# Soane and Swiss bridges

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## Introduction

The exhibition on timber bridges at the Soane Museum in 2003 provided a welcome opportunity to look at a part of their history in detail. Put together by Letizia Tedeschi at the Archivo del Moderno, it concentrated on John Soane's interest in bridges, from Caesar's bridge over the Rhine to the bridges of Switzerland, and was based upon his collection of drawings and some models of timber bridges. But, as the full title of the accompanying catalogue indicates, the coverage was rather broad and both reader and visitor had to work hard to get to the marrow of the subject[1]. An exhibition is there to stimulate the varied interests of the visitors, providing an opportunity for them to enlarge their own experiences, the bridges becoming a subject for landscape painting and an episode in the history of structural design. This one was a particular visual treat because the inclusion of some dramatic models that doubtless delighted all visitors but also allowed those with a specialist interest to examine the structures in a way that is scarcely possible from drawings. To some extent a catalogue needs to cover the same ground but is also an opportunity to present some of the latest scholarship on a subject, and here one could see a similar diversity. This is not necessarily a criticism. Indeed it should be welcomed because illumination of a subject from different points of view puts it into clearer perspective. Soane's interest in these structures was because of their technological virtuosity; that much is clear from his own sketches that formed part of the exhibition. Therefore perhaps it would have been appropriate if this had provided a clear starting point for discussion of the subject. To this extent it was a little disappointing because the bias was towards an art history approach rather than technological history. While that is probably a refection of present scholarship, it shows both how art historians have failed to grasp the issues of technological history and the lack of progress of the latter.

## The basis of Soane's collection

The collection of drawings that was assembled by Soane came about because of two men's interest in timber bridges, Soane himself and Frederick Augustus Hervey, Earl of Bristol and Bishop of Derry. Hervey had seen the bridge at Shaffhausen in 1766 when returning from his first visit to Italy and had determined to build a bridge over the Foyle at Derry[2]. The need for such a bridge was presumably brought home to him when waiting two hours in darkness for the ferry there and he soon solicited designs for it[3]. On his second visit to the Continent he had Michael Shanahan, commonly referred to as his factotum[4], visit and make drawings of a number of wooden bridges, mostly in Switzerland (Fig. 1). Shanahan planned to have the drawings published but this came to nothing when the engraver died before completing the plates. The original drawings have been lost but prints from the engravings that were made have survived. Meanwhile Soane, having met Hervey in Italy and been told about the bridges, visited and made sketches of some himself, principally the major works at Richenau, Shaffhausen and Wettingen. Eventually he was to have his pupils make copies of the prints from the Shanahan drawings and it is that collection of drawings that formed the core of the exhibition.

What Soane saw and drew himself included the two most dramatic of the bridges by the Grubenmann brothers, Johanes (1707-1771) and Hans Ulrich (1709-1783) who developed a

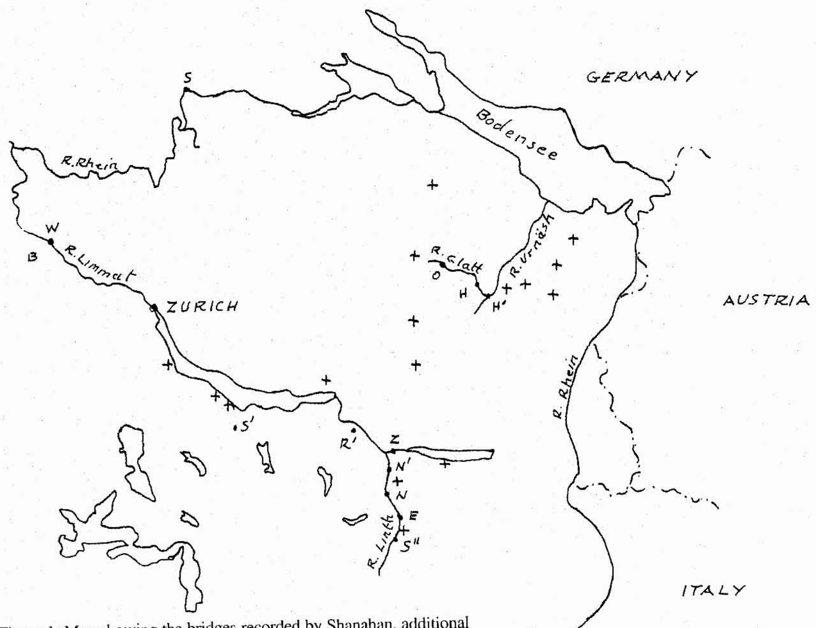


Figure 1. Map showing the bridges recorded by Shanahan, additional bridges known to thave been built by Hans Ulrich Grubenmann and churches by him. B- Baden: H- Hundwil; H'- Herisau; E- ennenda; N- Netstal; N'- Näfels; R- Richenau; R'- Reichenburg; S- Schafausen; S'- Schindellegi; S'- Schwaden; W- Wettingen; Z- Ziegelbrücke

reputation for their work that extended beyond Switzerland. From Soane's point of view the dominance of the Grubenmanns as bridge engineers is understandable. The bridges that he took time to sketch in detail during his journey back to England were both dramatically large in scale and technologically advanced. One can readily imagine that the huge structure of the Schaffhausen bridge, built between 1755 and 1758 with spans of 171 and 193 feet, would have greatly impressed the young Soane and left him with a lasting interest in bridge construction. The Wettingen Bridge (1765 – 6) was built using a single arch of laminated timber, a sufficiently novel form of construction to command attention. Thus the Grubenmann bridges form a second focus for the exhibition and its accompanying catalogue, but it is valuable to look beyond these to see how the work of these two carpenters fits into the overall development of timber bridge design.

One of the difficulties of tracing the history of timber bridges is that they are by nature rather ephemeral, subject to decay, flood and fire. The Schaffhausen bridge was destroyed by Napoleon's artillery in 1799 and the Wettingen bridge by the Austrian army. This means that we are dependent upon drawings or design models made either while the bridges were still standing or being contemplated. The result is a rather concentrated view of a small slice of history, presented through several kinds of material. These include topographical views containing the bridges, which are not very informative and sometimes of doubtful accuracy. In the exhibition construction details were seen through several sources: the models of bridges made by entrants for the Bishop's design competition for the Foyle bridge, the drawings made by Soane himself of the two major Grubenmann bridges, and the Shanahan drawings, although we do not have their originals. In addition to this material there are one or two drawings by Spengler, who repaired the Schaffhausen





bridge, and published illustrations of other bridges that place those by the Grubenmann brothers in a broader context. The bridges Shanahan drew ranged from some large enough and sufficiently well known to be illustrated by others to the small and obscure. Had his book been completed it might have provided a useful sample of timber bridge building on the Continent.

**Approaching the collection today**

Grumenmann's Reinbrücke at Schaffhausen (1756-8) was a particularly dramatic bridge and, as Nicola Navone's essay makes clear, its design was soon known outside Switzerland through various travellers who saw it.[5] But her discussion of French interest in its construction, deriving from Christoph Jezler's journey to Paris in 1771 with his drawing of the bridge that was seen by Blondel, is a little off the point. While her essay on the Grubenmanns' reputation outside Switzerland shows something of why their work was so well known, it does not address the more particular issue of whether they had any direct influence on or might be compared with the designs of others. Simply to say that "Grubenmann pursued similar goals to Perronet" and that "Perronet drew on the Roman tradition and Grubenmann on the medieval" is hardly very precise – nor necessarily all that accurate. What were these traditions and how did they affect the thinking about long spanning structures? These questions are partly answered by Laffranchi and De Giorgio who provide an excellent account of the way in which structures were seen to act and hence the kind of thinking that guided their design[6].

In approaching this material there are two viewpoints possible: to try to understand how the bridges were seen by their contemporaries, by travellers and writers of books, or to try to understand them as they were understood and designed by their carpenters. To a large extent the catalogue adopts the first of these while the second seems just as valid, but a more difficult task because of the limited physical evidence that survives. But even in presenting the first of these perspectives the writers of the essays are influenced by their own attitudes to what is fundamentally a technological issue, an aspect of the useful arts requiring a view of the world that sometimes seems closed even to those who write about it. The point is made in the essay by Fabio Minazzi on 'The *Encyclopédie* and the philosophical value of the mechanical arts' which he heads with a quotation from Diderot. 'How bizarre our judgements are! We expect that each should use his time usefully and yet we despise useful men'.[7] Here it is not that they are despised but that their world seems little understood and little addressed. There is some irony in this because Minazzi, discussing the background to the writing of the *Encyclopédie*, notes how Diderot rejected the approach of the earlier *Cyclopaedia* on the grounds that "its author dealt with technical subjects without ever setting foot in a workshop." The parallel is that here the subject of bridges is discussed with little attention given to the problems of design and construction that must have faced their builders, and to the intellectual world in which they operated. This is why it seems as if bridge design is treated as a branch or art history rather than as technical history that would have brought to it an understanding of the pragmatic processes involved.

Of course, in using the drawings to understand the design of bridges that for the most part have not survived we need to consider the way in which they were made, the extent to which they represent a sample of those actually built and the accuracy with which they have been subsequently represented. Soane was travelling home and was clearly directed by Hervey to the Shaffhausen bridge, taking this in on his journey, and would have had little difficulty in reaching the nearby bridge at Wettingen. With his interest in technical matters we have what we may presume to be accurate representations of both their overall structure and the details of their carpentry, or at least as much of it as he could see. What he does not show are the details below the deck that would have been difficult of access.

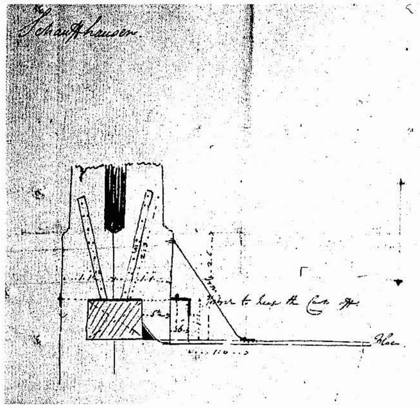

Figure 2. A cross-section of the Schaffausen bridge drawn by Soane (By Courtesy of the Trustees of Sir John Soane's Museum).

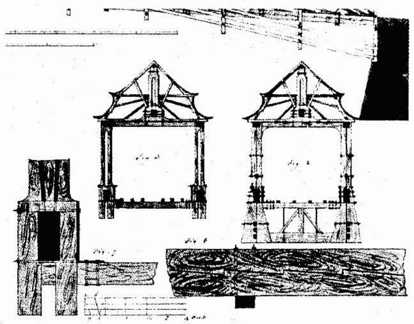

Figure 3. The same detail as in Fig. 2, but as shown in a Soane Office drawing after Shanahan (By Courtesy of the Trustees of Sir John Soane's Museum).

Given what we know of Hervey's journey through France on his second visit, the two French bridges a little south of Grenoble that are among the drawings (Cat. p. 97) were probably found by chance as his party travelled to Italy from the Langedoc where they were in the summer of 1770.[8] It is not clear exactly how and when other drawings were collected. Pemberton notes how Shanahan was sent off to make drawings by himself but by October of 1770 Count de Salis, who Hervey visited, wrote a letter noting his arrival with "a collection of the plans of bridges he has met with".[9] The letter also reported the arrangement that Hervey had made with Grubenmann's foreman to make a model of a proposed bridge for Derry. But a year later Shanahan was still working on the project because Hervey, then too ill to travel, is trying, through de Salis, to make contact with his architect to get plans from him to look at.[10] We have to imagine Shanahan, dispatched to make drawings of bridges. He would then surely have sought out the Grubenmanns, visiting them and drawing other bridges suggested by them. If so they might well have wanted him to see their latest work and that would account for the fact that his other drawings are of bridges that post-date the Shaffhausen bridge. We do not know how familiar Shanahan was with such carpentry but details shown in the drawings might well have been discussed with the Grubenmanns.

So much is supposition, but the pity is that the original drawings have been lost because something must also have been lost in the translation from the drawings to the engravings. This can be seen by comparing the cross sectional detail of the Shaffhausen bridge by Soane with that copied from the engraved plate. The straps clearly nailed across the surface of the posts in the Soane sketch have become larger in the detail in the later drawing apparently supporting the cross beams (Figs. 2 - 3). Moreover their lightness in the Soane drawing and the presence of larger bolted metal fasteners that support the cross beams in Shanahan's detail suggest that the nailed straps might have been only a temporary measure. The suspected inaccuracy here is in the relative importance given to features in the drawings but it also seems likely that some of the jointing details are incorrectly reproduced. Tie beams of the bridges are often in two layers of timber shown cogged together with a sawtooth form. While they would certainly have been connected in this way, the direction of the 'saw teeth' is critical and in some cases it seems unlikely that it was as shown. This is a detail that we will need to return to and it is one that we can imagine the engraver getting the wrong way round as he copied back to front something possibly unfamiliar to him.





Comparison of the drawings with some of those by others, particularly those by Krafft, also show differences in the disposition of structural members.[11] There are also some inconsistencies in the details shown in the drawings that might well have been in Shanahan's originals. Examples where different drawings of the same structure show quite different details can be found elsewhere[12] but the difficulty here is that for many of these bridges there is often only the rather suspect Shanahan version.

## Trestle and arch bridges

Because the exhibition was concerned with Soane's interest in bridges it went beyond the Swiss bridges to timber bridges in general starting with Palladio, and both his own bridge designs and his interpretation of Caesar's bridge over the Rhine whose design had been a long-running source of speculation. Palladio attempted a reconstruction of Caesar's bridge and Soane had a rather romantic drawing made of it complete with Roman soldiers (Cat. p.64) so that Piere Gros and Guido Belatramini discuss earlier attempts at its reconstruction based on Caesar's own description.[13] The simplest way of building a temporary military bridge was to drive piles into the river to form a series of trestles with beams between them – only one step up from throwing beams across a stream from bank to bank. While there were doubtless permanent bridges built on the same principle (see Cat. p.18), speed of erection and economy of means would take precedence over durability in a military bridge so that the trestle supports had to be as simple as possible. This would have applied particularly to the carpentry joining the inclined piles and the cross beams between them that supported the deck, and especially so as the joints in the piles had to be cut after they had been driven. Palladio's interpretation of this joint, as described by Caesar, concentrates on the self tightening action of the timber keys between the piles and the cross beam.[14] This he believed was achieved with the keys sitting in square cut trenches in the piles and simple notches in the cross beams (Fig. 4a). However, remembering that the cuts in the piles were probably made from a raft or boat, the joint would surely be simpler to make if the notches were the other way round (Fig. 4b); each pile then only requiring two cuts for the joint which could be made as deep as necessary.[15]

The simplest development from beam-and-trestle construction is to strut the beams from the supports as seen in the Rheinbrücke at Basel (Cat. p.192) and the basis of Palladio's design for a bridge at Bassano.[16] This inclined strutting was the first step to limiting the number of supports that had to be founded within the river at the expense of an increase in the complexity of the superstructure.[17] The exhibition catalogue includes an early nineteenth century painting by Roberto

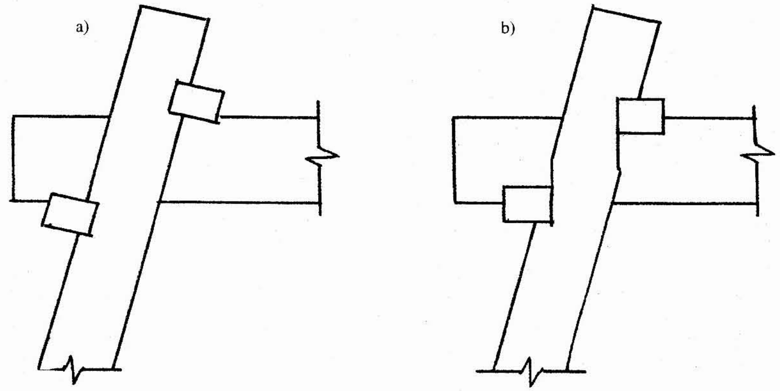


Figure 4. (a) Detail of Caesar's bridges as suggested by Palladio, compared with (b) a possible alternative arrangement

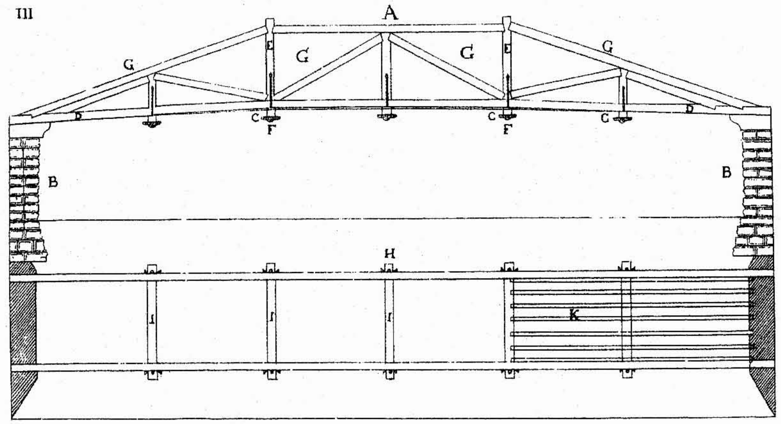


Figure 5. Palladio's design for the Cismone bridge (I Quattro Libri Dell 'Architettura, 1570, Book 3, Plate III)

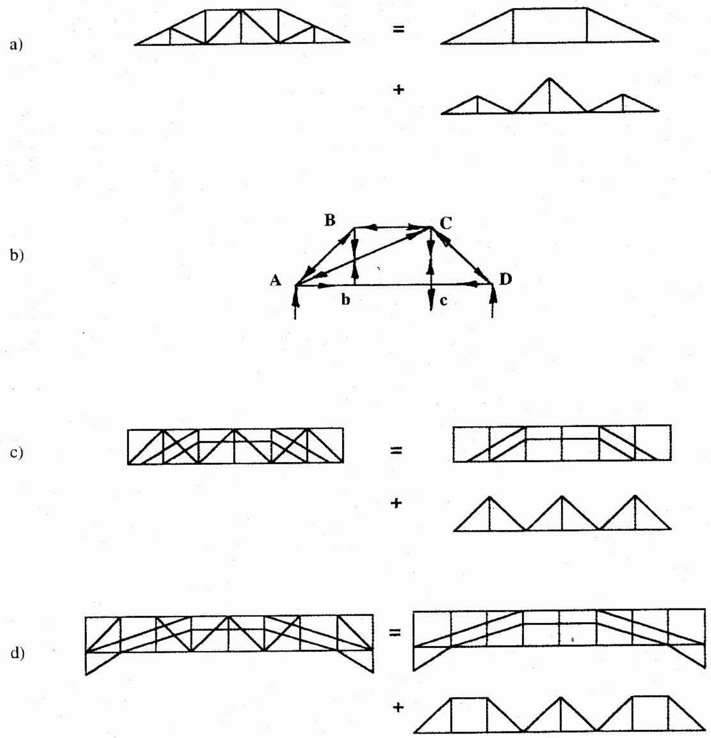


Figure 6. Truss layouts deissected: (a) Cismone brige, (b) a basic Queen Post Truss, (c) bridge at Reichenburg - see also Fig. 12, (d) bridge at Ziegelbrücke - see also Fig. 13





Roberti (Cat. p.85) of the Bassano bridge, presumably showing its condition as the Grubenmann brothers could have known it. All such bridges are likely to suffer from debris carried down stream that would damage the piers, or if it were held up by them, possibly resulting in damage to the superstructure. This bridge has been repaired and reconstructed more than once so that we are no longer looking at Palladio's original structure and the vicissitudes of the Bassano bridge have recently been chronicled by Carla Scapin.[18]

If the banks either side are steep enough and high enough above the river it is possible to bracket out from either bank and then put a beam between the ends of the two brackets. The natural development of this is the arch and this progression is seen in French bridges illustrated by Krafft. Those drawn by Shanahan each comprised four longitudinal beams to carry the deck with long raking struts propping all of them but also with shorter brackets under the outside beams. As these are the only examples of their type in Soane's collection we need to turn to other contemporary sources to place them in context. Krafft produced the largest published collection of nineteenth-century timber bridge drawings, and of the French bridges which he illustrated the majority use arch like strutting. An arch offers a number of advantages, not least that all the longitudinal deck beams can be supported by arching timbers, which are then protected from the rain by the deck itself. Bridges strutted from below were referred to as *sprengewerke*. Their vulnerability to flood and debris can be largely overcome by raising an arch like structure above the level of the roadway and hanging the latter from it.

## Hängewerke

The possibility of such *hängewerk* (truss frames) might have been obvious to English or Italian carpenters from their experience of roof construction in which the tie beam was routinely hung from the principal rafters by a king post or queen posts, but such structures did not suit the steeper pitched roofs of southern Germany and Switzerland. There a series of trestle like structures comprising beams and rafters, with braces between them to ensure stability, stood one upon the other. Therefore king and queen post trusses were not part of the Grubenmanns' vocabulary of roof forms although by then the trussed bridge form already had a long history, at least in theory if not in use.

The earliest drawings of anything resembling a trussed bridge were produced by Leonardo da Vinci. The basis of his first bridge sketch[19] is a number of overlapping king post trusses in which a large king post truss appears to support two others from the foot of its post. But the resolution of this idea is far from satisfactory. Leonardo was exploring a geometrical idea rather than a structural one because his other structure is hopelessly impractical. It has all the diagonals of a modern looking truss but has no top and bottom chords; a giant lazy-tongs. It was offered as an expanding bridge for military purposes, and to show his ingenuity to a prospective client rather than something that could be built and made to work. It suggests that Leonardo had little idea of the structural principles involved.

The earliest surviving practical design for a trussed bridge is Palladio's Cismone Bridge[20] recently analysed by Jacques Heyman[21]. Setting aside this modern analysis, the trussing each side must surely have been seen as a combination of a queen post truss and three king post trusses detailed very much like a series of roof trusses (Figs. 5 - 6a). The king posts are supported by strutting from the bottom of the queen posts. Struts are let into the posts as they would in roof trusses while there are metal straps, not to support the tie beam, as in a roof, but to support the cross beams. Tamperone and Funis[22] have recently suggested a detail for this based upon Palladio's description but Inigo Jones also sketched this detail in his copy of Palladio[23].

A curious feature of this bridge is that there is no method for stabilizing the trusses. The deck beams would normally extend beyond the posts so that the latter could be held in position by raking

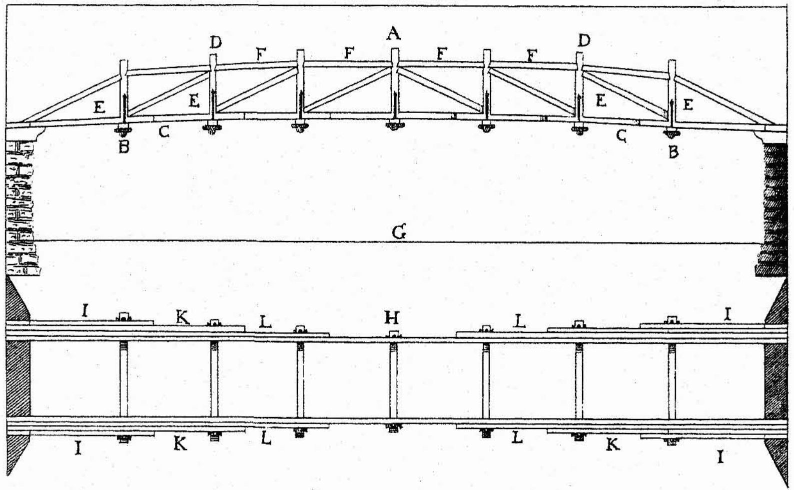


Figure 7. Palladio's alternative truss design (*I Quattro Libri Dell 'Architettura*, 1570, Book 3, Plate IV)

struts. It seems hardly possible that the connection at the deck was sufficiently stiff to ensure stability of the trusses so that the omission of this detail might throw suspicion on the accuracy of Palladio's illustration were it not that the Inigo Jones annotations show nothing either. Palladio says that the lower chords of the trusses were each of one piece of timber. These would have been single beams 100 ft long, which Palladio gives as the breadth of the river. Conifers of this size might have been available, but the ability to obtain sufficiently long timbers would still have limited the spans possible for an arrangement of this kind and carpenters needed a method for forming tie beams of more than one piece of timber.

Palladio's other truss design for the same bridge[25] (Fig. 7), while looking more like a modern truss in elevation, was clearly not conceived in that way because the plan shows a curious multiplicity of members in the bottom chord. What was supposed to happen in the top chord and how this could have been constructed in three dimensions is not clear. On plan the posts are wider apart the nearer to the supports, the whole structure looking like a curious chimera, a cantilevered structure in plan but a trussed structure in elevation while the top chords must have curved inward towards each other to accommodate the positions of the posts. While it looks superficially like a modern truss it would be a mistake to read it in this way. Certainly Palladio would not have seen it as a series of braced panels as we might today. His text implies that he was drawing something that he had not seen because he says that it was a form not used in Italy although reportedly used in Germany.

Clearly, Palladio is a possible source for the Grubenmanns but simple king and queen post forms for bridges had also been illustrated by Gautier in his *Traité des ponts*[26]. Thus in spite of some questionable arrangements these early examples show that the idea of trussing was well established by the time they were building their bridges. But it is important to be clear about the meaning of this term. During the eighteenth century and well into the nineteenth a truss comprised two or three members in compression forming an arch like arrangement from which were suspended one or two posts to 'truss up', i.e. to tie up, the tie beam and which were therefore in tension. That is the way in which the term is used here. It did not, and could not have implied a series of braced panels, which is how engineers think of trusses today. Therefore the truss was a close relative of the funicular arch.





While the Grubenmann brothers did not use trusses in their roof work they did use the funicular arch and that also appears in their bridges. Hans Ulrich used it in a number of church roofs in which the structural problem was the avoidance of outward thrust on the walls. Steinmann notes some 20 churches built by him (Fig. 1), the majority of which have simple flat ceilings provided for by a simple roof structure with tie beams.[27] However there are a small number with vaulted ceilings rising above the wall plate, a problem in any carpentry tradition because of the need to contain the outward thrusts on the walls. Raised tie beams were used in English carpentry with additional members to restrain the feet of the principals while American carpenters divided the tie beam and canted it upward to clear the ceiling.[28] In contrast Hans Ulrich favoured the use of longitudinal structures spanning between the gables and constructed as funicular arches. Laffranchi and Di Giorgio illustrate the one at Grub (1752) and note its use in two other churches.[29] The Grub structure can be seen easily because the arch spans the length of the roof immediately under the ridge and from which the rest of the roof framing hangs. However, this was not his usual arrangement and may have been unique. Instead he normally used pairs of funicular arches within the planes of the roof slopes with the wall plates acting as ties (Fig. 8).[30]

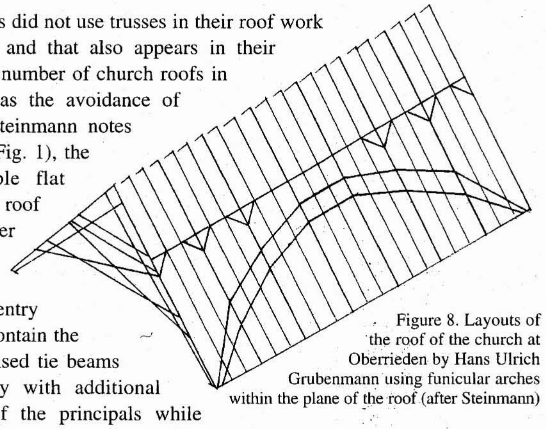

Figure 8. Layouts of the roof of the church at Oberrieden by Hans Ulrich Grubenmann using funicular arches within the plane of the roof (after Steinmann)

The clearest use of a funicular arch in the Shenahan drawings is that for a bridge he records as being at Näfels, although this might not be its location. A drawing by Spengler shows an identical structure that was undoubtedly at Netstal while Steinmann makes no mention of one at Näfels.[31] As the two settlements are only 4km apart it is possible that Shanahan mistook the location of the bridge. Bridges by Hans Ulrich Grubenmann that survive at Hundwil and at Kubel[32] also use the funicular arch, although these are more complex structures whose details will be discussed below.

## Trusses

Conditions in Switzerland that demanded covered bridges to cope with winter snow naturally favoured the trussed bridge. The truss structure would have been deep in comparison to the span while, partly supported by the trusses, the roof ensured their stability. The roof and side walls that kept snow off the deck also protected the structure which otherwise would have quickly deteriorated as water got into the complex jointed carpentry. But their structure was quite different in detail from the arch or strutted bridge and so there could have been no natural progression from one to the other. In the former all the structural members are parallel to the span with every beam strutted. In a trussed bridge there must be cross beams to carry the deck beams and bring the loads back to the trusses. The Grubenmann brothers only used the basic queen post truss in a small number of bridges of limited span.[33] The reason for this must surely lie in a disadvantage they have as the basis for bridge structures. While a simple queen post truss is suitable for a roof structure with its symmetrically distributed load, this is not true of bridges that have to carry large rolling loads.

Consider a load placed at one of the posts of a queen post truss. Ideally this would be supported by members AC and CD as shown in Figure 6b. Without the member AC the vertical component of the force produced in AB would be resisted by the post Bb in tension and the tie beam in bending. It would be sensible to include not only the member AC but also a member DB to take

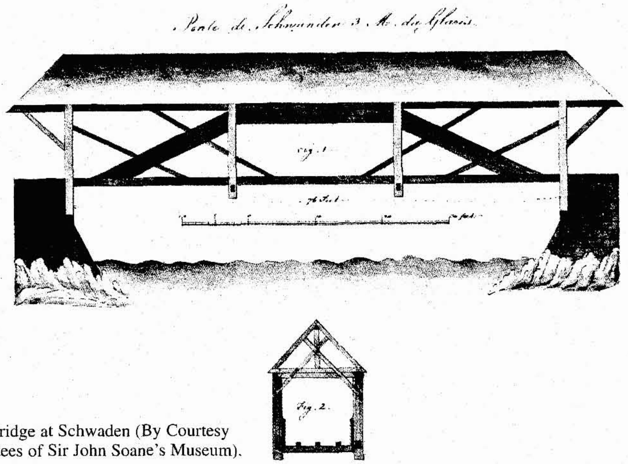

Figure 9. Bridge at Schwaden (By Courtesy of the Trustees of Sir John Soane's Museum).

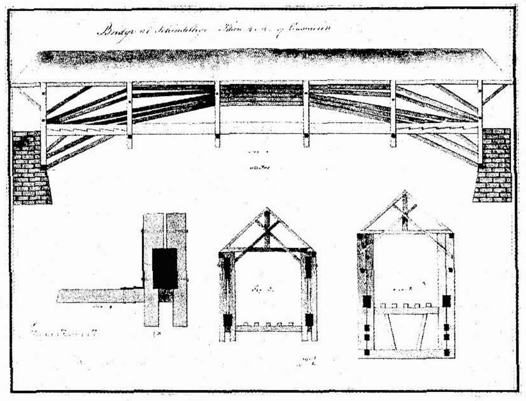

Figure 10. Bridge at Schindellegi (By Courtesy of the Trustees of Sir John Soane's Museum).

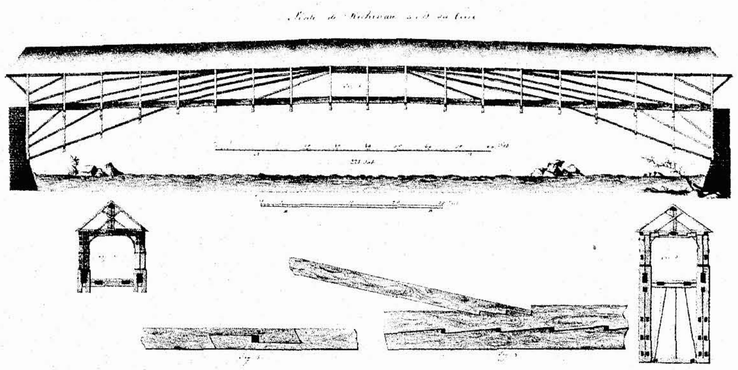

Figure 11. Bridge on the Lower Rhine at Reichenau (By Courtesy of the Trustees of Sir John Soane's Museum).





the load when it was at b. Laffranchi and De Giorgi present diagrams that explain how this works for uniformally distributed loads and demonstrate how bridges would have been seen as a pattern of overlapping trusses.[34] This is convincing for long spanning foot-bridges where the live load is small in comparison with the self weight but less so for bridges carrying the point loads produced by laden carts. Their explanation of this with its reference to the prestressing effect of the dead weight relies too much on a modern understanding of trusses not available to the Grubenmanns. For example we are aware today that the effect of a live load on such trusses depends not on its absolute value but on its magnitude as a proportion of the permanent load. Thus the effect of live loads could have been reduced if the bridge trusses had carried the weight of the roof as well as of the sides and deck. Instead of this the carpenters attempted to keep as much of the roof load as possible off the main structure. Rather than have simple roof structures spanning between the side trusses they provided a third truss under the ridge which, if fully effective, would have carried half the weight of the roof.

Bearing in mind that not all of the Swiss bridges drawn by Shanahan can be definitely attributed to the Grubenmanns they can be grouped into a number of types. Even the simplest three-bay bridges using queen post truss arrangements are not just that. In the bridges at Schwanden (1765) (Fig. 9) and Erlen Schwanden (Cat p. 102), with small queen post trusses of three panels, the inclined members and straining beam are of two and three members. The same arrangement was also used by Hans Ulrich in the Oberach-Brücke at Rehetobel, built in 1739[35]. The larger bridge at Einsiedeln (Cat. p. 100) appears to be a development of this with very widely spaced members producing two trusses one of five bays and one of three. As spans become longer so the number of struts forming trusses increases as at Schindellgi (Cat. p.99) (Fig. 10) and Reichenau (Cat. p.103) (Fig.11). Both these are further complicated by having struts under the ends of the deck, perhaps unsurprising for such long spans. (The bridges at Richenau span 135 ft and 207 ft.) The clear form of queen post like trussing is lost here in the multiplicity of struts so that the frames come close to resembling an arch. What prevents them from looking more arch-like is the spacing between the inclined members.

Rather than multiply the number of struts setting a series of 'arches' within each other, a more sophisticated arrangement is to overlap trusses. These work more like Palladio's Cismone bridge but with the smaller trusses placed outside the larger ones. The bridges, at Reichenburg (Fig. 12) (Cat. p. 100) and at Ziegelbrücke (1743) (Fig. 13) (Cat. p 63) of six and nine panels respectively, have such overlapping truss arrangements that have been dissected in Figures 6c - 6d. Steinmann attributes the

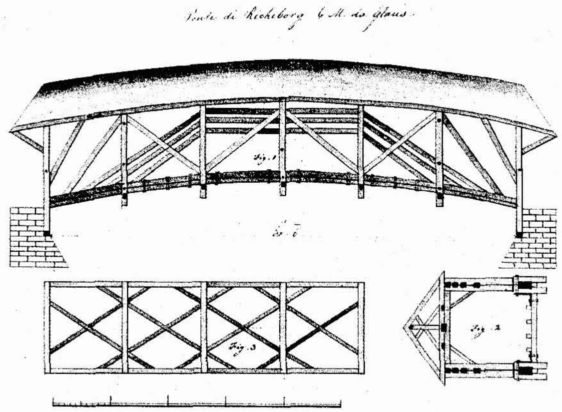

Figure 12. Bridge at Reichenburg (By Courtesy of the Trustees of Sir John Soane's Museum).

latter to Hans Ulrich[36] and also illustrates an eight panel bridge on a similar principle at Ennenda (1765) where the outer strutting forms a central king post truss flanked by queen post trusses.[37]

### Arch bridges

The bridge on the Glatt at Oberglatt, built by Johannes Grubenmann (1767 – 28m span) (Cat. p.131) is a true arch bridge with the arch made of several timbers strapped together. Laffranchi and De Giorgio provide tantalisingly little information on this. While they show that the arch is 'assisted' by a very modern looking truss structure, although one that could be conceived as a simple combination of king and queen post trusses, they do not provide a cross section to show how all this was assembled, nor how the vertical members transmit their forces to the arch. Being of smaller span this looks like a rehearsal for the true arch of the Wettingen Bridge, (1765-66) except that it was built later.

As Laffranchi and De Giorgio point out, for an arch of timber to work effectively the layers of timber have to be connected together. This was done at Wittengen by cogging the timbers together, an operation that must not only have been labour intensive but also more expensive in timber as the depth of the cogging must be lost in each layer. Whatever the relative effect of these two disadvantages the carpenters would have wanted to find other ways of fastening them. Bolting was a possibility, used together with the cogging at Wettingen and apparently by itself at Glatt, but Ritter apparently dispensed with both when he built two laminated timber arches in the 1790s.

Going from a funicular polygon to a true arch involves a little more that the realisation that timbers can be bent and fastened together to form an arch. Because individual timbers are not strutted against the posts, as in funicular arch designs, some other means must be found to transfer the compression from one timber to another, because it would be impossible to obtain timbers long enough for the full span. At joints the compression forces must be transferred from the timbers being jointed to their neighbours so that some innovative carpentry is required. The method used was simply an adaptation of the tie beam design. By breaking joints forces can be transferred between adjacent timbers by keying them together in some way. Of course this had always been necessary for the tie beams, the difference being that now it was compression forces rather than tension forces that needed to be transferred.

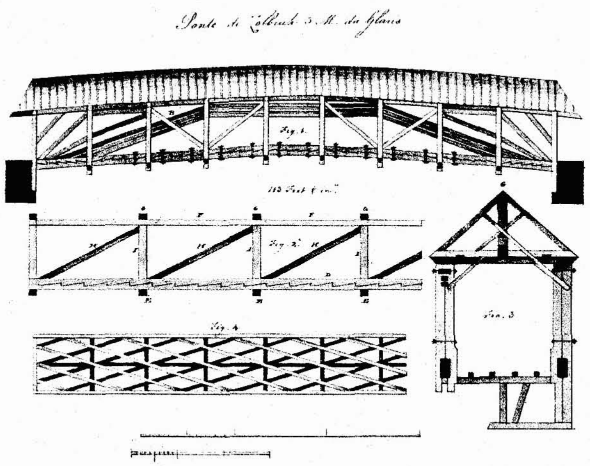

Figure 13. Bridge on the Linth at Ziegelbrücke (By Courtesy of the Trustees of Sir John Soane's Museum).





### Matters of detail

Consideration of how overall form might have been shaped by the way in which the carpenters saw the forces in the structures does not address all the issues they would have been dealing with. As any designer will be aware, the final form of a structure may be determined as much by consideration of details as by the overall forces. This is particularly true of timber structures where it is the transmission of tension forces that poses a problem. Moreover, some details of the bridges might well be determined by the construction process rather than by the loads to be resisted in service.

As truss forms were used, the construction of these bridges depended upon the ability to transmit tension forces both in the hangars and in the tie beam. The sequence of load transfer shown in the Shanahan drawings is from longitudinal deck beams to cross beams, which must then be attached to the hangars. In some cases where transverse deck beams are at closer spacing than the hangars load has to be brought onto the tie beams but the deck beams are still below them. The more recent drawings and photographs of the surviving Urnäschbrücken at Kubel and Hundwil show transverse deck beams bolted to the underside of their tie beams. Connecting vertical members to the cross beams is where Palladio used metal fasteners, which is certainly one solution and was used in some of the bridges drawn by Shanahan, the bridge at Einseideln for example. The other method of transmitting tension is to use pairs of timbers cogging them over the timbers they are jointed to. This is how the connection is made between the verticals and both the tie beam and the compression members of the trusses or arches. The clear sequence of construction is that the two side trusses were erected first with the verticals clasping these members and the cross beams were then connected to them.

What is not clear from the Shanahan drawings is the connection between what appear to be inclined tension members and the other members of the truss. These occur in the bridge at Schwanden, (Fig. 9) drawn by Shanahan, but also in the surviving funicular arch bridges at Hundwil and Kubel. Photographs of these surviving bridges show that these diagonals are trenched into the sides of the uprights and tie beams while the same device is clearly included in the model of the Kubel bridge.[38] If for no other reason, the absence of any obvious major fastening devices to these inclined members shows that they could not have been seen as significant load carrying members. Truss forms with inclined tension members that we are familiar with today would simply not have occurred to carpenters at that time so some other explanation has to be sought for these timbers.

A characteristic of timber bridges is their lightness, so it might be possible to construct them by cantilevering from either side rather than using temporary supports from below; clearly an advantage over ravines or swift flowing rivers. This would provide a reason for brackets at the supports even in those bridges that were otherwise trussed – combinations of *sprengewerke* and *hängewerke*. It also suggests the reason for the inclined hangars in the bridges noted above. Cantilevering is simple if there are struts beneath the deck but not so simple without them. Hangars would help to form stiff panels that could be cantilevered from the supports before the arch was complete. Of course, even in a temporary state the inclined members have to be fastened to the tie beam sufficiently to support the self-weight of the truss and this might prove difficult as the span of the bridge and hence the self-weight of the structure increased. Soane's sketches of the Shaffhausen bridge show iron hangars used in its construction which would have been easier to fasten and would have more easily carried a higher load. The argument for these two devices, bracketing struts and hangars as temporary measures, is supported by the absence of each in the presence of the other.

Carpenters could not always be as fortunate as Palladio in being able to obtain timbers as long as the span. Thus ties beams would have to be formed of more than one piece. This was the problem faced by Wren in his design for the roof of the Shedonian Theatre. There the span was about 70 ft for which he invented an arrangement of two layers of timber with overlapping pieces jointed together to transmit a tensile force.[39] His joints were rather complex, while what had been developed in Europe was a much simpler saw-tooth design, the kind of thing that a practical minded carpenter would devise with simplicity of carpentry in mind. Of course for a saw-tooth to work it must be the right way round so that compression forces are transmitted between the vertical faces. The correct arrangement is seen in the roof of the church at Grub where the arch thrusts against the upper timber that has then to transmit the force to the lower. The photograph in the catalogue (p.124) shows clearly that the upper timber is divided within the span. At this point the direction of the saw tooth joint must change so that the lower timber can transmit the force back to the next upper one. This is how the saw tooth is cut in the model of the bridge near St Gall (Cat. p. 135) and in the drawing of the bridge at Baden (Cat. p. 99). It should be possible to work out from the direction of the saw tooth cuts where the joints were in the timbers and so how many pieces were used in forming the tie, and this is possible in a number of the bridges.

Unfortunately it is not always as simple as that. This is not how the joint is shown in the drawing of the bridge at Erlen-Schwanden (Cat. p.102) nor in the bridge at Schindelligi (Fig. 10). For the bridge at Einsieden (Cat. p.100) the joint appears to be the right way round at one end of the bridge and the wrong way round at the other. The most glaring problem is the detail of the Reichenau Bridge (Fig. 11) where a compression strut is notched into the upper beam but this is not connected to the lower beam in a way that would allow it to transmit this thrust. These and other oddities need some consideration. The accuracy of the drawings has already been questioned and it is a pity that they cannot be relied upon because there is another reason for the use of a saw-tooth joint between two layers of timber that needs to be considered; beams could be precambered using this device. If a timber with a saw-tooth form on its upper surface is strained into an upward curve and a second timber scribed to fit it, compression forces would again be generated between the vertical surfaces when the two were released. The effect would be to prevent the two from returning to the horizontal thus resulting in a precambered beam. For beams in buildings, much more complex arrangements were used to overcome the problem of sag in long spans[40] but this idea must surely be the reason behind the two layers of timber at either end of the three-bay Schwanden bridge and the five bay Schindellegi bridges (Fig. 10). The spans of both are modest so that the tie beams are of one length of timber. Precambering is the only reason one can imagine for the labour involved in making the connection between the two pieces. The only trouble is that again the saw-tooth cuts seem to be the wrong way round.

**Discussion**

The irony of including illustrations of piling machines for bridge piers in the exhibition is that the essence of these timber bridge structures was to avoid the need for piers within the river. That is what Hans Ulrich Grumbenmann had wanted with his first ambitious design to bridge the river at Shaffhausen in a single span. Had the pier from the previous bridge not existed it is doubtful that as a carpenter he would have had the experience to build one. While Minazzi's article on the *Encyclopédie* quotes Diderot on the need to study the mechanical arts by visiting the workshops and talking to artisans, an aspect of these bridges is that they would have been produced in temporary workshops at remote sites. These were far from the range of those who produced the *Encyclopédie* text and its illustrations, and the tantalising thought is the possibility that Shanahan did discuss the designs with the Grubenmanns. Knowing his employer's ambitions to built a bridge would he not have made every effort to do so? More serious perhaps than the loss of the original drawings is the loss of the text that must have been written to accompany them. That there was to be such a text is apparent from the letters on the drawings identifying certain of the members and faithfully reproduced by Soane's pupils.

As not all the bridges in this collection of drawings are by the Grubenmann brothers they present something of the general state of the art of wooden bridge construction in Switzerland and her





neighbours. Those by the Grubenmanns show a degree of sophistication in design not generally found in the others. Given the fairly long time period covered by all the available drawings of timber bridges one might look for some progress in their design. Here the difficulty is that progress requires some shared knowledge and some similarity in the problem being tackled. There is little evidence of shared knowledge and the choice of bridges illustrated by those publishing on the topic sometimes seems rather arbitrary. Krafft illustrated the rather peculiar bridge on the Kander whose dramatic appearance may have made it a suitable subject for topographical artists (Cat. p.147) but whose singular structure derives from the shape of the deep gorge that it crossed. Foundation conditions as well as topography will have affected the nature of the design. There is a distinction to be drawn between the arch bridge at Wettingen and the later arch at Glatt and the various funicular arches. Only at Wettingen does the arch spring from the masonry below the bridge deck; all the others are tied arches. Unfortunately interest in the carpentry has been confined to just that and we know nothing of their foundations. Where foundations are poor trussed or tied arch bridges make sense as they only imposes vertical forces on the supports. Where a bridge is founded on rock arches can be used and there is no need for a tie beam. In the last century it was such conditions that allowed Maillart to build his dramatic concrete arched bridges in Switzerland.

With such a close focus on the Grumbemanns it is difficult to place them within the history of timber bridge building. The dramatic size of the Shaffhausen Bridge had the effect of capturing the imagination of contemporaries to the extent that we are still hearing the echoes today. But the historian of technology will surely want to know if we are simply looking at a backwater of history, only generating such interest now because of the availability of the drawings and hence the information on the Swiss structures. The young Soane with his interest in construction would have been naturally intrigued by the scale of the carpentry that he saw, but this had curiosity value rather than any practical consequences. There could be no development in England of this kind of construction. The lack of available timber meant that England had never been a country of long spanning timber bridges and by the middle of the nineteenth century, when large colonial timbers were being imported, iron was king. While there is evidence of German carpentry in North America this bridge technology was not exported there. Timber was available but America developed quite different designs in the nineteenth century. There is a however a possible line of development from Wettingen to the French work on laminated arches in the mid-nineteenth century, but this is only briefly and incompletely considered by Laffranchi and De Giorgi.

These observations do not diminishes the importance of the structures within the broader history of bridge building in their own region. This raises a wider question about the significance of such bridges within Swiss society. Plot the structures on a map (Fig. 1), add in the dates of the bridges that we know about, and one is tempted to ask about the more general demand for these structures. But such issues are understandably outside the scope of the exhibition, which is strictly on bridge technology. What we seem to be seeing is the peak of a technological development whose earlier history will necessarily remain obscure and from which there was no further development because events moved on. Only Laffranchi and De Giorgio compare the Grubenmann designs with those of subsequent builders. With a catalogue comprising independently written essays, one has the advantage of a number of different views of the subject, each fascinating in itself, but it would have made a stronger technological history if the Laffranchi and De Giorgio essay had been written first, with their argument informing some of the other contributors.

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**References**


1. Angelo Maggi and Nicola Navone (eds.), *John Soane and the wooden bridges of Swizerland. Architecture and the culture of technology from Palladio to the Grubnenmanns* (Archivo del moderno Accademia di architettura, Mendrisio Universita della Svizzera Italiana & Sir John Soane's Museum, London, 2003).
2. William Shakespear Childe Pemberton, *The Earl Bishop* (1925), p. 81.
3. ibid. p. 95.
4. Shanahan later acted as his architect for the building of his house at Downhill.
5. Nicola Navone, 'The eighteenth-century European reputation of the Grubenmann brothers', Catalogue pp.31-55.
6. Massimo Laffranchi and Paulo De Giorgio, 'Some remarks on the Grubenmanns' wooden bridge structures', Catalogue pp. 115-135.
7. Fabio Minazzi, op. cit., Catalogue pp. 167-81.
8. Pemberton, p. 103.
9. see Brian Fothergill, *The Mitred Earle: An Eighteenth-century Eccentric* (1974), p. 136. The original is in the Count Charles de Salis archive.
10. Pemberton, p. 117.
11. Johann Carl Krafft, *Plans, Coupes, et élévations de diverses productions de l'art de la Charpente, exécutées tant en France que dans les pays étrangers* (Paris, 1805).
12. See for example the different versions of the roofs of St Alphege, Greenwich and St Paul's, Covent Garden discussed in David Yeomans, *The Trussed Roof: Its History and Development* (Aldershot, 1992).
13. Pierre Gros and Guido Beltramini, 'Caesar's bridge on the Rhine', Catalogue pp. 183 – 211.
14. Andrea Palladio, *I quattro libri dell' architettura* (Venice, 1570), Book 3, Chapter 6.
15. Fig. 5a is based on Palladio's original sketch reproduced in the catalogue where it is discussed in some detail, pp. 204-05. The published versions all differ from this in having either no notching at the top of the beam or notching that would not hold the wooden key as it is drawn. These must surely be errors in engraving the plates.
16. Palladio, Book 3, Chapter 9, plate 6.
17. There is the additional problem of driving piles into the river bed on which to found the spans. It is the necessity of such foundations that led to the interest in the development of pile driver technology that so interested Soane and the reason for its discussion in the *Encyclopédie*. But such issues were not confined to the construction of timber bridges.
18. Carla Alberta Scapin, '"Ponte vecchio" bridge in Bassano: an historical "excursus"', *Proceedings of the First International Congress on Construction History* (Madrid, 2003), Volume III, pp. 1831-44.
19. Folio 23, Code B.
20. Palladio, Book 3, Chapter 8, Plate 4.
21. Jacques Heyman, 'Palladio's wooden bridges', *Architectural Research Quarterly*, 4, No.1 (2000), pp. 81-85.
22. Gennaro Tamperone and Francesca Funis, 'Palladio's timber bridges', *Proceedings of the First International Congress on Construction History*[5] Volume III, pp. 1909-19.
23. Bruce Allsopp, Inigo Jones on Palladio: being the notes by *Inigo Jones in the copy of I quattro libri dell architectura, di Andrea Palladio, 1601, in the library of Worcester College, Oxford* (Newcastle upon Tyne, 1970). Jones's sketch shows a metal strap at the foot of each post, rounded at the top with 5 fixings, four in the post and one in the beam. His note reads "The boult and the forlocke of Iron that sustent ye timbers that make ye Breadth of the bridge to the Collonelly."
24. The double line at the underside of the tie beam in the Ware edition of Palladio that suggests the possibility of an iron strap connecting timbers together is not in the original.
25. Palladio, Book 3, Plate IV.
26. Hubert Gautier, *Traité des ponts, etc.* (Paris, 1716).
27. Eugen Steinmann, *Hans Ulrich Grubenmann, Erbauer von Holzbrücken, Landkirchen und Herrschafthausern, 1709-1783* (Niederteufen, 1984).
28. David Yeomans, 'British and American approaches to a roofing problem', *J. of the Soc. of Architectural Historians*, 50 (1991), pp. 266-72.
29. 'Some remarks on structures', p. 116 citing J. Killer, *Die Werke der Baumeister Grubenmann*. Grub is not in Steinmann's description of Hans Ulrich's works.
30. These structures date from the church at Stein (1749) to that at Erlen (1764).
31. Steinmann, p. 35. There is both the Spengler drawing and a topographical drawing of the bridge that identifies the nearby village.
32. These are illustrated by Laffranchi and De Giorgio (Catalogue pp. 132-5) and by Steinmann, pp. 20-23.
33. Shwanden, p. 60, cat. 13 & p. 102 cat. 35; Einsiedeln, p. 100, cat. 30; Shwanden, p. 102, cat. 36 Reichenburg, p. 100. cat. 31.
34. A similar argument has recently been put forward by Tom Peters, in 'Bridge technology and historical scholarship', *Proceedings of the First International Congress on Construction History*, Volume I, pp. 61-67.
35. Steinmann, pp. 38 –39. This bridge still stands.
36. Steinmann, pp. 24-5.
37. Ibid p. 31. This is a drawing by Spengler, also reproduced in the Catalogue p. 127, and is an example of where Spengler's drawing is different in some details from that as drawn by Soane's pupil, and so presumably by Shanahan.
38. The catalogue, p.134 has a photograph of the bridge at Hundwil. Steinmann has photographs of both this and the other surviving bridge that shows similar construction.
39. The first published illustration of this is by Robert Plot, *The Natural History of Oxfordshire* (1667).
40. E. Giunchi et al (2003), 'Wooden composite beams: A new technique in the Renaissance of Ferrara', *Proceedings of the First International Congress on Construction History*, Vol 2, pp. 1023- 32.