Prefabricated wood-concrete Slabs

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Summary

The purpose of this research project is to develop a prefabricated wood-concrete product to widen the field of composite technologies. First an already known connection system has been technically and economically optimized in order to be used in a prefabrication process. Industrial prefabrication offers the advantages of dry construction and opens new application fields for wood-concrete floor systems. Several experimental investigations were necessary and completed by numerical simulations. The first applications were realized and tested in pilot projects in order to confirm the feasibility of prefabricated wood-concrete composites slab elements. High performances, wide spans, rapid execution and high precision could be achieved by an optimal connection system, fibrous concrete reinforcements and adequate joint connections. Acoustic performance, fire safety and seismic resistance are particularly important to combine the advantage of cast in place wood-concrete-composite floors with the benefits of prefabricated construction.

1 Conditions

The prefabrication process allows to use wood-concrete slabs for dry construction and to provide an advantage in market competition for wood constructions. Carpenters and wood building companies are not used to concrete technology and will need specific training to build with wood-concrete technology. A high degree of prefabrication can however ensure a quick assembly and therefore an economic building process. The use of wood for the lower part of the composite provide an a high quality ceiling, allowing the design of interesting aesthetic features. The industrial fabrication of the elements allows a precise control over the material process, fulfills high quality standards, and reduces considerably the construction time.

2 Execution

2.1 Materials

An industrial glulam panel is the basic wood component of the system. As a beam, lying in a horizontal position, it serves as form for the concrete layer and works as structural element with a width reaching 1.25 m. Since glued laminated panels have no joints over the length of the panel, they have the advantage to be stiffer than nailed laminated panels. The applied concrete layer on the top is connected to collaborate with the wood panel. The tested prototypes were built with spruce GL 24 and GL 27 and concrete C25/30 or more. The size of granules was limited to 16 mm. For the reinforcement against shrinkage, conventional steel rods were used, but investigations about fiber reinforcement showed higher performances. Following the on-site assembly of the prefabricated elements, the joints between the wood-concrete panels have to be made with high resistance crout to ensure transversal load transfer.
2.2 Connectors

After some comparative tests, an interlocked system with grooves had proved to be the most efficient to connect the concrete and the timber layer compared to various standard systems for the following reasons [1]:

- Continuous crossing grooves provide high stiffness and high loads.
- With an adapted groove design, the failure occurs by local crushing of the wood interface, leading to a ductile failure mode.
- The fabrication of grooves could be done by computerized cutting systems, providing competitive costs for connections.
- The test results show a small interval of deviation, which is an important advantage to other connectors systems.

Shear tests were made to optimize the geometry of the grooves regarding length, depth and angles (Fig. 1). The very first investigations and developments of grooves as shear connectors in nailed laminated panels were realized by J. Natteyer [2], further tests followed at the ETH Zurich [3] and the University of Stuttgart [4]. Different points of views concerned the question whether or not a steel connector is necessary to ensure a tension connection between wood and concrete. In our tests no tension forces could be detected, however steel connectors, such as screws, reduce the gap due to shrinkage between concrete and wood.

2.3 Shear and bending tests

Shear tests were not sufficient to analyse the global performance and the displacement characteristics of the connector. Therefore 12 bending tests were achieved. The geometry of the groove system was designed to lead to a ductile compression failure in the timber part of the section. Figure 2 is presenting the load displacement diagram recorded during experimental testing.

Following the shear tests on various connection systems and the parameter studies on the groove connection, bending tests were undertaken [5]. Full-size composite elements were tested in order to investigate the global behaviour of the elements, detect failure modes, and recognize the influence of the number and the position of the connectors.
3 Prefabrication options

3.1 Requirements

Prefabricated composite elements need a sufficient transversal stiffness to distribute point loads and to meet the requirement regarding ultimate and serviceability limit states. An transversal connection is also needed to reduce vibrations and to improve the fire resistance. Different systems of transversal connections were tested to ensure an efficient shear panel for bracing horizontal loads. Most conventional floor systems in wood are limited to uniaxial linear systems. Cast in place wood-concrete-composite floors achieve a transversal stiffness due to the continuity of the concrete layer.

3.2 Transversal Connection

To preserve this advantage, a transversal connection could be provided by the following options [6]:

- Grouting of the concrete layer
- Steel connectors in the concrete layer combined with welding
- Overlap of the layers
- Connection of the wood elements with for ex. spring groove profiles

To be efficient, the spring groove profiles of wood, as well as overlap of the layers, must be very precise which can cause fabrication problems. Connectors are a reliable solution but they are expensive and their assembling is time-consuming. The connection of the concrete layer using a profiled casting joint in the concrete seems to be a simple and economic solution. It was tested to resist shear forces in the two horizontal directions in order to contribute to the bracing system. A comparison of several connection solutions allowed to identify the best joint. Needing no reinforcement, cast-on-site joint using adequate grout showed satisfying static, dynamic and fire performances [7].

3.3 Geometry of transversal joints

The existing codes (i.e. DIN 1045; ÖNORM B 4705; ÖNORM EN 1992) for reinforced concrete structures provide details and requirements for casted joints between prefabricated concrete elements. These recommendations could not be applied since the thickness of the concrete layer is too small compared to conventional concrete slabs [5].

Consequently, special tests were necessary to investigate the joint. The first tests showed a good load transfer for both pointed and edgeless noses, but further investigations with dull angles confirmed a better performance. The geometry of the joint had to be adapted to the requirements of nose covering and angles (Fig.3).

![Fig. 3: Transversal joint](image-url)
3.4 Load bearing performance of joints

Since the investigated joint was not conform to the geometry defined in DIN 1045 (Figure 73a), specific tests were required. Experimental testing had to prove the feasibility of wood concrete composite slabs and show its behavior under loading, defining the load-displacement relationship. Investigations were made on full-scale prototypes, using load transmission tests between neighboured elements.

The force transfer in the grouting between two elements happens with struts according to the trussmodell. The horizontal component of this strut leads to a spread causing a crack in the concrete. As it was delicate to calculate the forecast of this failure, the influences and failure loads were determined by laboratory tests (Fig. 4). Small scale tests allowed to identify cracks and peak loads under changing conditions, and to link the results to existing design rules [8].

Fig. 4: Loading model for small-scale tests

Full scale tests were necessary to identify the load transfer between neighboured elements, the load displacement of both elements and the force progression along the connected side. Four-point-bending tests, with loading only on one structural part, identify the interaction between both elements under a realistic load scenario.

Fig. 5: Element bending tests

The test results showed how existing design rules could be adjusted to fit to the geometry of the composite joint. Therefore, the procedure in ÖNORM EN 1990 (2004) “design by testing results“ was applied. The variation of input parameters as well as the numbers of test had to be considered.

As a result, it was noticed that DIN 1045-1 (2004) provide a lower design level than the experimental results, but these investigations concern only one height of element. Furthermore, the DIN 1045 design rules for the joint are based on the work of Zillich and Paschen [9] using the deterministic design level. Consequently, the application of DIN 1045-1 seems to provide safe results for geometrically modified joint as there will be used for prefabricated composite elements. According to DIN 1045-1 the shear resistance of a 10 cm thick concrete layer \( V_{R,joint,0} = 7.5 \text{ kN/m} \) [10]. The influence of several heights and different concrete qualities can be adjusted by term (1).

\[
V_{R,joint,d} = V_{R,Fuge,0} \cdot \sqrt[3]{\frac{f_{ck,cube}}{45}} \cdot \left( \frac{h}{10} \right)^{1.44}
\]  

(1)
The width of the investigated prefabricated elements was limited to 1.2 m. To determine the highest load transfer only one element was loaded, while neighbored elements stayed unloaded. Numerical examinations of the bending test allowed to assert that up to 37% of the load is transferred from one element to the next. The proportion between pick load and average load along the element side is 1.44. The forces $Q_{\text{joint}, Ed}$ acting on the joint can therefore be calculated (2).

$$Q_{\text{joint}, Ed} = \gamma_Q \cdot q \cdot f_{\text{joint}} \cdot f_{\text{parab}} \cdot b_e \leq V_{R,\text{joint}, d}$$ (2)

- $\gamma_Q$: safety factor for variable loads
- $q$: carrying load [kN/m²]
- $f_{\text{Fuge}}$: =0.37 part to be transmitted by the joint (experimental value)
- $f_{\text{parab}}$: =1.44 ratio between maximal and mean value
- $V_{R,\text{joint}, d}$: Resistance of the joint (Term. 1)

$$Q_{\text{joint}, d} = 1.5 \cdot 5 \cdot 0.37 \cdot 1.44 \cdot 1.2 = 4.80kN/m \leq 4.86kN/m = V_{R,\text{joint}, d}$$

$V_{R,d}$: Resistance of the joint per m for concrete quality C30/37 (without horizontal anchorage)

4 Behaviour under vibrations

No scientific work on vibration behaviour of prefabricated timber concrete elements was found. The dead load offers not enough weight to avoid resonance under characteristic vibrations. Measurements on pilot projects helped to investigate the positive damping effect provided by a transversal connection system between elements. To determine the mass effect of the biaxial system, vibrations were applied by an impulse controlled incitation. The acceleration response of the composite element was recorded using an analyzer. A numerical calculation of the response was possible by segmenting in several short impulse loads (Duhamel’s integral allows to superpose the impulse responses) [11]. Since the stiffness and the damping effect are known, the effective mass can be determined (Fig 8).

$$m_{\text{Total}} \approx m_{\text{element}} + 2 \cdot m_{\text{Neighbour-element}}$$ (3)
5 Sound insulation

The impact of sound transmission is a decisive criteria to design wood floor systems in Austria. The required impact-sound-damping of 48 dB is a difficult barrier for most of traditional floor systems in wood. With the mass effect of concrete, connected timber-concrete systems can provide better properties, but only an adjusted superstructure guarantees sufficient results. Special investigations were made in a two-storey prototype building to determine the performance in combination with appropriate floor compositions.

6 Behaviour under seismic loads

The behaviour under seismic loads is also an important design criteria for floor systems since they have to contribute to the overall structural stability. Investigations under dynamic loading according to vibrations of earthquake loads had to be realized to determine the shear capacity of the wood-concrete interface as well as the stiffness of the floor system. The groove connection had to be improved in order to offer additional transversal stiffness. The interface connection must resist the horizontal accelerations of the concrete slab, as well as the bracing forces, to ensure the stability of the building under earthquake loads. Additional devices were tested to improve particularly the transversal strength of the floor system.
7 Conclusion

The so-called „Tyrolean timber-concrete floor system“ was developed for industrial fabrication of high performance slabs with excellent overall performances combined with the possibility of intensive prefabrication production. Besides the load carrying capacity, various requirements had also to be satisfied. Intensive analytical investigations, additional devices, new technologies and experimental testing were realized to optimize the overall performances concerning static, dynamic, acoustic and fire safety requirements. The results showed that prefabricated wood-concrete floor systems can satisfy the performances of cast-in-place timber-concrete-composite floors. The new floor system combines the advantages of connected wood-concrete floor systems (medium weight floors with high acoustic and fire safety performances) with the advantages of the prefabrication technology (dry construction process, quality of industrial production and shorter construction time). Finally, the economic competitiveness had to be shown and was calculated by the industrial partners of the project, as well as by other Tyrolean timber construction companies. The competitiveness of the product was obviously the main target of the project in order to bring an efficient industrial product on the exports oriented Tyrolean market.

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References


