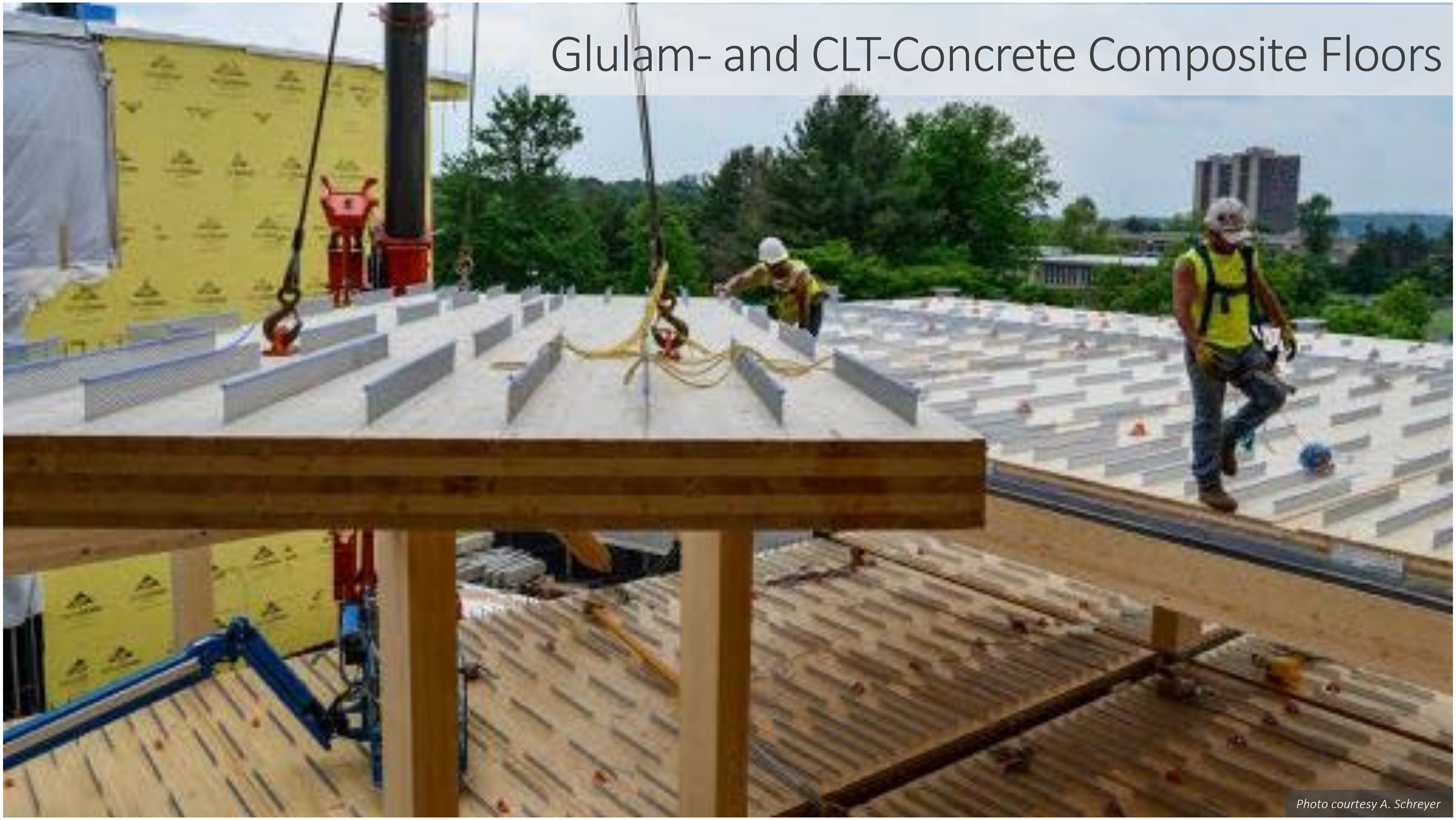
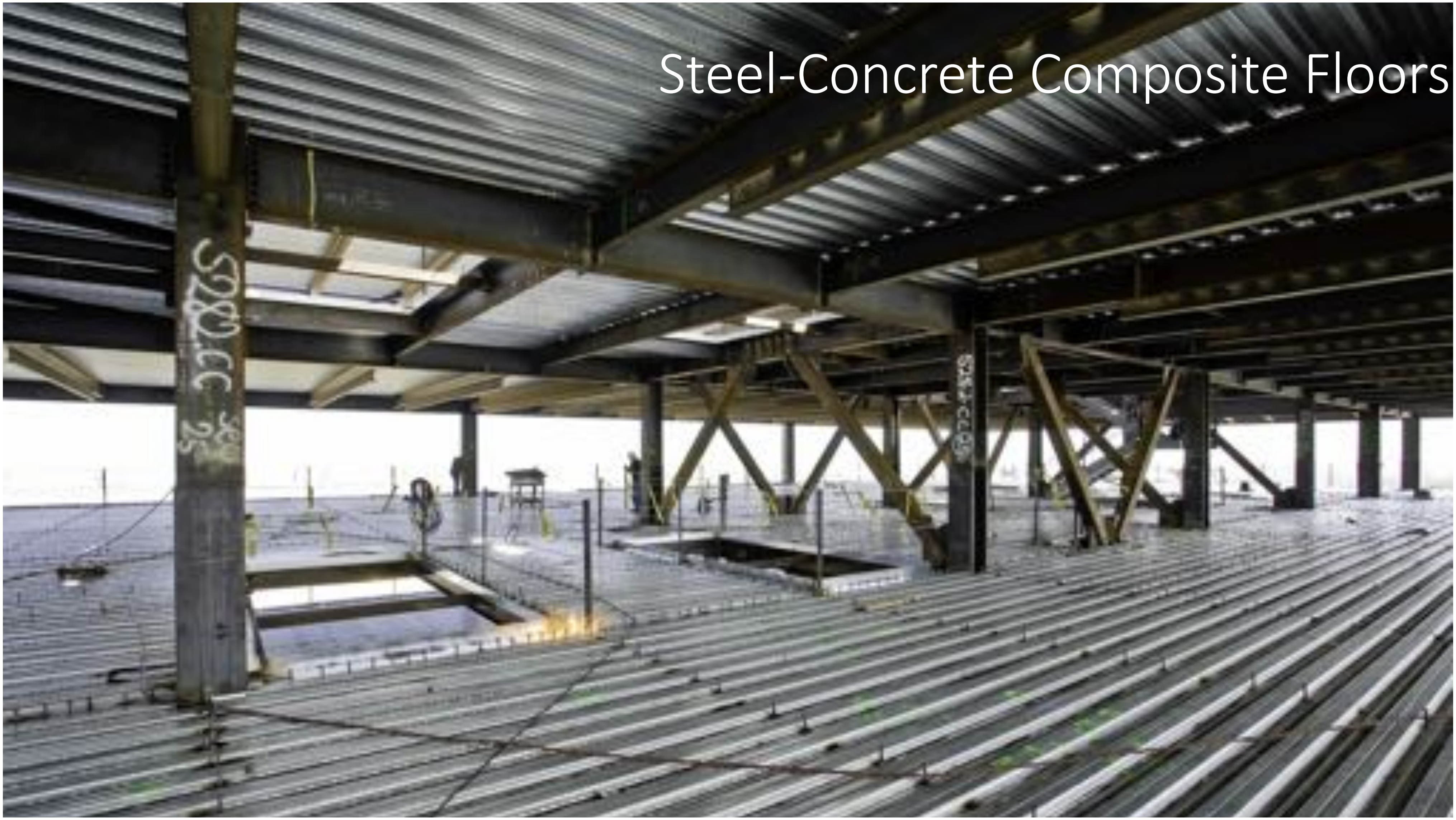


Photo courtesy A. Schreyer

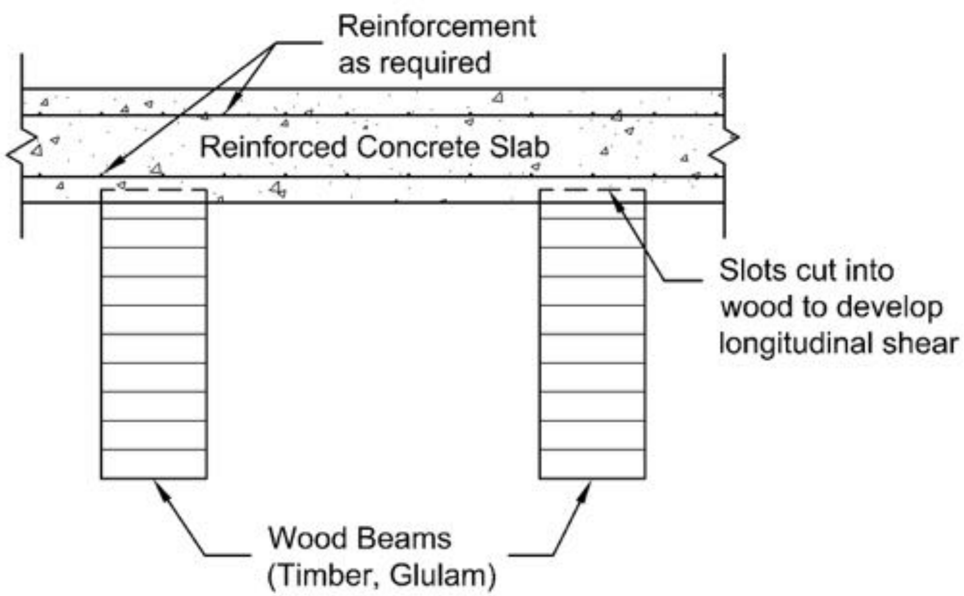
Steel-Concrete Composite Floors



Steel-Concrete Composite Floors


Photo courtesy A. Schreyer

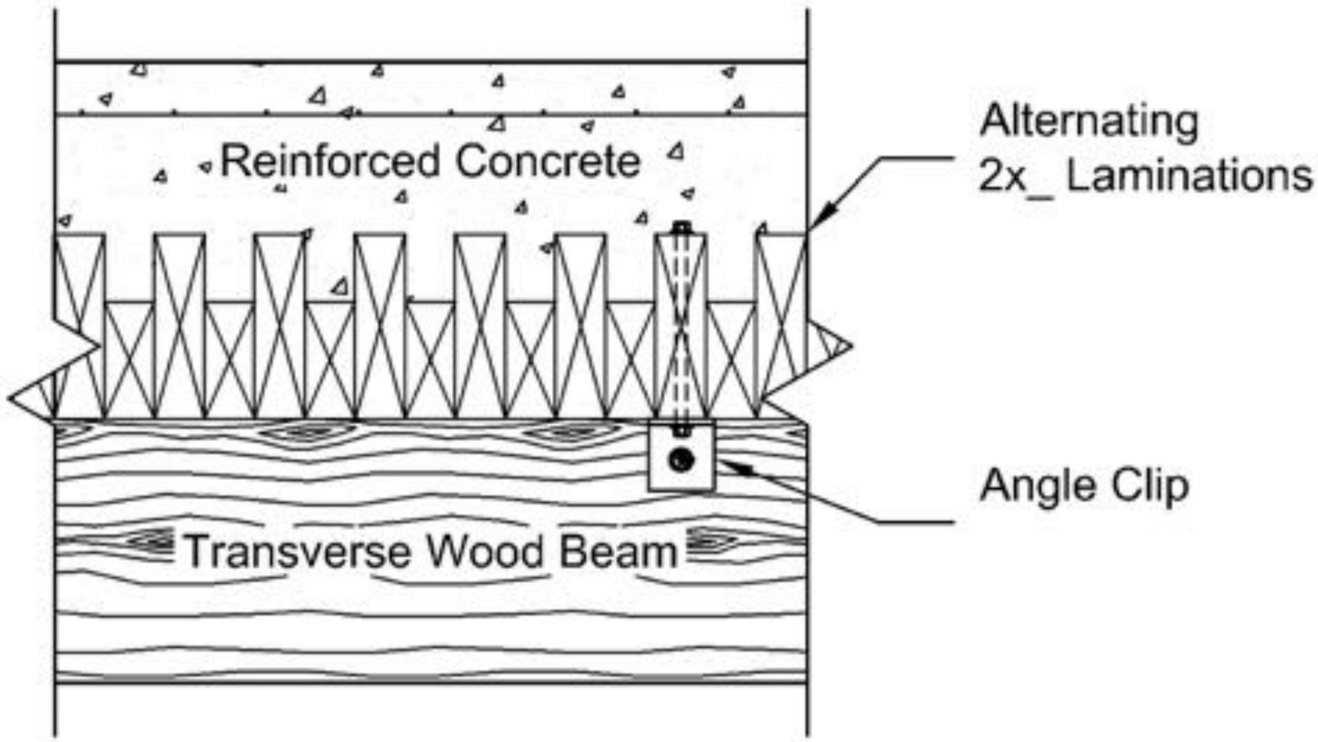
Timber-Concrete Composite … an old idea



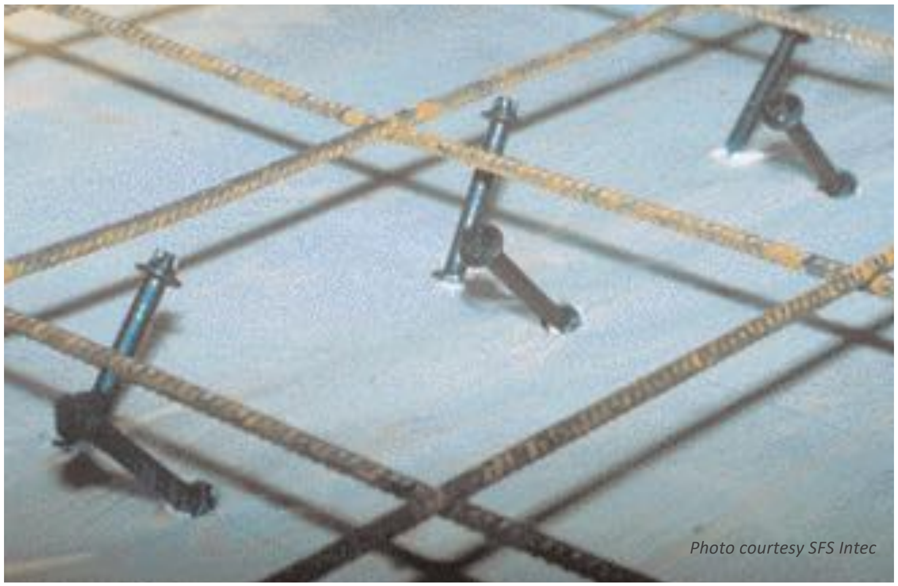
Slab-to-beam connection

Used since 1930s in US timber bridges

Traditional Composite Timber Bridge Deck



Today's State-of-the-Art Technology



VB connectors by SFS Intec© & rothoblaas

HBV® Connectors by TiComTec® GmbH

Advantages

- Improved sound insulation
- Enhanced damping
- Improved fire resistance
- Improved durability
- More rigid diaphragm

Compared to timber alone

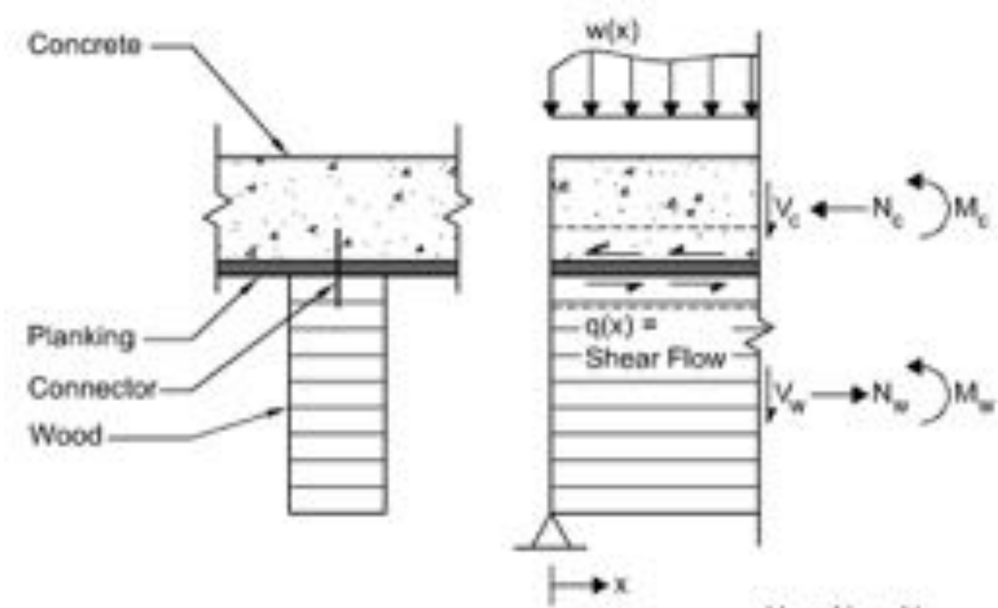
- **Composite action**

  Higher strength

  Higher stiffness

Compared to unconnected timber concrete floors

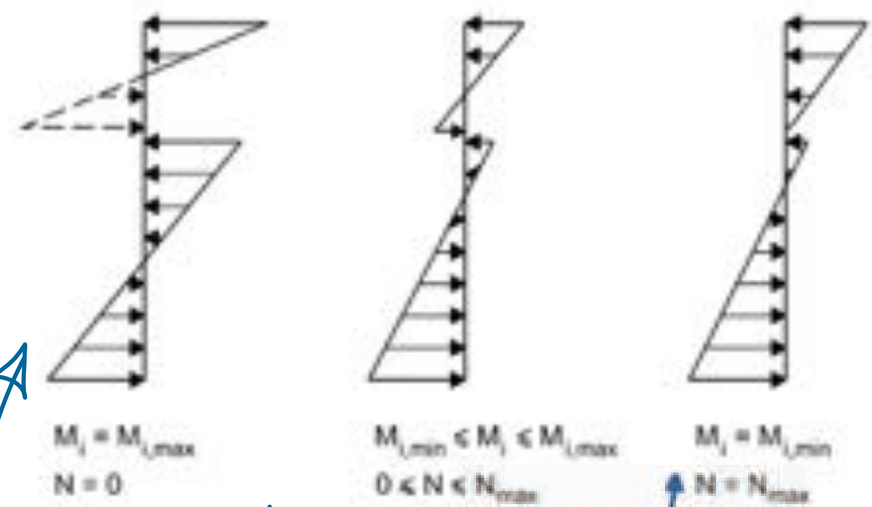
Composite Action



ideal

Connector Rigidity

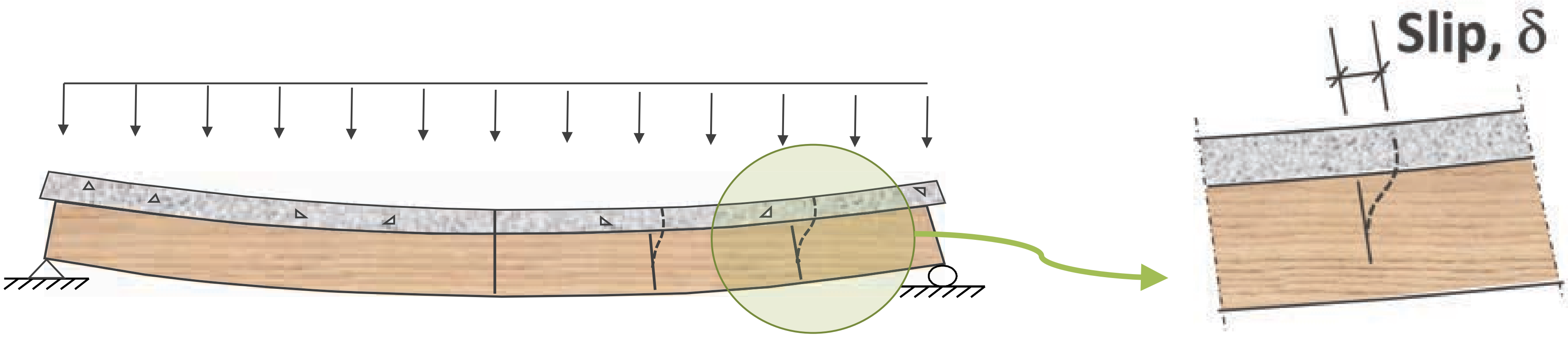
NONE (lower bound) | PARTIAL | FULL (upper bound)



acts as 2 separate beams.

acts as one beam w/ materials in unison

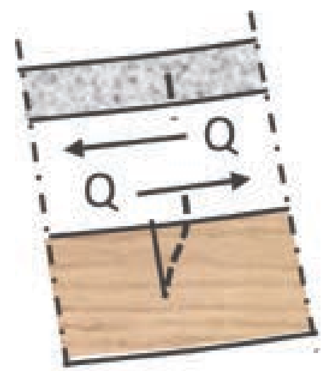
Partial Composite Action



Slip Modulus

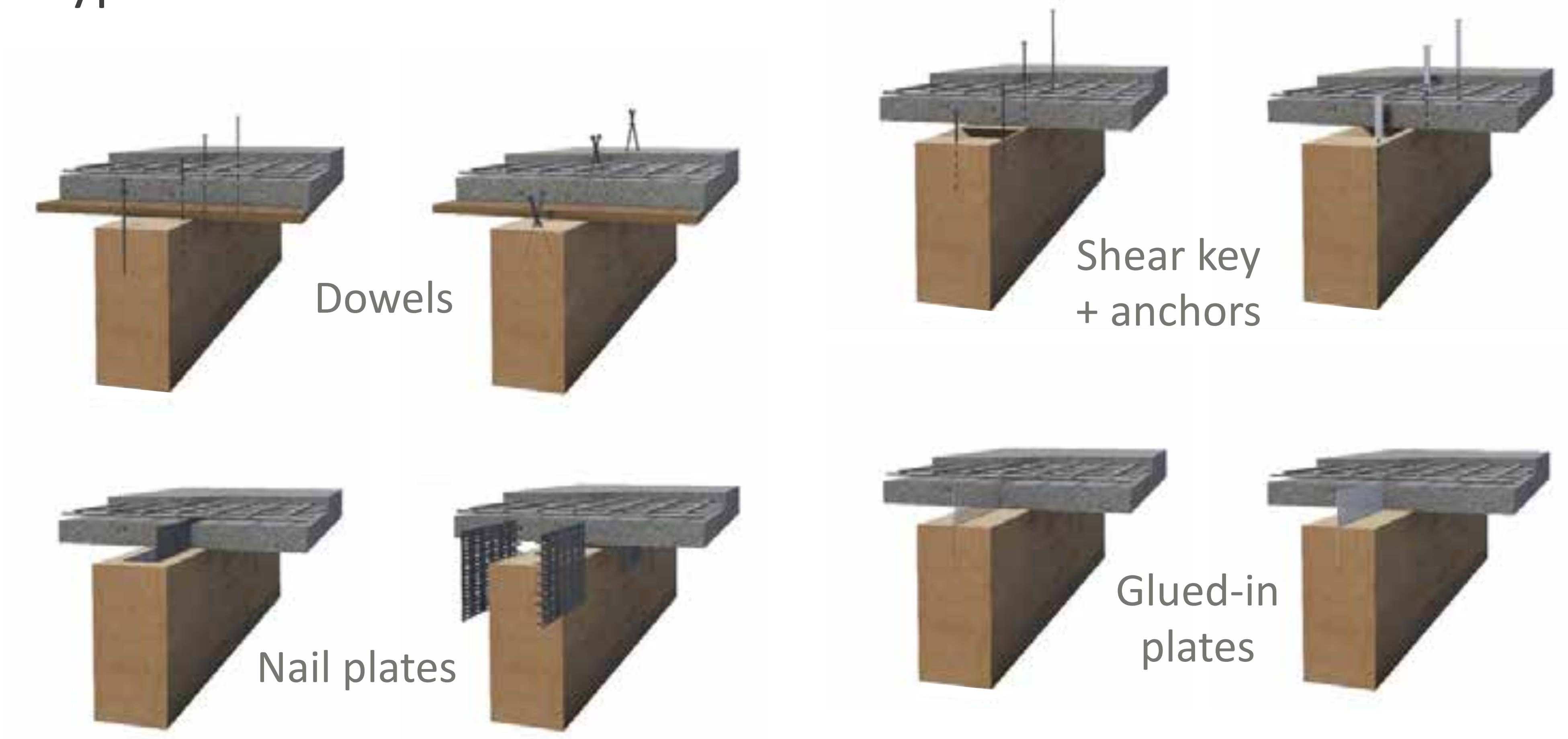
$$K = \frac{Q}{\delta}$$

Shear force, Q

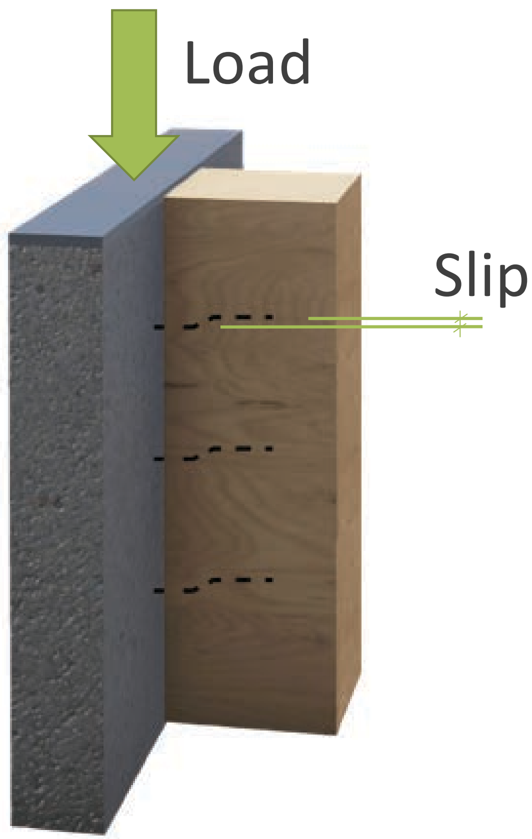


❖ The level of structural efficiency depends on the type of shear connector

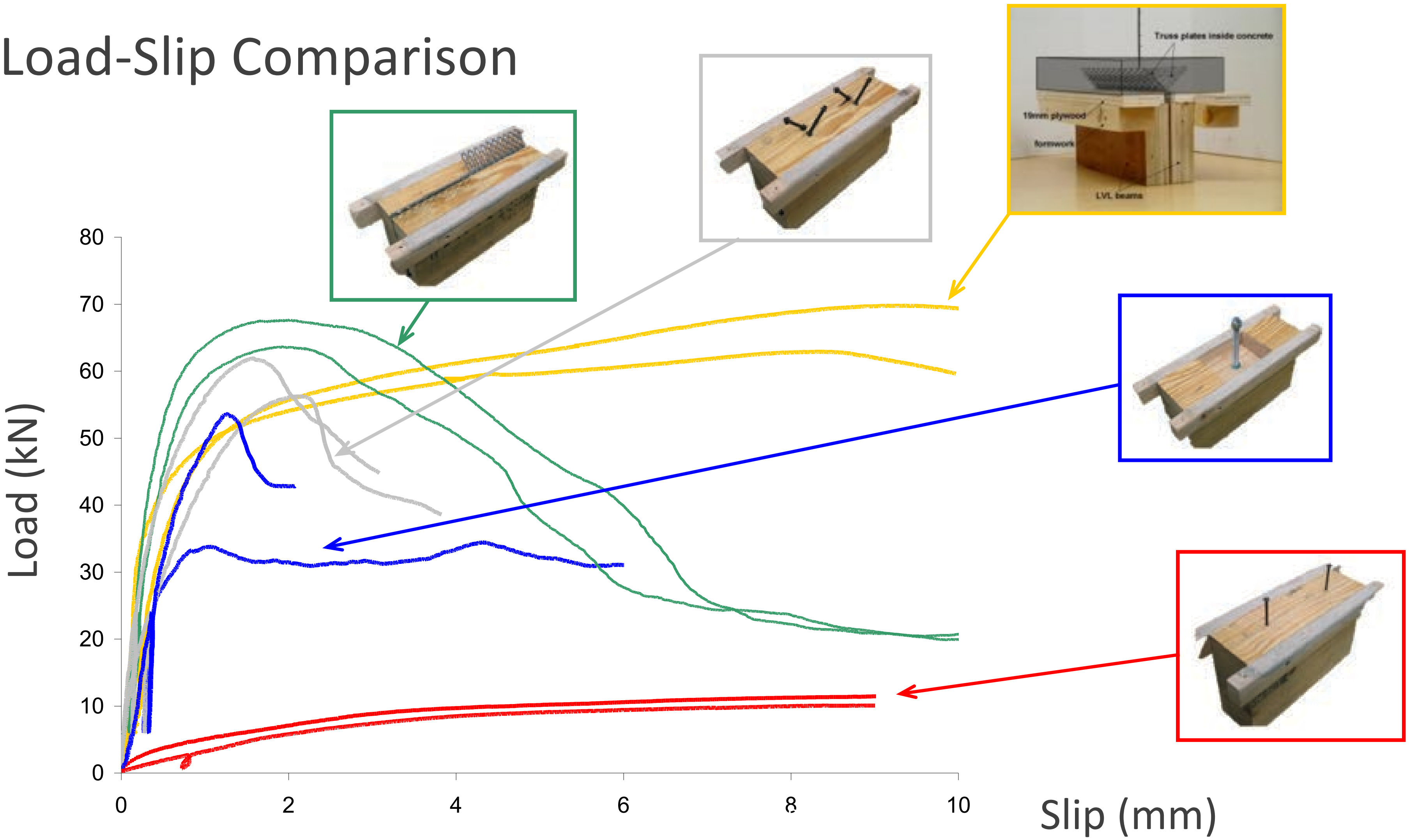
Types of Shear Connectors



Load-Slip Evaluation (Push-Out Test)



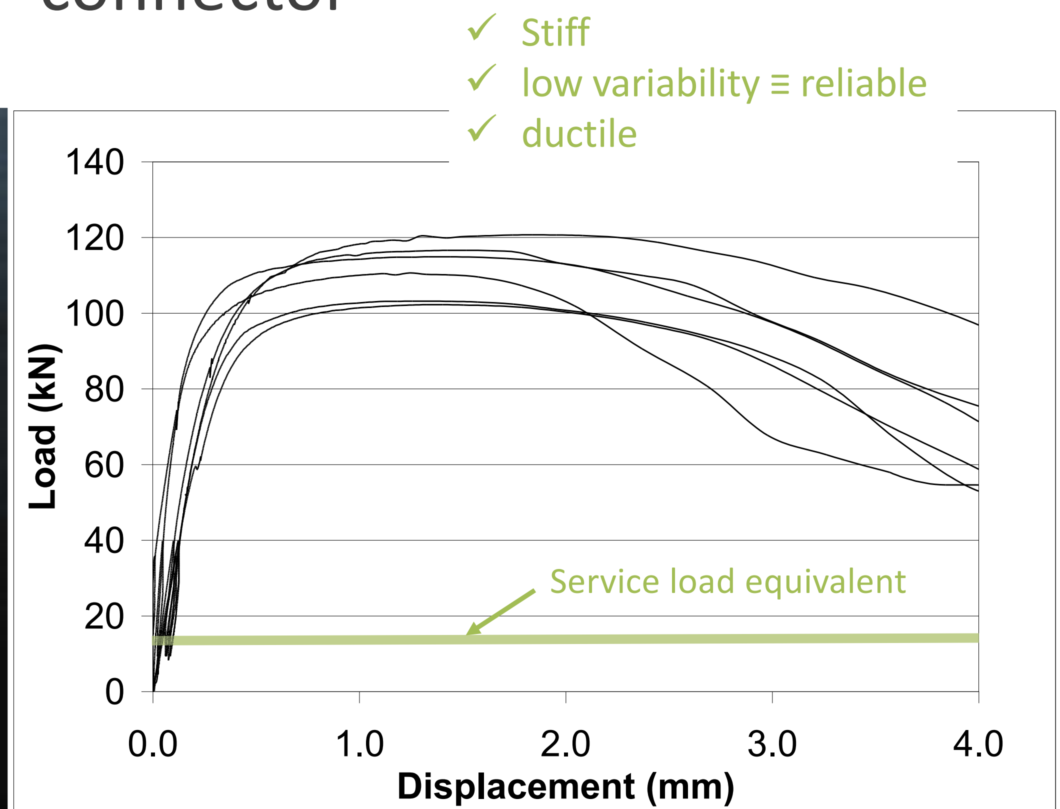
Load-Slip Comparison



Reference Documents for Connector Comparison

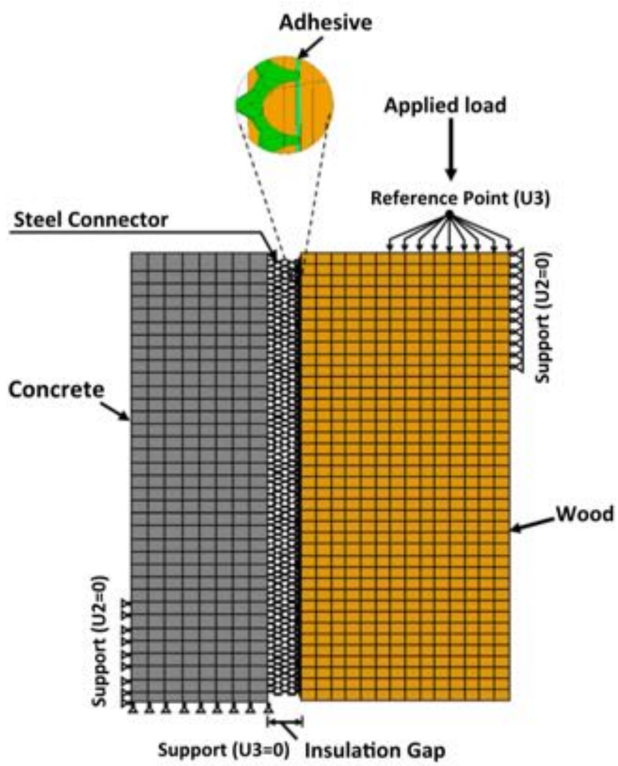
- Yeoh, D., Fragiacomo, M., De Franceschi, M., & Heng Boon, K. (2010). **State of the art on timber-concrete composite structures: Literature review.** Journal of structural engineering, 137(10), 1085-1095.
- Rodrigues, J. N., Dias, A. M., & Providência, P. (2013). **Timber-concrete composite bridges: state-of-the-art review.** BioResources, 8(4), 6630-6649.

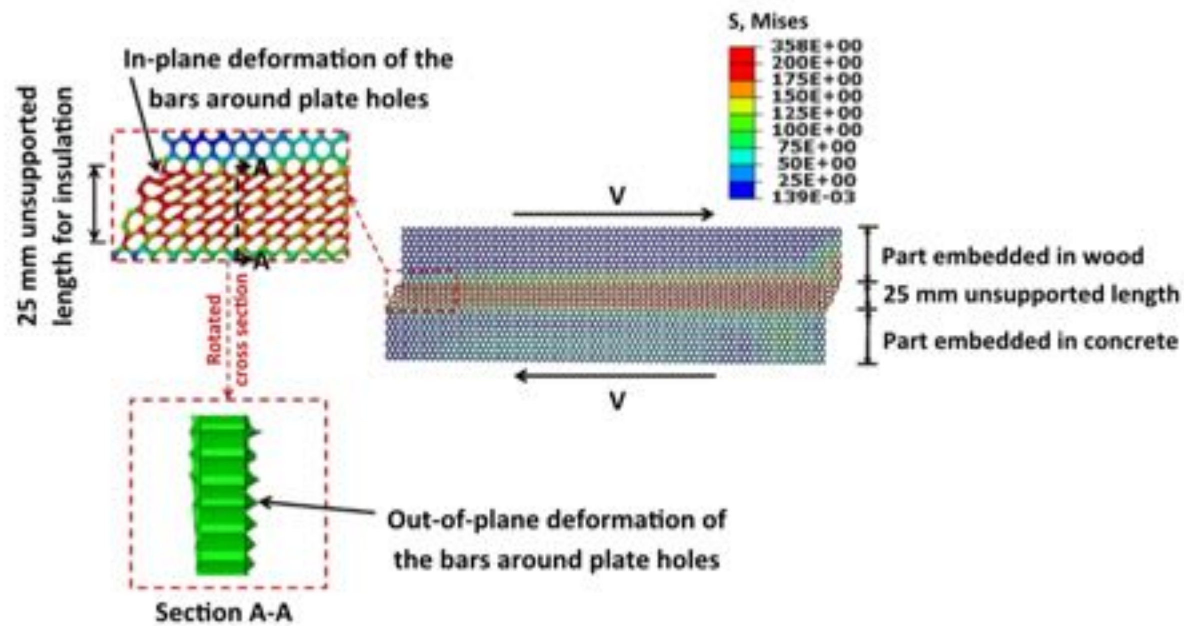
Design Philosophy of the HBV® connector



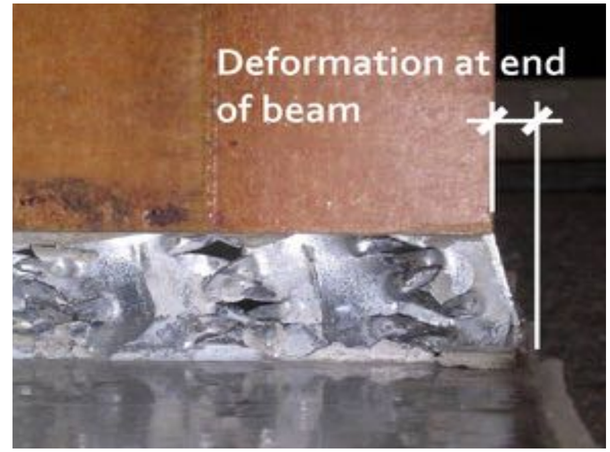
❖ Clouston P, Bathon L, Schreyer A. 2005. “Shear and Bending Performance of a Novel Wood-Concrete Composite System” ASCE Journal of Structural Engineering. 131(9), pp.1404-1412

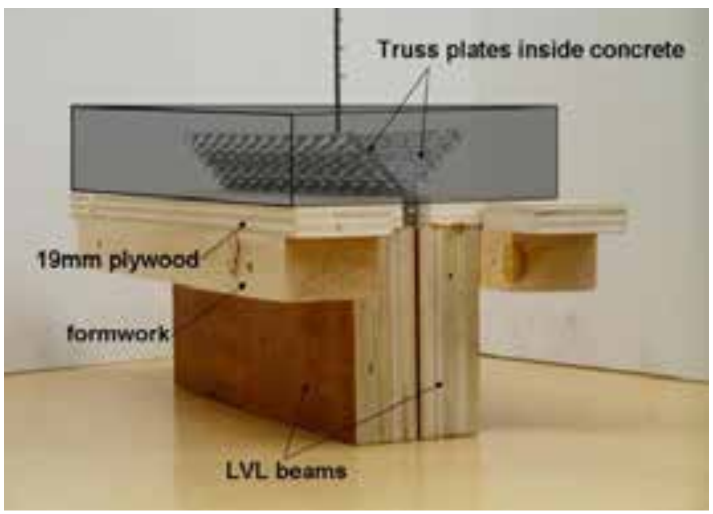
FEA Simulations | Parametric Studies





❖ Al-Sammari A, Clouston P, & Breña S. 2018. “Finite-Element Analysis and Parametric Study of Perforated Steel Plate Shear Connectors for Wood–Concrete Composites.” ASCE Journal of Structural Engineering, 144(10), 04018191





- Clouston P, Quaglia C. 2013. "Experimental Evaluation of Epoxy based Wood-Concrete Composite Floor Systems for Mill Building Renovations." International Journal of the Constructed Environment, Vol. 3, pp.63-74
- Clouston P, Schreyer A. 2012. "Experimental Evaluation of Connector Systems for Wood Concrete Composite Floor systems in Mill Building Renovations." International Journal of the Constructed Environment, Volume 2, Issue 1, pp.131-144.
- Clouston P, Schreyer A. 2011 "Truss plates for use as shear connectors in laminated veneer lumber -concrete composite systems." Structures Congress, Las Vegas
- Clouston P, Schreyer A. 2008. "Design and Use of Wood-Concrete Composites". ASCE Practice Periodical on Structural Design and Construction, 13(4), pp. 167-175
- Clouston P, Bathon L, Schreyer A. 2005. "Shear and Bending Performance of a Novel Wood-Concrete Composite System". ASCE Journal of Structural Engineering. 131(9), pp.1404-1412
- Clouston P, Civjan S, Bathon L. 2004. "Experimental Behavior of a Continuous Metal Connector for a Wood-Concrete Composite System". Forest Products Journal. 54(6) pp. 76-84

Design of Timber-Concrete Systems

- Design for ultimate and serviceability limit state

Rigid systems

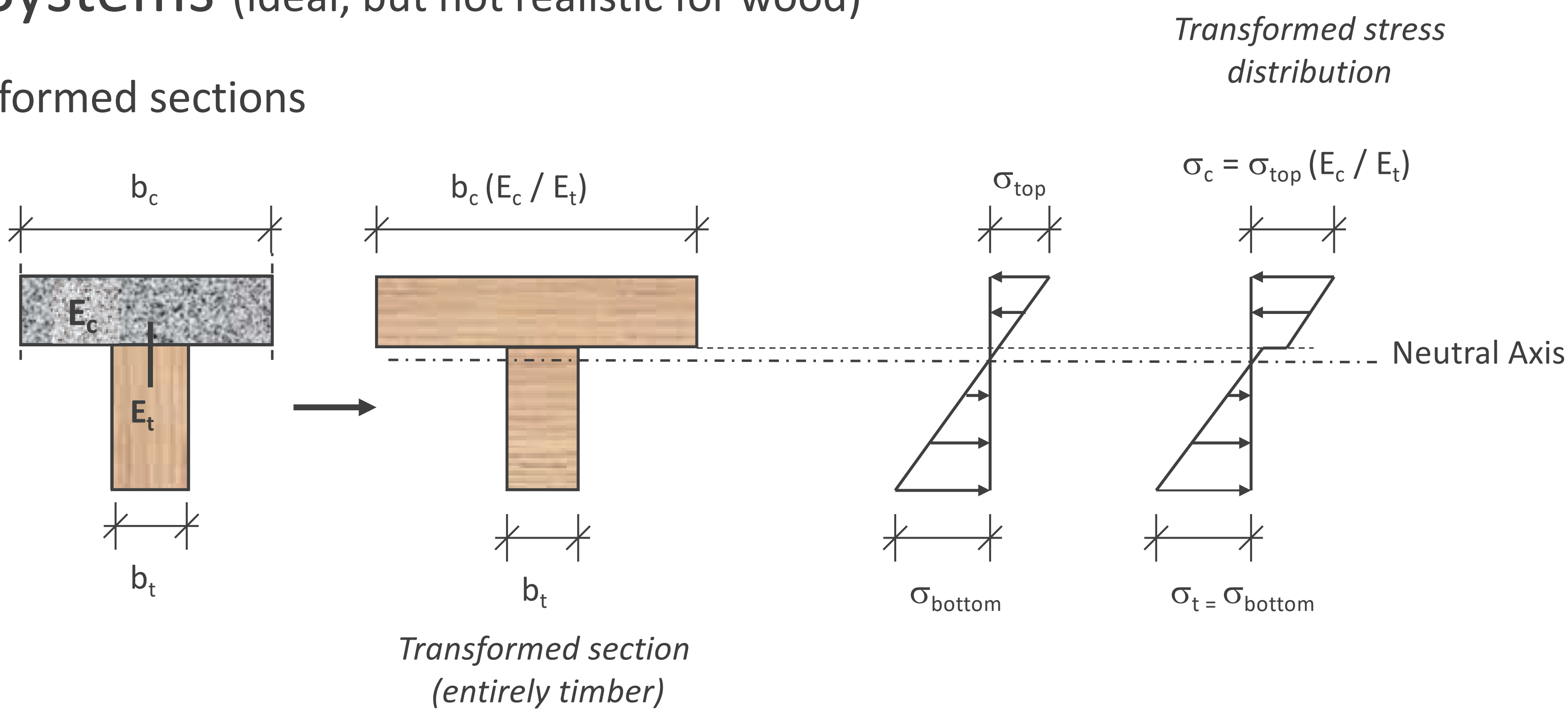
- Assume no slip between concrete and timber
- Use Transformed Section Method

Semi-rigid systems

- Acknowledge slip between concrete and timber
- Use Gamma Method: Eurocode 5, Part 2

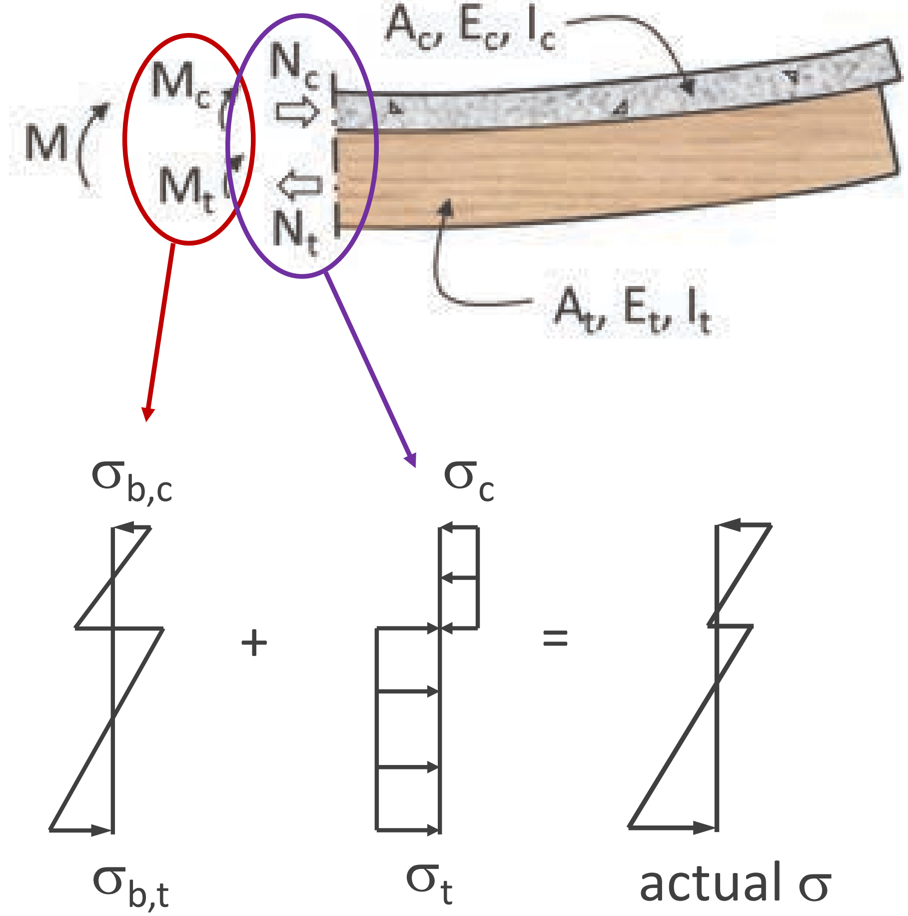
Rigid Systems (ideal, but not realistic for wood)

- Transformed sections

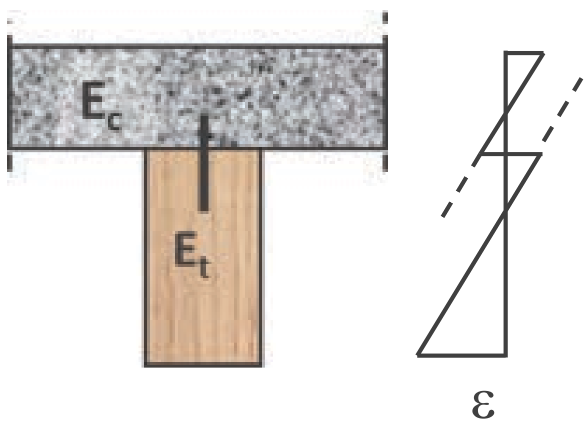


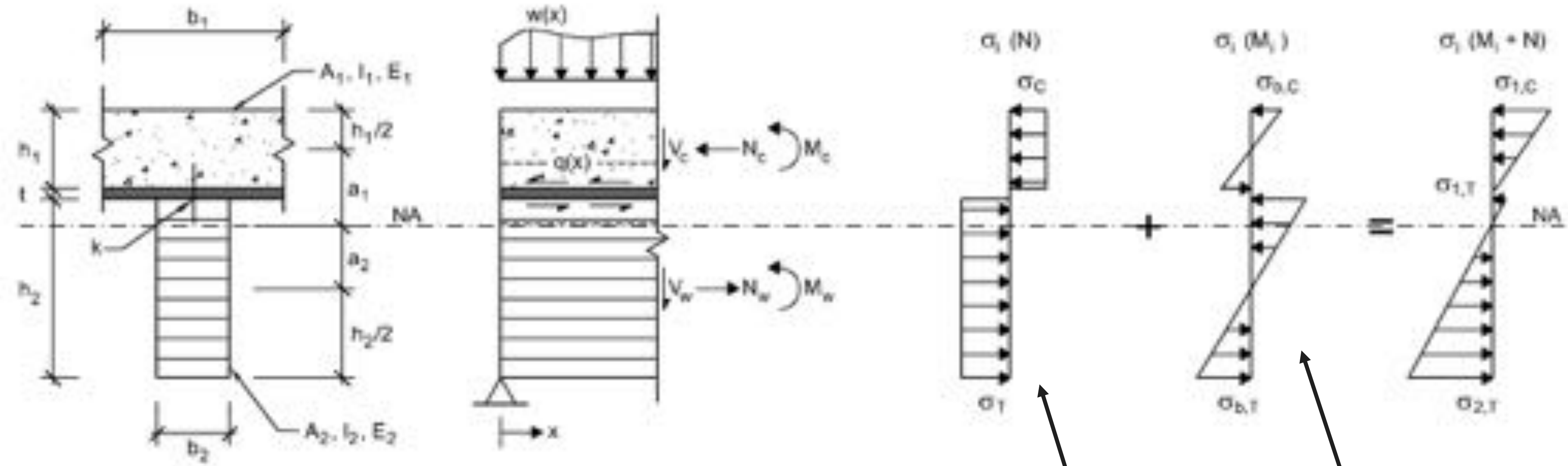
- σ_c = maximum compressive stress < allowable compressive strength of concrete
- σ_t = maximum tensile stress < allowable tensile strength of timber

Semi-rigid Systems (realistic for wood)



- The bending and axial stresses combine





$$\gamma_1 = \frac{1}{1 + \frac{\pi^2 E_1 A_1 s}{K l^2}}$$

$$(EI)_{ef} = E_1 I_1 + E_2 I_2 + \gamma_1 E_1 A_1 a_1^2 + \gamma_2 E_2 A_2 a_2^2$$

$$\sigma_i = \mathrm{f}\left(\frac{E_i A_i a_i K M}{EI_{ef}}\right) \qquad \sigma_{b,i} = \frac{0.5\, E_i h_i M}{EI_{ef}}$$

- ✓ **Strength**: check maximum stresses for both timber and concrete, shear stress in wood, and connector
- ✓ **Serviceability**: check short-term deflection and long-term creep

Reference Documents for Design

- Comité Européen de Normalisation (CEN). (2004a). “Design of timber structures—bridges.” Eurocode 5: Part 2, Brussels, Belgium.

- Worked examples:
  - ❖ **Ceccotti, A. (2002).** “Composite concrete-timber structures.” Progress in Structural Engineering and Materials, 4(3), 264–275.
  - ❖ **Fragiacomo (2006).** “Long-term behaviour of timber-concrete composite beams. II: numerical analysis and simplified evaluation.” ASCE Journal of Structural Engineering. 132(1), 23–33.
  - ❖ **Clouston and Schreyer (2008).** “Design and use of wood–concrete composites.” ASCE Practice Periodical on Structural Design and Construction, 13(4), 167-175.
  - ❖ **Tannert, T., Endacott, B., Brunner, M., & Vallée, T. (2017).** Long-term performance of adhesively bonded timber-concrete composites. International Journal of Adhesion and Adhesives, 72, 51-61.

Design Example

From: Clouston and Schreyer (2008). "Design and use of wood–concrete composites." ASCE Practice Periodical on Structural Design and Construction, 13(4), 167-175.

Material Properties

Concrete – medium density:

E_1 = 23,000 MPa

f'_c = specified compression strength = 25 MPa

Wood – Southern Pine, No.1:

E_2 = 11,700 MPa

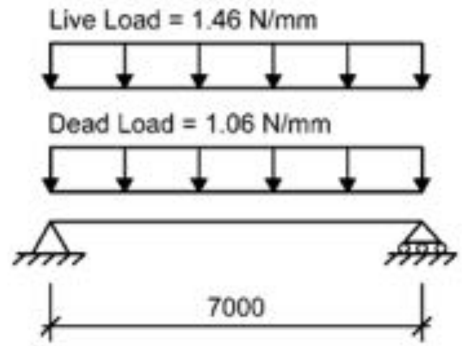
F_t = parallel to grain tension strength (unadjusted) = 7.24 MPa

F_b = bending strength (unadjusted) = 12.76 MPa

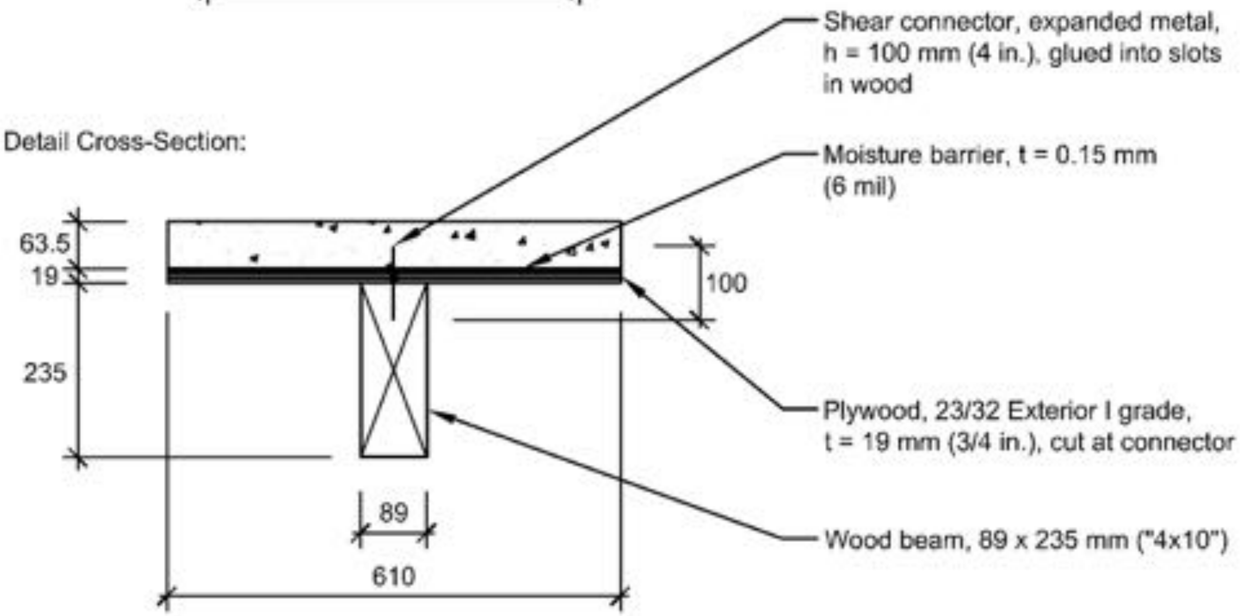
F_v = shear strength (unadjusted) = 1.21 MPa

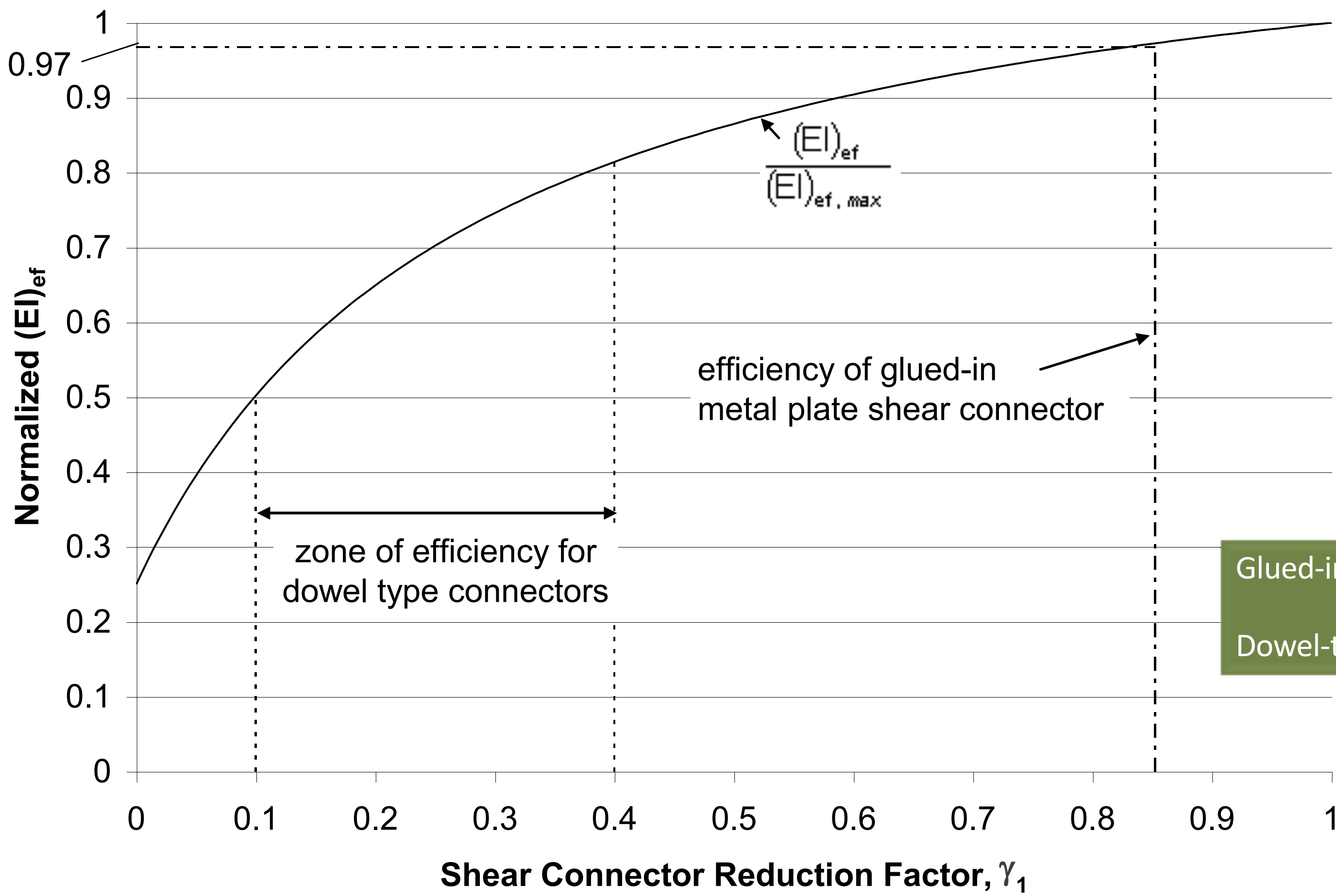
$$\gamma_1 = \frac{1}{1 + \frac{3.142^2 \cdot 23{,}000 \cdot (38{,}735)}{1039 \cdot (7000)^2}} = 0.85$$

System:



Detail Cross-Section:





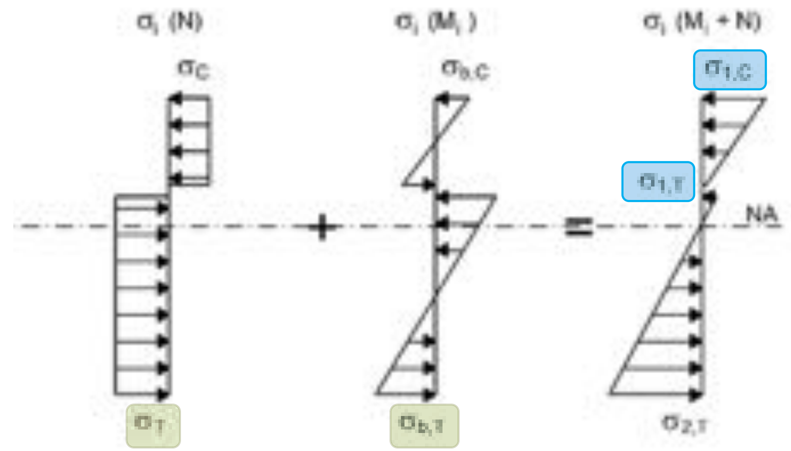
Glued-in plate → 97% composite action

Dowel-type → 50%-83% composite action

From: Clouston P, Schreyer, A. (2006). Wood-concrete composites: A structurally efficient material option. Civil engineering practice, 21(1), 5-22.

Design Example

✓ Strength check



Wood:

Tension and Bending:

$$\frac{\sigma_T}{F'_t} + \frac{\sigma_{b,T}}{F^*_b} = \frac{3.34}{7.24} + \frac{4.09}{16.07} = 0.72 \leq 1.0 \quad \rightarrow okay$$

Shear:

$f_v = 0.46\ MPa \leq F'_v = 1.21\ MPa \rightarrow okay$ {assuming wood carries all shear stress}

Concrete:

Compression:

$\sigma_{1,c} = 2.64\ MPa \leq F_c = 12.5\ MPa \rightarrow okay$

Tension:

$\sigma_{1,T} = 0.97\ MPa\ \ in\ \ compression \rightarrow okay$

Fastener:

Shear:

$q = 40.0\ \ N/mm \leq Q_a = 93.0\,N/mm \rightarrow okay$

Design Example

✓ Serviceability check

Live Load Deflection:

$$\Delta_{LL} = \frac{5wL^4}{384(EI)_{ef}} = \frac{5(1.46)(7000)^4}{384(6.66)(10)^{12}} = 6.8mm \leq 11.7mm = {}^{L}/_{600} \rightarrow okay$$

Dead Load Deflection:

$$\Delta_{DL} = \frac{5wL^4}{384(EI)_{ef}} = \frac{5(1.06)(7000)^4}{384(4.16)(10)^{12}} = 8.0mm$$

{assuming reduced E for long-term creep}

Total Load Deflection:

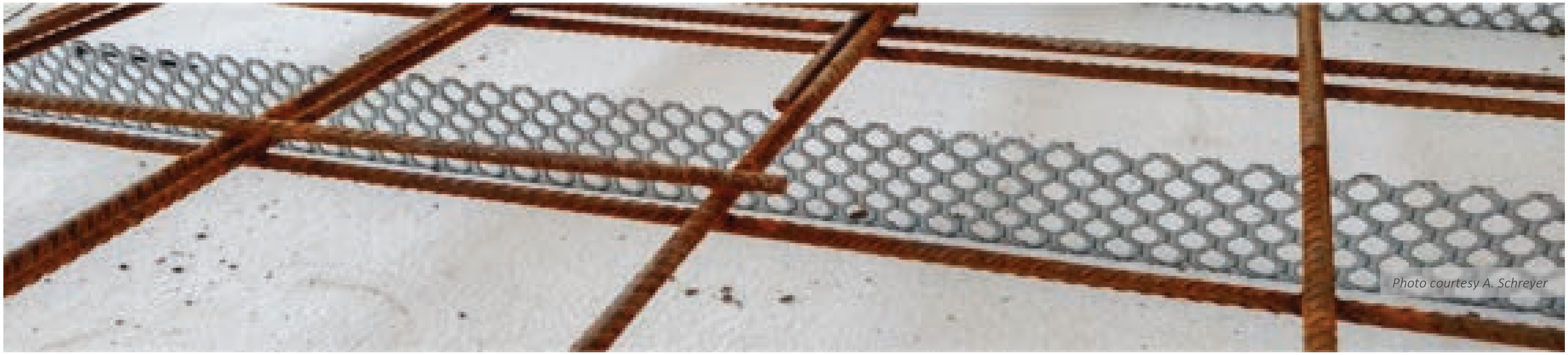
$$\Delta_{TL} = \Delta_{LL} + \Delta_{DL} = 6.8mm + 8mm = 14.8mm \leq 29mm = {}^{L}/_{240} \rightarrow okay$$

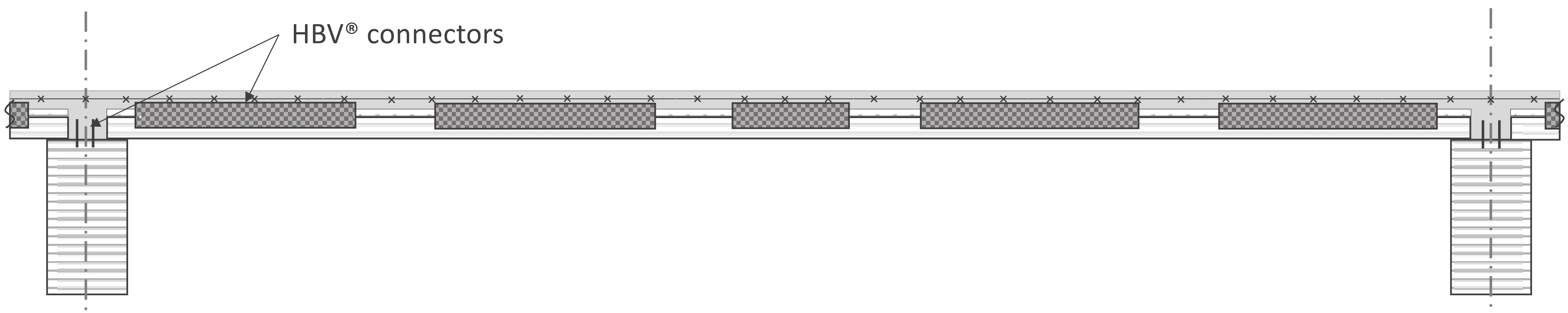
$\Delta_{TL} = 70mm$ (4.7 times as much) for *non-composite* section

Olver Design Building, UMass Amherst

the largest installation of wood-concrete composites in North America

Holz-Beton-Verbund (HBV®) System






Major axis
Minor axis
Photo courtesy A. Schreyer

Photo courtesy A. Schreyer


Photo courtesy: L. Bathon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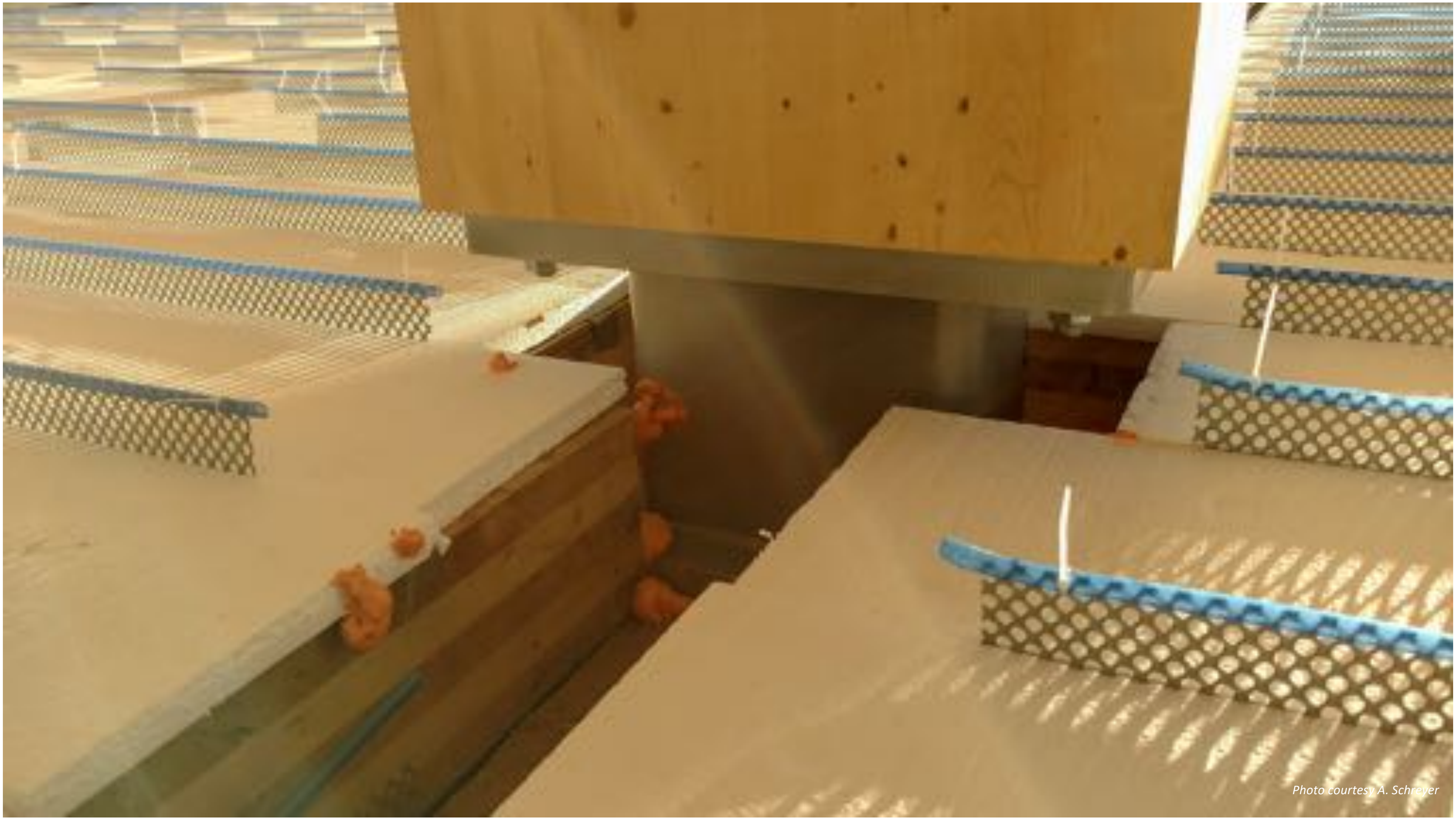
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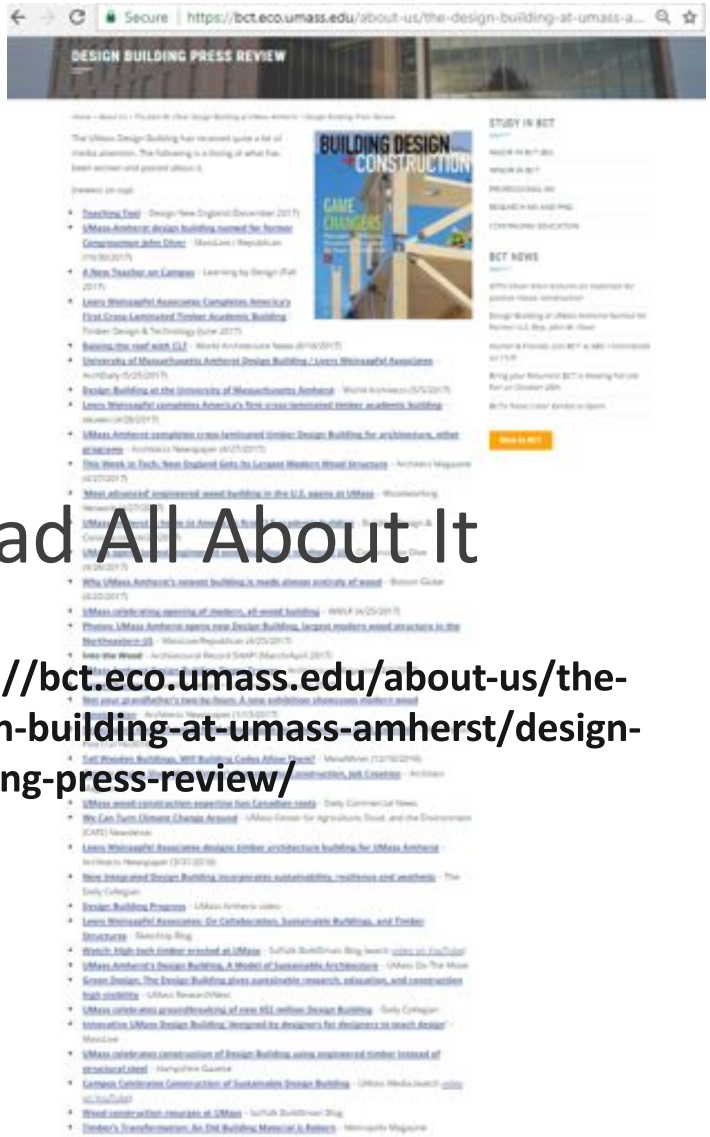
Key take-aways:

- Olver Design Building: a demonstration for wood building innovation
- TCCs are effective way to improve strength, stiffness, sound, and fire resistance of wood beams and floors
- TCC behavior is partially composite and dependent on the shear connector
- Adhesive connectors perform better than mechanical connectors
- Gamma method in use for TCC design

Photo courtesy Albert Vecerka/Esto



Read All About It

https://bct.eco.umass.edu/about-us/the-design-building-at-umass-amherst/design-building-press-review/

Thanks!

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QUESTIONS?

This concludes The American Institute of Architects Continuing Education Systems Course

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