

# Experience from timber based flooring systems at NTNU

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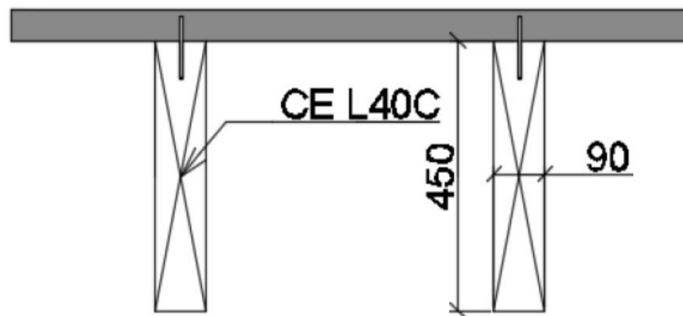
- 1) Summary on recent research on Timber-Concrete Composites (TCC) at NTNU
- 2) Summary on projects on TCC and TSC at the World Conference in Timber Engineering 2016
- 3) EN 1995-3 Structural design of timber concrete composite structures
- 4) Our concerns for development of TCC
- 5) Current research and testing on flooring systems at NTNU (Woodsol)
- 6) Guidelines for further work on flooring systems at NTNU

## Recent research on TCC at NTNU

Three full-scale tests of floors with structural shear connection between timber and concrete since 2013:

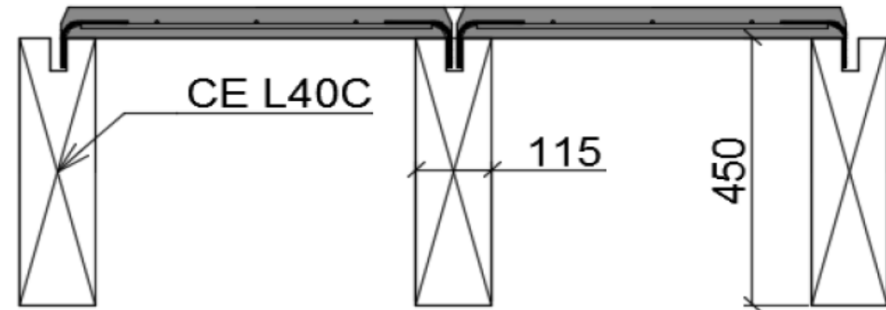
- Precast fiber-reinforced elements of concrete with glued shear connectors
- Iterations: Improved shear connection and reduced size of precast parts

Vibrations in Composite Timber-Concrete Floor Systems  
(Skaare et al., 2013)



Wood-Concrete Composite Floor  
(Frihetsli et al., 2015)

Short-term loads



Timber composite floor  
(Åby et al., 2016)

Long-term loads

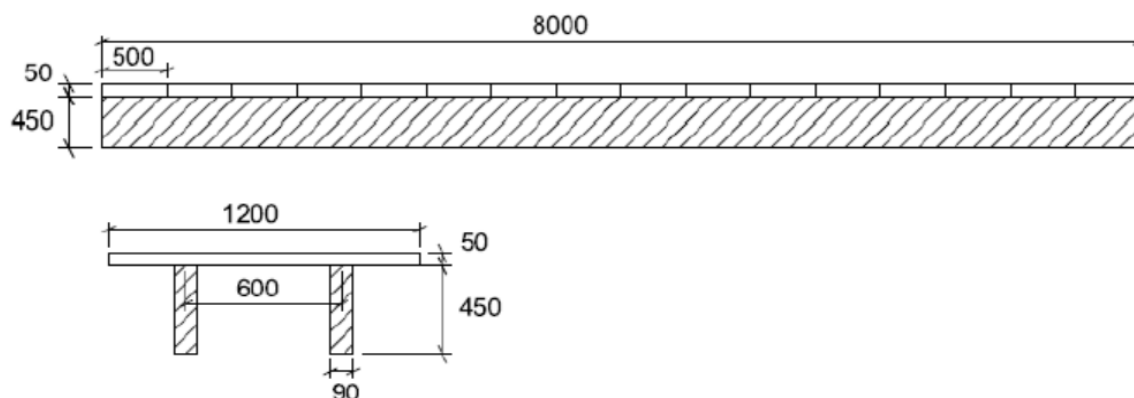
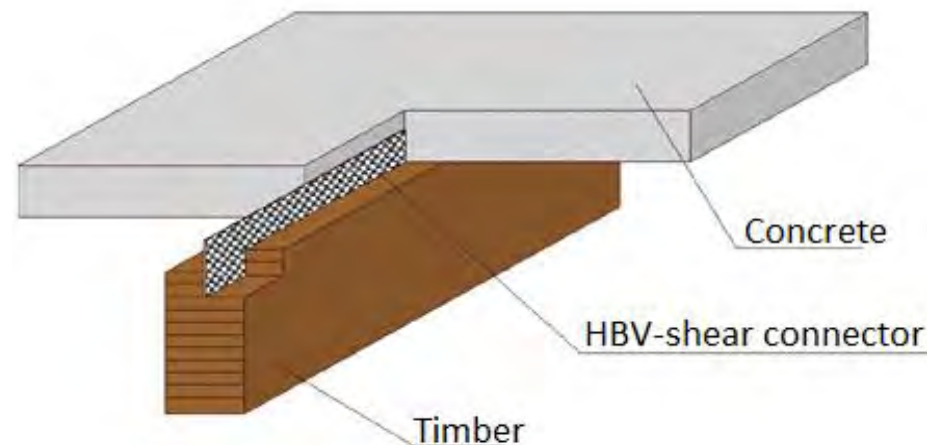
SKAARE, M. K., MALO, K. A. & KANSTAD, T. 2013. *Vibrations in Composite Timber-Concrete Floor Systems*. MSc, NTNU.

FRIHETSLI, O., ALM, O. & MALO, K. A. 2015. *Wood-Concrete Composite Floor*. NTNU.

ÅBY, K. A., HARTNES, M. & MALO, K. A. 2016. *Timber composite floor*. NTNU.

## Vibrations in Composite TC Floor Systems (Skaare et al., 2013)

- Dimensioning based on Eurokode 5 – Annex B
- Mechanically joint beams, and serviceability criterion by Hu & Chui ( $w < (\frac{f}{18.7})^{2.27} mm$ )
- Expanded metal (length 500 mm) grouted in elements of fibre-reinforced concrete
- Glued with epoxy (Mapepoxy L) in slits in glulam beams
- Full-scale ND-testing + test of shear connection
- Quantification of dynamic properties to compare with analytical/numerical model



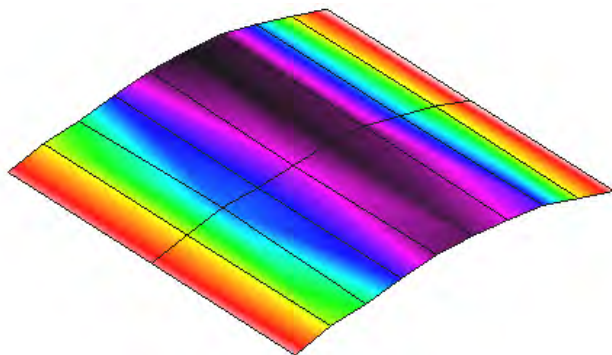
## Results 1/2 (Skaare et al., 2013)

### Test of shear connection:

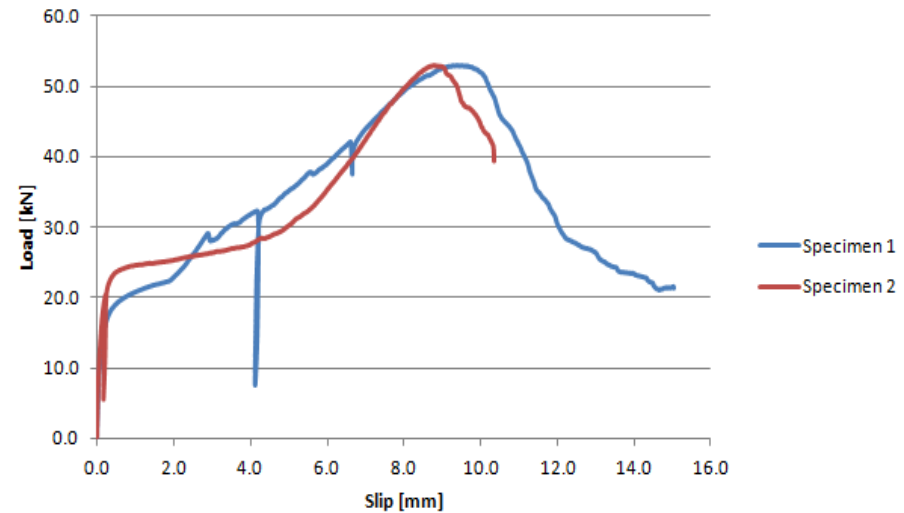
- Maximum stiffness:  $K = 216 \text{ kN/mm}$
- Both weaker and more ductile than comparable connections
- Incomplete grouting caused collaps and shear feailure in steel grid

### Test of natural frequencies:

- $f = 12 \text{ Hz}$ . Above critical range for vibrations according to Eurokode 5
- ABAQUS produce results in good correspondance to measurements



Mode 1 – 12.0Hz



## Results 2/2 (Skaare et al., 2013)

### Test of deflection:

- Deflection at 1 kN
- Three separate load conditions
- Effective bending stiffness (EI) and degree of composite action ( $\eta = \frac{EI_{real} - EI_0}{EI_{\infty} - E_0}$ )

#### Testing:

$$\eta = 61\%$$

$$EI_{eff} = 2,22e13 \text{ Nmm}^2$$

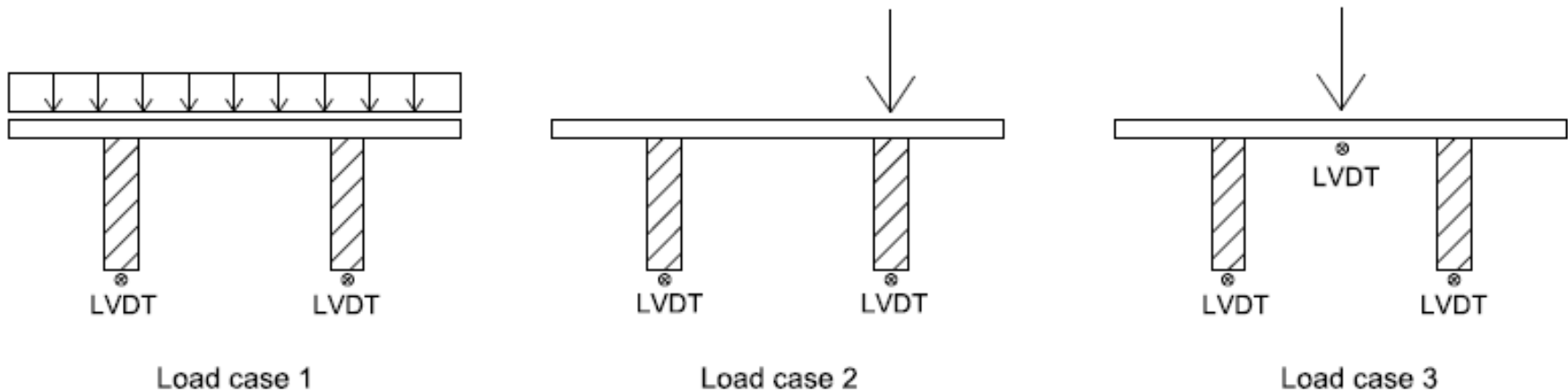
#### Analytical:

$$\text{EC5, tillegg B: } \eta = 80\%$$

$$EI_{eff} = 2,63e13 \text{ Nmm}^2$$

### Key findings:

- Degree of composite action lower than estimated by EC5
- Stiffness from shear testing overestimated
- Nonconformity in E-moduus
- ABAQUS produces a stiffer model





## Conclusions (Skaare et al., 2013)

- Satisfies criteria for dynamic response
- Degree of composite action weaker than expected
- Easily mounted
- Qualified procedure for grouting required



## Wood-Concrete Composite Floor (Frihetsli et al., 2015)

### General

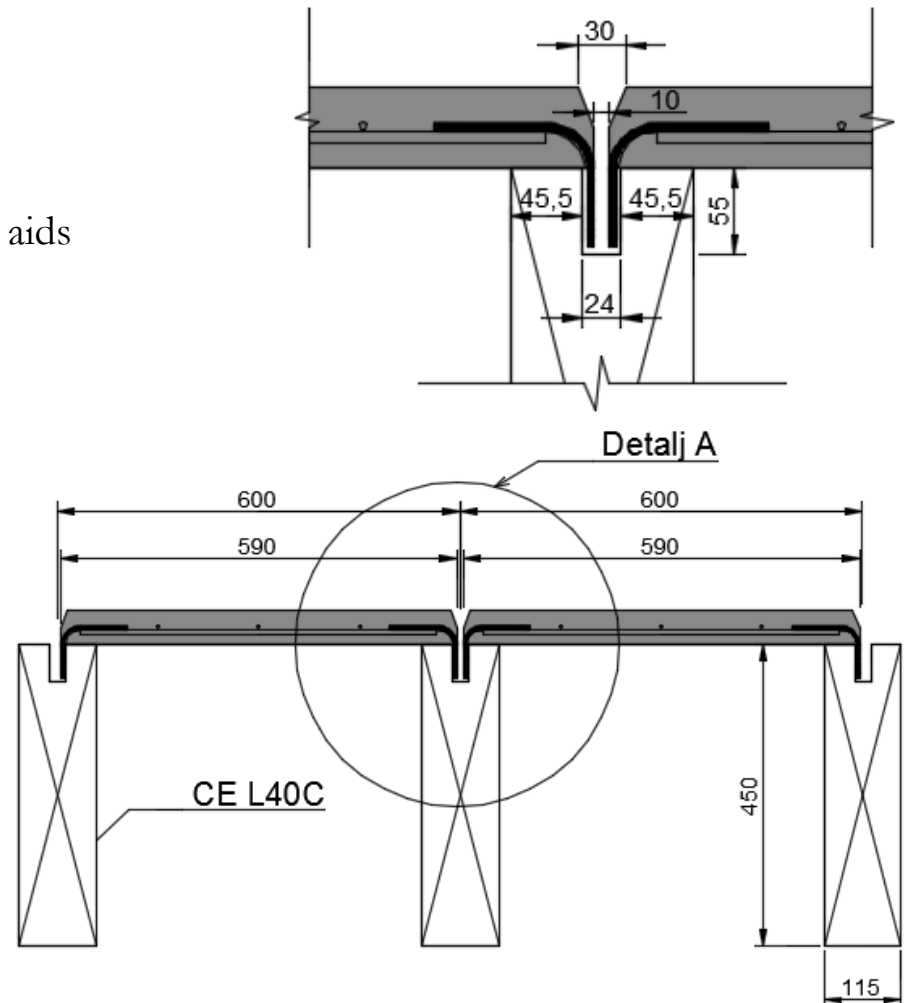
- Further development based on Skaare (2013)
- Focus on a rational and practical system
- Smaller precast components not requiring lifting aids
- Shear connection based on glued-in steel grid

### Experimental testing

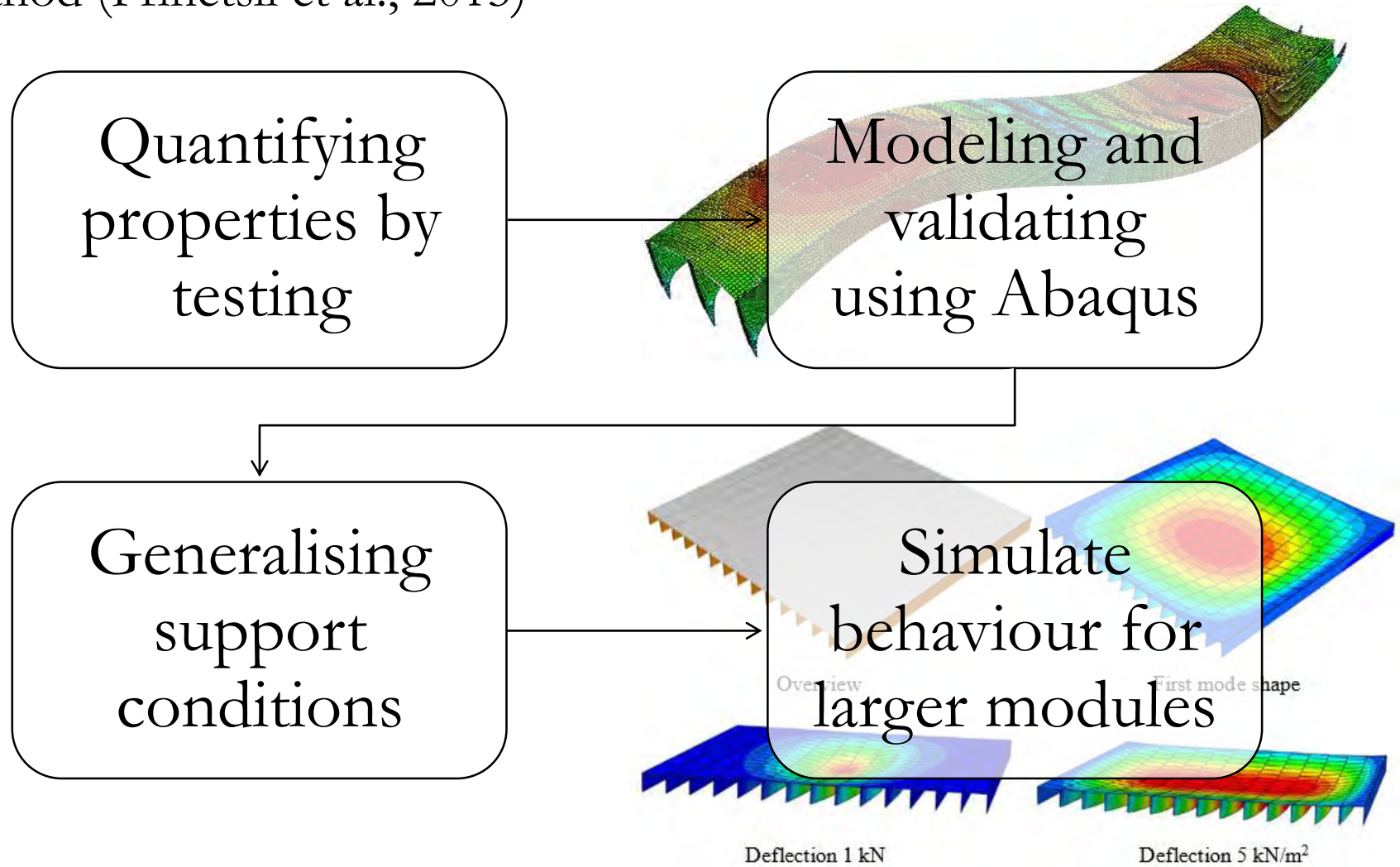
- Ultimate load test of previous model
- Testing of new model (to produce data for numerical analyses)
  - a) Shear test
  - b) Deflection test
  - c) Dynamic test

### Numerical analyses in Abaqus

- Virtual extension to larger flooring systems



Method (Frihetsli et al., 2015)





## Results (Frihetsli et al., 2015)

### Deflection 5 kN/m<sup>2</sup>

Module size	Eurocode (L/350)	Numerical magnitude
8 x 12 m	22,85 mm	5,54 mm
10 x 12 m	28,57 mm	11,95 mm

Floor Nr.	Lenght x width [m]	Frequency, $f_1$ [Hz]	$w_{max}, P = 1 \text{ kN}$ [mm]	$w_{1kN} = \left(\frac{f_1}{18,7}\right)^{2,27}$ [mm]	$\frac{w_{max}}{w_{1kN}} < 1$
U1	8 x 12	13,8	0,091	0,505	0,18
U2	8 x 10,2	13,9	0,096	0,514	0,19
U3	8 x 8,4	14,2	0,093	0,532	0,17
U4	8 x 6	14,7	0,095	0,576	0,16
U5	8 x 4,2	15,7	0,107	0,672	0,16
U6	10 x 12	9,5	0,129	0,217	0,60

## Timber composite floor (Åby et al., 2016)

### General

- Further development based on Frihetsli & Alm (2015)
- Assessing TCC with respect to four alternative timber based floor elements motivated by:

Reducing greenhouse gases

Width 2 m

Height < 0,5 m

3 joists

Span 9 m

Frequency > 12 Hz

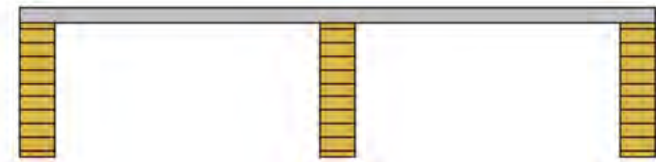
### Long-term test of previous model (9 months)

- Deflection test
- Dynamic test
- Ultimate limit (failure) test

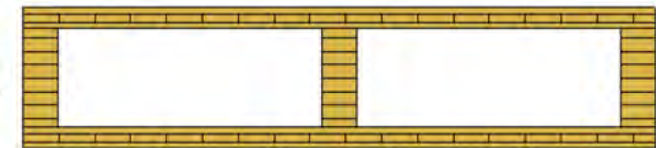
### Numerical analyses

- Modeling and simulation of five floors in Abaqus
- Efficient width; shear rigidity; deflection between joists

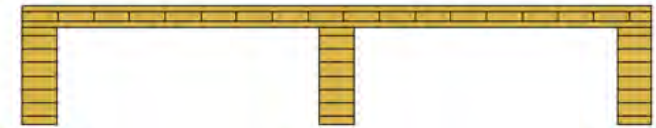
B+L



DM+L



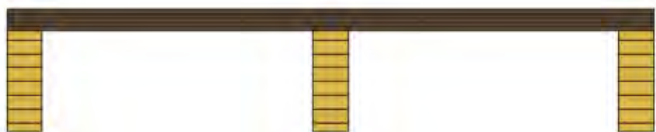
M+L



DK+L

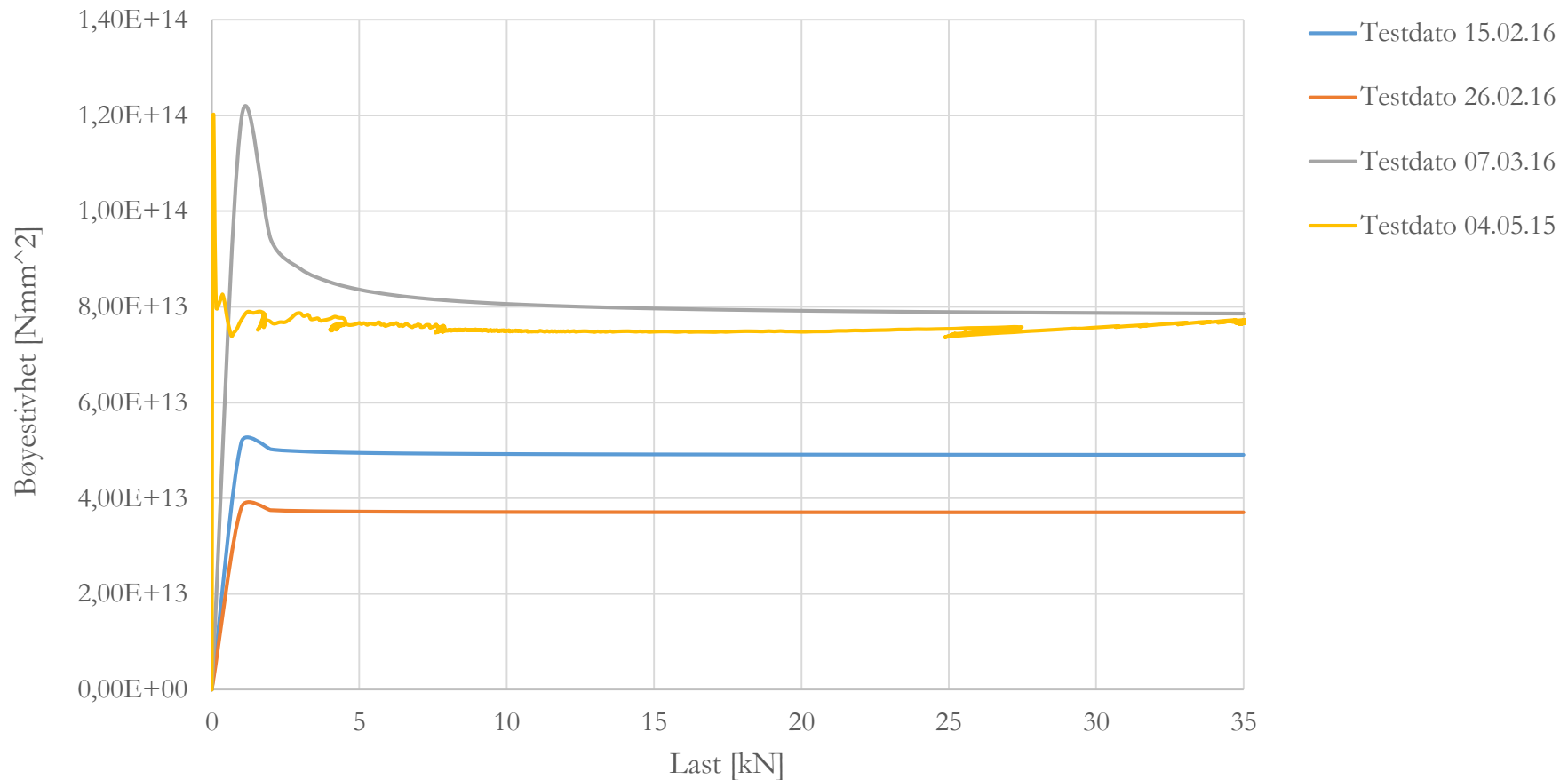


K+L



## Resultats from testing (Åby & Hartnes)

### Deflection test (Bending stiffness trials)

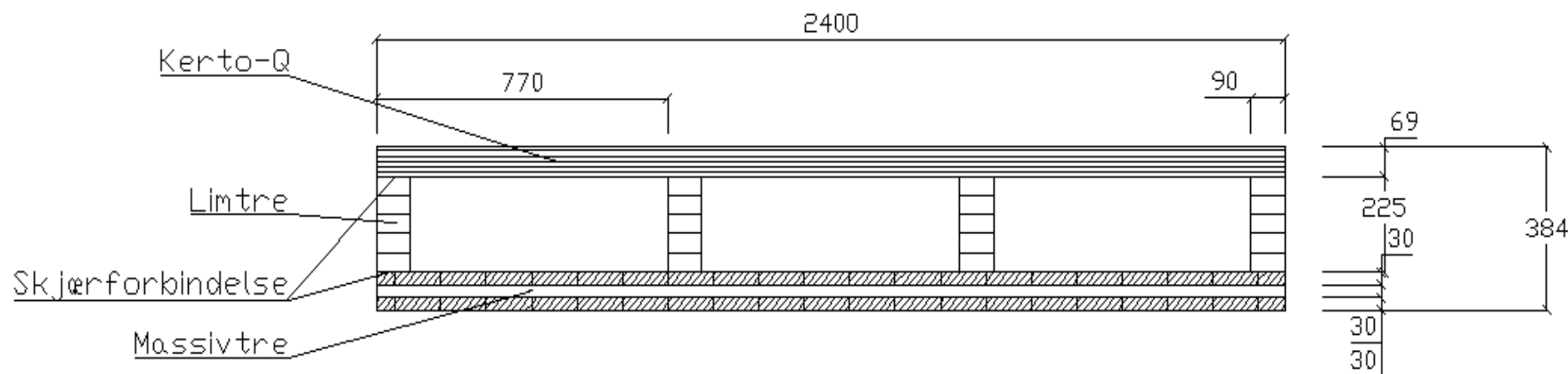


## Weighted comparison of properties (Åby & Hartnes)

	Weight [%]	DK+L	K+L	B+L	M+L	DM+L
Serviceability performance	50 %	5	2	3	1	4
Environmental performance	30 %	1	3	2	5	4
Material expenditures	15 %	1	3	5	4	2
Manufacturing operations	5 %	4	5	4	5	4
Sum	100 %	3,15	2,6	3,05	2,85	3,7

### Decided solution (modell 3 - KM+L)

Pre-fabricated component based solution; glued shear connection; fire resistance R90



## Results 1/2 (Åby & Hartnes)

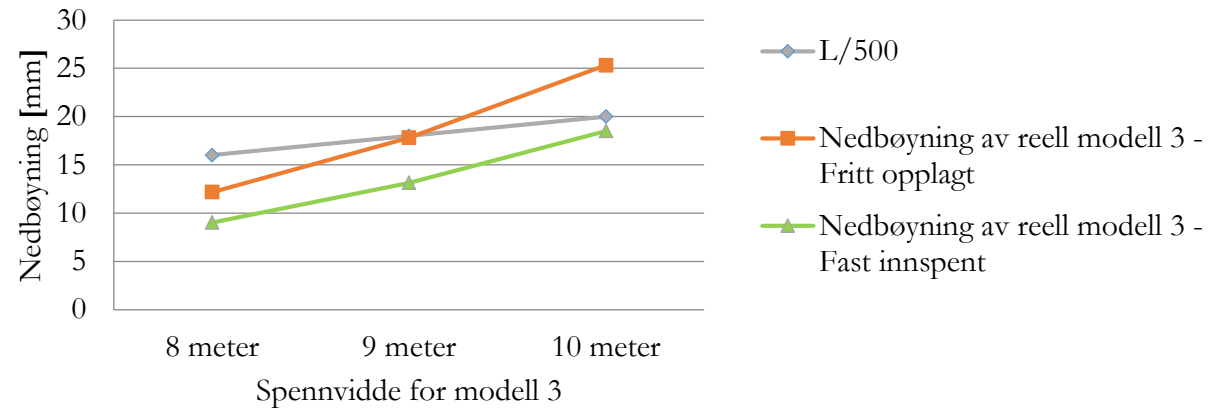
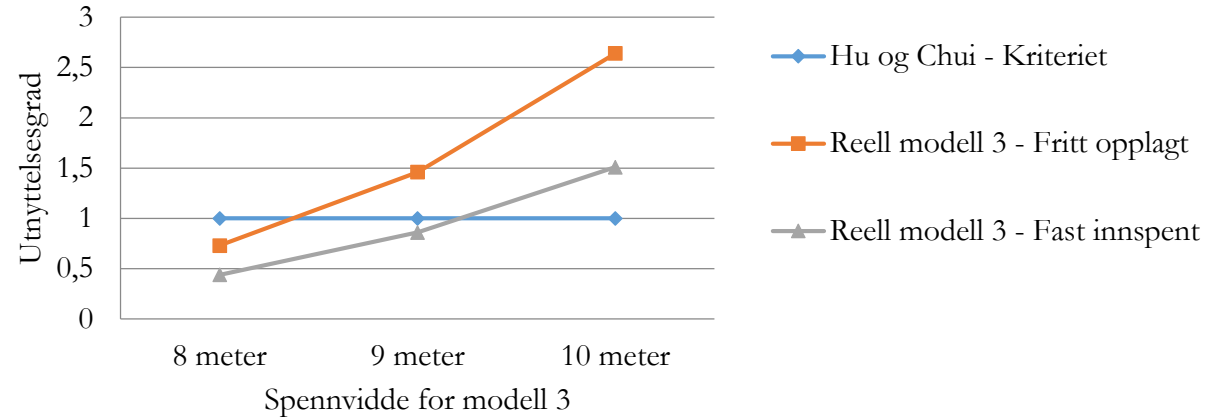
(Hu and Chui, 2004)

Serviceability criterion:

$$\frac{w_{1kN}}{\left(\frac{f_1}{18,7}\right)^{2,27}} < 1,0$$

Deflection 5 kN/m<sup>2</sup>:

Eurokode 5:  $W_{inst} < L/500$



HU, L. J. & CHUI, Y. H. 2004. Development of a design method to control vibrations induced by normal walking action in wood-based floors. *Proceedings of the 8th World Conference on Timber Engineering*. Lahti, Finland.



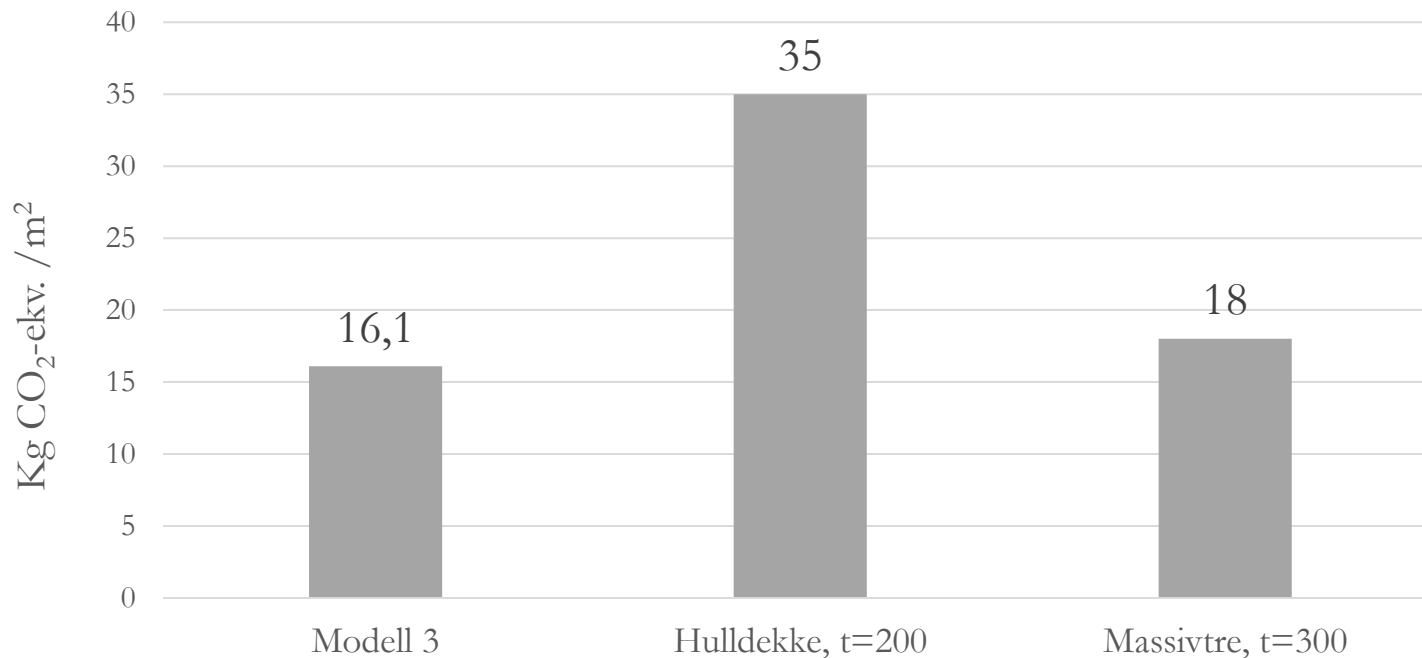
## Results 2/2 (Åby & Hartnes)

### Greenhouse gas emissions

- Selected solution (model 3)
- Hollowcore 200 mm
- CLT 300 mm

### Estimated expenditures

- Model 3 - 1384 kr/m<sup>2</sup>
- Hollowcore - 904 kr/m<sup>2</sup>



## Development of prefabricated timber-steel-concrete ribbed decks 1/2

Timber-steel hybrid beams (W. Winter, K. Tavoussi, A. Fadai, University of Vienna)

- Objective: Optimised web spacing due to research on effective flange width from the joint capacities of steel, timber and concrete slab
- No shear connection between timber and steel
- Cold formed steel profile to minimize  $\text{kg CO}_2 \text{ eq} / \text{m}^2$



## Further development of TSC ribbed decks 2/2

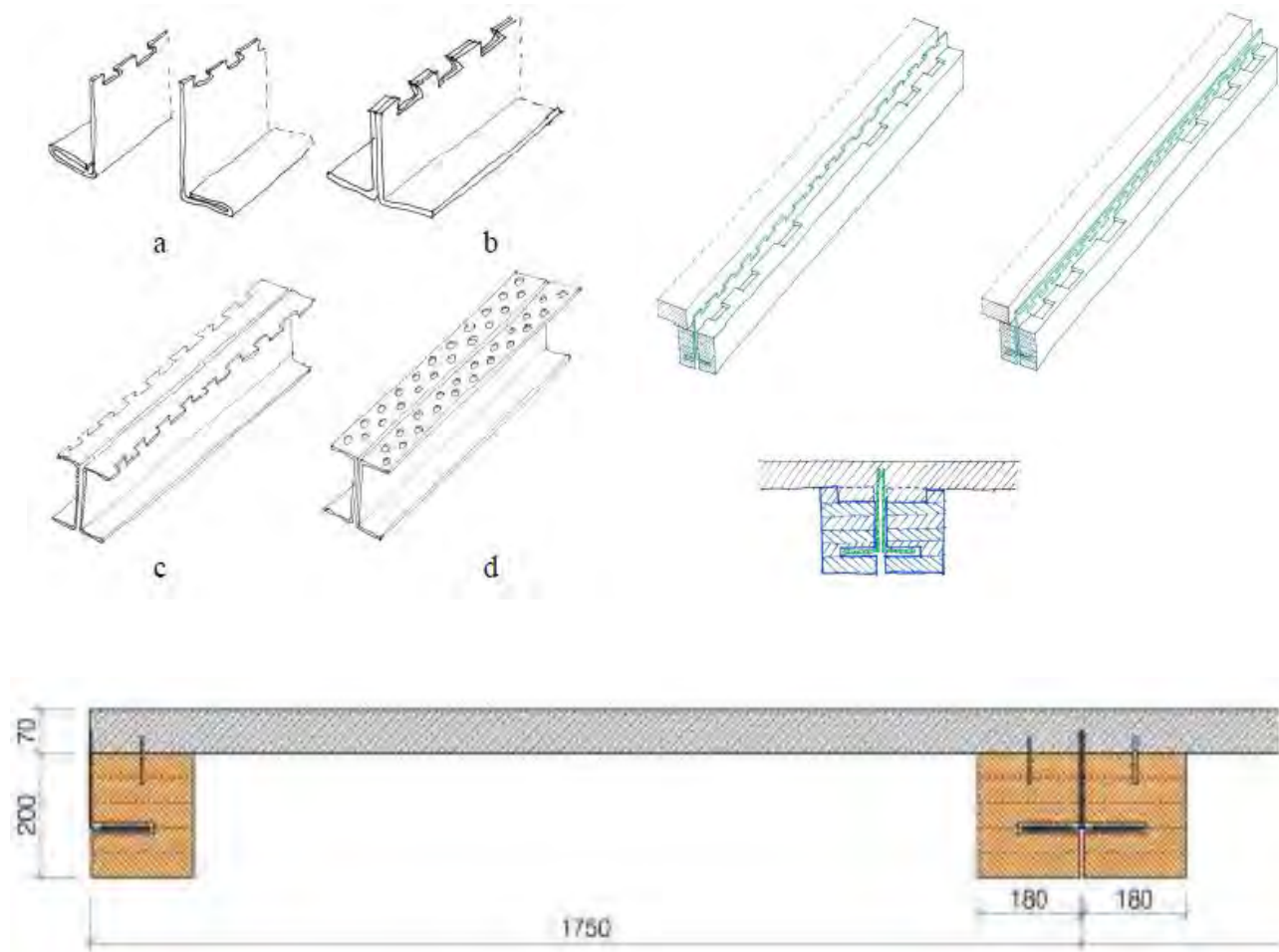
Various proposals  
on shear connection  
between steel and  
concrete



Parametric model  
used to estimate the  
efficient flange width



Finally solving the  
equation to optimise  
the hybrid flooring  
layout



## Timber Concrete Composite (TCC)

Several studies on various TCC shear connectors:

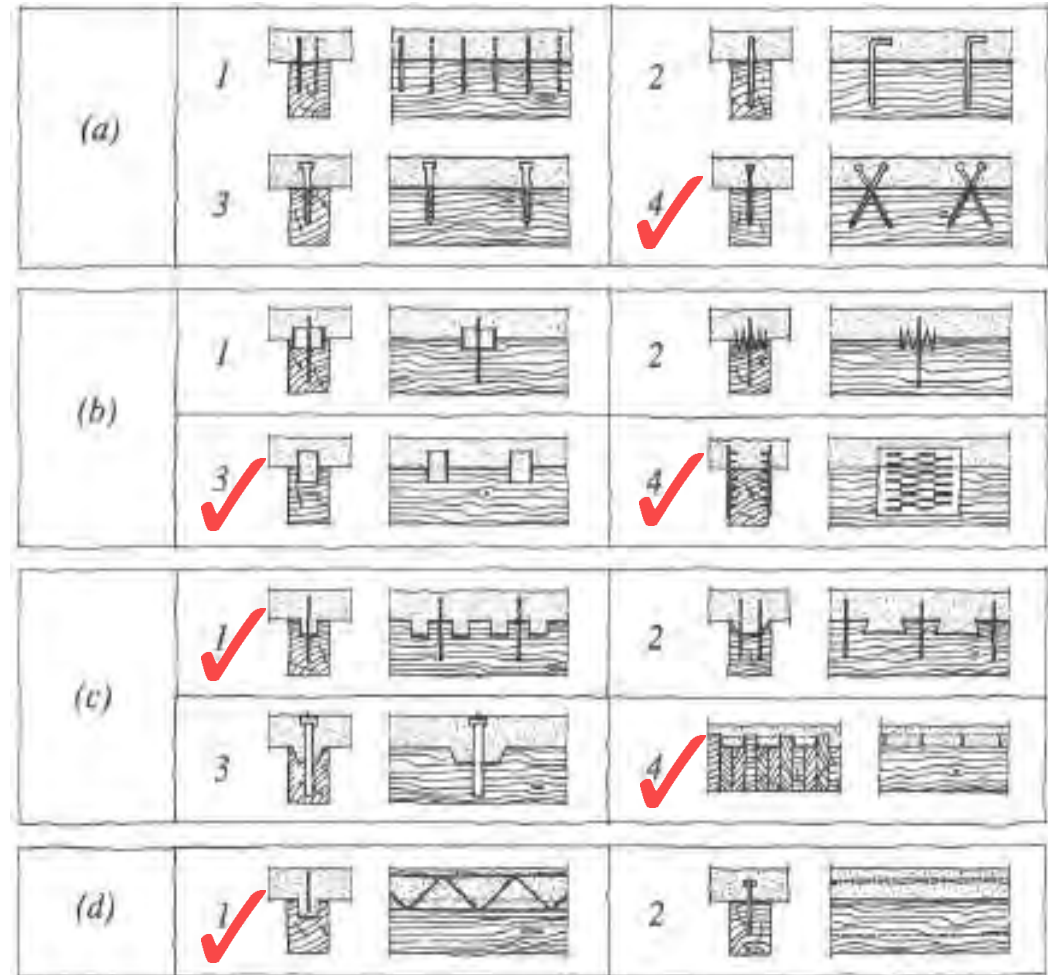
- Type of connector
- Methods of tuning density and distribution of connectors
- Efficient width of flange is essential
- Majority of studies on capacities of shear connections deployed in wet concrete (among others ARUP for commercial intents)

University of Kassel (Werner Seim): Long term behaviour (24 mnds) of adhesive-bonded timber-concrete taking into account time-effects such as:

- Residual stresses in bonding zone,
- deflections caused by moisture fluctuations,
- creep effects

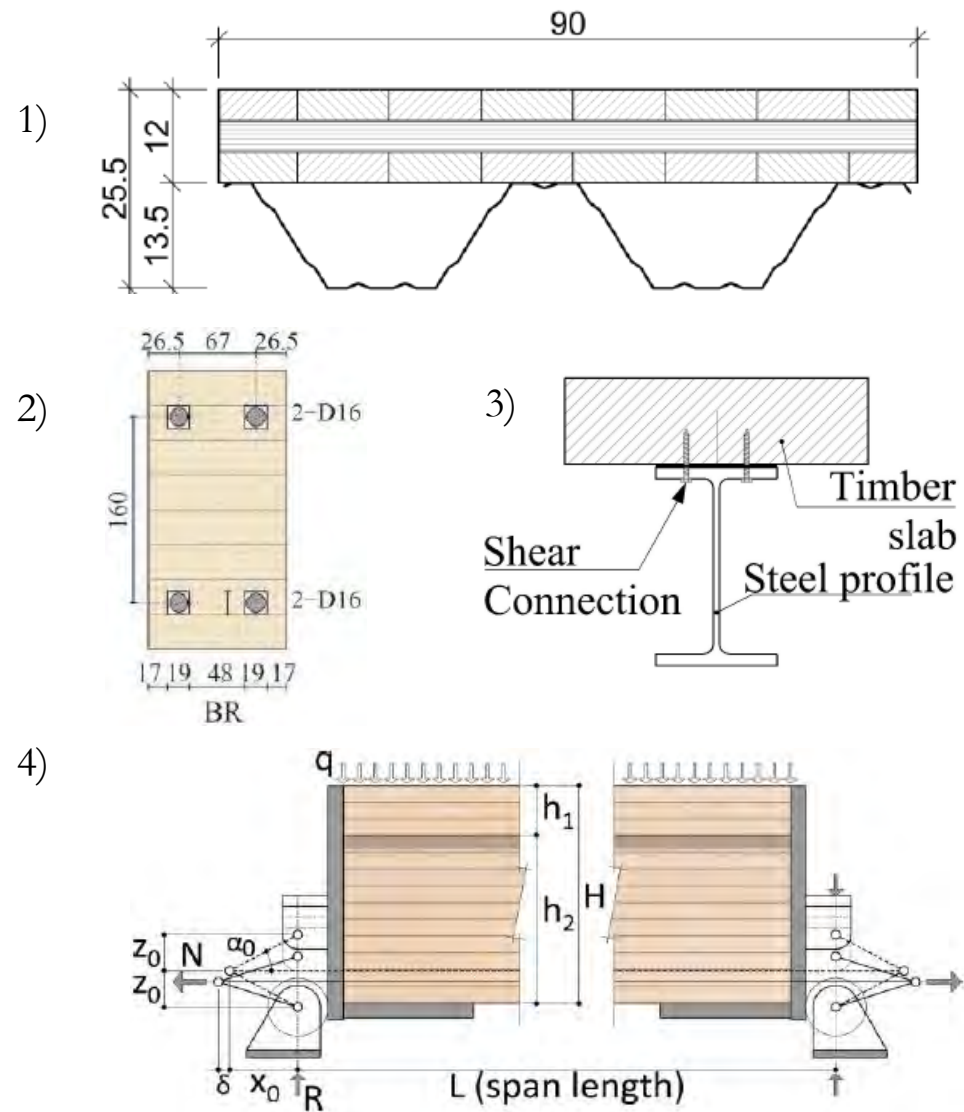
Studies also on non-bonded concrete topping (NUI Galway) + tuning of eigen frequencies of floors

Insufficient knowledge concerning durability of epoxy adhesives



## Timber Steel Composite (TSC)

- 1) Hybrid TSC-floor: Trapezoidal cross section steel profiles on CLT floors (S. E. Zimmer et al.)
- 2) Long term behaviour of steel tendon stiffened timber beams (K. Uchimura et al., Kagoshima University): Found to increase flexural creep coefficient from 1.72 to 1.27.
- 3) TSC system for large scale constructions (A. Hassanieh et al., University of New South Wales)
- 4) Active systems: Self-tensioning beams (J. Estévez-Cimadevila, et al., Universidade da Coruña)





# NS-EN 1995-3

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NS-EN 1995-3 Design of timber structures - Part 1-3: Structural design of timber concrete composite structures

Draft technical report 2017-05-03

CEN/TC 250/SC 5/WG 2 Timber concrete composites

Chairperson: Prof.-Dr.-Ing. Stefan Winter

Secretary: Mrs Annika Stenmark

Key personnel:

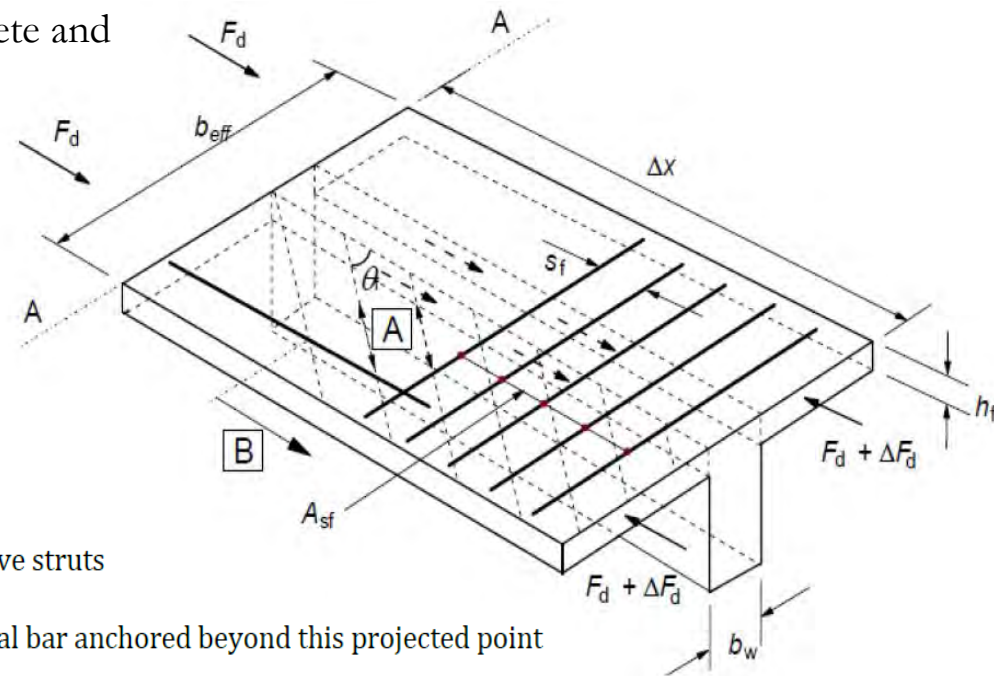
Alfredo Dias, Massimo Fragiaco, Richard Harris, Petr Kuklík, Vlatka Rajčić, Jörg Schänzlin

## Scope and validity

- Provides requirements for materials, design parameters, connections, detailing and execution to be used for timber-concrete composite structures.
- Annexes cover recommendations for design methods, environmental parameters (temperature and moisture content) and shrinkage
- Excludes glued timber-concrete composites and design of bridges

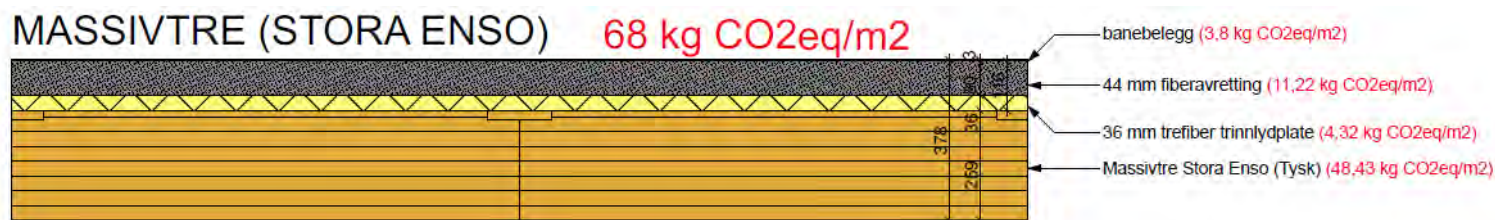
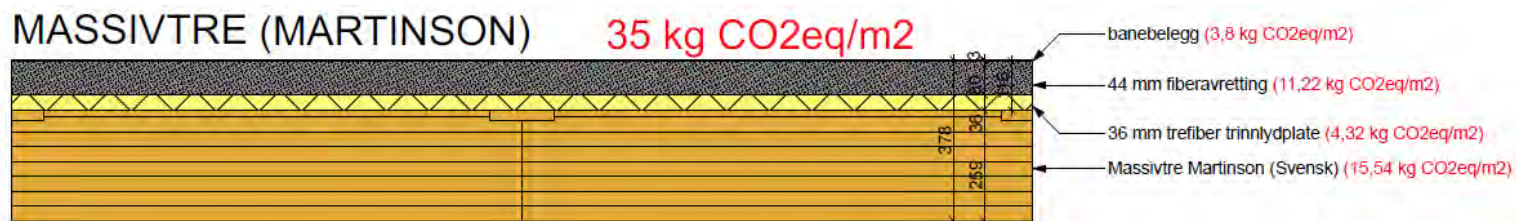
## Basis of design

- Strains due to temperature variations in concrete and timber, moisture content variations in timber, and concrete shrinkage determined as part of internal forces and the deflection.
- Solely based on reinforced concrete
- Plasticity of the connection may be used in the design.
- Capacity of notches described

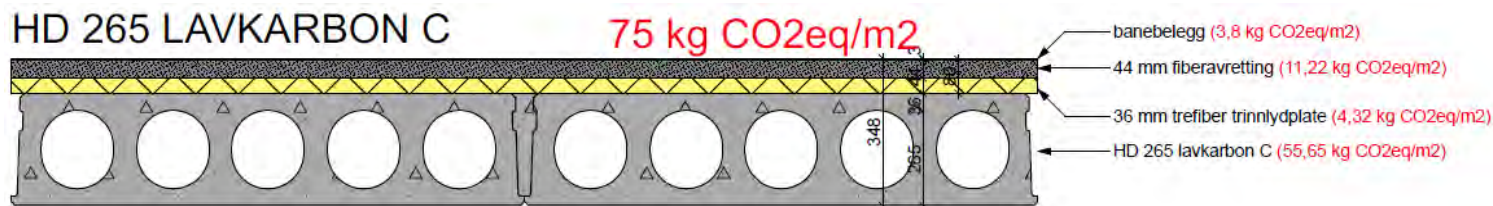


## Concerns: Steel reinforcement squeezing the margins

Insufficient research on long-term effects on the TCC composite action. However, research has produced sufficient documentation for the draft standard allowing easier engineering of TCC-floors, but the same research presuppose reinforcements that reduces environmental performances and competitiveness:



Reinforcement (K131) respectively of 2.10 and 3.15 kg/m<sup>2</sup> produces: 5.5 and 8.3 kg CO<sub>2</sub>eq/m<sup>2</sup>



Source: Dekkekalkulator (Bård Solem)

## Conceptual study of wooden composite floors with possibility of rigid attachment to glulam column (Bjørge & Kristoffersen, 2017)

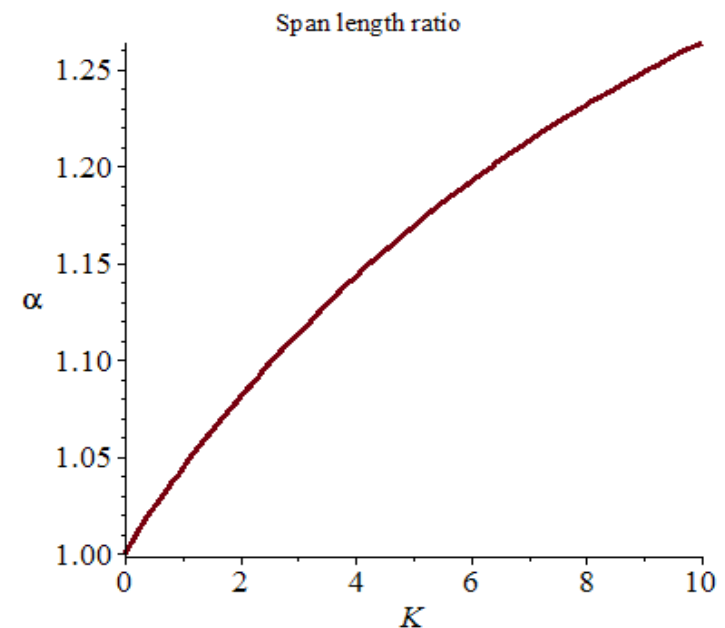
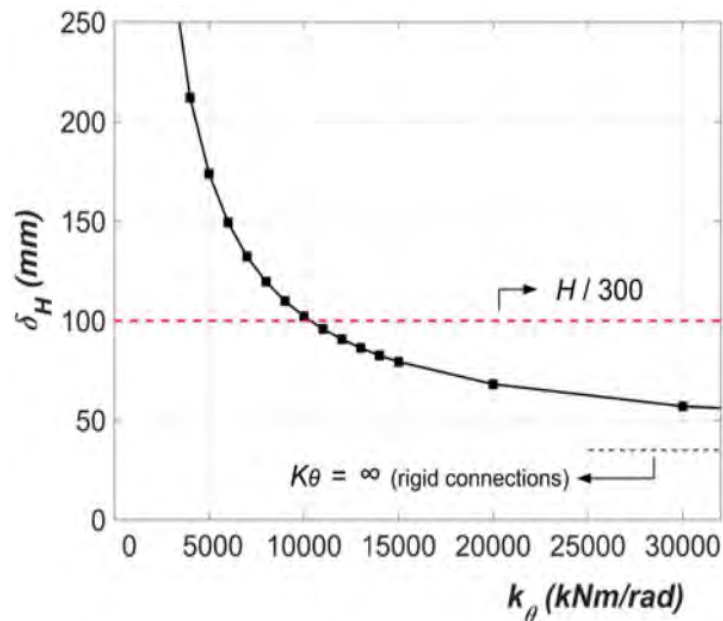
- Developing a competitive and rational module based flooring system capable of spanning 10 m
- Based on studies of commercially available system (Trä8(Moelven)/LVL rib-slab (Stora Enso)/Kerto-Ropa (Metsä Wood)/Lignatur), in addition to further development of work by Åby & Hartnes (2016)
- Floor element as structural component in the Woodsol building system



BJØRGE, H. & KRISTOFFERSEN, T. 2017. *Conceptual study of wooden composite floors with possibility of rigid attachment to glulam column*. NTNU.

## Woodsol building system

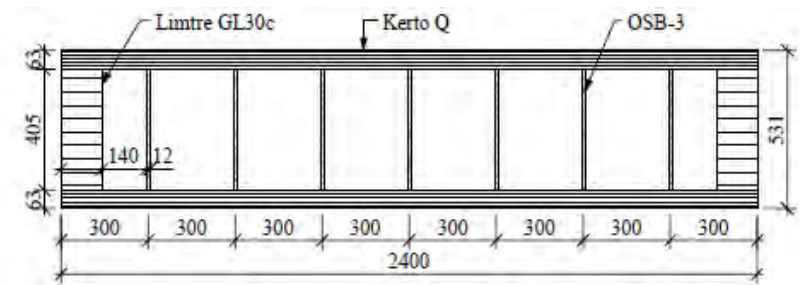
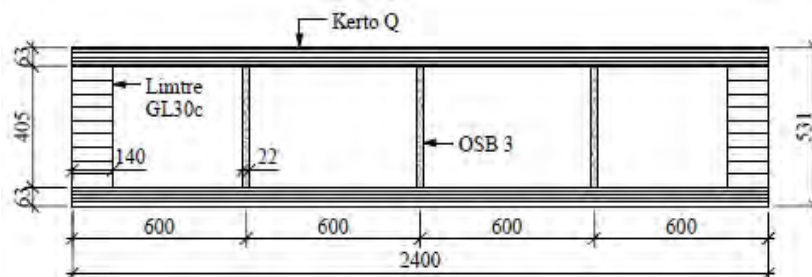
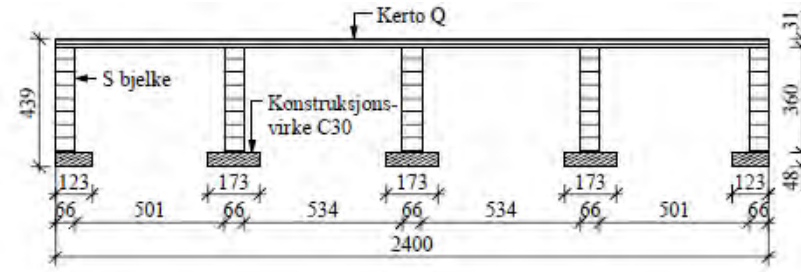
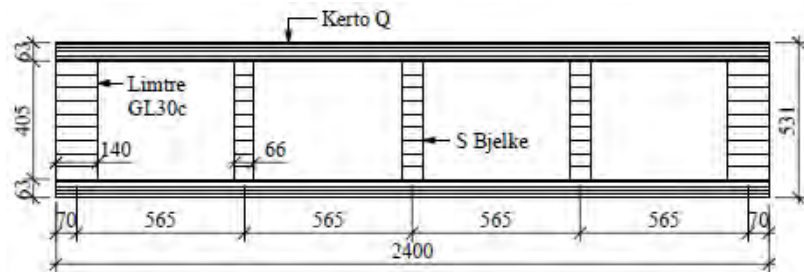
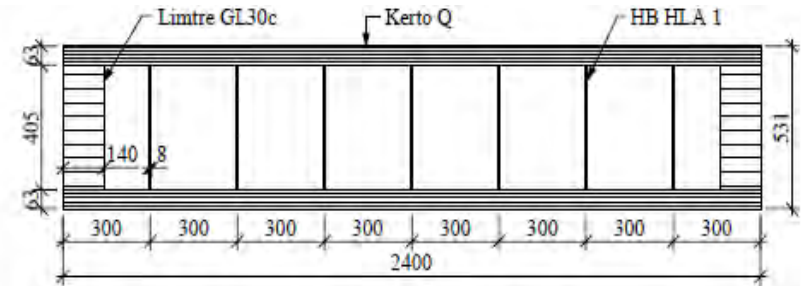
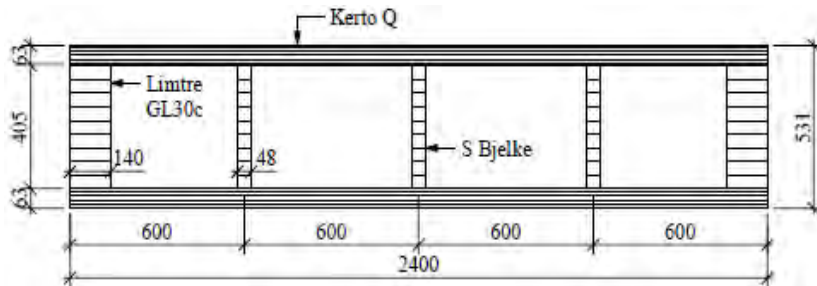
- Stability dependent on moment resisting frames consisting of columns and floor embedded beams
- Floor element an inherent structural component
- Deflection and frequency is sensitive to end restraint (Malo & Stamatopoulos, 2016)
- By end restraining (contentedly 7.5 MNm/rad), the span can be longer (relative to simply supported)



Malo, K.A. and H. Stamatopoulos. *Connections with threaded rods in moment resisting frames*. in *WCTE 2016 - World Conference on Timber Engineering*. 2016.



## Cross sections subject to analytical and numerical assessment



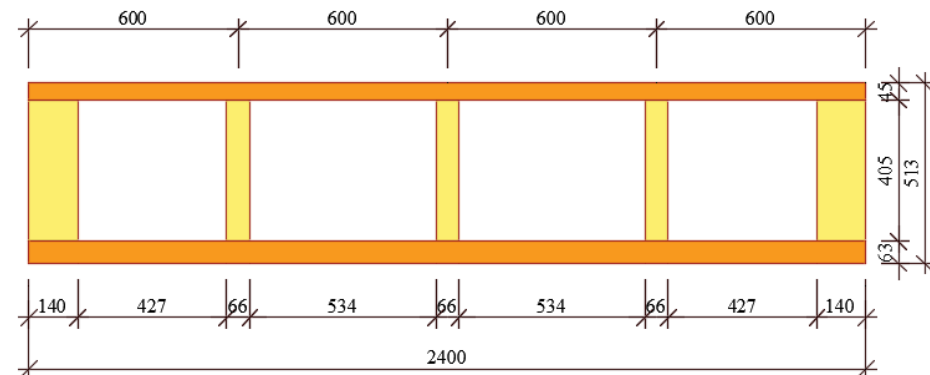
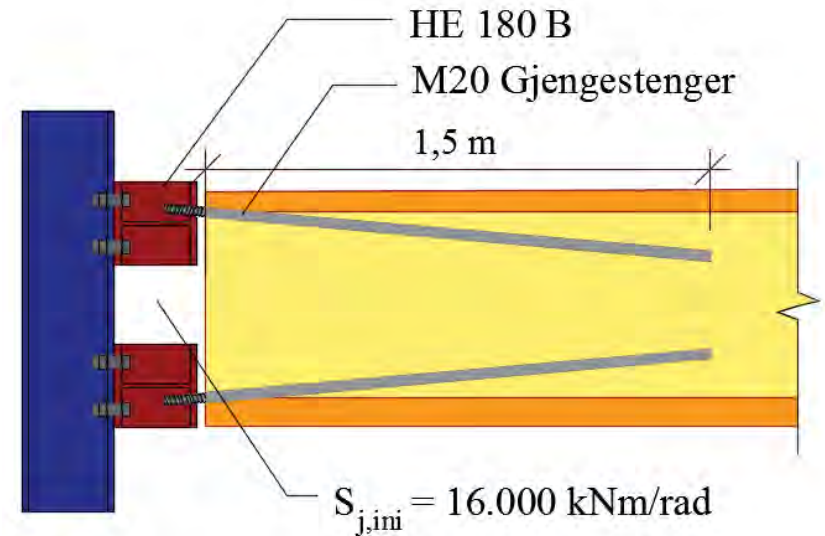
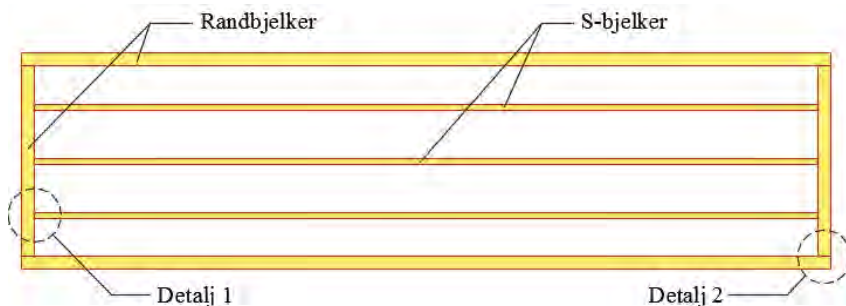
## Final floor element

### Particulars

- Width x span: 2.4 x 9 m
- Top and bottom flange in Kerto-Q (45 and 63 mm)
- Edge beams: 140 x 405 mm GL 30 c
- Web (joists): S-beam 66 x 405

### Tests

- Three different support conditions
- Deflection: Loading on point and line
- Natural frequency and deflection modes (Rowing hammer)
- Structural response from footfall loading



## Images of support conditions





## Results

### General

- Deflection less dependent of end restraints than expected
- Highest accuracy when simply supported: Increasing deviation between modelled and measured properties as end restraining is increasing
- Possible causes of error:
  - Vibration transfered to laboratory steel columns
  - Modelling inaccuracy and transverse stiffness
  - End restraining: Several links in series

### Serviceability performance

- Including modelled additional dead load consisting of: 50mm cast + 200 mm mineral wool + surface product: Total self-weight: 230 kg/m<sup>2</sup>
- Maximum deflection at 5kN/m<sup>2</sup>:  $\delta$  11.9 mm corresponding to L/756
- First natural frequency: 9.67 Hz
- Serviceability requirements satisfied for deflection and natural frequency.



# Guidelines for further work at NTNU

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TCC is more or less straight forward: New standard soon to be published

Time-dependent behaviour of concrete (creep and shrinkage) is requiring reinforcement which is causing environmental performance to decrease

Wet casting on timber is unfortunate and time-dependent behaviour the first 12-24 mnds must be taken into account

Alternative with storing precast for creep release is costly.

Glued shear connection currently not covered by draft standard

Concrete is part of the solution, but is not necessarily dependent on its structural performances

Integral cast and concrete as sole mass has advantages for serviceability and acoustic properties

Burnt blue clay as additives in concrete (current research at SINTEF/NTNU) gives promising prospects to integral casts with low greenhouse gas emissions

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