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Bridge replacement due to structural obsolescence. The case of the Ciudad Real-Badajoz railway bridges (Spain)

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ABSTRACT: The great railway bridges built in the 19th century are magnificent examples of the rise of civil engineering, and especially of the development of iron structures. Over time, however, the increase in railway rolling stock complexity and weight made some structures obsolete, and their replacement became indispensable during the 20th century. Such is the case of some bridges built in a section of the Spanish Ciudad Real-Badajoz railway line inaugurated in 1865, which crossed watercourses as important as the Guadiana River, the Aljucén River or the Gévora River. At two different times, during the 1920s and 1950s, the original iron lattice girder bridges were replaced by new concrete structures built in the same places. This study analyzes those structures, both old and new, and especially how the replacement construction was carried out without interrupting rail services. The original construction projects and the new bridges, some historic photographs of the replacement work, which include piers, formwork, arches and decks and dismantling of obsolete iron girders, are thus studied. The study provides evidence of their importance not only as territorial landmarks or major structures but also as elements with a construction history remarkable and extremely interesting in itself. Lastly, the destiny of the obsolete iron structures, sale for scrap, contributes to the discussion of the future of outdated bridges of our time.

1 INTRODUCTION

Throughout the 20th century, a diversity of technological advances took place in railroads. The engines became more powerful as the years went by and could therefore pull heavier loads; as a result, many of the bridges and overpasses became obsolete and had to be reinforced or replaced by others.

This text describes the replacement of four bridges in the railroad line between Ciudad Real and Badajoz. Several studies have approached aspects connected with this line (Blanch Sánchez 2013; Esteve García 2008; Peris Torner 2012), however, the literature contains hardly anything published on the replacement of its bridges.

The study is backed by several different documents kept in the *Archivo General de la Administración* (AGA) and in the *Archivo Histórico Ferroviario del museo del ferrocarril de Madrid* (AHF-MFM), in particular photographic reports made during construction by two photographers, Juan Salgado Lancha and Vicente Garrido Moreno, who made numerous reports on railroad construction throughout their professional careers.

2 CONTEXT

2.1 *The Ciudad Real-Badajoz Railroad*

The Ciudad Real-Badajoz Railroad was the first corridor built between Extremadura and the center of the peninsula. The construction of the line was divided into two sections. The first, which ran between Ciudad Real and Mérida, was planned in 1858 by civil engineers, Pedro Sierra and Santiago Bausá. The second, between Mérida and Badajoz, was also planned in 1858 by civil engineers, Carlos María de Castro and José Barco. Both sections were given an execution period of five years. Construction was begun in 1860, and shortly afterwards, on March 26, 1861, was legalized as the "Compañía del Ferrocarril de Ciudad Real a Badajoz", presided over by Alejandro Mon y Pidal, and directed by civil engineer, José Canalejas y Casas. The line was inaugurated by Queen Isabel II on December 11, 1866.

2.2 *The first bridges*

Some of the bridges in the project were never built: on December 25, 1860, the Guadiana River surged and flooded the valley and, as a result, in 1861, it was decided to draw up a new project for eleven of the structures located between Don Benito and Badajoz to enlarge the drainage capacity of the structures in the original project (AGA 25-07035). The author of the new designs was Manuel Peironcely, one of the most outstanding civil engineers of the 19th century and the company's technical director (Larrinaga Rodríguez 2006).

Almost all of the projected structures consisted of lattice girder sections on masonry piles. Even though the line was planned and built with a single track, it

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Table 1. Metal truss bridges designed by Peironcely.

Bridge	Length	Cost (real de vellón)
Ortiga	15.3 m + 19 m + 15.3 m = 49.6 m	687 137
Guadálmez	15.3 m + 19 m + 15.3 m = 49.6 m	687 137
Guadiana	42.6 m + 9 × 50 m + 42.6 m = 535.2 m	8 522 779
Aljucén	27 m + 7 × 32 m + 27 m = 298 m	2 678 029
Lácara (seven bridges)	2 × 10 m; 10 m; 2 × 10 m = 20 m; 4 × 10 m; 10 m; 4 × 10 m = 40 m; 10 m	744 516
Alcazaba	27 m + 32, 4 m + 27 m = 86.4 m	769 355
Guerrero	30.5 m	271 905
Aguas Blanquillas	8 m	74 785
Gévora (two bridges)	27.4 m + 32.4 m + 27.4 m = 87.2 m; 27.4 m + 3 × 32.4 m + 27.4 m = 152 m	2 420 925

was thought that future traffic might require widening to a double track, and so the abutments and piers were twice as wide as those strictly necessary for the single track.

The most prominent was the Zarza bridge over the Guadiana. Peironcely wrote that it was "The most important construction on this railroad and perhaps one of the bridges of most substance the Spanish railroads will offer." Located 14 km from Mérida, it consisted of eleven iron sections on abutments and masonry piers. Each of the end sections had a 42-m span and with the rest rising up to 50 m. The bridge was oblique, and the axes of the piers formed a 70-degree angle with the track. The total length was 565 m. This

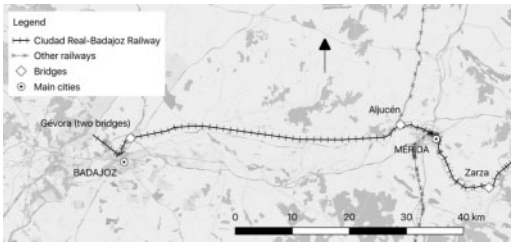

Figure 2. Emplacement of the bridges discussed. By the author.

notable structure has been described in detail several times (Anon 1865; Lavado Rodríguez 2015).

Other significant bridges were those at Aljucén and the two bridges in Gévora (Arévalo Hernández 2015; Plasencia-Lozano 2019). They were similar to the bridge over the Guadiana, although their spans were somewhat shorter: the Aljucén bridge consisted of nine arches, 27 m at each end and seven 32 m central arches.

The two bridges over the Gévora on the outskirts of Badajoz were consecutive. The smaller of the two had three arches and the larger five. The latter received the same length sections as the Aljucén bridge with both having arches 27 m long at the ends and 32.4 m in the center.

The origin of the metal structures is unknown but were probably built by *Parent, Schaken, Caillet et Cie* (Lavado Rodríguez 2015). They were delivered to Lisbon by ship and then taken by train to the construction site.

2.3 *Lifetime and end of the first bridges*

These bridges were put into service in 1863 and met their purpose efficiently for decades. On June 5, 1902, the *Instructions for drafting plans for metal bridges*

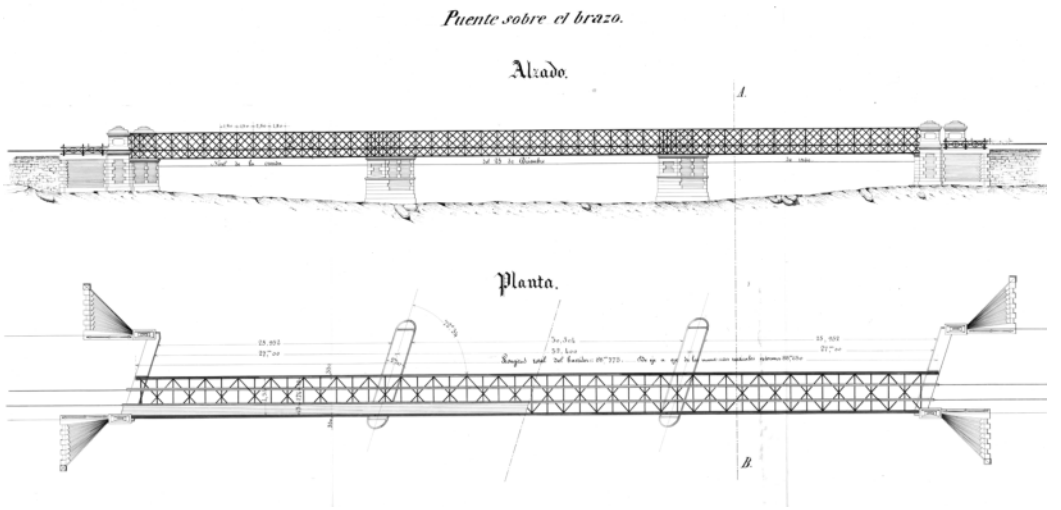

Figure 1. The first bridge on the Gévora river. Piers designed for double tracks (AGA 25-07035).

required that existing metal bridges be subjected to a load test and prior inspection. The bridges on the line were subjected to this inspection and, as a result, it was found necessary to add a series of reinforcements to several of them. Thus, from 1907 to 1909, reinforcements were added to the beam heads and lattice bars in the Zarza, Aljucén and the two Gévora bridges (AHF 0745-002).

In 1925, the new *Instruction for calculating metal sections*, among other measures, prohibited the use of iron as a structural material in bridges, and required biannual inspections of all existing bridges and load tests every ten years. The requirements were considerably stronger in this case and caused some bridges to have to be directly replaced as this was more economical. Such was the case with the Aljucén bridge and the two over the Gévora (AHF-MFM C-0750-001). That is also when the iron sections of the bridge over the Guadiana at Mérida were replaced with new metal sections similar to the previous sections in 1928 (Plasencia-Lozano 2016), or the one over the Guerrero stream, built with a Pratt truss in 1926.

Years later, in August 1956, a new *Instruction for calculating metal sections and predicting the dynamic effects of overloads in reinforced concrete* was published, which again increased the requirements for tolerable deformation under freight trains from those issued in 1925 and required the replacement or reinforcement of those sections that did not comply with this *Instruction*.

3 THE REPLACEMENTS

3.1 *Aljucén Bridge*

Aljucén Bridge did not meet the requirements of the 1925 Instruction and, therefore, its metal sections were replaced with mass-concrete arches according to a project by civil engineer, Rafael Ceballos (Ceballos Pabón 1930).

The structure was located near the Aljucén station. Past the bridge, there was a detour to the branch line to Caceres. However, as transferring that detour from the other side of the bridge to the station itself was of interest to line operations, it was decided that the new bridge should have two tracks: one going directly to Cáceres and the other to Badajoz.

The first action taken was to reinforce the pier footings at both ends as arches of various spans, and therefore with different pressures, met at them. The foundations of the abutments were also reinforced, as was Pier 7. The excavation was done manually and water was pumped out to facilitate the work.

Then the first half of the bridge on the longitudinal axis was executed making use of the existing piers (the width, as mentioned above, was dimensioned to support a double track). Half of each pier was taken apart down to the footings, although the cutwater was kept, and later rebuilt with a new geometry, making use of the existing foundation.

Arch centerings were mounted on provisional concrete supports. They consisted of a triangulated wooden structure to which braces were added, supporting a total of four metal arches, with a series of battens placed over them. A total of five sets of centerings were used for construction. To facilitate mounting, a temporary wooden catwalk was built supported by the lattice girder of the existing bridge as a sort of brace.

Once the arches were concreted, the spandrels were closed off and filled in; the exposed side was closed with ashlars from the piers that had been dismantled and the other side was closed off with a temporary stone masonry wall. After these operations, the track was laid and the first half of the bridge, now completed between both abutments, was opened to traffic. With the new track now in service, the metal bridge was dismantled using a mobile crane. The scrap was removed, and space was thus left for construction of the second half of the bridge in accordance with the same procedure.

This work sequence ensured track service continuity. We would finally note that the construction was executed by employees of the railroad company itself.

3.2 *The Gévora Bridges*

The metal sections of the Gévora I and Gévora II Bridges did not comply with the Instruction of 1925 either so it was decided to replace them with mass-concrete arches similar in length to those already in place, projected by the engineer, Rafael Ceballos (Ceballos Pabón 1931).

The construction procedure was similar to that used for the Aljucén Bridge. Likewise, the construction was also done by the company itself, which allowed them to take advantage of the previous experience acquired, and the centerings for that bridge (used for the Alcazaba Bridge as well) as their spans were very similar.

A work train with a 10-ton crane, which carried materials and auxiliary elements to and from the construction site, served for the construction work. At night, the train was kept in either the Badajoz or Talavera station, and during the day was temporarily left on the track on the bridge. As this track was still in service, a dead-end siding was laid nearby for the work train when a commercial train was passing. This dead-end siding was 600 m long and was connected to the main track at km 505.722 of the line, about 100 m from the Gévora River. The detour had a position signal and Bianchi bolt, and included Bouré locks and keys. For maneuvers, a document was drafted which included management of this siding, including the signals the switchmen should show and the sequence of telephone communications that should be made between this siding and the Badajoz Station. An operator always had to be on duty at the siding.

The timing of work on the bridge was also noteworthy: concreting and decentering took less than 48 days. When the centering was removed from an arch, a telegram was sent. For example, at 1:47 pm on November 13, 1929, the following telegram was sent from Mérida

Figure 3. Aljucén Bridge. Top: soil excavation near the abutments; dismantled pier; rebuilt pier. Middle: centering; frame in the top of the arch; spandrel made of ashlars. Bottom: a train in the first half of the bridge; crane dismantling the metal bridge; new bridge already completed. Photos by Juan Salgado Lancha (AHF-MFM MZA- 0232-IF_10-20-; MZA- 0276-IF_10-23-; MZA- 0282-IF_10-23-; MZA- 0284-IF_10-23-; MZA- 0271-IF_10-22-; MZA- 0235-IF_10-20-; MZA- 0241-IF_10-20-, MZA- 0250-IF_10-21-; MZA- 0229-IF_10-19-). The collection consists of 64 photographs taken from 29.09.1926 to 05.11.1929.

to Mr. Ceballos, Assistant Engineer for Fixed Materials: "Centering removed from Gévora Arch nine. Nothing new to report." After removal of the centering, reinforced concrete spandrel walls were built on the arches before the bridge deck was built on top. The design of the spandrels was therefore different from the Aljucén Bridge.

When the new track had been put into service, the metal structure was dismantled. Unlike the previous case, the first structure was moved sideways to temporary supports: in August and September 1929, it was dismantled and taken by train to the Seville and Villaverde Bajo to be scrapped. The metal sections replaced in the first bridge were estimated to weigh 169 tons, and in the second 294 tons, and the scrap was sold for 1.15 Pesetas per kilo.

The whole construction project was executed in 20 months at Gévora II and 14 months at Gévora I (AHF-MFM C-0751-001).

3.3 *Zarza Bridge*

The Zarza Bridge over the Guadiana River was replaced from 1954 to 1958, two years before the 1956 Instruction. The company itself may have been aware that the structure could not support modern rolling stock and decided to go ahead with its replacement before the official regulation required it. We do know, furthermore, that the bridge structure had already been reinforced in 1907 (AHF-MFM C-0742-002) to comply with the 1902 *Instruction*.

This situation shows some similarities as regards the other two: the original bridge piers were wide enough to house a deck for a double track even though only a single track was laid. Therefore, the construction procedure had points in common with those already described.

However, there were also notable differences from the bridges replaced three decades before: the new arches had a different parabola directrix, new intermediate supports were also built between those previously existing in all the bays, except at the Northern end, and the new bridge could take only a single track.

The foundation consisted of a rectangular footing. The first stage of the piers up to the arch springers was built on top in reinforced concrete. These piers were designed with a different geometry from those already there; with a pointed cutwater. In some photographs from 1954, they can be seen emerging from the waters of the Guadiana. The construction must have been interrupted for over a year as there is another photograph from May 1956 in which the bridge still looks the same.

The next stage consisted of formwork and pouring concrete for the arch springers. Formwork was produced with the wooden shuttering supported on the

Figure 4. Gévora first bridge; temporary supports for metal bridge, first bridge moved; new bridge already completed. Photos by Juan Salgado Lancha (AHF-MFM MZA- 0356-IF_10-28-; MZA- 0366-IF_10-29-; MZA-0364-IF_10-29-; MZA- 0371-IF_10-29-). The collection consists of 46 photographs taken from 20.06.1928 to 12.06.1930.

foundation and the first stage of the piers, which stood out from the upper stage. At the same time, the part of the old piers that was going to support the new deck was dismantled down to the foundation as well as half of each abutment. The ashlars in these piers were then reused to cover the new piers and the old modified ones to provide a more uniform look.

The arches were constructed using a set of centerings. These consisted of two semi arches held up by a Warren truss connected at the keystone. Braces were arranged at the base. According to photographs, there were up to four sets so the work would go faster. When the arches were finished, the spandrels, consisting of two outer walls and filling from the quarry, were completed. Last, the deck was completed with concrete slabs on which the ballast and track were laid.

The bridge was built from the two ends toward the center. Thus, in March 1958, it could be observed how on the left side it had progressed to the seventh arch and on the right four arches had been built. We think that the personnel reached the base of the foundations by crossing the Guadiana in carts pulled by donkeys. In the photographs, at least two carts can be seen, and they may possibly also have served to distribute small machinery and utensils during construction.

The new bridge was probably opened in 1959. The metal sections were removed after it was put into service.

4 CONCLUSIONS

The research above enables some conclusions to be reached.

First, this demonstrated the importance of photographs as a documentary source for ascertaining out how construction was done.

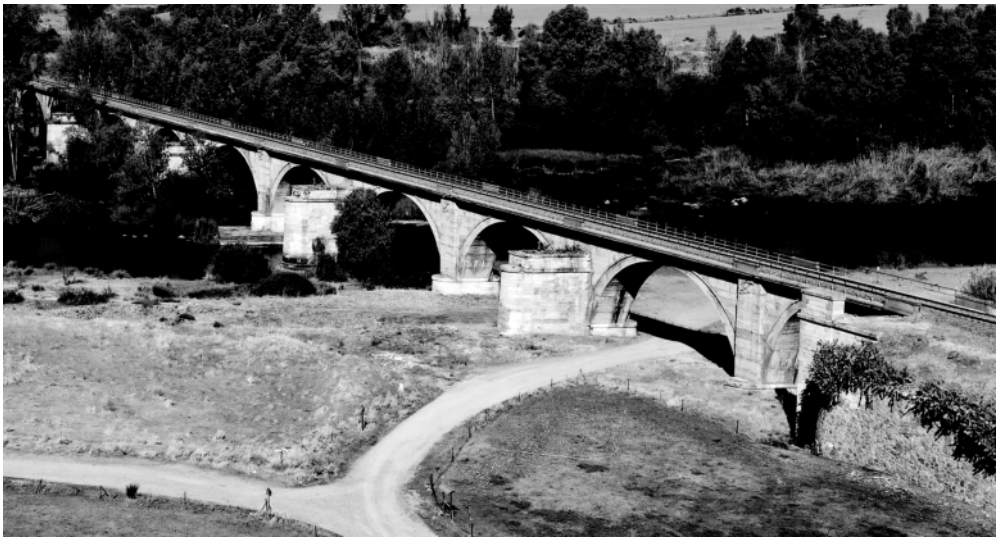

Figure 5. Section of Zarza Bridge, present state. (Photo by Pedro Plasencia-Lozano).

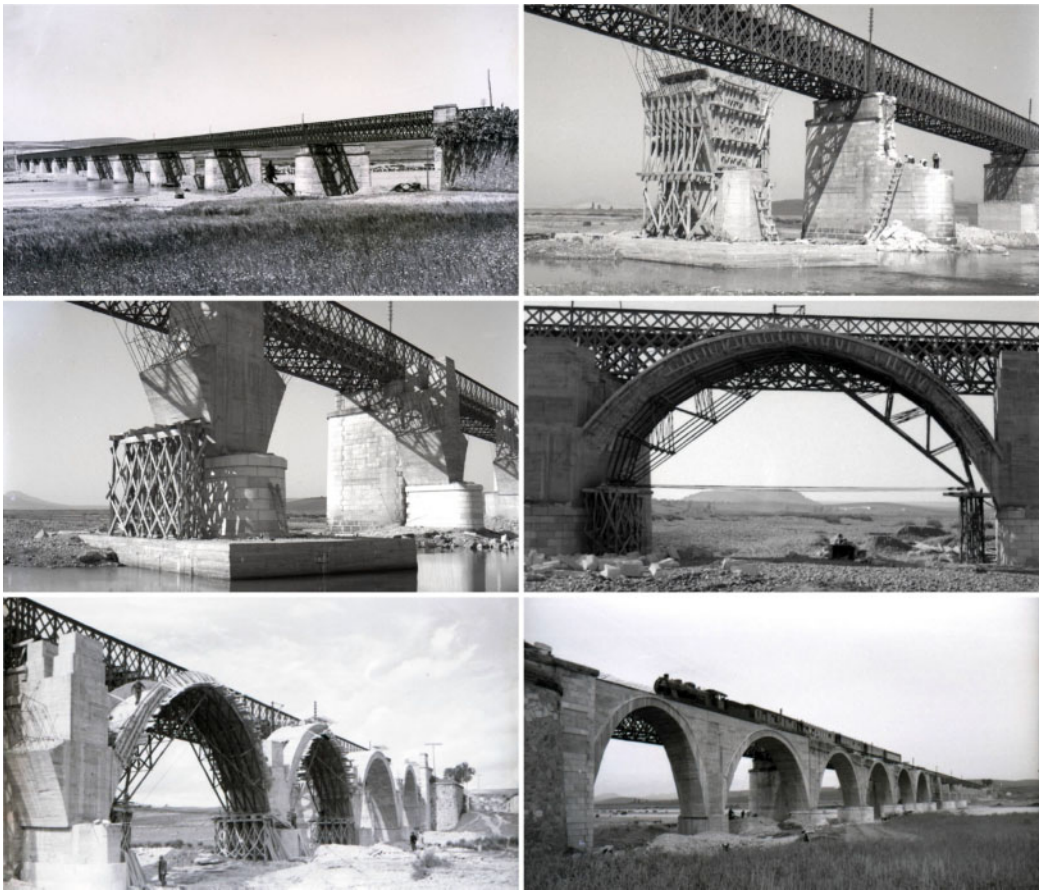

Figure 6. Zarza Bridge. Top: old bridge; execution of the new piers while former piers are being dismantled. Middle: piers already executed; centering. Bottom: groups of centerings; train on the old bridge while the new bridge is under construction. Photos by Vicente Garrido Moreno (AHF-MFM VG-IF- 2229-; VG-IF- 2244-; VG-IF- 2257-; VG-IF- 2256-; VG-IF- 2264-; VG-IF- 2288-). The collection consists of 68 photographs taken from 1954 to 28.03.1958.

Furthermore, the study of three cases enabled similarities and differences to be found. The importance of repeating the structures in a linear infrastructure over the Aljucén and Gévora to save costs was confirmed. However, this repetitiveness of spans did not impede design of distinctive elements in the structures, such as the spandrel.

The 1862 planning of wide piers, able to support two tracks, proved an excellent idea as, although they had no immediate use, they were useful years later when it became necessary to replace the decks. The 1920 bridges were constructed with a view to the future (the Gévora bridges currently have a double-width but only one track); however, by 1954, that future vision had been lost.

Finally, the demolition of the metal structures is to be regretted as their current value as heritage would certainly exceed the price of scrap at the time. Fortunately, current heritage regulations would not allow the same thing to happen again and would require the restoration of such historic structures.

ACKNOWLEDGEMENTS

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REFERENCES

Anon 1865. Ferrocarril de Ciudad Real a Badajoz. *Revista de Obras Públicas* 13(1): 161–165.

Arévalo Hernández, E. M. 2015. Puente metálico del Gévora. Cuestiones resueltas. *Las carreteras de Extremadura*. https://lascarreterasdeextremadura.blogspot.com/2015/12/

puente-metalico-del-gevora-cuestiones.html (Accessed 10 May 2018).
Blanch Sánchez, A. 2013. Los orígenes del ferrocarril en Extremadura. In *150 años de tren en Extremadura*. Badajoz: Diputación de Badajoz: 40–43.
Ceballos Pabón, R. 1930. Nuevo puente sobre el río Aljucén. *Revista de Obras Públicas* 78(1): 69–74.
Ceballos Pabón, R. 1931. Tres nuevos puentes en la línea de Madrid a Badajoz. *Revista de Obras Públicas* 79(1): 504–507.
Esteve García, J. P. 2008. *El ferrocarril Madrid-Ciudad Real-Badajoz. Historia del primer acceso ferroviario a Portugal*. Mollet del Vallès: Luis Prieto.
Larrinaga Rodríguez, C. 2006. Aproximación biográfica al Ingeniero de Caminos del siglo XIX Manuel Peironcely. *Revista de Obras Públicas* 3468: 49–56.
Lavado Rodríguez, F. 2015. El puente metálico de La Zarza (1865-2015): 150 años de historia. *Diario Hoy* (April).
Peris Torner, J. 2012. Ciudad Real á Badajoz (y Almorchón a las minas de Carbón de Bélmez). *Spanish Railways*. https://www.spanishrailway.com/ciudad-real-a-badajoz-y-almorchon-a-las-minas-de-carbon-de-belmez/ (Accessed 1 September 2020).
Plasencia-Lozano, P. 2016. An analysis of Merida's iron railway bridge: an example of a Linville truss bridge in Spain. *Construction history* 31(1): 161–172.
Plasencia-Lozano, P. 2019. El conjunto de puentes del río Gévora en Badajoz, paisaje cultural de la ingeniería. In *Tercer Congreso Internacional Hispanoamericano de Historia de la construcción*. Madrid: Instituto Juan de Herrera: 863–874.