Bloc Glued Laminated Decks for Timber Bridges

- by now, a proven design in Germany

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1. Introduction

In timber bridge construction major designs developed as early as the 19th century (see also [3]). The development of new glueing methods ("Hetzer" girder, veneered laminated woods, derived timber products) and of connecting techniques, the analysis of the dynamic load resistance of parts and connectors, the application of close-graded surfaces, and intelligent assembly methods have opened up, time and again, new possibilities for laminated structural timber constructions. The harmonisation process in the course of the establishment of European and international standards was also instrumental in the exchange of expertise and findings.

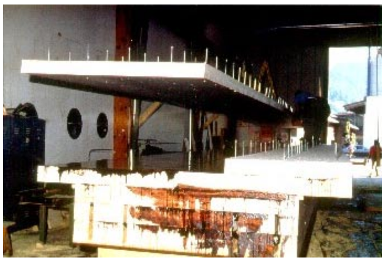
Timber bridge constructions received an enormous drive with the evolution of glueing techniques. In the following, some bridge constructions in Germany with glued box-sections, made of so called "bloc glued" laminated girders, are presented (see also [2]). The experiences made in Germany with different types of glue, glueing techniques and moisture behavior of box-sections are also shown.

2. Examples of bloc glued bridges

2.1 Horizontal bloc glueing by the example of the bridge in Reichenbach

In 1989/90 the first bloc glued bridge made of timber girders, curved in plan and elevation, was built in Reichenbach city over the river Fils. The bridge for pedestrians and cyclists with an overall length of 204 m, spans the river Fils and the national highway B 10 (*Fig. 1*) and additionally the Stuttgart-Ulm railway line [6], and has an asphalt surface.

Fig. 1 View of pedestrian and cyclist bridge at Reichenbach / Fils (D)



As *Fig. 2* shows, the box-section consists of six 16 to 24 cm wide glued laminated girders which were glued with a special resorcin adhesive with a filling capacity. During the horizontal glueing process, pressure was maintained by wire nails. The compression to be achieved according to the recommendation of FMPA in Stuttgart was 5 N/mm². As it was a so called "open" bridge (without a roof, but with a mastic asphalt surface), extensive investigations were performed outdoor in 1989 (*Fig. 3*) with respect to the load-bearing capacity and deformation characteristics of the glued laminated girders.

Fig. 2 Nail pressure glueing of the laminated box-section

The result was, that there was no increase in load-bearing capacity – also the glue bond showed no cracks.

Fig. 3 Testing girder Reichenbach bridge – Continuous test

2.2 Vertical bloc glueing by the example of the bridge in Wernau

In close vicinity of the Reichenbach bridge, in the city of Wernau, a bridge was built over the river Neckar two years later (*Fig. 4*). Here too, glued laminated girders, curved in plan and elevation were used [6]. *Fig. 5* shows the prestressing formwork fabrication. The box-sections 55/220 cm were made of glued laminated timber beams, 16/55 cm, in an upright position. With this „vertical glueing method“ the glue joints are nearly unstressed once the girder is erected.

Fig. 4 View of pedestrian and cyclist bridge in Wernau spanning the river Neckar (D)

Fig. 5 Prestressing formwork of bridge in Wernau / Neckar (D)

2.3 Road Bridges in Germany

Fig. 6

Toll road over the "Sausenden Graben" between Wallgau and Vorderriß

Timber bridges for heavyweight traffic are (still) rare in Germany – in Austia they have an experience for more than 20 years [3]. Following bridges built in 1985 in Stuttgart-Weilimdorf, a further road timber bridge was built in Germany in the mid-90ies.

Fig. 6 shows the toll road bridge over the "Sausenden Graben" between Wallgau and Vorderriß in Bavaria. After a limited design competition which required the use of timber, this bridge replaced the badly dilapidated concrete road bridge, class 30/30, in 1996. A bridge class 30/30 means, that two vehicles with a total weight of 30 kN can stand on the bridge. The bridge has a total length of 34,50 m and a width of 6,50 m. The superstructure rests on two concrete abutments and four wooden cross-columns (cf. *Fig. 7*).

The bloc glued laminated bridge-section were delivered in two halves which were connected, resistant to shear and bending, via a nailed longitudinal joint. Wood protection was realised with 27 mm thick KERTO veneer laminated wood panels, which were glued in advance on the top and bottom, and a mastic asphalt surfacing. More details are available in [1].

Fig. 7

Detail view of bridge support over the "Sausenden Graben"

3. Glue and glueing methods

Fig. 2 and Fig. 5 already reveal that the production of bloc glued sections require a high degree of workmanship. Dimensional accuracy of the wood surfaces in the area of the glued joint plays a crucial role for this type of connection. Joint-filling glues must be used since planeness can only be guaranteed within the range of a few mm.

At the same time, the compression of 8 N/mm² required for resorcin type glue [11], would have implied the application of enormous prestressing forces in view of the large surfaces to glue. The development of glues therefore was aimed at providing joint-filling glues which required lower compressions.

As shown in the example of the bridge in Wernau, the initial approach was to glue bridges in an upright position so that the glued joints are not exposed to shear stress due to bending but distribute wheel loads over several girders.

After more than a decade of research, scientific support and testing, new glues based on epoxy resin and polyurethane are allowed to be used in Germany [12]. In this way, the requirements specified earlier can now be complied. In the future, this will allow glueing in a horizontal position and still provide satisfactory stability - also in view of the shear stress on the glued joint - when dimensioned according to [13].

From aesthetic aspects, a frequent question concerns the use of colorless glues so that the dark brown joints of the resorcin glue don't show off so prominently.

From economic aspects, the glued laminated girders lying outside and inside are also produced with different glues, as can be seen by the example of the bridge in Rheinfelden (Fig. 11).

In the case of massive box-sections it would often be reasonable to design hollow-cross-sections in terms of economic efficiency, as shown in the following example.

4. Moisture behavior ,
Calculation example of a hollow box design

Fig. 8 shows the pedestrian and cyclist bridge near Weikersheim city. It features a hollow-box-section for the integration of pipes. The cost of the superstructure totalled Euro 43.700,-- net, with a span of 22,5 m and a clear width of 5 m (777,-- Euro/m² of bridge area). This also included the lighting integrated in the handrail.
This bridge design offered savings in material of approx. 30% leading to a price which was approx. 5.000,00 Euro lower than for a massive box-section without any holes.

Such special designs frequently lead to questions concerning the possibility of water condensation inside the hollow box and thus of premature decay. The following study shows that the author considers this possibility as very improbable. The depicted bridge has therefore been fitted with a small access hatch. Over a period of 12 months the climatic conditions in the hollow box will be measured with a hygrometer in order to deliver data on the problem. Additionally, this bridge has a ventilation of the interior by means of an air inlet and outlet is recommended. The in- and outlets should be arranged in such a way, that they provide a continuous draft.

Fig. 8 Pedestrian and cyclist bridge "Heiliges Wöhr" at Weikersheim

5. Costs

5.1 Pedestrian and cyclist bridge over the motorway A 98 near Rheinfelden

Fig. 9 Pedestrian and cyclist bridge over the motorway A 98 near Rheinfelden

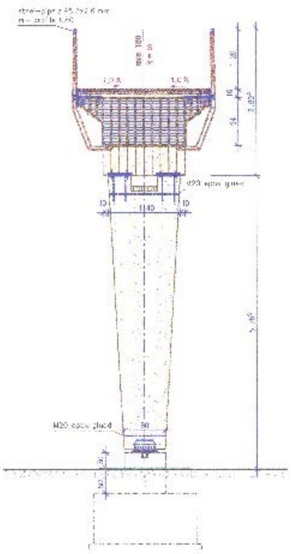


Fig. 10
Bloc glued cross-section (above)
and view of the bridge column

The bridge fig. 9 was planned as a wooden construction to fit the landscape and the traditions of the southern Black Forest. Other proposals offering other materials, however, were also admitted. The evaluation of proposals showed that the best proposal of a reinforced concrete bridge, which ranked fifth place, had costs 10% higher then the official tender.

The construction is a framed bridge with effective spans of 14,85 / 30,30 / 18,35 m measured in bridge axis. Two individual piles fig. 10, made of glued laminated timber, serve as the centre support for the superstructure. These piles are arranged parallel to the motorway and centrically under each web of the superstructure. They are 30 cm thick; their width tapers from 1,40 m at the joint to the superstructure, to 0,80 m at the block foundations.
The superstructure was planned as a vertically glued bloc-T-beam.

All wooden surfaces were painted with a chemical wood preservative against fungi and insects, and with two protective hydrophobic coats. The glued laminated girder was protected against direct climatic effects by the tight surfacing of the walkway. The on-cutted wood fibres of the girders on the lower side were protected by subsequently mounted cover segments. The diagonal members were protected on all sides against climatic effects by means of a glued vertical board formwork or by wooden panels.

The first step in construction was to form a 1.60-meter-wide box-section. The two outside girders of this section were glued with resorcin glue, whereas the inner trusses were glued with a resorcin-phenol-formaldehyd-glue (*Fig. 11*). The girders themselves were glued with a resorcin-based glue. To do this, the trusses were stacked on top of each other, stressed together with a conventional tool by stiff steel beams, placed at a sufficient distance in a double-layer of black foil and heated to 23°C. By additional spacers and tapping screws in the underside web member, the resorcin-glued cantilever arms of the T-cross-section were then jointed with the rectangular box section by means of resorcin-based glue. The glue was applied with a specially developed device that took into account the relief grooves, i.e. surfaces to which no glue is applied.
The bridge was fully constructed in approximately four months.

Fig. 11
Box-section of wood
used for the completed deck

5.2 Hollow box bridge Uttenreuth

Fig. 12 shows the cross-section of the pedestrian and cyclist bridge Uttenreuth with a width of 2.50 m and a span of 3.70 m. According to the information from the construction company the hollow cross-section had been selected because of the cost savings of approx. 16% - taking into account the lower dead weight and material savings - compared to a box-section of the same bearing capacity (see also bridge Weikersheim, fig. 8). In relation to one square meter of bridge area this would lead to savings of 170,-- Euro/m².

The cost of this bridge totalled approx. Euro 70.000,-- net; the savings in material as a result of the hollow cross-section of the same bearing capacity, amounted to approx. 43% (also see fig. 8).

Especially for difficult cases of foundation it must be taken into account that the reduced weight of a hollow cross-section provides for savings in the foundation itself.

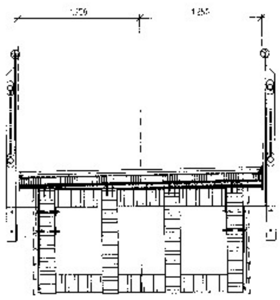


Fig. 12 Hollow cross-section Uttenreuth bridge

5.3 Special proposal road-bridge Donaueschingen

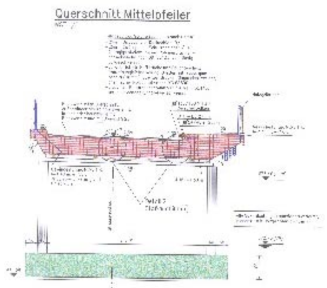


Fig. 13

Design of a box-section for road bridge, bridge class 60/30 (that means one vehicle with a total weight of 30 kN, one vehicle with a total weight of 60 kN)

Figure 13 shows the special proposal for a two-span, two-lane road bridge near Donaueschingen city with spans of 14 m and a mastic asphalt surfacing. In the meantime however this bridge was built in prestressed concrete, in line with the official design. Yet, an important finding in this project, which was in agreement with the calculations of the engineering office, was that the annual maintenance costs of both bridge types were roughly in the same order of 1,3 %.

On the basis of much more than the 62 wooden bridges, described in [3], it was shown in the studies [10], [7] and [9] that the maintenance costs amount to

- **maximum 1.3 %** **for protected, i.e. roofed timber bridges or bridges with covered girder elements, or**
- **maximum 2.1 %** **for unprotected, i.e. bridges with open surfacings**
- related to the cost of new construction, including inspection and control. These values are lower than the values currently specified for maintenance costs in the applicable rules of 1980 of the Federal Republic of Germany (so-called “Ablöserichtlinien“). A revision of these directives however is pending.

In this context it must be taken into account that this draft still distinguishes between roofed and non-roofed bridges instead of between protected and unprotected main load-carrying elements.

The fact that the 1999 issue of DIN 1076 [14] no longer links the intervals of recurring inspections to the bridge material used, is further evidence that the durability of well-designed, protected timber bridges is by now generally acknowledged and accepted in Germany’s professional circles.

The opening of the tenders revealed that the companies which had offered pure reinforced-concrete designs ranked 1st, 3rd, 5th and 7th , followed closely in the ranks with even numbers, by the offers of timber construction companies (see fig. 14). It was interesting to note that the price advantage of the construction companies working only with reinforced concrete was between Euro 30,000.00 and Euro 50,000.00 in relation to what was offered by a reinforced-concrete construction company which had been subcontracted by the timber construction firm for the substructure. This simply means that the reinforced-concrete construction firms included the profit margin calculated for their own proposal, at 100% into their subcontractor proposal to the timber construction firm. For more than 20 years this has been a well-known practice from the field of composite structures in steel and concrete, which led to the fact that over many years the steel construction industry with their new designs faced a very difficult market environment.

Carpenters and foresters often criticise that non-roofed timber bridges with glued box-section and a reinforced concrete carriageway or mastic asphalt surfacing lack the typical character of a (pure) timber bridge. However, in this context it must be taken into account that the requirements posed to bridge constructions have increasingly been stepped up in the last decades. The robustness required especially for road bridges and the resulting lower construction and maintenance costs were instrumental in pushing timber bridges to the background over the last hundred years. Now that it is possible to glue individual trusses into bloc glued laminated girders, i.e. into solid closed box-sections, it is also possible to build road bridges with a timber superstructure at a competitive price. The examples of Donaueschingen and Rheinfelden are clear evidence of this.

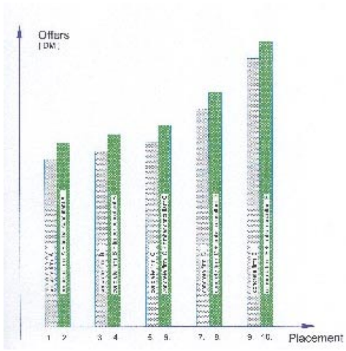


Fig. 14

Schematic diagram depicting the result of a tender

6. Summary

In recent years timber as a natural and reusable resource has gained importance for bridges design and building. In addition to the virtually unlimited design options, the rising costs for energy, the modification and dismantling possibilities, and the disposal are in favour of timber as a building material. Proper treatment provided (especially constructive wood protection) timber offers a high service life; timber bridges over 200 years old – especially in the Alpine countries - prove that *(Fig. 15*). Timber offers advantages in comparison to other building materials on account of its high bending resistance in relation to its light weight. And last but not least the low maintenance costs speak for themselves ([7], [10]); especially of roofed bridges (Fig. 14) and of timber bridges with close-graded surfacings (Fig. 4 or Fig. 9).

Fig. 15

Road bridge Andelfingen over the river Thur (CH), built up in 1815

The evolution of glueing techniques and close graded surfacings permit wooden bridges of attractive design. The experiences made in Germany with Bloc Glued Laminated Girders were presented in detail. With the new german standards [12], [13] it is fully justified to speak of a proven design.

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