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A methodology for the analysis of historical bridges, applied to the Jaraicejo Bridge. History and evolution of construction phases

Metodología para el análisis de puentes históricos aplicada al puente de Jaraicejo. Historia y evolución de fases constructivas

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ABSTRACT

This paper proposes a method for the analyses of historical bridges. This method is developed on the study of the Jaraicejo Bridge, located on the Almonte River in the province of Cáceres, Spain. The most important studies of the bridge to this date have been supported mainly by the historical documents; in this text, however, a full analysis of the structure is performed, developing a new approach that brings together fieldwork, archival work and office work, with the analysis stemming from contrasting data for interpretation, and leading to new conclusions on the construction phases, especially the final stage. The research method could fall within the methods known as archaeology of architecture.

Keywords: Extremadura; heritage; engineering; 18th century; archaeology of architecture.

RESUMEN

El texto propone un método para el análisis de puentes históricos. Esta metodología se aplica para estudiar el Puente de Jaraicejo, situado en el río Almonte en la provincia de Cáceres, España. Los estudios previos sobre la estructura se han apoyado en la documentación histórica. Sin embargo, en este texto se realiza un análisis global que parte de las fuentes históricas originales, y continúa con un trabajo de campo que incluye un análisis visual y un levantamiento topográfico. La interpretación de los datos recogidos permite llegar a nuevas conclusiones acerca de la evolución histórica del puente. La investigación realizada puede ser incluida en los métodos de la arqueología de la arquitectura.

Palabras clave: *Extremadura; patrimonio; ingeniería; siglo XVIII; arqueología de la arquitectura.*

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1. INTRODUCTION

The Jaraicejo Bridge (Figure 1) is one of the most important historical bridges erected in Spain. The most important studies of the bridge to this date have been supported mainly by the historical documents available in archives; in this text, however, we perform a full analysis of the structure, developing a new methodology that brings together fieldwork, archival work and office work, with the analysis stemming from contrasting data for interpretation.

2. METHODOLOGY

We developed the following methodology:

1. Visual analysis and proposing questions.
2. Analysis of historical sources and documents.
3. Analysis of previous research on the bridge.
4. Topographical survey of the bridge.
5. Analysis of the data collected in the field and formulation of hypotheses on the different construction phases.
6. Conclusions.

This method could fall within the methods known as archaeology of architecture, applied both to buildings and to building typologies (1); however, bridges have some particular characteristics that demand a specific approach.

There are other possible historical structure research methods with non-destructive techniques that are complementary to the one developed here: georadars, infrared thermography, sonic methods, conductivity measurements acoustic emission (2), laser scanning (3) or photogrammetric rectification (4), or structural analyses based on finite elements (5), (6), (7). The use of these methods cannot omit two fundamental matters: historical sources and visual analysis. In addition, they may be impractical in research environments that do not have the necessary devices.

3. VISUAL ANALYSIS

Bridges are located in a particularly aggressive natural environment, since rivers in general have flow patterns with strong periodic surges that may cause partial destruction of the structure. When an accident or surge caused the structural collapse of one or several vaults, it was customary to proceed to the reconstruction of the bridge if this was possible, additionally improving the drainage capacity of the affected spans (8). This historical process of successive reparation using the same type of material and the same type of arches makes it difficult to clearly establish the period of a bridge's construction (9), or that of its different parts, and associations of a particular aesthetic type or concrete dimensions with a particular historical period cannot be guaranteed, not even for the Roman period (10).

Furthermore, experience dictates that, since Roman times, newly planned bridges tend to present a sole design for all their elements, save for exceptional cases, caused by a strong asymmetry of a waterway or the existence of support points along the riverbed.

These two conditions will allow for easy identification of different construction moments based on the visual analysis of the bridge: the appearance of dissimilar elements, whether typological, of material or of colour, are clear signs of reconstructions or modifications. Additionally, works meant to increase the number of spans or increase the width of the existing spans can be considered construction events undertaken after the building of the original bridge.

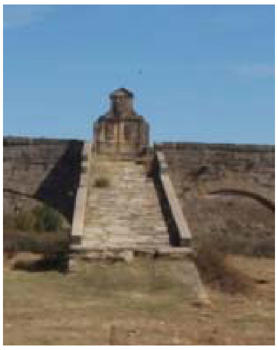
Regarding the Jaraicejo Bridge, the visual analysis of the structure (Table 1) allows us to identify the following elements:

- Nine arches. Two of them are similar, one is segmental and six are almost identical.
- Several types of breakwater.
- Arches with one order and arches with two orders.
- Asymmetrical.
- It includes a ramp between two of the arches.
- Ornamental elements: an asymmetric niche and a set of escutcheons.

The visual analysis (Table 1) shows the existence of two very different construction phases. The arches and breakwaters to the north are different from those on the south side, and the three-centred arch is a joining element between both groups of vaults. It is more complex to determine which part was

Figure 1. Photograph of the Bridge.

Table 1. Summary of Visual Analysis.

Arches	 Two arches, north side, semi-circular and with two orders	 Transition arch, three-centred and one order	 Six arches, south side, semi-circular and one order	
Breakwaters	 North side breakwater, upriver	 North side breakwater, downriver	 South side breakwater, upriver	 South side breakwater, downriver
Others	 Ramp	 Niche	 Niche	 Asymmetry

built before the other, how the original bridge might have looked and how the different construction phases that have resulted in the current bridge could have developed.

If we examine the colouring of the ashlars of the bridge (Figure 2), it seems as though there is a difference in the hue between the first two arches and the third: the first two arches and the tympanum on the first pier have a yellowish colour, while the third and the parapet present a more greyish colouring; in addition, there is an ashlar that projects from the intrados in the third arch, perhaps evidence of the existence of a former arch that took off from this point. Finally, a breaking line in the second breakwater can be appreciated.

Regarding the colouring and typology of the joints between ashlars, it is hard to differentiate some areas from others.

4. HISTORICAL SOURCES

The sources that we currently have to learn about the history of the Jaraicejo Bridge's construction go back to 1579, the year of the date on the manuscript by Correas Roldán, schoolmaster of the Plasencia Cathedral, which is currently kept at the Chapterhouse Archives (1579). This is the oldest and most serious work on Plasencia and its bishopric, based on the documents, both civil and ecclesiastical, that Correas Roldán was able to consult (11). Along the same lines we find the manuscript that Campomanes wrote about his journey to Extremadura around 1778, which is currently kept in the Biblioteca Nacional de España. The importance of this work lies in the fact that it collects data from sources that have not made it to us, as is the case of practically all the notarial protocols of Jaraicejo (12).

Other reliable sources are the well-known work (1829) by Spanish writer and politician Eugenio Llaguno y Amirola, *Noticias de Los arquitectos y arquitectura de España desde su restauración* (13), as well as the important work by the Cantor of the Plasencia Cathedral, José Benavides Checa (14).

As an aid to our research, we have also consulted the Cadastre de Ensenada, available in the Archivo General de Simancas

Figure 2. (Up) North Half of the Bridge, (down left) view of third arch and second breakwater with a break line, and (down right) detail of the Springer of the Third Arch.

(15), and the works of Tomás López (16) and Pascual Madoz (17), all of which provide interesting information about the state of the bridge, or partial descriptions of the same, at the moment they were carried out.

5. HISTORICAL DOCUMENTS

The first bibliographical reference on the construction of the bridge dates from the 16th century, and corresponds to the schoolmaster from Plasencia, Juan Correas Roldán. In his 1579 manuscript, he points out that construction began at the request of the Bishop, Juan de Carvajal (1446-1469), the most illustrious of the prelates that have occupied the diocese of Plasencia, and a renowned builder: he is credited for the well-known Cardinal Bridge over the Tagus, as well as some important interventions on the Old Plasencia Cathedral (18).

For the construction of the structure in question, Juan de Carvajal sought the services of the master quarrier of Plasencia, Pedro González, who was also in charge of the aforementioned Cardinal Bridge (19). Llaguno y Amirola places the year 1442 as the construction date for both structures (20), so we must deduce that the Jaraicejo Bridge must have been built in the mid-fifteenth century. Its conclusion took place slightly before the year 1462, date on which it is already mentioned in a Papal document, in which Pope Pius II forbids the imposition of any type of bridge toll (21). We have accounts of an important restoration it was submitted to due to imperfections caused by road traffic, documented at the end of the 15th century, at which time repairs were made at the request of the Honourable Council of the Mesta (22).

A second construction phase of the bridge is mentioned by Campomanes in the manuscript he signed in Madrid on May 4, 1778, to put his trip to Extremadura on the record, where he paid special attention to the work he considered necessary to undertake for repairing roads or building new stretches, considering of his nomination as director general of the Postal Service in 1775.

According to the letter that was sent him by Lucas de Salas and from the documents then filed in the notarial protocols of the town, practically lost to us this day, the second documented construction phase on the bridge was undertaken between 1635 and 1639 "at the expense of the Province of Extremadura", using for this purpose ashlar stone from the estate of Torreaguda, in the municipal area of Trujillo (23). The craftsman responsible for the work was, according to geographer

Tomás López, master quarrier Lucas González de la Gándara. The work was sponsored, according to Vela Santamaría, by the towns located at a distance of 20 leagues in all directions; a total cost of 26,300 maravedis, covered by 293 local townships and almost 20,000 inhabitants, in 1636 (24).

In the Cadastre of Ensenada we have a brief description of the bridge, dated April 9, 1753: "and thus there is an ashlar bridge of nine arches over the Del Monte River between the end of this town and the city of Truxillo without the carters paying anything for their crossing (...)" (25); the toll exemption is also reflected at the end of the 18th century, in the examination of the Royal Audience of Extremadura, where only the Barquilla Bridge is mentioned, at a distance of two leagues from the town, because it charged a toll (26).

In the digital service of the National Cartography Library of France, there is a plan dated 1662 and signed by Portuguese cartographer Pedro Teixeira that shows the existence of a bridge next to *Serezejo* (Jaraicejo) (27): this confirm the important that the structure must have had on the road Madrid-Lisbon. At the Simancas General Archives, there is also a very interesting plan with the profiles of the road that Dionisio Sánchez planned to make along the downwards and upwards slopes of the Almonte River in 1764 (28). Without a doubt, this work was due to the poor conditions of the road in the early 1760s, year in which Italian writer Baretti mentioned the terrible condition of this road leading up to the bridge (29).

From the second half of the 1770s, we have a very interesting description included by Campomanes in his manuscript. In his writings, Campomanes describes the bridge the following way:

> "The Bridge is made of stone with ten arches that can be seen coming from either way, because I passed it in the morning from both directions, and it divides the jurisdictions of Jaraicejo and Truxillo. At the entrance, on the right, on the parapet, we find the arms of the Bishop of Plasencia and Lord of Jaraicejo: at the exit of the same bridge we see the arms of the city of Truxillo. An inscription reads thus: 'Ruling his Catholic majesty Philip IV great King of Spain in the year seventeen hundred and thirty-nine'" (30).

In January of 1797, and for the first time in the whole historical series we have described (Table 2), English traveller Robert Southey describes the bridge in a very similar way to how it is preserved today. He mentions the existence of nine arches and then a buttress that allows access to the bridge and forms a road to a small island in the middle of the river (31).

Similarly, in 1847, Pascual Madoz mentions the existence of the aforementioned ramp or rampant. Considering the argument that Madoz makes to describe the works undertaken that, in that time, by the Bishop Don José González Laso (1766-1803), it is possible to attribute the episcopal arms that were then, according to Madoz, on the main arch of the bridge to this dignitary and, thus, adjudicate the construction of the aforementioned ramp to González Laso. Madoz's description, though sparing, is very revealing: "touching the boundary on the north the Tagus River, and on the south the Almonte, for the space of a league and a half, with a good bridge of 9 arches and 76 yards in length, all of ashlar, with a magnificent rampant that, giving the bridge strength, serves as a crossing for transiting cattle and sheep. On the main arch, one can see the episcopal mitre and arms carved, which show that it has been paid for by the most illustrious Bishop, Lord of the town" (32).

6. PRIOR RESEARCH ON THE BRIDGE

Currently, there is no monograph dedicated exclusively to the study of the construction stages of this bridge over the Almonte. However, we must mention a series of previous studies that have analysed it. We can highlight the research done by Hernández Fernández and Hernández Alonso in their book dedicated to the *Puentes de Extremadura* (33), along with the study by Lozano Bartolozzi and Méndez Hernán (34). Regarding the latter author, we must also mention the work where he studied the aforementioned plan by Dionisio Sánchez (35).

7. DATA COLLECTION IN THE FIELD

The field data collection was performed using classical topography with Topcon 7503 Total Station and Topcon miniprism, starting from bases with relative coordinates. For the parts of the bridge where it was not possible to take a survey using the prism, we used measurements without prism in normal mode (1.5 m – 250 m). In total, we obtained 461

Table 2. Information Outline, Based on the Sources that provide it.

Source	Year	No. of Arches	Length	Existence of Ramp	Others
Papal Document	1462	-	-	-	First mention of the bridge.
Juan Correas Roldán Manuscript	1579	-	-	-	The structure's patron is Juan de Carvajal, and the author is Pedro González.
Catastro of Ensenada	1753	9	-	-	
Dionisio Sánchez Aguilera Plan	1764	-	~96 m	No	First reliable representation of the bridge. It is a plan.
Campomanes Manuscript	1778	10	-	-	Reveals the existence of the arms of the Bishop of Plasencia and the city of Trujillo. It also mentions an inscription. It indicates the existence of an important repair between 1635 and 1639.
Robert Southey	1797	9	-	Yes	Mentions the bridge for the first time as we recognise it today.
Tomás López	1798				Establishes the construction year between 1634 and 1637. The author of the bridge is Lucas González de la Gándara.
Pascual Madoz	1847	9	76 yards (64-69 m)	Yes	Indicates that the bridge displays the arms of José González Laso Santos de San Pedro, Bishop of Plasencia between 1766 and 1803.

points; we also took photographs of the bridge to insert them in the survey, in order to detail particular elements and to differentiate the different types of stone.

The data processing in the office and the creation of the plans was done with NDTv4 and CAD software.

8. DISCUSSION OF INFORMATION AND PROPOSAL OF HYPOTHESIS

The information from historical sources is confusing because there are discrepancies even in matters as evident as the number of arches, the length or the ramp.

8.1. The Dilemma of the Bridge Built in 1640

The first mentions of the bridge date back to the 15th century. However, there are also mentions of the building of the bridge by Philip IV in the 1640s. Two possibilities, thus, come to mind:

1. The bridge was built in the 15th century and then restored in the 1640s. The two sections of the bridge that we currently see date from both these years: one half is what remains of the 15th century bridge, and the other was built in 1640.
2. There was a bridge built in the 15th century at that location. That bridge was destroyed and a whole new bridge was built in 1640 on the same site. The new bridge was built completely from one design, and the observed differences between the north half and the south half are due to a restoration that had to have been done after 1640.

We believe that the second theory carries more weight than the first. The sources that mention the construction of the bridge in the 1640s don't speak of restoration or remodelling, but of "construction." Historian Pablo Alzola also writes that the "Garaicejo" Bridge was erected between the years of 1630 and 1640. Alzola does mention the restoration of other bridges during the same period, such as the Salamanca Bridge (36). On the other hand, Madoz mentions the existence of the coat of arms of a bishop who ruled Plasencia between 1766 and 1803; it can be deduced that the bridge was subjected to some important restoration work during that period, to justify the inclusion of an escutcheon.

Therefore, one part of the bridge that we can see today originated in the 1640s; the rest of the bridge is due to a restoration after 1640, possibly between 1766 and 1803.

8.2. Dionisio Sánchez's Plan

Dionisio Sánchez's plan (Figure 3) is the first graphic representation of the bridge that we have. This plan is part of a project for a road going down from and up to the bridge; therefore, the bridge that is represented therein already existed at that time.

The plan must be considered very exact, as the letter accompanying it indicates that everything has been undertaken with "delicacy, clarity, intelligence and zeal". Its legend explains each part of the road in detail, and includes a series of cross-section profiles of the road and the bridge itself.

The most interesting element of the plan is the non-existence of the ramp towards the middle of the bridge platform (Figure 4). However, the southern rampart was significantly longer and had two small access points to the riverbank. The legend on the plan itself indicated the existence of "exits on one and the other part (...) for free transit of the royal bridleway when they ford the river". Regarding the width of this rampart, it mentions that the road leading to the bridge had a width of 5 toises, about 8.4 m.

According to Sánchez, the width of the bridge was "13 feet in amplitude", and proposed to widen it "to 15, so that carriages can come and go without getting in each other's way". Since a Castilian foot equals 28 cm, Sánchez suggested adding 56 cm to the width. This modification would have been done by opening the parapets.

If we compare cross section "21-22" contained in the Sánchez's plan with the graphic scale of the plan itself, we can confirm the drawing's high precision, since in fact, the width of the vault and the platform is 2.5 toises, a measurement equal to 15 feet, or 4.2 m (Figure 5, up). The current width of the platform, measured with modern topography, is 4.24 m; this datum proves that the amplification was undertaken, and also that Sánchez's plan matches reality.

Using the plan, we can also figure out the length of the platform. It is true that there is no scale on the plan, since the graphic scale used only refers to the cross-section profiles. In addition, there is no indication, anywhere, of the number of arches that make up the bridge. However, there are two elements whose measurements we know: the width of the platform and the width of the rampart. If we compare these two known measurements and the length of the bridge (Figure 5, down), we can deduce that the latter measurement is 93.66 m. We must highlight the consistency of all the dimensions in the plan, since the result, 93.66 m, was obtained comparing two different measurements. The current bridge, from the arch edge to arch edge, measures 111.76 m.

Thus, the bridge portrayed in Sánchez's plan, from 1764, has at least four significant differences with the current bridge:

- It does not include any type of ramp in the centre.
- It includes a series of access points in the ramparts, which do not currently exist.
- The length of the bridge is 93.66 m, compared to the current 111.76 m.
- The junction with the road is through a right-handed curve. However, the remains of the road leading to the bridge on the south side trace a left-handed curve.

8.3. The Campomanes Datum

The Campomanes manuscript mentions the existence of 10 arches on the bridge in 1778. However, a document from 1753 and one from 1797 both state that there are only 9 arches. This inconsistency can have different explanations:

- A writing error by Campomanes himself, who could have made a mistake at some point when transcribing the copious notes he took during his journey.
- The existence of a span with scant clearing in a rampart. Campomanes could have interpreted this span as another arch, while other authors could have seen it as a spillway.
- The existence of a "changing" arch: an arch that was open at some time and was closed at a later date.
- The existence of different construction phases.
- The superposition of two of the previous options.

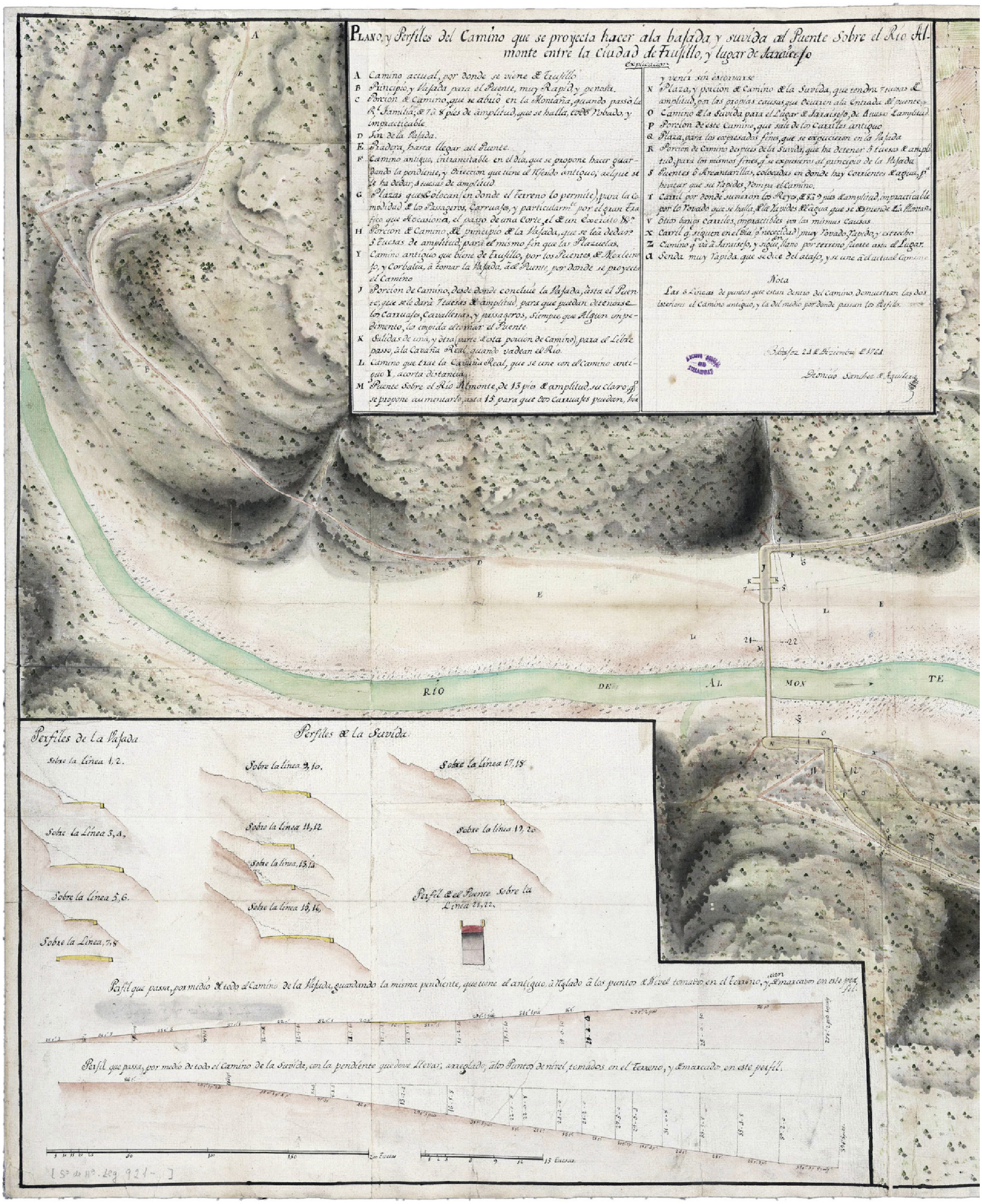


Figure 3. Fragment of Sánchez's Plan.

8.4. First Hypothesis on the Bridge's Historical Evolution

Dionisio Sánchez's plan contains geometric data on the structure that existed around 1764, and it also reflects the non-existence of a ramp in the centre. Using this information, we can formulate a first hypothesis explaining the historical evolution of the Jaraicejo Bridge.

The original bridge, built in 1640, was made up of a succession of similar arches to the two semi-circular arches on the right side (Figure 6.a). After 1764, but before Campomanes

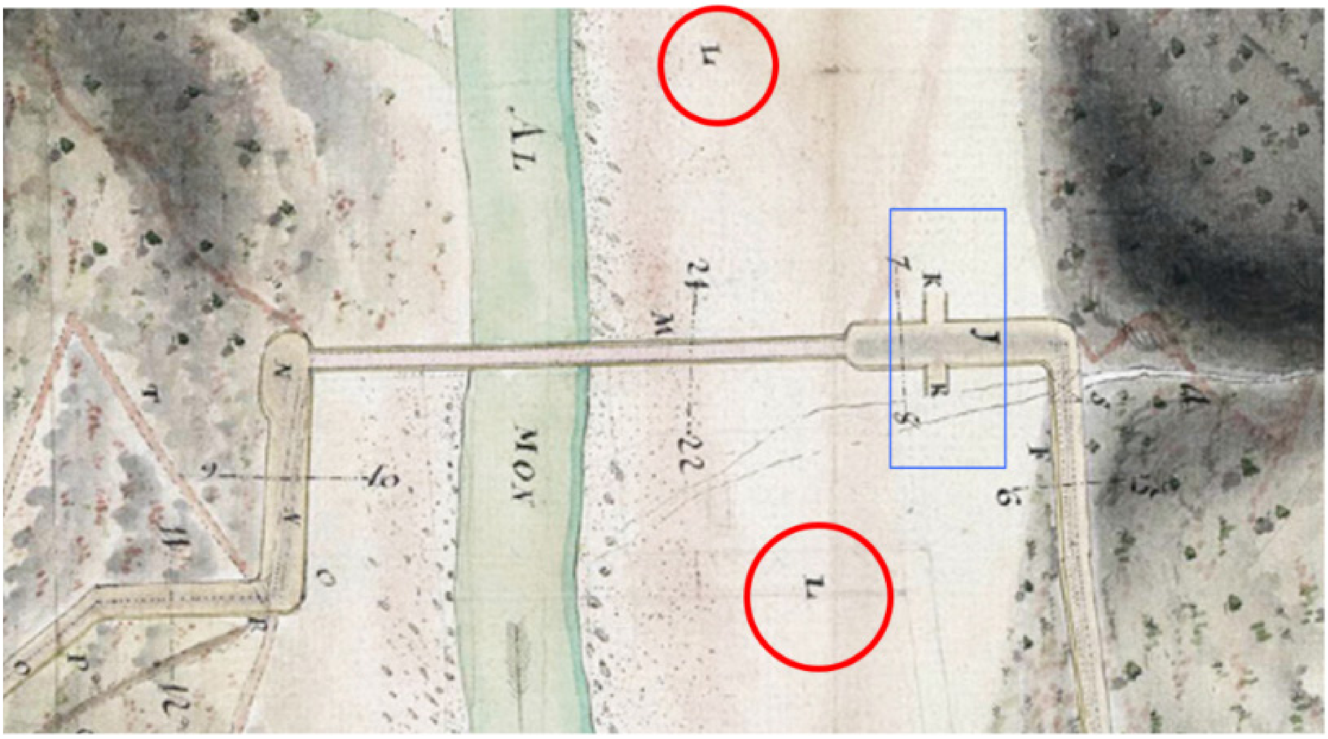


Figure 4. Letter K represents access points. Letter J is the road leading to the bridge. Letter L represents the Royal Bridleway.

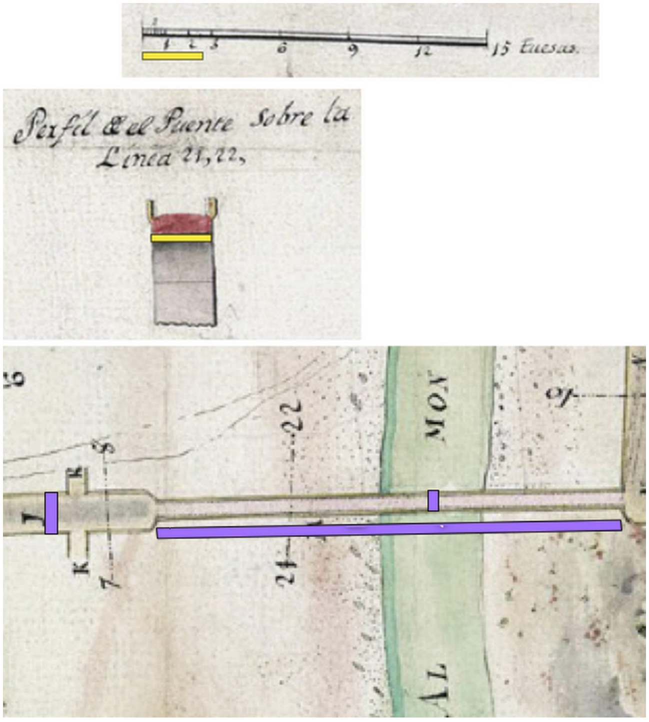


Figure 5. (Up) Comparison Between the Section of the Bridge Named "21-22" and the Graphic Scale Accompanying the Profiles. (Down) Graphic Measurements of Sánchez's Plan.

travelled there in 1778, there was a surge that ruined part of the bridge, leaving only the two right arches standing (Figure 6.b).

In order to avoid future problems with the bridge, its reconstruction included a series of decisions that contributed to making it more stable and robust.

Thus, they decided to widen the span of arch 3, the one most exposed to surges. The new arch also needed to maintain the same rise, to guarantee the maintenance of the same gradient of the platform. This led to the decision to build a three-centred arch. If they had decided to build a semi-circular arch larger than the ruined one, the height of the span would also have increased, leading to the modification of the gradient.

At the same time, they decided to increase the number of arches to increase the hydraulic capacity. The amplification was done to the south half of the bridge, since the south rampart was noticeably long and allowed for reconversion into a set of arches (Figure 6.c).

But there was a problem with expanding the bridge to the south: as we've seen in Sánchez's plan, this rampart had an access point to the Royal Bridleway that runs next to the bank of the Almonte River. Converting this rampart into a set of arches meant that this access point had to be placed elsewhere, and the decision was made to place this access to the bridleway on pier 3 of the bridge, which had to be rebuilt. This solution can be considered ingenious: not only was there a place to put a ramp, but this ramp would also have a structural function, serving as a resistant support for the bridge in the case of any future surge.

Finally, the ornamental elements that could be recovered from the collapsed bridge were used during the reconstruction. The niche and other details we find, and that are mentioned in the construction of the bridge by Philip IV, must have been located somewhere else. Perhaps the surge affected the niche or the escutcheons; that would explain the fact that the preserved remains of the niche are not symmetrical, and could even be part of a larger ensemble. It would also explain the significant colour differences that exist among the ashlars that comprise the escutcheon set, as if this set had been restored using original and adapted pieces.

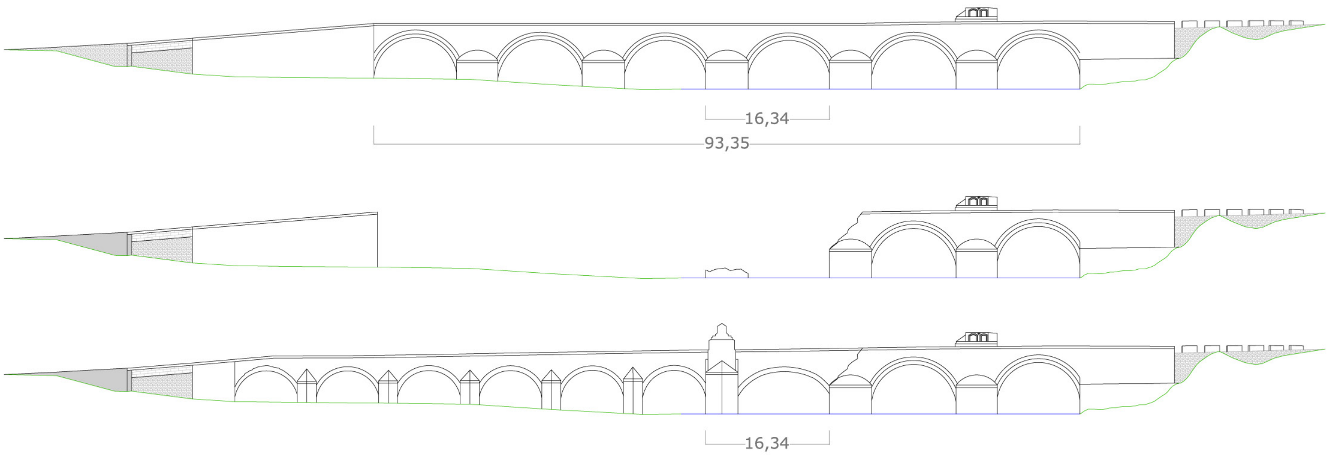


Figure 6. (a) The Original Bridge, with Six Arches; (b) State of the Bridge after the Surge; (c) Current State of the Bridge.

In order to analyse the validity of this hypothesis, we have drawn the reconstruction of the original bridge, the collapsed bridge after the surge, and the re-built bridge (Figure 6). The drawing of the reconstruction has been created following these steps:

- The two north arches are measured, along with the two immediate piers.
- The hypothesis that the bridge originally had only one type of arch and pier is formulated.
- The hypothesis that the south face of the original pier 3 coincides with the south face of the current pier 3 is also formulated. This hypothesis considers that the foundations of the old pier 3 must have been used to rebuild the new one.
- We assume that pier 3 must have measured the same as pier 2.
- We assume that the original bridge was symmetrical.
- The measurements adopted are reflected in the attachment, and prolonging the gradient of the current bridge over the north side arches, we have drawed the bridge in its original state (Figure 6.a). Using this drawing, we can draw the moment at which the bridge was partially destroyed by the surge, as well as its reconstruction, which has remained to this day.

The possibility that the different historical phases of the bridge coincide with the hypothesis described above has several solid arguments in its favour. Firstly, the six-span bridge has a length of 93,35 m, making it very close to the 93.66 m on Sánchez's plan. Additionally, it explains the appearance of a ramp in the middle of the bridge. Lastly, this sequence of events fits the totality of the information found in the historical sources, except for one, which is described below.

On the other hand, the colouring of the ashlars mentioned in the Visual Analysis section (Figure 2) coincides with the phase represented in Figure 6.b; the projecting ashlar in the intrados of the second pile, also mentioned, would coincide with the springer for the third semi-circular arch of the bridge described in Figure 6.a, located below the springer of the current three-centred arch; the same thing could be written about the break line already described on breakwater number two.

The main weak point of this theory lies precisely in that it does not fit the information contained in the Cadastre de Ensenada, which mentions the existence of 9 arches in 1753, 8 years before Sánchez's plan.

Another weak point is that the south arches show greater quality of craftsmanship than the north arches, and in general, restorations tend to be of lower quality. The high aesthetic quality of the new arches demonstrates that there must have been sufficient funds to undertake the work. In this case, we can additionally ask ourselves: why weren't all the new arches made with greater size? If the purpose was to improve the structure so it could withstand future surges, the logical course of action would have been to not only build more arches, but to make them more spacious than the existent arches.

However, it is convenient to remember that the information contained in the Cadastre de Ensenada does not come from the Marquis' own observations, but from data collected by third parties. In this sense, these documents occasionally have significant errors; without going any further, we can mention that the measurement indicated by Madoz in 1847 for the bridge is 76 yards, or 64 meters in length, a wrong measurement.

8.5. Second Hypothesis on the Bridge's Historical Evolution

The previous section is proof that there are two pieces of information that are difficult to fit together: the data from the 1764 plan, which define a bridge measuring 93.77 m, and the description of Ensenada in 1753, which mentions the existence of 9 arches. If we consider both data valid, we can formulate an alternate hypothesis. We will rule out the possibility of Sánchez reproducing the bridge erroneously, since the survey he performed was done with very precise instruments, as can be confirmed by the nearly exact match between the width of the bridge measured for this study and the width he drew.

This second hypothesis assumes that the bridge described by Ensenada, of 9 arches, is the same that Sánchez later reproduced. We rule out, then, the possibility that the bridge mentioned by Ensenada is different from the one drawn by Sánchez, since it would be exceedingly rare to have two reconstructions in such a short period of time: one between Ensenada and Sánchez and another between Sánchez and the creation of the ramp, which we know existed by 1797.

If we analyse the geometry of the existing arches and piers on the south side, we can see that the measurements are around

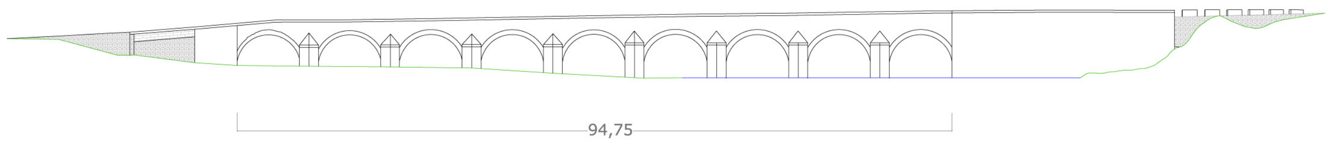


Figure 7. Drawing of a possible 9-Arch Bridge, "South" Type Model.

8.30 m for arches and 2.52 m for piers. A nine-vault bridge built using this type of arches would have a length of almost 95 m.

If we assume that the six arches of this type that currently exist date from that period, the original bridge must have looked similar to Figure 7, which presents a length of 94.75 m. However, there is a series of circumstances that contradict this possibility. In fact, the lowest-level area in the riverbed would have been occupied by the north rampart, and not by arches. Additionally, Sánchez described a very long south rampart and a very short north rampart. Thus, this configuration makes little sense.

Nevertheless, it could be that some of the current arches on the southern end were added later. The original bridge could have been the one described in Figure 8.a, made up of 9 vaults of the south model and a long southern rampart that included the access points to the Royal Bridleway.

A surge that took place before 1797 (date at which we have evidence of the existence of a ramp) destroyed the five arches located in the lowest part of the valley. The reconstruction that was undertaken consisted of substituting the five collapsed arches with three new arches with greater span and more robust piers. Additionally, another two arches were added on the southern end, imitating the model of the four remaining arches, and thus shortening the rampart on that side and eliminating the possibility of accessing the Bridleway from there. Just as we described in the previous hypothesis, the solution was to create the ramp attached to the theoretically weakest pier in the structure, seeking to reinforce it from a structural point of view.

The strongest argument for this possible historical evolution of the bridge is that it can support absolutely all of the known information regarding its geometry and number of arches.

Additionally, as we have mentioned before, restorations usually have worse craftsmanship than the original bridges. In this sense, the vaults on the north side were built with less quality than those on the south side, and there are even two types of arches, considering both shape and number of orders.

This could also explain the asymmetry of the niche that stands on pier 1, which would have originally been located elsewhere. It is possible that, during the restoration, they decided to reposition it on the recently built breakwater, adapting its width to that of the breakwater.

9. CONCLUSIONS

Throughout the paper, we have undertaken different research tasks using an interdisciplinary, crosscutting methodology. We have tried to open a path for the analysis of one of the most interesting structures in Spanish heritage in the field of engineering. Its location on a complex waterway, its purpose of human and livestock transit, the diversity of historical observers and reporters all enrich it as proof of cultural identity. To sum up, we have extracted the following conclusions:

- The task of reconstructing the historical development of a bridge places the complexity of working with historical data in evidence. On occasion, relevant temporary gaps are revealed, and other times contradictory historical facts appear, in light of which hypotheses must be established. In the case before us, thanks to the rigorous analysis of the sources found, we have managed to reduce the hypotheses to two; however, in other circumstances a considerably greater number might arise.
- The plan made by Sánchez shows the importance of analysing the scales contained in the document itself. Thanks to this, we have been able to determine the dimensions of the bridge at a specific historical moment.
- The method used, which combines archival research, topographical surveying, visual analysis and office work with the data is proven to be valid in the discovery of new data and the elaboration of theories about historical bridges that present several construction phases.

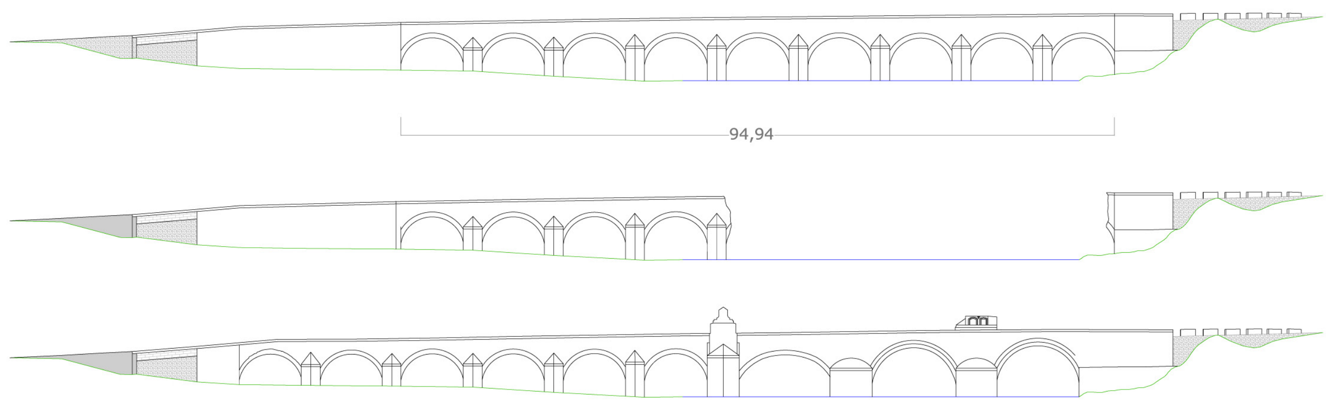


Figure 8. Different Images of the Bridge Structure: (a) The Original Bridge; (b) the Four Arches that remained after the Surge; and (c) The Rebuilt Bridge.

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APPENDICES

Measurements of the Drawing Contained in Figure 6.a.

Element	Measurement	Justification
Arch 1	10.93 m	Real measurement.
Pier 1	5.46 m	Real measurement.
Arch 2	11.14 m	Real measurement.
Pier 2	5.60 m	Real measurement.
Arch 3 + pier 3	16,34 m	Real measurement. Formulation of hypothesis that the current south face of pier 3 coincides with the old south face of pier 3.
Pier 3	5.60 m	Same as pier 2.
Arch 3	10,74 m	The result of subtracting the previous two measurements.
Arch 4	10,74 m	Same as arch 3.
Pier 4	5.60 m	Same as pier 2.
Arch 5	11.14 m	Same as arch 2.
Pier 5	5.46 m	Same as pier 1.
Arch 6	10.93 m	Same as arch 1.
Total length of the bridge	93,35 m	

Measurements of the Drawing Contained in Figure 8.a.

Element	Measurement	Justification
Arch 1	8.30 m	Same as arch 9.
Pier 1	2.53 m	Same as rest of real, existing, piers.
Arch 2	8.27 m	Same as arch 8.
Pier 2	2.52 m	Same as rest of real, existing, piers.
Arch 3	8.27 m	Same as arch 7.
Pier 3	2.52 m	Same as rest of real, existing, piers.
Arch 4	8.36 m	Same as arch 6.
Pier 4	2.52 m	Same as rest of real, existing, piers.
Arch 5	8.36 m	Same as arch 6.
Pier 5	2.52 m	Same as rest of real, existing, piers.
Arch 6	8.36 m	Real measurement of current arch 4.
Pier 6	2.52 m	Real measurement of current pier 4.
Arch 7	8.27 m	Real measurement of current arch 5.
Pier 7	2.52 m	Real measurement of current pier 5.
Arch 8	8.27 m	Real measurement of current arch 6.
Pier 8	2.52 m	Real measurement of current pier 6.
Arch 9	8.30 m	Real measurement of current arch 7.
Total length of the bridge	94.94 m	

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