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Palladio's timber bridges

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Andrea Palladio, in his Treatise «*I quattro libri dell'Architettura*» (1570), after a short introduction on timber bridges containing general indications on their planning, presents the bridge on the Rhine, Figure 1, ordered and described by Caius Julius Caesar in the *Commentarii* of the Gallic war, as a model from the classical antiquity; of this work and of its structure Palladio also presents, with text and drawings, a personal interpretation that he calls inventione», elaborated in his youth as he says.

In subsequent pages of the Treatise, he describes a few timber bridges of his own «invention».[1]

Of the bridges represented in figures 2 through 6, only the Cismon river bridge, Figure 3, the Brenta bridge in Bassano, with a covered road, Figure 2, and the Bacchiglione bridge in Vicenza (a work which was planned following Palladio's interpretation of Caesar's Bridge and was considered an experiment) are ever actually built, according to a contemporary witness;[2] on the latter only a few written references remain (Palladio, Scamozzi). The Bassano bridge, probably the most famous, has been destroyed many times and rebuilt in accordance to the original specifications. In his Treatise, Palladio presents three more *inventioni* of great interest but without reference to a particular location or situation.

The Caesar's bridge interpretation matches the palladian restoration of the remains of the Titus arch in Rome, one of the more philologically correct and certainly, amongst the several available drawings

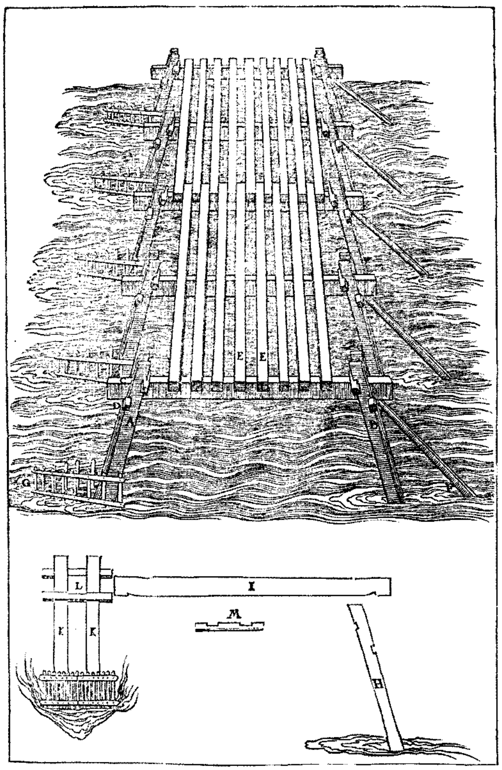

Figure 1
The bridge on the Rhine in the interpretation of Andrea Palladio. Palladio 1570. 3: 14

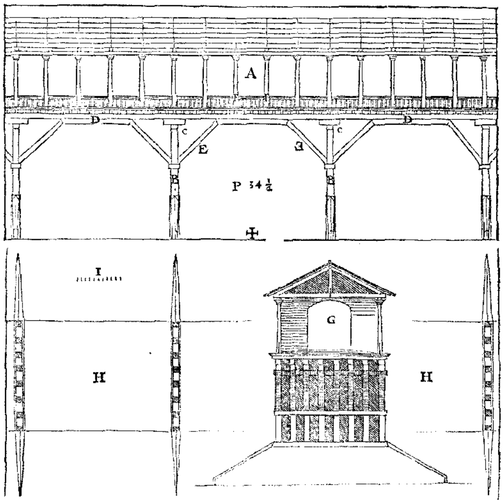

Figure 2
The Brenta bridge in Bassano. Palladio 1570. 3: 20

elaborated by other Authors, the closest to the original features of the monument as the excavations and investigations carried out in Rome in the beginning of the XIX c. by Raffaello Stern and Giuseppe Valadier demonstrated.

The whole set of bridges, whether built or only described, presents an outstanding interest. The Cismon river bridge and the first invention can be assumed, to a certain extent, as the most representative of the palladian technology on the subject and of the advances achieved by Palladio.

The term «invenzione», from the Latin «*invenio*»

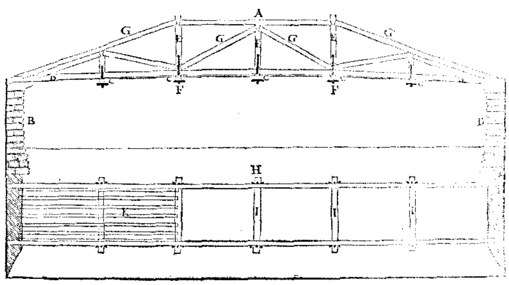

Figure 3
The Cismon river bridge. Palladio 1570. 3: 15

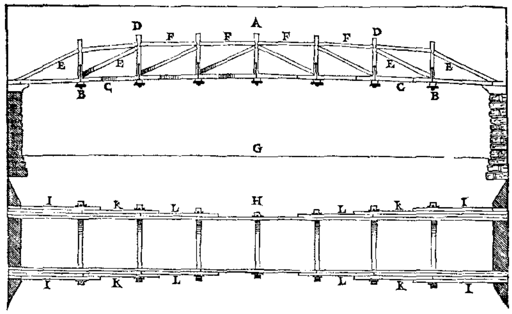

Figure 4
Drawing of the «*prima inventione*». Palladio 1570. 3: 17

(to find, discover, invent, device etc.) means, in general, to achieve a discovery, or, a contrivance. For Palladio, «invention» also means a building, realized or just simply planned; a fruit of a very personal and original elaboration, different from anything seen up to date. In the eighth chapter of Book II, Palladio maintains that. Palladio maintains that he intended the Treatise to be a collection of drawings of «quelle fabbriche, le quali overo fossero compiute, overo cominciate, e ridotte a termine che presto se ne potesse sperare il compimento: ma conoscendo il più delle volte avvenire, che sia di bisogno accomandarsi a i siti, perché non sempre si fabbrica in luoghi aperti, mi sono poi persuaso non dover esser fuori del nostro proposito, lo aggiungnere à disegni posti di sopra alcune poche invenzioni fatte da me, a requisizione di diversi Gentiluomini, le quali essi poi non hanno eseguito».[3] Invention is, in the Palladio's writings, also «interpretation» of an ancient literary text, such as Caesar's description of the bridge on the Rhine river. In the case of the bridges, the term invention connotes an idea which is original, never before seen.

Inventione, for Palladio, is also a model, something (an idea, an interpretation of architecture, an architectural type, a mechanical device for the construction etc., expressed by a literary description, a maquette or simply a set of drawings) which is new and original but independent from contingent situations and can be applied when the general situations occur.

To this purpose it is interesting to note that Palladio, as his contemporaries, thought that it is possible to extend with no limits the span of the bridges in general and of his owns in particular, only increasing, in a proportional way, the dimensions of the parts; a conviction that Galilei was able to demonstrate not true for the arithmetic *ratio* of the dimensions and possible only to a limited extent.

An interesting comparison can be made to the french contemporary architect Philibert de l'Orme, who also uses the word *invention* in his Treatise *Nouvelles inventions pour bien bastir et a petit frais* (1561). The meaning of the term, applied mainly to the light timber vaults made with boards centrings, first described by Vitruvius as the *concamerationes*, is certainly closer to the today's one because the Author proposes, with several examples, many detailed configurations and possibilities for making easy and inexpensive coverings of very fashionable spatial shape.

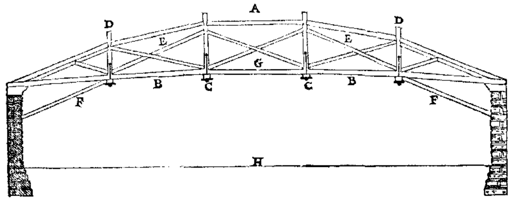

Figure 5
Drawing of the «*seconda inventione*». Palladio 1570. 3: 17

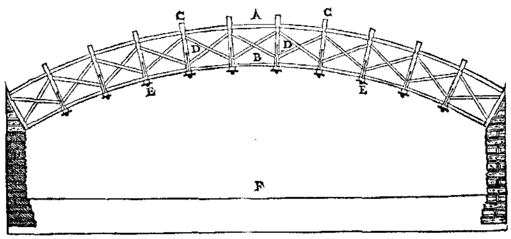

Figure 6
Drawing of the «*terza inventione*». Palladio 1570. 3: 18

ADVANCES IN BRIDGE DESIGN

The technology of planning and building bridges are presented in the Treatise as a continuity and, at the same time, as advances of the roman technology of a highly significant period, the passage from the end of the first century b.C. and the beginning of the following, i.e. at the Vitruvius's time.

Palladio knew well both the *Commentarii* by Julius Caesar, that he read in his youth, and the *De Architectura* by Vitruvius (a handbook for the architects but more an ideological source for every cultivated man of the Renaissance) especially because he had prepared xylographic drawings for the editions of the two works (Venezia, Marcolini, 1556 and Venezia, De Franceschi, 1567) cared by the learned Daniele Barbaro, the Patriarch of Aquileia, also the appointed Historian of the Venetian Republic.

Mainstone[4] noted that the drawings of the timber bridges of the Treatise are «the first surviving fully detailed designs for bridge trusses»; it is anyhow important to observe that still they are schematic, affected with omissions of some peculiar details which are essential for their full understanding.[5]

The substantial Palladio's contribution to the understanding of the bridge on the Rhine is the interpretation of the joints, which were connected by means of the *fibulae* (buckles), connectors of which he proposes the design (made of timber?), and therefore the interpretation of the clever way in which the bridge is progressively built and assembled. It is worth noting that the other Authors who tried to give interpretation of the classical text[6] generally designed the *fibulae* as rope bindings: these are absolutely different from the Latin word and far from its peculiarity, in any case, not really efficient in such a work; certainly too rough and primitive to meet the Caesar's requirements of dignity.

One more concept is assumed as fundamental by Palladio, this is that with the adopted configuration and, more specifically, the designed joints, the more the bridge is solicited by the stream and the loads, the more its stability is increased because the parts get tighter and the work is made firm. In the Palladio's drawings no bracings, as usual, are present.

In the description of his personal inventions, Palladio strictly follows the same Caesar's exposition scheme, the same style, concise and effective, essentially explaining the characteristics of the river (the parameters are the breadth, the height of the banks, the speed of the stream), showing the disposition and the dimensions of the members, the building process, the invention of the special connection device etc.; the terms employed are the same too, of course translated in *Volgare* from Latin, as for instance the «natura del ponte», the «fermezza dell'opera» (*operis firmitudo*).

With the said similarities Palladio starts, on the ideal and practical level, a personal continuity with the great classical technology expressed by one of the most celebrated engineering work; but this is also a way to legitimate his work trough the authority of the *Commentarii*'s Writer and the occasion to show the advances he was and is able to achieve.

The most important advance is the fact that his bridges are made «senza porre altrimenti pali nel fiume», that means structures without intermediate supports, conceived with the purpose of avoiding damages to the piers caused by floating trees shafts, violence of the stream, vessels. The same span, 100 feet of Vicenza (36 m about) for the Cismon river bridge, is exceptional; there is only the witness of the Trajans bridge at Drobeta, planned by Apollodorus from Damascus, long more than 1100 m, on 20 piers large 18,5 m and then each bay reaching a span of almost 33 m. On this fantastic achievement (103–109 a.D.) it is important to note that each bay benefits of the continuity with the adjacent ones, each end of the bay can be considered with fixed joints, a relevant advantage for both strength and stability. Reproduced in bas relief on the Trajan Column in Rome, Figure 7, it constituted later the obliged reference for many bridges such as, for instance, the famous Ironbridge on the Severn, Shropshire, in 1779, which is designed with a very similar structure of cast iron, the first structure of this material.

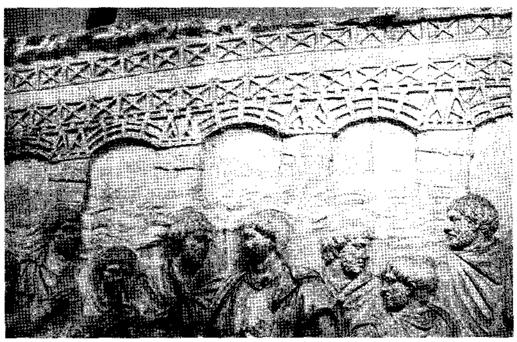

Figure 7
Trajans bridge planned by Apollodorus from Damascus, reproduced in bas-relief on the Trajan Column in Rome

The Caesar's bridge (which can be considered directly inspired by the pontoon-bridges in spite of the intentions to do something different for the dignity of the Commander and of the Roman nation), composed as it is by a certain number of piers at a distance that we can estimate not exceeding 10 metres (about 30 feet) and, in a similar way, the Trajan's bridge, being modular, have the advantage to be extendible with no limitations.

The Palladio's configuration of his timber bridges is quite different in comparison with the others mentioned. It is based on the use of a net of triangular meshes which is not deformable if the three sides are rigid rulers.

The use of the triangle in architecture is to be considered quite ancient if one only recalls the roofs profile of the buildings and the pediment of the classical architecture. But the theorization of the properties of it in the building technique is due to Leonardo da Vinci,[7] Figure 8; we can assume, however, that Palladio did not know the Leonardo's writings on the subject.

The palladian bridge structures can be considered lattice girders, certainly amongst the first employed with a consciousness of the benefits they can give —strength, minimal weight, attitude to keep the shape etc.— and systematically adopted. In the

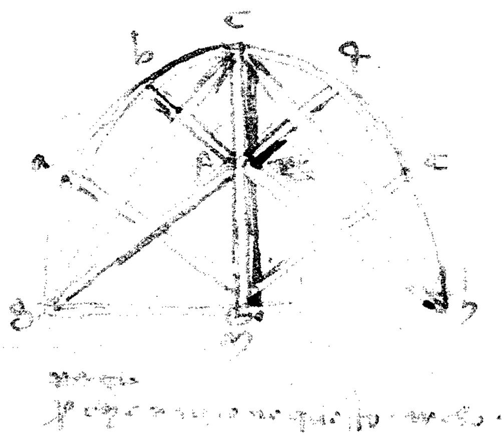

Figure 8
The theory of the «not deformability of the triangle» by Leonardo da Vinci. Leonardo da Vinci. 1987. Manoscritto B. 19v

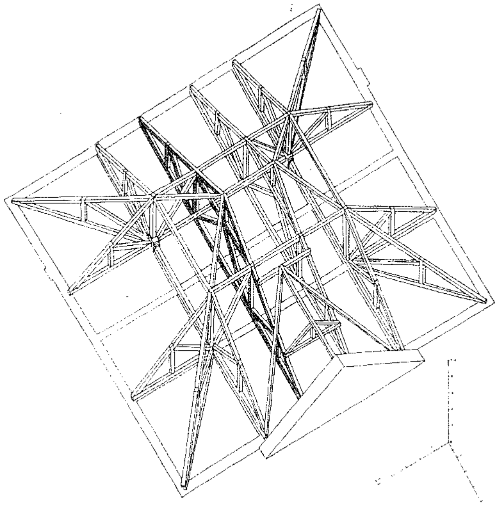

Figure 16
Trusses in the palladian villa Emo in Fanzolo. Drawing by Bordignon Favero, G. 1970

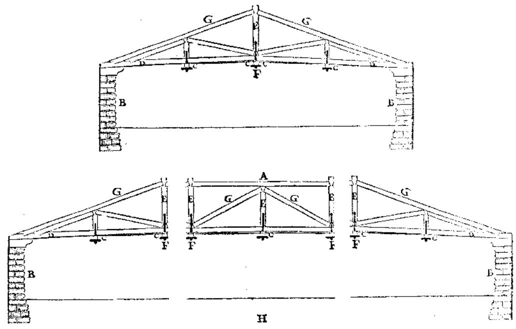

Figure 17
The origin of palladian bridges' structural configurations straight from the trusses

Palladian structures, every member is essential up to the point that if one of them is subtracted, the structure fails; besides, because these structures are made of timber, the joints can be considered, at least to a certain extent, hinges. Essential to note that in the Leonardo's drawings as in the Contemporaries to them, the timber structures are generally redundant as for the number of rulers, in the attempt to make them not deformable, therefore really hyperstatic.

The structural configurations of the palladian bridges, i.e. the shape of the structures, originate straight from the trusses. It is clearly so, for instance, for the Cismon river bridge, a direct proliferation of a classical truss[8] (see for istance the palladian villa Emo's trusses, Figure 16, 17). Both concepts of triangular mesh and truss as an elementary structure expansible are to be recognized in the current realizations of the XV and XVI c. in Italy and in the drawings and works by Simone del Pollaiolo detto il Cronaca, Sebastiano Serlio, Giuliano da Sangallo il Giovane, Giorgio Vasari and Others; but in the palladian proposals there is much more of rationality.

The cord of the Cismon river bridge and of the first invention has a slight rise, an original and advanced feature for generating favourable auto-tensions during working of the structure; the whole mechanism becomes active due to the presence of this sophisticated arrangement. The rise is also present in the first invention and, of course, in the second and the third. This too is an important palladian invention. The timber palladian bridges are, in a way, arches, especially in consideration of the fact that also the extradox is shaped as an arch (portione di cerchio minor di mezzo circolo).

A few built-up beams designed by Leonardo show, incidentally, a rise;[9] the Polonceau Truss (1839) too has a rise.

Funis, the first to notice a double line (which was omitted in the late editions of the Treatise, also in the Carampello edition, 1581, Figure 9, but not in the english edition, 1738) at the intradox of the front view of the Cismon bridge, interprets this line, together

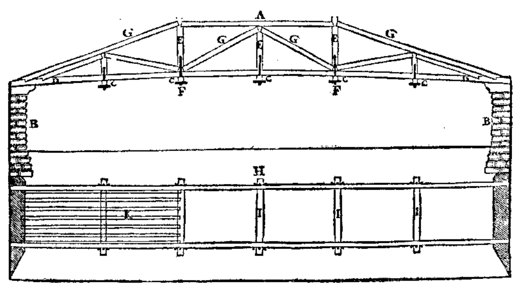

Figure 9
The Cismon river bridge. Palladio 1581. 3: 15

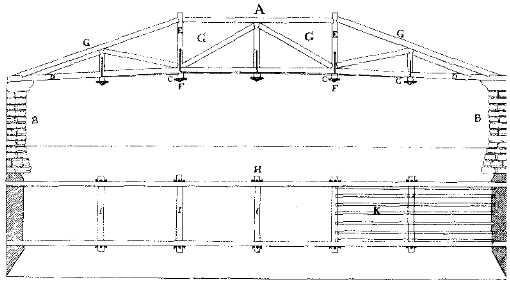

Figure 10
The Cismon river bridge. Palladio [1738] 1965

with the wedges at the top of the transversal beams, as a device for a softer union of the road with the course on the bridge, obtained keeping lower the profile of the course in comparison with that of the structure:[10] a disposition meant to improve the *commoditas* of the whole work, a quality clearly mentioned by the Author, also one of the three fundamental requirements (*firmitudo* and *venustas* are the others) indicated by Vitruvius.

The other fundamental advance is the connector, a true Palladio's invention in the modern meaning of the term, by him called «arpice» or «arpese», of which a detailed drawing is given here, Figure 11–14, a cramp, in a way a bolt, used as a device to connect the rulers convergent to the principal nodes of the structure in all his bridges.

The importance of this invention is that it allows the prefabrication of the work by means of the easy, therefore also quick and cost-saving, assembling of the members constituting the bridge.[11] It must be stressed that the same building process,[12] Figure 15, exposed for the Cismon bridge similarly to Caesar's bridge, is highly simplified by the use of the *arpesi*: in fact these are analogous to the *fibulae*. The invention of the arpesi has probably been suggested, as key of the whole mechanism, by the reflections about the Caesar's connectors.

Palladio gives an accurate description of the arpesi, also shown, at least partially, in his drawings, and many Authors have tried to interpret the description, mainly with drawings.[13]

In a literal interpretation, from the text, of the shape of the arpesi and with a close exam of the drawings of the Treatise, they are flat (*diritti, e piani*) and perforated (*forati*) where they are to be connected, by means of nails (*inchiodati*), to the uprights (*the colonnelli,* «small columns»); they are thick (*grossi*) where they pass trough the hole made at the ends of the transversal beams (fatti passare per un bucco fatto a questo effetto nelle teste delle dette travi . . . che fanno la larghezza del ponte). Because the hole in the transversal beams, 27 cm thick, can only have cylindrical shape (except in complicate and expensive workings to make them with a square or rectangular section, which are not usual, because expensive, in building carpentry), this part of the arpesi can only be of the same shape and of the same calibre of the holes in order to fit them in the best way. The arpesi were probably obtained by segments of round rods heating and hammering one side to make it flat, then operating the perforations at the top and at the bottom. The arpesi are solicited mainly to tensile tension in the longitudinal direction, also at shearing tension at the section close to the connection between the side beams and the transversal ones.

The arpesi are locked (*serrati*) at the lower end by means of small iron bars (*stanghette*) that we can imagine in number of two, wedge-shaped, each one

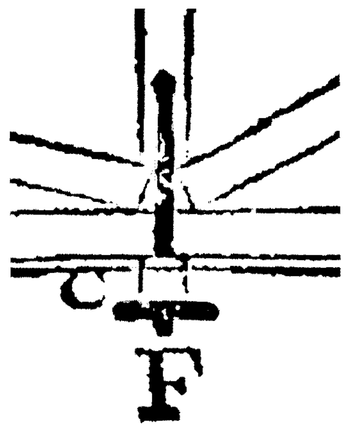

Figure 11
Detail of the *arpice*. Palladio 1570. 3: 15

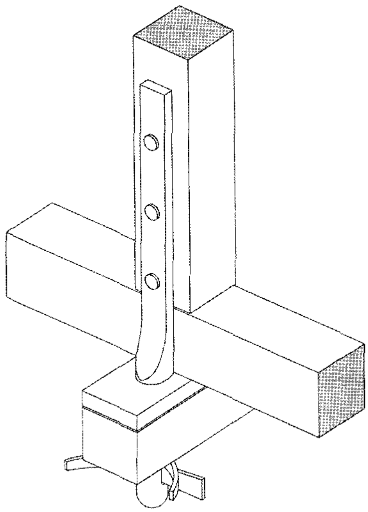

Figure 12
Palladio's *arpice* interpreted by Gennaro Tampone; perspective drawing made by Pietro Copani

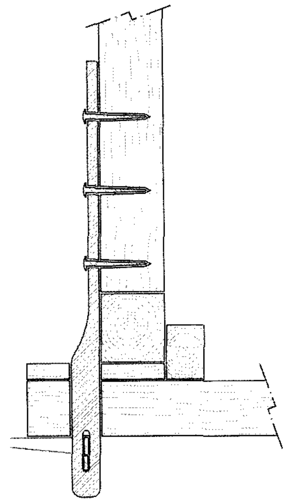

Figure 14
Palladio's *arpice* interpreted by Gennaro Tampone; section drawing made by Pietro Copani

being bent at the narrower end, which meets the notations of both the drawings given in the Treatise, the side view and the plant. Palladio shares with Giorgio Vasari, a contemporary of his, the merit of

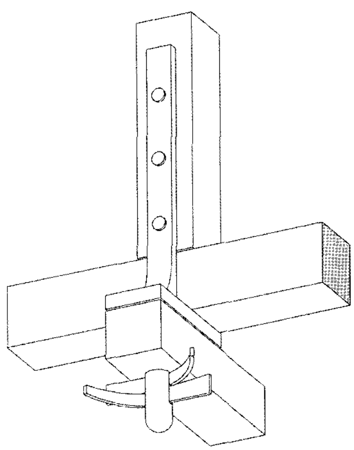

Figure 13
Palladio's *arpice* interpreted by Gennaro Tampone; perspective drawing made by Pietro Copani

having given special attention to the iron connectors in the timber structures and designed precocious, effective devices[14] which would not be paralleled by anything similar for at least the two following centuries.

Modularity is achieved by the standardized dimensions of the transversal beams, pierced at both extremities for the insertion of the *arpese* and therefore acting like a template, and by the side beams. It is worth noting that the side beams are kept in the assigned position by the arpesi and by the lateral «travicelli», i.e. the secondary beams, the firsts preventing horizontal sliding movements outwards, the others inwards.

For the connection of the six segments constituting the side beams or the bottom chord of each of the two girders in the Cismon bridge,[15] (with a different interpretation Mainstone maintains that «its bottom chord was shown as continuous throughout the span, though it is doubtful whether single timbers of the required length could have been found») which are not drawn in details in the Treatise, suggestions (see drawings) can come from the central connections in the chords of the trusses of some palladian buildings, by instance Villa Badoer in Fratta Polesine. The

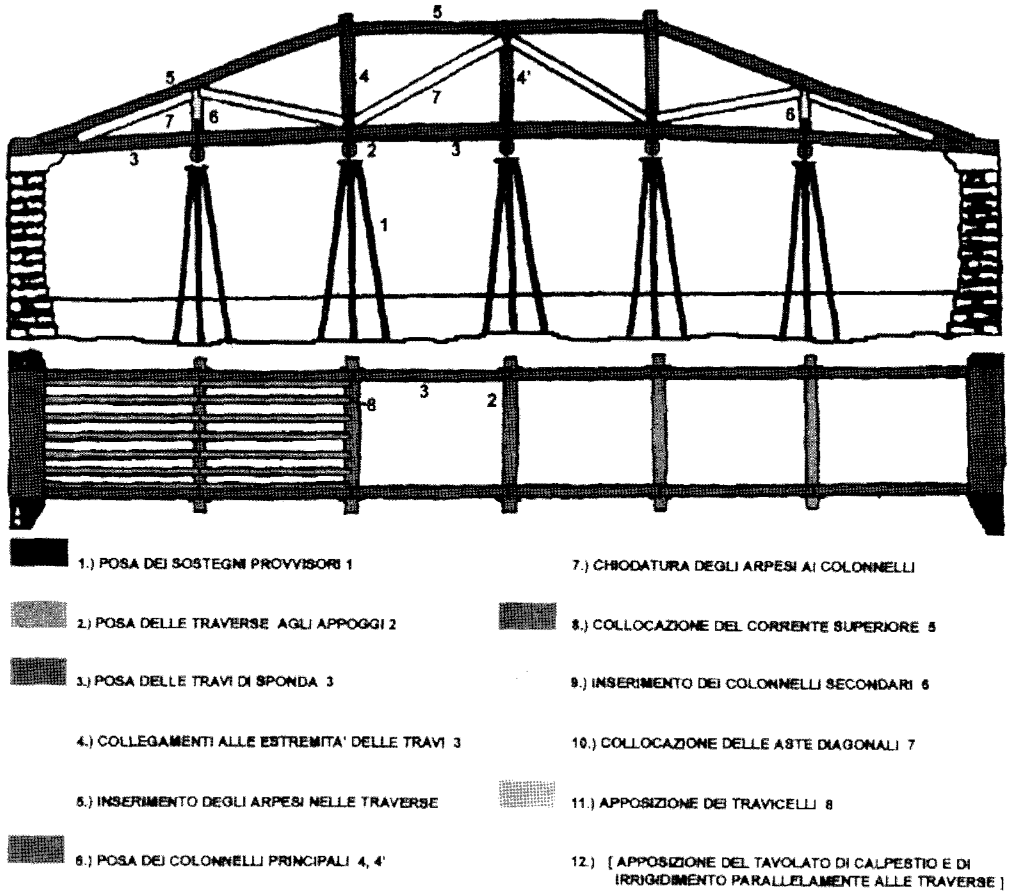

Figure 15
Building process of the Cismon river bridge

connections of the members of the timber tie (*catena dè castagni*) designed (according to a traditional technology) in the first twenty years of the XIV century by Filippo Brunelleschi for the dome of the Santa Maria del Fiore in Florence (Tampone, 1996), still *in situ*, can also provide useful suggestions.

Russo Ermolli, assuming the hypothesis that the bridge is conceived as constituted by two lattice girders on two hinges, one of them with possibility of horizontal sliding, calculated[16] in somewhat less than 50.000 kg the stress in the segments (about 50 kg per square cm), an enormous tension for this kind of joints: Tampone had already expressed in his latest contribution on the matter[17] (where also other inconsistencies are evidenced) his doubts about the efficacy of tended joints to face this stress, especially in the long term.

Therefore the authors of the present paper suggest here that a different possible hypothesis, on which research has begun, should be taken into account, namely that both hinges cannot move in the horizontal direction, for instance in force of the shape of the piers. The side beams would be in this case compressed, the joints of the side beams would be very simple, the extremities of the segments would be just cut almost perpendicularly to the longitudinal axe, and faced. The arpese and the *travicelli* would keep them in the designed position. Palladio's words: «onde le parti una per l'altra si sostentano, e tale viene ad essere la lor natura, che quanto maggior carico è sopra il ponte, tanto più si stringono insieme, e fanno maggior la fermezza del ponte (Caesar: Tanta erat operis firmitudo, atque ea rerum natura, ut quo maior vis aquae se incitavisse, hoc arctius illigata tenerentur)» would acquire a more specific and fitting meaning.

Fundamental is the innovation of the dimensioning of the timbers, of which Palladio does not give the criteria but the values only (Cismon bridge): $^3/_4$ of foot of Vicenza the breadth (27 cm), 1 foot (36 cm) the height.

The proportion between base and height of the beams, 1,333, is[18] consciously, by intuition, chosen very close to that of the maximum strength, i.e. 1,4142 for a bent timber member obtained by a shaft.

All the members of the two lateral girders are thinner and narrower than any member of Caesar's work: the remarkable result is obtained, no doubt, because the Architect's configuration is that of a structure conceived as a unit with an excellent distribution of the tensions.

The supplementary ruler at the ends of the rafters, where the tensions are higher, is also very appropriate; the same device is applied in the structural design of the most advanced architects of the time, for instance Giorgio Vasari at the ceiling of the Salone dei Cinquecento in Palazzo Vecchio, Florence (1563–1565), Giuliano da Sangallo il Giovane (about the same years, drawings in the Uffizi's Drawings Cabinet) and so on.

The dimensions of the transversal beams having the same dimensions of the other members, with a span of 4,40 m and with a bay of almost 6, and of the *travicelli* which cover a span of about 6[19], are still problematic. Furthermore, it is impossible to explain the stability of the bridge without transversal bracings at least at the upper level of the girders, omitted in the Treatise.[20]

The bridge designed in the «prima inventione», Figure 4, is of outstanding importance because an other element of bridge-planning is introduced: the special building process. Here the invention is the progressive launching of parts of the one-bay bridge, which are temporarily supported, at both sides, by the parts already built, that means without piers nor centrings. Due to the difficulties of imagining for such a bridge the position and the role of each member, not only in the final destination, but also during the transfer, we must take for granted that Palladio prepared solid models of this invention and, probably, also of the others.

A major problem is the lack of bracings in all the bridges. It has been supposed that they were present, the lack of indication in the Treatise being an omission. It ought to be remembered, however, that the awareness of the necessity of such members was completely reached only at the end of the XIX century.

The use of the arpesi and the prefabrication, in general, give raise to another kind of problem, namely the deformability of the work, which is higher for a structure with a large number of joints.

Palladio's technical drawings in orthogonal projections of his timber bridges were designed for the Treatise, which means some twenty years after the realization of the Cismon bridge. But we must assume for sure that he also used models, i.e. maquettes, as it was customary and as is documented for his very famous bridge of Bassano.[21] Models were very useful because they could allow the understanding by everyone even if not a technician, to ease the study of structural details such as the joints, for the estimate of the whole work and the forecasting of the time necessary to completion.

The fortune of Palladio's timber bridges

Palladio's Treatise was disseminated everywhere in the centuries following its first edition and the Palladian timber bridges became very famous, in part because of the graciousness of the drawings. A more critical and technical approach to these bridges was adopted beginning in the XVIII c., for instance in the treatises on the bridges written by Gautier,[22] by the Encyclopaedists, and later by Gauthey,[23] where attempts to interpret Palladio's inventions are to be found. Rondelet's fundamental work, edited at the beginning of the XIX c. and disseminated in all Europe, marks an important moment in the scientific interpretation of the objects of our study. In England, thanks to two important editions of Palladio's work in the XVII c., the Promoters of the Palladian Revival, Palladian projects were highly appreciated and the bridges amongst these: reproductions of the bridges were built, as footbridges and ornamental elements called «paladian», in the gardens and in the parks of the estates of the peerage.[24]

NOTES

1. The following chapters of Book III (chapters 11–15) are dedicated to stone bridges. Palladio 1570. 3: 21–30.
2. Palladio 1570. 3: 15–20.
   For the Cismon and the identification of the remains of the piers, see: Funis 2000. 15–18.
3. Palladio 1570. 2: 71.
4. Mainstone 1975.
5. Funis 2000; Tampone 2000.
6. Leonardo da Vinci 1901; Caesar C. J. 1514.
7. On this matter see, amongst the others, Funis, with systematic references. Funis 2000.
8. Tampone 2000; see also Mainstone, 2001, cit.
9. Leonardo da Vinci. 1987.
10. Funis 2000. 10–11.
11. Funis 2000; Tampone 2000.
12. Tampone 2000.
13. See, for instance, Laner 1997; Funis 2000; Copani Funis 1999; Tampone 2000.
14. Tampone 2000.
15. Mainstone 1975.
16. Russo Ermolli 1996.
17. Tampone 2000.
18. Funis 2000.
19. Tampone 2000.
20. See Funis 2000; Tampone 2000; Russo Ermolli 1996.
21. Azzi Visentini 1980. 25.
22. Gautier 1716.
23. Gauthey 1843.
24. Ruddock 1979.

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