Short report to the research project

Prestressing of CLT-structures

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The responsibility for the content of the report lies with the authors.

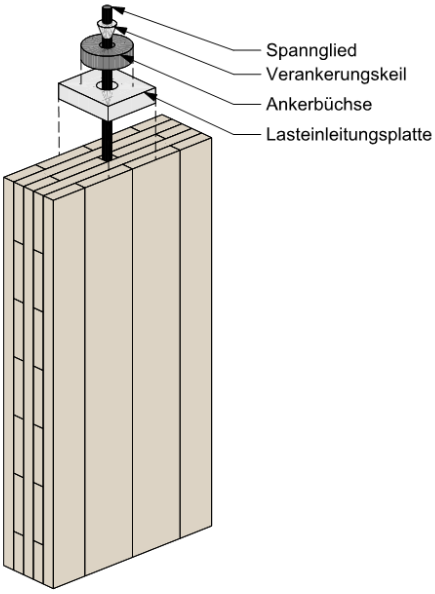
1 Initial situation

Highrise structures such as towers and multi-storey buildings are loaded horizontally by wind and earthquake loads. The resulting forces are often decisive for the design of the load-bearing structure. Their influence increases with increasing hight of the buildings, and with decreasing deadwight of the structure. Therefore, high rise timber structures typically need to bear significant vertical tension forces in the bracing elements. The objective of the project was to study possibilties in using vertical post-tensioning of bracing elements for high-rise timber structures, in order to reduce or superimpose these vertical tension forces generated by horizontal loads.

2 Objective

2.1 Anchoring points

Anchorage points of unbonded tendons transfer relatively high loads in the narrow edges of the CLT-panels. Necessary prerequisite is therefore the development of rules for design and execution of such anchorages.



(a) principle drawing

(b) Stack of speciemens

Abbildung 2.1: Drawing and picture of anchorage test specimens

The load-bearing and deformation behaviour of load introduction points at the narrow edges of CLT-panels was investigated by seven test-series and two additional preliminary tests. Aim was to determine the local compression strength of the CLT, and the behaviour of the UHPC ancorage plates. The speciemens where equipped with slots for one ore two tendons.

It was found that the bearable forces exceed locally the compression strenght when designed according to EN 1995-1-1 and the standardised material strength. The application of the test results enables significant reductions in the necessary dimension of the anchorage plates, without compromising the security level according to EN 1990. Anchorage plates of UHPC can be used alternatively to plates of steel, if they are able to bear the resulting tension and shear forces. Type HA-2 with confinement by a steel pipe segment satisfied this requirement.

2.2 Load distribution in-plane

Beside of the question of load bearing capacity it needs to be clarified how a concentrated in-plane load introduced by the anchorage of a prestressing tendon distributes downwards into the CLT-panel. This was exmined by means of a FE-parameter study and additional mechanical tests (see fig. 2.2).

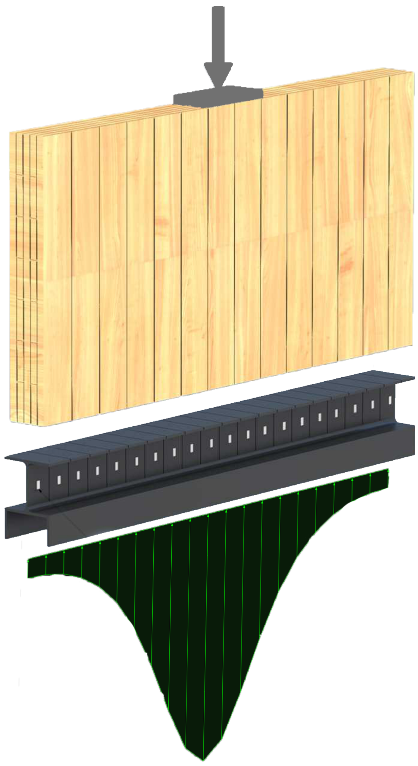


Abbildung 2.2: Load distribution by a single load in-plane

The objective of the mechanical tests was to measure the force per unit length along the bottom edge of a CLT-plate, which was loaded on the upper edge by a concentrated in-plane load. The measurement of the force per unit length at the bottom of the CLT-panel was done by placing it on a specially designed steel beam, which was equipped with 56 vertically oriented strain gauges (see fig. 2.3).

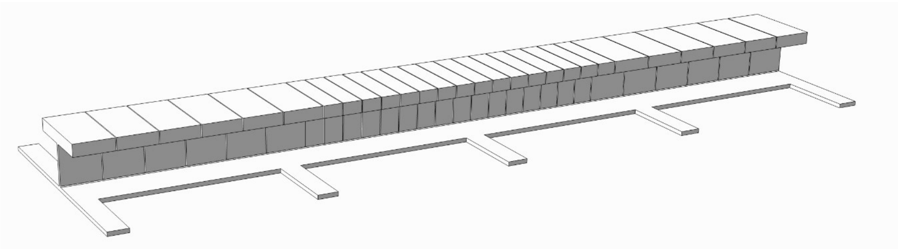


Abbildung 2.3: Drawing of the steel beam for measurement of forces in the contact line between CLT and steel

The measured strain and derived mechanical stress distribution showed a bell-shaped curve, as expected with the maximum value in the symmetry line of the load application. This result fitted well with the derived load distribution angle from the results of the FE-model. For practical use the recommendation can be made to assume the angle of load distribution for cross layer proportions from 20 % to 50 % with 25°.

2.3 Creep behaviour of CLT

Overall seven creep tests have been conducted. The 8 m long specimens where stressed longitudinally each by a single unbonded monostrand tendon. By different cross sections, three different load levels where achieved (see fig. 2.4). The tendon force was measured over the time, together with material temperature, timber moisture content, air humidity and deformation of the specimen. Three different climate conditions where used: a constant 20/60 climate, the natural outdoor climate, and a weekly cyclic climate cycle between 40 % and 90 % RH. The extrapolation was done by the rheological model introduced by *Pfefferle* (1971), which consists of two springs and one non-linear damper.

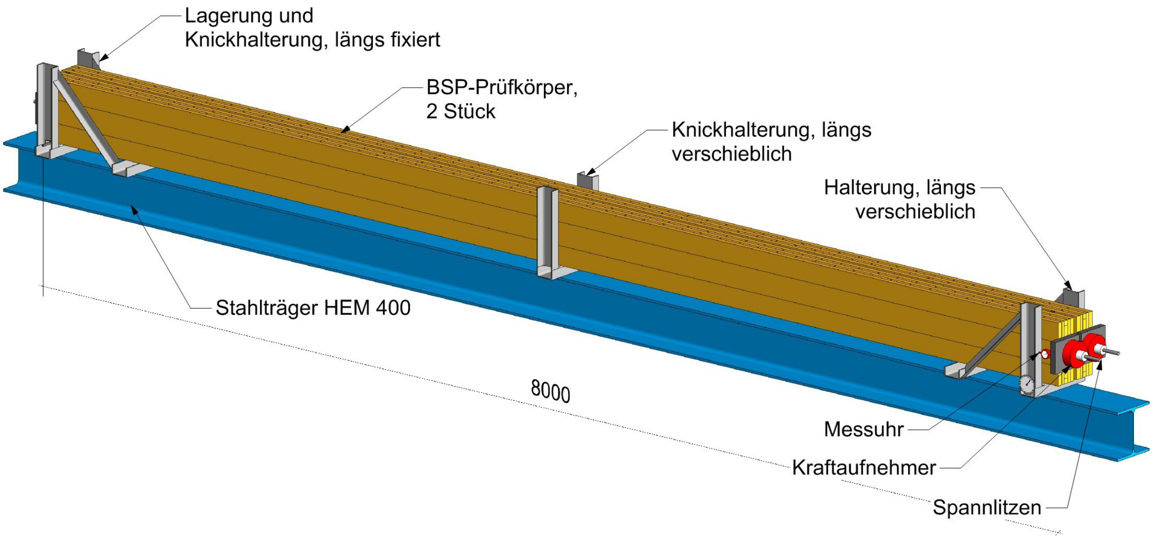


Abbildung 2.4: Test setup for the creep tests

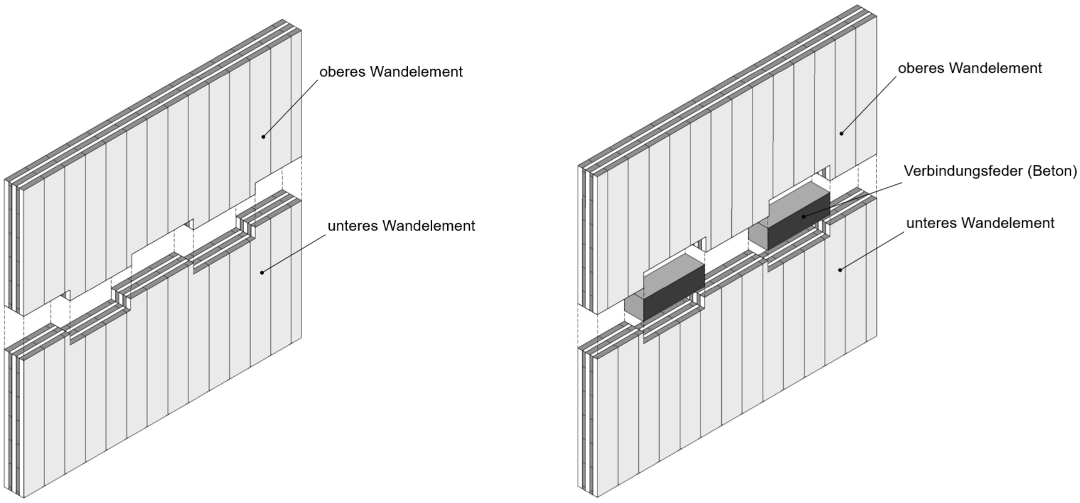
The test results show creep deformations which are significantly lower than expected from literature and design standards (e. g. *Gressel* and EN 1995-1-1). For the calculation of creep deflections of prestressed CLT elements, it is recommended to differentiate between *bending* and *compression* forces. *Longitudinal* long-term deflections due to compression forces can be calculated by the creep values from table 2.1, while deflections from bending forces sholud be derived from the values from EN 1995-1-1 as usual.

load level	SC1	SC2
over 30 %	0,2	0,4
15 % to 30 %	0,15	0,3
up to 15 %	0,1	0,2

Tabelle 2.1: Recommendation for creep values k_{def} for longitudinal compression depending on the load level and and the service classes

2.4 Form fitting connections

Buildings of CLT are usually erected storey-wise, with mechanical connections at each horizontal joint. As more slender and higher the buildings are, as bigger are the resulting forces in the joints, and respectively the number of necessary fasterners. This situation can be optimized by the use of form-fitting connections cut in the CLT-panels themselves. To identify suitable types of connections and determine their mechanical properties, a extensive finite-element study in combination with a mechanical test series has been conducted.



(a) direct wall-wall joint (b) indirect wall-wall joint

Abbildung 2.5: two types of wall-wall joints

The investigated types of form-fitting connections enable horizontal stiffnesses, which are achievable by mechanical fasteners only in rather big numbers and accordingly high cost efforts. The mechanical tests consisted of 21 wall-wall-joints and two wall-ceiling-wall joints. The mechanical behaviuor can be described by the following general rules:

- As bigger one single notch is, as bigger its stiffness is.
- As shorter one notch is, as stiffer the connection is when referred to the lenght-unit.
- Gaps between the single boards within the notch in not-narrow-face-bonded CLT lead to significant lower stiffnesses.
- The quality of the machining of the notches and the accuracy of fit have siginificant impact on the stiffness.
- The load bearing capacities can be calculated by rather simple methods by hand.
- Ductile behaviour can be ensured by the geometry of the notches, while each single notch can be shorter than expected.

3 Conclusion

This research project examined the possiblities for vertical prestressing of bracing elements for multi-storey buildings made of CLT. In detail, the mechanical behaviour of CLT loaded with concentrated loads on the narrow edges, the creep behaviour of CLT loaded logitudinaly, the design of form-fitting connections and anchorage points of prestressing tendons has been investigated. The project's outcome is intended to enable structural engineers to design applications of presstressed CLT structures in practice by the provision of any necessary technical information.

Key figures

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