The construction of road bridges as timber-concrete composites

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Summary
The construction method with timber-concrete composites has been developed in building engineering. This technology will also be interesting in bridge construction in the future. Especially the combination of log-glued laminated beams with a concrete slab establishes new opportunities for the building of road bridges. Hybrid timber bridges have a lot of advantages in comparison to simple timber bridges. The paper gives a survey of the present development status of bridge building with timber-concrete composites and shows static and constructive specifics. The development and use of sufficient stiff connectors between timber and concrete is very important for bridge composite constructions. The results of short-time shear tests with different connector types accomplished at the Bauhaus-University are presented.

1. Introduction
Since ancient times timber has been using for building viaducts. During the rapid development of new structural materials in the 20th century it became modern to use steel and concrete for building constructions, so these materials squeezed the traditional timber out of the market. The usage of timber will be progressive again due to new technologies, innovative products and the increased environmental sensibility. A lot of timber bridges, that have been built in the last 25 years, demonstrate, that efficient load-bearing structures, aesthetic design, durability and economy are practicable by building with a natural material.

The construction of hybrid timber-based elements could be of interest for building timber road bridges in the future. Material’s favourable properties could be expediently used by combining concrete in the compression zone with timber in the tension zone to a composite structure. Especially the combination of log-glued laminated beams with concrete slabs is promising. Aesthetics of high quality are realisable using multiform slim cross-sections curved in ground plan and elevation.

2. Timber-concrete composite construction in bridge building

2.1 Development status
In the Thierties of the last century bridges as timber-concrete composites were built for the first time. Any remarkable buildings have been developed especially in the USA, like the Keystone Wye Bridge, South Dakota. Timber-concrete composite bridges have also been built in Australia since at least 1945 [1]. Switzerland, Austria, France and Finland bring forward this new construction method in Europe [2], [3]. A model code for timber-concrete composite bridges with spans from 10 to 30 m and road widths from 4,50 to 8,50 m has been developed and put into practice within the large research program “Nordic timber bridge project” in Finland [4].

The superstructure of a timber-concrete composite bridge consists of a concrete slab ductile connected with timber main girders. Slabs and T-beams are possible as cross sections. It is favourable to design hybrid timber bridges with T-beam-cross sections because of the constructive criterion of the minimum concrete heights and in consideration of meaningful stiffness proportions between the partial sections.
A single-web T-beam cross-section is shown in Fig. 1 as an example for a viaduct of a single-lane road. The analogue construction of a dual-web T-beam cross-section is possible for a viaduct of a two-lane road.

Many problems occurring at timber road bridges could be solved by a combination of log-glued laminated beams with a concrete deck. Advantages like high load-bearing capacity with small construction height and improvement of vibration performance are well known from building engineering. Moreover, additional advantages arise for bridge building with timber-concrete composites in comparison to pure timber bridges. The concrete deck provides an ideal constructive wood preservation. The life cycle of such protected bridges is twice as high as that one of simple timber bridges [1]. Investment for maintenance decreases. The distribution of high loads per axle and the transmission of horizontal loads can be realised more easily by the concrete deck. Connection details proved in construction of concrete bridges and have been accepted by the national highway administrations could be applied. The stiffness and dimension stability of the superstructure increase when log-glued laminated beams as main girders are used. Previous constructive restrictions regarding the gauge of the main girders are cancelled. Log-glued laminated elements could be produced horizontally or vertically (Fig. 2).

Additionally the superstructure is lighter in comparison to concrete bridges. Therefore it is possible to effect economy in the fields of foundations and bases. A high prefabrication level, short assembly and cut-off time could be realized by the application of precast concrete components.
A disadvantage of timber-concrete-composite constructions is the different time and climatic 
dependent behaviour of the composite materials. Cognitions of building engineering concerning 
these differences could not be transferred easily to bridge building, because the variation of 
moisture and temperature which has to take into consideration for design of bridges is much higher 
than that of constructions inside a building.

2.2 Connectors

The design of the connection is very important for the load-bearing capacity of hybrid 
constructions. The stiffness of the hole construction is considerably influenced by the connector’s 
stiffness, its numbers and location in the cross section.

The stiffness and design load of connectors having been developed for slabs in building engineering 
are too small for bridge building. Using form closure should be the best solution to transfer the high 
shear loads in the joint of bridge construction. Connectors being suitable for bridges are shown in 
Fig. 3.

![Connectors for timber-concrete composite bridges](image)

The stud connector has been developed by Steurer [5]. It consists of a steel plate with 4 studs on 
concrete side and a welded trapezoid border on timber side. So the bond to concrete is realised by a 
standardised connection and the bond to timber functions analogue to traditional step joints. This 
connector has been tested in 2 short-time shear tests and has been used in the building of the 
Crestawald Bridge (Sufers, Switzerland).

Natterer [6] devised a groove connector also using form closure. Special re-stretchable dowels 
being laminated into the timber should increase the friction resistance. Re-stretching is not possible 
in bridge building because the sealing and the pavement protect the concrete’s up-side. In [7] it was 
noticed, that the concrete is alone able to transfer the moment resulting from the eccentric shear 
loading.

A similar joint is the so called console cam developed by Glaser [8]. The tension force in the 
console is transferred by a grid-shaped reinforcement bar being laminated into timber.

The BVD-anchor is a frame-shaped steel unit transferring the shear force by two contact areas. This 
connector has been tested in short-time bending tests and has already been proved in real bridge 
projects [9].

Within the Nordic timber bridge project a lot of joints have been tested in shear tests [10]. Inclined-
glued reinforcement bars, the so called X-connectors, have been applied in most pilot bridges, 
sometimes combined with grooves.
Though any of the above-mentioned joints have been used in practice, standardised parameters for stiffness and design load do not exist. Dynamic tests of such composite joints were not accomplished contemporarily.

2.3 Specifics in load bearing performance

Some special problems occur and have to be taken into consideration when calculating a timber-concrete composite bridge.

At first it is necessary to consider the ductile bond. The compliance of the joint causes nonlinear influence functions, while the location of extreme forces is the same like in rigid bonded structures. In ductile bonded girders normal and shear forces decrease and bending moments in the partial sections increase in comparison to rigid bonded beams. This influence is especially large in the location of moment points under single loads because the jumping gradient of shear forces in rigid bonded beams has to transform in a continuous one.

Calculation of timber-concrete composites is possible in several ways. Using the lattice frame model (Fig. 4) is preferred to analytic or derived solutions because single loads could be applied, joints could be assembled discontinuously and jumping gradients in normal forces and moments are considered [11]. Concrete slab and timber beam are simulated as members in their cross section axis’s. Both parts are coupled by articulated members to enforce an equal displacement of concrete and timber. Joints are modelled as short cantilever beams getting an equivalent deflection stiffness depending on the real joint stiffness and the deflection stiffness of the several parts of the cross section.

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g \text{(concrete)} + g \text{(extension)} + p \text{(UDL, sidewalk)}
\]

![Fig. 4: Frame model for the calculation of a timber-concrete composite bridge](image)

To evaluate the long-time load-bearing capacity it is necessary to take the different time-, temperature and moisture indicated behaviour of the composed materials into consideration. The spectrum of the temperature and moisture gradients is much higher in bridge building than in building engineering. Temperature load has an enormous influence on the internal forces of hybrid bridges because timber and concrete have different temperature extension coefficients. Temperature causes constraint stresses in both parts of cross section. Bending moments due to warming a bridge at 27 K reach the values of bending moments under dead load. Deformation under warming also achieves values of self-loaded deformation. It is not possible to make a simple prediction about stress distribution in the cross section of timber-concrete composites under temperature loads in contrast to homogeneous material. The distribution depends on temperature load, stiffness of the sectional parts and of the joint. There is no proportionality between the internal stresses under different temperature loadings.

The different creeping of timber and concrete causes relocations of stretches and forces. This effect influences the serviceability and the load-bearing capacity considerably. At the Bauhaus-University a special finite element program has been developed by Hartnack [12] to simulate the creeping of timber. The rheological model for description of the long-term load-bearing behaviour of timber includes a time-, load- and moisture-dependent creep part and a swelling and shrinking part. In long-term simulations of hybrid timber-concrete composite bridges load transferring is obtained.
from the concrete to the timber section. The normal forces in both sections and the bending moment in the concrete part decrease whereas the moment in timber increases strongly. The direction of the shear forces in the outermost connectors even could change under swelling of concrete.

Details about the specifics in load bearing performance are explained at an example in [3].

3. Experimental tests

3.1 Intention and configuration

At the Bauhaus-University Weimar systematic shear tests with three different connector types have been taking place. Short-time shear tests are intended to determine the stiffness and the ultimate load of each joint at the initial state. The influence of moisture and temperature variation under long-term loading in service class 2 on the stiffness of the connectors will be recorded by long-time shear tests. Shear tests under cyclic loading will be arranged for evaluation of fatigue behaviour. These tests should show, how the stiffness decreases and the slip between the composite materials increases.

The tested connectors are shown in Fig. 5. All test specimens consists of glued laminated timber GL28h and reinforced concrete C25/30.

Fig. 5: Test specimens

The stud connector of the series S consists of a steel plate with 2 cm thickness, anchored in concrete with 2 welded studs with 19 mm diameter. The transmission of the shear force in series K occurs by grooves of 20 mm depth without any dowels. Respectively two tension and compression reinforcement bars with a diameter of 14 mm were inclined-glued into the timber part of the test specimens of the series X. A two-component epoxy resin adhesive has been used for gluing.

3.2 Short-time shear tests

In September 2005 short-time shear tests as push-out tests were accomplished with the described timber-concrete composite elements. Experimental procedure and load history were taken according to DIN EN 26891 (Fig. 6). Relative displacement between timber and concrete was recorded with 4 dial indicators placed at front and back side in the middle of each joint.
Fig. 6: Experimental procedure and load history of short-time shear tests

Fig. 7 shows the load-displacement-curves of several test series. All test specimens showed a real ductile performance until reaching the ultimate load. Test specimens of the K-series have broken down under longitudinal compression and shear forces at timber and under concrete cracking in the grooves zone. The failure of the S-specimens happened analogue to those of K-series by fracture under longitudinal compression and shear in the timber zone in front of the grooves. Specimens of X-series failed at the breaking of a tension bar.

Fig. 7: Load-displacement-curves of short-time shear tests
X-specimens showed the highest stiffness and reached the highest ultimate load in comparison of all series. Both mechanical properties depend on specimens geometries and could be adjusted to required values by variation of geometry parameters.

Short-time shear tests of S-series should be verified using a finite element program (Fig. 8). A complex 3-dimensional nonlinear material model, developed by Grosse [13], has been adopted for description of material behaviour of timber. This model considers the specific anisotropic and load dependent strength and degradation behaviour. Characteristic failure modes of timber are included in a multi-surface yield criterion. Cracks are not represented discretely but as plastic strains. The experimentally observed failure of timber in front of the grooves of S-specimens could be well pictured by the computation (Fig. 9).

3.3 Long-time shear tests and dynamic loading

For building bridges as timber-concrete composites it is necessary to consider the different time-, temperature- and moisture-dependent behaviour of both composite materials and the behaviour of the joint especially under conditions of service class 2.

Since December 2005 respectively 3 specimens of the 3 series have been testing in long-time shear tests. About 30 % of the ultimate load being determined at the short-time shear tests have been applied by a spring construction. Displacements at each joint and moisture of timber are recorded manually while climate chronicle is permanently captured digitally. Test configuration and measurement system are adjusted to the climate conditions of a 5 year roofed outside-storage.

Shear tests under dynamic loads are presently accomplished. Loading procedure has been chosen so that stress amplitudes and load cycles being relevant for road bridges are included.

After finishing all test series principle statements about the suitability of form closure for joints in timber-concrete composite bridges are possible.

4. Conclusions

Innovative ideas and new technologies could promote the appliance of timber in bridge building. Transferring the innovation of timber-concrete composites into bridge building a new viaduct system could be developed that could coexist equally beside concrete and steel-composite bridges.

An essential prerequisite for this development is the standardised determination of modulus of displacements and design loads of suitable connectors. Systematic analysis is necessary in short-time, long-time and cyclic tests taking the different time-, temperature- and moisture-dependent behaviour of both composite materials into consideration. The results of such tests could contribute to verify the shear stiffness approach of the connection between timber and concrete which is the most evident construction parameter for timber-concrete composite road bridges. Shear and bending tests with stud connectors and a comprehensive parametrical study for hybrid timber bridges will be accomplished at the Bauhaus-University within the next month.
5. References


