A brief analysis of the Roman bridges of the way "La via de la Plata"

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ABSTRACT: This paper analysed four roman bridges from the road *Via de la Plata*. Through the analysis of the geometry and constructive typology is tried to identify the possible arithmetic and geometric rules by roman constructor to design the different elements constructive of a bridge, so to realise a first approximation to the methodology used by the construction of this type of works.

1. INTRODUCTION

This report has been development in the frame of the study of the historic bridges of "La Vía de la Plata". This work is included in an agreement between the "Consejería de Cultura de la Junta de Extremadura" and the "Centro de Estudios y Experimentación de Obras Públicas", in connection with the project of tittle "Alba Plata". It is an itemised study that takes in account very different questions (history, geometric definition, characterisation of the materials, typological description, pathologies, …). The work includes fifteen different bridges, therefore in the present seminary is not possible to consider neither all bridges nor all questions.

The selected bridges for this article are coming from Roman period, since it is claimed to give some data to improve the knowledge of this type of bridges. This is due to that in many cases they are considered Roman bridges some that are not or other that they only have some reused broad stone.

The selected bridges for the study have been the following:

- Bridge over the Ambroz River in Cáparra
- Bridge over the Tajo River in Alconetar
- Bridge over the Albarregas River in Mérida
- Bridge over the Guadiana River in Mérida

The first problem that is posed in the study of any historic construction is the knowledge of the geometry, based in the inspection and research "in situ", the collection of data and their backed analysis. With these data, it's analysed the possible dimension of the utilised roman foot, the geometry and dimension of several structural elements of the bridges: Arches (round arch, segmental arch, …), piers and cutwaters, the dimensions and worked of the ashlars, the width of the roadway, the grade of the way/ … Afterwards it's analysed the relations between the principal elements: span arch / solid, thickness ring course / span arch, rise / span arch, ...

Through the analysis of the geometry and constructive typology is tried to identify the possible arithmetic and geometric rules by roman constructor to design the different elements constructive of a bridge, so to realise a first approximation to the methodology used by the construction of this type of works.

2. GENERAL DESCRIPTION OF THE BRIDGES STUDIED

These bridges have a point in common and it's the relationship with what was the way called "La Vía de la Plata". The three last bridges were in the cited way while the first one was in a transversal secondary roman way that started in Cáparra and it went to the way of the "Valle del Jerte".

"La Vía de la Plata" is the roman way of the west of to Punish Iberian that communicated Mérida with the military camp of Astorga and Leon.

All of these have roman trace though some parts have been reformed. This work is dedicated exclusively to the structural elements of every bridge that is possible to certify with sufficient security that they are roman construction.

2.1. *Bridge over the Ambroz River in Caparra*

The Caparra bridge is situated over the Ambroz River, near to roman ruins of Caparra. Actually, the bridge support/carry the regional road that unite Villar de Plasencia and the little place of Gabriel y Galán barrage basin.

The bridge contain/include four semicircular arches, two main central arches and other two lateral arches of minor size. The ashlar masonry constitutes the vaults and the central two-spandrel walls and hoasting/dressed stone of different sizes forms the rest.

This bridge is not all authentically roman. Some authors said that it has the two central arches roman (De Griño Frontera, 1997; Fernández Casado, 1982) and other authors indicate that only there are roman an arch and the firsts courses of the central pier.

2.2. *Bridge over the Tajo River in Alconetar*

Actually, after it has been moved, this bridge is located in the Alcantara barrage basin, in the town limit of Garrovillas.
Now, the bridge has complete tree piers, other incomplete four piers, four vaults and a part of abutment in the right margin.

The masonry is formed by granite ashlar, except the vaults 3 and 5 realised in rubblework. The ashlar masonry is a good quality granite, with a reddish colour debit to iron oxides.

The four arches present circular direction line but they are segmental arch type. The use of this type arch in substitution of the semicircular arch answers to a short period in the roman construction. One of the best examples is the bridge over Danubio River, which is practically disappeared, so it only remains ruins and any documentary references about this work.

The two roman arches conserved present the voussoirs arch stone with a very regular shape. The spandrel wall has a very care bond that it connects very well with the springing voussoirs. Besides, so the piers 1 and 2 has been repaired in the bottom part, the pier 3 present signs that permit to said that it is conserved just as it was in the origin period.

2.3. *Bridge over the Albarregas River in Merida*

It is located in the town of Merida, very near to Milagros aqueduct, to the Norwest of centre-city and close to train station. The road "Via de la Plata" was its origin in this bridge.

This bridge is constituted for four semicircular arches in ashlar masonry and the abutment with two spillways realised in rubble works.

2.4. *Bridge over the Guadiana River in Merida*

The bridge is situated joining the ancient part of the city with a new part, in the other river margin.

This bridge doesn't belong to the road "La Vía de la Plata", but it was a connection point with other roman roads (Iter ab Hispali Emeritan, Iter ab ostio fluminis anae Emeritam usque, Iter ab Olisipone Emeritan). In other way, the roman characteristics can bring important data for this study.

Actually, this bridge presents a length approximately of 783 m, with 60 semicircular arches, tree of them are buried. They are able to consider the following parts:

- Three independent roman bridges
- A bridge from XVII century, between the first and the second roman bridges
- A bridge from XIX century into the second ruins bridge

3. METROLOGY STUDY

In the study of the metrology was tried to identify the average value of the roman foot used in each one of the studied works. At the bibliography that possible consulted about the theme, it was deduced that measures of roman foot there are practically so many as authors and studied monuments.

Neither of the realised studies of measures until the moment have could obtain a concrete measure valid for all the geographic extent of the Roman culture and during all the time that it existed. Is reasonable to think that this measure isn't ever and only it's possible to define certain spatial and temporal tendency through the metrology study about each work with its geographical location and its dating the most exactly possible.

Before to start the study is necessary to decide that dimensions of the elements of the work can be considered as authentically roman and which are not. But it is very doubtful so it shall take in consideration only the first dimensions and to give the possible major rigor to the study.

The followed method has as base to optimise the average value of the centimetres by foot so the standard deviation was minim value. It has considered for the major dimensions a maxim definition of ¼ foot; but for the minor dimension a maxim precision of $^{1}/_{16}$ foot.[1]

3.1. *Bridge over the Ambroz River in Caparra*

In this case, the two centre arches and the intermediate pier are considered completely roman construction.

In the following table are indicated the measures of different elements, the number of feet and the centimetres by foot, and the average and standard deviation corresponding to sample.

Table 1: Average value of roman foot in Caparra bridge.

Element	Measure (cm)	Nº feet	cm/foot
Arch span Nº 2	877	29 ¾	29,48
Arch span Nº 3	903	30 ¾	29,37
Width pier Nº 2	355	12	29,58
Thickness ring course – arch Nº2	110	3 $^{12}/_{16}$	29,33
Thickness ring course – arch Nº3	110	3 $^{12}/_{16}$	29,33
Average value = 29,42 cm		Standard deviation = 0,110	

3.2. *Bridge over the Tajo River in Alconetar*

It is considered as roman construction the following structural elements: the two first arches (nº 1 and 2), the springing right wall and the wall that unit the two aforementioned arches and the three piers that actually they are conserved.

The following arches (nº 3, 4 and 5) don't present the original construction and it's possible that the dimension isn't original due to the precarious conservation state.

In the following table are indicated the measures of different elements, the number of feet and the centimetres by foot, and the average and standard deviation corresponding to sample.

[1] VITRUVIO: But they after observing that both numbers *ten*, and *six* was perfect, they united its, and they had the most perfect *sixteen.* All this was the origin of the foot; because if of the elbow is subtracted two spans, remain the foot, that it is composed of four; and having the span four fingers, the foot had sixteen (Third book, First chapter. *Of the composition and symmetry of the temples*)

Table 2: Average value of roman foot in Alconetar bridge

Element	Measure (cm)	Nº feet	Cm/pie
Span – arch Nº 1	672	22 ¾	29,54
Span – arch Nº 2	728	24 ¾	29,41
Width – wall Nº 1	1412	48	29,42
Width – wall Nº 2	1348	45 ¾	29,46
Width – pier Nº 1	440	15	29,33
Width – pier Nº 2	425	14 $^{2}/_{4}$	29,31
Width – pier Nº 3	437	14 $^{3}/_{4}$	29,63
Thickness ring course arch Nº1	120	4 $^{1}/_{16}$	29,54
Thickness ring course arch Nº2	120	4 $^{1}/_{16}$	29,54
Rise arch Nº1	166	5 $^{10}/_{16}$	29,51
Rise – arch Nº2	219	7 $^{7}/_{16}$	29,45
Radius – arch Nº1	465	15 $^{3}/_{4}$	29,52
Radius - arch Nº2	433	14 $^{3}/_{4}$	29,36
Average value = 29,46 cm		Standard deviation = 0,094	

3.3. *Bridge over the Albarregas River in Merida*

It is considered as Roman the four main arches and the three intermediate piers. Is necessary to admit that probably the arch number three was reconstructed, but due to its typology and the arrangement of the springing is very probably that the measurements of the span and adjacent piers was not modified in relation to the Roman originals measurements.

With regard to the thinness of the ring courses, it is considered only the vaults numbers one, two and four, seeing that the reconstructed vault number three has thinness little minor.

In the following table are indicated the measures of different elements, the number of feet and the centimetres by foot, and the average and standard deviation corresponding to sample.

Table 3: Average value of roman foot in Albarregas bridge

Elements	Measure (cm)	Nº of feet	cm/foot
Span arch Nº 1	530	18	29,44
Span arch Nº 2	532	18	29,56
Span arch Nº 3	530	18	29,42
Span arch Nº 4	532	18	29,56
Width pier Nº 1	294	10	29,40
Width pier Nº 2	325	11	29,55
Width pier Nº 3	310	10 $^{2}/_{4}$	29,52
Thickness ring course	65	2 $^{3}/_{16}$	29,71
Average value = 29,52 cm		Standard deviation = 0,101	

3.4. Bridge over the Guadiana River in Merida

In the metrological study it is considered only the first section of the bridge. It is the part between the city and the first down ramp to the river; and only the first six arch and the first six piers, because this is the preserved in original state without reconstruction.

This bridge has other two sections with Roman arches and piers, mainly in the most removed to a distance of the city section, but we have preferred no study these parts because the following causes:

- In the first place because some authors think that each section was constructed in different moments inside of the long Roman period, and as has been said is possible that the *Roman foot standard* would be different in the space and the time.
- In the second place the bridge has suffered important silting mainly in the third section, the three last arches are buried and in other it is not seen the springing of the arches, therefor the possible measurements would be minor in the spans and major in the piers.

In the following table are indicated the measures of different elements, the number of feet and the centimetres by foot, and the average and standard deviation corresponding to sample.

Table 4: Average value of roman foot in Guadiana bridge

Elements	Measure (cm)	Nº of feet	cm / foot
Span arch Nº 1	740	25	29,60
Span arch Nº 2	760	25 2⁄4	29,80
Span arch Nº 3	890	30	29,67
Span arch Nº 4	951	32	29,72
Span arch Nº 5	1037	35	29,63
Span arch Nº 6	954	32 1⁄4	29,58
Width pier Nº 1	475	16	29,69
Width pier Nº 2	490	16 2⁄4	29,70
Width pier Nº 3	490	16 2⁄4	29,70
Width pier Nº 4	546	18 2⁄4	29,51
Width pier Nº 5	544	18 ¼	29,81
Width pier Nº 6	497	16 ¾	29,67
Thickness ring course	80	2 11⁄16	29,77
Relieving arch Nº1	130	4 6⁄16	29,71
Relieving arch Nº2	150	5 1⁄16	29,63
Relieving arch Nº3	150	5 1⁄16	29,63
Relieving arch Nº4	180	6 1⁄16	29,69
Relieving arch Nº5	160	5 6⁄16	29,77
Relieving arch Nº6	130	4 6⁄16	29,71
Average value = 29,68 cm		Standard deviation = 0,076	

4. GEOMETRICAL STUDY AND MEASURES RELATIONSHIP

In general, the following relationships are idealised: width pier/span arch, thickness ring course/span arch, rise arch/span arch.

The next measures is expressed by feet according to the previous values:

4.1. *Bridge over the Ambroz River in Caparra*

Table 5: Relationship width pier/span arch

Arch	Span (feet)	Left pier (feet)	Right pier (feet)	Width left pier/span arch	Width right pier/span arch
2	29 ¾	---	12	---	0,4034
3	30 ¾	12	---	0,3902	---

Table 6: Relationship thickness ring course/span arch

Arch	Span (feet)	Thickness ring course (feet)	Thickness ring course/span arch
2	29 ¾	3 12⁄16	0,1261
3	30 ¾	3 12⁄16	0,1220

4.2. *Bridge over Tajo River in Alconetar*

Table 7: Relationship thickness ring course/span arch

Arch	Span (feet)	Thickness ring course (feet)	Thickness ring course/span arch
1	22 3⁄4	4 1⁄16	0,1786
2	24 3⁄4	4 1⁄16	0,1641

Table 8: Relationship rise arch/span arch

Arch	Rise arch (feet)	Span (feet)	Rise arch/Span arch
1	5 $^{10}/_{16}$	22 $^{3}/_{4}$	0,2473
2	5 $^{7}/_{16}$	24 $^{3}/_{4}$	0,2197

4.3. *Bridge over Albarregas River in Merida*

Table 9: Relationship thickness ring course/span arch

Arch	Span (feet)	Thickness ring course (feet)	Thickness ring course/span arch
1	18	2 $^{3}/_{16}$	0,1215
2	18	2 $^{3}/_{16}$	0,1215
4	18	2 $^{3}/_{16}$	0,1215

Table 10: Relationship width pier/span arch

Arch	Span (feet)	Left pier – width (feet)	Right pier – width (feet)	Width left pier / Span arch	Width right pier / Span arch
1	18	---	10	---	0,5556
2	18	10	11	0,5556	0,6111
3	18	11	10 $^{2}/_{4}$	0,6111	0,5833
4	18	10 $^{2}/_{4}$	---	0,5833	---

4.4. Bridge over Guadiana River in Merida

Table 11: Relationship thickness ring course/span arch

Arch	Span (feet)	Thickness ring course (feet)	Thickness ring course/span arch
1	25	2 $^{11}/_{16}$	0,1075
2	25 $^{2}/_{4}$	2 $^{11}/_{16}$	0,1054
3	30	2 $^{11}/_{16}$	0,0896
4	32	2 $^{11}/_{16}$	0,0840
5	35	2 $^{11}/_{16}$	0,0768
6	32	2 $^{11}/_{16}$	0,0840

Table 12: Relationship width pier/span arch

Arch	Span (feet)	Left pier – width (feet)	Right pier – width (feet)	Width left pier / Span arch	Width right pier / Span arch
1	25	---	16	---	0,6400
2	25 $^{2}/_{4}$	16	16 $^{2}/_{4}$	0,6275	0,6471
3	30	16 $^{2}/_{4}$	16 $^{2}/_{4}$	0,5500	0,5500
4	32	16 $^{2}/_{4}$	18 $^{2}/_{4}$	0,5156	0,5781
5	35	18 $^{2}/_{4}$	18 ¼	0,5286	0,5214
6	32 $^{1}/_{4}$	18 ¼	16 ¾	0,5659	0,5194

5. CONCLUSIONS

From a formal point of view, it is observed that all bridges studied have used the arch with circular direction line, mainly the semicircular arch and only in Alconetar bridge has used the segmental arch. The geometric analysis of these vaults has allowed to check that theses are conserved without almost deformation. The span arches analysed are taken in between 18 and 35 feet (532 and 1037 cm), the width of the piers between 10 and 18 $^{2}/_{4}$ feet (294 and 546 cm), the thickness of ring courses between 2 $^{3}/_{16}$ feet and 4 $^{1}/_{16}$ feet (65 and 120).

About the types of masonry it is observed a set of common characteristic, just as the utilisation of ashlar masonry of “*opus quadratum*”, which the pieces sculpted with a view to the foot module, 1 ½ feet or 2 feet. In the other hand, in relationship with the carving, it was used the type called rustication. The voussoirs of the ring courses have dimensions bigger than the rest of the masonry, presenting a perfectly defined extrados.

For the disposition of the arch, centering was disposed a projecting course like a moulding, except in Alconetar bridge where the vaults 1 and 2 support directly in the soil and it is not necessary.

In relationship with the metrology study of the studied bridge, it is concluded that the standard roman foot changes between 29,42 and 29,68 cm.

About the dimensional relationship analysed, it is observed:

- Average width pier/span arch around to 1/2 (de 0,40 in Caparra and 0,58 in Albarregas).
- Average thickness ring course/span arch from 1/8 a 1/11 to semicircular arches (1/8 in Albarregas and Cáparra and 1/11 in Guadiana) and 1/6 to segmental arch (Alconetar).
- Average rise/span arch of 0,23 in segmental arch in Alconetar.

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Fig. 1: Bridge over the Ambroz River in Caparra

Fig. 2: Bridge over the Tajo River in Alconetar

Fig. 3: Bridge over the Albarregas River in Mérida

Fig. 4: Bridge over the Guadiana River in Mérida