World Conference on
Timber Engineering
Oslo 2023

# DELTABEAM® WITH TIMBER FLOOR JOINTS – LOAD BEARING CAPACITY AT AMBIENT TEMPERATURE AND IN FIRE SITUATION

**Salla-Mari West[1], Elena Camnasio[2], Simo Peltonen[3]**

**ABSTRACT:** DELTABEAM® Composite Beam represents an excellent solution for creating a slim floor structure with timber slabs. Hybrid structures are nowadays increasingly popular as the combination of steel, concrete and timber enables the optimization of the design by taking advantage of the strong points of each material. However, the combination of different materials and the use of innovative design details set the challenge for assessing the safety and reliability of the solution. Therefore, Peikko investigated the load bearing capacity of the joints between DELTABEAM® and cross-laminated timber slabs both at ambient temperature and in fire situation. Load transfer tests, a charring test and a loaded fire test were carried out in order to prove the effectiveness of the transverse reinforcement, which ties the beam and slab together and secures the load transfer. As far as DELTABEAM®, the fire resistance is ensured by inner rebars so that no additional fireproofing is needed. In particular, the full-scale loaded fire test confirmed the satisfactory performance of both edge and intermediate DELTABEAM®s with cross-laminated timber slabs. The results allowed for developing test-based design recommendations and showed how the typical timber slab details can be used in a new and more efficient way with DELTABEAM® slim floor solution.

**KEYWORDS:** composite beam, slim floor, hybrid structure, timber slab, fire performance, full-scale tests

## 1 INTRODUCTION

Innovative construction solutions are nowadays needed to meet a wide range of design requirements, like complex architectural shapes, optimized use of the materials, demanding load conditions, sustainability aspects, and even cost-efficiency, among others. In this regard, DELTABEAM® hybrid timber structures represent a perfect way to tackle these aspects simultaneously [1]. DELTABEAM® slim floor structures [2] have been widely approved and successfully used in projects over the years. Recently, the solution has been adopted in combination with timber slabs as well [3]. Compared to traditional timber structures, the use of a steel and concrete composite beam integrated into the floor allows to achieve longer spans and to avoid load-bearing walls (Figure 1). This gives more architectural freedom, enables smooth ceilings, reduces the volume of the materials, and eases the construction process.

One of the main benefits of DELTABEAM® solution is that additional fireproofing of the beam is not needed. This is particularly convenient for timber structures, where fire design might be critical. DELTABEAM® fire rebars that are embedded in the concrete inside the steel profile guarantee the resistance of the main structural load bearing element in the event of a fire. Such reinforcement is designed depending on project fire rating requirement according to Eurocodes [4] and [5] and its performance has been extensively proved by testing in the past [6].

*Figure 1: DELTABEAM® slim floor structure with mass timber slab.*

However, additional testing is needed for hybrid constructions to give evidence that timber, concrete and steel can satisfy the design demands in overall, as their combination is not yet comprehensively standardized. In order to fill the lack of regulations and give reliable proof at the same time, Peikko conducted a wide research program on DELTABEAM® hybrid timber structures, which took into account not only its behaviour in fire situation but also other design issues, such as the vibration performance [7] and the way how to connect other timber elements and how to ensure the timber-concrete composite action [8].

The part of the research on the load carrying capacity of DELTABEAM® timber floor joints both at ambient temperature and in fire situation is herein presented.

[1] Salla-Mari West, Peikko Group, Finland, salla-mari.west@peikko.com
[2] Elena Camnasio, Peikko Group, Italy, elena.camnasio@peikko.com
[3] Simo Peltonen, Peikko Group, Finland, simo.peltonen@peikko.com


https://doi.org/10.52202/069179-0413

## 2 DELTABEAM® TIMBER FLOOR JOINTS

Joints and their design usually have a major impact on a structure's properties. In fact, the joints affect its load-bearing capacity, stability and fire performance, thus even influencing the type of failure that can occur. This can be even more critical for timber structures that have many different joints and connecting details [9].

Beam-floor joints have to be designed to prevent the separation between the parts and to transfer the forces from the slab to the supporting structural elements depending on different design conditions. In case of hybrid timber structures, the interaction between concrete and timber at the interface between the composite beam and the floor panel should be considered as well. Moreover, when accounting for the fire situation, beam-floor joints need generally to be protected by concealed connections, fire-rated gypsum boards and/or intumescent paints or seals in order to get the required fire resistance [10].

The above-mentioned design challenges can be effectively solved by using DELTABEAM® with timber slabs. The load bearing capacity at DELTABEAM® floor joint is ensured by a strut-and-tie mechanism that relies on DELTABEAM® inclined web. In fact, in the final composite stage, the loads are transferred to DELTABEAM® through a compression arch against the inclined web (Figure 2). Such mechanism is valid both at ambient temperature and in fire situation.

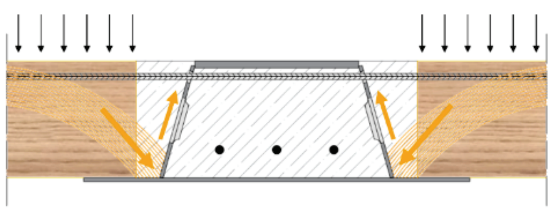

***Figure 2:*** *Load transfer mechanism of DELTABEAM® hybrid timber structure at final stage.*

Compression forces are taken by the concrete surrounding DELTABEAM® steel profile while transverse rebars carry tension forces [3]. This means that the load is supported directly by the steel ledge only at installation stage and not after concrete hardening. During construction, the presence of the ledge allows for fast and easy positioning of the floor elements on the bottom flange of DELTABEAM® and it is suitable for different slab types, such as mass timber slabs, composite timber slabs and beam decks.

The transverse reinforcement is essential in securing the load transfer mechanism at DELTABEAM® floor joint (Figure 3). Rebars are usually placed through DELTABEAM® airholes, web holes, and additional web holes or within the concrete topping in case of composite slabs. In case of solid timber slabs, grooves are cut in the panels for rebar installation. More information about the detailing of DELTABEAM® timber floor joint can be found in [3].

***Figure 3:*** *Transverse reinforcement for solid timber and composite timber slabs.*

## 3 RESEARCH PROGRAM

As joints are generally the weakest part of a timber structure, especially when exposed to fire, the main scope of the investigation regarded the fire performance of DELTABEAM® floor joints. However, the load carrying capacity of the joint has been first studied by finite elements and then verified by load transfer tests at ambient temperature. Such investigation is important to validate the assumed load transfer mechanism and useful to understand how the fire exposure possibly affects the behaviour.

A charring test and a loaded 90-minute fire test were then carried out on DELTABEAM® and timber slabs as continuation of the load transfer tests at ambient temperature. Cross-laminated timber (CLT) floor panels were used for all the tests, as being one of the main representatives of mass timber products [11].

### 3.1 LOAD TRANSFER TESTS

Load transfer tests were carried out on full-scale specimens of both timber and composite timber slabs supported by DELTABEAM® Composite Beam. Aim of the test was to prove that the failure would eventually take place in the slab, either in timber or in concrete, but not at DELTABEAM® support with load level well above the practical loads in projects. In the purpose of investigating the load capacity of the floor joint only, the beam behaviour was excluded by supporting the central part of DELTABEAM® bottom flange along its length. Thus, only the steel ledge was left unsupported and free to deform under the load.

The specimens were grouped by type as shown in Figure 4. The depth of DELTABEAM® standard profile was selected to match the thickness of the slab, which was built with 5-layer assembly CLT panels. In particular, composite timber slabs had a concrete topping thickness equal to 1/3 of the total thickness, as it occurs in most of the real cases. The shear connection between the timber panel and the concrete topping was a notched one with large head screws inside the notches [12].

Each specimen had a different detailing of the interface between the timber panels and the outer concrete of DELTABEAM® to cover possible cases that are used in projects. The end face of the timber panel was cut either vertical or inclined so to be parallel to the web of the beam. In case of the inclined end cut, additional details that consisted in pockets or chamfers along the end face were introduced to check the improvement of the resistance of the joint given by such tailored geometry (Figure 4). More information can be found in [1] and [13].

A preliminary check of the load transfer capacity of the joint in a simulated fire situation was performed during this phase of the research program by removing the supporting ledge in three of the specimens with the inclined end cut. This represents the worst-case scenario by assuming the complete loss of stiffness and resistance of the ledge, which in reality occurs progressively when exposed to fire. Similar simulated fire situation was even previously tested by removing artificially the bottom part of a CLT panel and performing bending tests on a simply supported single span timber slab with edge DELTABEAM® [3].

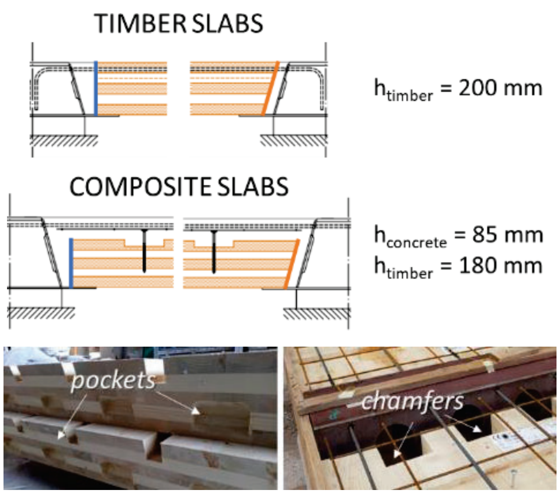


***Figure 4:*** *Types of the tested specimens and close up-view of the panel end faces with tailored geometry.*

The test setup consisted of two symmetric 3-meter long CLT spans supported by one intermediate DELTABEAM® and by roller supports at the ends (Figure 5). The slabs were loaded with a line load and slab deflections were measured below, at a distance from the centre line of DELTABEAM® that equals three times the thickness of the slab. Compared to distributed load in normal design conditions, this is an unfavourable condition, which maximizes the shear and forces the failure in the area close to the beam. Test results can be then assumed on the safe side with respect to standard design loads.

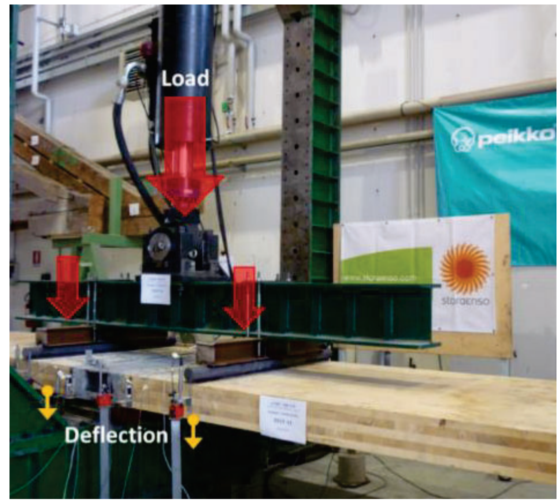


***Figure 5:*** *Test setup of the load transfer tests.*

### 3.1.1 Timber slabs

Specimens with timber slabs exhibited a rolling shear failure in the slab area between the applied load and the support, as expected (Figure 6). In fact, timber exhibits limited resistance to shear forces that act orthogonal to grain direction, which determines the low rolling shear capacity of the CLT panels and may trigger the failure in circumstances such as concentrated loads and short spans like the ones in the tests.

Despite the severe test conditions that induced high shear stresses in the panel area close to DELTABEAM®, the load bearing capacity of the support was kept until the end of the tests, although the steel ledge deflected up to 20 mm, which was due to a significant rotation of the slab end.

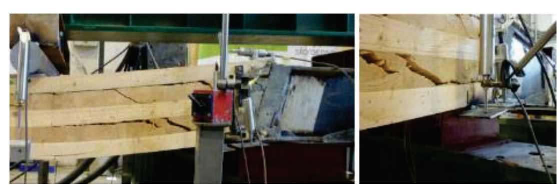

***Figure 6:*** *Rolling shear failure and ledge deflection in timber specimens.*

The satisfactory performance of the joint was observed even in the specimens without the supporting ledge. This proves that the ledge does not support the load directly and that the assumed load transfer mechanism is actually established. However, the presence of the ledge is favourable for the confinement of the bottom part of the slab, thus preventing the tensile failure due to the stresses orthogonal to the fibres of the longitudinal bottom layer.

On the contrary, such failure type occurred in the two specimens representing the simulated fire condition (Figure 7) even though it did not hinder a satisfactory load carrying capacity. These specimens had both the inclined end cut of the panel and one of these had the pockets along


https://doi.org/10.52202/069179-0413

the end face. In this case, the joint was stiffer, and the bearing resistance was even higher thanks to the concrete parts inside the pockets that can offer back-up support to the slab. Such detail is useful to improve the performance of the joint especially when the edge of the timber panel is cut vertically.

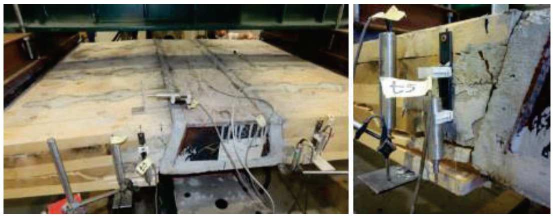

***Figure 7:*** *Timber panel failure in specimens without DELTABEAM® ledge.*

Figure 8 shows the load-deflection curves of the timber slab specimens. The load represents the support reaction on both DELTABEAM® sides, which was about 80% of the total load applied on the slabs in all cases. This is due to the test setup with concentrated load close to the beam support, but it also shows that DELTABEAM® floor joint can provide a higher degree of fixity to the slab end compared to the simply supported condition that is usually assumed for timber slabs.

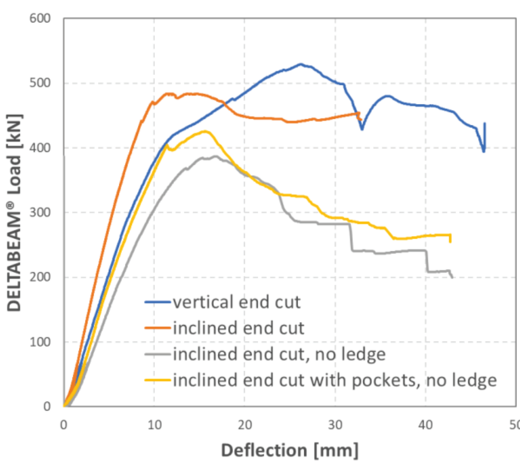


***Figure 8:*** *Load-deflection curves of timber slab specimens.*

The peak loads were significantly high. Even in the simulated fire condition that showed the lowest load carrying capacity, the applied force corresponded to a load of about 130 kN/m on one side of the beam. This is far beyond standard design loads. Moreover, the results showed that the load carrying capacity of the support was maintained even for a slab deflection up to about 40 mm for all cases, which is above usual design deflection limits.

### 3.1.2 Composite slabs

The failure type of the composite timber slabs was mainly the cracking of the topping, which started from the separation between timber and concrete in the area close to the beam that had no connectors to take the tensile forces. The crack pattern clearly indicated the direction of tensile stresses, which were orthogonal to the orientation of compression forces pointing from the applied load to the notches (Figure 9).


***Figure 9:*** *Concrete topping crack pattern development in composite timber slabs.*

Rolling shear in timber and/or bending failure of the slab occurred as well. The latter one usually develops in CLT panels when the composite action between concrete and timber is lost. Slight pull-out failure of the large head screws was also observed, as the actual failure load exceeded the expected one (Figure 10). In fact, such failure modes occurred at load levels that were far higher than the standard design ones. The simulated fire condition, i.e. DELTABEAM® with no ledge, was tested in case of composite slab as well. Similarly to what observed with solid timber slabs, the bottom layers of the timber panel failed due to tension orthogonal to the grain. The support was anyhow able to carry the load without failing.

***Figure 10:*** *Failure modes in composite timber specimens: bending, rolling shear, screw pull-out and tension orthogonal to the grain (clockwise).*

Figure 11 shows the load-deflection curves of the composite timber slab specimens. The load carried by DELTABEAM® was about 74% of the total load applied

https://doi.org/10.52202/069179-0413

on the slabs in all cases. Composite timber slabs are generally stiffer and more resistant than timber slabs of equal height, when concrete is properly connected to the timber panel. That is why the composite specimens showed greater stiffness and higher peak load values than the solid timber ones.

In particular, the specimen with inclined end cut of the timber panel and chamfers cut along the edge reached the maximum load capacity of the actuator (100 tons) without failing. The failure occurred then by keeping the load constant for few minutes. The improvement of the bearing capacity, which is due to the development of concrete struts close to DELTABEAM® web holes, shows the effectiveness of the tailored geometry and supports the assumptions of the model of the load transfer mechanism.

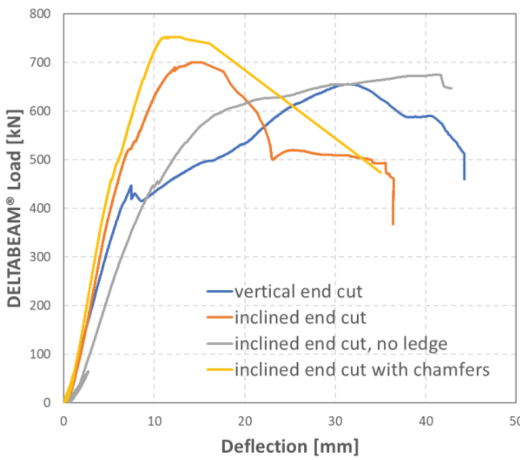


***Figure 11:*** *Load-deflection curves of composite timber slab specimens.*

## 3.2 FIRE TESTS

The charring test and the 90-minute loaded fire test concerned DELTABEAM® Composite Beam with solid timber slabs without any top concrete. Composite timber slabs are usually stiffer and performed better in load transfer tests in ambient temperature. Because of this, solid timber slab structure was selected for the two fire tests to test the most unfavourable situation.

### 3.2.1 Charring test

Due to the fall of charred layers, the carbonization of the CLT board is not linear and progresses at several carbonization rates [14]. To design CLT slabs against fire, it is recommended to use the reduced cross-section method described in EN 1995-1-2 [15]. In the reduced cross-section method, the parts of the cross-section with assumed zero strength and stiffness are removed and no longer contribute to the resistance of the cross-section. The charring depth is the distance between the bottom surface of the original member and the position of the char-line and should be calculated from the time of fire exposure and the relevant charring rate. The position of the char-line should be taken as the position of the 300-degree isotherm [15].

The two-hour charring test concerned DELTABEAM® with commonly used timber slab details adapted for a slim floor structure. Based on the load transfer tests in ambient temperature, experience and performed fire design calculations, the most suitable joint details were selected for the test. The specimen for the charring test had seven different details, which were equipped with thermocouples. DELTABEAM® Composite Beam was not fireproofed in any of the seven cross-sections. CLT 200 L5s and CLT 280 L7s timber slabs were placed on the DELTABEAM® Composite Beam ledges or downstands. The DELTABEAM® and the CLT 200 L5s slabs had equal depth. In Figure 12 the finished specimen for the charring test is presented. The temperature data from the charring test proved that the charring depth is smaller in the joint area between DELTABEAM® Composite Beam and CLT slab than in the middle of the CLT slab area, without any additional fireproofing.


***Figure 12:*** *Specimen for the two-hour charring test without loading.*

There are different options for the edge geometry of the timber slab, like vertical or inclined end cut shown in Figure 4. The geometry of the CLT slab end does not affect the load-bearing capacity of the structure or joint. Figure 13 shows the temperatures in the joint area between DELTABEAM® and CLT slabs without any additional fireproofing under the beam or under the CLT slabs. The charring rate with the vertical end cut is higher in the beginning, but in the end, the effective charring depth is about the same for both end cuts. At a distance of 100 mm from the CLT soffit the temperature has settled to 100 degrees for both end cuts.

Before the charring test, the effective charring depth was calculated for the CLT slab without any additional fireproofing. The effective charring depth would be 108 mm according to [15] and the CLT product charring rate [16]. After the test, the effective charring depth was calculated according to [15] and the temperature data. Figure 13 shows that the 300-degree char-line at 120 min is between 60 mm and 80 mm. To be on the safe side, 80 mm will be selected. By adding the thickness of material close to the char line with zero strength and


https://doi.org/10.52202/069179-0413

stiffness according to [15], the effective charring depth for both end cuts is then 87 mm. With both CLT end cuts, the effective charring depth proves to be less in the joint area between DELTABEAM® and CLT slab than the calculated effective charring depth at the midspan of the CLT using CLT product charring rate.

In conclusion, both vertical and inclined end cuts are safe to be used in CLT slabs in fire situation. Moreover, based on the extensive measurement data from the various details, it could be clearly seen that DELTABEAM® Composite Beam had no negative impact on the charring rate of the CLT panel in any of the investigated details.

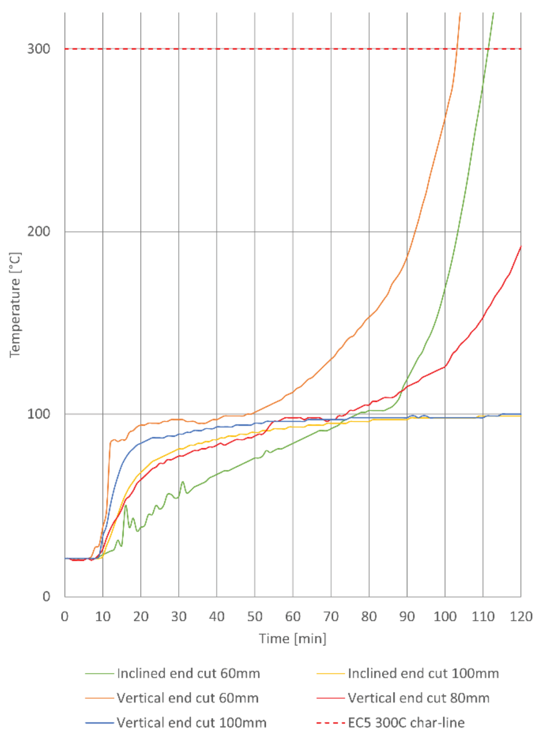


***Figure 13:*** *Temperature in the CLT slab in the joint area, 60-100 mm from the CLT soffit.*

### 3.3 90-MINUTE LOADED FIRE TEST

In the REI90 fire test, CLT 200 L5s timber slabs were placed on the DELTABEAM® Composite Beam ledges. The specimen consisted of DELTABEAM®s and CLT slabs which all had an equal depth of 200 mm. No additional fireproofing was used in DELTABEAM®s or in CLT slabs. In Figure 14 the finished specimen for the 90-minute fire test is presented.

The load was constant during the entire 90-minute fire test. The load arrangement simulated DELTABEAM® and CLT slab structure with 8 m CLT span, 1.7 kN/m$^2$ permanent load and 5 kN/m$^2$ live load ($\psi_1$=0.7). Therefore, the support reaction in the joint area between DELTABEAM® Composite Beam and CLT slab was equal to 20.8 kN/m on each side. This corresponds to only the 16% of the maximum support reaction measured in the simulated fire condition (Paragraph 3.1.1). This shows that standard design conditions are well on the safe side when compared to the maximum load carrying capacity of the joint, that was evaluated at ambient temperature with no ledge.

***Figure 14:*** *Specimen for the 90-minute loaded fire test consisting of two edge beams, an intermediate beam and two CLT panels.*

Rebars with 12 mm diameter and 600 mm spacing were used in DELTABEAM®s. At the intermediate beam, the transverse reinforcement passes through the air holes at the top end of DELTABEAM® web plates. At the edge beams the transverse reinforcement passes through the web holes (Figure 15).

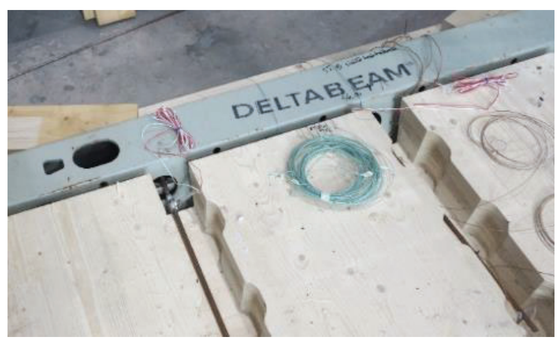


***Figure 15:*** *Reinforcement in edge beam situation.*

The 90-minute loaded fire test proved that the interface between DELTABEAM® Composite Beam and timber floor can sufficiently transfer loads from the floor to the beam in both edge and intermediate beams during a fire situation. Due to the protecting effect of the DELTABEAM® ledge the charring depth in the joint area was not as deep as in the middle of the CLT span. After the 90-minute loaded fire test, the specimen was demolished to investigate the charring of the structure. Figure 16 shows that the charred timber above the DELTABEAM® ledge stays in place. This is due to the presence of the steel ledge, which prevents the spalling of the charred parts and the possible tensile failure orthogonal to the remaining timber fibres (Paragraph

https://doi.org/10.52202/069179-0413

3.1.1), despite having completely lost its strength and stiffness after 90-minute exposure. In addition, this charred timber keeps protecting the joint area after the bottom lamella of the CLT slab has fallen along the span.


***Figure 16:*** *Specimen from below after 90-minute loaded fire test.*

### 3.3.1 Load bearing capacity, integrity, and insulation

In the case of fire, structures shall be designed and constructed in such a way that they can maintain their load-bearing capacity during the relevant fire exposure. Where fire compartmentation is required, the elements forming the boundaries of the fire compartment, including joints, shall be designed and constructed in such a way that they maintain their separating function during the relevant fire exposure. The criteria for integrity and insulation must be fulfilled when relevant [15]. In the 90-minute fire test with loading, all REI90 requirements for load-bearing capacity, integrity and insulation were met.

Deflections were measured in the middle of the CLT elements, in the middle of the intermediate DELTABEAM® and in the middle of the edge DELTABEAM®s. The deflections at 90-minute were between 40 mm and 50 mm for DELTABEAM®s and CLT slabs, which are less than $L^2/400d$ mm = 136 mm (depth of the specimen d is 200 mm, and the span L is 3300 mm). The deflection rate was less than $L^2/9000d$ mm/min = 6.05 mm/min. Therefore, the criteria of the load-bearing capacity R were met.

The average temperature rise for the whole structure at 90 min was 62 degrees. This value is smaller than the value of 140 degrees, which is the limit temperature of the insulation criterion. The highest temperature rise was equal to 92 degrees at 90 min. The highest temperature rise was less than 180 degrees, which fulfils the insulation criteria at any point of the specimen. Based on the high number of measured temperature values in the joint area between DELTABEAM® Composite Beam and CLT slabs, the insulation I criteria for average and the highest temperature rise were met.

There were no flames on the unexposed surface and no gaps in the specimen. Based on the visual observations, the integrity E criteria were met.

### 3.3.2 Load transfer

Figure 17 shows how the loads are transferred to DELTABEAM® through a compression arch against an inclined web in a fire situation. The angle of inclination of the compression arch slightly changes during fire exposure and the support shifts to the bottom corner of DELTABEAM® profile. As a result of the compressive stresses path, the charred timber part remains in the confined space between the beam ledge, the concrete grout and the uncharred timber slab. This provides an insulation to the joint area during fire and slows down the charring of the portion of the timber panel above the ledge.

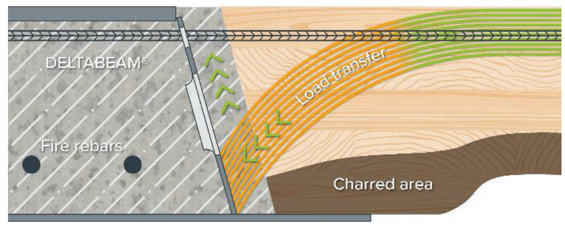


***Figure 17:*** *Load transfer in a fire situation.*

Based on visual observations of the REI90 fire test, the charring happens only at the bottom of the timber slab, as expected. The joint concrete is clean without any damage. The fire has not burned through the joint. After the fire test, when the specimen had cooled down, the specimen was cut into three pieces at mid-spans of the CLT parallel to the beam. Finally, a section of the CLT slab next to the edge and intermediate DELTABEAM® was removed to investigate the charring in the joint area.

Figure 18 and Figure 19 present that there is about half of the second lamella remaining in the joint area, while in the middle of the CLT span the second lamella is already fully charred. The depth of the uncharred timber in the middle of the CLT span was between 120 mm and 135 mm, meaning that about 70 mm of the CLT slab depth was charred. On the contrary, about 50 mm of the CLT slab depth was charred in intermediate and edge beam cases at the joint area. The specimen continued to burn during disassembling the load arrangement and lifting the specimen. Due to this, the measured remaining timber slab depth is on the safe side. The charring depths measured during demolition support the temperature data measurements and prove that the calculated effective charring depth is conservative.

All displacement transducers were set on DELTABEAM® as a reference. The relative displacement between the top end corner of CLT slab and the top plate corner of DELTABEAM® was measured in vertical and horizontal direction (Figure 20). The measured relative displacement values show that the joint area performs well during a fire situation, as no major slip was observed. The results prove that the transverse reinforcement effectively ties DELTABEAM® Composite Beam and CLT slab together, thus securing the load transfer.


https://doi.org/10.52202/069179-0413

*Figure 18: Charring in the DELTABEAM® and CLT slab joint, next to the joint concrete.*

*Figure 19: Charring in the middle of the CLT span.*

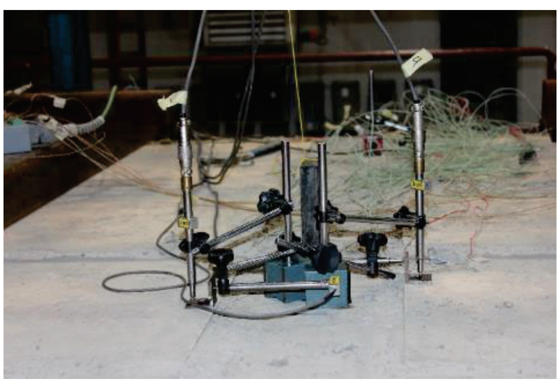

*Figure 20: Assembled displacement sensor in the joint area at mid beam span in vertical and horizontal direction.*

### 3.3.3 Normal stresses in transverse reinforcement

In Figure 21 the normal stresses in the transverse rebars in edge and intermediate beam situations during the 90-minute loaded fire test can be seen. The normal stresses were highest in an edge beam situation due to the unsymmetric load. Based on the stress-strain curves of the transverse rebars, the normal stress increases linearly and then decreases linearly following the same path. This shows that the transverse rebars do not yield since there are no permanent deformations according to the stress-strain curves.

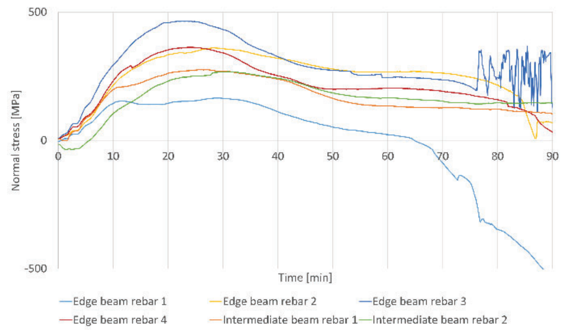


*Figure 21: Normal stresses vs time in the transverse rebars.*

In Figure 22 the changes of the bending stiffness of DELTABEAM® Composite Beam during the 90-minute loaded fire test are presented. The highest reduction of the bending stiffness can be observed during the first 30 minutes. At the same time, the normal stresses in the transverse rebars increase the most.

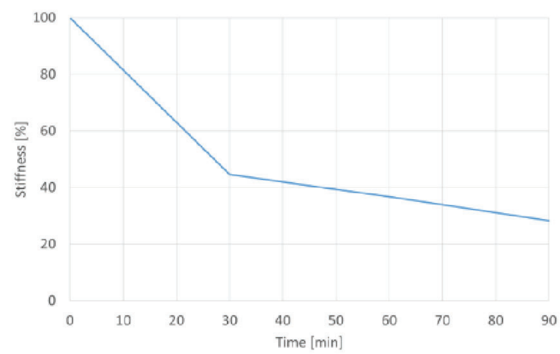


*Figure 22: Bending stiffness of DELTABEAM® Composite Beam vs time during the 90-minute loaded fire test.*

## 4 TIMBER FLOOR JOINTS DESIGN RECOMMENDATIONS

Relevant design recommendations for DELTABEAM® timber floor joints can be drawn based on test evidence. The load transfer mechanism is safely established regardless the shape of the end face of the timber panel. In fact, the results showed that both the vertical and inclined end cut of the timber panel give adequate resistance to the joint. However, the inclined end cut can provide higher peak values of the load capacity, as friction reaction forces that develop between the outer concrete of DELTABEAM® and the inclined side of the panel are in favour of the strut-and-tie mechanism. The additional details such as pockets and chamfers proved to be effective as well and are therefore recommended. In any case, proper concrete filling of the gap between the beam and the timber panel should be ensured.

The use of transverse reinforcement is essential to carry the tensile forces that develop through the joint. The effectiveness of the tying system was proved by the performance of the specimens at ambient temperature, where any rebar failure such as pull-out or blow-out failure occurred despite the high load level and severe test condition.

The results of the load transfer tests also confirmed that joints of the composite slabs are stiffer and more resistant compared to timber ones with same thickness. Moreover, the reinforced concrete topping provides continuity between adjacent slabs, is favourable to reduce floor vibrations and allows for easy installation of the transverse rebars through or above DELTABEAM® steel profile.

On the contrary, grooves need to be cut in solid timber slabs for the installation of the transverse reinforcement. The required length of the grooves depends on the needed amount of notches to secure the load transfer from timber slabs to DELTABEAM®. In fact, grooves are filled in with concrete so that compressive stresses between concrete and timber develop at the locations of the notches (Figure 23). The distance between the notches has to be designed in a way that it will not fail in shear. In order to transfer the total force properly, the tie rebar shall also extend beyond the last notch up to the end of the groove. Therefore, the rebar length depends on either the required length of the grooves or the required anchorage length according to [4], whichever the maximum. For example, for the REI90 fire test specimen, the anchorage length of the rebars was determined by the design of the grooves. The minimum concrete cover according to [4] should be also guaranteed.

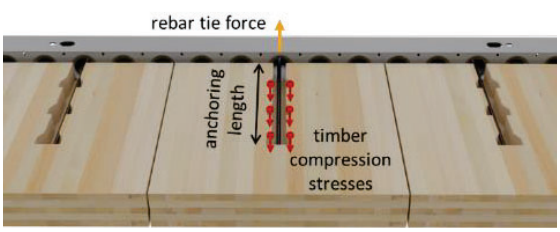


***Figure 23:*** *Force in transverse rebar creates pressure in the notches.*

It is important to have wide enough grooves especially when the transverse rebar is not only securing the load transfer but also carrying an unsymmetric load, for example. In fact, having a wide enough concrete block, along with a sufficient amount of reinforcement, prevents the concrete from cracking, which might occur when tensile stresses get higher. For example, the grooves in the fire test specimen for the edge beam situation were two times wider than in the intermediate beam. Moreover, the load eccentricity causes compressive stresses to the topmost part of the timber panel (Figure 24). Such compression must not exceed the design compressive strength of timber along the grain.

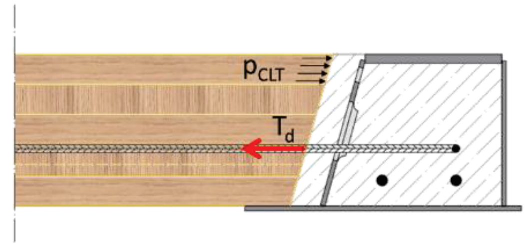


***Figure 24:*** *Unsymmetric load in the edge beam situation.*

In case of unsymmetric load, which occurs in the edge beams, the transverse rebars should be located as low as possible in order to maximize the lever arm between tension and compression resultants. Deeper grooves are then needed and rebars are generally placed through the web holes or through additional lower holes depending on the project. However, the progression of the charring in the timber panels and the temperature increase in the slab at fire exposure have to be considered. In fact, transverse rebars should be placed satisfactorily above the area affected by the major temperature increase so as to limit the steel strength reduction that shall be accounted for according to [5].

After the timber under the groove has charred away, the concrete would heat up following the standard fire exposure. According to the measurement data at 90-minute fire exposure, this design assumption is on the safe side. In fact, the temperature on the bottom of the groove was 100 degrees, while the temperature in the transverse rebar was 114 degrees in the joint area. According to [5], rebar steel strength reduction is 80% at 200 degrees. This proves that the mechanical properties of the transverse rebars were reasonably not affected by the temperature increase during the entire test, which confirms the satisfactory performance of DELTABEAM® timber floor joints in fire situation.

## 5 CONCLUSIONS

The extensive research program, which included load transfer tests at ambient temperature, a charring test and a 90-minute fire test with loading, assessed that timber floor joints equipped with proper transverse reinforcement can safely transfer the load from the slab to DELTABEAM® Composite Beam. In particular, it has been proved that the assumed strut-and-tie design model is established and effective in fire situation too without any additional fireproofing under the beam or the timber slab, so to achieve a slim floor structure that can be left exposed and used together with various common timber floor details used in real-life projects.

Peikko is nowadays continuing the research on DELTABEAM® hybrid timber structures in order to optimize the solution even more, provide reliable design information and give engineering support to customers. Future investigations will concern shear connection tests and beam tests, among others.


https://doi.org/10.52202/069179-0413

## ACKNOWLEDGEMENT

The authors would like to thank Stora Enso for providing the technical support and the CLT slab elements. Peikko also greatly acknowledges Eurofins Expert Services Oy (Finland) and the University of Trento (Italy) for performing the tests.

## REFERENCES

[1] Camnasio E., Peltonen S.. Load transfer tests on DELTABEAM® with hybrid timber floors. *Proceedings of the Italian Concrete Conference (ICC)*, Napoli, Italy, 12th-15th October, 2022.

[2] Peikko Group. *DELTABEAM® Composite Beams – Slim Floor Structure with integrated fire proofing*. Technical Manual, 2021.

[3] Peikko Group: *DELTABEAM® Slim Floor Structure with timber construction*. Technical Manual, 2023.

[4] CEN European Committee for Standardization. *SFS-EN 1992-1-1 - Eurocode 2: Design of concrete structures. Part 1-1: General rules and rules for buildings*, Brussels, 2004.

[5] CEN European Committee for Standardization. *SFS-EN1994-1-2 - Eurocode 4: Design of composite steel and concrete structures. Part 1-2: General rules - Structural fire design*. Brussels, 2004.

[6] Beckmann O., Klein-Holte R.. *Design recommendations for hollow core slabs supported on DELTABEAM® – Position of support reaction forces*. White Paper, www.peikko.com, 2022.

[7] Yrjölä J., Salonen J.. *Performance of DELTABEAM®-CLT floors in human-induced vibration*. White Paper, www.peikko.com, 2021.

[8] Peikko Group. *Hybrid solutions*. https://www.peikko.com/products/hybrid-solutions/overview/, 2022.

[9] Swedish Wood. *The CLT Handbook. CLT structures – facts and planning*. Stockholm, 2019.

[10] McLain R., Breneman S.. *Fire Design of Mass Timber Members*. WoodWorks, www.woodworks.org, 2019.

[11] Stora Enso. CLT by Stora Enso, Technical Manual. https://www.storaenso.com/en/products/wood-products/massive-wood-construction, 2021.

[12] Yeoh D., Fragiacomo M., De Franceschi M., Heng Boon, K.. State of the art on timber-concrete composite structures: Literature review. *Journal of structural engineering*, *137*(10), 1085-1095, 2011.

[13] Camnasio E.. *DELTABEAM® with hybrid timber floors load transfer tests*, White Paper, www.peikko.com, 2022.

[14] Puuinfo: PALOTURVALLINEN PUUTALO Asuin- ja toimitilarakentaminen, 2021. https://puuinfo.fi/suunnittelu/ohjeet/paloturvallinen-puutalo-asuin-ja-toimitilarakentaminen/

[15] CEN European Committee for Standardization. *SFS-EN1995-1-2. Eurocode 5: Design of timber structures - Part 1-2: General - Structural fire design*. Brussels, 2004.

[16] Stora Enso: Cross-laminated timber (CLT). https://www.storaenso.com/en/products/mass-timber-construction/building-products/clt, 2022.