# New connector types of laminated timber-concrete composite element joints

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## Abstract

The connection between timber and concrete is of fundamental importance for stiffness and carrying performance. Using nail-laminated timber elements in the composite construction with vertically arranged boards whose narrow sides are on top, in most cases it is impossible to keep a sufficient edge distance for dowel-type connectors. Therefore this type of mechanical connector is unsuitable for this kind of construction. In this contribution a so called „flat steel lock“-connection is introduced. The carrying behaviour of flat steel locks is examined under the dependency of different configurations of the contact surface between the timber and the concrete layer. Since the load-carrying capacity and the slip modulus are quite high, compared to dowel-type connectors, the distances of the flat steel locks may be kept relatively large and can be adapted to the desired carrying behavior. This contribution gives an overview about the experimentally investigations like shear, performed to find out about load-slip characteristics, and bending tests of full sized floor elements. Based on the test results the load displacement behavior of the connectors is described and a design concept is introduced. For this kind of discontinuous, only at discrete points bonded composite floors an easy proposal for the determination of the required internal forces by using a framework-model is submitted.

## 1. Introduction

Timber-concrete composite systems have been mainly applied as T-beam cross sections. The transfer of shear forces is realised by dowel-type connectors. Numerous publications about the structural behavior of such systems show the favourable interaction of wood and concrete.

The application of certified dowel-type connectors causes a series of problems though. These problems are of constructive, technical and economical nature and hardly solvable. It is especially difficult to keep the least edge distance of the connector


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perpendicular to the grain at the narrow edges of a nail-laminated element, which would require thick members. This can be avoided by applying „flat steel locks“, inserted in transverse direction, allowing the use of narrow laminated members at the edges also. In addition dowel-type connectors have to be applied in large quantities. Traversing connectors in transverse direction could save time and material.

The object of a research program, initiated at the Bauhaus-University Weimar, was the development of new different mechanical connectors for transferring shear forces in nail-laminated timber-concrete composite elements. From different test series the results of a shear connection with so called "flat steel locks" will be introduced here. In the paper an overview is given to experimental investigations like shear and push-out-tests, performed to find out about load-slip characteristics, and bending tests of full sized floor elements. The structural behaviour of the connection is illustrated using test data and pictures.

Because shear connection then only exists at discrete points in discontinuous distance for this system, a calculation according to the theory of Moehler [4] is not possible. A simple proposal for determination of the required internal forces by using a structural model is therefore submitted.

## 2. Shear connection

Arrangement and construction of the so-called "flat steel locks" is shown in figure 1. This steel connector serves as shear connection between nail-laminated timber elements and the also load-bearing concrete. They consist of zinced flat steel with cross-section 5/40 mm, which are driven into sawing cuts in transverse direction of the nail-laminates with a 5°-angle to the vertical. If the compressive force in the concrete layer not sufficient, an additional reinforcement right above the locks is necessary to cover the tension force, which results from a lever effect by the flat steel.

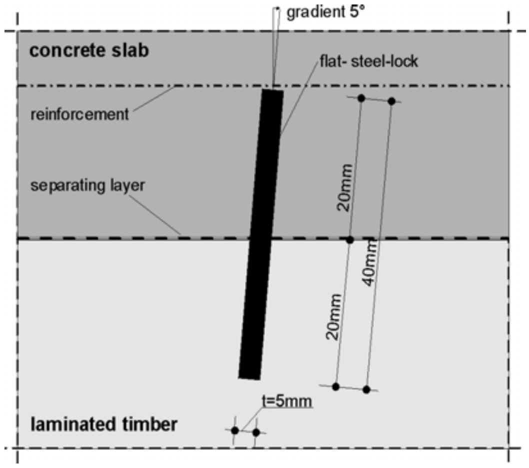


*Figure 1: Structural dimension - longitudinal section*


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## 3. Shear tests

For the carrying and deformation behavior of composite structural sections the characteristics of the compliant connectors in the composite joint between timber and concrete are very important. To enable a structural model the load-slip characteristics, failure load and failure mechanism of the connection type are determined in experimental tests. Shear tests using specimen with only one shear joint as illustrated in figure 2 have been conducted first.

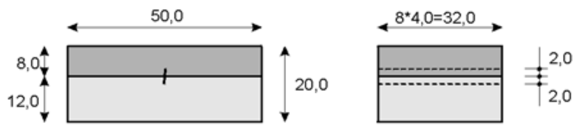
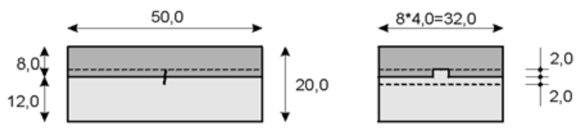
| Type | connector | Structural system |
|---|---|---|
| HVS/F | Flat steel lock without embattled board |   |
| HVS/FL | Flat steel lock with embattled board |   |

*Figure 2: Setups of shear joints (sheartest)*

So called “Pushout- tests“ with symmetrical setup and two compound joints were additionally alternatively performed. The test setup is shown in figure 3.

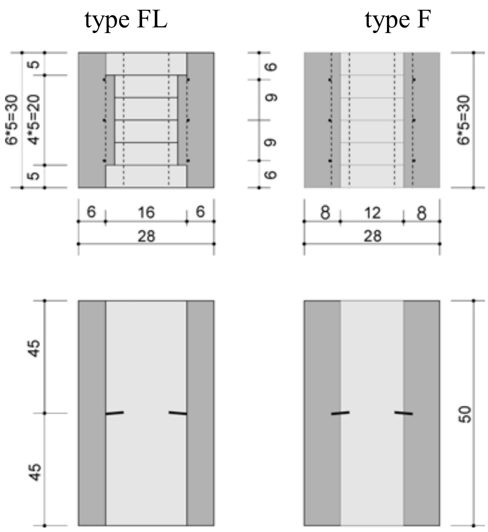



*Figure 3 : Setups of shear joints (pushout-test)*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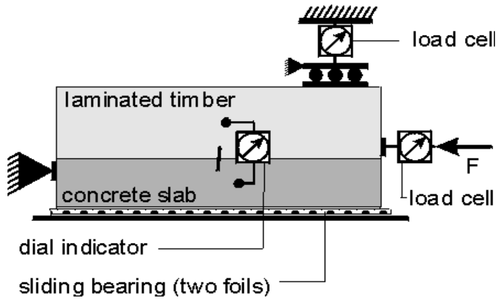
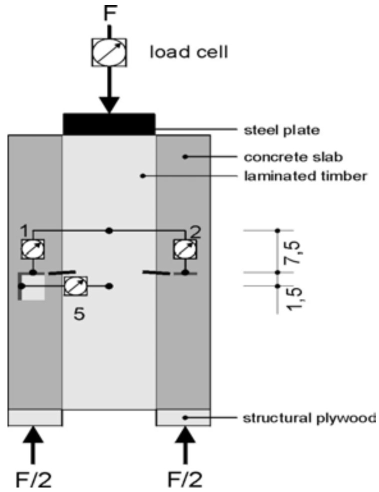
The experimental procedure and applied load history was taken according to DIN ENV 26891. Test setup with dial indicators are illustrated in figure 4.




*a) b)*

*Figure 4: Measuring points of a)Sheartest b) Pushout- Test*

| Average timber properties timber: C24 (picea abies) | | | Average concrete properties concrete: C20/25 | | |
|---|---|---|---|---|---|
| dry density $\rho_0$ [g/cm³] | moisture content u [%] | E-modulus [N/mm²] | compressive strength $\beta_{W28}$ [N/mm²] | raw density $\rho_B$ [g/cm³] | E-modulus [N/mm²] |
| 0,43 | 11,5 | 14867 | 44,3 | 2,25 | 27100 |

*Table 1: Material properties*

## 4. Bending test

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 figures 5 and 6. 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 ($EI_{concrete}<EI_{timber}$).


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Figure 5: Type HVB/F

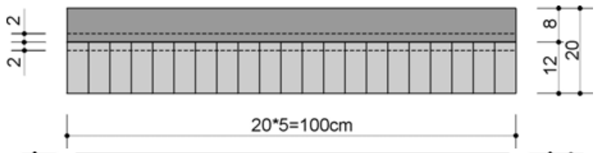
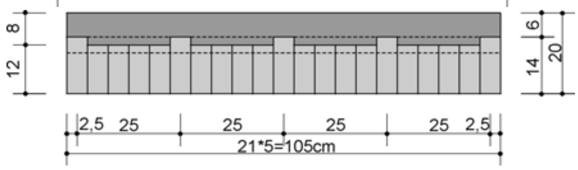



Figure 6:Type HVB/FL




For each type at least 5 composite elements were tested. In figure 7 and 8 the experimental setup with dial indicators can be found. The applied loads were measured at the compactor (f). Deflections (d), lift-offs (a) and relative displacements (v) along the compound joint and at the front were registered for the composite element.

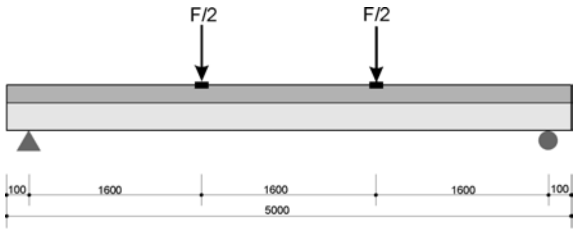



Figure 7: Test system

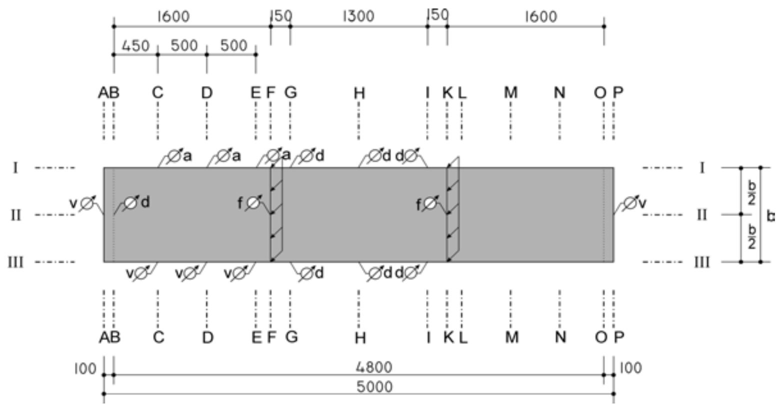



Figure 8: Plan of dial indicators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## 5. Results and conclusion

### 5.1 Results of the shear-tests

Typical load-deformation-curve, determined in the tests, are presented in the following diagrams. The diagrams were chosen, where compliance in the tests corresponded best to mean values of the series. Due to the lever effect of the flat steel lock in the concrete a crack occurred, which developed angular towards the upper concrete surface. Further load increase changes the direction of the crack, which now runs parallel to the shear joint in height of the reinforcement. Failure of the shear connection can be attributed to failure in the compression zone of the concrete in front of the lock in all cases. This can be seen by the distinctive horizontal progression of the load-deformation curves.

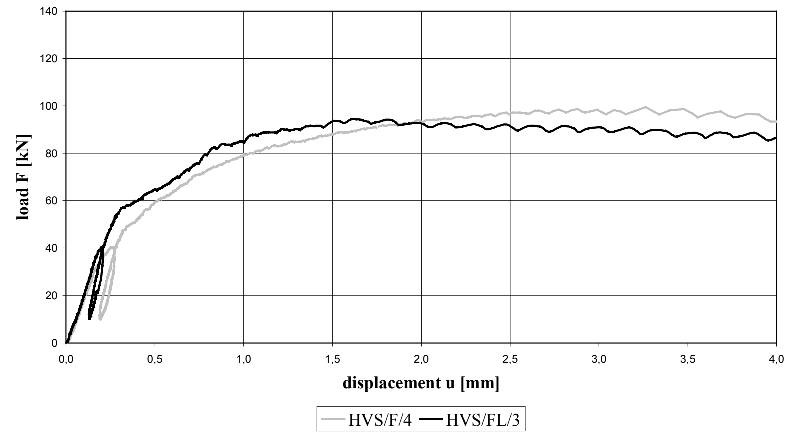


*Figure 9: Load-displacement-curves of shear test*

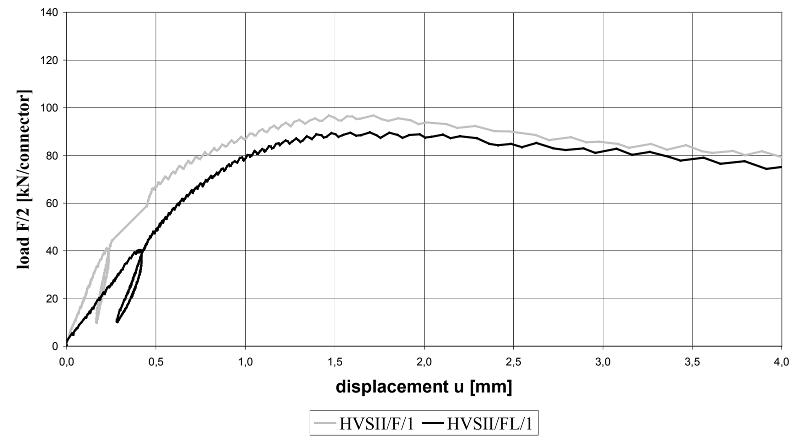


*Figure 10: Load-displacement-curves of pushout-test*


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### 5.2 Results of the bending tests

*Specimen HVB/F*

At the load-displacement-curves of the deflection (figure 12) 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. At the front edges no relative displacement between nail-laminate and concrete cover was observed in the 0 to 3,5 kN range. In the range of 3,5 to app. 65 kN 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 in increase from the supports to midspan 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 45 kN. 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 the connector locations and the compound joint was opening.

*Specimen HVB/FL*

For these specimens a constant increase of deflection was also observed (figure 11). The curve shows an approximately linear progression at first, followed by a plasticating area. No relative displacements at front edges between timber and concrete were registered under low load level. Only after further load increase relative displacement grew linear up to loads of approximately 85 kN. 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 figure 11 it has to be kept in mind, that the nailed laminate of the FL-series features a higher bending stiffness because of varying lamella height.

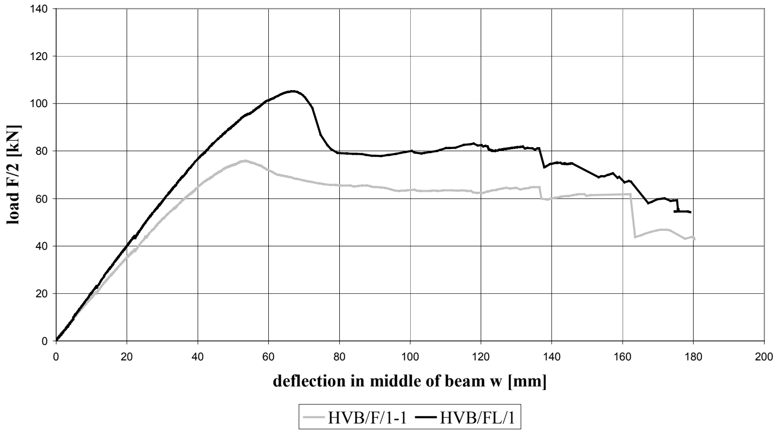


*Figure 11: Load-deflection-curve of a typical variant*


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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 app. 540 kN/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 HVB/FL did not result in an improvement of connection compliance also.

### 5.3 Failure behaviour

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 for HVB/F and HVB/FL-series firstly occurred in the area of the flat steel lock, which was closest to the support (axes C and N, figure 8). For the timber only hardly observable plastifications occurred in the area of flat steel connector.

## 6. Modelling of structural behaviour

The modelling of the composite construction is quite complicated. The formulation of equilibrium and compatibility conditions of the elastic connection between cross-sectional parts produces differential equations, which usually not allow a closed-form solution. For the special case of a simply supported beam with continuous shear connection a specific solution can be found in german code DIN 1052-part 1. This solution is based on a contribution by Moehler [4]. The method may be applied to timber-concrete composite structures, if certain conditions are kept. Other calculation-methods are the γ-method by Aicher/Roth [5], a strict solution of differential equations by Natterer/Hoeft [6], a transfer matrix method by Kneidl [7] or Hoeft [8], lattice frame models [9] [10], a bending beam model with shear deformation by Kreuzinger/Scholz [11] and other finite element formulations.
The simplified method according to DIN 1052 cannot simply be applied to nail-laminated composite elements, which only connected at discrete points by flat steel locks. The use of flat steel locks is characterised by larger distances between the connectors, so applying a framework model seems suitable. Because of simplicity such a model seems also advantageous under practical aspects.
In the proposed framework model, concrete and nailed laminate will be simulated by structural members in longitudinal axis direction. The deflection of both members is coupled by further elements. At the connector locations additional elements are arranged perpendicular to main axis of concrete and timber. These elements are simply hinged at compound joint location.


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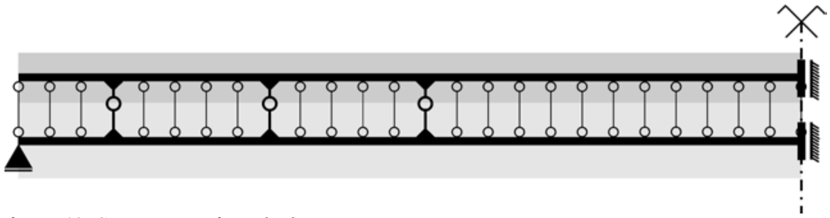


*figure 12: Static system for calculation*

The model permits an arbitrary location of the flat-steel-locks and additionally considers the skips of internal moment, resulting from eccentric load transfer at the locks. The internal forces of the model can be taken for design without modifications.

## 7. Summary

The test series have shown, that the practical application of flat-steel-locks for the transfer of shear forces in the compound joint of timber-concrete composite elements is principally possible. Although only three connectors were taken in the outer third of the member, an increase of bending stiffness was obtained. For most practical applications the prove of serviceability becomes decisive, so design load could be increased considerably.

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