WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

PRACTICAL DESIGN CONSIDERATIONS FOR TCC-ELEMENTS WITH CLT-SLABS

Thomas Moosbrugger[1], Harald Krenn[2]

ABSTRACT: The timber-concrete composite (TCC) construction method is looking back to a long period of use in construction and with the availability of planar elements like cross-laminated timber (CLT), also flat TCC-elements are being used increasingly in construction practice. These TCC-elements may be designed according to CEN/TS 19103:2021 [1] or other provisions [7] when notches are used to transfer the shear forces between the two parts of the composite element. One of the most debated and controversial issues regarding this design method is the uplift force acting in the notched connection. This paper attempts to evaluate the uplift force acting in real design situations.

KEYWORDS: timber-concrete composite (TCC), cross-laminated timber (CLT), composite, design, notch

1 – INTRODUCTION

Timber-Concrete-Composite (TCC) construction has been used extensively over the last 100 years, with the focus in the past being on the connection of concrete with linear timber elements. Much more recently, flat cross-laminated timber (CLT) has been combined with concrete. For both applications, the design has not been previously regulated and therefore a variety of design methods have been used. While the composite joints for notched connections have largely been calculated using engineering methods, national or European product assessments have been available for various types of joints using mechanical fasteners.

With the introduction of CEN/TS 19103 [1] in 2021, a possible verification method based on the theory of flexible composite connections (also known as the gamma-method of EN 1995-1-1 [4]) has been made generally available for design practice.

As an alternative verification method to CEN/TS 19103 [1], the European Technical Assessment (ETA-22/0769 [7]) can be used for the design of these notched systems from the end of 2022.

Figure 1.Largely deformed concrete composite test specimen with CLT [6] failied in tension at the bottom lamination

[1] Thomas Mossbrugger, Head of R&D, Rubner Group, Kiens, Italy, thomas.moosbrugger@rubner.com

[2] Harald Krenn, Head of Structural Engineering, KLH Massivholz GmbH, Teufenbach-Katsch, Austria, harald.krenn@klh.at

https://doi.org/10.52202/080513-0311

2 – BACKGROUND

2.1 INTRODUCTION

In the design of timber-concrete composite elements, one of the main aspects is the verification of the shear connection between timber and concrete in order to achieve the stiffest possible composite joint. Where notches are used (which is by far the most economical solution in the case of a planar CLT element), CEN/TS 19103 [1] requires the use of dowel-type fasteners (usually self-tapping screws) whose axial load-bearing capacity ($F_{t,Ed}$) should equal to 10% of the shear force in the notch ($F_{v,Ed}$) unless more detailed models are available.

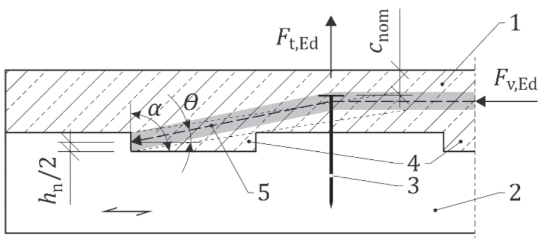

Figure 2. Arrangement of uplift restraining fastener [2]

This force conservatively represents the uplift component that occurs in the simplified strut-and-tie model (see Fig. 2). The behaviour in the concrete compression zone is complex and depending on many parameters (geometry, stiffens, reinforcement, …). ETA-22/0769 allows deviations from the requirements defined in CEN/TS 19103 [1] for various composite joint designs.

2.2 TESTING VS. DESIGN

When TCC elements are tested in the laboratory, the ultimate failure mechanism observed is quite often tension failure of the wood fibers at the bottom of the CLT element (see Fig. 1). In this test, the failure occured at a very large deformation (56 mm = L/63) with an ultimate load of 197 kN (corresponding to ca. 128 kN/m²).

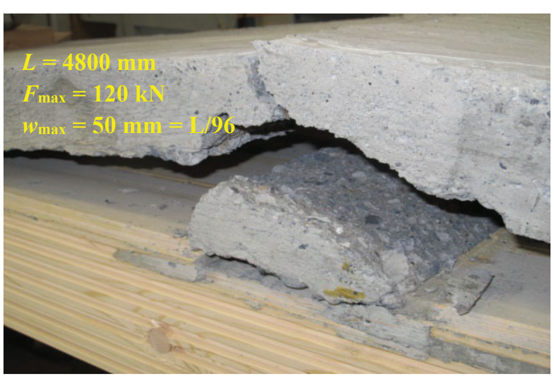

Figure 3. Failure of a notch without restraint uplift

In cases where the uplift component is not directly restraint by the arrangement of screws, the expected failure of the concrete in the vicinity of a notch can be observed (see Fig. 3) if the geometry of the specimen prevents premature tension failure. In that test, the failure occured also at a large deformation (50 mm = L/96) with an ultimate load of 120 kN (corresponding to ca. 57 kN/m²). It can be noted that failure of the tension zone of the CLT is not an undesired behaviour.

3 – DESIGN CONSIDERATIONS

3.1 TYPICAL DESIGN SITUATION (SLS)

The purpose of this publication is to give an example of the design of timber-concrete composite members with CLT and notches, focusing on the design relevant checks. As with most other timber structures (especially flat elements such as CLT with its low construction depth), the critical checks are to be found in the serviceability limit states (SLS), see example in Fig. 4 and [7]. In particular, the verification of deformation under long-term loads is of importance for composite elements. Due to the higher stiffness and especially the higher mass of these composite elements, vibration design, which is typical for CLT slabs alone, becomes less relevant.

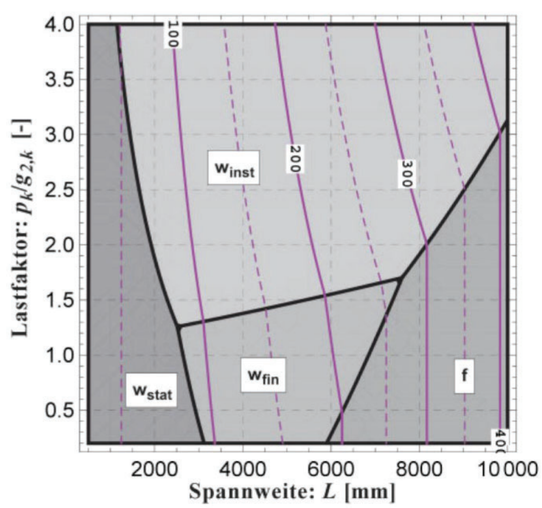

Figure 4. Design chart for CLT slabs in floor performance level I [10]

While the uplift component and the associated separation of the two parts, wood and concrete, are partially observed in laboratory experiments (see Fig. 3) when the ultimate load-bearing capacity is reached, they could not be represented at the corresponding SLS design level.

In this context, the question arises as to whether a 30% to 40% reduction in the practical ULS load-bearing capacity

https://doi.org/10.52202/080513-0311

means that the uplift restraint doesn't need to be included in the design – resulting in a significant reduction in the number of fasteners required to fabricate TCC elements.

In addition, the loading of a floor differs from the standardised 4-point bending tests of EN 408 [3]. In reality, the loads are applied distributed over a large area, which further counteracts the uplift.

3.2 LOAD LEVELS IN ULS AND SLS

The load level in the shear connection differs greatly in the individual design limit states. In the ultimate limit state (ULS), the verification of the shear connection can become critical, in that case, the load on the uplift restraint is theoretically also very high. However, this is much less true for the design relevant verification of long-term deformation in the serviceability limit state (SLS). In this loading condition, the utilisation of the notch reaches much lower values.

The subsequent Fig. 5 shows the utilisations for all relevant verifications (ULS, SLS, fire) of two different typical TCC-systems having concrete C30/37 on top of KLH®-CLT [5] panels with notches:

- left: office occupation with heavy floor build-up | cross-section: 90+180 | 7.25 m span
- right: residential occupation with heavy floor build-up | cross-section: 70+160 | 6.1 m span

total	99 %	total	98 %
moment KLH® – CLT	69 %	moment KLH® – CLT	78 %
shear force	56 %	shear force	61 %
compression concrete	57 %	compression concrete	61 %
tension concrete	37 %	tension concrete	51 %
notch	43 %	notch	50 %
failure mode	c) shear timb.	failure mode	c) shear timb.
serviceability limit state		serviceability limit state	
appearance	99 %	appearance	98 %
avoid damages	60 %	avoid damages	61 %
vibration	DKL I	vibration	DKL I
fire		fire	
moment	63 %	moment	57 %
shear force	29 %	shear force	25 %

Figure 5. Percentages of utilization for 2 typical TCC slab designs calculated using KLH software for TCC design

3.3 OTHER STUDIES [8]

Several authors were discussing the necessity of mechanical fasteners to prevent uplift in notched TCC elements in the past. Kuhlmann and Aldi [8] for example discuss the subject in detail in their paper, based on a literature review combined with their own tests.

According to their [8] findings, the wide scatter of material parameters, combined with the variable geometry of the composite joint design and the possible loading situations, does not allow a general recommendation to omit an uplift restraint. On the contrary, it may be necessary for beams with a single load at midspan. In situations where the load is uniformly distributed (typical floor situation), no recommendation is given for the arrangement of additional uplift restraint.

In a practical design example, they [8] show the relevance of SLS verification for TCC slabs. With about 95%, the utilisation ratio for the SLS verifications clearly exceeds the ratio for the ULS case with approx. 65%. An independent recalculation performed with the available KLH software for TCC design yielded very similar numbers for both described situations (notch stiffness variation: $K_{\min} = 429$ kN/mm/m, $K_{\max} = 1462$ kN/mm/m).

Michelfelder [9] shows that for varying geometry parameters no increase in capacity was achieved by installing uplift restraints (screws). She found that no relevant open joints could be observed at SLS level and described the difficulty of measuring the uplift force using screws with strain gauges attached.

4 – TESTING

A method to attempt to test the uplift force in a notched TCC connection will be presented in this chapter. The test series covered a total number of 12 tests performed at HFA (Holzforschung Austria, Vienna) during 2023 and 2024.

4.1 GENERAL TEST SETUP

The composite joint was tested in a 4-point bending test following EN 408 [3] with a shortened span to maximize the load in the notch (see Fig. 6 for details).

In order to obtain the mechanical properties, the compressive force of the cylinder and the global and the local deformations were measured. To determine the MOE, a force-controlled load cycle was performed with the limits 40% | 10% | 60% with respect to the estimated ultimate load ($F_{\max,\text{est}}$). The ultimate load ($F_{\max}$) was obtained deformation-controlled, within the test duration of 300 ± 120 s.

4.2 MEASURING THE UPLIFT FORCE

To investigate the uplift effect, measuring screws were made from commercially available pan head screws with a nominal diameter of 8 mm. To attempt to measure the axial forces, two opposing strain gauges were attached to the screw shafts (see Fig. 7).

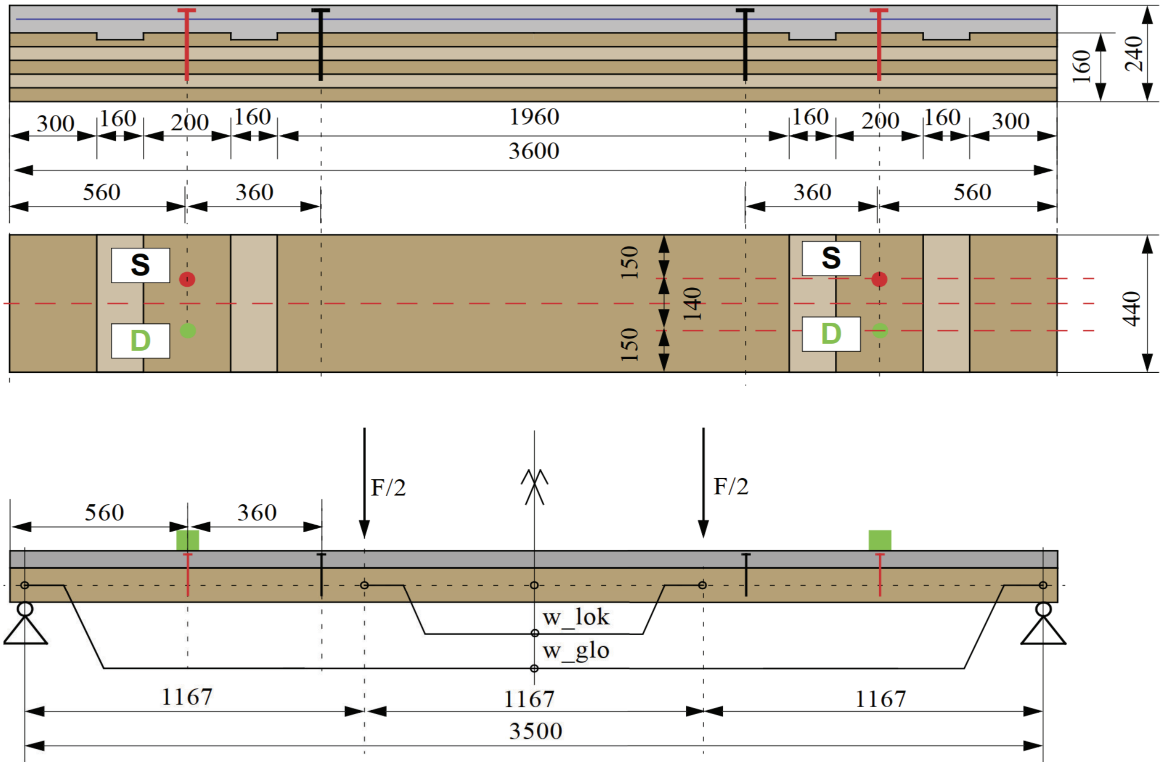

Figure 6. Geometry of the test specimen (top) and test setup following EN 408 [3] (bottom)

The ideal arrangement of 3 strain gauges, to avoid bending effects, was geometrically not possible. The subsequent calibration was carried out in tension up to a load level of 10 kN. The screws were inserted perpendicular to the shear plane and fully embedded in concrete (see screws in red marked [S] in Fig. 6).

Figure 7. Measuring screws with applied strain gauges in the CLT surface and reinforcement mesh

In addition to the determination of the internal uplift force by means of the measuring screws, an additional external measurement equipment (see Fig. 8) was installed on some test specimens using load cells and threaded rods in a casing tube (see green boxes marked [D] in Fig. 6). The elastic bearing should reflect the flexibility of the adjacent measuring screw as good as possible and the equipment should be able to qualitatively confirm the load-displacement behaviour of the measuring screws.

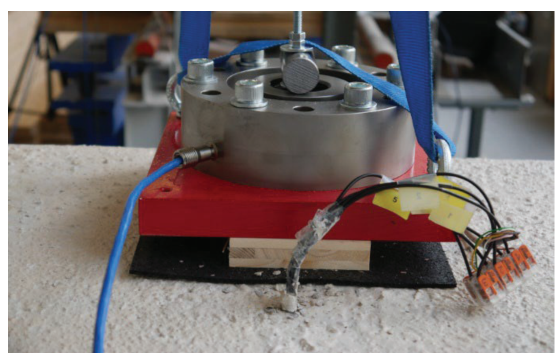

Figure 8. Load cell to qualitatively measure the uplift force curve in the notch

4.3 RESULTS – GENERAL OBSERVATIONS

Despite the fact that the test specimens were designed for a notch failure, all tests essentially showed a (quite desirable) failure of the timber section (bending or rolling shear failure). Therefore, no immediate conclusions can be drawn about an initial loss of load-bearing capacity due to a possible uplift of the concrete compression zone.

https://doi.org/10.52202/080513-0311

The load-displacement diagrams for all comparable test specimens within one series showed a pronounced agreement in terms of stiffness and also good comparability in terms of ultimate loads. All load-displacement curves showed a clearly linear-elastic behaviour for the SLS load level.

4.4 RESULTS – DETAILS OF SPECIMEN S5/2

The results of test specimen S5/2 containing measuring screws and the extra load cell equipment for the uplift force as described in 4.2 shall be discussed in more detail.

The behaviour of specimen S5/2 is shown in Fig. 9 as a load-time diagram providing the following information under the assumption that the single tested value of resistance would equal to the characteristic value of resistance (meaning the coefficient of variation over several tests would be zero, being the most conservative approach for the present discussion):

- external force F in % of the maximum tested value of F_{max} = 197 *kN*
- measured forces in screws [S1] and [S2] in *N* (until 500 sec as continuous line, from 500 sec as dotted line, as bending effects obviously became dominant)
- forces in load-cells [D1] and [D2] in *N*
- load levels for ULS (65% of F_{max}) and SLS (40% of F_{max})

The forces of the measuring screws [S1+S2] show a decreasing tendency even before reaching the maximum load, with a clear change of sign due to unavoidable bending deformation in the screws (dotted from 500 sec).

The externally placed load cells [D1+D2] reached their maximum measured values at the same time as the maximum capacity F_{max} of the specimen was reached.

The intact composite joint after fracture also indicates that no uplift restraint was required to reach the load-bearing capacity of this specimen.

Depending on the model used, the calculated shear force in the notch $F_{v,Ed}$ amounts to 290 - 330 kN. The resulting uplift force $F_{t,Ed}$ would therefore be around 30 kN per notch (ideally being the sum of the measured forces of [S] and [D]).

This amount of forces was clearly not reached when considering the ULS level (red vertical line, 65% of F_{max}) and by far not reached in the SLS level (yellow vertical line, 40% of F_{max}). Both levels are basically within the linear range of measured results.

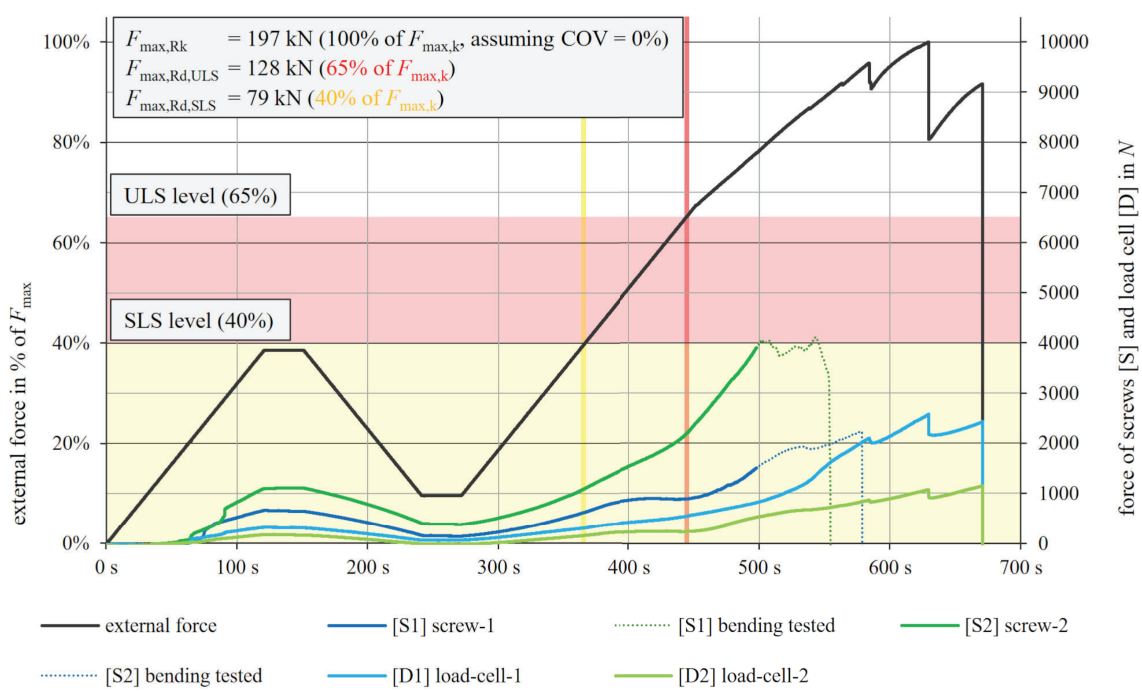

Figure 9. Load-time diagram for test specimen S5/2 including measurements for screws [S] and load-cells [D]

5 – SUMMARY AND CONCLUSION

The experimental observations and the described considerations in this paper are intended to contribute to the ongoing discussion on the necessity of an uplift restraint around the notch of TCC elements with CLT.

Daily design practice clearly shows the driving factors in dimensioning timber or timber-concrete composite elements being SLS in the overwhelming number of cases. The load level in SLS seen as proportion of the ultimate load of TCC elements is very low and lies around 40%. The practical maximum ULS utilisation is typically never higher than 65% when design is targeting at 100% SLS utilisation. In these cases, the amount of required uplift restraining elements (i.e. screws) is reduced drastically from the proposed value in [1].

Nevertheless, the statements regarding uplift restraint are limited to single-span beams with uniformly distributed loading. As also mentioned in [8], differing situations as in continuous systems or asymmetrical loading (e.g. heavy point loads), require the existence of an uplift restraint.

It should be noted, that only single-span floors are within the scope of the present CEN/TS 19103 [1]. However, it is to be assumed that this restriction is circumvented in construction and design practice.

Using a minimal number of screws in a notched joint of single span TCC elements with CLT under uniformly distributed load would ease the application and increase the competitiveness of this type of floor element in the construction process. It should be noted that the existence of a certain number of screws is likely necessary during the production, transport and installation process.

Finally the authors want to inform the reader that a much more extensive publication containing more information on the tests and also a wide literature review will be published soon.

6 – REFERENCES

[1] CEN/TS 19103:2021 “Eurocode 5: Design of Timber Structures — Structural design of timber-concrete composite structures — Common rules and rules for buildings”, (2021).

[2] Austrian National Annex of CEN/TS 19103/NA:2024 “Eurocode 5: Bemessung und Konstruktion von Holzbauten — Berechnung von Holz-Beton-Verbundbauteilen — Nationaler Anhang, Wien, (2024). (in German)

[3] EN 408:2012 „Timber structures — Structural timber and glued laminated timber — Determination of some physical and mechanical properties”, (2012).

[4] EN 1995-1-1:2014 “Eurocode 5: Design of Timber Structures — Part 1-1: General — Common rules and rules for buildings”, (2014).

[5] ETA-06/0138:2021 “KLH® – CLT”, KLH Massivholz Gmbh, OIB – Austrian Institute of Construction Engineering, (2021).

[6] ETA-18/0303:2022 “Rubner XLAM – Rubner CLT”, Rubner Holding AG, OIB – Austrian Institute of Construction Engineering, (2022).

[7] ETA-22/0769:2022 “Rubner TCC-Timber Concrete Composite”, OIB – Austrian Institute of Construction Engineering, (2022).

[8] Kuhlmann, U., Aldi, P.: „Schubübertragung in Brettstapel-Beton Verbunddecken ohne mechanische Verbindungsmittel zur Abhebesicherung“, DGfH/Aif 14497: Final Report, Stuttgart (2008). (in German)

[9] Michelfelder, B.: Trag- und Verformungsverhalten von Kerven bei Brettstapel-Beton-Verbunddecken, Universität Stuttgart, Institut für Konstruktion und Entwurf, PhD tthesis, Stuttgart, (2006). (in German)

[10] Moosbrugger, Th., Krenn, H., Bogensperger, Th.: „Bemessungsdiagramme für den biegebeanspruchten Stab im Holzbau Teil 2: Deckentragwerke mit inhomogenem Stabquerschnitt“, in Bautechnik 92 (2015), Heft 4. (in German)

 https://doi.org/10.52202/080513-0311