Plate Girder Bridges in Andalusia, 1850-1910. The Spread of an Unusual Genre of Iron Bridges

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Introduction

After their remarkable appearance in Great Britain around 1850, the use of plate girder bridges spread rapidly throughout many countries. However, compared to the popularity of iron truss bridges, their acceptance was low and they were generally rarely used from the 1870s.

Nonetheless, such bridges were used for quite some time in Andalusia, the southern region of Spain. Between 1850 and 1910, about ten projects for bridges of this type were submitted, most of which went on to construction.

In this interesting group of bridges, especially in the earlier ones, British iron construction had a notable influence, both in design (through the experiences of Fairbairn and Hodgkinson, and Fairbairn, which were followed with interest by Spanish engineers) and in construction, some of the bridges being manufactured in the United Kingdom and later taken to Spain.

This paper aims to report on the history of these original bridges, exploring all different perspectives.

The Emergence of Tubular and Plate Girder Bridges

The earliest iron bridges were built at the end of the 18th century mainly in Great Britain (Coalbrookdale, 1776; Buildwas, 1796; Sunderland 1796), but also in Germany (Laasan, 1796) and France (Louvre, 1803) [1].

They were all made with cast-iron elements, following models taken from traditional bridges: wooden piece truss and voussoirs vaults [2].

Some experimentation in cast iron bridge construction was seen in the first three decades of the 19th century. In 1819 Sir John Rennie built the Southwark bridge which comprised three arches, each of 64 metres in length. For his part, French engineer Polonceau introduced a new concept using hollow profiles for the arches [3].

In the first half of the century, innovations in design came in the form of suspension bridges, which were pioneered in Europe by the great Telford on the Menai Bridge. The success of this led to other suspension bridges, notably those at Clifton (by I.K. Brunel) and the famous chain bridge over the Danube between Buda and Pest, built by the Tierney brothers [4].

Also at this time in France, the use of this type of bridge increased greatly, to which was contributed both the work of Henri Navier for its technical design and the constructive impulse from the company of the Seguin brothers. Many bridges of this type were built during this period in France and other countries, including Spain [5].

The railway network was then expanding, which necessitated the rapid construction of many bridges. Suspension bridges were soon ruled out as a result of some notorious collapses. Initially, the traditional methods of construction such as masonry or brickwork arches continued to be used, but they had important limitations of spans and cost (especially due to the falsework required for erection).

Thus, the railway engineers who were faced with these new problems, not the least being the time factor, reverted to the most elementary type of bridge: the simple beam - the log placed across the stream by primitive man.

In 1820, Ithiel Town, a builder from New Haven (USA) patented a new type of bridge in such a way. It was made of wooden planks crossed in a diamond pattern and fastened with wooden pins [6].

During the early rush of railway construction, Town timber bridges were largely built, sometimes to save time and many of them not as a definitive solution.

Nevertheless, engineers quite naturally found the solution: a simple transposition from this timber structure to cast and wrought iron with which they were familiar and was then being commercially produced.

In the 1850s the process to produce wrought iron was much improved and finally the industry could provide plates, angles, tees, etc. It was then possible to make beams of a large size for use in bridges by riveting together these sections [7].

The idea was first adopted by Robert Stephenson in 1845-50. After small beginnings with short spans of under 10 metres (like the river Nene bridge at Wisbech [8]), he decided to build a wrought-iron bridge of great magnitude and singular novelty for the railway crossing of the Menai Straits. The Britannia bridge was designed by Stephenson and Sir William Fairbairn with the assistance of Professor Eaton Hodgkinson, the mathematician, to provide a stiff decked bridge for train loading [9].

It was an original design, drawn from a wide range of investigations, including the use of scale models. Apart from the drawing of the major section of the bridge, new processes of physical construction had to be elucidated, and empirically the positive structural performance of continuous spans deduced.

The Britannia Bridge (completed in 1850) represented an amazing advance in bridge-building. It was the forerunner of the tens of thousands of plate-girder bridges that can be seen all over the world today [10]. Stephenson, Fairbairn and Hodgkinson had originated a new era in bridge-building with the plate girder based on an entirely novel principle of construction [11].

However, despite their originality, plate-girder bridges did not have a long life [12]. Barely a decade later, they had virtually disappeared from the scene, replaced by an iron Town lattice girder. These were much cheaper and more aesthetically pleasing. In the last third of the century, engineers turned to triangulated beams (Warren, Howe, Pratt, etc.), incorporating increasingly complex configurations (cantilever) and again resorting to arches.

Nevertheless, in the south of Spain, tubular and plate-girder bridges did have a notable development. Only two years after the construction of the Britannia Bridge, Stephenson and Fairbairn's advances were quickly accepted and they were used in the design of a bridge in the city of Málaga. Before long, the first bridge of this type was built, which was followed by many others. Some of them were even built in the first decades of the 20th century.

The Alameda tubular bridge in Málaga, by Diego Ramírez (1852)

In the mid-19th century, Malaga was a city in expansion, one of the most important in Spain [13], where a thriving economic activity based on commerce and an incipient metallurgical industry was driving the realisation of remarkable urban development.

In the style of the large European cities, new areas of this bourgeois city were laid out, which included several bridges over the Guadalmedina River, which traversed the city.

Malaga was a cosmopolitan city, receptive to modern advances and ideas. It is not surprising, therefore, that when the construction of the new bridge was considered, eyes were turned towards the extraordinary British innovations:

'The whole world now admires as one of the wonders of this century the construction of the Conway and Britannia bridges, and engineers of all nations, following the path opened by Stephenson and Fairbairn, are adopting with a predilection for their work a system which combines the strength and rigidity of fixed bridges with the cheapness, lightness and low material requirements of suspension bridges [14]'.

Diego Ramirez, the engineer responsible for the new bridge, proposed a structural solution consisting of two main 1,80 x 0.70 metre tubular beams made up of riveted wrought iron plates, with the deck below (Fig. 1).

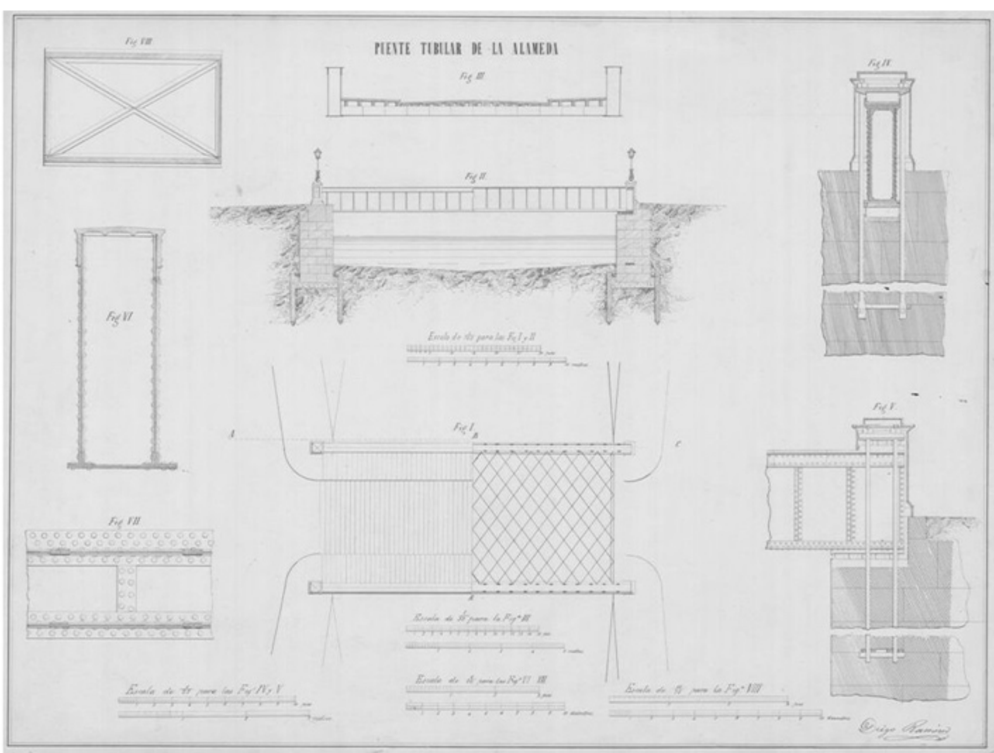

Figure 1: Original drawing of the Alameda bridge in Málaga. Diego Ramírez, engineer. 1852. Archivo del Ministerio de Fomento, Spain.

Inspiration from British models also reached the structural design. Ramirez relied on the empirical formulae deduced by Fairbairn from his experience on the Conway and Britannia bridges [15].

The bridge was built with a significant modification, that being a central pier, leaving it with two continuous spans [16].

It remained in use until 1910. By then it was in a very bad condition, with a large number of its plates affected by corrosion (it was located near the coast). Curiously, considering the fact that the original configuration of iron plate girders was then already anachronistic, the original metal part was replaced. The new bridge, designed by the engineer Eduardo Franquelo, lasted until the 1960s (Fig. 2).

Figure 2: Second bridge of La Alameda (Tetuan) in Málaga. Built in 1910 by the engineer Eduardo Franquelo. Archivo Histórico Provincial de Málaga.

Bridges of the Córdoba-Sevilla Railway (1858-1860)

The railway was introduced to Spain quite late, relatively. In the 1850s, the main lines began to be built, mostly promoted by foreign companies.

A consortium of French and Belgian entrepreneurs was in charge of the construction and operation of the important line from Seville to Cordoba, which ran along the Guadalquivir River Valley [17]. Built between 1857 and 1860, it comprised four plate girder bridges each with single or two continuous spans as well as the superb 154 metre bridge over The Guadalquivir River in Lora del Río, formed by eight continuous spans upon cast-iron cylindrical piers [18].

All these bridges were designed by the English Engineer Joseph Lane Manby, who was working in association with the French building company Savalette [19] (Fig. 3).

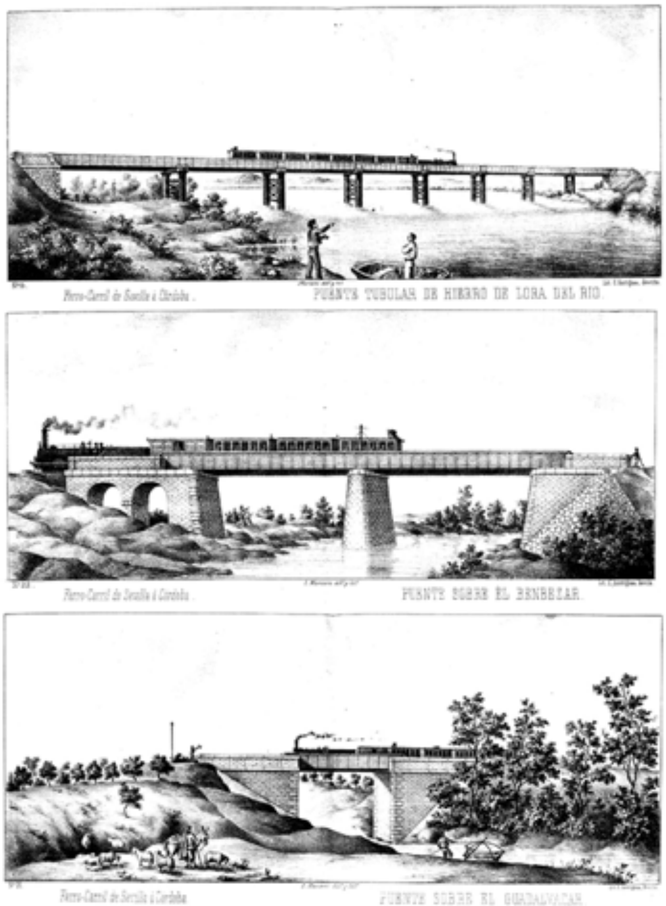

Figure 3: Some of the bridges of Córdoba-Sevilla Railway, designed by the engineer Joseph Lane Manby (1858-1860). Biblioteca Virtual de Andalucía.

The River Víboras iron bridge (1863)

Once the conflicts that had destabilised the country in the first half of the 19th century were over, the Spanish Government was able to push ahead with the deployment of the national road network from 1860 onwards.

To assist the engineers in charge of designing and building these new roads, they set up technical commissions to study the standard elements.

Thus, a commission of three civil engineers (Lucio del Valle, Víctor Martí, Ángel Mayo) was charged with introducing the new iron bridges in Spain. The plate girder bridges were adopted by then as the main design concept and in the early 1860s a number of bridges of this type were built all over the country.

One of the most significant was the Víboras river bridge, included in the road that was to link the cities of Jaén and Granada. Of all the bridges designed by the commission of engineers, it is the only one that has survived to the present day (Fig.4).

Figure 4: River Víboras iron bridge, which nowadays is still in use. Del Valle, Martí and Mayo, engineers.

This 60 metre bridge (in two continuous spans) was designed using new rational theories of Strength of Materials, developed in the first half of the 19th century (Fig. 5).

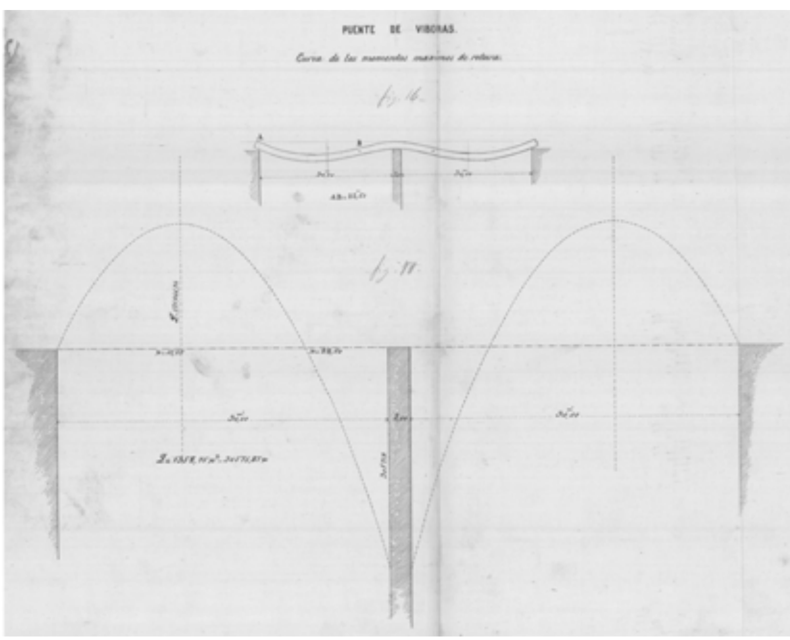

Figure 5: Bending moment diagram calculated for the iron bridge of river Víboras. Archivo General de la Administración, Spain.

The British contribution to this bridge was also very important. Its metal part was manufactured by the company John Butler Iron Works, from Staningley (near Leeds). It was transported by ship to Seville port and moved later to Jaén on an arduous three-month journey through the Spanish countryside. Finally, the two spans that formed the bridge were assembled and mounted over the masonry supports in September 1863. This operation was carried out by technicians sent out by John Butler's company [20].

The design of the superstructure was utilised as a model for all of the bridges of this type that were built later. It consisted of an upper deck supported on two main beams (plate girder in double Tee section). The interior of the bridge was reinforced with X bars (Fig. 6).

Figure 6: Superstructure of Víboras bridge

Plate girder bridges of the last quarter of 19th Century

The river Víboras bridge had a great impact on the design of bridges in this region of Spain between 1685-1875. In this period, four similar road bridges were drafted in the provinces of Jaén and Almería (Fig. 7).

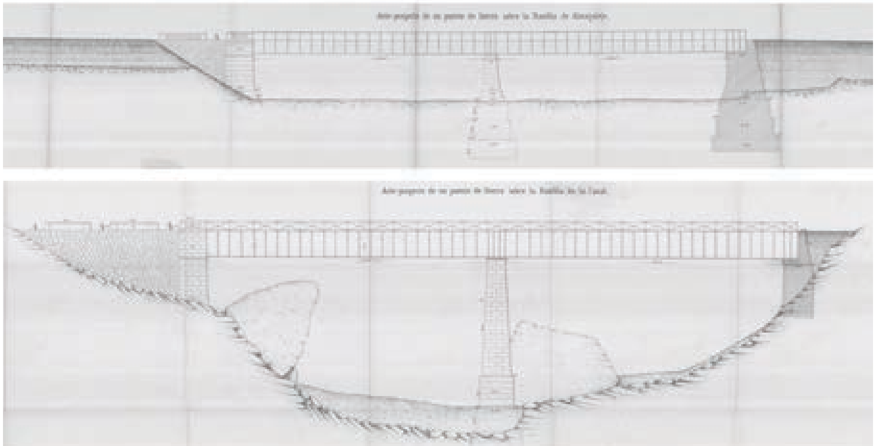

Figure 7: Preliminary drafts of Rambla de Almajalejo and Rambla de la Canal bridges, 1876. Province of Almería. Rafael Moreno Levenfeld, engineer. Archivo General de la Administración, Spain.

But the success of this design was as brief as it was sudden, none of these bridges ever being built with plate girders. From 1875 onwards, the Town lattice truss became practically universal in road bridges, while on the new railway lines, foreign engineers began to introduce triangulated girder models. Masonry arches, for their part, were also brilliantly used in road bridge construction.

However, the plate girder bridges did not disappear completely, at least in the eastern part of Andalusia. The insistence of a Spanish engineer, José María Iturralde, prolonged its validity in this region until the arrival of the 20th century. In 1881 he designed the bridge over the river Guadalimar (Province of Jaén). It had three 30 metre continuous spans (Fig. 8). Problems with the foundations of the supports delayed their materialisation until 1889. In this case, the metal parts were manufactured by a Belgian company.

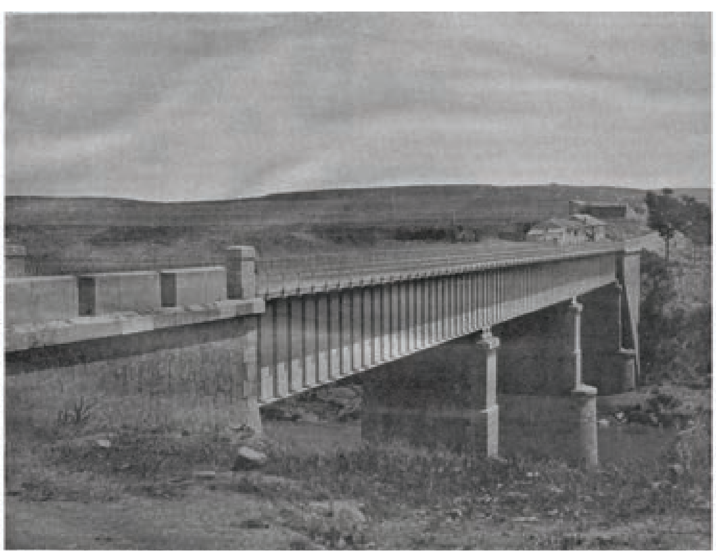

Figure 8: Original setting of the bridge over Guadalimar river, province of Jaén, 1889. José Iturralde, engineer. The University of Granada Library.

The engineer Iturralde was a convinced advocate of this type of bridge [21], and he insisted on its use until nearly the 20th century. In 1891 he applied exactly the same design for the bridge at Galera, in the province of Granada.

Both bridges are still in use nowadays. The one in Galera is in the same condition as when it was built. However, the Guadalimar Bridge was reinforced in the 1940s, two warren beams being added under the deck of each span, giving it the unusual structural configuration it has today (Figure 9).

Figure 9: Guadalimar (left) and Galera (right) bridges, nowadays. J. Iturralde, engineer.

The Veguetas bridge, on the Sierra Nevada Tramway line (1925)

The swan song of plate girder bridges in Andalusia was the Veguetas bridge, built-in 1925 for the tramway line from Granada City to the mountains of Sierra Nevada.

This was an innovative infrastructure, in which reinforced concrete was used to build all of the bridges on the tramway. Its project was presented in 1924 [22].

However, as a concession to the previous tradition, an iron bridge was included in its layout: a single 15 metre span over both masonry arch supports (Fig. 10).

Figure 10: The Veguetas bridge, on the Sierra Nevada Tramway line. Carlos Morales Lahuerta, engineer. Archivo Histórico Provincial de Granada.

Interestingly, this last realisation of plate girder bridges reiterated the primitive configuration of the pioneers: a deck upon two main beams with double T-section, made up of riveted wrought iron plates.

The tramway was closed in 1974, a major part of which, including Veguetas Bridge, is now under the water of a modern reservoir.

Conclusions

The concept of plate girder bridges was especially followed in the south of Spain during the second half of the 19th century.

Originally the design of these bridges was made using models and empirical knowledge developed by British Engineering.

British ironwork companies manufactured some of these bridges and then Spanish engineers undertook their design, applying the rational principles of the Strength of Materials.

More than a century after their construction, many of these bridges are still in use, proving the validity of their design and construction.

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