The world's largest timber bridge

H. Krenn, Th. Moosbrugger and Th. Bogensperger
Graz University of Technology, Institute for Timber Engineering and Wood Technology, Graz, Austria

ABSTRACT: In 2005 the Authority for Substructures of Graubünden (Switzerland) carried out a project competition for a bridge spanning 240 m across the River Inn. The project guidelines were very high in technical as well as architectural respects. Within the scope of this competition, the Institute for Timber Engineering and Wood Technology at the Graz University of Technology worked out a concept, that was tendered entitled "GHW – Größte Holzbrücke der Welt" by the Swiss engineering consultants timbatec® Stefan Zoellig. The designed load bearing system consists of prefabricated concrete carriageway slabs which are borne by parallel and lengthwise shifted arranged glued-laminated timber beams. These beams are supported by glued-laminated timber columns. Approximately two thirds of the total length are spanned by a parabolic arch with 36 m rise of arch and support points at different levels. The arch itself consists of five parallely arranged box girder elements composed of glued-laminated and cross-laminated timber.

1 INTRODUCTION

In autumn 2005, the Authority for Substructures in the canton of Graubünden (Switzerland) carried out a project competition with the aim to connect the two communes of Tarasp and Vulpera by a new bridge, spanning 240 m across the River Inn. The standards of that projection were very high in technical as well as in architectural respects. The geology and the precipitous terrain bear risks and crossing high over the ravine leads to high demands on the appearance of the bridge. At the same time an economic solution had to be found. During the competition, a first project had to be worked out including a clarification of the technical feasibility.

Within the scope of this competition, a concept for a timber-concrete-composite spandrel-braced arch bridge was worked out at the Institute for Timber Engineering and Wood Technology at the Graz University of Technology. A slightly modified concept was later presented at the project competition by the Swiss engineering consultants timbatec® Stefan Zöllig entitled "GHW – Größte Holzbrücke der Welt".

This paper deals with the requirements of the awarding authority, the engineering aspects with respect to timber engineering and in particular with the technical feasibility of this timber structure.

2 PROJECT DESCRIPTION AND TENDER

2.1 *Requirements of the canton of Graubünden*

The commune of Tarasp shall be made accessible by a new, approximately 240 m long bridge off the Engadin Road to Vulpera. The existing narrow communication road to Tarasp is partly

in bad condition and has many blind bends. It is used by many commuters everyday and briskly by tourists. The narrow hairpin bends and an inclination of up to 12 % hinder the access, specifically in the hibernal months. Although it was intended to make the commune of Tarasp directly accessible by a bridge some time ago, this project was not part of the main road project until 1997. Another important requirement is to guarantee the accessibility of the existing old Engadin Road for the public traffic during the whole construction time.

The new bridge shall cross the old Engadin Road on the left hand side of the steep valley and the River Inn at an elevation of 70 meters. The bridge shall have two traffic lanes designed according to Load Model 1 of SIA 261 (conforming with EN 1991-2) and will have an inclination of 7.5 %.

2.2 Architectural requirements

The new bridge will dominate the area of the Inn-Ravine and mould the landscape. This aslant laying element will have the nature of a barrier because of the lack of other valley-crossing elements. 70 meters above the River Inn, the bridge will not be able to hide behind trees. This situation sets high standards and requires an architectural pleasing structure.

2.3 Subsoil

This part of the valley is geologically remarkable in two different aspects: On one hand the spas of Scuol and Tarasp are of great regional importance and the spring water must not be influenced by the construction works, and on the other hand there is limited stability of the subsoil. The tapping of the spas Sfondraz lies approximately 100 m upstream of the planned bridge. Single small spas are located near the bridge in the riverbed. The whole project area lies within a groundwater protection zone.

The in-situ Bündnerschiefer is partly sunken and highly weathered. In the area below the old Engadin Road on the left hand side of the valley, the layer of the brittle Bündnerschiefer falls steeply down (cp. Fig. 2). It is layered parallely and covered by granular soil of up to 12 m thickness and slope creep or slope failure can not be precluded. There are no indications of instabilities on the right hand side of the valley, even though the Bündnerschiefer there is weakened by cracks. The layer-thickness of granular soil reaches a maximum of six meters.

2.4 Aim of the project competition

The aim of the project competition was to work out a feasibility analysis and to clarify the technical feasibility, to evaluate the appearance, to estimate the costs and to audit the efficiency. In the course of the technical feasibility study, all relevant concerns of the construction process had to be studied, the geologic-geotechnical risks had to be assessed and adequate measures proposed.

2.5 Project overview

Fig. 1 shows the site plan according to the competition documentation including the course of the bridge, terrain, the riverbed and the traffic connection. Due to the traffic planning, it can be recognized that the bridge will cross the valley at an angle of about 60° to the course of the river, which directly leads to an extension of the free span of about 30 m compared to a perpendicular crossing. Because of the planned routing, there are straight as well as curved parts of the bridge. The whole building project is located at 1240 m above sea level.
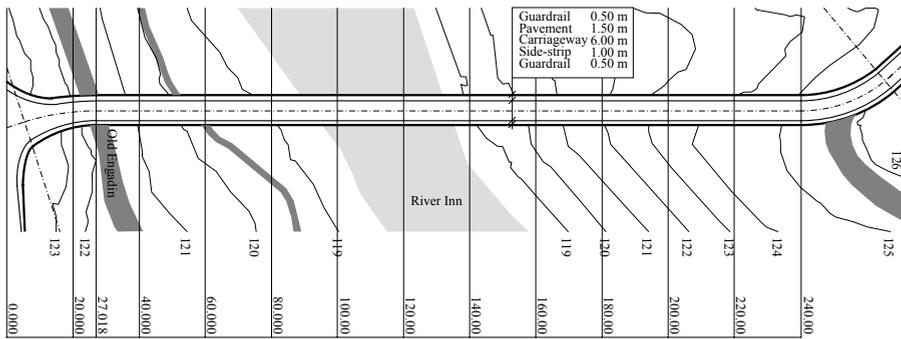
Fig. 1: Site plan

Apparent from the longitudinal section in Fig. 2, the terrain can be called a typical V-shaped valley with steep slopes which leads to a carriageway of the bridge relatively high above the riverbed. As a result of the traffic connection there are different altitude levels (approximately 18 m) of the traffic transitions as defined by the competition documentation, which corresponds to an inclination of 7.5°.

The above mentioned zones with difficult geological circumstances (cp. 2.3) and the riverbed of the River Inn are labelled in dark grey. These facts as well as the requirements mentioned in 2.1 to 2.3 restrict the amount of possible plan variants.
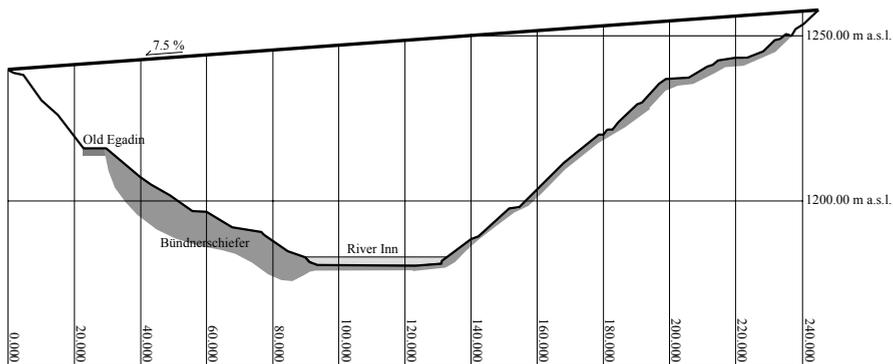

Fig. 2: Longitudinal section

3 SOME ASPECTS OF THE TIMBER STRUCTURE

As mentioned in 2.5, the course of the road resulting from the traffic planning leads to straight and curved parts of the bridge. Several reasons argue for a construction of the different parts with different construction materials, whereas the curved parts (left and right bridge bearing) are designated to be made of reinforced concrete and the remaining straight main-structure of the bridge (approximately 240 m) as timber structure. Some of this reasons are:

- clear separation of the three parts in architectural and functional ways
- clear, obvious static system with a reduced span of the main-structure
- no design eccentricities within the main-structure
- clear support points are a prerequisite for an easier construction of the timber structure
- optimal constructural wood preservation

Another very important reason in favour of a timber structure lies within the fact that the approximately required 3200 m³ of glued laminated timber (8000 m³ of logs) grow again within the Swiss Forests within only 10 hours, which positively affects the CO_2-balance.

3.1 Actions

The loads on the bridge were applied according to the Swiss Standard SIA 261 (corresponds with the European Standards of the series EN 1991 and has to be applied to all types of structures). For the traffic loads, Load Model 1 with an adjustment factor $\alpha_{Qi} = \alpha_{qi} = 0.9$ was applied:

- Lane No. 1: An axle load of $\alpha_{Qi} Q_{ki} = 300$ kN for the tandem system and a uniformly distributed load of $\alpha_{qi} q_{ki} = 9$ kN/m² for the remaining area.
- Lane No. 2: An axle load of $\alpha_{Qi} Q_{ki} = 200$ kN for the tandem system and a uniformly distributed load of $\alpha_{qi} q_{ki} = 2.5$ kN/m² for the remaining area.
- Remaining area: A uniformly distributed load of $\alpha_{qi} q_{rk} = 2.5$ kN/m² for the remaining area.
- Horizontal forces (breaking and acceleration forces): A breaking and acceleration force of $QA_k = QB_k = 900$ kN was applied along the carriageway axis uniformly distributed over the loaded length.

The wind load applied to the arch, the carriageway and the traffic was determined to $w_k = 1.75$ kN/m². Snow loads have not been superimposed to traffic loads.

3.2 Structural aspects

A few structural aspects of structural engineering in timber are covered within the following listing:

- Logistics: The dimension of the components is limited by the narrow communication road to a maximum length of 30 meters, which influences the degree of prefabrication of the components. Due to the limited space near the construction site, the delivery of the components has to be just in time, hence possible negative influences from climate changes (swelling and shrinkage) on the timber components are minimized.
- Assembly: The limited capacity of the crane leads to limited size and weight of the components. A systematised, simple layout of the field connections facilitates a quick assembly and helps to avoid defects.
- Prefabrication: The degree of prefabrication in timber construction is very high and only limited by the potential of the wood working machines ($h \leq 2500$ mm, $l \leq 50$ m, $b \leq 240$ mm but can be much larger by block-gluing).

3.3 Constructural wood preservation

In timber engineering, considerable attention has to be drawn to the topic of constructural wood preservation during the planning process, whereas the listing below gives some recommendations for this delicate topic (cp. Unterwieser (2006)):

- The main structural parts have to be covered by expendable parts (wood or other materials) or have to be protected by the carriageway (reinforced concrete carriageway slabs) from the elements.
- The intersections between the foundation (concrete) and the main structure (timber as well as concrete at the abutments) have to be kept free from vegetation and a good aeration has to be assured (a minimum distance between two parts of approx. 10 to 20 cm, dependant from the depth of the structure). Certainly, this is true for the timber connections as well.
- The conduction of regular bridge inspections, maintenance operations and a potential rehabilitation have to be ensured. However, this topic gains more and more importance for all structures, and to bridges in particular, built with other materials than wood.

3.4 Examination of alternatives

Several alternatives have been worked out and discussed with respect to the technical feasibility, economic efficiency and architecture during the design phase. In this chapter, three selected alternatives are given exemplarily.

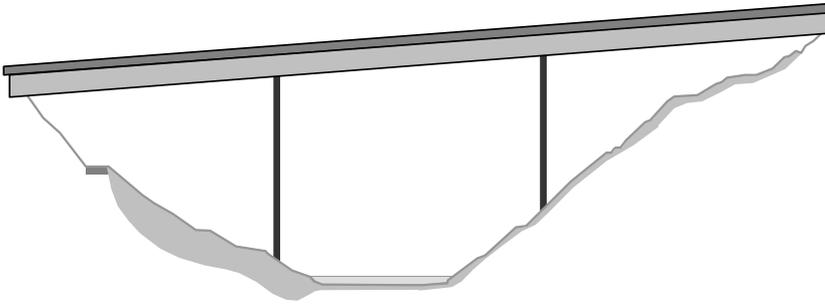#### 3.4.1 Alternative A – "Typical, fully encased timber bridge"

Fig. 3: Alternative A – Three-span fully encased timber bridge

One of the first images during the search for a suitable alternative was a fully encased "typical" timber bridge. Many of these, partly ancient (early 18th century) but still modern bridges, can be found in Switzerland, Germany and Austria across steep mountain valleys. The reason for their durability lies within the fact that the whole bridge (bearing structure and carriageway) is fully encased (like a house with walls and roof) and therefore is protected from the elements.

The main bearing structure consists of two trusses with an effective depth of approx. 6 to 8 meters ($\frac{1}{10}$ to $\frac{1}{15}$ of the free span) executed as three single span beams resting on two reinforced concrete columns with fixed supports. The transverse loads are carried by a truss within the roof structure and one within the carriageway structure.
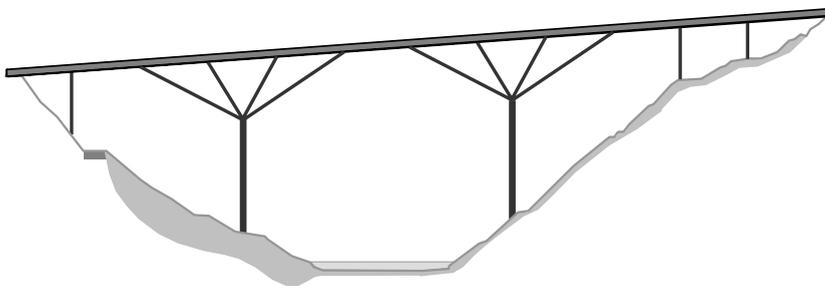
3.4.2 Alternative B – "Continuous beam"

Fig. 4: Alternative B – Continuous beam upon a "tree" structure

Alternative B shows a continuous timber-beam (with solid web) system with a single span of approx. 20 m. The reaction forces of the girder in the middle of the bridge, are carried off by a slender "treelike" timber structure resting on massive reinforced concrete columns with fixed supports. The outer three columns consist of reinforced concrete as well and are designed as hinged columns.

The advantages of this system lie within the fabrication, the transportation and the assembling of the components. Due to the small number of columns, only little interference with the sensible soil is required. The carriageway, made of reinforced prestressed precast concrete elements, guarantees a protection from the elements for the timber structure beneath.

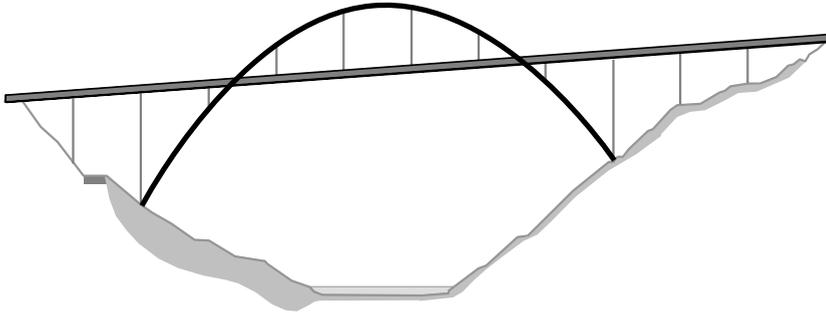Alternative C – "Arch structure"

Fig. 5: Alternative C – Arch structure with central carriageway

This alternative represents a classical timber-arch-structure with a central carriageway executed as a continuous system. In opposition to an arch bridge with continuous elevation, the length of the columns/suspenders is considerably smaller. The introduction of the normal forces within the arch into the soil takes place nearly perpendicular to the shear planes of the Bündner-schiefer.

However, the freestanding timber-arch-structure, which is not protected from the elements by the carriageway, as well as the huge timber-arch (140 m free span, 70 m rise of arch) mark important unfavourable factors.

3.5   Opted alternative: Alternative C – Arch structure with arch below the carriageway

The shape of the valley, the span and the actions as well as the mechanical properties of wood (high compressive strength) lead to the logical result of an arch structure to carry the vertical loads (cp. 3.1). As an improvement compared to alternative C, the arch is placed below the carriageway ("spandrel-braced arch") and the free span is reduced (cp. Fig. 6).

The continuous elevation at an interval of 15 m has several positive effects like reduced spans for the superstructure (continuous beam) and a roughly continuous load introduction into the arch structure, which is the most favourable case for an arch. The introduction of the normal forces within the arch into the foundation takes place nearly perpendicular to the shear zones of the Bündnerschiefer.

The horizontal loads (axial forces due to the inclination or breaking forces as well as design transverse forces due to wind forces) are carried off by the carriageway, consisting of prestressed, precast reinforced concrete slabs, into the abutments on both sides of the bridge. The high architectural demands will be satisfied the best way with a slender arch structure.
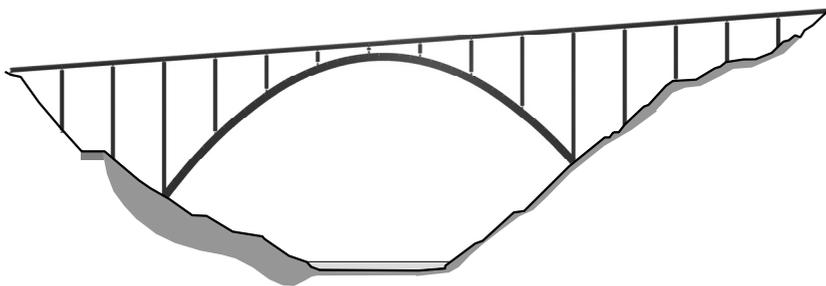
Fig. 6: Opted alternative – spandrel-braced arch structure

3.5.1 Structural system and structural members

The main structure consists of a parabolic, two-hinged arch and support points at different levels (Δh = 10 m). The free span comports to 122 m (approx. half of the total length of the bridge) and the rise of arch is set to 36 m. The shape of the arch is polygonally approximated by prefabricated components with straight longitudinal axis. The arch itself consists of five parally arranged, lengthwise shifted box girder elements, which are composed of glued-laminated timber (GL) webs (b x h = 360 x 1600 mm²) and cross-laminated timber (CLT) flanges (b x h = 1600 x 375 mm²). Internal steel frames establish torsional rigidity and serve as connection element (cp. Fig. 7). The loads from the columns and the diagonal bracing elements are transferred to the box girder elements by steel sections which provide a good load distribution as well, and are fixed to the box girder elements by glued in rods.
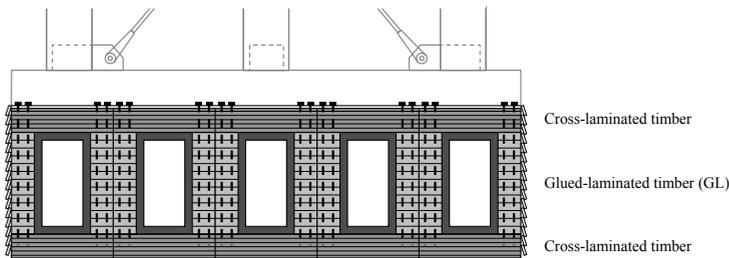

Cross-laminated timber

Glued-laminated timber (GL)

Cross-laminated timber

Fig. 7: Cross section of the timber-arch

The elevation consists of three block-glued hinged columns (720 x 1200 mm²) connected with truss members (working as a build-up column) and a maximum length of 40 m (slenderness ratio $\lambda \approx 115$).

As can be seen in Fig. 8, a similar steel section like the one at the base of the columns (cp. Fig. 7) is fixed to the column capital, providing a good load distribution. The main bearing structure, acting as continuous beam over two openings, consists of 10 parally placed, with spacing arranged, block-glued gluelam beams (360 x 1200 mm² and 30 m length) upon these steel sections. The butt joints of two neighbouring beams are shifted lengthwise by 15 m to achieve a continuous beam system.

The carriageway slab, which is used to carry off the horizontal loads towards the abutments, is made up by prestressed, precast reinforced concrete slabs. The connection between the concrete slabs and the timber beams beneath is executed as fixed bearing in transverse direction and as movable bearing in direction of the carriageway-axis. Upon the concrete slabs, a layer of asphalt serves as wearing course.
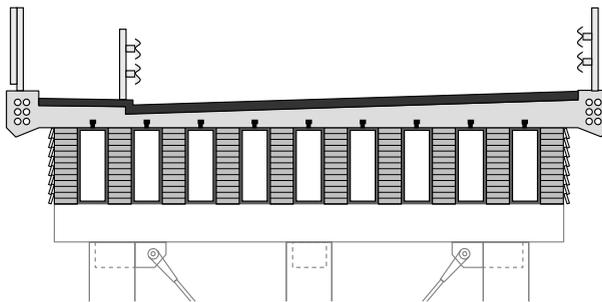

Fig. 8: Cross section of the carriageway

3.5.2 Design of the timber elements

The timber elements were designed according to SIA 265 (confirming with EN 1995 series). The following utilisation rations η (approximation with the maximum internal forces but without considerations of the stability) could have been found:

- Arch structure (N + M and V in the controlling axis): $\eta_{N+M} \approx 0.66$, $\eta_V \approx 0.19$
- Column (N for the highest column): $\eta_N \approx 0.15$, $\lambda \approx 115$
- Carriageway beam (N + M and V in the controlling axis): $\eta_{N+M} \approx 0.76$, $\eta_V \approx 0.62$

3.5.3 Structural dynamics

Although the single components of this structure seem to be relatively massive, the overall structure is quite slender and therefore, structural dynamics have to be considered. As the most relevant vibrations, wind and traffic induced vibrations can be named.

From a dynamic calculation of the whole bridge structure, the following Eigenfrequencies and associated Eigenshapes could have been found:

- Eigenshape 1: $f_1 = 0.64$ Hz (carriageway, transverse)
- Eigenshape 2: $f_2 = 1.17$ Hz (carriageway, torsional)
- Eigenshape 3: $f_3 = 1.37$ Hz (arch, anti-symmetric)
- Eigenshape 4: $f_4 = 1.60$ Hz (arch, symmetric)

3.5.4 Constructural wood preservation

To satisfy the requirements of constructural wood preservation, all exposed members have to be protected from the elements by a sheathing made of wood or wood products or metals (cp. Unterwieser et al., 2007). Good aeration has to be provided as well (cp. 3.3).

3.5.5 Assembly

Due to the size and the weight of the single components and the size of the construction site (length of more than 250 m) as well, a suspension crane has to be used for the assembly. The prefabricated elements have to be delivered just in time and assembled subsequently.

4 CONCLUSION

In fall 2005, the Authority for Substructures of Graubünden carried out a project competition for a bridge spanning 240 m across the River Inn. In the course of this project competition, the Institute for Timber Engineering and Wood Technology at the Graz University of Technology worked out a concept with the aim of showing the technical feasibility and the economic efficiency.

During the design phase, some alternatives have been worked out and evaluated with the result of a wooden arch bridge, consisting of a spandrel-braced arch structure with a parabolic arch of the span of 120 m.

Finally, a slightly modified project was tendered entitled "GHW – Größte Holzbrücke der Welt" by the Swiss engineering consultants timbatec® Stefan Zoellig. Unfortunately, the winner of this project competition was a team that proposed a traditional reinforced concrete bridge as continuous beam resting on two massive columns.

REFERENCES

Unterwieser, H. 2006. Wartungsmanual für Holzbrücken – Ein Leitfaden zur Brückenüberwachung (in German). Graz: Graz University of Technology, Institute for Timber Engineering and Wood Technology and proHolz Styria.

Unterwieser, H., Schickhofer, G. 2007. From the fabrication to the maintenance – a report of the history of the Mur River Wooden Bridge in Styria/Austria. Proceedings of the 5th International Conference on Arch Bridges (ARCH07).