Testing connector types for laminated timber-concrete composite elements

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1. Introduction

The idea of combining the constructionally favourable characteristics of concrete and timber is not new. The thereby mainly tension-stressed timber and compression-stressed concrete offer good carrying behaviour. A good overview of possibilities and state of research of shear connections in timber concrete composite elements is given by Blaß & al. (1996), Kreuzinger (1999), Meierhofer (1994) and Ruske (1998).

The connection between timber and concrete is of fundamental importance for stiffness and carrying performance. Since these systems have usually been realised as timber-concrete composite beams which are mainly taken for bridges or revitalisation of timber beam floors, dowel type connectors were normally studied and taken for the transfer of shear forces.

At the Bauhaus-University Weimar a research program was initiated to develop new connectors for transferring shear forces in laminated timber-concrete-composite plates. In the context of this paper the joints with flat-steel-locks, punched steel sheets and concrete cams are introduced.

An overview of shear tests, performed to examine the load-slip characteristics and bending tests of full sized composite floor elements is also given. Test data and picture material are presented.

2. Constructions of shear connection

2.1 Flat-steel-locks

So called “flat-steel-locks“ are zinc-coated flat steels with a cross- section of 5/40mm, which are driven into sawing cuts in transverse direction of the nail-laminates with a 5°-angle to the vertical. The locks must be arranged only at few points in the compound-joint of a composite element (figure 5). If the compressive force in the concrete layer is not sufficient, an additional reinforcement right above the locks is necessary to cover the tension force, which results from the lever effect by the lock.

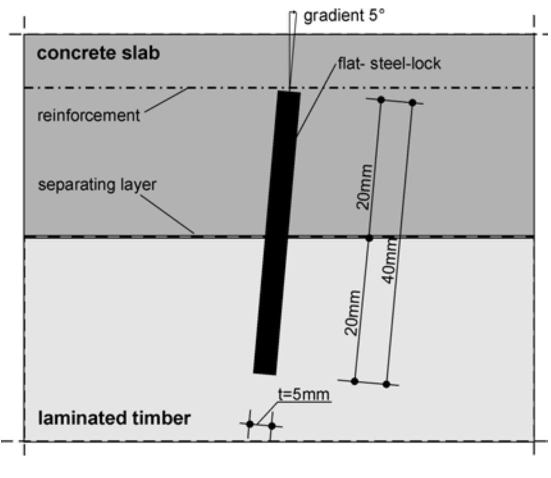


Figure 1: Construction of the flat-steel-lock

2.2 Punched steel sheets

25mm-holes are punched in zinc-coated steel sheets (thickness t=0,75mm) in 50mm-distance (figure 2b). The sheets are placed between two laminates and lengthwise turned down to enable automatic machine-nailing (figure 2a). Before pouring concrete sheets have to be straighten up again and reinforcing steel is placed through the holes in transverse direction.

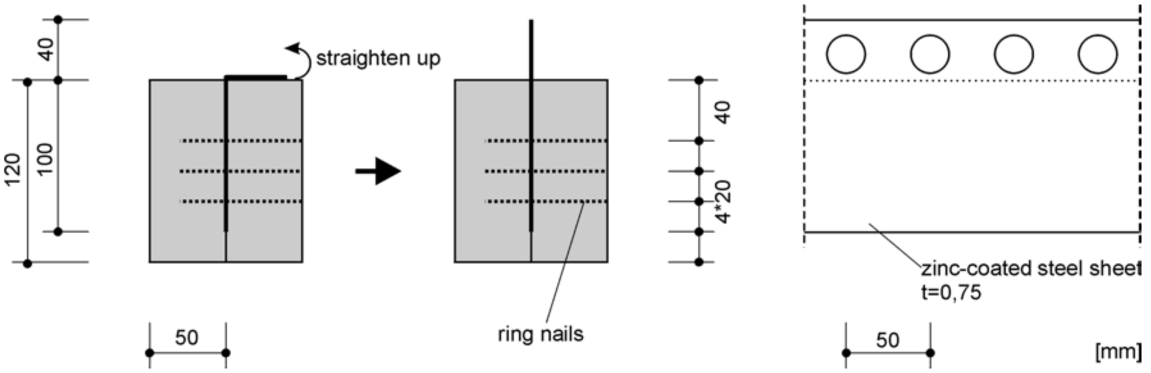


Figure 2: a) Prefabricated lamella for shear connection *b) Zinc-coated punched sheet*

2.3 Concrete cams

30mm-diameter-holes are equidistantly drilled into the vertically arranged out-sticking timber laminates (figure 3). The holes can be easily filled out with concrete. These “concrete-cams“ can transfer shear forces between timber and concrete in bending stressed composite elements. In this construction the cams are double-shear stressed. Additionally it can be assumed, that the concrete slab will wedge if transverse stiffness of the laminated timber element is sufficient. Differing to other test configurations the concrete was this time reinforced by steel fibres and a filter line of 0/8 mm was applied.

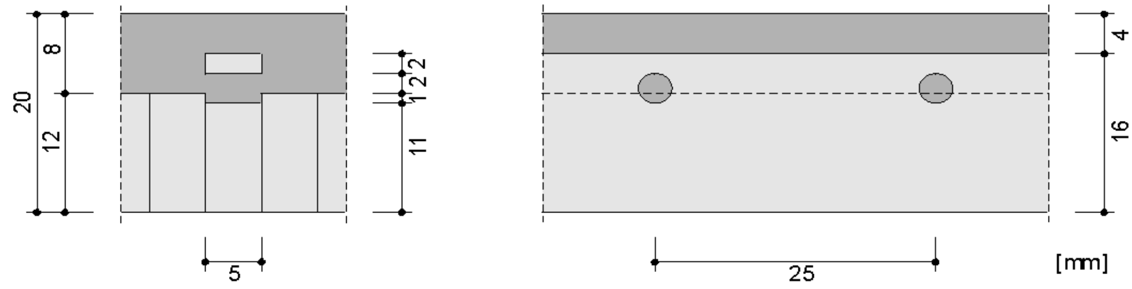


Figure 3: Concrete cam construction

3. Shear tests

The behaviour of the shear connector in the composite joint between timber and concrete is extremely important for the carrying and deformation performance of composite structures with compliant connections. To enable a structural model the load-slip-characteristics, failure load and failure mechanism of each connection type was determined by experimental tests. Shear tests using specimens with only one shear joint have been conducted as illustrated in figure 4. Table 1 shows five different tested variations of specimens. To get meaningful results a sufficient number of short-term shear tests have been conducted. Experimental procedure and applied load history were taken according to DIN ENV 26891. Test setup with dial indicators and load cells are illustrated in figure 4. The versions HVS/F and HVS/FL have been additionally tested by symmetric shear test with two shear joints, also known as “Push-out“-arrangements.

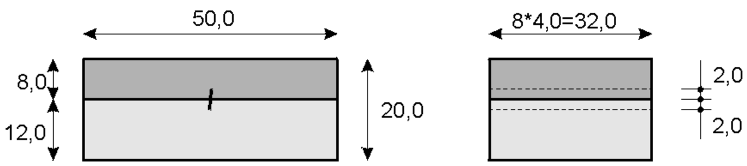
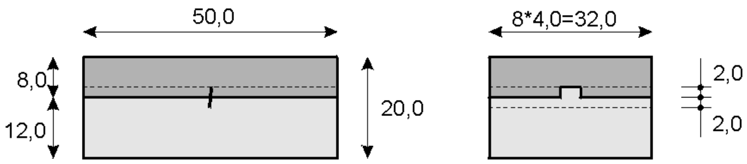
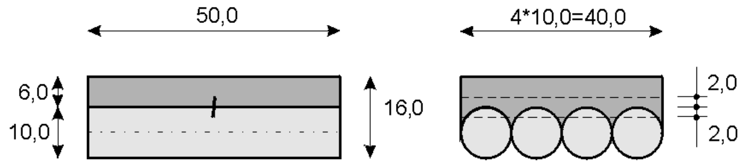
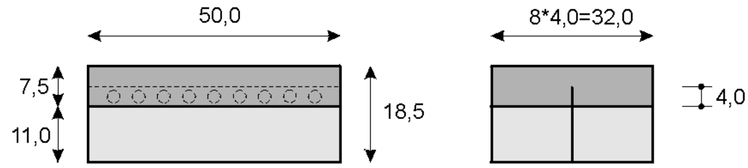
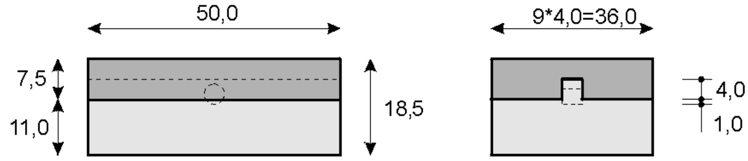
Type	connector	Sketch of structure
HVS/F	Flat-steel-locks	
HVS/FL	Flat-steel-locks with out-sticking boards	
HVS/FR	Flat-steel-locks using round timber	
HVS/LB	Punched steel sheets	
HVS/BN	Concrete cams	

Table 1: Specimens for shear tests

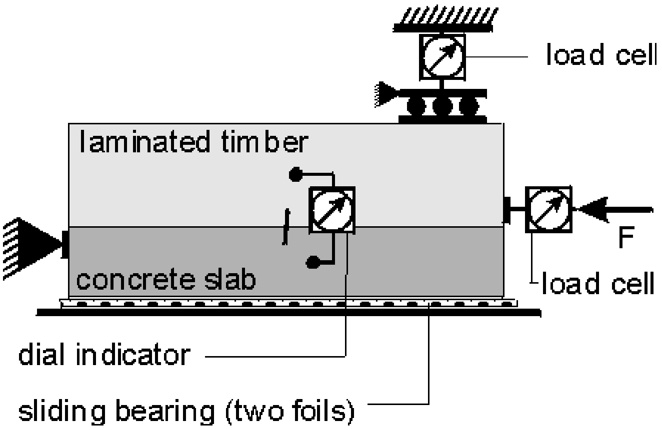


Figure 4: Experimental setup of shear tests

4. Bending tests

Structural size 4-point bending tests with complete composite members were performed to verify the results of shear tests and the structural model. The span of the elements was 4,80 meters. Cross-sections were taken according to table 2. The thickness' of timber and concrete layer were chosen in a way, which gave the nail-laminated timber a higher bending stiffness than the concrete layer ($EI_{concrete}<EI_{timber}$).

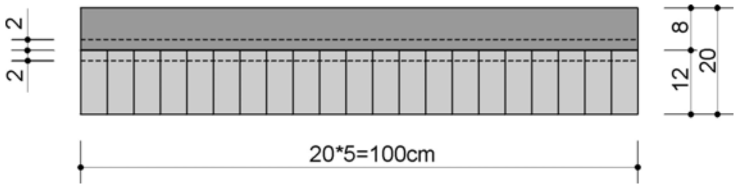
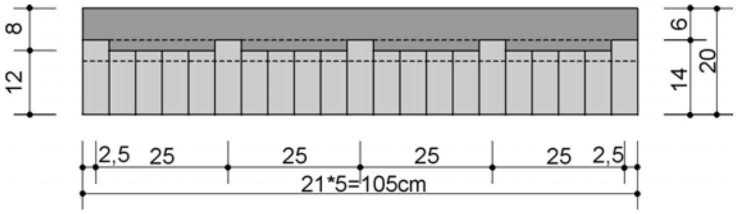
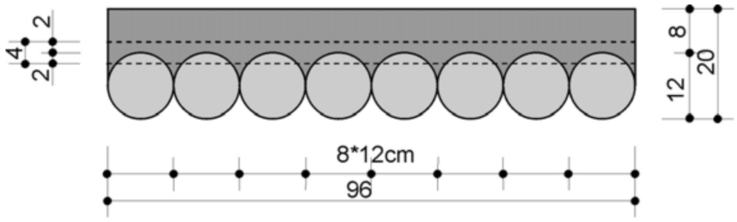
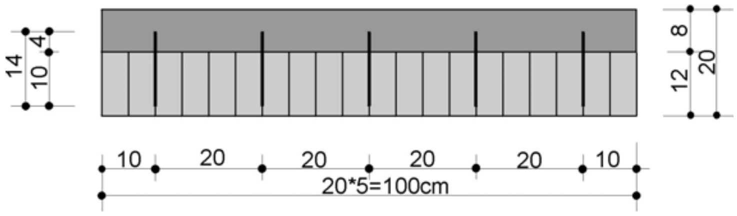
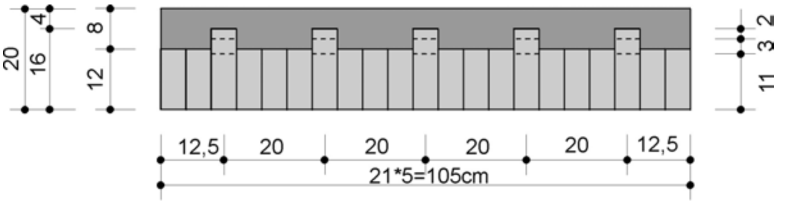
Type HVB/F	
Type HVB/FL	
Type HVB/FR	
Type HVB/LB	
Type HVB/BN	

Table 2: Cross-sections of bending tests

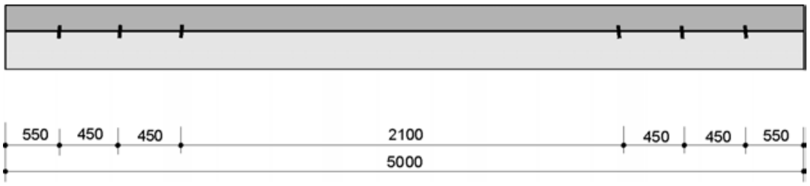


Figure 5: Configuration of the flat-steel-locks for specimens HVB/F HVB/FL and HVB/FR

At least 5 composite elements were tested for each type. Figures 6 and 7 show the experimental setup with dial indicators according to DIN EN 408. Applied loads were taken at the points "f". Deflections "d", lift-offs "a" and relative displacements "v" along the shear joint and at the front edges were registered.

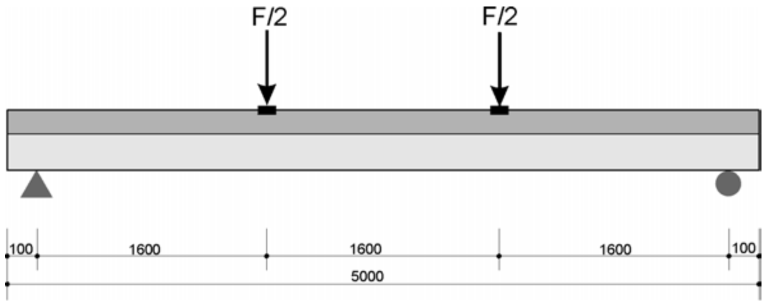


Figure 6: Test system

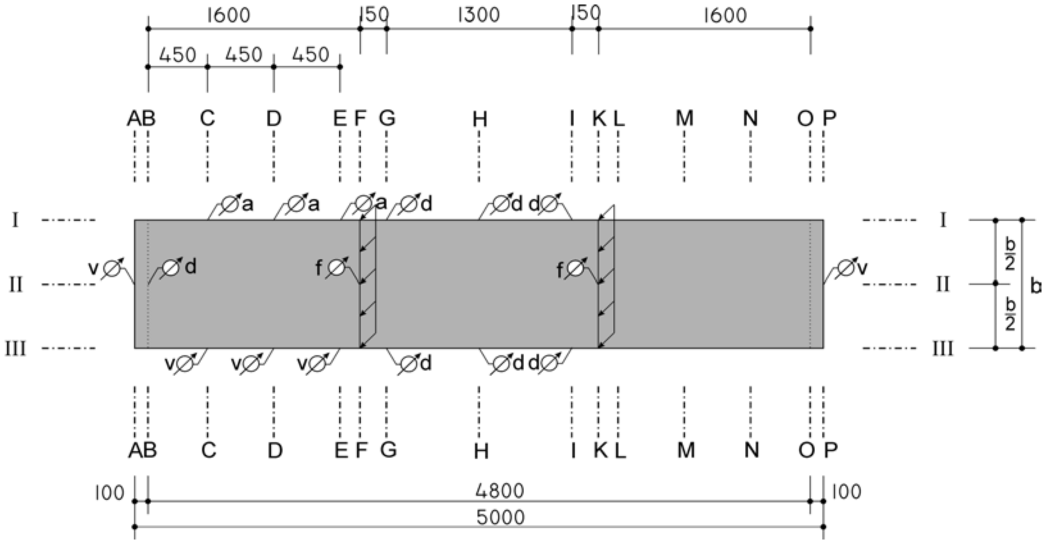


Figure 7: Locations of measuring points

5. Results and conclusions

5.1 Results of the shear-tests

Respectively to DIN ENV 26891 the maximum load F_{max} has been determined and the modulus of displacement k_s has been computed. Mean values are given in table 3. Typical load-displacement-curves, determined in the tests, are presented in the following diagrams (figure 8 to 9). Such diagrams were chosen, where test compliance's corresponded best to mean values of the series. Comments concerning failure mechanisms will be given in chapter 5.2.

Connector type	Number of specimens	Mean value respectively		based
		F_{max} [kN]	k_s [kN/mm]	
Shear tests				
HVSI/F	10	272,7	468,6	per meter width
HVSI/FL	10	295,7	607,5	per meter width
HVSI/FR	10	302,8	455,8	per meter width
HVSI/LB	3	63,6	139,1	per steel sheet
HVSI/BN	10	27,9	105,8	per cam
Push-out-tests		*referring to one flat-steel-lock*		
HVSII/F	5	326,7	539,3	per meter width
HVSII/FL	5	303,3	325,3	per meter width

Table 3: Results of shear tests

- **Single-point connections using flat-steel-locks**

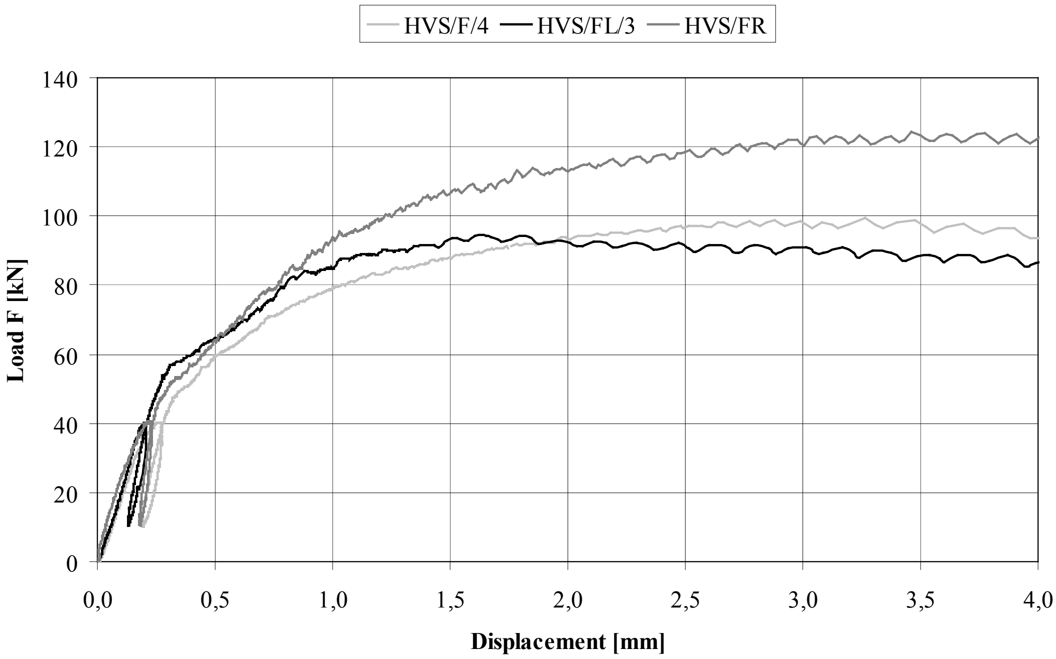


Figure 8: Load-displacement-curves of shear tests, single-point connections using flat-steel-locks

- **Continuous shear connection with punched steel sheets resp. concrete cams**

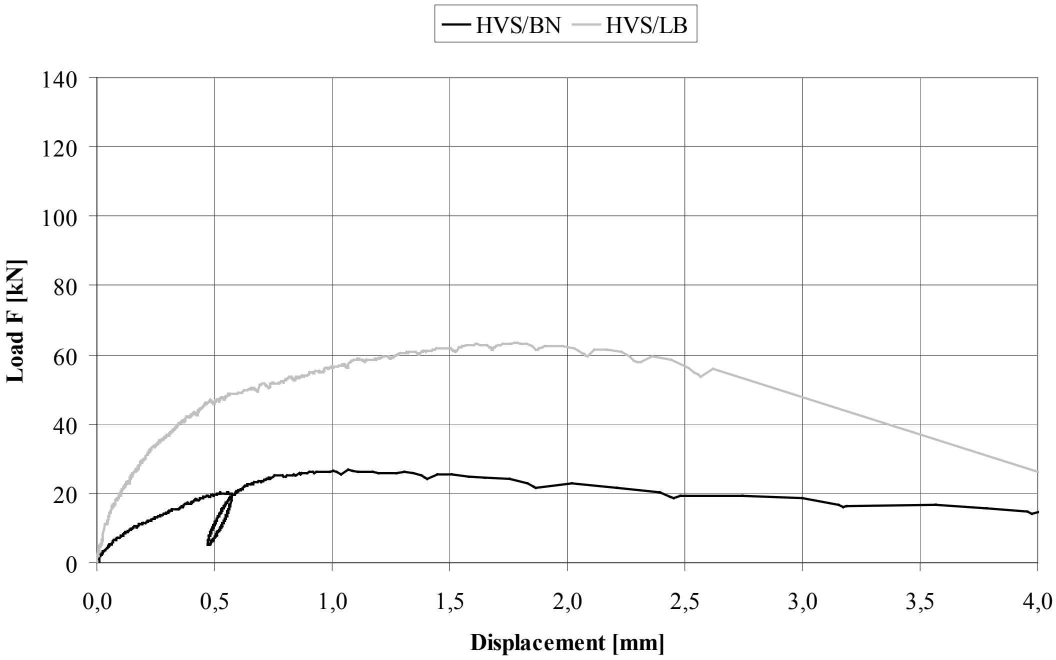


Figure 9: Load-displacement-curves of HVS/BN and HVS/LB series

5.2 Results of bending tests

- **Specimen HVB/F**

The load-deflection-curves (figure 10) show, that midspan-deflection exhibits an approximately linear progression after load application. In the upper load-bearing range deflection starts to increase disproportionally indicating some kind of plasticating behaviour. At the front edges no relative displacement between nail-laminate and concrete cover was observed in the 0 to 3,5kN range. In the range of 3,5 to approximately 65kN linear behaviour can be assumed.

As expected the horizontal relative displacements alongside of the element within the area of the three flat steel locks showed an increase from midspan to the supports under same load. The cracks in the concrete each occurred at the three flat-steel-locks, symmetrically arranged to load axis. The first crack developed at the outermost connection in a load range of 35 to 45kN. Up to maximum load no unusual relative displacement was observed in perpendicular direction to compound joint (take-off of concrete cover) before and during the test. Only after passing the maximum load and therefore after failure of the shear connection the concrete cover started coming off at locations of the connectors and the compound joint started opening.

The structural-size bending tests showed, that failure of the composite structure initiates in the failure behaviour of the shear connection. As primary cause of failure is the local destruction of concrete in the area of shear transfer at the flat steel locks for all specimens, which was also registered during shear-tests. A pull-out of the flat steel from the sawing cut was not observed before concrete failure. As expected concrete failure first occurred in the area of the flat-steel-lock, which was closest to the support (axes C and N, figure 7). For the timber only hardly observable plastifications occurred in the area of flat steel connector.

- **Specimen HVB/Fl**

For these specimens a constant increase of deflection was also observed (figure 10). The curve shows an approximately linear progression at first, followed by a plasticating run. No relative displacements at front edges between timber and concrete were registered under low load level. Only after further load increase relative displacement linearly grew up to loads of approximately 85kN. Afterwards displacements continued growing under decreasing load.

Horizontal and vertical displacements and crack development in the area of flat steel locks behaved as already described for the series HVB/F.

Interpreting the diagrams it has to be kept in mind, that the nailed laminates of the FL-series feature a higher bending stiffness because of varying lamella height. This explains the higher slope of the load-deflection curve of the composite element. The computational model of the tests did not result in a substantially higher rigidity of the connection, which was determined to approximately 540kN/mm per meter. This value acknowledges the results of shear-tests for flat steel locks with constant lamella height (series HVS/F). The additional support of the locks by out-sticking lamellas in series HFB/FL did not result in an improvement of connection compliance also.

- **Specimen HVB/FR**

In this series the shear connection failed early. The concrete slab joined almost loose on the laminated timber. This can be seen in the progression of the load-deflection-curve (figure 10). Compared to series HVB/F and HVB/FL there was only a small contact area of lock and round timber for transferring shear forces. This resulted in a heavy compression of fibres causing some kind of embedding failure. The bending strength could not be exceeded for maximum piston stroke, so fracture did not occur for specimens HVB/FR.

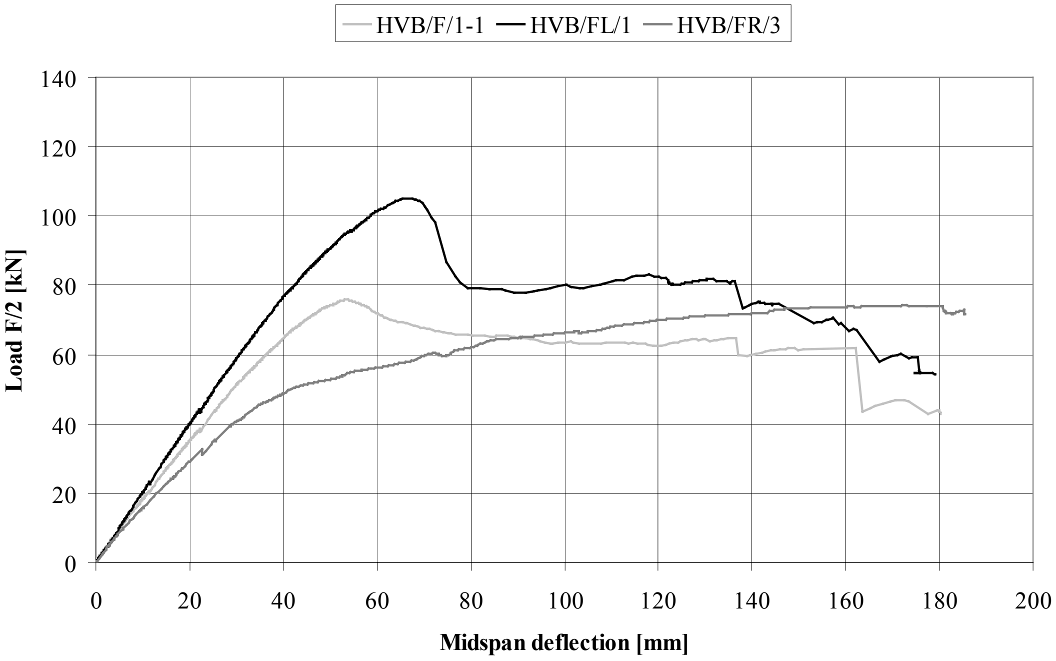


Figure 10: Load-deflection-curve of bending tests, single-point connections using flat-steel-locks

- **Specimen HVB/BN**

Up to 20kN per press no relative displacement between nail-laminate and concrete cover was observed. For a load (F/2) up to 60kN a linear elastic load-displacement progression can be assumed. Failure of the shear connection occurred beyond that point, caused by rupture of the concrete cams. So interaction of concrete slab and nail-laminated timber was not possible anymore. After failure of shear connection an observable lift-off of the concrete slab was registered. On approximately 85kN per press rupture of timber occurred.

- **Specimen HVB/LB**

Looking at the load-deflection-curves (figure 11) it can be observed, that midspan-deflection exhibits an approximately linear progression after load application. In the upper load-bearing range deflection starts to increase disproportionally indicating a plasticating behaviour of the test specimen. The rupture of the composite element finally occurred because of failure at the tension edge of the lamellas followed by compressive failure of concrete.

At the front edges no relative displacement between nail-laminate and concrete cover was observed in the 0 to 60,0kN range. The take-off of the concrete was not characterised by unusual failure appearances before and during the test. Because of the continuous connection of nailed laminated timber and concrete slab a take-off was registered relatively late during test procedure.

Damage of the shear connection is mainly caused by a pull-out of punched steel sheets from timber and concrete layer respectively. The thickness of steel sheets is therefore crucial for load-bearing capacity and compliance of the connection, but for practical use it is limited to ensure nailing without predrilling.

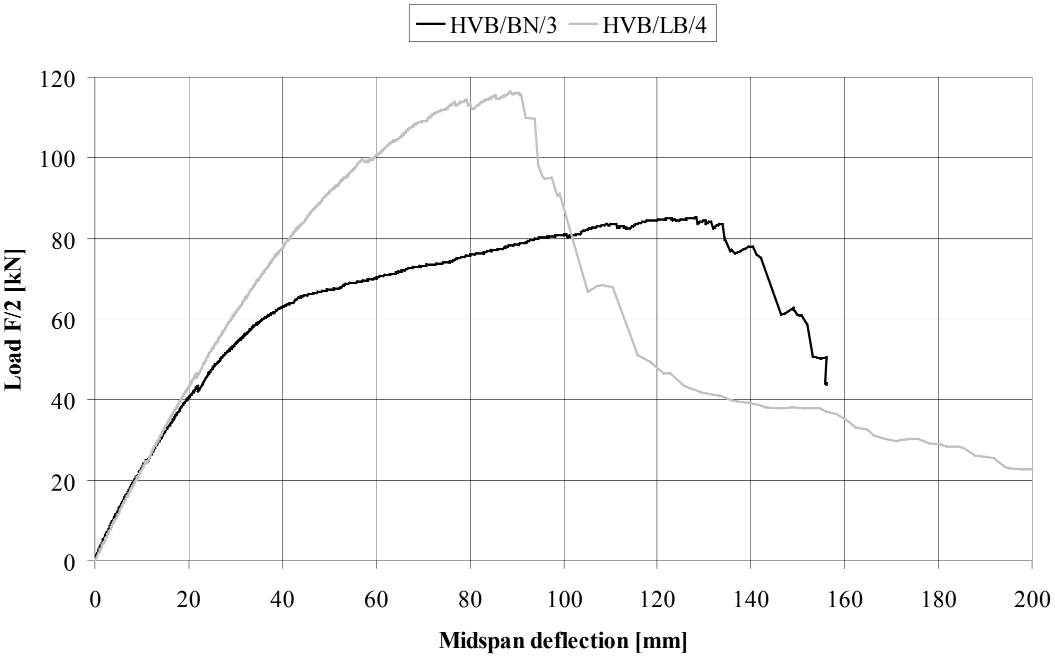


Figure 11: Load-deflection-curve of bending tests, continuous shear connection using punched steel sheets and concrete cams

6. Conclusion

The application of dowel-type connectors in continuously connected timber-concrete composite elements causes constructive, technical and economical problems, which can be hardly solved. It is especially difficult to keep the least edge distance of the connector perpendicular to the grain to the narrow edges of a nail-laminated element, which would require thick members. In addition dowel-type connectors have to be applied in large quantities. The studied connecting methods should enable an easy and economical use in laminated timber-concrete- composite plates.

The series HVB/FR and HVB/BN fell short of expectations, because shear connections failed quite early. For all other joints the results of the shear-test could be verified.
Although only three connectors were taken in the series HVB/F and HVB/FL in the outer third of the members, an increase of bending stiffness was obtained. The same applied on the use of continuous connections with punched steel sheets.

An substantial increase of the load-bearing capacity compared to the pure nail-laminated timber element was not possible with the chosen arrangement of the flat-steel-locks. The shear connections fail first, after a further deflection increase a bending fracture occurs at the lamellae. To prevent failure of the locks and achieve an increased load bearing capacity more connectors could be attached.
Only for the specimens with punched steel sheets a failure of the shear connection was not registered. Bending failure firstly occurred at the tension edges of the lamellae. This was followed by very high deflections leading to failure of the concrete pressure zone in the area of load application.

The application of flat-steel-locks and punched steel sheets for the shear connection yielded good results. Practical use seems easily possible. The increased stiffness leads to smaller deflections of the composite element. This can already be obtained by applying only few flat-steel-locks For most applications the prove of serviceability becomes decisive so design load could be increased considerably.

Code reference

DIN 1052; Holzbauwerke; Teil1- Berechnung und Ausführung (04/88); Teil 1/A1- Änderungen 1(10/96); Teil 2- Mechanische Verbindungen (04/88); Teil 2/A1- Änderungen 1 (10/96)

DIN EN 408:1995; Bauholz für tragende Zwecke und Brettschichtholz- Bestimmung einiger physikalischer und mechanischer Eigenschaften (04/96)

DIN EN 26891:1991; Holzbauwerke – Verbindungen mit mechanischen Verbindungsmitteln, Allgemeine Grundsätze für die Ermittlung der Tragfähigkeit

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