ANDREA PALLADIO'S LEGACY IN THE CONSTRUCTION OF THE INTERNATIONAL BRIDGE ON THE RIVER ÁGUEDA (1887): BRIDGE TYPOLOGIES

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1.- Introduction.

> "*Andrea Palladio (1508–1580), an Italian architect, is thought to have been the first person to use modern trusses. He may have revived some ancient types of Roman structures and their empirical rules for proportioning them*". (McCormac, 1997:5)

The influence of the Italian architect has been massive, as have been the works about him and his large body of work. A curious example will suffice: Google searching his name results in more than two million entries[1], owing to the fact that Palladio is a reference in the History of Art, Architecture and Construction Science, merely to name a few examples. But his influence exceeds the architectural field. The sentence at the beginning of the introduction, by professor Jack C. McCormac, featured in his celebrated book *Structural Analysis: A Classical and Matrix Approach*, came from the description found in his Architecture treatise *I Quattro Libri dell'Architettura*, more exactly in the Third volume, where the famous architect defines the instructions for the construction of wooden bridges, comparable to armors. There is no doubt that the construction of structural elements in order to bridge distances that would be *a priori* unreachable comfortably has been a perennial endeavor of humankind (Steinman, 1979). It is precisely because of the systems formulated by Palladio for the construction of bridges, that great distances could be gapped amidst inconceivable terrain. An example of that is to be found in a

1 Retrieved 3 September 2022.

magnificent work of a huge scale and symbolic value like the International Bridge on the River Águeda.

Palladio was, as we shall see, a man ahead of his time. In a simple but rigorous manner, he introduces structural typologies which continue to be used to this day, centuries after him. That is true to such an extent that, in the words of Spanish architect and History of Building scholar Santiago Huerta Fernández,

> *"Andrea Palladio is one of the most representative architects of the Renaissance. His treatise* The four books of architecture, *published in Venice in 1570, is probably one of the most influential books in the history of architecture".* (Huerta, 2004: 193)

2.-The impact of the Treatise *I Quattro Libri Dell'Architettura* di Andrea Palladio.

I Quattro Libri Dell´Architettura[2] quickly obtained wide circulation both within and outside Italian. From the *Editio Princeps* of 1570 onwards as well as subsequent publications, such as the one by Domenico de Franceschi, published also in Venice that same year, several Italian editions followed, like the ones in 1581, 1601 and 1626. These Italian editions as well as many others soon became well-known and began to be used in European art circles, especially in countries like France, England and Spain[3]. In spite of all that, Palladio's influence or the so-called "Palladianism" was both long the subject of discussion and harsh criticism. Even though that debate is not our concern, it is precisely in the History of Art and the History of Architecture where it attained the most relevance among researchers. As to Palladio's influence,

2 *I Quattro Libri dell'Architettura*, by architect and essayist Andrea di Pietro della Gondola, is divided in four parts called "books", each of them paginated separately. Its cover is also used in books II, III and IIII. Referring to the original version as faithfully as we could, we translated the ordinal 4 as IIII, as Palladio does in his treatise, instead of the most common IV.

3 In France, Marie Joseph Peyre shows more Palladian influences than the rigid French rationalist phenomenon; like the German F. Schinkel in works such as his Schauspielhaus in Berlin; also the Polish P. Aigner, J. Kubicki and A. Corozzi; Russian Palladianism, as introduced by G. Quarenghi; in Czechoslovakia by F. Caratti and C. F. Schurich; the brothers M. and L. Pollak in Hungary. In England was Colen Campbell and William Kent; finally, in Spain we can find it in the architect Juan de Villanueva with works like the Museo del Prado or the Astorga Observatory. (VERA BOTÍ, n.d: 213-214) (GUTIÉRREZ; VIÑUALES, 1971).

there are several Spanish historians who contributed to the awareness of the Italian's influence and who have been crucial for his growing influence in the Spanish-speaking world. During the 18th International Congress of Art History, which took place in Venice in 1955, Nikolaus Pevsner stated Palladio had enjoyed *poca voce in Spagna*. Ever since, very few historians focused their studies and research on establishing the presence of his work in Spain. Among them, George Kubler, who considered Palladio's influence to have been fundamental at two important times in Spanish art: the first one during the late 16th century, and then again with the development of Neoclassicism in Spain.

More recently, the debate has become polarized into two different aspects: on the one side, attempts have been made to validate the scope of Palladian theory and provisions, focusing on the presence of the Italian treatise in the Spanish cultural and art landscapes. On the other hand, with emphasis placed on the resonance of his body of work, used as a model for architectural creation by Spanish masters. Both lines lead to debates on what is to be understood as "Palladianism" and if it is possible to speak of a "Spanish Palladianism"[4]. In the first instance, several desk and art studies have proved the existence and knowledge of the (manuscript) writings of Palladio in Spain, during the last third of the 16th century and beginning of the 17th century[5]. The subject is introduced into the wide diffusion of architectural theory of the Italian Renaissance in specific art milieus in the Peninsula, where Alberti, Serlio and Vignola became compulsory reading, contributing to the formulation of a Classicist architecture[6]. As for Palladio, opinions differ since he couldn't have exerted such a strong theoretical influence himself, and in most cases his name appears as secondary literature, except in the case of Castile and León. There are several reasons which could explain the small incidence of Palladio in the Spanish art world, such as the complexity of his treatise, the unsuitability of his civil architecture in the context of the Spanish Crown's social and economic reality, as well as the late introduction of his work there. In spite of all that, Palladio's insights into the Ancient World were a decisive factor in the development of Spanish Classicism (Bustamante García, 1979: 39). That said, Palladio's presen-

4 To find out more: MARÍAS; BUSTAMANTE, 1980.

5 In some architects' libraries the text by Diego de Sagredo, Alberti, Serlio and Vitruvio are more common (GUTIÉRREZ; VIÑUALES, 2008: 56).

6 To find out more: BUSTAMANTE GARCÍA, 1979.

ce in Spanish architecture was only that of an authority offering models akin to Classicism as well as some elements used for the formulation of the Classicist lexicon. (Palladio, 2003: XXV- XXXII)

3.- Third Book of Palladio´s Architecture, which deals with roads, bridges, squares, basilicas and palestras.

Several sections of *I Quattro Libri Dell´Architettura*, revolve entirely around a specific typology of great importance to civil engineering: bridges, indeed. Palladio provides definitions and instructions on how and where to build them. A great deal of information and reflections on urbanism are deployed in those chapters. They don't only feature bridges (our subject matter), he introduces squares, basilicas and arenas, using as examples both ancient and modern constructions, including some of his own invention.

It is impossible to establish when the necessity arose to bridge the sides of a river. We can only ascertain that water currents must have disrupted the passage of our ancestors countless times. It is entirely possible that a tree trunk or boulders sufficed to bridge gaps. Made of wood or stone, bridges evolved with each newly discovered obstacle, making the passage over water more accessible and comfortable. There would always appear a need to gain height in order to circumvent river floodings and, later, with the purpose of bridging broader streams, its supports and structure would be reinvented, allowing for a greater reach. That being said, in Chapter III, Palladio gives us instructions on how to make the choice of the ideal location for a bridge and what it must be like. For Palladio, bridges are "a path made above the water", which requires a specific aesthetic, some conveniences and, most especially, he insists that they must be able to withstand time. For the sake of convenience, he understands that both the bridge and the path must possess the same quota. He also devotes a few lines to its "beauty" and lifespan, telling us that he will afterwards provide us with guidelines on the manners and measures we must follow for that purpose.

In relation to *where*, our author specifies that it should be in the midst of a region or city, a place of convenience to its inhabitants, and where the river course is not too wide, but rather regular and continuous. The location of the bridge within a city is a subject he tackles with particular attention, making the importance of convenience clear for the location within the city, be it within its walls or outside, in order for it to be accessible to its inhabitants.

The choice of a river area is essential, and its construction must be economically cost-effective. It must be built, as we have said, in the least deep area, but Palladio also gives certain warnings such as avoiding pelagic zones and whirlpools, places where the river bed is in constant movement, because it would result in the work's collapse. The place where the river bed's stream runs straightest, in order to rule out locations where debris tends to be collected after river floodings.

As to *how*, Palladio makes a distinction in the construction of bridges based on the material used to build them, wood or stone, given that those were the only options available in his time. He provided guidelines for each material, on how to develop it as well as designs, both ancient and modern. We must keep in mind that the iron and steel age as applied to this structural typology wouldn't arrive until much later, mainly from the 19th century onward.

In Chapter V, which bears the title *On water bridges and the warnings to consider before building them,* Palladio insists on what he said before, and specifies that said infrastructures are either built just for the occasion or for continuous usage. He adds that some are built to span geographical features in times of war, using as an example one of the works that Julius Caesar built to cross the Rhine[7].

4.- The typology of Palladian bridges.

Bearing in mind that "Palladio was ahead of his time. His most simple forms were the only ones to be ever used and his work became forgotten until the late 18th century" (Steinman; Ruth 1979: 97), one of our initial aims was, besides showcasing the Palladian contribution to the realm of the structural typology of bridges, specifically truss bridges, to show the influence and significance his legacy had on the construction of the heritage railway infrastructures of the 19th century. An example of that, would be the Águeda river International Bridge. That is because, even though Palladio devised and built wooden truss bridges in the 16th century, nobody followed in his wake. That is why the truss had to wait almost two more centuries before it was rediscovered and given its deserved attention. (Steinman; Ruth, 1979: 127).

7 Part of Chapter VI is devoted to this work.

As we shall see in the following figures, engineers took for example the most common typologies in such constructions[8]. A quick survey will allow us to observe Palladian influence, since they all exhibit said aspects, implicitly or explicitly, commented on in the Third Book.

> *"The most significant contribution of the Renaissance is doubtlessly the invention of the lattice truss as a structural principle"* (Steinman; Ruth, 1979: 95)

Having surveyed the main features of bridges seen in the Treatise, we shall focus fundamentally on the concrete case of lattice truss bridges, their features and the way Palladio himself introduces them. Professor Frank Ching includes in his book *A Visual Dictionary of Architecture* the following definition of a lattice truss:

> "*A structural frame based on the geometric rigidity of the triangle and composed of linear members subject only to axial tension or compression*" (Ching, 1995: 259).

Our wish, before moving on to bridge typology, was to focus on the analysis of the previous sentence, since it contains in a very specific way the genesis of the lattice truss typology, the foundation of the bridges we will analyze. With that in mind, we will examine separately the meaning of the word groups *the geometric rigidity of the triangle*, *composed of linear members* and, finally, *members subject only to axial* since they contain the key to all that follows.

4.1.- The geometric rigidity of the triangle.

Imagine a structural element composed of four bars which form a square. Analyzing the element on figure 1, subject to horizontal efforts, we can see that the qualitative deformation, technically Δ, is significant. We must keep in mind that horizontal efforts, such as wind action on an element or the action of external pressure exerted by a generic element, can become important in the structural field.

8 They began to be studied rigorously from the 19th century.

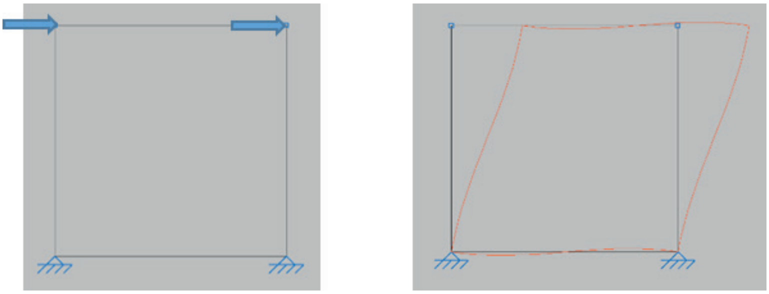

Figure 1. Deformation of a square subject to horizontal efforts.

The same thing would happen if the element we are studying was a structural portico.

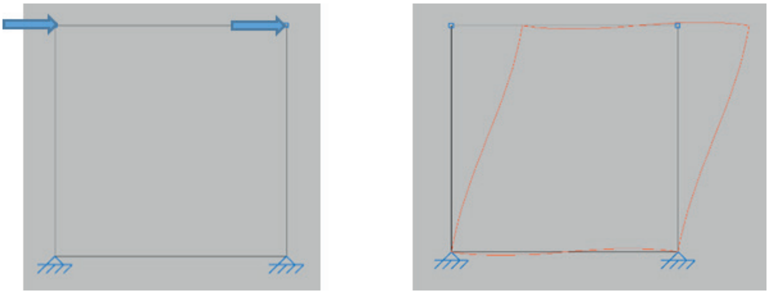

Figure 2. Deformation of a portico subject to horizontal efforts.

In order to solve this problem engendered by an explicit Δ deformation of the superior nodes, it is usual to resort to the triangular element which is doubtlessly the most rigid possible.

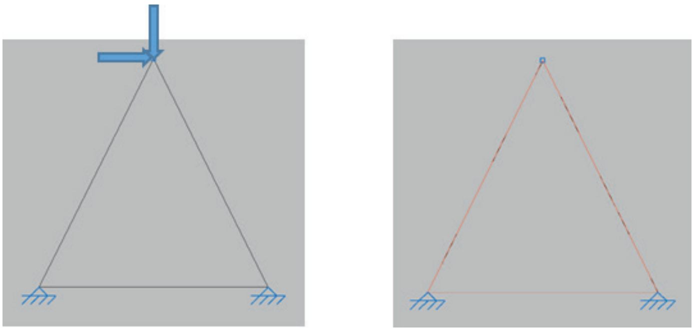

Figure 3. Deformation of a triangular element.

This application is commonly used for structures which, subject to different loading conditions, may become affected by important Δ horizontal displacements which could end up resulting in relevant secondary efforts. Applying triangulation to structures, deformation becomes minimal. They are commonly known as bracing elements or *Saint Andrew's crosses.*

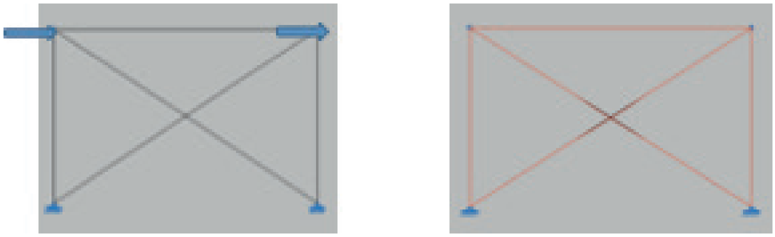

Figure 4. Portico braced using Saint Andrew's Crosses

Figure 5. Examples of structures containing Saint Andrew's crosses. PONS (2014).

4.2.- Composed of linear members.

Thanks to the increased rigidity provided by the triangular element, it would seem that the problem of deformation in structures has been already solved. That is not always the case. Imagine we had to span the course of a river – as we discussed earlier. The first option could be implementing a bar system which, used as beams and joists, could be assimilated to a classical slab allowing for the passage of people and freight across it.

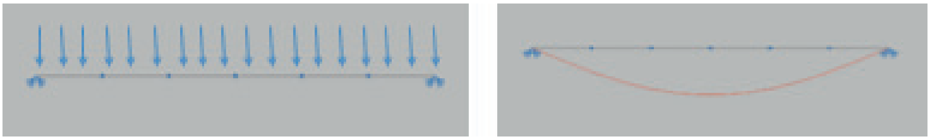

Figure 6. Beam subjected to uniform applied load and its corresponding Bending Moments Diagram.

As seen on figure 6, the arrow (deformation) – understood as a displacement perpendicular to the steering axle -, grows to reach a maximum value at the center (in accordance to the applied load), implying significant deformation at the same spot. The problem could be minimised by using one or several additional support elements, which would doubtlessly minimize the effect of vertical displacement. A procedure, incidentally, common in architecture.

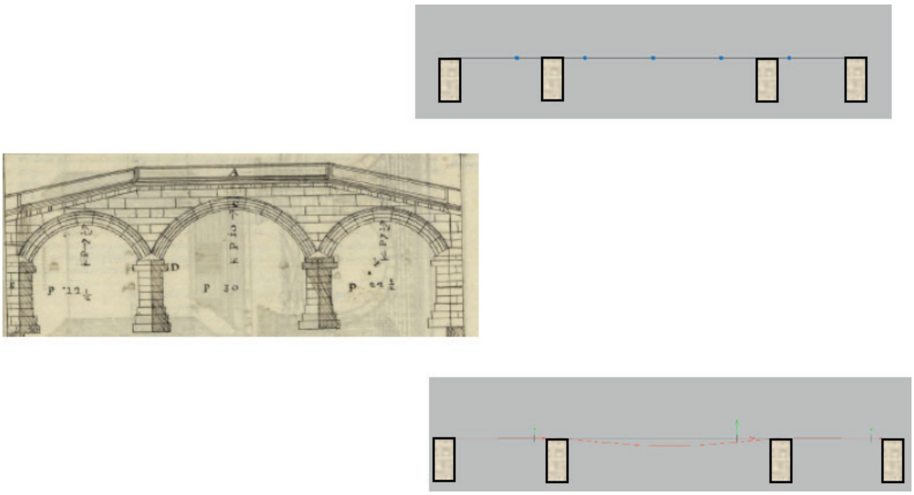

Figure 7. Simulation of a bridge with intermediate piers.

This certainly useful solution, widespread in the architectural and civil world, requires the usage of intermediate piers as well as complicating the calculation of the resistive element, changing from an isostatic to hyperstatic one. We will now tackle this problem.

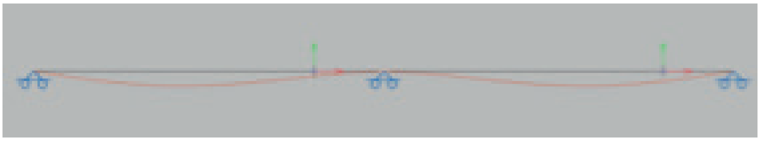

Figure 8. Deformation of a structural element with intermediate supports.

4.3.- Members subject only to axial.

We were just mentioning the calculation problem which entailed the distinction between isostatic and hyperstatic structures. The former, also known as statically determined structures, are those which contain three unknowns to be solved.

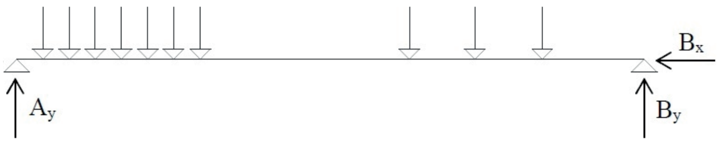

Figure 9. Example of an isostatic beam.

In applying the Rouché-Frobenius theorem[9] we will therefore need three independent relations to solve it, Statics equation. That said, we will now examine the balance of horizontal (F_x) and vertical forces (F_y) as well as the corresponding balance of moments (M_z)

$$\sum F_x = 0, \sum F_y = 0, \sum M_z = 0 \tag{1}$$

9 Sometimes known as the Rouché-Capelli Theorem.

The previous structure would then become a hyperstatic one if point A was added a further unknown, since we would now have four elements to solve using the previous relations only. The structural problem, now in the category of indeterminacy, couldn't be solved using the previous relations, which would make it necessary to introduce at least one new relation (Pons 2014). That way the unknown relations in the problem seen on figure 10 could be found.

Figure 10. Example of a hyperstatic beam.

However, it is commonly accepted in the case of the lattice truss typologies that we are discussing to perform the calculation (as a first approximation) considering them as articulated nodes, which allows perfectly the usage of Statics equations in order to obtain the results of reactions, both exterior and interior.

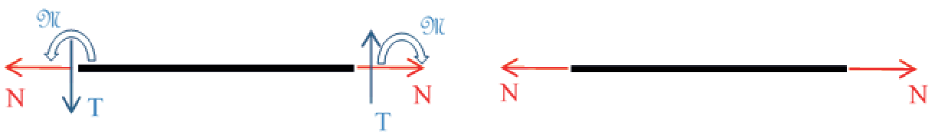

Figure 11. Simplification of a junction subject to a Bending Moment (**M**), Shear Effort(T) and Axial Effort (N) to just the action of the Axial Effort (N).

This consideration as an articulated node simplifies the calculation notably, translating in the non-existence of bending moments (**M**) and shear efforts (T) in it, working exclusively on a normal effort (N), be it tension or compression. This simplification enables a resolution of the node which is quick and easy, prior to dimensioning or verification of the bar element we are studying.

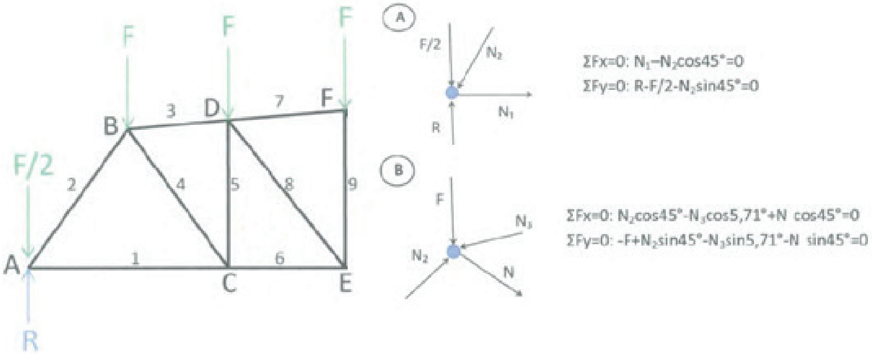

Figure 12. Application of statics equations to nodes A and B respectively.

These three premises extracted from the preceding sentence by professor Ching will allow us to introduce the lattice truss typology featuring articulated nodes we can find described in Palladio's books. Possibly, the Italian did not consider these resistive and dimensioning concepts, but history has drawn from his legacy – we will subsequently see some examples which years after him have been analyzed and calculated in a most rigorous manner. In fact, structural calculation proper wasn't born until centuries later[10], but its new applications would validate a great deal of Palladian contributions to lattice truss structure calculation, showing that those examples the Italian introduced were characterized by simplicity not lacking in any case rigor and excellence.

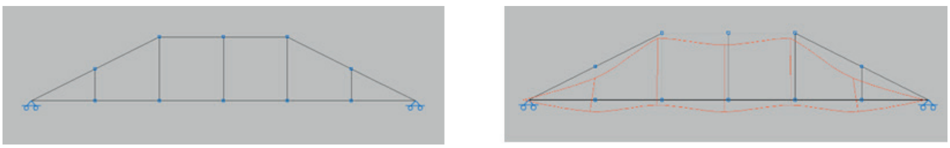

Figure 13. Deformation of a truss without triangular elements.

10 The publishing date of the Three Moments' Theorem (1857) is taken as the starting point of the analysis of the theory of structures, since it made the study of the continuous beam possible (PONS, 2014).

Figure 14. Deformation of a truss with triangular elements.

5.- Bridges included in the Third Book.

> *"In Book 3 of his Four Books on Architecture, Palladio gives alternative designs for a wooden truss bridge to span a river 100 ft. wide. The designs are ingenious, and an analysis of Palladio's proposals shows that the bridges would have been effective. Palladio's wooden bridges".* (Heyman, 2000)

We will underscore two words from professor Heyman's quote which doubtlessly define the bridges we can find in the Third Book: ingenious and efficient. In this section, we will analyze four of the bridges introduced by Palladio. Three of them feature the lattice truss we have been specifying. The remaining one, the first to be studied, has been included here even though it doesn't feature this specific structural typology. The reason to include it is to show a model that is simple but not lacking in constructive coherence and a clear structural element formulated by the Italian.

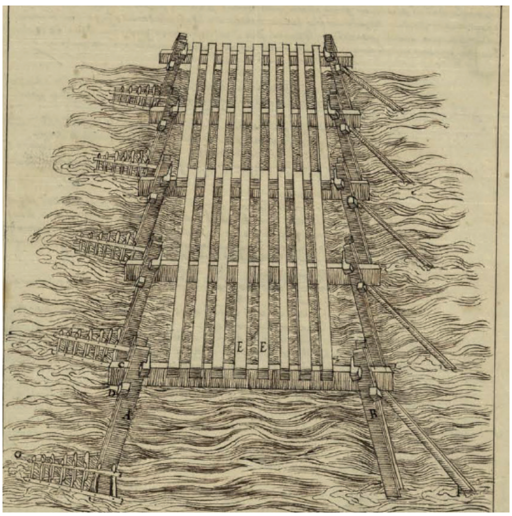

Figure 15. A braced bridge.

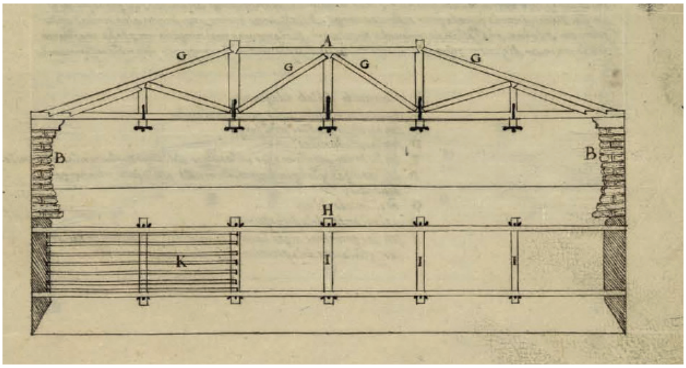

Figure 16. A lattice truss bridge (I). Bridge on the Cismon.

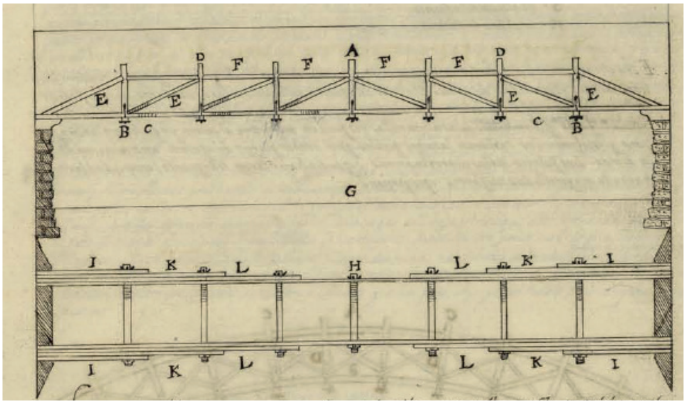

Figure 17. A lattice truss bridge (II).

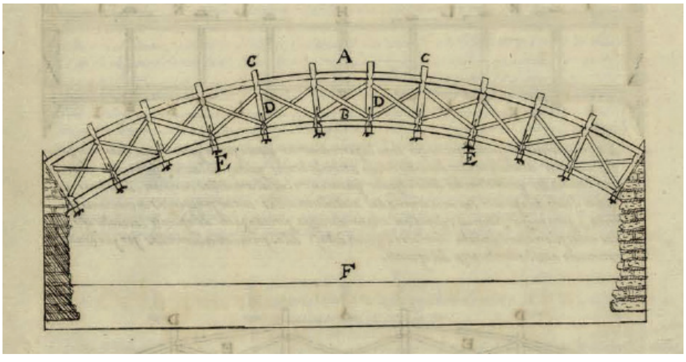

Figure 18. A lattice truss bridge (III).

5.1.- Braced bridge (figure 15).

The first case brought by Palladio is without a doubt the simplest among them. We will highlight that speaking of its simplicity doesn't entail a lack of rigor, but ease. A set of wooden boards are supported by beams which are in turn supported by braces pinned on the river itself. This disposition could be compared to the case of a beam simply supported[11] with a uniformly distributed load corresponding to the action of beams supported in the corresponding tributed area.

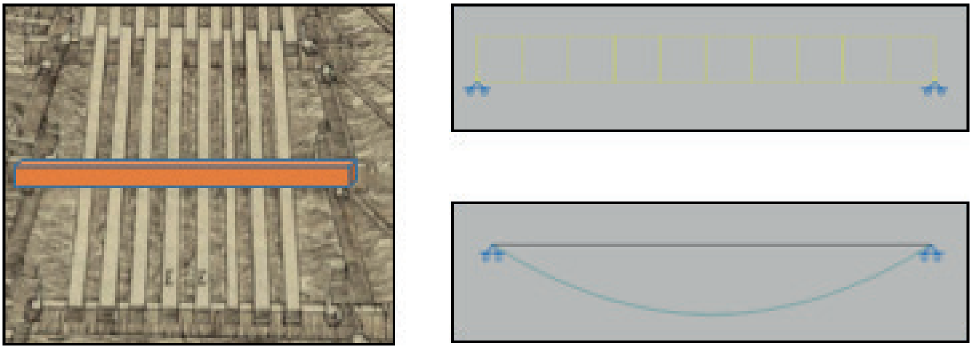

Figure 19. Simplification of the study of the braced bridge. Distribution of shared efforts and resulting Moments Diagram.

Should we want to analyze the beam in an academic way, being it an isostatic disposition, we could apply the previous statics relations (1).

The bending moments law in an x point of the beam subjected to load distribution q, would be:

$$M(x) = -q\frac{x^2}{2} + q\frac{L}{2}X \qquad (2)$$

Through symmetry, it is deduced that the maximum bending moment's value is to be found in its center taking as its value $\| M_{center} \| = \frac{1}{8}\ q \cdot l^2$,

11 In this case we measure up external function against embedded external junction.

having zero value at the junctions (Timoshenko 1946:76). This value would allow us to dimension (or verify) the beam.

5.2.- Lattice truss bridges (figures 16, 17, 18).

We previously introduced that the lattice truss typology allows, on a first approximation, to consider the junction of the node as an articulated one, meaning that statics equation can be perfectly applied in order to obtain the results very quickly. These enable us, *a posteriori*, to dimension the truss or else to verify the different components. The previous simplification will be reflected in figure 20. A virtual section of any bar in this structure would be subject to normal efforts (N) having zero value both the shear effort (T) as the bending moment (**M**).

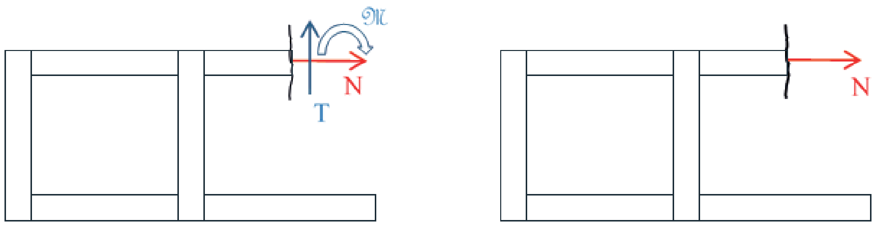

Figure 20. Simplification of the efforts in a generic point of a bar: from **M**, T, N to just the action of N.

Applying this consideration, we can then consider the study of a generic node of the typologies previously shown. If we consider node A from the case introduced in figure 16 – keeping in mind that the analysis would be the same for each of the nodes -we can use again statics equations.

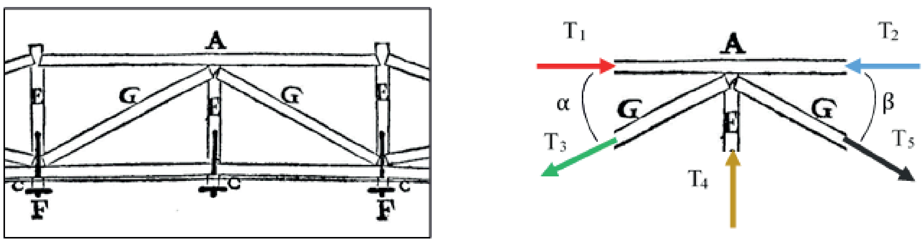

Figure 21. Distribution of efforts on node A from lattice truss II.

Using the statics equations, $\sum F_x = 0$, $\sum F_y = 0$ we obtain the relations between the different T forces les relacions entre les distintes forces T_i of the bars:

$$\sum F_x = 0 \rightarrow T_1 + T_5 \cos\beta - T_2 - T_3 \cos\alpha = 0 \qquad (3)$$

$$\sum F_y = 0 \rightarrow T_4 - T_3 \sin\alpha - T_3 \sin\beta = 0 \qquad (4)$$

That is, knowing either the geometric relations α and β or the longitude relations which make it possible find both (α and (β, the problem would be solved.

$$\begin{pmatrix} 1 & -1 & -\cos\alpha & 0 & \cos\beta \\ 0 & 0 & -\sin\alpha & 1 & -\sin\beta \end{pmatrix} \cdot \begin{pmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \qquad (5)$$

The system's resolution (5) is easy to approach using *the Rouché-Frobenius Theorem* or any other lineal system resolution method. Keeping in mind that Rank (A) = Rank (A/B) = 2, the system therefore can be solved. However, bearing in mind there are five unknowns to solve, the system becomes indeterminate. Thence a fundamental law for the solving of the node typology in an armor is deduced: the unknowns we are able to find in a node are two.

5.3.- Graphical method.

The node-solving system we used previously had been formulated analytically. As an alternative procedure, commonly used in civil engineering, we can resort to the graphical method (Pons, 2008, 2014). We will not talk here about its variations (Pons, 2020), it should suffice to quote that it was extensively used in his day, especially in architecture. For that purpose, we could outline the funicular polygon, the reading of which will allow us to find the unknown values (just as in the previous case, once the frame's geometry is discovered, we can only have two unknowns in the node).

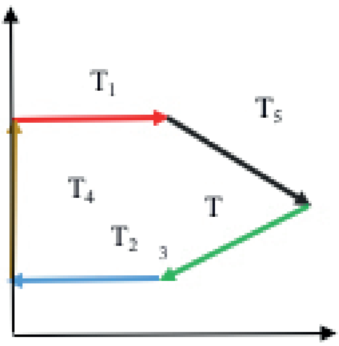

Figure 22. Funicular polygon of efforts distribution on node A in lattice truss II.

6.-The truss typology after Palladio…

After years of ostracism, the use of truss typologies would quickly become widespread, especially from the early 19th century onwards. Its formulation, calculation and implementation eventually became a staple of strength of materials and/or structures theory books.

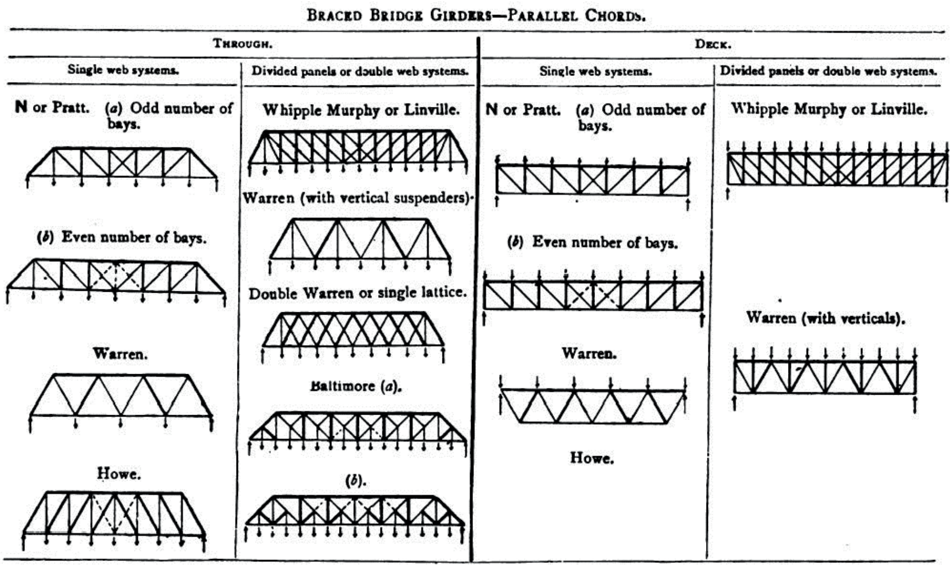

Figure 23. Braced bridge girders parallel chords

An example of that can be found in professor Arthur Morley's book *Theory of structures*[12] - as of today, a classic of the field – which, in 1912, offered us a wide array of the braced bridge girders parallel chords typology. However extensive, the aforementioned relation can be explored in further detail in specific literature on this subject with different typologies which are also used in civil engineering. In spite of that, the most recurring ones have been the Pratt[13], Howe[14] and Warren[15] typologies.

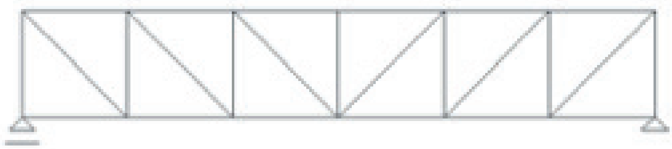

Figure 24. Outline of a Pratt typology

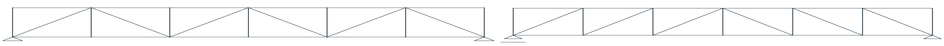

Figure 25. Outline of the Warren and Howe typologies.

As can be observed here, typologies are introduced with triangular and linear stiffening elements, without external supports other than the two side ones and the junctions between riveted bars. The disposition of diagonal and upright supports in the previous frames will be different according to their mode of operation: Tension (Pratt), Compression (Howe), Compression - Tension (Warren), therefore, merely axial effort. Furthermore, due to their disregard of Moment (**M**) and Shear (T) the calculation (or verification) of the truss becomes simplified. It is remarkable that in horizontal trusses with a vertical gravitational load we see that the upper section (corresponding to the upper strand) is compressed, being the lower section (corresponding to the lower strand) the one in tension.

12 Arthur Morley was a professor of mechanical engineering in University College Nottingham.

13 The Pratt truss owes its name to engineer Thomas W. Pratt (1812-1875) and his father Caleb Pratt.

14 The Howe truss owes its name to architect William Howe (1803-1852).

15 The Warren truss owes its name to engineer James Warren (1806-1908).

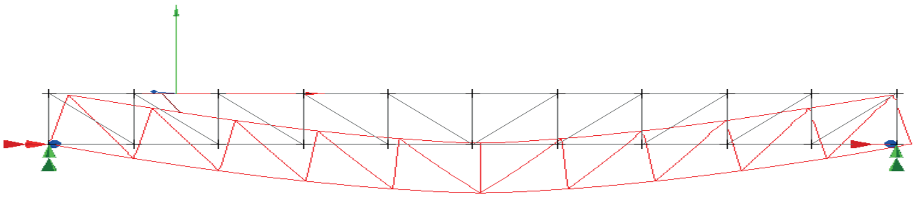

Figure 26. Deformation of the Pratt truss. The upper section is compressed being the lower one in tension.

Having obtained the effort value (kN) which the bar has to sustain by any of these methods, the following step is its dimensioning or verification. To this effect it is fundamental to ascertain whether this is a tension or compression effort. A case of bars in tension is relatively easier to solve, whereas the ones in compression are more complicated due to the critical phenomenon of buckling (Pons, 2009). Both cases correspond to problems covered in strength of materials and / or structures theory handbooks.

7.- The Barca D'Alva –La Fregeneda to Fuente de San Esteban International Line: International Bridge of River Águeda.

The river Duero is the natural border between Spain and Portugal and along its course there is a deep encasement including 500 m slopes in the area known as Los Arribes del Duero and Arribes del Águeda, located at the end of the course of river Águeda as it flows out in the Duero. There, as is shown on the map, is the river wharf of Vega de Terrón and the defunct railway's International Bridge.

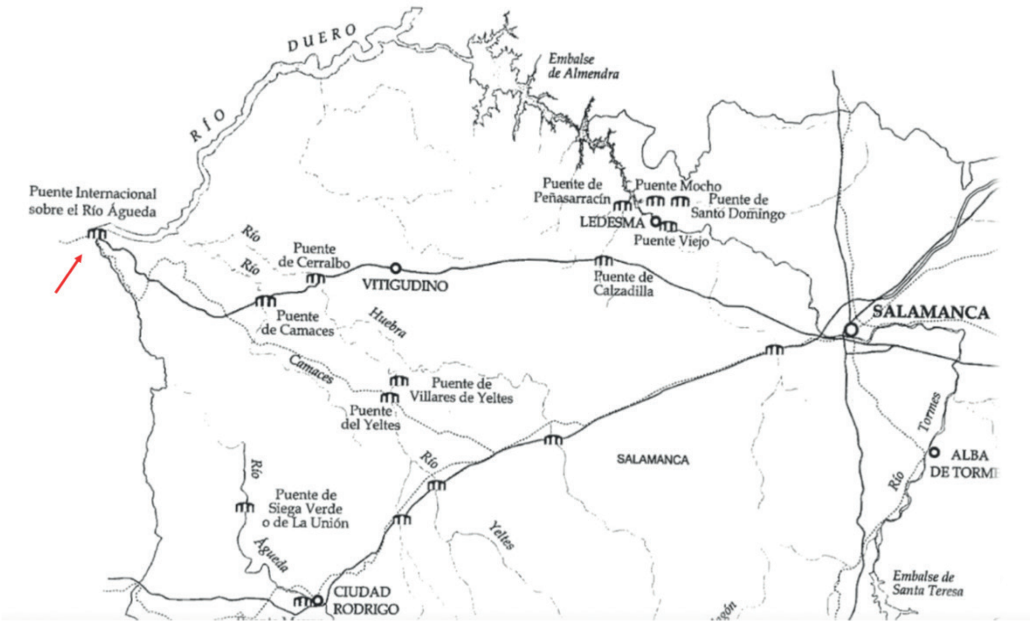

Figure 27. Detail of a map of bridges in the Salamanca province (César A. Martín Pescador).

The 19th century was a period of great industrial development, and the introduction of railways forced the development of a track layout which was auspicious for economic impact. A clear example is the union of Porto and Salamanca, a long envisaged idea, because of the existing need for economic exchange (wine and grain), previously carried out using the natural pier of Vega de Terrón. Its construction implied a technological challenge, due to the execution of many public works, tunnels, bridges, overpasses, on top of human effort and hardships. The orographic problems they had to bridge, especially in the stretches of river which were closer to the border, Pocinho - Barca d'Alva and from the outflow of the Águeda into the Duero to La Fregeneda station, originated a number of works which nowadays, with the railway closed to rail transit, has become a unique heritage of industrial engineering in Europe. (D'Abreu; Rivas Calvo, 2005: 61, 64-66).

The international line of Barca d'Alva - La Fregeneda to La Fuente de San Esteban was the railway area connecting the Duero line alongside Portugal's Northeast to the Spanish railway network and which, until the closure of this section in 1985, was where freight and passenger trains regularly ran between Porto and Salamanca. It was opened on the 8th of December 1887, terminating the briefest and most beautiful connection of Portugal with the center of the Iberian Peninsula and Europe via railway (D'Abreu; Rivas Calvo, 2005: 66). The opening ceremony of the *Linha do Douro* (Porto– Salamanca) took place Barca d'Alva, in the mid-section of the bridge, and was thus described by the journal "O Occidente":

> *«A ponte estava vistosamente embandeirada com os pavilhões das duas nações. Os dois comboios, o portuguez que ás 4 horas a três quartos da manha partia do Porto, e o hespanhol que sahira de Salamanca ás 7, chegaram ás 11 horas e meia á ponte internacional, parando respeitosamente junto dos encontros, e avançando depois até o centro da ponte, onde os cabeçotes das duas machinas se tocaram entre vivas aclamações. Então o comboio portuguez recuou, trazendo engatado o hespanhol, para a estação de Barca d'Alva, onde foi servido aos convidados um almorço de 100 talheres. Á 1 hora da tarde os excursionistas pozeram-se a caminho tendo-se reunido os dois comboios de inauguração, em um só que, rebocado pelas duas machinas, transpoz a ponte internacional, avançando rapidamente pela Hespanha dentro»* (Costa, 1888: 21)

In the same way, but using visual support (fig. 28), the event was chronicled by *La Ilustración Española y Americana*, which recorded in 1887 the opening of the International and Bridge and Railway from the border to Portugal, direct link to Porto. The print on page 396, made from a photograph by D. Santos Tordesillas, pictures the moment of the inauguration when the trains are smoothly joined on the locomotives' buffers in the middle of the bridge.

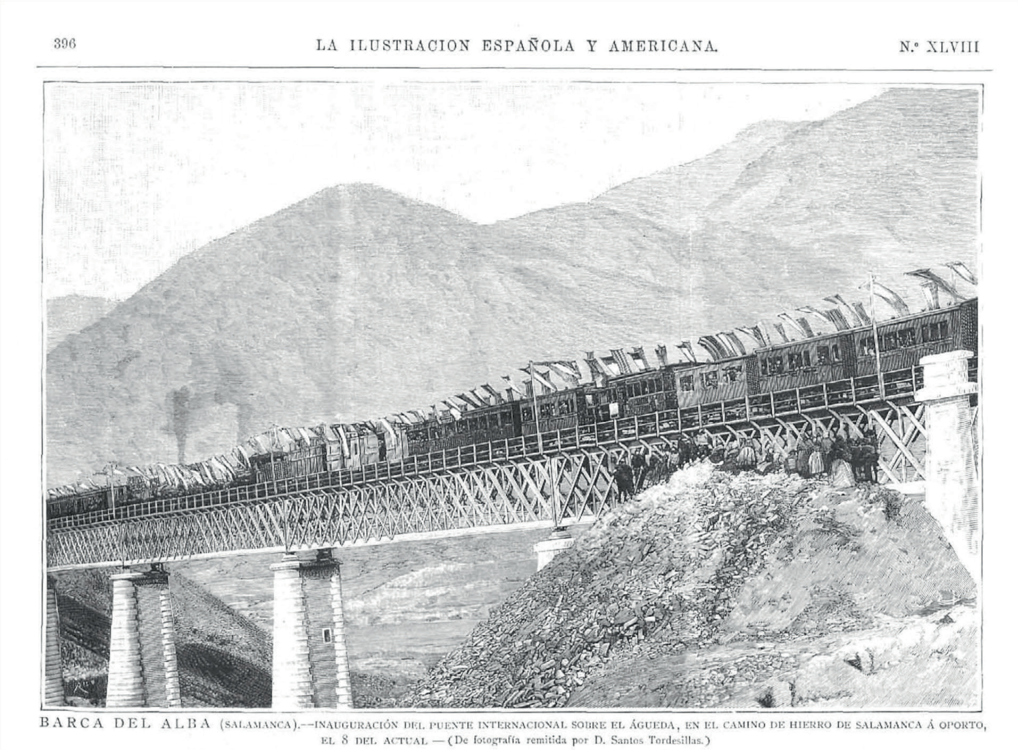

Figure 28. Print of the opening of the International Bridge on the Águeda

The bridges comprising this railway network were able to gap great distances between ravines, creeks, dells and dales, all of which compelled its engineers to search for alternatives in order to build bridges of great significance and technical worth. They are among the most impressive, both because of their intrinsic value from an engineering point of view and their location. Among them features prominently the international bridge on the river Águeda, also known as Ponte do Rio Águeda, located in a remarkable spot. The natural environment in which sits the ridge on the river Águeda meets a number of special conditions in which technique and engineering have proved suitable to its surroundings (D'Abreu; Rivas Calvo, 2005: 68).

The land topography was steep and irregular, with remarkable folds created by the winding course of a number of ravines and dales in the great ridges formed by the rivers Águeda and Duero. That would be the location designed by the International Engineers' Commission for the junction with the *Linha do Douro* (Rebolledo, 1880; D'Abreu; Rivas Calvo, 2005: 70). That being said, the works made to bridge the Águeda was a bridge whose deck had to be 22 meters above the shallow waters or 24.50 m approximately above the river bottom, made up of three metal sections comprising altogether 129,39 m from pier to pier (D'Abreu; Rivas Calvo, 2005: 69). The project, drafted by Portuguese engineers on the 21st of June 1884 was signed by the construction management of Caminos del Hierro del Miño y Duero, being its Engineer Manager Augusto Luciano Simões de Carvalho, and chief development engineer Alfredo Soares as well as José Vieira Padilha as chief of service. The project was inspected in Madrid y the Chief Engineer of the West Division of Railways, Mr Boureyou on the 20th of January of 1885, and passed by a Real Warrant on the 4th of February the following year. The descriptive memory lists as a precursor the agreement in Porto on 19th June 1879, signed by Pedro Martínez Gordón, Eusebio Page, Boaventura José Vieira, Pedro Alves d'Avellar and José Bandeira Coelho de Mello (AGAE 1884, 1879; D'Abreu; Rivas Calvo, 2005: 71).

They eventually settled for the construction of five spans, which meant the first and fourth abutments would be close to the river banks, and the second and third abutments would support small flows, circumventing in this way the main stream of the Águeda. Moreover, the central abutments include a niche on each side of the border, in order to be blasted in case of war escalation. The foundations did not pose much of a problem, an estimated 4 meters could be undertaken. The abutment's maximum height would be 19,60 m above the highest water level, and the breakwaters are clad in rustic stone inside, and exposed stone outside. It also includes a passageway along the length of the bridge, below the upper deck, with approaches on both ends. The structure has a double inclined mess of 45 degrees and the bars which resist the strains are built in rectangular section iron, and those resisting compression are made of U-section iron. Finally, those devised to resist both efforts keep an elongated section in U reinforced with edgeboards. The windbreaks, both horizontal and vertical are made up of Saint Andrew's crosses completing the superstructure.García Mateo and others, in their Inventory of Railway Bridges of Spain, describe the bridge as structured in lattice trusses and parallel strands (Rengel, 2002; García Mateo et al., 2004; D'Abreu; Rivas Calvo, 2005: 72). The project also takes into account a lineal meter 30 km railway supported by several oak traverses. It also has check-rails and surface passes in place along the length of the bridge.

During the decade of the 1950s the International Line was in decline, facilitated by the Government of Spain, which established a new international connection via Vilar Formoso. And on the 1st of January 1985 the International Line was finally closed. Nowadays, it's in a pitiable neglected state due to the corrosion of its component parts. However, the passing of time has not effaced its beauty or its memory[16].

8.- Conclusions.

> *"Even though Palladio designed and built wooden lattice truss bridges in the 16th century, nobody followed suit. That is why the lattice truss had to wait for almost two hundred years before its rediscovery and being given due attention"* (Steinman; Ruth, 1979: 127).

We were referring in the introduction to the extensive body of work of the Italian architect Andrea Palladio. In this article, we intended to assert the Palladian influence on civil engineering, specifically on the formulation of bridges (iron and steel) which were accomplished during the Industrial Revolution of the 19th and 20th centuries applied to railway networks. More exactly we have discussed, on the basis of his *Third Book,* the formulation and implementation of lattice truss bridges he himself calls for. Because the Padovan has been considered to be a forerunner of this structural typology, even though he hasn't been granted that merit very often concealed by his vast architectural body of work. The lattice truss typology, so commonplace these days, not just for railway bridges but also in other construction works, had part of its origin in those drawings that almost 500 years ago he left to posterity. As an example of that, we have featured a bridge, the international bridge on the river Águeda, which reminds us of those examples formulated by Palladio in his Treatise, showing his abilities and foresight with the usage of the truss as a structural principle. All that is proof that it's untrue that Palladio didn't enjoy much "resonance in Spain", since in such an important

16 As an initiative of the Tourist Campaigns Centre of Arribes del Duero, the Royal Decree 1934/2000 of November 24 was passed, by which the La Fuente de San Esteban - La Fregeneda railway line (Salamanca), was entered as an Asset of Cultural Interest, classed as a monument. (HORTELANO, 1996; D'ABREU; RIVAS CALVO, 2005: 77)

moment as the 19th century with its industry and communications (the steam machine), attention was drawn to the typologies that this great architect and engineer had already laid down.

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