The Durcal and Gor Viaduct: A Bridge Built Twice (1885-1925)

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Abstract

We present an investigation into an iron bridge which can be seen near to the city of Granada, Spain. The bridge was originally built in 1905 in a different location to where it is now. Its creation was the result of an integrated process of design, in which Belgian, British and Spanish techniques were used. The bridge became unusable due to technical problems at its first location. Some years later it was transferred to another site where it was utilized in a different transport infrastructure. In this article, we analyse the process of its design and construction and the particular circumstances that were experienced that reveal interesting aspects of bridge engineering of that epoch.

Keywords

Iron Bridges, Engineering design, Construction, Railways, Spain

Introduction

In the town of *Dúrcal* (20 kilometres to the south of the city of *Granada*, Spain) there is an interesting metal bridge. It is a large viaduct, exceptional because it was the only one built over a river in Spain using the cantilever system. This bridge is not only special because of its characteristics, it is also interesting because of the vicissitudes of its design and construction. The bridge was planned and built at a different site and for a different rail infrastructure. There are doubts about its first creation and a number of recent investigations have not, unfortunately, clarified certain questions regarding its construction. The investigation that we present in this article will try to shine some light on this matter by presenting hypotheses regarding its creators. We will also discuss the facts relating to its first construction, providing explanations for its abandonment. Finally, we describe the circumstances of its transferral to its final location.

Through the development of the above objectives, this investigation will reveal aspects of interest regarding the design and construction of bridges in Spain around 1900. The historical discussion about the bridge will coordinate many direct testimonies (documents and studies of remains). Individually considered, they supply valuable information regarding the structural design, the geotechnics and the methods of construction in the epoch in which the bridge was built (twice).

The Granada to Murcia line

The first half of the nineteenth century saw a revolutionary period in Spain, but the conflicts that had arisen with the end of the Old Regime hampered the advance of the Industrial Revolution. The modernization produced uneven impetuses and did not benefit all parts of the country. The delay and deficient installation of railways was one of the main factors that contributed to the backwardness and at the same time, one of the principal consequences.[1] In the middle of the century (1855 - 1865) there was a relatively long period of stability and economic growth including that of the principal axes of the Spanish railway system. The Spanish administration was not capable of developing a national railway system for the whole of the country so the lines that were constructed were done so through private initiative. In this way, a deficient system was created in that large areas of the country were left without any communications, the extreme south east of the peninsula finding itself without a single line, resulting in a profound transport vacuum.[2]

The development of the Spanish railway system was created through a system of concessions. The administration would sign over the rights to operate a line, which a private business would have to construct. The Spanish industrial base was little developed, most of the Spanish economy being monopolized by foreign companies who implemented their particular systems of working as well as bringing in their own raw materials. At the beginning, many British companies were interested in railway construction in Spain, even leading to the construction of the first lines, among them, the one from Barcelona to Mataró (the first peninsular railway, built in 1837). However, from 1845 onwards, UK companies mostly withdrew from Spanish railway business, largely due to the negative impressions formed by the brilliant English engineer George Stephenson (1803 - 1859) after making studies in situ in 1845. This left the field free for the French companies, which practically monopolised the construction of railways in Spain during the second half of the 19th century.[3] Of course, with those came the technology. Truly, "Spain was invaded by young graduates of the *École Polytechnique*"[4], who contributed in introducing the new techniques of construction from the industrial era, especially iron bridges. Meanwhile, competent Spanish civil engineers were occupied in the construction of the railway network.

In 1867 the Spanish government tried to rationalize the network with a general railway plan. They looked at the construction of new lines that would enhance the homogeneity of the national network[5]. In this plan the priority was the line between Granada and Murcia, whose main function was to connect the networks between Andalusia and the East, until then unconnected.[6] However, after the boom of 1855-65 diverse circumstances inhibited the expansion of the railways. The main factor was that businesses did not respond as expected. Due to the complex Spanish topography, the cost of construction of the lines was seen to be prohibitive. Equally, there was no guarantee of sufficient passenger or goods traffic to make a project profitable enough to give a return on the investment. The construction of new lines was paralysed.

The Spanish railway network would never have existed, were it not for the exploitation of mines. The Spanish deposits of iron ore and coal became a source of competitive supply for important steel works. Financial consortia of foreign countries wasted no time in stimulating the creation of the necessary infrastructure for its extraction and transport. In this way, the reactivation of railway construction took place with foreign investment, but this time the French had to share the market with the British.[7]

The Southeast of the peninsula, which had been forgotten in the first wave, was now one of the areas that attracted the attention of these new railway entrepreneurs. There were two mining areas of interest in Andalusia: *Linares* in the north-east of Andalusia and *Sierra de Los Filabres* to the East. The railway network was formed due to the desire for a connection between the mines and the Mediterranean ports. To this end a Franco-Spanish consortium, *La Compañía de Caminos de Hierro del Sur de España*, built the line between *Linares* and the port of *Almería* between 1889 and 1899.[8] (Fig. 1)

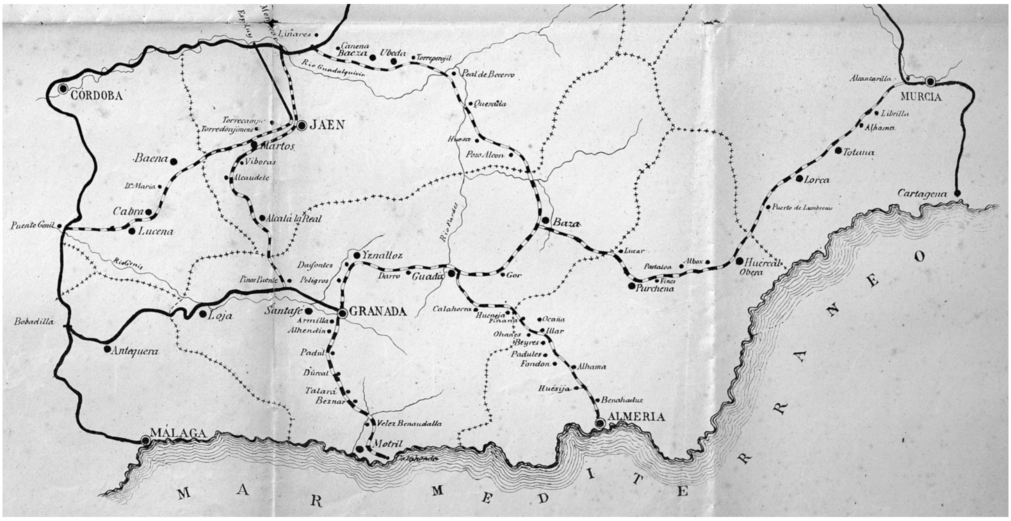

Figure 1. Planned network of railways of the Southeast of Spain according to the plan of 1867.[9] Library of the Hospital Real, Granada University.

The other great potential line in the south-east was the *Granada* to *Murcia* via *Lorca* line. The Spanish government included this in the priority plan for new lines, with the intention of encouraging its construction with a substantial subsidy.[10] In 1872, the Spanish engineer *Serafín Freart* created a technical project for the line. He presented a project of some 318 kilometres passing through the northern border of the *Bética* mountain chain, the highest mountains in The Iberian Peninsula, and including the *Sierra Nevada*.[11] This proposal would result in a difficult and very expensive project of dubious profitability considering the initial approximations of traffic, but the situation changed with respect to the increasing mining activity in the *Sierra de Los Filabres*. The eastern section of the line, which was to pass near to the mines, would offer an ideal means of carrying the ore to the Mediterranean coast. These circumstances attracted the interest of a British capitalist called Edmund Sykes Hett, who won the auction for the concession of the line on 7th March 1885,[12] being the only bidder. Two years later it was transferred definitively to a consortium of British investors in the form of The Great Southern of Spain Railway Company Limited (GSSR).[13] For his part, Hett reserved the rights to the construction of the railway for his enterprise, Hett, Maylor & Co Ltd (which included engineers Fforde, Mercer, Ogilvie, Maylor, Livesey, Kennedy, Lecoq and Popkiss).[14]

Immediately, they initiated the necessary actions for the construction of the line. The first was the technical revision of the 1872 project which had been acquired by the British engineers. They introduced improvements and completed designs for the stations[15], links with other lines[16], some of the bridges and other significant items. The construction started in earnest in 1887. They started on the eastern part, the mining section (between *Lorca* and *Baza*) which was of most interest to the owners of the company. Being managed by British engineers, the construction was effected efficiently over a period of four years. However, the construction company, Hett, Maylor & Company Limited (HM) had not appreciated the difficulties involved with the construction of the line. Costs outstripped estimates, causing the bankruptcy of the company on 11th August 1890. Little was left for The GSSR to do but struggle on to overcome the difficulties and after 1891 they were able to continue works with the constructor The Marquis of Loring (an experienced Spanish industrialist specializing in railways). However, it was left in serious difficulties such that in 1894, on completion of the line to *Baza*, the almost penniless GSSR considered that they had achieved their objectives and taking advantage of the slackness of the Spanish administration, they washed their hands of the rest of the line. Their rights (and obligations) regarding the rest of the line to *Granada* were passed to another company, the theoretically independent The Granada Railway Company Limited (TGR). The Spanish government authorized the transfer but retained the deposit and made the condition that the subsidy would be paid on completion of the line.[17] From this moment, The GSSR concentrated their energies on the organization of a great infrastructure for the transport of iron ore from the rich deposits of *Sierra de Los Filabres* to The Mediterranean Sea[18]. For this purpose, they applied for and received permission to build a branch line of 30 kilometres from their line to the coastal town of *Águilas* in whose bay they constructed a magnificent pier for the loading of ore onto steamers (the 172 metre *El Hornillo* steel pier, opened on the 12th August 1903)[19]. In this way they completed the infrastructure for the transport of Almerian iron ore which was exploited advantageously during the first third of the twentieth century.

Initial ideas for the construction of the Gor and Baúl viaducts (1887-1890)

Until recently there have been few documents regarding the GSSR project for the line between Baza and Granada. Usually railways kept to the original plans written in 1872, however they would have had to define the main elements. The line had two especially difficult points: the crossing of the rivers *Baúl* and *Gor*, which were some seven kilometres apart. Neither river is anything more than a small stream but with the passage of the millennia they have become deep gorges. The *Gor* valley particularly is some hundreds of metres in width. A project revision by Spanish engineers in 1884 that was produced to state the conditions for the concession explicitly advised that the line must avoid the *Gor* valley.[20] However, GSSR's British colleagues didn't listen, at least initially, to the advice of the Spanish and decided to undertake the construction of a bridge of extraordinary style and size.

At that time in Spain, the main type of metal bridge was generally that of Town Lattice Truss. This type of beam had been introduced some twenty years previously during the first railway growth wave[21]. However, in the 1880s new styles of iron truss arrived with three basic configurations: 'Howe', 'Pratt' and 'X'-girder. Construction during the second wave of railway growth favoured the implementation of these new styles, keeping as a practically universal solution the use of continuous spans. Logically, in these circumstances the proposed GSSR bridge which was to be built over *Río Gor* attracted admiration. In October of 1891 the *Revista de Obras Públicas* (the official journal of Spanish civil engineers) announced that "the railway line from *Murcia* to *Granada*, in the place called *Arroyo de Gor*, between *Guadix* and *Baza*, will have a chromed steel bridge, which will be one of the longest on the Spanish railway network".[22] The viaduct, for a variety of reasons, was to be a work of exceptional engineering. Firstly, it was to be the first Spanish bridge to be built with steel (steel's use became common in Spain only during the second decade of the twentieth century[23]) but what was truly unique was its unusual structural form. It had a 125 metre singular span three hinged arch as its main element with two 90 metre continous spans on both sides, placed over iron truss piers (Fig 2).

The project (the only one with extant plans), included the structural calculations, which were truly advanced. The central arch and the side-viaducts were calculated separately using the methods of Graphic Statics. These calculations were done following advanced approaches, considering alternating loads and taking into account wind action. There is some doubt as to the authorship of this exceptional project. All of the plans were signed by Neil Kennedy, the General Manager of The GSSR. He was a

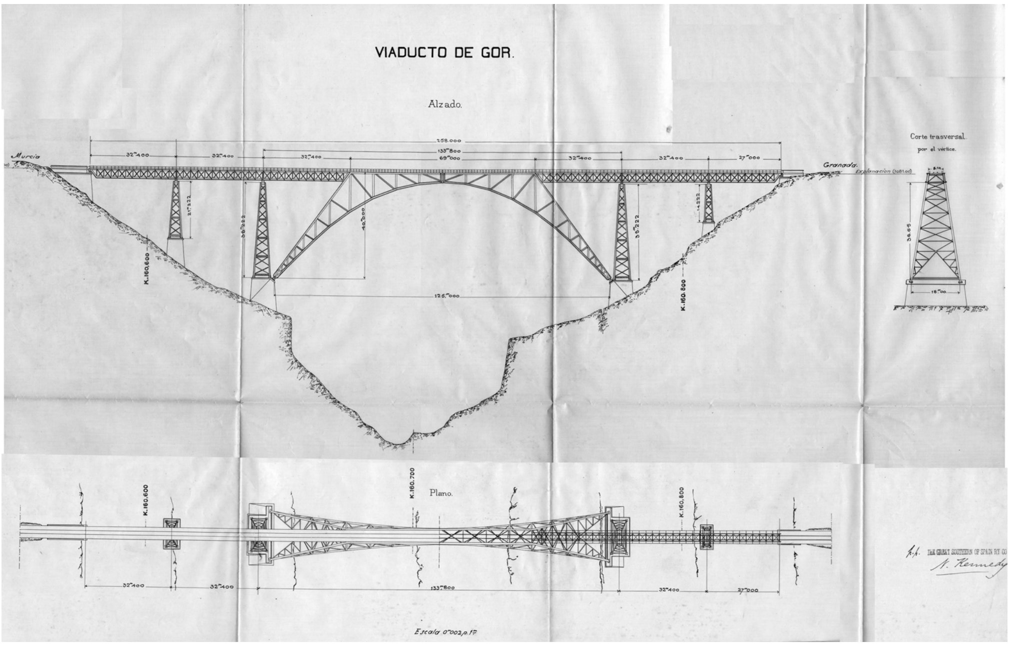

Figure 2. The first project for the Gor viaduct produced by The GSSR. 1890[24]*. Archivo Histórico Ferroviario. Fundación de los Ferrocarriles Españoles.*

Scottish engineer who had been working in Spain since 1872, being occupied in many parts of Spain such as *Huelva* and *Bilbao* in the construction of various mining railways.[25] He was working for a British company that was building a mining railway with a loading pier when the GSSR arrived in *Almería*.[26]

Mr Kennedy was a competent railway builder but he was not an expert in bridges. In fact, he was a technical expert in topography, about which he published a book in 1904.[27] Aware of this, he looked for specialist engineers. There is great evidence that it was the British engineer James Livesey who was one of the creators of the design of the *Gor* bridge. He was a brilliant civil engineer who had built a lot of bridges and railway lines all over the world (including Spain from 1860).[28] Having a Spanish wife, he understood very well Spanish idiosyncrasies. Around 1885 his consultancy company made a deal with The GSSR to design some elements (mainly stations) of the railway line from *Granada* to *Murcia*.

The first works to be executed were either to be contracted to HM or directly by The GSSR working with Livesey. However, after 1893, Livesey, Son & Henderson Limited was integrated as his official engineering consultancy[29] and as a result of this, in 1900 they created the project for one of their most important constructions, the *El Hornillo* loader in *Águilas*, *Murcia*.[30] In this way, Livesey was to be a support for Kennedy in the execution of the project for the great viaduct. However, he wasn't to be the only one. Other documents reveal an important paper stating that the Belgian metal construction company *Auguste Lecoq & Cie* was involved.

Regarding the construction of the railway between *Granada* and *Murcia*, in October 1889 the local press was reporting the presence in the zone of "the representative of the construction company, Mr Kennedy, accompanied by Messers Napier, Balmer and Lecoq, the latter being the son of the manufacturer of metal bridges, who came here to take charge of the construction of the great viaducts at Gor, Baúl and another of equal importance".[31] *Auguste Lecoq & Cie* were not new to metal construction. For more than thirty years they had been designing, manufacturing and constructing important works of engineering architecture worldwide,[32] all of which came from their factories in *Halle* (near Brussels, Belgium), as the *modus operandi* of the company was the prefabrication of parts and subsequent assembly on site as was the case regarding the metal bridges on the *Granada* to *Murcia* line, including the viaducts of *Gor* and *Baúl*. Even in these cases, considering the magnitude of the works, the design would have had to have been executed in conjunction with the engineers of the building company, the engineering consultant and the iron construction engineer, namely Kennedy, Livesey and *Lecoq*. In addition, it seems that in the case of the *Gor* viaduct they were inspired by a previous project. This was concerning a project presented by Andrew Handyside, the British constructor of iron works, (probably drawn by Ewing Matheson) to the competition in 1880 regarding the building of the *Luis I* bridge over the *River Duero* in *Oporto* (Portugal). Even though it was *Teophile Seyrig* who won the contract, the Handyside proposal was highly valued, especially for its excellent resistance.[33] (Fig. 3)

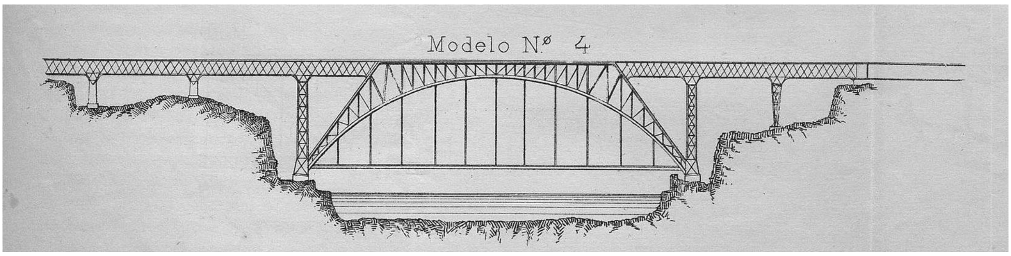

Figure 3. Proposal for a bridge presented by Andrew Handyside & Co at the competition for a bridge over Río Duero in Oporto (November 1880)[34]. Library of the Hospital Real, Granada University.

The creator of this superb design was undoubtedly the masterly English engineer Ewing Matheson, technical manager of the firm, for which he built dozens of bridges in several countries.[35]

Given the extraordinary similarity in design with the *Gor* viaduct, it is inevitable that both projects are associated with each other, especially when one considers that *Lecoq* also made a presentation at the same competition (with an unsuccessful proposal), so Handyside and Lecoq must have known each other. The GSSR also had, in 1890, a project for the other great element of the line, the viaduct at *Baúl*. Sadly, this document does not now exist to our knowledge, but we know of its previous existence due to a technical document by the *Junta Consultiva de Caminos*, an arm of the Spanish administration charged with the supervision of all public works projects, including a description of the work that, due to its significance, we reproduce here (in translation):

> "In session on 20th January 1893 we give a report of the project of the viaduct to cross the Arroyo de Baúl, on the railway from Murcia to Granada via Lorca. The project is to cross the stated gorge with a viaduct of three spans, the central one being of 92.98 metres and with two side spans of 68.25 metres resulting in a total span of 230 metres. The central area will be composed of three parts: two laterals that are a prolongation of the spans of 26.55 metres each in the form of corbels, leaving a central space of 29.88 metres for the metal section which rests on these corbels, holding in place the central part by large bolts on each side".[36]

This was another exceptional design, the first use of a cantilever bridge in Spain, the type that was used in the construction of The Forth Railway Bridge.[37] In fact, The GSSR decided to build the bridges following this design and they had reached the point at which excavations for the Baúl and Balata bridges had been completed when the decision to change route was made. These sites have been found (Fig. 4).

Once it had decided on the design of the great viaducts, The GSSR wasted no time in ordering the fabrication through *Auguste Lecoq*. Of these, there are diverse reports in the local press. For example, from 13th March 1890, an article announced that they had started to bring material from Brussels for "the giant *Gor* bridge".[38] Some months later, it was stated in another newspaper that the iron spans of the *Gor* and *Baúl* viaducts were being built in "one of the most accredited foreign foundries".[39]

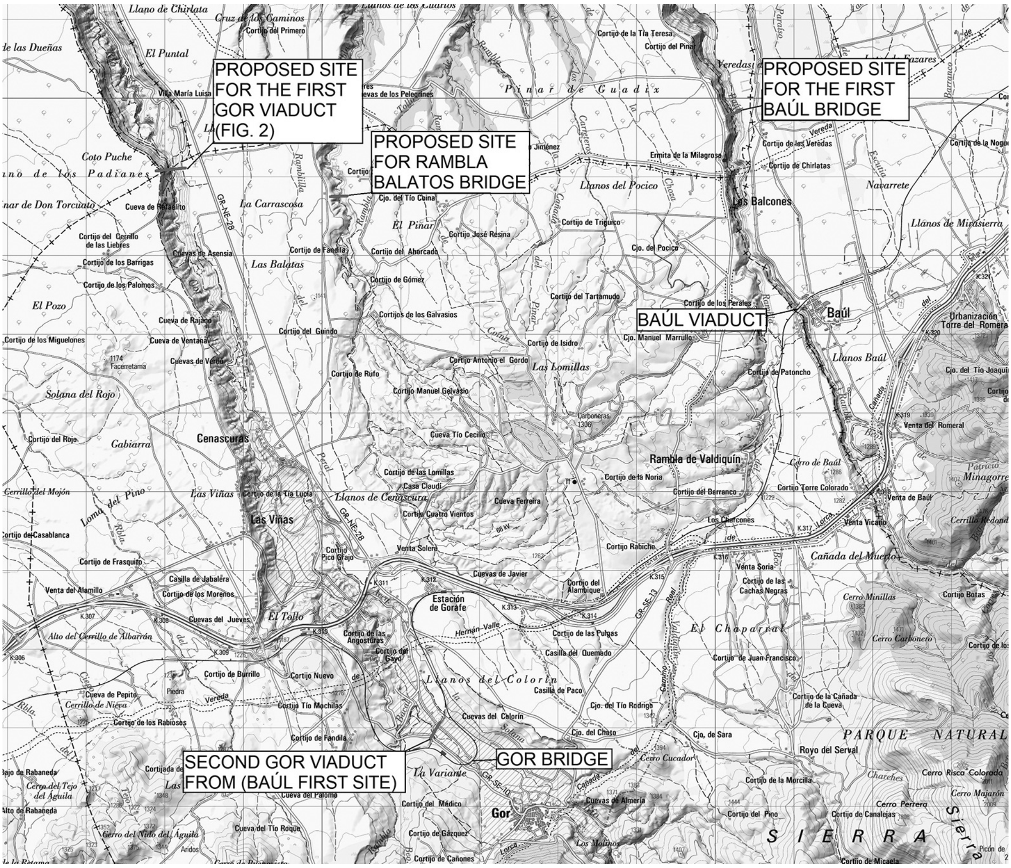

Figure 4. Hypothesis of first location of the Baúl and Gor viaducts, together with the final locations. Drawn by the authors on sheet 0993 of the National Topographic Map of Spain. Instituto Geográfico Nacional. There have now been identified four aligned excavations separated by exactly the same distances as described in the document i.e. 63, 98 & 63 metres at which points there were to have been built the supports for the projected bridge. These were found 2.7 kilometres downstream (to the north) of the existent Baúl Bridge (Fig 5).

The Baúl excavations were abandoned as a result of the HM bankruptcy and the fact that The GSSR had insufficient funds to finish the Baza - Granada section of the line. They did try to ameliorate the situation by re-routing said section but they finally had to sell the concession, as stated above.

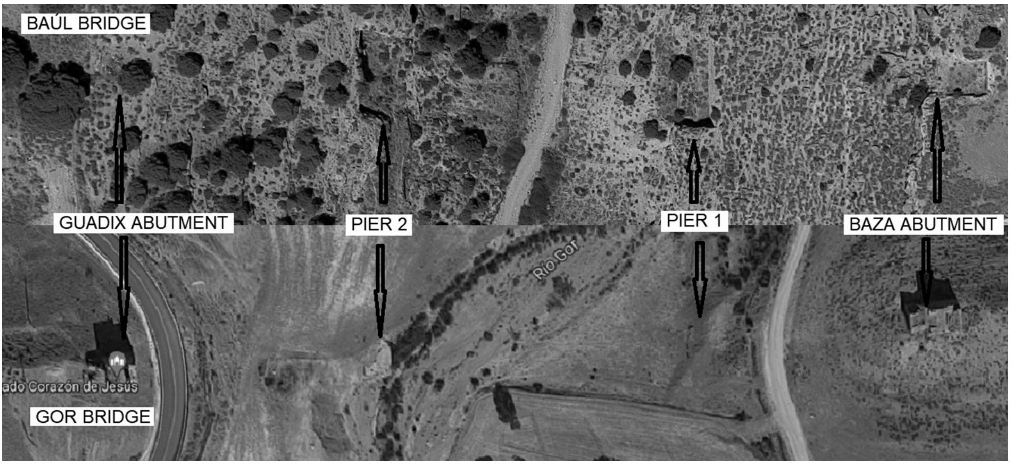

Figure 5. Aerial photographs of the sites (Copyright Google Maps). The distances between the excavations match the distances given in the document referred to above.

Change of plans and choice of a definitive design (1891 - 1894)

At the end of 1891, The GSSR was able to overcome the crisis caused by the HM bankruptcy,[40] and came out of it with new plans for the creation of the railway. Initially they kept their commitment to continue with the construction of the line to Granada, but truly conscious of the difficulties of its construction, they decided to take measures to simplify it and to reduce costs. The risks of gambling on the bridges at *Gor* and *Baúl* were discussed at length. In the case of the *Gor* viaduct, its daring design and dimensions weighed against the uncertainty of the security of its foundations. At the chosen site the land was very irregular, there being a large difference between the two sides of the valley.

To construct such a large bridge in such terrain would certainly be complicated, for which reason it was decided to change the site. If one were to move the crossing point 8.4 kilometres upstream (to the south) there would only need to be a small bridge of much more modest dimensions. In simplifying the crossing, it would be necessary to lengthen the line by some 16.8 kilometres (Fig. 4). However, they opted for an intermediate solution by moving the site 7.8 kilometres upstream with the intention of building a bridge with a span of exactly 230 metres, which was the exact length of the *Baúl* project, and effectively this same bridge would be constructed on the *Gor* river. The justification for this apparently arbitrary and illogical decision can only be that the Baúl viaduct had already been pre-fabricated and The GSSR couldn't revoke the contract for it, so moving the site would save a considerable sum of money. The change would be clearly beneficial for the new *Baúl* bridge constructors, whose location was also to be moved to a place where the span would be 145 metres instead of 230. In addition, the new site at *Baúl* presented ideal conditions for the foundations, there being compacted rock on both sides of the gorge. The construction of the new bridge would be much more straightforward, being formed by three continuous spans.

The modifications were to be put into action immediately, before the planned completion of the line in 1894. *August Lecoq & Cie*, who continued to manage the bridges of the line[41] started the construction of the *Baúl* viaduct at its new site for The GSSR which is why one can see the marks of the company (GSSR) on the bottom chord today (Fig. 6).

Figure 6: Baúl viaduct as finally built in 1904. Note the 'GSSR' marks on the bottom chord (detail). Photographs by the authors.

Second project and first construction (1902-1905)

In 1894 the concession for the *Baza* to *Granada* section of the *Granada* to *Murcia* railway was transferred to TGR. The intention of the British capitalists for The GSSR was to transfer the section of the railway that was unfinished to the *Compañía de Caminos de Hierro del Sur de España*, the concessionary of the other great line of the south-east (The *Linares-Almería* railway). This company had already bought the rights for the section between *Granada* and *Guadix* from The GSSR, but did not accept the responsibility for the rest of the line from *Guadix* to *Baza*. Therefore, TGR was left with a reduced section of the *Granada* to *Murcia* railway, namely the section between *Guadix* and *Baza*. It was a residual section, of some 50 kilometres in length whose traffic could hardly have any impact on 'The *Linares-Almería*' nor on the mining railway *Lorca-Baza-Águilas*. Due to this, TGR had no other resort than to adapt its activities to the convenience of the *Compañía de Caminos de Hierro del Sur de España,* officially as an independent company but in reality subservient to it.

Once the exceptional metal viaducts of *Guadahortuna* and *El Salado* had been completed in the March of 1899, *Compañía de Caminos de Hierro del Sur de España* opened a service between *Linares* and *Almería*.[42] Therefore, it was decided that the junction between TGR and *Compañía de Caminos de Hierro del Sur de España* was to be at *Guadix* station. The Spanish Government confirmed the decision through a decree published on the 9th March 1902.

The works were immediately started on the definitive construction of the line by using materials that had been left by The GSSR in 1894. A new layout was created by the young civil engineer *Rafael de la Escosura*. The decisions that had been made some years previously were ratified, revisiting the arguments about the problems of the foundations due to the moving of the viaduct. In re-locating the bridge, a new official project had to be sent to the Spanish Administration as if it were a different bridge. Now, the *Baúl* three spans viaduct was the solution presented for the *Gor* river crossing.[43] The definitive project for the bridge was drawn in 1904[44]. It was signed by a young Spanish civil engineer, Juan Cervantes Pinelo, in his first job as an engineer (Fig.7).

A comparative analysis with the first (never built) 1890 project shows some evident similarities (Figs. 2 and 6). The main beams show the same form (an unusual in Spain deck-truss configuration with X-triangular beams), the same form in the outside spans and identical bearings. Additionally, both bridges have the same piers. Conclusively, the new *Gor* viaduct had exactly to the millimetre the same configuration and dimensions as was described thirteen years previously for the *Baúl* project in the *Junta Consultiva de Caminos* report (see above). All of this is evidence that both projects contained many of

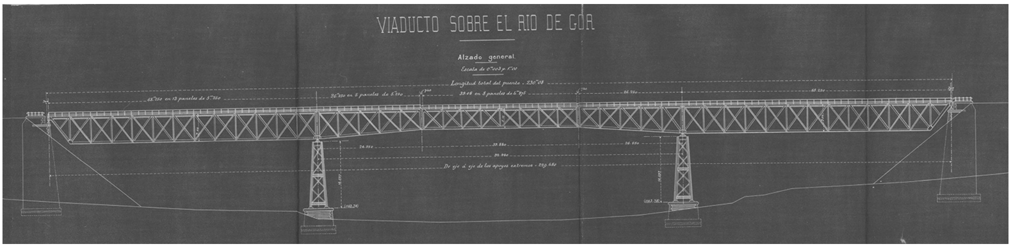

Figure 7. Project for the Gor viaduct from 1904, produced for TGR. Archivo General de la Administración, Spanish Ministry of Culture.

the same design concepts. It is therefore confirmed that the bridge included in the *Gor* project of 1904 was the one that had been planned thirteen years earlier for the *Baúl* gorge.

Having commenced some months previously, works on the line went rapidly and without unseen complications. In June, one of the three spans of the definitive *Baúl* bridge (Fig. 5) was already assembled. For its part, materials for the *Gor* viaduct were already in place ready for construction at the same time[45]. The structural adequacy of the metal parts was tested by the prestigious construction materials laboratory of *Escuela de Caminos* (The Spanish School of Civil Engineers in Madrid).[46]

The construction of the *Gor* viaduct took place between 1904 and 1905. Two monumental embankments (about 20 metres in height) had to be built at either end of the bridge and next to them two large masonry abutments. Once the bases of the *Gor* viaduct were finished, there began the assembly of the metal structure. The structure was assembled in situ from the Guadix side using a sliding auxilliary structure, a rolling system, the spans being assembled and mounted on the supports with the aid of provisional scaffolding (Fig. 8).

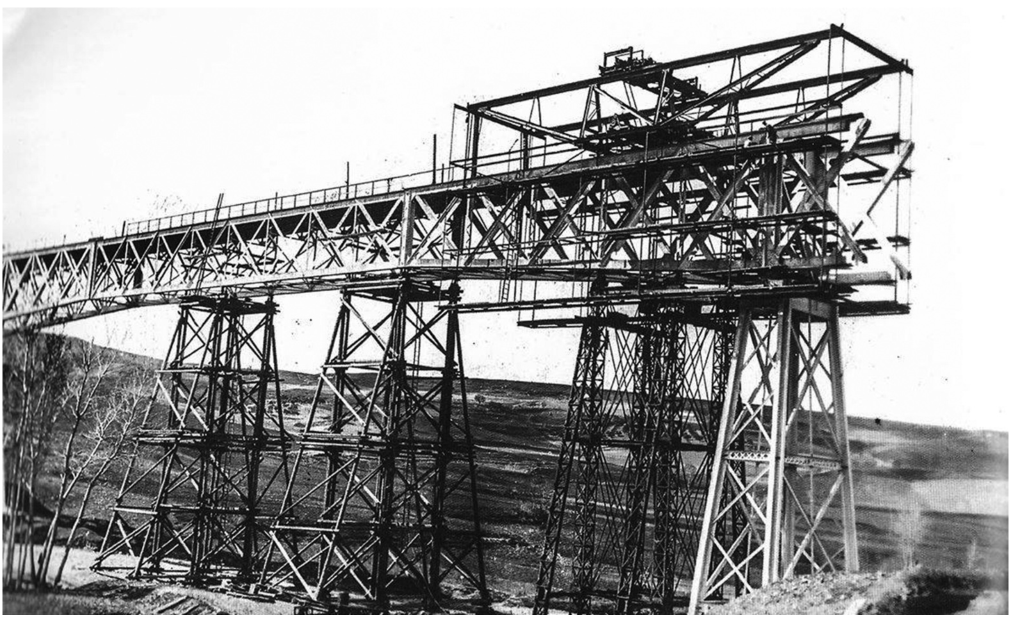

Figure 8. Assembly of the superstructure of the Gor viaduct in 1905. Photograph taken by Gustave Gillman. Courtesy heirs of Gustave Gillman.

The Baza abutment was reached in the first days of December 1905, finishing the construction, but as soon as the metal structure was in place, the embankment started to slide, moving the abutment and risking a serious collapse of the whole viaduct.[47]

Survival of the viaduct in Gor (1905-1912)

Even if there hadn't been any further problems, it put into question the design of the embankment and the abutment. Certainly the foundations had been studied in detail, a project of the construction of the foundations having been drawn, dated June 1906, which was put into practice (one can still see the remains of this) before its official presentation. Thanks to a number of diverse studies, a layer of calcareous marl was detected which was considered able to support the foundations of the viaduct. In the

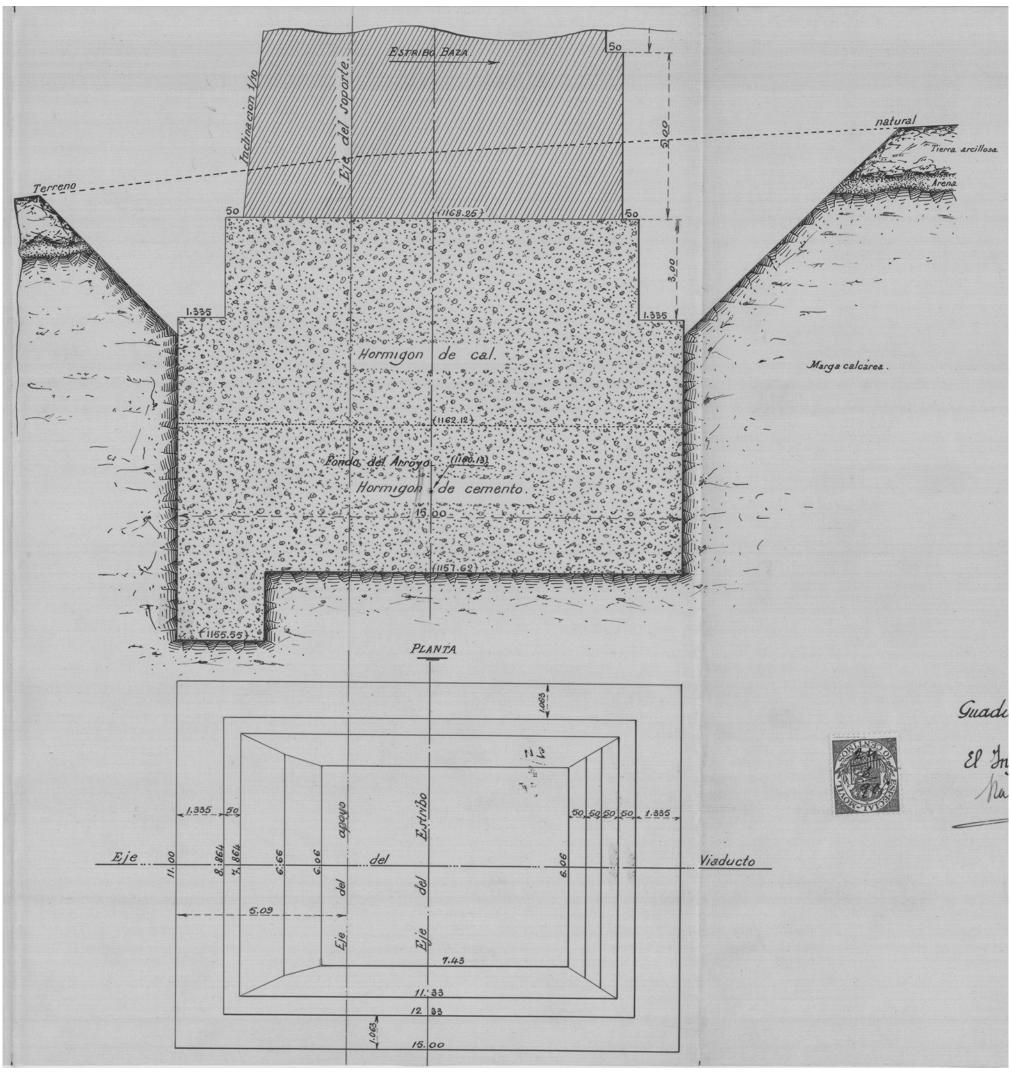

Figure 9. Foundations of the Baza support, included in the project for the Gor viaduct. 1905 Archivo General de la Administración, Spanish Ministry of Culture.

case of the *Baza* abutment, there was an excavation of 12 metres depth, resulting in a hole of 11 x 15 metres (1,980m^3). A trench was installed on the inside wall of the excavation to drain groundwater during the construction (Fig. 9).

It was filled with concrete, forming a layer 10 metres in depth, the inferior half being of hydraulic (Portland) concrete. It was calculated that these foundations would transmit a pressure of 380 kN/m^2 on the ground below, a value inferior to that considered at the time for calcareous marl.

In isolation, it was a reasonably safe solution. However, the stability of the abutment was also associated with the stability of the embankment that abutted its rear wall, whose stability was very difficult to guarantee. The loamy limestones upon which the abutment was built are susceptible to humidity such that, due to changes in their resistance, do not constitute a trustworthy base. The infiltration of water in the body of the embankment contributed to its movement, and with an immense mass of terrain pushing on its back, the abutment could not resist the force. Initially, poor construction of the base was blamed for the problem, for which a new base was ordered to be built with larger foundations. Supporting the superstructure on scaffolding, the original base was demolished (Fig. 10). The new support was built during the Winter of 1906, under strict supervision of the engineers, using carefully chosen materials and was placed 8 metres deeper than that of the original.[48]

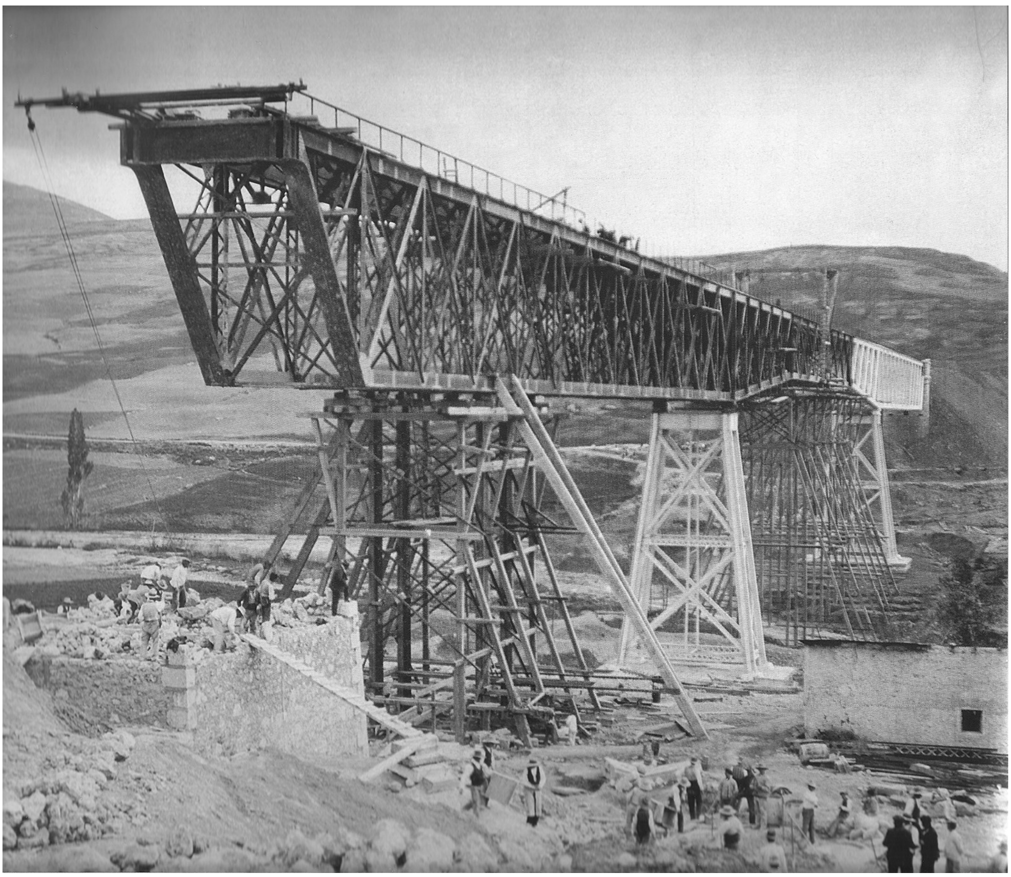

Figure 10. Works to build the new abutment, Winter 1906. Workers are demolishing the old abutment, while the viaduct is provisionally resting on trestles. Photo by Gustave Gillman, 1906. Courtesy heirs of Gustave Gillman.

At the same time, drainage ditches and pipes were installed around the embankment with the intention of ameliorating the ingress of water. Unfortunately, all of these works were unsuccessful and the embankment continued to put pressure on the abutment to the extent that it had moved longitudinally along the track 3.6m towards the pillars and water underneath caused a subsidence of 0.5 metres to date and an inclination from vertical of 0.7 and 0.25 metres. In the June of 1906, intending to resolve the situation, the company called an expert, *Stanislav Vasinsky*, the highly experienced Franco-Polish engineer who had been brought to Spain by the company Fives-Lille for the management of the construction of the outstanding viaducts of the Linares-Almería railway (completed in 1899). However, he could do nothing other than to confirm the impossibility of correcting the continuing movement of the embankment and to propose the substitution of the viaduct for a much smaller bridge upstream. A year later, the engineer *Escosura* presented the project for the relocation of the crossing.[49] Bearing in mind the experiences of the viaduct, he ensured that the supports wouldn't cause even the slightest problem. So, for the new positioning of the crossing it was important that the bridge was as low as possible and the piles be situated near the river bed. It would be situated 600 metres upstream.

At the same time, having learnt their lesson through those previous problems, the engineer suggested building a wooden bridge whose flexibility would allow it to adjust to any ground movement. Accepting the need to build this new bridge in the shortest possible time, TGR put the line into service, provisionally, using the unstable iron viaduct. Over a number of years, trains were crossing it with extreme caution, the passengers being obliged to alight and cross on foot. The *Baza* embankment never became secure, the company having to continuously repair it to prevent the loss of the abutment. A photograph taken in 1909 shows the weight on the abutment being somewhat reduced by the use of wooden beams in the form of a scaffold (Fig. 11).

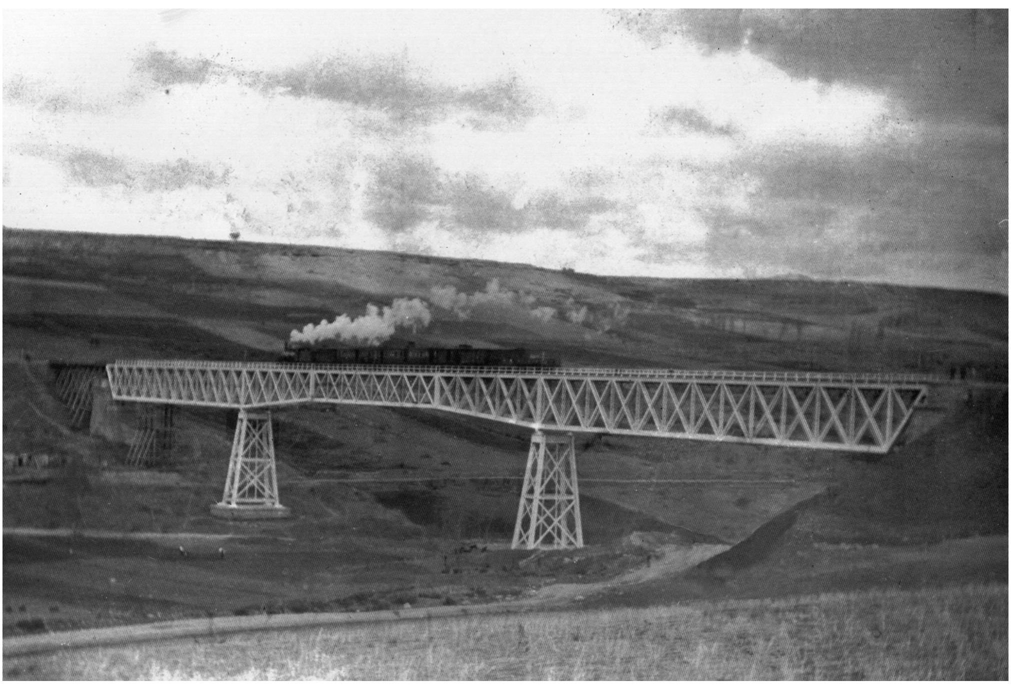

Figure 11. The Gor viaduct in 1909. The iron superstructure is supported and the terrain removed from the rear of the Baza abutment. Courtesy of Doña Encarnación López Sánchez. Asociación cultural "Amigos de Gor".

The situation was unsustainable. The administration urged TGR to execute the detour that had been projected in 1907. Even so, by December of 1912 the works were still incomplete, with an important change: in place of a wooden bridge a metal one was constructed. Its project was written by the Spanish engineer *Silvestre Fernández* in 1909. TGR was no longer willing to take any more risks and imposed the construction of an extremely conservative solution, based on a deck plate girder bridge of continous spans, supported by disproportionately large masonry piers (Fig. 12).

Figure 12. The definitive Gor bridge, 1909. Three 5,60 metre continous spans. Photograph by the authors.

In spite of this, *Vasinsky* offered to repair the viaduct, and in 1910 he presented a proposal to stabilize it by modifying its geometry[50] which he achieved by studying it in situ. Sadly, he didn't gain approval for this project. After the rejection of this last suggestion, the viaduct's future was set.

Transfer to *Dúrcal* and the second construction.

In the first decades of the Twentieth Century a network of tramways was developing in the city of *Granada*. About 1920, the very favourable growth in this infrastructure stimulated the owners to undertake a great project: a tramway which would connect the old Nazarine king's capital, *Granada*, with the nearby port of *Motríl*, its natural link to The Mediterranean Sea.[51]

This was a highly risky chance to take, for the infrastructure would have to pass through the most geologically and geotechnically complex region of the whole Iberian Peninsula. However, in two years the first sections were built, arriving at the town of *Dúrcal* in the first months of 1923. Here the line encountered its biggest obstacle, a 50 metre deep, 200 metre wide gorge.

To resolve the issue, the company *Tranvías Eléctricos de Granada* had the happy idea of buying the abandoned Gor viaduct, which would fit in its new location with minor modifications. To do this, it was necessary to reduce its span from 230 metres to 200. This was done without any major difficulty by eliminating in an orderly way some of the triangulated sections from the corbels and the central articulated span. The greatest complication would be the adaptation of the supports which had to be extended with reinforced concrete structures. The final design was completed with a stonework arch on its northern side (that which had generated all of the problems in *Gor*), through which passed all of the road traffic between *Granada* and the coast (Fig. 13).

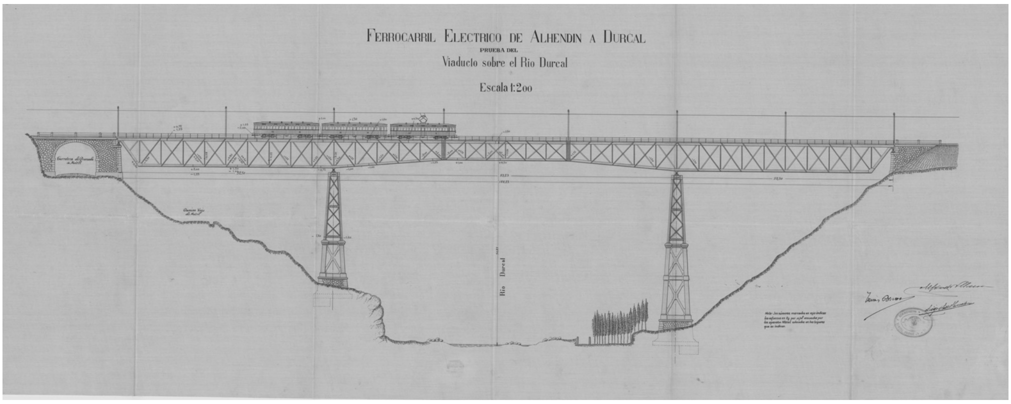

Figure 13. Definitive configuration of the Dúrcal viaduct. Archivo General de la Administración, Spanish Ministry of Culture.

For this second construction *Dortmunder Union*, a German company specializing in the construction of metal bridges, was contracted. The *Gor* viaduct was disassembled and transported via road to *Dúrcal*. Again, the procedure which is usual in metal bridge construction, was not followed. The assembly was performed from both sides simultaneously with the use of sliding cranes (Fig. 14).

Conclusions

The two great metal viaducts that the British company The GSSR needed for its railway line between *Granada* and *Murcia* (in the southeast of Spain) were projected in 1890 by the company's engineers, some British consultants and the Belgian engineering company *Lecoq* which was charged with the manufacture. These bridges had exceptional designs, unusual for Spanish bridge engineering of the time. Of these two designs, only one was finally built. In 1904 the *Río Gor* viaduct was constructed, which was originally designed and fabricated for another site (*Baúl*). It was the first and only cantilever construction in Spain. The bridge stayed unused due to the failure of one of its abutments. Over a number of years there were many attempts to solve the problem, but it was impossible. Eventually the route was modified so as to build a new, smaller, more stable bridge. The great viaduct was abandoned. Eight years later the viaduct was acquired by a tram company and transported to *Dúrcal* where it was assembled for the second time, after minor changes to the original design. One can visit the viaduct today in its second home, it being used as a pedestrian crossing (Fig. 15).

Figure 14. The second construction of the viaduct at its new site in Dúrcal (1923). Photograph taken by José Martínez Rioboo in 1925. ©Fundación Rodríguez-Acosta. Donación Martínez Sola.

Figure 15. The viaduct of Gor and Dúrcal at present. Photograph taken by the authors.

The line had two more bridges, one of which was located near to the city of Guadix called Barranco del Grao. This too was conceived at the time of The GSSR. It consisted of a simple span in Pratt configuration (40 metre length) supported by masonry arches[52]. The other was to span the 220 metre wide Rambla de Balata. No documentation regarding this bridge has been found to date. Proof of its existence is by evidence of excavations on the site where the first route would have crossed.

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