SYSTEM SOLUTIONS FOR POINT-SUPPORTED WOODEN FLAT SLABS

Philipp Zingerle¹, Roland Maderebner², Michael Flach³

ABSTRACT: The challenge with point-supported flat slabs is the stress concentration at the supporting points. The small strength of the wood perpendicular to the grain should not reduce the load carrying capacity of the CLT –Panels. Therefore, there are some existing state of the art methods of reinforcement with self-tapping screws, which open up the possibilities to increase the resistance of transverse pressure and rolling shear. These improvements are important, but not sufficient for a breakthrough of flat slabs in wood. Additional solutions have to be combined with these methods. As a result a building systems of economic interest for multi-storeyed buildings in a wood adequate flat slab building method should be offered. A promising way to achieve the objectives provides the concept “SPIDER Connector” which is applied for patent by the University of Innsbruck. Initial results show a local increase of the stiffness and improve the load carrying capacity in the transition area between plate and support. Extensive studies are planned in course of a research project that should check a sufficient capacity and serviceability of the system.

KEYWORDS: cross-laminated-timber, point-supported flat slab, multi-story wooden buildings, reinforcement, connection system

1 INTRODUCTION

The rapid development in the use of plane elements such as cross-laminated-timber (CLT) since the 1990s opens entirely new areas of application for wooden constructions. Large scaled plate- and wall structures can now be carried out, similar to concrete constructions. Today one-way CLT slabs are frequently used instead of classic wooden beam constructions. The wooden slabs are mostly carried by continuous supports like walls or beams. Point-supported wooden slabs are only very sporadic and limited to small column grids, otherwise the loads in the introduction points are getting to high. Due to the unfavorable ratio of stiffness to mass with wooden slabs compared to concrete slabs there is a frequently higher appearance of undesirable slab-vibrations.

In architectural concepts of building plans a flat ceiling with the widest possible grid of columns is often required. Therefore conventional wooden solutions become complicated and inefficient.

Figure 1: Load-bearing structure of the point supported student residence in Vancouver [1]

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At the moment a worldwide competition in the matter of multistoried buildings in wood is taking place. In Vancouver a 18 stories residential home for students (Figure 1) is arising and in Vienna the so called HoHo (wooden skyscraper) with 24 stories is right before its realization. A study in London even deals with the feasibility of a 300 m „skyscraper“ in wood. This trend indicates that wooden constructions are no longer confined to single-family homes, but that in future larger buildings are built with structural elements in wood. To intensify the use of wood as a building material with the largest CO2 - reduction potential, further solutions, which can substitute energy-intensive building materials, must be offered [2].

2 STATE OF SCIENTIFIC KNOWLEDGE

As Cross Laminated Timber (CLT) is arranged of orthogonally and glued together wooden board plies it theoretically has two main structural directions. Currently CLT is available on the market in widths of 1,25 m to 3,50 m and (almost) unlimited length. For these reasons, usually a dominant load transfer direction is present and can be calculated on dimensional panel strips. The transverse layers in this case practically act as "distance" for longitudinal layers - and must, however, transmit the resulting shear forces.

Suitable models according to the Eurocode 5 for dimensioning CLT with normal and bending loads are the shear force analogy, the orthotropic plate and the girder grid [14]. Figure 2 shows a simplification of the distribution of normal-, bending- and shear stresses in both main bearing directions.

![Figure 2: stress distribution in the longitudinal and transvers cross section [3]](image)

The arising stresses must be compared with the corresponding strengths. Particular attention must be paid to the rolling shear, since the rolling shear strength compared to the strength in direction of the grain is small [4]. In Figure 3 the rolling shear failure of the cross layers is displayed.

![Figure 3: rolling shear failure [5]](image)

### Table 2-1: characteristic properties of a single layer of CLT

<table>
<thead>
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<th>N/mm²</th>
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<tr>
<td>shear</td>
<td>( f_{v,k} )</td>
</tr>
<tr>
<td>rolling shear</td>
<td>( f_{r,k} )</td>
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The characteristic values for shear in grain direction and rolling shear according to ÖNORM EN 1995-1-1 Eurocode 5 is displayed in Figure 4.

Several works show that stress interactions that result from a multi-axial load transfer (plate bearing effect) can affect the rolling shear properties positively and allow an increase in the strength [4,5,6,7]. More load carrying capacity is generated through a 2D - load transfer [8,9].

As an additional problem location of point supported / loaded CLT plates, the compressive strength perpendicular to the grain must be mentioned. Despite an increased strength of CLT compared to glulam (GLT) and solid wood [10,11] the resistance perpendicular to the grain is far from sufficient to transmit the column loads of several floors through the plate without damage. Also reinforcing measures with full-thread screws are not efficient enough.

The Swiss scientists Boccadoro, Frangi and Zöllig 2013 presented first studies on the feasibility of flat slabs made out of wood [12]. Therefore an attempt was made to enable a 4-storey model house in wood construction without beams. This research group has dealt primarily with the use of beech veneer woods in the highest stress areas of load application. Figure 5 shows the test setup of a combined spruce-beech plywood plate.
As preliminary result from the investigations it was clear: „... due to the large cutting forces that occur in the joints, the high forces can not be transmitted economically with the help of conventional rod-shaped connecting means ... Even with slotted plates and dowels the effort would be excessively high. Therefore new connection systems based on these requirements have to be explored.” As it is apparent from these quotations of Zöllig, no satisfactory solutions have been developed at the ETH Zurich despite these investigations.

Anyway, the participation of a total of three partners from industry expressed “the strong interest in this design principle” by the construction industry [12].

In addition to research and studies in Switzerland, 2011 Mestek already wrote his dissertation at the TU Munich about the possibilities of shear reinforcement in point supported CLT plates using fully threatened, inclined screws [5]. Thereby a simple statical dimensioning concept has already been developed. At a critical section the shear verification for both supporting directions (x- and y-direction) has to be done. The rolling shear strength of the middle layers is of dimensioning relevance in this concept. The point support creates increased lateral stresses at this section. Further reinforcement and additional increase in the transverse compressive stress generated by the screwed-in 45 ° fully-tapped screws, which are designed as tie rods on a framework model. In this concept, the rolling shear strength may be increased by a maximum of 20% Figure 6.

3 REQUIREMENTS

Based on the existing scientific work the subject point supporting of flat slabs of wood was picked up at the University of Innsbruck in concept developments. Ideas for reinforcement of the high loaded areas emerged associated with modular construction systems [13]. A requirement profile for this connection means is shown in Figure 6.

<table>
<thead>
<tr>
<th>Requirements: Connection System for point supported flat slabs</th>
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<tr>
<td><strong>ULS</strong></td>
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<tr>
<td>support grid (5 - 6 m)</td>
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<tr>
<td>min. 3 wooden floors (4-story building)</td>
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<tr>
<td>assembling loads</td>
</tr>
<tr>
<td>vertical load bearing system</td>
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<tr>
<td>ductile / plastic behavior</td>
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<tr>
<td>resistance against fire</td>
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For the load carrying capacity of a prefabricated flat slab there are two points of special interest. On one hand the point of load introduction between column and plate and
on the other hand the joint between the different plates. To create performance specifications a 4-story residential building with a free span between the columns of min. 5 m was chosen. For horizontal loads walls or staircase-cores can be used as stiffening members. For the Connection-System just the vertical loads are taken under account. Also special loads during the assembling and the resistance against fire are to consider. In case of a collapse of the system plastic failure with advanced notice is aspired. For reaching the limits of serviceability (SLS) – deflection and floor vibrations – stiffness and mass are the main factors of influence. Beside local stiffness mainly the stiffness and mass of the whole floor-system is important. Beside the mechanical properties, raising requirements for sound insulation also have to be fulfilled.

The main advantages of the system with point supported flat slabs is the high flexibility in the floor plan and a simple adaption for future requirements. Many architects and builder also decide to use this method because of the smaller use of construction volume. Due to the no longer necessary beams, the volume and the overall costs can be reduced. Often esthetical requirements of a flat ceiling is desired, and also the more easy way of installation is an advantage.

Economic efficiency calculations were carried out to compare the flat slab system with a plate and beam system. Although it is necessary to use thicker plates for the flat slab, the construction volume can be reduced appreciable. If this construction method is used for a building with 10 floors, and following the standards for ceiling heights, one additional floor is possible within the same height of the building.

4 STRUCTURAL SYSTEM

In the first step, the load bearing structure is simple. CLT Plates with dimensions of 2,5 m width can be hoisted at the columns. Therefore, the columns have to be spread during the assembling process. The so-called belt-strip as main load-bearing system runs continuously between the columns. For reaching the requirements of 5 m of free span, a secondary load-bearing system of 2,5 m width has to be hang in between the two main plates. The main load bearing direction of the so-called field-strip is orthogonal to the belt-strip. A big challenge is to find a solution for the transition between the two plates. Therefore the joint is situated at a place where the bending moment has just small values. Figure 9 shows how the different plates could be assembled to a flat slab.

Figure 8: comparison of flat slab with beam construction

Figure 9: concept of assembly and construction

At the places with red circles in Figure 9 (right) the load introduction into the CLT plate is critical. There the
“SPIDER Connector” can be mounted for reinforcement of the CLT plate. Figure 10 and Figure 11 show a detailed concept of the system.

Figure 10: 3D Model of the SPIDER Connector [15]

1. Contact face at the column head
2. Overhead suspension of the slab with connection-elements
3. Load pass through the plate with compression member
4. Local shear reinforcement
5. Continuous joint of the CLT elements

Figure 11: Concept of the SPIDER Connector

For reducing compression perpendicular to the grain the contact face just has to resist the loads during the assembling process. After mounting of the inclined screws the main load is running across the cantilever arms of the connector. The inclined screws also increase the resistance of rolling shear [5]. Steel parts penetrate through the CLT plate for carrying the loads from the upper floors.

5 FIRST TESTS AND RESULTS

This construction method of “activation of many reserves” in and around the connecting point of the column, as well as an additional activation of wooden volume, the load carrying capacity is significantly increased. Based on the initial results of preliminary tests at 5-layered CLT with a thickness of 160 mm (Figure 12) the potential of this concept is rated as very high.

Figure 12: test setup

In Figure 13, the local increase in stiffness of the plate tests with SPIDER reinforcement by approximately 50% in the linear elastic range can be seen. Furthermore almost twice the load can be transmitted at the displacement of 10 mm in the middle of the plate. The first tests were carried out with a maximum of 300 kN in the center of a square plate of 2.4 m. The behavior of the CLT plate with Reinforcement-System shows just elastic deformations. No failure or cracks were detected at this stage.

So far studies found out, that it is absolutely necessary to coordinate the different levels of stiffness and to use the full capacity for the design of the connection. This is necessary because of the interaction between contact, suspension, compression member and shear reinforcement. Further investigation about the increasing of stiffness and floor vibrations have to be carried out during a FFG project.

Figure 13: evaluation of the preliminary tests

ACKNOWLEDGEMENT

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