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INFILL PANELS AND THE TUBE CONNECTION IN TIMBER FRAMES

A.J.M. Leijten¹, A.J.M. Jorissen², J.C.D. Hoenderkamp³

ABSTRACT: In recent years timber infill panels have been proposed for multi-story column-beam frame structures with the aim to substitute the stabilizing function of column-beam moment connections. The preliminary study reported in this paper considers a column-beam timber frame where stability is assured by cross-laminated timber (CLT) infill elements. The performance of the system depends on frame-panel connections as well as the dimensions of the CLT panel. The desk research focused on the behaviour of such an assembly using high performance reinforced frame-panel connections comprising steel tube fasteners. The numerical investigation is aimed at optimizing the interaction between frame and infill as a function of CLT panel stiffness in addition to the number and location of the connections. It is shown that the overall lateral stiffness of timber infill frames compares well with concrete infill steel frames

KEYWORDS: Connection, cross laminated, portal frame, infill, racking, reinforced, tube, timber, wood

1 INTRODUCTION

Portal frame structures are well known and used in many multi-storey buildings, particularly in steel structures. Since timber, as structural material, gains more and more credit being an environmental friendly material with low carbon foot print, feasibility studies are carried out to show what the conditions are for successful application. Although structural timber is well known and mainly used for residential and low rise apartment buildings, new innovative timber products may offer new opportunities. In particular CLT- Cross Laminated Timber is such a product that becomes increasingly popular in Europe. In particular its structural properties open new horizons in structural design. In this desk study CLT is being proposed as stability element in a timber portal frame. If the stability of portal frames is assured by only column-beam connections, so-called sway structures, the demands on the connections to achieve the required lateral stiffness are high. Alternatively, diagonal bracing can be applied without much effort, resulting in an easier and highly effective way to satisfy the demand, Figure 1. Since partition walls are often located between the beams and columns, the opportunity to let them contribute to the lateral stiffness is evident. These partitions are designed to resist fire and should satisfy sound transmission demands and therefore usually made of masonry or concrete. To speed up the erection of the building,

partition walls can be prefabricated; however, the connections are crucial in the structural frame

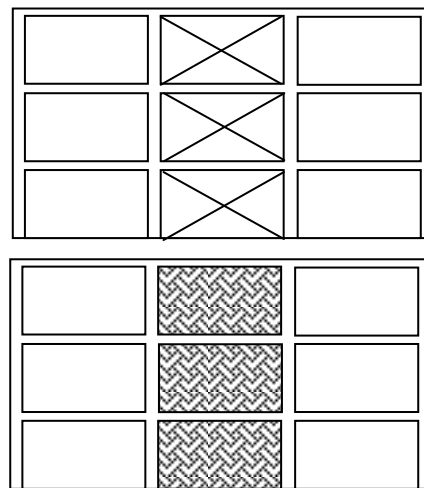


Figure 1: Lateral stiffness assured by diagonals or partition walls.

behaviour. These prefabricated elements are called infill elements. Apart from the connections, the structural behavior depends on the interaction between the infill element and the portal frame. The interaction is complex and involves many parameters. Over the years research was mainly focused on steel portal frames with masonry infills that were not purposely fixed to the frame [1]. Infill elements of in-situ cast concrete and prefabricated concrete infill elements followed [2]. With respect to

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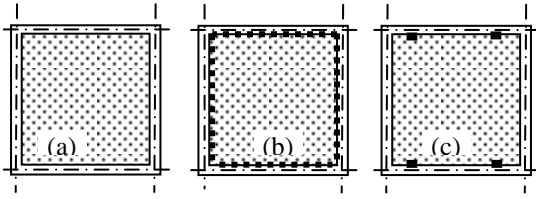


Figure 2: Type of frame to wall fixing.

the connection between the frame and the partition walls, three types of connections can be distinguished: not connected but tight fitting, Figure 2 (a), fully connected along the wall perimeter, Figure 2 (b) and discretely connected, Figure 2 (c). Assuming the same infill element for these cases, the case where no connections are used leads to the stiffest and strongest portal frame provided no clearance is left between the infill and the frame. However, this option is difficult to achieve from a builders perspective. The continuously connected infill element takes position between the discretely and non-connected elements. In contrast to masonry and concrete infills no study is known to the authors that investigates timber infill elements. Traditional timber frame elements, studs with top and bottom rail, are not suitable for this application because of the low racking stiffness and strength compared to what the portal frame demands. In this respect the performance of CLT elements is much better. For this reason it is interesting to investigate the potential for successful application.

2 CROSS LAMINATED TIMBER

Cross-laminated timber (CLT) is produced from softwood (Spruce) lamellas that are stacked in crosswise layers and glued together, Figure 3. The crossways arrangement of the longitudinal and crosswise lamellas reduces the swelling and shrinkage in the board plane to a minimum - static strength and shape retention increase considerably compared to conventional timber



Figure 3: Cross-Laminated Timber

construction products. Cross-laminated timber offers new possibilities when it comes to load transfer. Not only can loads be transferred in one direction (as is the case, for example, with supports, girders, etc.) but on all sides (referred to as "genuine plate and sheet action"). The CLT product finds application as wall, ceiling, floor

and roof element throughout Europe. The commercially available maximum dimensions are 4.8×20m. The overall thickness depends on the thickness and number of the individual layers. The maximum thickness is 500mm. In the analyses the thickness of the CLT is taken to be 216mm, which means about 5 to 7 layers. As usual in timber, structural connections are essential as they usually are the weakest link. For connections between CLT panels normally long self-tapping fully threaded screws are used. An example of what can be accomplished with CLT panels is demonstrated by the 8 storey high City Hall, Marray Grove building in London (UK). It took an assembly team of four people to erect this structure in 27 days.

3 STEEL-TO-TIMBER CONNECTIONS

For the application of infill elements screws and threaded rods are not considered suitable to adequately connect CLT to portal frames. In addition, the requirements for stiffness and strength are high and no clearance is allowed to limit storey drift. Especially the latter requirement disqualifies traditional fasteners such as bolts or dowels (drift pins) that require hole clearance for easy assembly. For this reason the high capacity DVW reinforced connections with hollow steel tubes as fasteners have more potential and therefore have been selected for this study [3]. The DVW stands for densified veneer wood, Figure 4, which is commercially available high density beech plywood with strength properties between tropical hardwoods and mild steel. This material consists of many cross-wise layered veneer sheets which during the densification process are exposed to compressive stresses perpendicular to grain of 20MPa as well as temperatures of about 160°C. After densification a sudden temperature drop consolidates the densified situation, Figure 4. This process dates from the end of the 19th century. DVW produced with beech veneers have shown to yield the highest mechanical properties, particular with respect to the embedment strength, [3]. This commercial plywood product has a thickness ranging from 6 to 80 mm thickness. However, for this investigation 18mm thick sheets suffice. The bearing or embedment strength (120 N/mm²) is approximately six

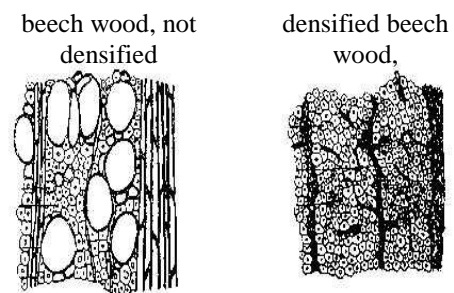


Figure 4: Densification perp to grain

times as large as the embedment strength of not-densified timber. It is applied by gluing it to the timber surface where high bearing stresses are expected. The DVW material not only enhances the bearing capacity, it also prevents premature splitting of the timber. Instead

of bolts, hollow mild steel tubes are inserted in oversized holes. The tubes are loaded in lateral direction like



Figure 5: Three member connection with dvw glued to the timbers separately at the shear planes of the expanded tube.

bolts. The tubes are expanded in diameter after assembly to remove any hole clearance, Figure 5. The maximum tube diameter ever tested is 38mm. This connection has been successfully applied in many heavy timber structures, especially in statically indeterminate portal frames as column-beam connection, [4]. Although originally designed as timber-to-timber connection, later studies have shown that steel-to-timber connections are also possible [5]. Figure 5 shows a built-up connection with two side members and middle member each with DVW glued separately to its surface, so in total four DVW plates. The middle member in Figure 5, with its two DVW plates glued on the surface, can be exchanged for a steel plate, resulting in a steel-between DVW sheets connection. The minimum end and edge distances are 3.5 times the fastener dimension (tube diameter).



Figure 6: DVW connection with steel side plates

In Figure 6 the side members are replaced by steel plates, resulting in a steel-on DVW connection. This figure also shows the mode of failure: steel tube shear failure after considerable plastic deformation. An example of a structure that uses the steel to DVW connection with expanded tubes is shown in Figure 7. At the top of the columns the horizontal glued laminated member with glued on DVW plates fit between two steel side plates. In this way a moment connection is created

able to transfer the full bending moment capacity of the glued laminated roof member leading to a considerable reduction of the amount of timber and deflection.



Figure 7: DVW connection with steel side plates

4 STARTING POINTS OF FEM STUDY

In the study, the storey height and the distance between the beams of the frame are 3.4 m. This allows a free space between ceiling and structural floor for sound isolation purposes and other facilities. The distance between the columns is the same as for the beams, so a square infill element is foreseen. The beam-column connection of the frame is assumed to be pinned, which is a safe approximation.

4.1 CONNECTION STRENGTH AND STIFFNESS

In order to evaluate the performance of the frame with CLT infill elements the strength and stiffness properties for the connection are required. Compared to a traditionally bolted connection the strength and stiffness capacity of the DVW reinforced connection with expanded tube fasteners is four and eight time larger, respectively [3]. The tube diameter chosen for the analyses was 21.3mm. This choice is based on the requirements regarding the minimum edge spacing and the available space to accommodate the connection. The characteristic strength per shear plane per tube is 55 kN/shear plane per tube [1]. However, this value is derived after considerable plastic deformation. For the purpose of this analysis only the linear part of the load-slip curve is considered, and therefore the strength and stiffness are set to 36 kN and 48 kN/mm per shear plane per tube, respectively.

Summary of the properties used in the numerical simulation:

Calculation method: 2D - 1e order linear elastic, infill element: 3.4×3.4m, portal frame beam and columns, hinged, dimensions beams and columns 400×400mm, strength class GL28h (MOE parallel= 12600N/mm², MOE perp= 420N/mm²), infill panel CLT 216mm thick

with structural properties $MOE_{parallel} = 8250 \text{ N/mm}^2$, $MOE_{perp} = 2750 \text{ N/mm}^2$, $G_{parallel} = 518 \text{ N/mm}^2$, $G_{perp} = 173 \text{ N/mm}^2$.

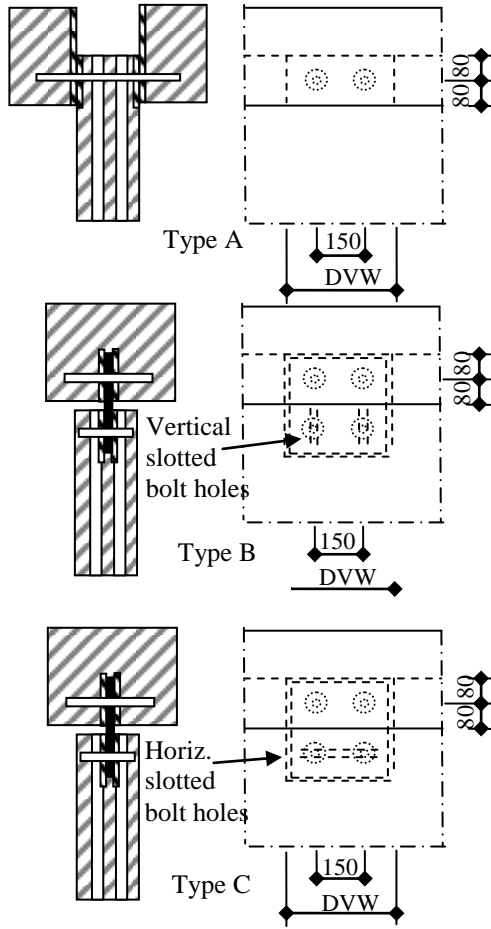


Figure 8: Load transfer types

4.2 THE NUMERICAL MODEL

The FEM is carried out using the commercial software Abaqus. The aim of the FEM is to assess the strength and stiffness of the frame with CLT infill elements, and to gain insight into the parameters that affect its behaviour. The frame is build up with beam elements:

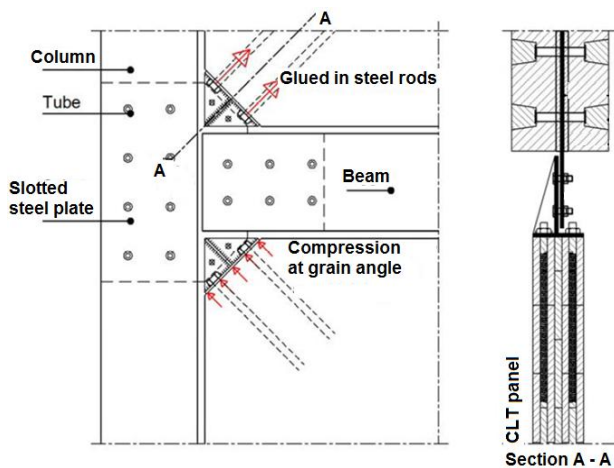


Figure 9: Alternative load transfer type

B23 and B22 beam elements. This element allows significant shear deformations to be taken into account. Based on sensitivity analyses regarding the dimensions of the four node plane stress element (CPS4R), used to simulate the CLT infill, a mesh of $80 \times 80 \text{ mm}$ is chosen. The connection between the infill and the frame is represented by linear elastic translation springs. Figure 8 shows three load transfer Types. Type A represents shear load transfer in two direction. In the other two cases, Types B and C, a slotted steel plate with elongated holes prevents shear load transfer to the frame in perpendicular or parallel direction, respectively. Alternatively the connection can be located at the frame corners in a different way, Figure 9. This figure shows a slotted steel plate that connects both column and beam with expanded tubes using the DVW reinforcement. The transfer of the forces from the steel plate to the CLT panel is assured at the corners with glued-in steel rods.

4.3 INTERACTIONS OF FRAME AND INFILL

The most advantageous location for the connections is investigated by comparing four analyses. The only difference between the alternatives is the number of, and the load transfer direction in the connections. Three alternatives I to III used connection Type A, B and C, with 2×2 connections situated at every corner, Figure 10. Alternative IV looks like frame type (b) of Figure 2 using with 68 connections in total along the perimeter of the infill element. The latter alternative applies Type B connection, Figure 8.

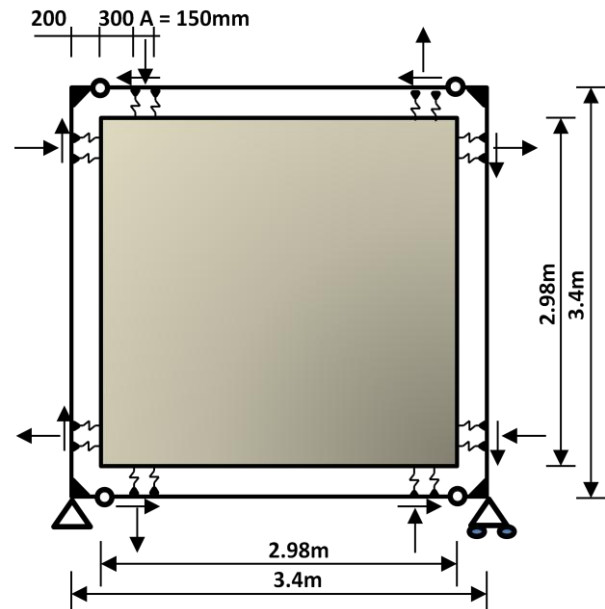


Figure 10: Load transfer, Alternative I with Type A connection.

The comparison focussed on differences in stiffness and load transfer by the infill element to beam and column. For a given racking load of 250 kN the horizontal deformation is given in Table 1. Having noticed the number of connections and differences in horizontal deformation Alternative II was considered the best for a number of reasons. This option

is most effective in that the shear forces at the column beam connection are much less than in the other alternatives. Because of the vertical elongated holes in the connection of Alternative II the storey floor load that rests on the beam will not be transferred to the infill element. A high normal force in the beam is not considered as a problem.

Table 1: Comparison stiffness and options

Alternative No.	Type Conn ection	Number connections	Horizontal Deformation [mm]
I	A	16	6.0
II	B	16	6.6
III	C	16	16.6
IV	B	68	3.8

5. SALIENT PARAMETERS AFFECTING LATERAL STIFFNESS

To optimize the stiffness of the assembly, the contribution of each element in Alternative II is evaluated. For this reason the influence of the thickness of the CLT panel, the dimensions of the beam and columns of the frame, the location and number of connections are assessed separately in more detail. The thickness of the CLT panel was varied from 51mm with three layers of 17mm thick boards up to a thickness of 297mm consisting of 11 layers of nine 33mm thick boards. The influence of frame column and beam dimensions was varied in steps of 50mm from 200x200mm to 700x700mm. Although these cross-sections are rare the intention is to compare the relative stiffness influence.

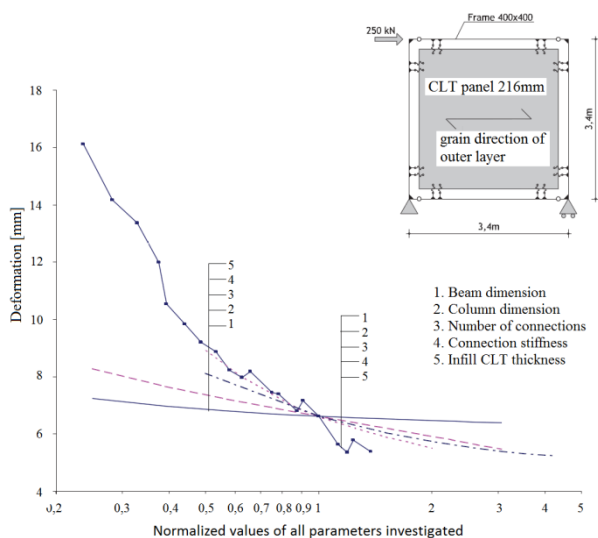


Figure 11: Summary of the parameter study results

The influence of the connections is investigated by varying not only the stiffness, but also the location and the number of connections. The stiffness of the connection is varied from 48kN/mm up to 192kN/mm to cover all the different tube diameters. The most effective location of the connection is obviously at the corners but other locations away from the corners have been

investigated too. Starting point for determine the influence for number of connections are four connections at the corners. This number is increased symmetrically over all corners and connections are added adjacent to the previous added. To combine all results of the parameter study into Figure 11 the horizontal axes contains normalized values, while the vertical axis represents the horizontal deformation. The horizontal racking load is set at 250kN. The steepest curve represents the CLT thickness. This indicates that the stiffness of the infill structure is mainly governed by the CLT thickness. The steepest but one represents the stiffness of the connections. As expected the two almost horizontal curves, representing the beams and column

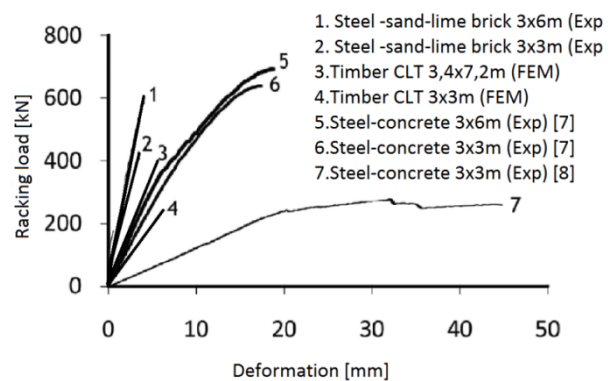


Figure 12: Comparison of results

dimensions of the frame, hardly show any influence. To optimize the structural behaviour clearly the attention should focus on the stiffness of the CLT infill element and the connection. In addition the numerical model was also used for a larger 3.4x7.2m CLT infill, which makes comparison with experimental results from previous studies possible. An overview of previous experimental and FEM stiffness studies when dealing with steel frames with other type of infill elements such as sand-lime brick and concrete, varying in dimensions, is provided in Figure 12.

6 Conclusions

CLT is a good alternative to supply lateral stiffness. The application of connection Type B in assembly Alternative II is preferred. It allows only load transfer parallel to the infill edges, while the horizontal stiffness is close to the stiffest of Alternative I, II and III. In comparison with other type of infill panels the performance of CLT compares well to other tested options with steel and concrete infill elements. However, confirmation by experiments is required before any definite conclusions can be drawn.

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