Timber bridges

STEP lecture E17
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Objective

To describe the use of timber in modern bridges.

Summary

A short history of timber bridges in Europe is given as a background to design. Structural forms and details of the principal structural elements are considered and examples shown. Timber is thus shown to be effective, economic and durable for bridge construction and to allow innovative and aesthetic solutions.

History

The oldest known timber bridges go back to 600 years BC. The limited information available on these bridges shows the builders to have had excellent knowledge of timber properties and applications to structural forms. Whilst masonry bridges have survived for many centuries, these early timber bridges were mainly destroyed by war, natural disasters or fire.

One of the oldest timber bridges in existence in Europe is the Kapellbrücke in Luzern. It was built in 1333 and over the centuries much of the structure has been rebuilt. Originally, the overall length was 285 *m*, but in the 19th century this was reduced to 222 *m*. The bridge is covered and is formed of simply supported beams on interconnected timber piles. In August 1993 a large part of the bridge was destroyed by fire.

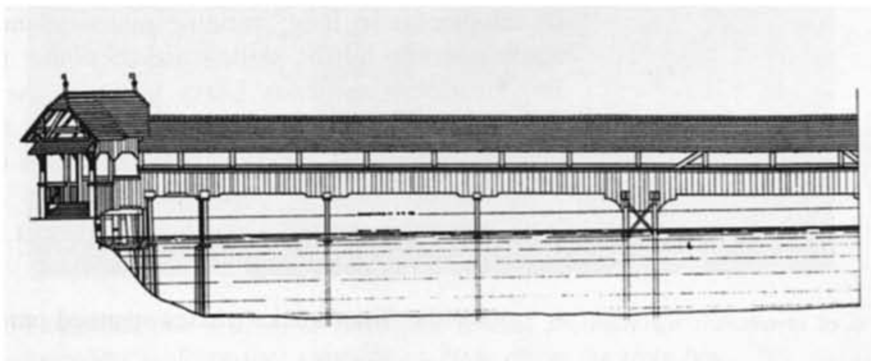

Figure 1 *Kapellbrücke; longitudinal section.*

Rebuilding of the bridge following the original form began immediately and the bridge was reopened for pedestrian use in April 1994. The supporting structure mainly consists of oak piles driven into the bed of the river Reuss. Cross-girders again of oak connect the pile caps and support the 26 spans of the main bridge structure; the average span is 7,65 *m* and the maximum span is about 13,5 *m;* the total length is now 204 *m*.

Between 1755 and 1758 the master carpenter Hans Ulrich Grubenmann built the well-known Rhinebridge at Schaffhausen. He designed the bridge as a single span of 119 *m* but was forced by the town authorities to change the design and incorporate an existing central pier into the bridge. Shortly after the completion of the bridge he removed packing members over this pier and was able to demonstrate that his original concept had been possible.

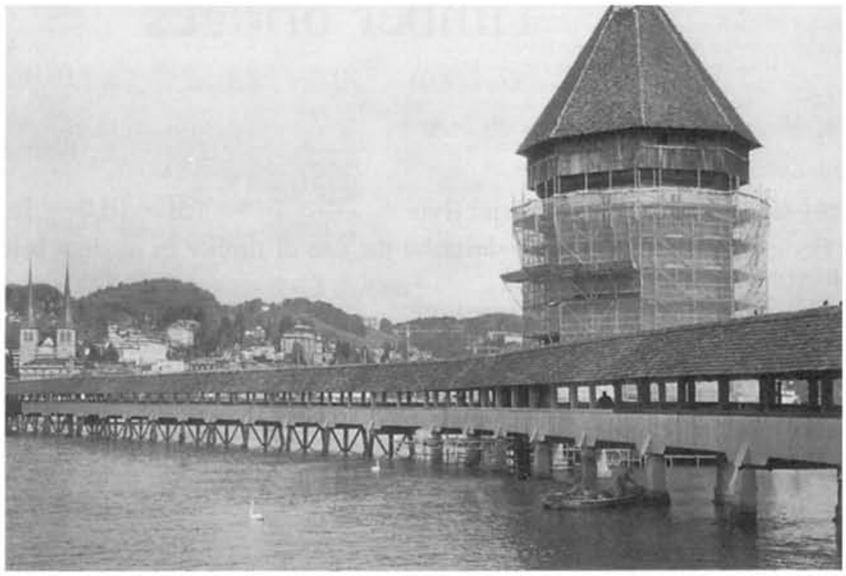

Figure 2 *Kapellbrücke after rehabilitation (1994).*

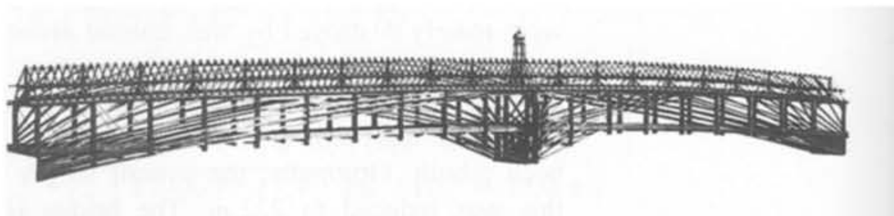

Figure 3 *Rhinebridge at Schaffhausen (1755-1758) by Hans Ulrich Grubenmann.*

Developments in long spanning masonry and reinforced concrete bridges were made possible by the skilled use of timber falsework which itself had to span large distances and carry heavy loads. At the turn of the century Richard Coray (1869 - 1946) constructed the falsework for some of the most important bridges in Switzerland. His structures were examples of daring and imagination:

- the falsework of the Wiesner viaduct (1906/1907) cantilevered out over the 88 *m* deep gorge,
- for the Sitterbrücke trusses spanned onto a scaffolding tower 96 *m* high,
- for the 100 *m* span Langwieser viaduct an unconventional roundwood fan was developed.

Once the main structure had been built, these temporary bridges were dismantled or demolished.

The development of timber bridges in the United States was in two main areas. Firstly in the use of the through truss, often covered to protect the structural timber, used in increasing lengths to carry roadways over rivers and secondly in the use of timber trestles. The latter use shows no technical advances in the use of timber but is noted for the volume of wood used in bridging and which allowed the railways to be developed quickly and cheaply through very difficult terrain without the need of highly skilled labour whilst using the raw material of the forest, through which the railway passed.

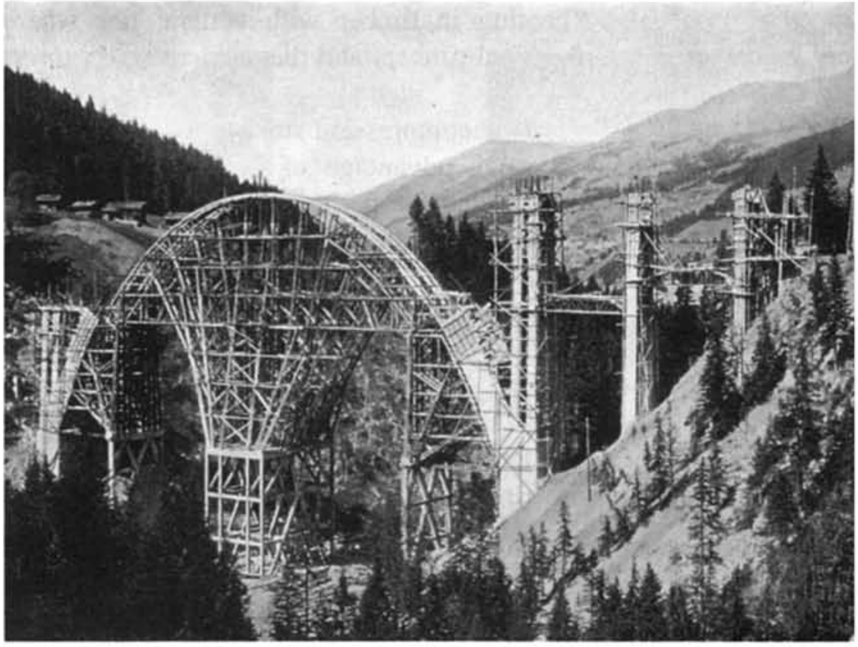

Figure 4 *Langwieser viaduct 60 m above the valley.*

Figure 5 *Suspended bridge close to Brail (1910) used for material transports to a tunnelling building site; span 168 m, 60 m above the river Inn.*

The early professional bridge builders in America were Palmer (1751-1821), Wernwag (1770-1843) and Burr (died 1822). They all patented different truss forms, mainly combining the truss with an arch and using mechanical lamination to achieve large spans. Wernwag's Collosus Bridge over the Schullylkill River at Philadelphia built around 1805 had a span of 111 m with a shallow arch forming the bottom chord of a superimposed truss.

The first modern truss design not relying on an arch component was developed by Ithiel Town in 1920. His trusses had a single or double web lattice and were very simple to fabricate and build. Their use was wide spread and they soon became the most common form of American covered bridge.

Other truss systems were developed, but in the 1840's Howe and Pratt both introduced trusses incorporating iron tie members. Howe's patent used diagonal bracing in timber with vertical ties whereas Pratt reversed the process using vertical timbers and diagonal cross bracings.

The precompression stresses available by tightening the end nuts on the iron rods had the advantage of stiffening the joints between the large section timbers improving the performance of the bridges. However the advent of iron into these trusses brought about the demise in popularity of the timber truss bridge as more elements of the truss were replaced with iron and later steel. Covered timber trusses are still around today especially in forestry areas. In many areas timber trusses are still seen as a competitive solution in bridge design.

The British engineer I.K. Brunel (1806-1859) was a great believer in the structural use of timber and incorporated many timber structures in his London to Bristol Railway. However, in timber bridging he is best known for his railway viaducts built mainly in South West England and the Welsh valleys. On the main line route through Cornwall there were 43 viaducts with an aggregate span of 8 *km* built between 1850 and 1859. These were slender graceful structures often built on sweeping curves to bridge the deep valleys of the area at heights of up to 50 *m*. The viaducts followed a number of standard designs mainly incorporating fan like supports. The main beams used 300 *mm* by 300 *mm* section of yellow pine. They were often mechanically laminated using Brunel's special "joggle" or shear key to achieve greater spans. A special feature of the designs were that any structural member could be replaced within about an hour without disruption to service. The timbers were expected to last 30 years but as labour costs for maintenance increased the bridges were replaced and most had gone by 1940. In developing these bridges Brunel was noted for his analytical work and structural testing of timber elements.

During recent years a real renaissance of timber bridges has taken place. One reason is the increasing interest in using such a durable and ecologically sound building material as timber. Apart from that, technological developments have contributed to new and more efficient jointing techniques and the use of wood-based materials. Timber bridges are thus shown to be effective, economic and durable and to allow innovative and aesthetic solutions.

Structural background

Planning and construction

Road bridges carry the traffic loads of main or secondary roads, footbridges and cycle bridges are mainly used by pedestrians and cyclists and only occasionally by maintenance vehicles or ambulances. Due to their lower loadings, footbridges and cycle bridges are mostly lighter than road bridges and are often seen to be more suited to the use of a low modulus material like timber.

With regard to appearance and also to structure, open and covered bridges are distinguished as two main types of bridge. The choice of the best structural form of a bridge depends on several parameters:

- topography and landscape,
- span,
- loading,
- clearance and clear width,
- soil conditions,
- architectural features.

Figure 6 *Open bridge (left) and covered bridge (right).*

Another principal distinction concerns the position of the carriageway relative to the main structure: the carriageway may be on top or at the base of the main structure. For the structure itself, a large number of forms are possible but most bridges consist of one of the basic forms shown in Figure 7 or a combination thereof.

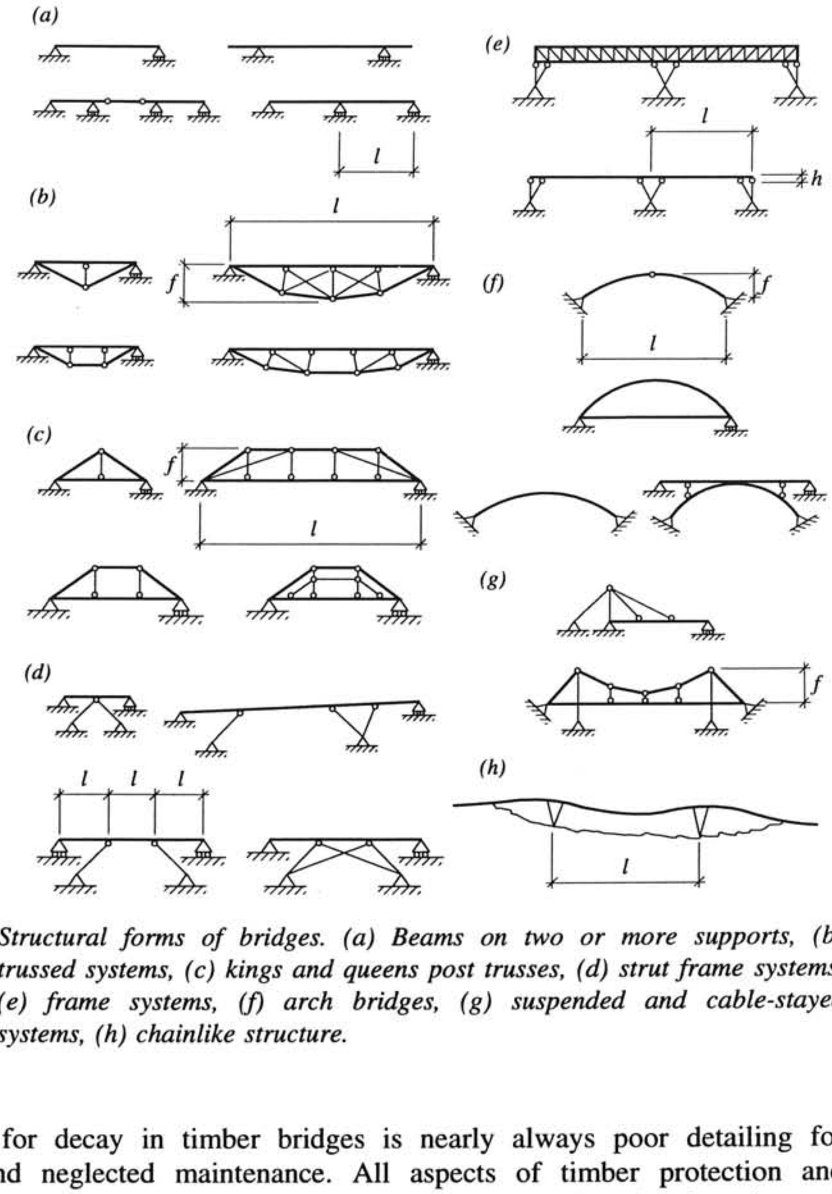

Figure 7 *Structural forms of bridges. (a) Beams on two or more supports, (b) trussed systems, (c) kings and queens post trusses, (d) strut frame systems, (e) frame systems, (f) arch bridges, (g) suspended and cable-stayed systems, (h) chainlike structure.*

Durability

The reason for decay in timber bridges is nearly always poor detailing for durability and neglected maintenance. All aspects of timber protection and maintenance should therefore be considered even during the planning phase of the bridge.

Wood as a natural product is part of a life cycle of growing and decomposition. One method to break this cycle and hence preserve the timber is to keep the wood material constantly dry. This is a very effective method to preserve the load carrying capacity and the functioning of the bridge during its planned life time. This goal can be achieved using a timber protection plan relating to the elements shown in Table 1.

Element	Objective	Measure
Conceptional design	Prevention or decrease of intense weather exposure	Roof or covering of the main structure
Choice of material	Prevention of damage through adequate choice of materials	Use of either naturally durable or preservatively treated timbers; low moisture content during erection
Design of details	Prevent unfavourable consequences of shrinkage and swelling due to water contact	Covering of horizontal surfaces, of joints and of end grain; enable quick drying out of wet parts
Preservative treatment	Prevention of fungal or insect attack	Pressure treatment using chemical solutions
Surface treatment	Prevent weathering of surfaces; achieve dimensional stability and avoid cracks; limited protection against fungi or insect attack	Several layers of pigmented coating

Table 1 Timber protection plan.

Depending on the actual structure, single elements of the timber protection plan can be omitted. The strict application of the other measures then becomes more important.

Figure 8 Effective protection against the influence of the weather: (a) traditional roof, (b) easy to replace inclined and vertical cladding, (c) waterproof deck with lateral cladding.

Detailing for durability

Detailing for durability is by far the most effective way to protect structural timber elements. All old covered timber bridges still in use today have survived because of careful and consistent detailing for durability but often the covering is considered sacrificial in its protection of the more important structure below and can be quickly and easily replaced. When designing modern timber bridges a roof is often omitted for architectural reasons. In these cases the structural protection of the main structure has to be achieved in different ways. Examples are a deck which acts as a roof, or a covering of the main structure with lateral cladding.

Preservative treatment

Pressure treating sawn and glued laminated timber using CCB or CCF salts can protect the timber members against fungal attack as well as against surface decay due to the influence of the weather. It is important that preservative treatment is supported by a careful detailing of the timber structure.

Protection of fasteners

Apart from the timber members the metal fasteners and fittings have to be protected against corrosion. Especially from the use of salt to keep the roads free from ice and snow in the winter and the use of salts for treating the timber which leads to accelerated corrosion of steel parts. Because fasteners in timber connections are not accessible after erection of the structure, they have to be protected permanently. Hot-dip galvanising and eventually additional layers of protective coating lead to a prolonged lifetime of fasteners and metal fittings. In more aggressive environments stainless steel is preferred.

Maintenance

A regular check of the whole bridge should be made at intervals not exceeding three to five years. The extent of regular maintenance is small if detailing for durability of the structure has been consistently applied. The regular checks should cover the following points:

- weathering of surface coating of timber members,
- cracking of the timber,
- delamination of glued laminated timber parts,
- mechanical damage,
- fungal growth,
- growth of plants,
- collection of dirt.

Deck

The deck made of planks or plates may be designed as an open or closed construction. The deck may be used for two main functions:

- Load-carrying

  The deck distributes the concentrated wheel loads and transfers them to the main structure. If the deck is designed as a diaphragm, it can be used to brace the main beams and to transfer horizontal wind or brake loads.

- Protection

  The deck protects the main structure from moisture and mechanical damage from traffic. An effective and durable protection of the timber structure is achieved with closed decks.

Since the 1940s timber decks have been used in USA and Canada. Nail-laminated joists were used which were also connected with to main structure by nailing. Later glued laminated beams connected through shear connectors were also used. Nowadays timber decks exist in a great variety of designs utilising round timbers, sawn timber, glued laminated timber or wood-based panels and sometimes as composite beams together with a concrete compression zone and wearing course.

Prestressed timber decks consist of laminated joists transversely prestressed using high strength steel. Although the stiffness of timber is low perpendicular to the grain, prestressing allows a plate action in the deck. In order to avoid damaging the timber due to the high bearing stresses perpendicular to the grain under the end blocks of the prestressing steel, edge members of hardwood or steel channels are used. Prestressed timber deck plates may be either glued laminated or not glued.

The shear forces between joists in non glued plates are transferred by friction made possible through prestressing. This method is very simple and economic. The joists are often treated with creosote before assembly.

Gluing enables timber plate decks to have larger dimensions. Here, prestressing avoids cracking of the deck plate due to bending stresses perpendicular to the grain.

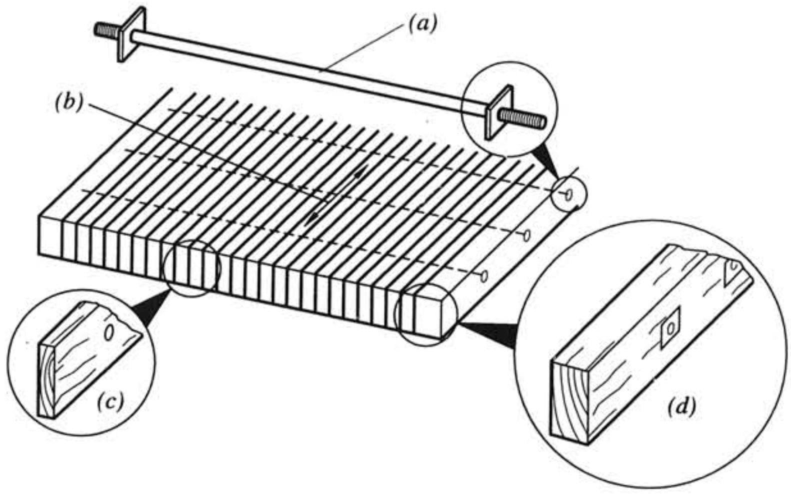

Figure 9 *Unglued prestressed timber plate deck. (a) corrosion protected steel prestressing bar, (b) direction of span, (c) spruce/fir joist, (d) oak edge member.*

Due to shrinkage and creep the prestressing force decreases with time. Measurements in timber decks in service, however, show that the necessary force can be maintained at an adequate level for a long time. If necessary, early in the structural lifetime, restressing can be done. Prestressing decreases moisture induced variations of timber dimensions and provides dimensionally stable members. The prestressed plate therefore is suited to serve as base for durable wearing surfaces like asphalt. Prestressed timber decks are increasingly used to replace existing decks as well as to provide a simple and effective deck structure in new timber bridges.

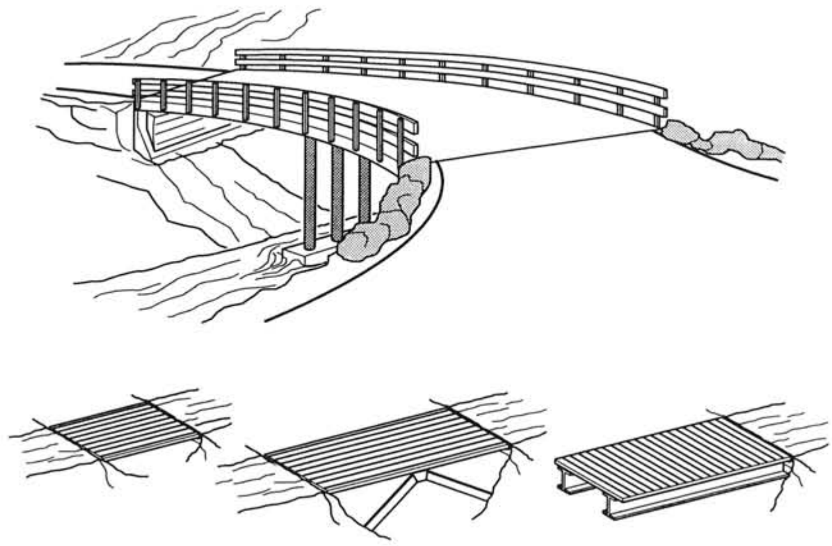

Figure 10 Straight and curved (r = 20 m) prestressed timber decks.

Modern examples of timber bridges

Dörfli-Brücke Eggiwil, Switzerland (1984)

Two-lane road bridge for normal highway loading consisting of double axle loads of 270 *kN* each and including an allowance for impact together with a uniformly distributed load of 4,2 kN/m^2.

The bridge is a direct replacement for the original timber structure built in 1885. It is a covered bridge designed to follow the appearance of the traditional bridges of this region. However, it represents a milestone in the development of modern bridges. Behind the traditional covered roof structure the structural framework incorporates many developments made possible by research work and testing. For the first time a 200 *mm* deep continuous deck structure spanning over the cross girders made from glulam has been adopted. The deck is transversely prestressed with threaded steel rods to provide plate action instead of the low stiffness of timber perpendicular to the grain. The wearing surface is isolated from the deck by protective membranes which ensure the durability of the deck and the supporting cross girders.

For the first time the cross girders have been connected to the structural arches by hangers made of glued laminated beech. A high quality timber was necessitated by the high loads of up to 500 *kN* transferred by the hangers which are at 4,5 *m* centres. The beech is preserved by creosote. The hangers are connected to the arch using slotted steel plates and dowel bolts. The cross girders are built as double beams encompassing the hanger. The limited clearance, the long span and the high load has necessitated these members being built also of glued laminated beech.

The glued laminated timber arches span 30,6 *m* carrying the 6,5 *m* wide carriageway and 1,5 *m* footpath. The clearance under the bracing members linking the arches is 5,0 *m*.The vertical loads are transferred from the deck through the cross girders and the hangers into the arches. The horizontal wind loads are transferred both by the stiff plate deck and a wind girder system under the roof supported at the ends of the bridge by portal frames. The longitudinal braking forces are transferred to the foundations through the deck.

Erection

For transportation reasons, the arch was manufactured in two halves. As with the hangers, the connection between the arch halves was made with slotted steel plates and high strength dowel bolts. The deck unit was manufactured in three parts 2,2 *m* wide by 30,6 *m* long which were glued together on site and then prestressed.

Materials used

Glued laminated timber (spruce/fir)	112 m^3
Glued laminated timber (beech)	36 m^3
Sawn timber (spruce/fir)	42 m^3
Steel sections, plates, bolts	13000 *kg*
High strength dowel bolts	2300

Figure 11 *View of the Dörfli-Brücke, Eggiwil.*

Figure 12 *Erection.*

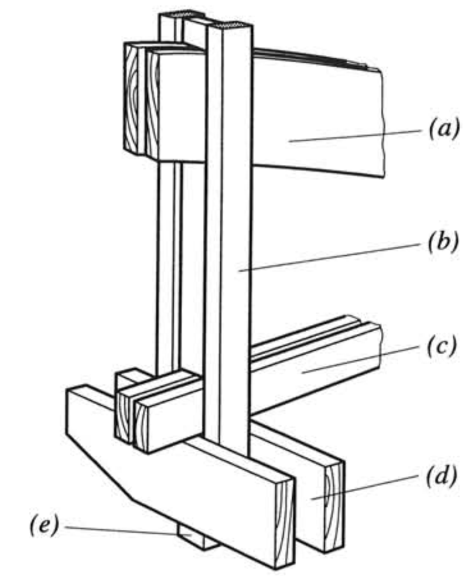

Figure 13 *Cross girder with hanger. (a) Spruce glulam arch, (b) beech glulam hanger, (c) spruce glulam tension tie, (d) beech glulam cross girder, (e) steel fitting for cross girder support.*

Langlaufbrücke Pradella, Scuol, Switzerland (1990)

This bridge is used in the summer as a footbridge and in the winter as part of a cross-country ski trail when it must carry the load of special tracked vehicles. The characteristic loadings are a uniformly distributed imposed load 4,0 kN/m^2, concentrated imposed load 30 kN and snow load 3,4 kN/m^2. The total length is 85,0 m broken into three spans of 21,5, 42,0 and 21,5 m. The outer spans are continuous with a suspended centre span. Four main beams at 1 m centres carry a 4,5 m wide carriageway. The beams are 200 mm wide and vary in depth between 1287 mm and 1650 mm. Cross girders (90 mm by 140 mm) link the beams at 1 m intervals and support the deck which is made from 39 mm thick laminated veneer lumber erected in 22 m lengths. This deck distributes well the concentrated load and acts as a diaphragm in resisting the horizontal forces. In order to protect the main timber structure, the deck acts as a roof. The asphalt wearing surface is isolated from the deck by a polyurethane foam layer. A vertical cladding system is used to protect the exposed faces of the beams. This cladding together with the handrails is fabricated from durable larch which renders unnecessary any preservative treatment. The lamella boarding of the cladding is used as an architectural feature achieving a ribbon-like appearance.

Erection

Temporary towers were erected at the hinge positions in the main beams and then the main beam units were positioned using mobile cranes. The cross girders together with the hand rail supports were prefabricated as u-shaped sections. The erection of the main beams and cross girder units was completed in four days. Finally the cladding was fixed from a travelling scaffold.

Materials used

Glued laminated timber	98 m^3
Sawn timber (spruce/fir)	22 m^3
Laminated veneer lumber	16 m^3
Larch cladding	306 m^2

Figure 14 View of the Langlaufbrücke Pradella.

Figure 15 Detail of main structure.

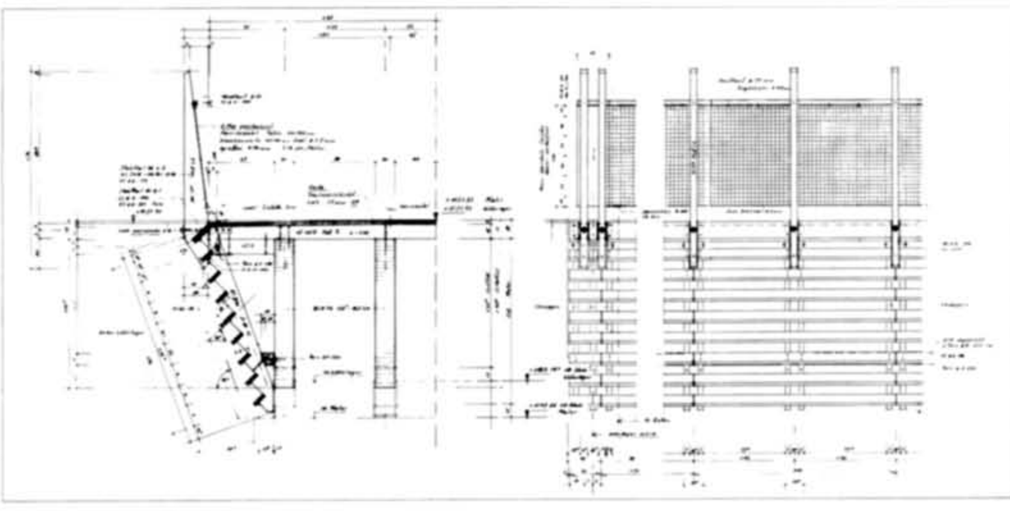

Figure 16 Cross-section and elevation of main structure.

Bicycle and pedestrian bridge over the Simme at Wimmis, Switzerland (1989)
As a focal point of a pedestrian and cycle way system this covered, transparent looking slender bridge crosses the river Simme 25 *m* above water level. A standard characteristic load of 4,0 kN/m^2, uniformly distributed, together with a snow loading on the roof of 1,8 kN/m^2 was applied. Additionally a requirement for a concentrated imposed load of 35 *kN* to allow access for emergency vehicles was stipulated.

The design was chosen in competition with steel and concrete. The position of the two concrete piers was determined by the topography and the need to provide a clear span over the river. This resulted in spans of 27,0 , 54,0 and 27,0 *m*. The columns are clamped in the foundations and are connected to the main structure through concrete diaphragms at the top of the column (1,2 *m* by 5,2 *m*). Two continuous trusses at 4,4 *m* centres and 2,94 *m* deep represent the main structure. Top and bottom chords (200 *mm* by 700 *mm*) and the diagonals (240 *mm* by 360 *mm*) are manufactured of glued laminated timber and are reinforced with lateral layers of laminated veneer lumber (2 x 63 *mm* by 400 *mm*) glued to the glulam members. Depending on the forces, the vertical members are either of sawn or glued laminated timber. The width of the carriageway is 3,5 *m* and the clear height 2,5 *m*.

The top and bottom chords of the two main beams are connected by cross girders 6,75 *m* at centres. Crossed steel diagonals together with the cross girders under the bridge deck form the bracing truss for the transfer of horizontal loads. The piers and the end supports of the bridge form the supports of this horizontal truss.

Careful detailing for durability made a chemical preservation of the timber members unnecessary. The roof cantilevers 1,5 *m* on each side over the main trusses and a lateral cladding of the railings made from larch as a more durable timber species additionally protects the structure. The connections between the timber members are formed using nailed on steel plates and a central bolt which transfers the load between the plates and provides a perfect hinge. Additionally, specially made steel shoes were used which allow loads up to 700 *kN* to be transferred.

Erection
Although the river bed provided enough room for the preparatory erection work, this area was endangered by flooding. The deck structure of the bridge consisting of main truss bottom chords, cross girders, longitudinal secondary beams and steel cross ties was prefabricated on the ground in units 36 *m* long. These parts with a weight of 13000 *kg* were lifted into place using mobile cranes. The ends of the two parts covering the 27 *m* spans cantilevered into the middle span and were supported by temporary columns built up of three logs each. After that, the middle part was connected to the two end parts using steel plates and ringed shank nails. The timber deck structure then served as a working platform for the erection of the remaining bridge parts.

Materials used

Glued laminated timber	95 m^3
Sawn timber	51 m^3
Laminated veneer lumber	18 m^3

Larch deck	27 m^3
Larch cladding	1150 m^2
Steel sections, plates, bolts	7000 kg

Figure 17 *View of the bridge over the Simme at Wimmis.*

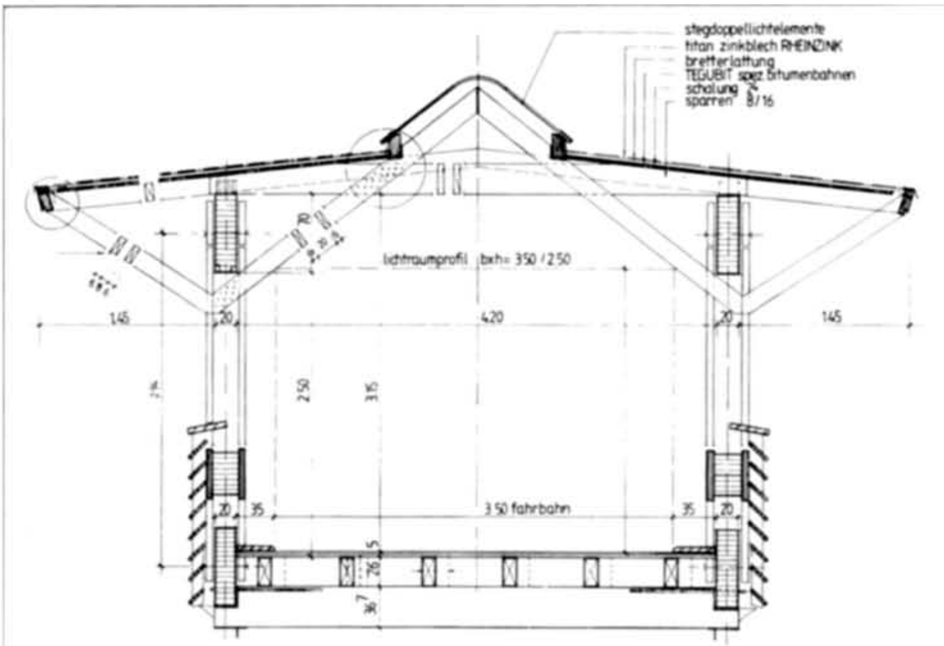

Figure 18 *Bridge cross-section in the middle of the span.*

Figure 19 *Internal view.*

Figure 20 The transparent looking bridge rests on concrete piers.

Flurwegbrücke over the river Aabach, Uster, Switzerland (1986)

This bridge is used as a pedestrian and bicycle bridge and is situated in a nature park. The characteristic loadings are a uniformly distributed imposed load of 4,0 kN/m^2 and a concentrated imposed load of 10 *kN*.

Two main beams of glued laminated timber (200 *mm* by 1200 *mm*) carry a 3,4 *m* wide carriageway on the bottom chord of the glulam beams. For architectural reasons the main beams have a camber of 200 *mm*. The span is 14,2 *m*. U-shaped units of cross girders and vertical tension members made of glulam connect, and at the same time brace, the main beams at 2,4 *m* intervals and support the deck which is made from longitudinal beams (120 by 180 *mm*) and diagonally placed deck planks 70 *mm* thick. To avoid slipping on the deck surface, it is covered with a layer of sand in epoxy.

To protect the main timber structure, structural detailing as well as chemical preservation of the glulam was used. The white fir laminations of the glued laminated timber were pressure treated before gluing. Additionally, the glulam members were coated with several layers of surface coating. On the inner side, the main beams are covered with a cladding which acts as a protection against mechanical damage and the weather. This cladding consists of pressure treated spruce planks and can easily be replaced. The water is led away from the bridge through gaps between the deck planks.

Erection

The whole bridge was completely assembled in the workshop. The transport of the 10000 *kg* structure to the building site was arranged during the night.

Materials used

Glued laminated timber (white fir)	12 m^3
Sawn timber (white fir)	3,6 m^3
Larch deck planks	3,6 m^3
Spruce cladding	61 m^2

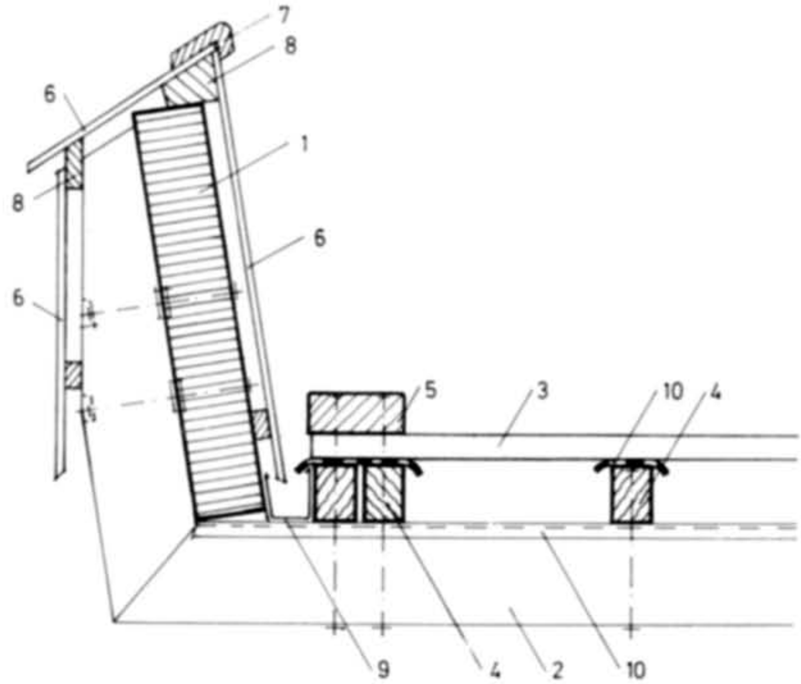

Figure 21 *U-shaped bridge cross-section of the Flurwegbrücke over the river Aabach at Uster.*

Figure 22 *A mobile crane is used to erect the bridge.*

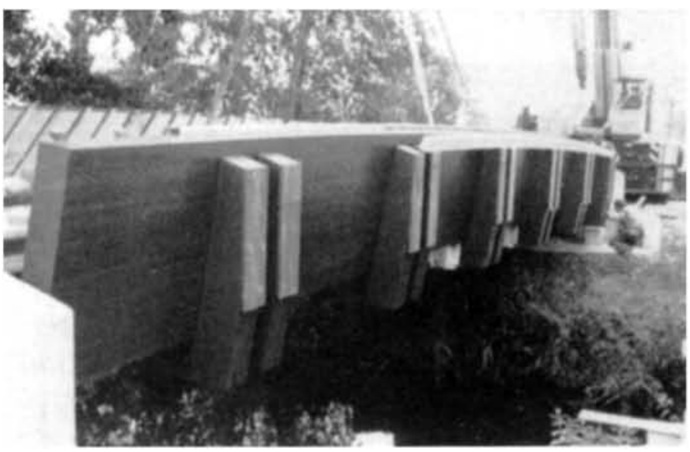

Figure 23 *Bridge resting on supports.*

Drostobel-Brücke, Klosters, Switzerland (1992)
The new forest road bridge replaced a derelict concrete structure from the 1920s. The characteristic loadings are a uniformly distributed imposed load of 5,0 kN/m^2 and four concentrated imposed loads of 75,0 *kN* multiplied by an impact factor of 1,8.

The length of the bridge is 18,0 *m* and the width of the carriageway 3,6 *m*. The structural system is a strut frame with a continuous beam which carries the deck. The strut frame consists of diaphragms rather than beam elements. The deck is built up of closely spaced glulam beams connected with two layers of laminated veneer lumber 39 *mm* thick. The laminated veneer lumber distributes well the concentrated load and acts as a diaphragm in resisting the horizontal wind and bracing forces. The bridge gives an unconventional architectural image.

Erection
The whole bridge was completely assembled in the workshop and quickly erected using a mobile crane.

Materials used

Glued laminated timber (spruce)	23 m^3
Sawn timber	2 m^3
Laminated veneer lumber	5 m^3
Sawn timber cladding	45 m^2

Figure 24 *View of Drostobel-Brücke, Klosters.*

Figure 25 *View of the cladded strut frame.*

Footbridge and cycle bridge over the N9 motorway, Ballaigues, Switzerland (1989)
The bridge is part of a forest trail for walkers. The loadings are a uniformly distributed life load of 4,0 KN/m^2, a snow load of 2,8 KN/m^2 and a concentrated load of 10 *kN*.

For the traffic on the N9 it was necessary to provide a clearance of 4,80 *m*. The span of the bridge is approximately 24 *m* and the width 2,50 *m*. The local contours dictated a sloping deck and environmental considerations suggested the use of round wood and a cable-stayed structure with an inclined tower. The soil on the high side was retained by a wall of close centred concrete piles which were then used to provide support for the tower with an anchorage system for the back tie. The lower side approach ramps consisted of simply supported beams spanning 5,0 *m*. The main bridge is also made from single beams of 4,35 *m* and 5,10 *m* supported by cross girders which are in turn supported by the inclined cables.

The structural system comprises pressure impregnated round wood made from Spruce and Fir. Slots were machined into the timber to control the points at which cracks due to shrinkage will occur. Compression members are made from a single log and bending members from pairs of logs. Larch was used for the deck and handrails. The cables and bracing members are made from round reinforcing rods with turnbuckles to adjust the tension. The joints of the ties to the top of the tower, and to the cross members, are made from steel and the forces are transmitted by bearing pressure. All steel parts are hot-dipped galvanised except the parts of the main supports which are made from stainless steel (quality V4A) in order to resist corrosion from road salts in the winter.

Erection
During construction it was important that the traffic on the main road should not be disrupted. Construction was carried out in stages: erection of the approach ramps, erection of the tower and back tie and construction of the five deck elements of the main span starting from the higher lever.

Materials used

Roundwood (spruce)	30 m^3
Sawn timber (larch)	12 m^3
Steel	2500 *kg*

Figure 26 View of the foot bridge, Ballaigues.

Figure 27 View of the access ramp from below.

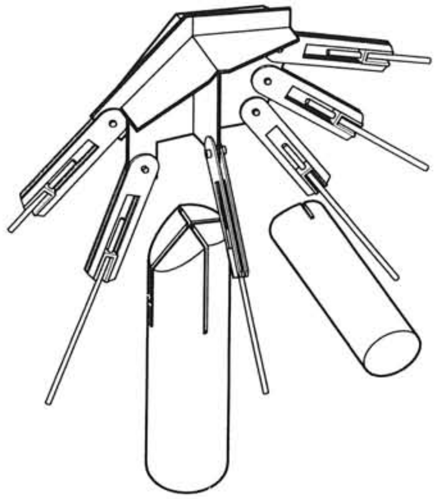

Figure 28 Drawing of the steel fitting at the pier head.

Foot and cycle bridge over the river Neckar, Remseck, Germany (1988)

The bridge is a part of a foot and cycle path system and is designed for a uniformly distributed load of 5 kN/m^2 and 4 kN/m^2, respectively, according to DIN 1072.

The main feature of this innovative construction spanning 80 *m* is its lightness and transparency. The main structure comprises three trusses used to form an equilateral triangular system with a side length of 7,56 *m*. The truss member connections are made using dowelled steel-to-timber joints. The covering to the sides is made from safety glass so that the user has the impression that he is invited to pass through and while crossing he is in immediate contact with his surroundings. The covering improves the long-term durability of the timber.

Erection

The whole bridge was constructed on one river bank and then one end was lifted onto a barge and the span floated across the river to reach its permanent supports.

Materials used

Glued laminated timber (spruce)	296 m^3
Sawn timber deck planks	10 m^3

Steel	20000 *kg*

Figure 29 *View of the foot and cycle bridge over the river Neckar.*

Figure 30 *View into the bridge.*

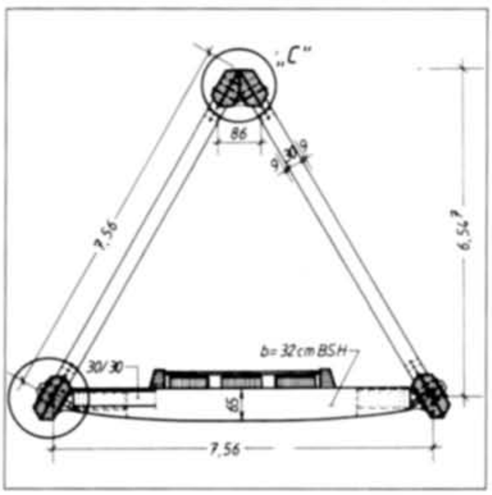

Figure 31 *Drawing of a bridge cross-section.*

Wennerbrücke over the river Mur, St. Georgen/Murau, Austria (1993)

Two-lane road bridge for normal highway loading consisting of double axle loads of 250 *kN* each together with a uniformly distributed load of 5 kN/m^2 or alternatively, a single axle load of 600 *kN*.

The main structure consists of four parabolic three-hinged arches (360 *mm* by 1200 *mm*) supporting the horizontal deck by evenly spaced columns (360 *mm* by 360 *mm*). The clear arch span is 45 *m* and the arch height 12,5 *m*. The total length is 85 *m* and thus represents the longest timber road bridge in Europe.

Between the end supports of the bridge and the columns supported by the arches V-shaped columns (360 *mm* by 600 *mm*) support the deck. Together with the four longitudinal main beams (360 *mm* by 1000 *mm*) they form a strut frame and transmit part of the braking forces. The arch tops are connected to the main beams through slotted steel plates.

The total width of the bridge is 8,6 *m*. The deck consists of prefabricated prestressed concrete elements. Between the main beams and the concrete deck an 8 *mm* neoprene layer is inserted. Glued-in steel rods with a diameter of 30 *mm* provide the connection between concrete elements and main beams. The horizontal bracing is made of steel tubes and steel ties.

Erection

For transportation reasons, the longitudinal main beams were manufactured in four parts and the arches in two halves. First, the eight identical parts consisting of an arch halve, one inclined column and the longitudinal beam connecting both were assembled on site. Using a mobile crane, the assembled parts weighing 21000 *kg* each were positioned and connected. After that the bridge parts connecting the arches with the end supports were positioned.

Materials used

Glued laminated timber (larch)	300 m^3
Steel sections, plates, bolts	69000 *kg*
Prestressed concrete decks	180 m^3

Figure 32 *View of the Wennerbrücke over the river Mur, St. Georgen, Murau.*

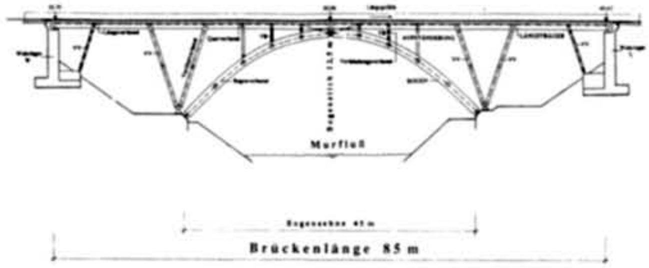

Figure 33 *Bridge structure.*

Figure 34 *Deck seen from below with three-hinged arches, longitudinal beams, inclined columns, columns on arches and bracing.*

Pedestrian and cycle bridge. Main-Donau Canal near Essing, Germany (1987)

The bridge spans the Main-Donau Canal, a main road and two secondary roads. To check the stability of the structure it was necessary to carry out a static analysis and a study of the dynamic effects induced by wind and the normal uses of the bridge. The latter study was undertaken both by analysis and by performing tests in a wind tunnel.

There were two conditions to be met. First the bridge had to harmonise with its surroundings and this led to the slender shape of the bridge. Second there had to be sufficient clearance for the ships on the canal. This form was chosen to enable vertical loads to be resisted by tension action with the bridge acting like a chain. This is the first timber bridge to adopt this form of construction over such a large span. The structure consists of nine glulam beams (220 *mm* x 650 *mm*) which are grouped together in threes. These tension members run continuously over three V-shaped lattice supports and are shaped like a chain. The calculated maximum force is 4000 *kN*.

The total length of 190 *m* is made up of spans of 30, 32, 73 and 35 *m*. At the end supports the bridge is anchored by transmitting the tension into high tensile steel wires and hence to anchor blocks. The forces in the wind braces are transmitted by diagonal tension members to the supports. In the upper part of the deck the planks are arranged diagonally and made watertight using a titanium zinc layer. The components of the joints of the main structure are made from cast iron or stainless steel.

Erection

The glulam tension members were prefabricated in the factory with lengths between 32 and 43,5 *m*. On site they were connected by large finger joints.

Materials used	
Glued laminated timber (spruce)	320 m^3
Sawn timber (larch)	20 m^3
Diagonal decking (spruce)	1330 m^2
Deck wearing surface(ekki)	665 m^2

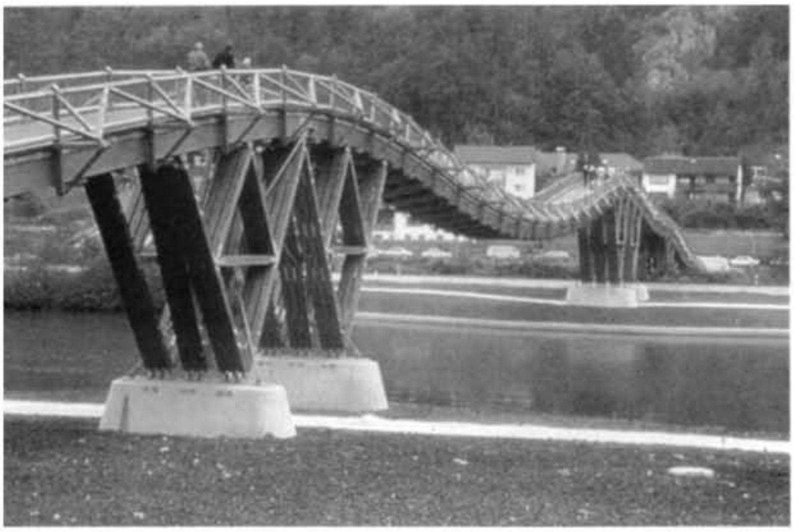

Figure 35 *View of the foot and cycle bridge at Essing.*

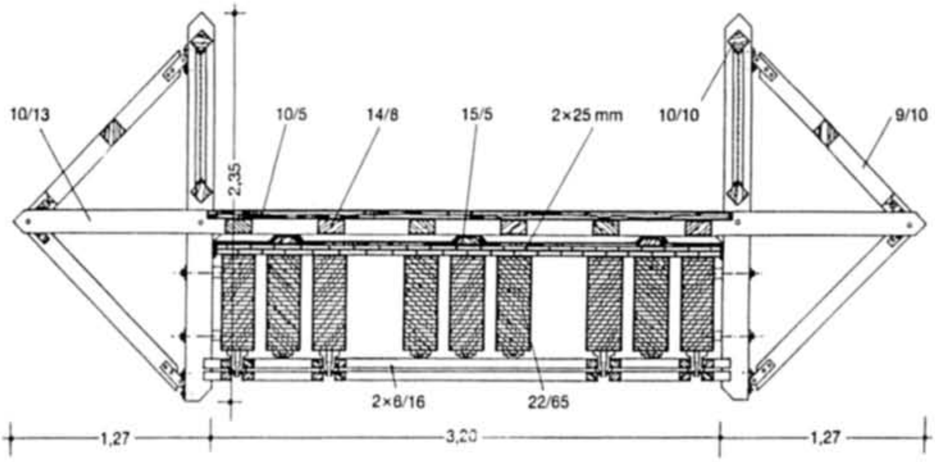

Figure 36 *Bridge cross-section.*

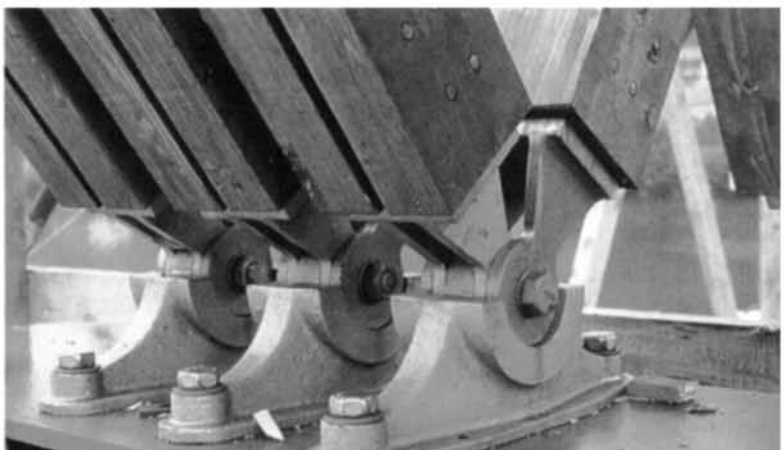

Figure 37 *Detail of trussed columns acting as supports.*

Road bridge San Nicla, Tschlin, Switzerland (1992/93)
The bridge forms part of a bypass and crosses the river Inn. The road is a one-way system but with no load limitations. The load assumptions relate to a truck with two axle loads each of 205 *kN* and a distributed load of 3,2 kN/m^2.

The bridge is an arch bridge with a U-shaped cross-section and has no roof. It employs new research information both in the field of grading of lamination using ultra sonic and in connection techniques. The glulam arches have a span of 39 *m* and variable cross-sections both in width and depth. At the abutments of the arch the cross-section is 800 x 1000 *mm* and at the crown 650 x 1500 *mm*. The heavily loaded cross members are vertically laminated and have beech plywood at each end. The spruce glulam and the beech plywood are connected by large finger joints, and consequently, allow the full shear strength to be developed. The different connections between the arch and hanger, arch and cross-beam, arch and support are made from a newly developed anchorage system. The end plates of the arch are fitted with steel lugs. Threaded rods are screwed into the plate and inserted into pre-drilled holes in the glulam and fixed by the injection of epoxy resin. With this system it is possible to transmit tension forces up to 500 *kN*. An essential requirement was to protect all timber parts from the effects of changes in the environment. The consequence was that the arch ribs, the edge beams and the cross beams were covered on top with copper and on the sides with Larch boarding. The cross beams made from Beech were coated to avoid changes in moisture content.

Erection
The moment resisting connection between the arch ribs at the crown was made using an 80 *mm* thick steel plate. The steel lugs meet like fingers and are joined by 20 *mm* diameter bolts arranged over the full depth of the section. The connections which can transmit tension and compression forces are joined to the end grain by the system described above.

Quality assurance
The client specified in the preliminary project phase a plan for the use of the bridge and for quality assurance. This plan specified a life of 100 years as there are many examples in Switzerland of timber brides of this age. Also the client engaged the Swiss Federal Institute of Technology in Zürich in order to achieve quality control in areas including production of the components, the grading of laminations, the accuracy of the dimensions of the members and the processes of gluing and prestressing of the deck.

Figure 38 *View of the glulam arches of the San Nicla bridge.*

Materials used	
Glulam	180 m^3
Laminated veneer lumber	15 m^3
Larch boarding	500 m^2
Steel	11000 *kg*

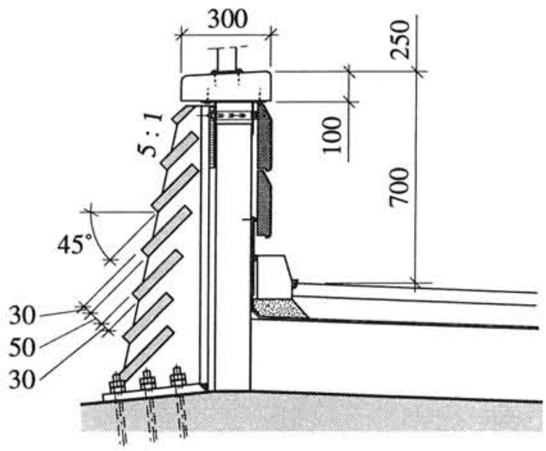

Figure 39 Cross-section of the main structure.

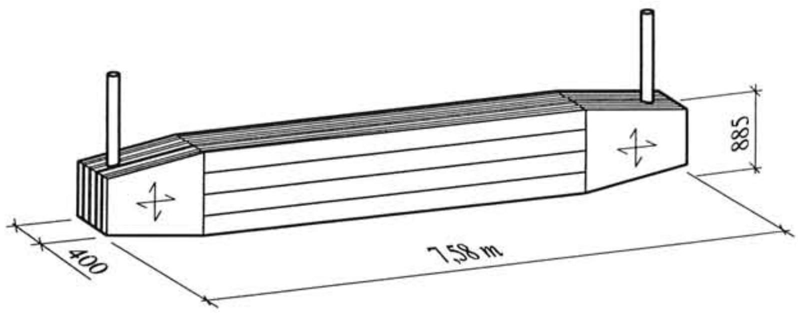

Figure 40 Cross girder with beech plywood reinforcements at the ends.

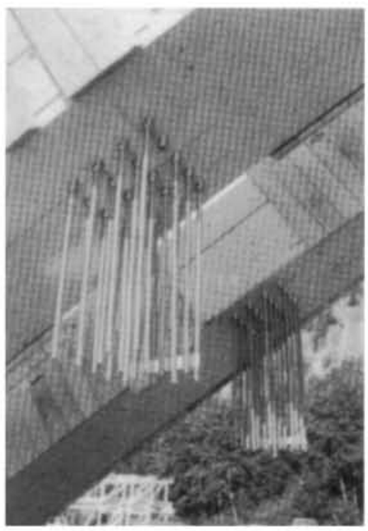

Figure 41 Detail of connection between hanger and arch.

Pedestrian bridge Werdenberg, Sevelen, Switzerland over the N13 motorway (1989/90)
The bridge connects two service stations. There were many conditions imposed by environmental factors, traffic, wind load, use, Local Authority regulations and last, but not least, the risk of corrosion from road salt. Live load is 4,0 kN/m^2 and 10 kN concentrated load. The snow load is 1,2 kN/m^2 and the wind load 1,7 kN/m^2.

The total length including both access towers which are made in reinforced concrete is 103 *m*. The internal width is 1,8 *m* and the internal clearance 2,4 *m*. The clearance for the motorway traffic is 5,5 *m*. The main glulam beams running over three equal spans of 30 *m* have hinges in the spans to make the system statically determinate. The cross-section is 200 *mm* by 1419 *mm* tapered to larger depths over the supports. The wind bracing is in the plane of the floor and comprises a horizontal I-beam made from 45 to 63 *mm* thick LVL webs and flanges made from sawn timber.

The cross-section of the bridge is formed as a series of box frames, spaced at 2,45 *m* centres, fixed to the main beams. These box frames carry the roof and are braced against lateral forces. The timber structure is protected against moisture at all exposed points using wood based panels. The traditional type of covered bridge was not considered appropriate in this instance. The chosen architectural form is more like an pavilion-like building or a look-out tower. It has a very light appearance, not solid, and so does not form a visual barrier. Because of the high risk of corrosion the structure was built with few parts made from steel. The welded parts are hot-dipped galvanised and in the joints that are exposed to the weather cast iron has been used. All steel parts are additionally painted.

Erection
The columns and access towers are made from concrete. The wooden bridge was constructed in three parts on the ground beside the road and then lifted by two mobile cranes overnight. These parts were 43 *m* long and weighed 35000 *kg*.

Materials used	
Sawn timber (Spruce & Fir)	37 m^3
Glulam	53 m^3
Roof cladding (Spruce & Fir)	410 m^2
Three layer panels (Ash)	160 m^2
Roundwood (Robinia)	72 pieces
Cement bonded panels	160 m^2

Figure 42 View of the pedestrian bridge Werdenberg, Sevelen.

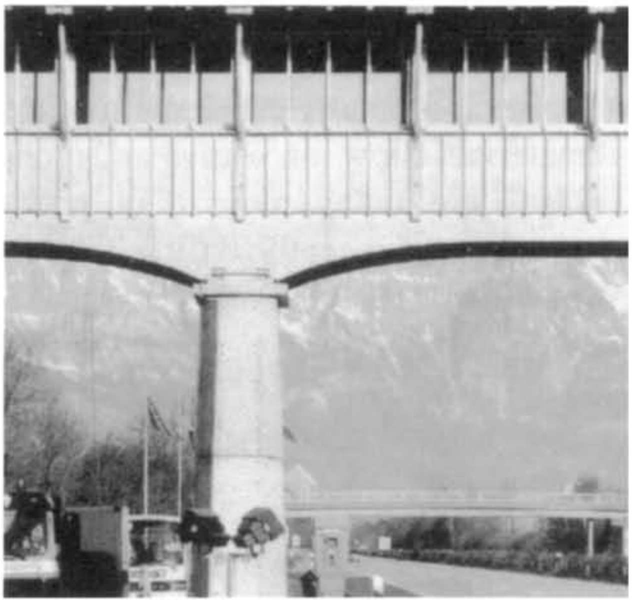

Figure 43 *Bridge support.*

Figure 44 *Internal view.*

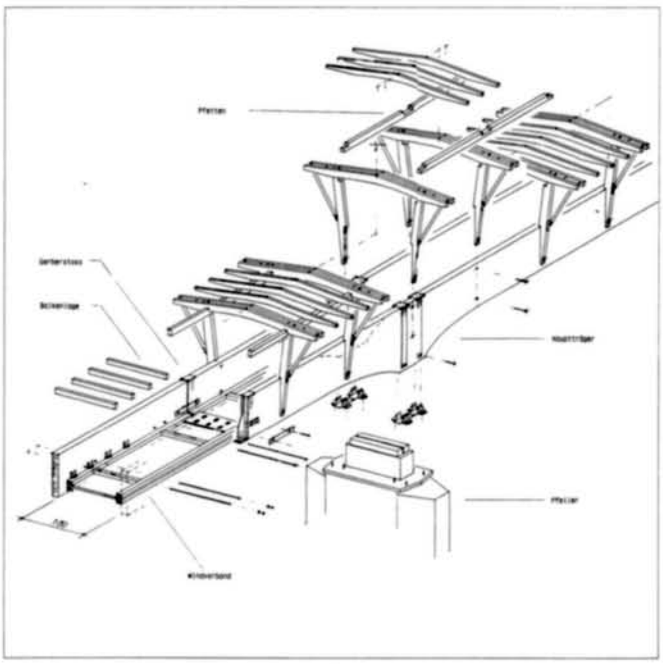

Figure 45 *Isometric representation of the main structure.*

Conclusion

In Central Europe the use of timber as a structural material for bridges has increased considerably during the past ten years. Engineers, architects as well as building authorities have again discovered this traditional way of building bridges. The developments of new, efficient fastener techniques and of new wood-based structural materials allow innovative and architecturally pleasing structures. Modern timber bridges are much more than just an alternative for concrete bridges. Numerous structures recently built either to replace existing bridges or as new bridges prove this fact.

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