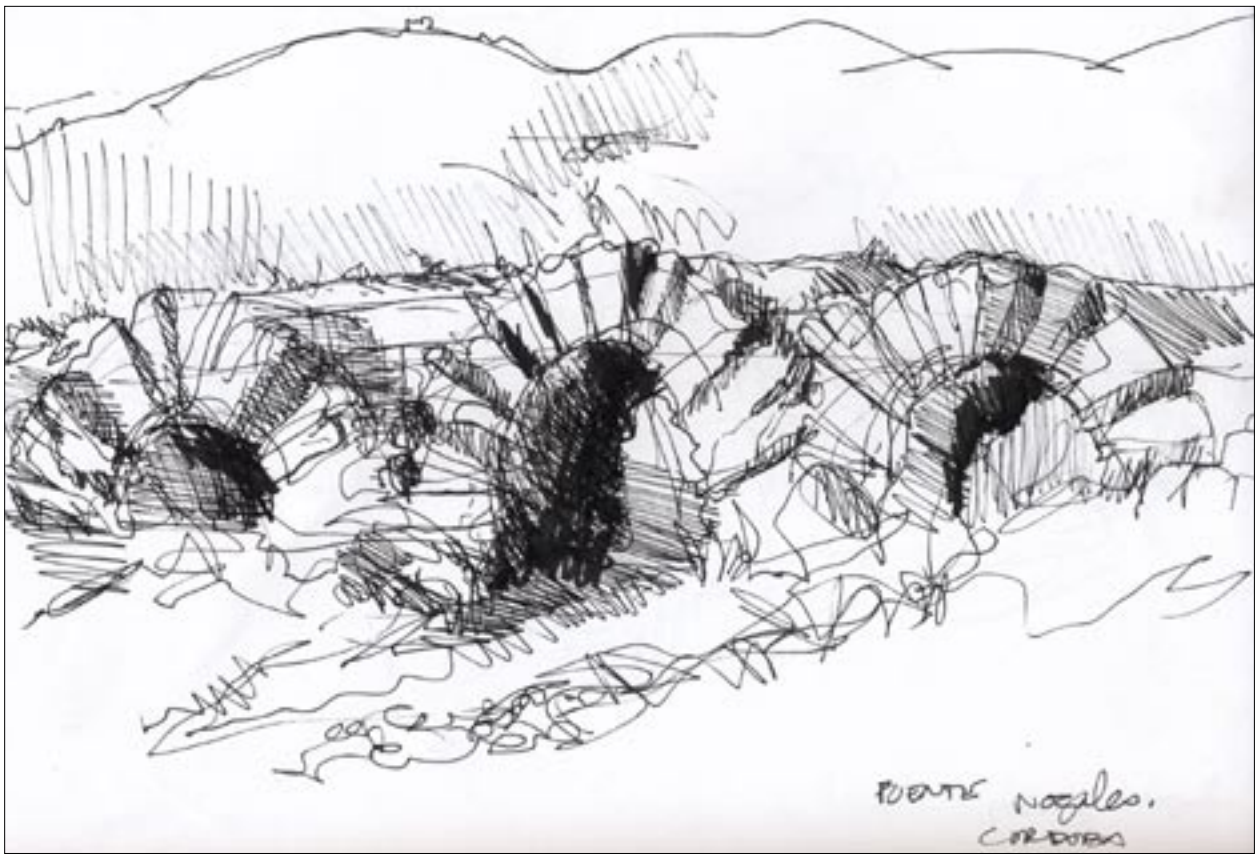
Moorish Bridges of Andalucia



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Acknowledgements

This paper presents research on bridges built in southern Spain during the eighth through the twelfth centuries AD. I travelled to eleven existing bridges in Andalucia in January 2005 to collect information about their geometry and structural characteristics. The work was a collaboration with Amber Frid-Jimenez, who took the majority of the photographs. She also set the type and performed the graphic design required by the paper. The research was advised by Professor John Ochsendorf and funded by a travel grant from the Aga Khan Program for Islamic Architecture at the Massachusetts Institute of Technology. It is intended to provide the groundwork for subsequent scholarly inquiry into the influence of Moorish builders on bridge design within the Islamic world and Western Europe.

Introduction

The advanced state of Islamic architecture, mathematics, and astronomy during the Umayyad and Abbasid periods of rule in the middle east is well-documented. However, the contributions of Islamic builders to bridge design have rarely been studied. As O'Conner states in the conclusion of his exhaustive study Roman Bridges, "…it appears that no accurate review has ever been published of bridge construction in the post-Roman period… such a review should pay closer regard to regions with civilizations which continued in the Post-Roman period, such as Turkey or Moorish Spain." (O'Connor 188). Moorish domination on the Iberian peninsula lasted from their arrival in 711AD until their dispersal at the hands of the Spanish monarchs Ferdinand and Isabel in 1492. The centers of power shifted during this time between Cordoba, Sevilla, and Granada, which became the three principal cities of Andalucia, whose name is inherited from the Arabic al-Andalus (Collins 163-224). Along with mosques and palaces erected during the almost 800 years of Muslim rule, the Moors also built or restored a network of roads, which required bridges across the rivers lying in their paths. In some cases, such as probably occurred in the bridge at Cordoba, this meant repairing existing Roman bridges that had deteriorated since the breakdown of Roman administration on the Iberian peninsula around 200AD (Richardson 231-235). In numerous other instances, such as the three existing Moorish bridges between Cordoba and Sevilla, the Muslim inhabitants of Spain constructed bridges where there had been none previously. The attempt to distinguish the Moorish lineage in the bridges of Andalucia is complicated by the fact that in many cases, the bridges were in service long after the departure of the Moors (of the eleven bridges investigated, five are still carrying traffic). Their continued use means that in addition to the work that might have predated the structure, one must also attempt to distinguish Moorish work from alterations occurring over the thousand-odd years since completion of the structure.

During a literature review at the outset of the project, I was fortunate to find a work of Basilio Pavón Maldonado entitled *Tratado de arquitectura hispano-musulmana*, published in 1990. This source was suggested by a member of Archnet who responded to a query posted about Moorish Bridges. Maldonado has written extensively in Spanish on Moorish bridges, dams, and irrigation structures, and the first of two volumes, entitled *Agua*, functioned as a guide as we travelled around Andalucia looking for the bridges included in the study. A full treatment of the dimensions and geometry of each bridge is summarized in appendix 1 at the end of the document.

The bridges investigated in the study consist of the following:

Name	**Location**
Puente Aljibillo	Granada
Arco del Darro	Granada
Puente sobre el Rio Genil	Granada
Puente de Pinos Puente	Pinos Puente
Puente Romano	Cordoba
Puente Nogales	Cordoba
Puente Califal sobre el arroyo Cantarranas	Cordoba
Puente Califal sobre el Guadiato	Cordoba
Puente Quebrado	Hornachuelos
Puente Sobre el rio Guadalbacar	Setefilla
Puente Arabe	Ronda

These bridges of Andalucia, generally built between 711 and 1400 are of particular interest because of their cultural and geographical location. Andalucia was for many years the locus of a peaceful and fertile collaboration between Muslim and Christian scholars(Collins 200-207). As such, it was a prime interface in the transfer of knowledge between two empires. A bridge is a technological expression of a culture. I hope that this field research will lay the groundwork to begin to appreciate the transfer of advanced knowledge and method from the Muslim to the Christian world in the area of bridge design.

Overview of Bridges

The bridges visited fall into three major geographical areas: those in and around Cordoba, those lying on the Moorish road that follows the valley of the Guadalquivir river to connect Cordoba to Sevilla, and the bridges of Granada. The descriptions below follow the approximate chronology of the center of Muslim political power in Spain. They begin with the bridges in and around Cordoba, the original seat of Muslim power on the Iberian Peninsula. After this they treat the bridges between Cordoba and Sevilla, before proceeding to the bridges of Granada, the location of the last Muslim emirate on the Iberian Peninsula.

I. Bridges of Cordoba

The Moors crossed the strait of Gibraltar into the present city of Tarifa, in Spain, in 711 AD from what is now Morocco. From Tarifa they travelled overland approximately 220 kilometers to the Roman city of Corduba, establishing a regional caliphate which functioned for several hundred years as a outlying colony of the Umayyad dynasty administered from Damascus. (Collins 151). When the power shifted from Umayyads in Damascus to the Abbasidds in Baghdad, the Cordoban Abd al-Rahman declared himself caliph in 929, effectively establishing the independence of Cordoba. The Caliphal period lasted from 929 to 1031, during which lavish palaces and public buildings were constructed in Cordoba. (Collins 171).

Puente Romano

Puente Romano

Early accounts by Moorish travellers arriving in Cordoba indicate that they were impressed by the ruins of a seventeen span Roman bridge crossing the Guadalquivir River (Maldonado 96). The original bridge, which lies on the Via Augusta, may have been built in the time of Augustus (O'Connor 104, who cites Gazzola). Maldonado interprets the chronicles of Julius Caesar to suggest that a Roman bridge of boats or heavy timber supported by baskets filled

with stones predated the masonry structure, but also theorizes that the bridge may have been built during the time of Octavius (Maldonado 94). During the Moorish domination of the city the bridge connected the Torre de la Calahorra, a fortress tower on the south eastern bank, to the mezquita, or mosque, on the northwest bank of the Guadalquivir.

Whatever the lineage of the bridge across the Guadalquivir prior to the 8th century, Muslims arriving in Cordoba after 711 found a bridge partially destroyed, probably by the passage of time and floods. Arab chronicles written during the time of the caliph of Damascus Umar ben Adb Aziz state that the bridge was reconstructed by al-Samh, who apparently came to Andalucia to undertake the repair in 719-720, after receiving authorization from the caliph. Notably, al Samh offered to repair the masonry of the bridge using stones from the existing walls surrounding city, which were in turn to be replaced with bricks if suitable stone was unavailable (Maldonado 95). Presumably the walls were from Roman times, like the bridge itself. Thus the portions of the bridge repaired by the Moorish builders might be expected to blend well with the remnants of the bridge surviving intact from Roman times, making it difficult to accurately assess which parts of the bridge were rebuilt by the Moors. At present the wide range of sizes and shapes of the arches, as well as subtle and obvious differences in design of breakwaters both upstream and downstream, attest to the centuries of repairs and modifications made to the bridge since its initial construction, both before and after the period of Muslim domination. In various locations in the piers and arches the original masonry of the bridge is interrupted by later repairs of what appear to be a soft sandstone, similar to that employed in other Moorish bridges between Cordoba and Sevilla. These repairs sometimes incorporate baked bricks of a dimension common to the bricks used in the mosque of Cordoba.

Puente Romano

Puente Romano

The bridge is large, consisting of 17 spans, which are generally each 10 meters long. There is considerably more variation in the piers, which begin close to 10 meters wide on the side of the mosque and diminish to closer to 7 meters at the tower end of the bridge. This might be accounted for by the greater amount of current on the mosque side of the river; according to Maldonado floods have carried away sections of the mosque side of the bridge as recently as the 16th century (103). A catalog of the spans, their shapes, with speculation on the builders responsible for the various sections, arches, and breakwaters, can be found in Appendix III

at the end of this report. A complete study of this bridge is beyond the scope of this investigation but might begin to acknowledge the contribution made by Muslim builders to a bridge which is commonly considered exclusively Roman, in name and historical pedigree. The bridge currently carries pedestrian traffic across the Guadalquivir, but until recently it carried vehicular traffic, which from casual inspection it seems easily capable of doing.

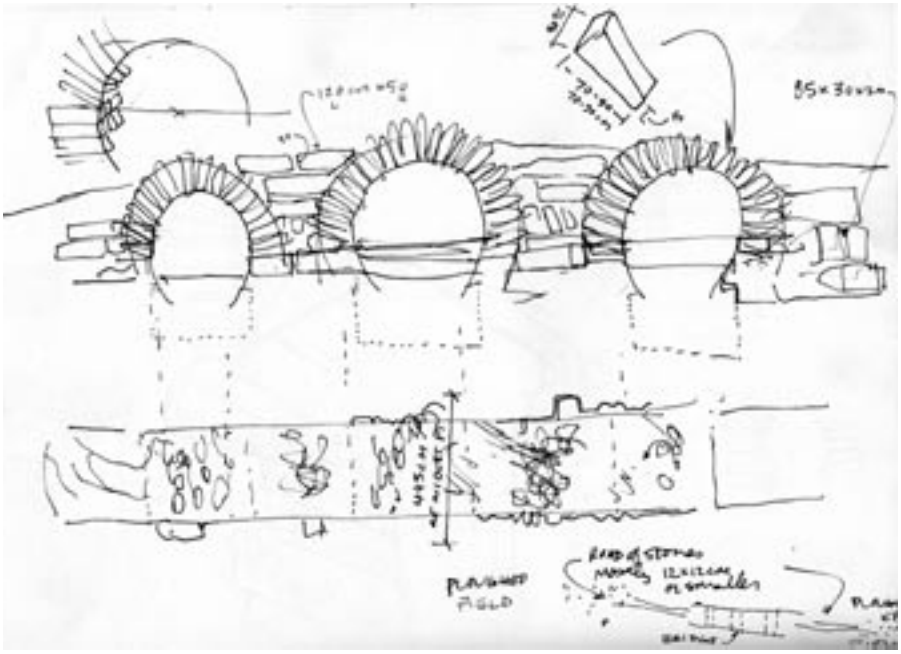
Puente Nogales

The mosque of Cordoba, built on a site occupied previously by a visigothic church, functioned as the administrative center of Andalucia just after the arrival of the Moors on the Iberian peninsula in 711 until 1031. Eight kilometers northwest of the city lies Madinat al-Zahra, a palace complex constructed between 936 and 945 by Abd al-Rahman III for use as a summer palace (Collins 171). The Medinah, or village, is today the site of an extensive archaeological dig. Numerous sites of historical importance exist between Cordoba and Madinat al Zahra, including norias, acueducts and bridges. I will focus on two bridges lying on two separate roads which led from the mosque to the summer palace.

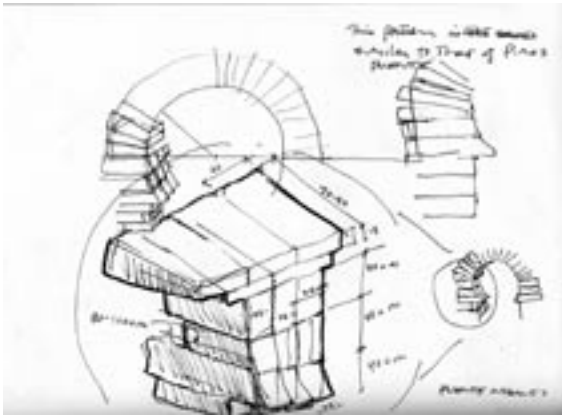
Puente Nogales

The first bridge, puente Nogales, consists of three spans which cross a stream which was barely a trickle during our winter visit. Although all three spans are intact, the bridge has experienced moderate deterioration over the course of its life. A small number of concrete voussoirs have been installed, presumably by archeologists, to prevent further deterioration of the structure. A fabric mat is installed between the stones of the spans and the soil on top of them, suggesting that the bridge has been the site of an archaeological investigation within the past five years.

The bridge lies amidst a field currently under cultivation. A great multitude of round stones measuring in the vicinity of twelve centimeters were



Puente Nogales



Puente Nogales

observed scattered in the furrows of the field on either side of the bridge extending out in a straight line in both directions. These were likely to be of the part of the paving of the original Moorish road from the mosque in Cordoba to the Madinat al-Zahra. The bridge consists of a span of 2.9 meters flanked on either side by arches of 2.2 meters, with piers approximately as wide as the two outside spans. The voussoirs of the center span vary between seventy to ninety centimeters high, making them very large for the relatively short distance of the spans. The bridge is 4.5 meters wide and has no visible breakwaters up- or downstream. Stones of dimensions up to 120cm long by 50 cm high of unknown depth (but not likely to be less than 25 cm) were observed in the spandrel area between the arches.

Although all three spans of Puente Nogales appear today to be semicircular, there is ample reason to believe that at least the two flanking arches, and perhaps the central span, are horseshoe shaped. A ledge of a depth of approximately 20 centimeters, consistent with the bottom return of the horseshoe shape was visible at the base of the left hand arch. A small amount of excavation at the base of the right-hand span revealed a similar ledge. While the variability of river flows make it difficult to reliably predict a standard rate of soil accumulation (Jimenez-Camino, 2005), it seems reasonable to suggest that soil was deposited about the bridge, making what were originally horseshoe arches appear today to be semicircular. The bond of the stonework at

the bottom of the arches further supports this theory. Three courses of stones 25cm wide by 40cm high by 80-100cm long are placed on edge, forming the bottom of the horseshoe arch. This pattern of stonework is found in the horseshoe arches of the bridges at Pinos Puente, over the rivers Guadiato, Bembezar, and numerous others. The hypothesis raises the possibility that breakwaters forming an original part of the bridge have likewise been buried. A small sign at the bridge indicates indicate that puente Nogales like puente Cantarranas, is administered by archeologists currently excavating Madinat al-Zahra, and a further analysis of the bridge would profit from consulting these sources.

Puente sobre el arroyo Cantarranas

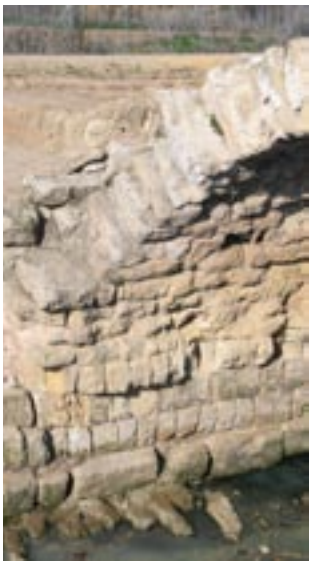
Puente over the arroyo Cantarranas

Approximately 2km south of Puente Nogales lies the bridge of Cantarranas, whose picturesque nature contrasts with its surroundings. The fetid stream passing beneath the single span appears to consist principally of sewage from the scrappy residential neighborhood in which it is situated, behind an electrical substation. During the duration of the visit a pipe approximately 20 meters upstream issued what seemed to be greywater from its broken end. The bridge, like puente Nogales, is administered by the archaeologists of Madinat al Zahra, who have erected a small sign at the location. This protection is fortunate as a heavy-equipment crew came to survey the arroyo, which they were in the process of cleaning and widening, while I was measuring the bridge. The site of a recent archaeological excavation, Cantarranas was an especially intrigu-

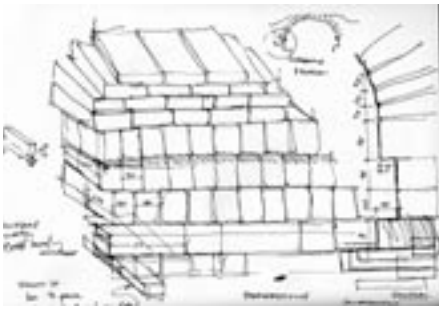
Puente sobre el arroyo Cantarranas

ing bridge to visit, as much of the underlying stonework is revealed for study.

The single span of puente Cantarranas is semi-circular and measures 4.97 meters from abutment to abutment. The bridge could have been as wide as 8 meters originally, judging from the width of the abutments. The current span measures 4.2 meters wide at the abutments, dwindling to a scant 3.3 meters wide at the center of the arch. A considerable number voussoirs seem to have fallen since the completion of the structure. The stones appear to be laid dry, with no evidence of mortar anywhere in the bridge. Typical voussoirs measure 100cm high, making them among the largest of the bridges studied. Stones forming the spandrels above the arches generally measure 120x 45 x 30 cm. These are set in courses with the long axis alternating between perpendicular and parallel to the direction of the traffic, but always resting on the side measuring 35 cm. This configuration seems inherently less stable than if the stones with their widest face down. The use of stone placed regularly throughout the spandrels of the bridge was unique compared to the rest of the bridges in this study; when it was possible to observe the spandrels, they generally seemed to consist of stone walls at the upstream and downstream faces, with rubble or soil infill between them. This would seem a faster and more economical method of construction, especially when the great weight of the stones forming the spandrels of Cantarranas is taken into account.



Puente sobre el arroyo Cantarranas



The method of setting stones on their narrower edge can also be observed at the ledge of the springing of the arch. The regular voussoirs comprising the span of the arch are set upon a course of cantilevered stones laid up on edge. This course of cantilevered stones, which normally would comprise the bottom ledge of a horseshoe arch, here defines a small rebate beneath a semi-circular arch. The stones of the ledge course the are followed by the regular voussoirs of the arch laid in a more stable manner (see Fig. _). The pattern of stonework, as well as the semi-circular shape of the arch, distinguishes Cantarranas from other Moorish bridges at Nogales, Pinos Puente, Guadiato, puente Quebrado over the rio Bembezar and other, in which the voussoirs compris-

ing the main part of the spans lay on top of two further courses of stones set on edge above the course comprising the ledge. This pattern is also followed in many of the exterior arches of the mosque of Cordoba, although not in the arches between the columns on the interior. In the Cantarranas, the voussoirs are set directly on this first course of stones forming the ledge, although the course of the ledge is supported by two other courses of stones also laid on edge. Cantarranas is different for the shape of the arch and the type of stonework comprising it.

II. Road from Cordoba to Sevilla

Four bridges which Maldonado dates from the caliphal period (corresponding to the caliphate established in Cordoba from 929-1031) can be found between Cordoba and Sevilla. These bridges over various tributaries over the Guadalquivir river were a part of a Moorish road which roughly paralleled the Guadalquivir River to its north side (Maldonado 112). This road would have been distinct from the Roman road established close to a millennium earlier, which connected the Roman city of Corduba to Hispalis (modern Sevilla) via a road which paralleled the Guadalquivir River to the south, passing through Ecija and Carmona (O'connor 19).

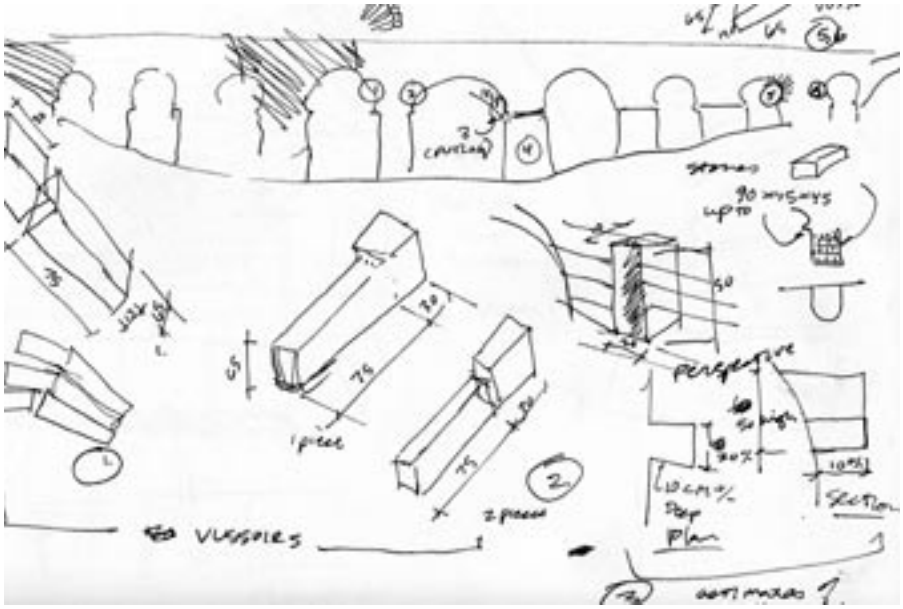
Puente Califal sobre el Guadiato

Puente de la Tejera sobre el Guadiato

In the hills to the northeast of Cordoba lie two bridges within a kilometer of one another, one caliphal and the other apparently of Roman origin, although Maldonado claims that the latter bridge also dates from the time of Moorish domination. This assertion is puzzling as the two share very few characteristics, such as the type of stone, shape of arches, or method of construction,

Puente Sobre el rio Guadanuno

which is different in each. The two bridges cross two different streams, the Guadiato and the Guadanuno, close to their confluence. The caliphal bridge is commonly known as the puente de la Tejera sobre el rio Guadiato and is impressive in size, consisting of 9 spans, all but three remain intact today. The bridge crosses the Guadiato river on a road which connected Cordoba to Villaviciosa, 20 kilometers to the northwest, before joining a road that led to Badajoz (Maldonado 108). The river valley is striking and the bridge a beautiful testament to the knowledge and skill of Moorish builders.



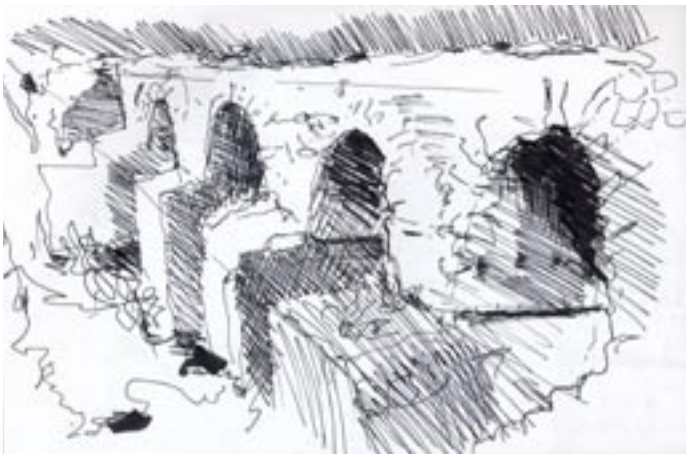
Puente Califal sobre el Guadiato

The bridge measures eighty meters long and is constructed of what appears to be a relatively hard stone with voussoirs composed of a soft sandstone throughout. The bridge follows a symmetrical layout. A central span measuring over eight meters is flanked on either side by slightly ogival arches, although only one of these remains intact. The first three spans from either abutment are all of comparable size (just over four meters each). On the left hand side of the bridge, these arches are horseshoe shaped; on the right side two of the three spans have been destroyed, but it seems reaonable to surmise that they would have been the same shape as those of the right side. The voussoirs of the flanking horseshoe shaped arches measure approximately 65 cm high, while those of the three center spans alternate between voussoirs cut from of a single piece of stone 105 cm high and those of the same measurement but comprised of two pieces. Maldonado claims that the voussoirs of the spans grow from the spring-

Puente
Califal sobre el Guadiato

ing to the keystone (although this trait was not noted in my visit) , which suggests to him that the bridge was constructed prior to Abd al Rahmann III. (Maldonado109). The remaining arch on the right side is completely made of brick, which is puzzling and goes unmentioned by Maldonado. Several large cracks run through it. The presence of an architvolt of small round stones following the outside periphery of the voussoirs on the central arches suggests an affinity with the bridge over the Guadalbacar, in which the same trait can be found. The piers of the bridge over the Gaudiato are built of stones measuring 90 x 45 x 45cm, whose size further suggest to Maldonado that the bridge was constructed sometime during the tenth century (Maldonado109).

The bridge is notable in part for the massive size of its foundations, which for the most part rest on the solid rock of the river bed. The breakwaters are semicircular in plan upriver and rectangular downriver. Both of the fallen spans are likely to have collapsed due to problems with their foundations, although admittedly the soil around the failed pier have could have accumulated since the bridge was completed approximately 1,300 years prior. The fact that nearly the entire block of the foundation remained joined together even in failure speaks to the strength of the mortar used throughout the bridge, which is approximately one centimenter thick at most of the joints. The third collapsed span terminated onto a steep sandy bank at the end of the bridge. This arch has apparently failed since the last visit of Maldonado to the site, because he only mentions the collapse of one of the arches. Ruins of what looked to be a failed wingwall were observed in the brush at the end of the bridge; movement of the soil at the abutment is likely to have played a hand in the destruction of the final span.



Puente Califal sobre el Guadiato

The collapse of the third span points to the importance of increased awareness about the historical importance of bridges of this type; although the bridge is reasonably well known, appearing in guidebooks of the region, the only evideence of other visotors when we visited the bridge in 2005 was the presence of sheep droppings and the remains of several small campfires. Perhaps if more attention were paid to the care of the bridge the second collapse could have been averted by the stabilization of the slope.

Puente Quebrado sobre el rio Bembezar

Proceeding from Cordoba toward Sevilla, the next Moorish bridge crosses the

Puente Quebrado

is the rio Bembezar, a little less than a kilometer south of the town of Hornichuelos. The picturesque town nestled in the foothills of the Sierra Alta, boasted the remains of a Roman bridge before construction of a resevoir at the southern end of the town flooded the site of the bridge (Morales). The remains of the Moorish bridge, known to some of the inhabitants as Puente Quebrado, or Broken bridge, stands below the dammed section of the river, and are accessible via a footpath from the dam. There is some disagreement about the correlation of this bridge to the one mentioned in the Moorish chronicles; Maldonado cites the account of Ibn Idari of a bridge over the Qais river, which for various other authors is the Monbasar, corresponding to the Bembezar, but there is some disagreement about this point. Certain sources suggest that the Moorish bridge is 9 kilometers from the confluence of the Guadalquivir and the Bembezar; Idrisi claims that the bridge was 12 miles from the town to the bridge does not agree with the 800 meters from the present location of the town of Hornachuelos (Maldonado 112).

Unknown Bridge, Est. Hornachuelos

Attempting to locate the Moorish bridge over the Bembezar just below Hornachuelos, we found ourselves in Estacion Hornachuelos, which lies nine kilometers from the former and is named for the train station which is its only feature. We were led to the remains of a different bridge approximately 700 meters below Estacion Hornachuelos by an inhabitant of that town. This five span bridge, of which two spans remain intact, was covered in cane grasses and underbrush and appeared to be of Roman construction. It is located in a dry channel of the Bembezar river and its presence was unknown to the inhabitants of Hornachuelos with whom we spoke. It does not appear in other catalogues of Roman bridges in the vicinity.

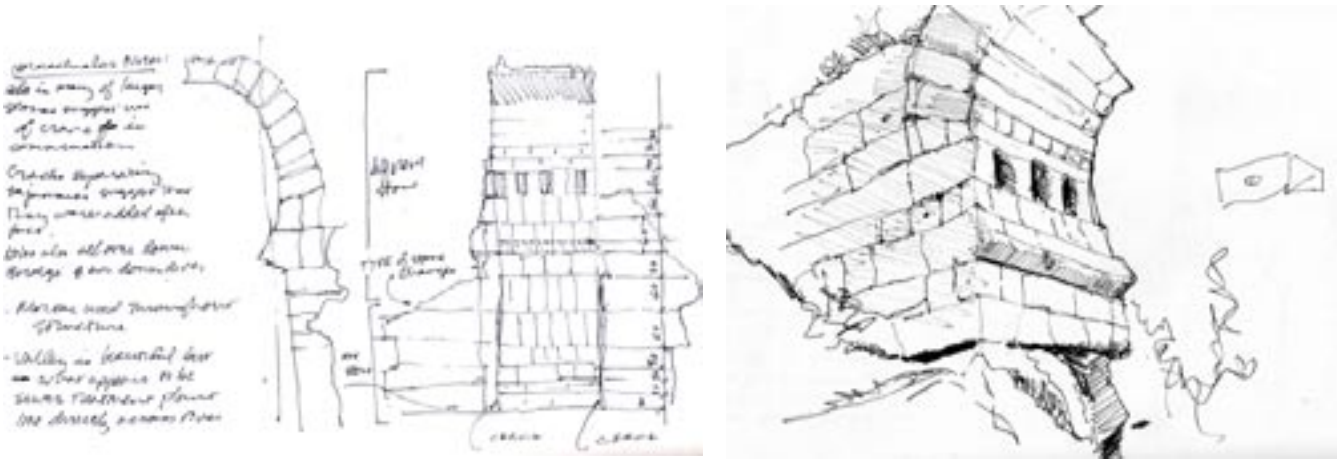
Later that day we found the remaining span of what was probably a four span Moorish bridge over the Bembezar, located approximately 800 meters south of the resevoir in Hornachuelos. Maldonado speculates that this bridge consisted of two central spans of 7.9 meters each (113), which seems reasonable from evidence at the site, although there were no foundations from them visible . The sole remaining arch has a pronounced horseshoe shape, with a breakwater whose plan matches those of Puente de la Tejera: semi-circular upstream and rectangular downstream. The arch measures 4.5 meters across, consisting of voussoirs 95cm high by 60cm thick by 30cm on the underside of the barrel vault. The remaining pier is three meters across and stands on solid rock, probably the reason that it is still in place. Maldonado mentions that the piers consist of concrete inside the outer facing of rock (Maldonado 114), but

Puente Quebrado

we were unable to verify this during our visit. Notably, the breakwater on the down river side was pulling away from the pier in a way that suggested that it was added after the construction of the pier. The reason for the separation of the two elements was not immediately clear. The stones of the breakwater were not knit together with the stones of the pier and a large crack had developed as a result. The largest stones of the pier measured approximately 50x60x120cm. The type of stone changes five courses from the bottom of the pier.

Puente Quebrado

The bond at the springing of the horseshoe arch of the bridge over the Bembezar river similar to that of other bridges such as Pinos Puente and Tejera and others: three courses of stones laid on edge form the bottom of the horseshoe above the ledge, upon which the voussoirs of the main body of the arch are placed. One characteristics distinguishes Puente Quebrado from other caliphal bridges, however. The presence of numerous holes of a diameter of 8cm, of an unknown depth, in a significant number of the voussoirs and stones comprising the piers and spandrels of the bridge. Most of the holes occur at what appears to be the approximate centroid of the stones, which lends credence to Maldonado's theory that the holes might have been used to provide a purchase for lewis pins used to lift them in place with some sort of machinery. If we assume sandstone to have a unit weight of 20kN/m3 (Heyman 12), a single stone measuring 50x50x100cm would weigh 5kN, or over 1,100 lbs. Stones of this weight suggest that the builders the Guadiato, Cantarranas, and Bembezar bridges would have been likely to have used machinery in the erection of the bridges. Nevertheless, the Bembezar river bridge is the only



Puente Quebrado

Moorish bridges in this investigation to contain evidence of this type of construction. Notably, the remains of the apparently Roman bridge approximately 8 km down river in the town of Estacion Hornachuelos has ample amounts of holes of similar dimensions in voussoirs and the stones comprising the piers and spandrels.

Puente sobre el rio Guadalbacar

Puente sobre el rio Guadalbacar

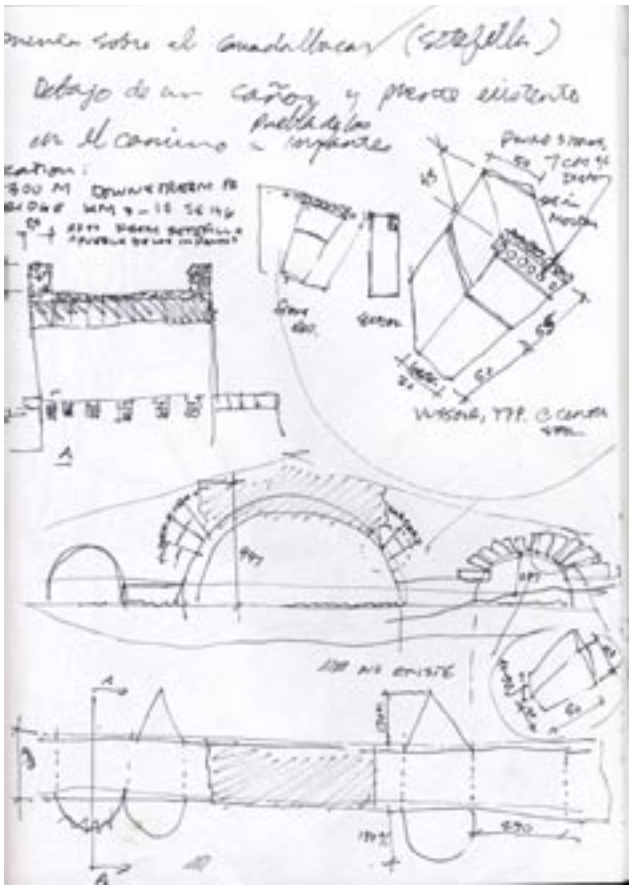
The next bridge encountered on the Moorish road from Cordoba to Sevilla is located approximately 2km north east of Setefilla, a small village given over to the production of oranges. Only the two peripheral spans, measuring approximately 2.8 and 3.8 meters, remain intact of what Maldonado hypothesizes was a bridge consisting of three spans over the Guadalbacar river. (Maldonado 117). This theory seems plausible given the angle of the springing of what might have been the central arch, which remains intact on the right side. If this theory were true, the road over the bridge would have had a pronounced ridge in the center, as the fallen middle arch would have had to rise considerably in order to span the distance required, even if the arch were flattened from semicircular to slightly segmental, as Maldonado has drawn it (117). A central arch so much wider than the two flanking arches would distinguish the bridge from the other bridges in the investigation so far; although central many of the bridges encountered have slight larger spans in the center, the central arch of the Setefilla bridge would be almost three times the spans of those at the extreme edges. This ratio contrasts with the other bridges in the study such as the bridge over the Guadiato river, whose larger central spans are less than double those of the periphery. The width of the bridge, 4.4m, is in keeping with the other bridges studied in this investigation.

The stonework of the bridge over the Guadalbacar further differ-

Puente sobre el Rio Guadalbacar

entiates it from many of the other bridges in the investigation. Alternating voussoirs are typically broken into two segments, which when taken together typically measure 105cm tall, a characteristic also found in the bridge over the Guadiato. The remaining voussoirs of the central arch of the Guadalbacar are distinguished by a recess at their outermost edge, into which round stones measuring approximately 7cm across have been set in mortar. This treatment of the voussoirs in an apparently decorative manner is similar to decorative treatment of the voussoirs of the bridge over the Guadiato. There, the voussoirs of the three larger central spans are shaped with what appears to be a decorative reduction in size at approximately 30cm from the extrados. The two side spans have voussoirs measuring 50 cm in height, corresponding to their shorter spans and have no distinguishing decorative stonework.

The left-hand pier of the bridge over the Gaudalbacar river is 410cm wide, angled in plan upstream and semicircular in plan downstream, and it seems reasonable that the other side would be comparable. Maldonado claims that the pier of right hand side of the bridge are angled both up- and downstream; this portion of the bridge was so overgrown with thorny undergrowth that his assertion was impossible to verify. He surmises that the unlikely shape probably indicates a later repair. Evidence of repairs are in the left hand pier and springing of the arch, in which baked bricks have been used to repair



Puente sobre el Rio Guadalbacar

Puente sobre el Rio Guadalbacar

both the pier and the springing. Maldonado claims that bricks used in the foundation of the right hand piers have the same dimensions of bricks found in 12th century structures in Sevilla: 30-15-4cm (Maldonado 117); this span was inaccessible upon my visit but the bricks of the left hand span looked similar to what he describes and seemed more to indicate repair work than original construction, which would suggest that the bridge was repaired in the 12th century and constructed sometime before that. However, Maldonado claims that the coursing of the masonry of the vaults is similar to that found in the sections of the Puente Romano most likely to have been constructed by Almohads during the 12th century; this combined with angled putlog holes leads him to postulate that the Guadalbacar bridge was constructed sometime during the 12th century.

III. Bridges of Granada

With the Christian overthrow of Sevilla in 1248, the Emirate of Granada became the last locus of Moorish power on the Iberian Peninsula. During the 1300's, Yusuf I and Mohammad V contributed to Alhambra in Granada, which grew from a fortress into a palace until the fall of Granada in 1492 to the Spansish monarchs Isabel and Ferdinand. When Boabdil, the last emir of Granada, exchanged the keys of Granada for a territory in the Alpujarras and 30,000 gold coins, it ended almost 800 years of Moorish control in Andalucia (Harvey 323). Between the Alhambra and the Albaycin, the old residential neighborhood of Granada, there existed several bridges built by the moors over the rio Darro which separates the palace from the old town. Of these two, only a small part of each remains.

Puente del Aljibillo

Puente del Aljibillo

The northernmost crossing of the rio Darro between the Alhambra and the Albaycin was at the bottom of the Cuesta de los Chinos, where today one encounters a bridge apparently built upon the foundations of the Moorish

Puente del Aljibillo

structure. The bridge crosses the river in a single span of about 7.3 meters; the present bridge is 490 meters wide, but it is difficult to say whether this dimension is unchanged since the bridge was rebuilt, probably in the 16th century (Maldonado 130).

At the left-hand abutment there appear to be four courses of voussoirs which corresponds to Moorish construction. These voussoirs are of a stone which appears to be soft sandstone, in constrast to the rest of the bridge, which appears to be of a stone substantially harder than the four courses at the springing of the arch. The erosion of the stones in so great that at first glance it seems as though each voussoir is made of numerous layers of stone 5cm thick; upon closer inspection these layers appear to be striations in the stone. This may be why Maldonado refers to seven courses of original voussoirs in the present bridge. The real dimension of each voussoir approximately 20cm wide by 65cm high. The soft stone of these voussoirs appears in a significant lower portion of the extensive abutment downriver from the bridge, suggesting that at least a part of this work was also constructed by the Moors. The putlog holes in the abutments are somewhat confusing, as there are a different number at each

Aljibillo putlog holes at springing top: left; bottom: right.

abutment. The left-hand abutment contains seven holes, whereas the right has 10 on one level and six on another. This suggests that reconstruction of the bridge was significant enough to require new centering to be built under the arch; the extra holes are on the side of the arch containing the original voussoirs, which would give further creedence to the they that they remain from previous construction. Neither portion of the bridge suggests that the geom-

etry was ever a horseshoe arch. The bridge sits on a foundation of what appears to be concrete but might have easily been added during the course of repairs. The stones below this are of unknown thickness, but measure 145x40cm and were mortared in place. These too, however, could have been added after the initial construction. Elswhere in the portion of the abutment likely to have been constructed by the moors the stone sizes range between 45x25cm and 35x25cm. All work appears to be of a soft sandstone.

Arco del Darro

Proceeding down the rio Darro from the Aljibillo one passes several other picturesque single-span bridges whose construction suggests that they were built after the Moorish domination of Granada, before rriving at the impressive foundation of a bridge which crossed the Darro. The bridge served a dual purpose: it was used to cross the river to the bathhouse and the town, and it provided protected access to the water of the Darro in the time of an attack upon the fortress on the hill above (Maldonado 110). Access to the bridge

Arco del Darro

from the fortress was via a walled path down the hill; presumably this path led to a hexagonal tower built adjacent to the back of the bridge, which could be descended to gain access to the water below. The outline of a door and with a flat arch above remain in plain view in the foundation, although the opening has long since been filled in with brick masonry.

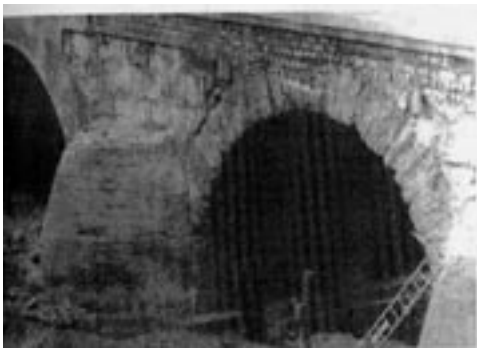
Maldonado commments that the hexagonal shape of the tower recalls

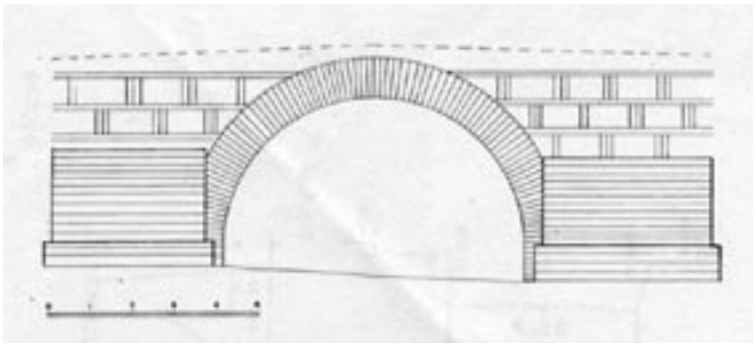
the angled breakwaters of other moorish bridges, which seems a reasonable assertion. The remaining stonework of the horseshoe arch of the bridge differs from other horseshoe arches found in moorish bridges elsewhere. Unlike the bridges at Pinos Puente, Guadalbacar, and Guadiato, the arch springs from a single row of stones turned on edge and cantilevered to form the bottom ledge of the horseshoe shape. The voussoirs begin immediatley above this course, in contrast to the three courses of stones turned on edge that is characteristic of the other bridges mentioned. This single course of cantilevered stone upon which voussoirs are layed occurs elsewhere in moorish Architecture, such as Corral de Carbon in Granada, commonly attributed as being from the 14th century, and in various arches in the interior and exterior of the mosque in Cordoba, but rarely in bridges. It also seems significant that this is the only single-span Moorish bridge which utlizes a horseshoe arch; the horseshoe arches generally occur on the smaller spans of bridges surrounding the longer main spans, as is the case in puente de Pinos Puente, bridge over the Guadbacar, Guadiato, and Nogales rivers. It seems possible that the unique configuration of the voussoirs of the Arco del Darro among bridges has to do with a more cermonial aspect of the bridge related to its proximity to the Alhambra.

Puente sobre el Rio Genil

The third bridge of probable Moorish provenance in Granada crosses the Rio Genil below its confluence with the smaller Darro, which passes through the center of Granada underground. The five span stone bridge presently functions as a pedestrian bridge, although it appears as through it could easily support traffic. The bridge consists of five semicircular spans of slightly different size. The spans originating at the abutments measure 5.5 meters, while the central span measures approximately 7 meters. The piers are all approximately 4.5 meters wide, pointed upstream and semi-circular downstream in a common

Puente sobre el Rio Genil





Puente sobre el Rio Genil
Puente de Pinos Puente

Moorish configuration. It is difficult to get a sense of the stonework in the majority of the bridge, as it has been parged in concrete for most of its length, although some of the parging has been removed to allow a view of a number of the voussoirs. The voussoirs from a distance appear to be of the soft stone and dimensions common to Moorish bridges, including those of Granada. The present bridge rises .75m from both ends toward the center, in accordance with the slightly larger central span, although it appears flat in the elevation drawn by Maldonado. It is possible that the road surface of the original bridge was flat, although the road surface presently follows the angle of the sides of the bridge. The sides of the bridge above the road surface appear to have been added later, being of a stone that looks newer than the rest of the stones of the bridge.

Puente de Pinos Puente

The town of Pinos Puente, approximately 12 kilometers northwest of Cordoba on the old road to Granada, has an impressive stone bridge whose Moorish provenance is visible in the horseshoe arches of the two spans flanking the longer center span. The town of Pinos Puente is less picturesque than the bridge itself, which has impressive mounds of garbage collecting at both ends and in the river below and is still in active service. The right and center spans

Puerta de Sevilla, Carmona

Puente de Pinos Puente

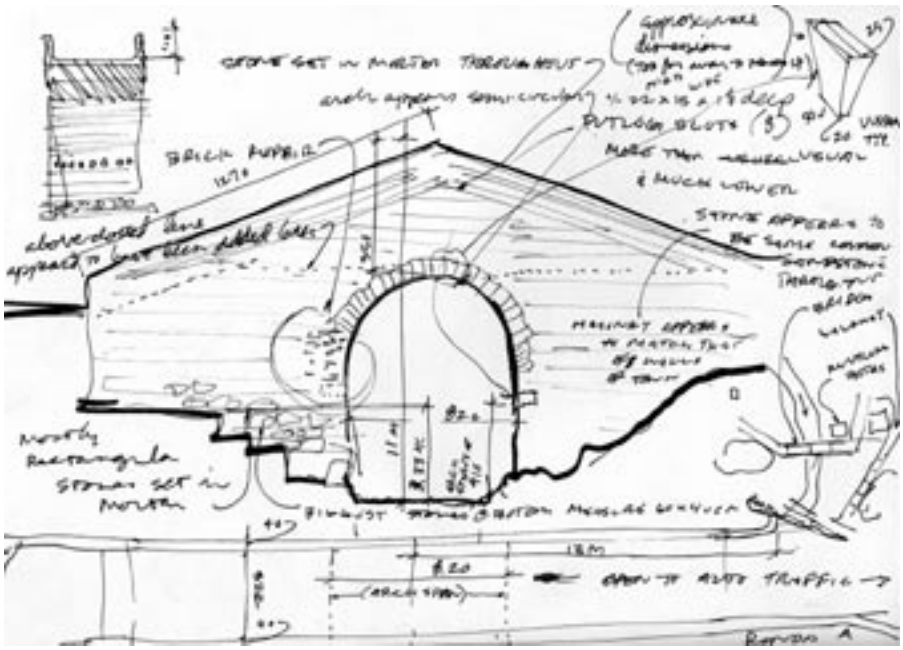
measure 6.5 meters and 10 meters respectively, with the left hand span visually in the vicinity of the right hand span. The bridge is massive in every way, with the road two full meters above the extrados of the arches. The piers are close to 5 meters wide, projecting close to 3 meters from the up- and downstream faces of the bridge. The breakwaters are semicircular above and rectangular below, in accordance with many of the Moorish bridges so far investigated. The size of the stones match the scale of the bridge: the faces of the stones of the piers measure 90x55cm, with the perimeters of the faces dressed in a way that was not observed in any of the other bridges of the investigation. Maldonado claims that the stonework of the bridge of Pinos Puente is similar in appearance to that of the addition to the Mosque of Cordoba performed by Abd ar Rahman II, and he further notes that the notched voussoirs are similar to the puerta de la ciudad, in Tarifa (120). The same configuration is visible in the Puerta de Sevilla in Carmona.

The horseshoe arch on the right side of the bridge begins with a course of stones carved in the shape of a cove; above this are three courses of stones 50 cm high laid on edge, upon which rest the regular voussoirs of the arch, which measure 25x42cm at the intrado, of a height of approximately 85cm, although lack of clear access made precise measurement difficult. Still more difficulty was encountered in the form of a pack of children from the town, whose shouts from the bridge above soon gave way to jeers. Ultimately they drove me from my work beneath the arch of Pinos Puente by throwing clods of dirt, followed by stones when the former did not have the desired effect.

Puente Arabe

Puente Arabe

In Ronda there is a bridge of disputed origin which still carries vehicular traffic over the rio Guadalevin at the southeast end of the Tajo gorge. Next to the bridge there is a fine museum of Moorish baths which are attributed to the 12th century in the museum literature. The bridge crosses the river in a single span measuring 8.2 meters between abutments by 4meters wide. The arch is semicircular rather than horseshoe shaped, which is common for single span Moorish bridges, with voussoirs measuring approximately 50 cm high, rather small for the length of the span. The stones are set in mortar throughout the bridge, which has a pronounced angle leading to its center, 3.5 meters above the intrado of the keystone of the arch. The chevron elevation of Puente Arabe seems more characters tic of medieval Christian than Moorish bridges, although Guadalbacar also may have had such a shape. In the case of



Puente Arabe

the puente Arabe, however, there is ample evidence to suggest that the present shape of the sidewalls above the arch is not the original configuration of the bridge. Inspection of the upriver face of the bridge suggests that the masonry above an horizontal line corresponding with the extrado of the keystone does not match the rest of the bridge in either color of the stone or construction method, suggesting that this material may have been a later addition. Thus the bridge as originally constructed may have been flat. The eight putlog slots at either abutment are much lower relative to the arch than is generally the case in Moorish bridges; they are located 4.2 meters from the water, at the lowest springing of the arch. Brick repairs to the left hand springing of the arch are evident on the upstream side. The stone of the lower portion of the bridge appears to match the stone used elsewhere in construction in the town.

General Characteristics of Moorish Bridges

The horseshoe arch is most obvious defining characteristic of a Moorish bridge. How do we know that this is a sign of Moorish construction? The horseshoe arch appears in religious and governmental buildings of indisputably Moorish origin. These include the mosque in Cordoba, the Alhambra in Cordoba ,and the Alcazar in Sevilla. Moreover, various city entrances dating from the Moorish period display this shape. These examples should suffice to show that this configuration can safely be attributed to the Moors. At the outset of this project I expected the ogival, or gothic arch to be the defining characteristic of Moorish bridges, because examples of gothic arches are to be found in Syria as early as 561 AD (Hill 88). However, not a single bridge visited in the course of this investigation exhibited an ogival arch.

The geometrical characteristics of the horseshoe arch in Moorish bridges are generally constructed as follows: an horizontal stone laid on edge

Left: Corral del Carbon
Right: Mezquita

cantilevers to forms bottom course. This is generally followed by two more horizontal courses on edge, followed by voussoirs generally of a softer stone, 65-100cm high, laid flat. Putlog holes generally occur in the third course of horizontal stone set on edge. This indicates that the first three courses were laid before any centering was built. The flat voussoirs would then be laid over the centering. Voussoirs utilized by Moorish builders are considerably narrower than those of their Roman counterparts. Most common sizes are 25cm at the bottom, widening to 35 or 40 cm at the top, 70-105 tall, and up to 90cm long. The maximum height of a voussoir observed was 110 cm. This number was never exceeded, even when the voussoir was split into two pieces. Some of the bridges utilize a distinct type of stone for fabricating voussoirs and another in the rest of the bridge. In every bridge visited the voussoirs were shaped from a soft brown stone which appeared to be sandstone, perhaps chosen for the ease of working it into the long this shapes favored by Moorish builders. Every vault observed made use of stretcher bond.

The configuration of the coursing and geometry of the horseshoe arches seems to indicate that the builders were at least partly aware of the behavior of forces within the horseshoe arch. The shape is structurally inefficient, but the reason for adopting this shape might be more ceremonial than structural. This would accord with its use in peripheral spans rather than larger center spans of the bridges. No one-span bridges were observed with a horseshoe arch other than Arco del Darro, whose form might be expected to be exceptionally ceremonial due to the location and function of the bridge. Stones are generally configured in accordance with the forces acting within them to resist sliding. The line of intrados was never observed to go outside the vertical line of support of the columns, which would result in a dangerously weak shape.

The ratio of span to voussoir height generally falls between 1:3.5 and 1:12.5. This is a wide variation which is difficult to reduce due to the relatively low number of bridges visited. The range exhibited here is substantially lower than the range between 1:10 and 1:20 which O'Connor observes in Roman bridges. Extreme case in Moorish construction is Puente Arabe in Ronda, where the ratio exceeds 16, but this is an isolated case. The span to pier ratio is generally greater than 1:1.5 and less than 1:2.2 . This is a reasonably modest number, when compared to the range of 1:2 to 1:5 given by O'Connor for Roman bridge construction.

Lastly, it seems nearly certain that the Moorish builders made use of some sort of machinery for lifting the stones when erecting bridges. Such a machine would be necessary for the large-sized stones weighing upward of 1,100 pounds encountered in many of the bridges, and the theory is further strengthened by the presence of holes possibly used for lifting in the bridge over the Guadalbacar.

Conclusion

The bridges documented in this study show that the Muslim builders in Andalucia were capable of erecting sophisticated structures requiring advanced structural understanding. That many of these bridges are still standing a millennium or more after their completion is convincing testament of the knowledge of their builders. The accomplishment is not diminished by the presence of Roman bridges, of which they were doubtlessly aware. Two bridges might be indistinguishable to a casual observer at their completion, but constructed by vastly different processes. These processes by which a structure is realized are as important as the overall design and the material from which it is fabricated. Unlike the other two aspects of construction, which persist long after the builder has left the site, the process is lost when the culture of the builder disappears. At the time of the Muslim's arrival on the Iberian Peninsula, nearly 500 years had passed since the last of the Roman builders had raised a stone there. It is one thing to appreciate a bridge, and another to possess the skill and understanding to build one. While acknowledging the Moorish invention of original constructional processes, we should not lose sight of the fact that the bridges built by the Moors are far from identical in either design or material to their Roman precursors. Rather, the Moorish builders used their structural knowledge to create a unique geometry, the horseshoe arch, which was theirs alone. A bridge is a technological expression of a culture. Hopefully this field research offers a foundation to begin to appreciate the of advanced knowledge and method of the Muslims in Andalucia in bridge design and construction.

Appendix I

Name and Location of Bridges

Name	River/ Stream	Town	Number of Spans	Longest Span	Height	Voussoir Height
Puente Aljibillo	Darro	Granada	1	7.32m	3.1m[1]	
Arco del Darro	Darro	Granada	1			
Puente sobre el Rio Genil	Genil	Granada	5	7.02m[1]		80cm
Puente de Pinos Puente	Cubillas	Pinos Puente	3	10.58m[1]	5.05m[1]	
Puente Romano	Guadalquivir	Cordoba	15	12.82m[1]		
Puente Nogales		Cordoba	3	2.9m	1.2m	80cm
Puente Califal sobre el arroyo Cantarranas	Cantarranas	Cordoba	1	4.79m	2.63m	100cm
Puente Califal sobre el Guadiato	Guadiato	Cordoba	9	8.30m	2.8m[1]	65cm
Puente Quebrado	Bembezar	Hornachuelos	4	7.9m[1]		95cm
Puente Sobre el rio Guadalbacar	Guadalbacar	Setefilla	3	8.3m[1]	3.9m[1]	105cm
Puente Arabe	Guadalevin	Ronda	1	8.2m	3.4m	50cm

Appendix II

Ratio of Spans to Piers and Spans to Voussoirs

Bridge	longest span (cm)	pier width (cm)	voussoir height (cm)	span/ pier	span/voussoir
Puente Aljibillo	732		65		11.3
Puente Sobre el rio Genil	715	482	80	1.5	8.9
Arco Del Darro					
Puente de Pinos Puente	1058	478	86	2.2	12.3
Puente Romano*	1040	700	90	1.5	11.6
Puente Nogales	291	220	80	1.3	3.6
Puente Califal sobre el rio Guadiato	830	375	105	2.2	7.9
Puente Califal sobre el arroyo Cantarranas	479		100		4.8
Puente Quebrado (Hornachuelos)	790	300	110	2.6	7.2
Puente sobre el rio Gaudalbacar	830	410	105	2.0	7.9
Puente Arabe	820		50		16.4
*Puente Romano span and voussoir taken from section most likely to be of moorish origin					

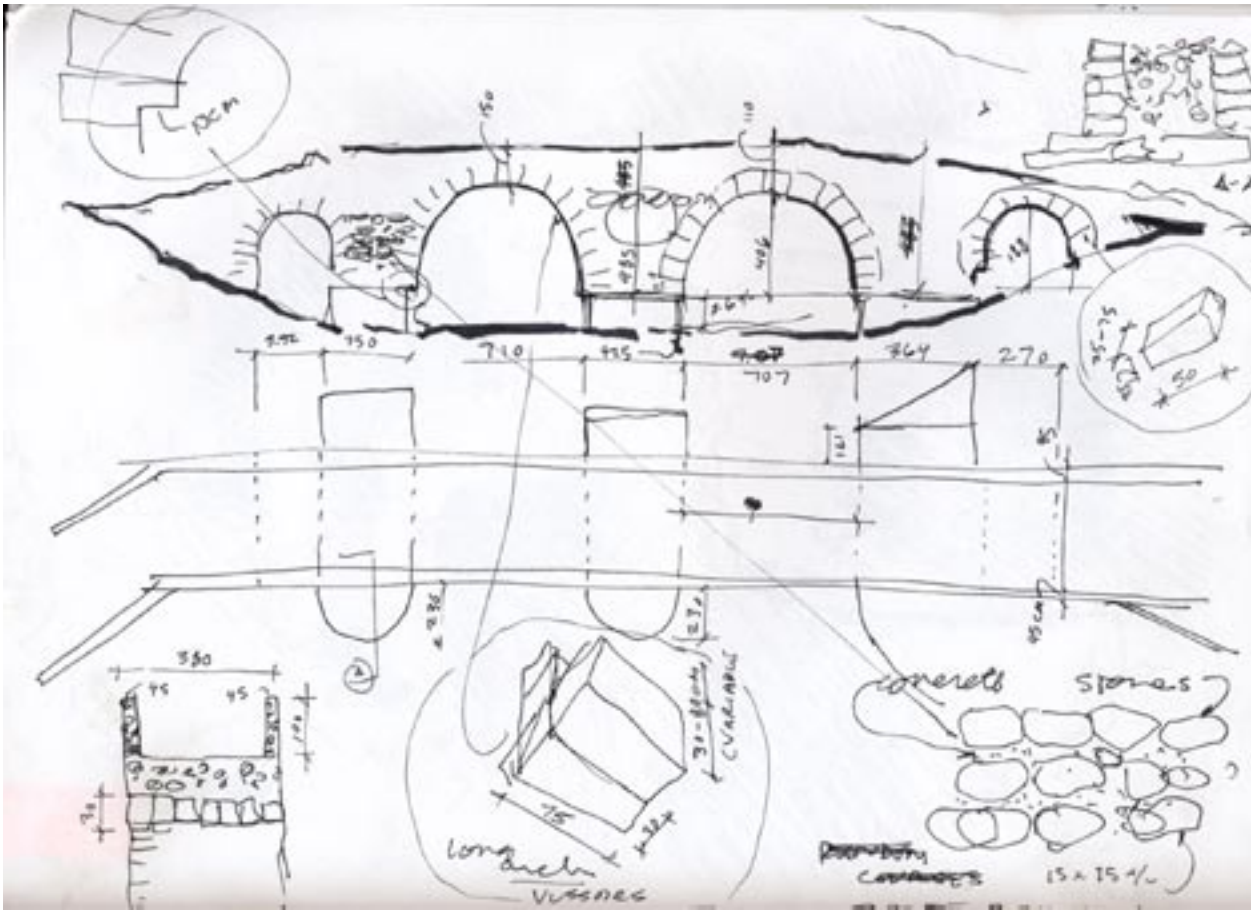
Appendix III

Puente Romano

span letter	span (cm)	pier #	pier width (cm)	shape of pier upsteam	shape of pier downstream	remarks (Maldonado)	likely provenance
Mezquita Side (NW)							
a	1282					segmental	
		1	?	pointed	semicircular	breakwater similar to Moorish construction	
b	948					ogival	
		2 (26,25	950	pointed; step back pronounced	semicircular	breakwater similar to Moorish construction	
c	975					ogival	
		3(24-23	1003	pointed; step back pronounced	semicircular	breakwater similar to Moorish construction	
d	1031						
		4(22-21	1040	pointed; step back pronounced	ogival	upstream breakwater ogival	Medieval Christian
e	1049						
		5 (20,19	1064	pointed	semicircular		Medieval Christian
f	1078						
		6(18-17	1095	pointed; step back pronounced	semicircular	breakwater similar to Moorish construction	
g	1112						
		7(16-15	1150	pointed	rectangular	breakwater similar to Moorish construction	
h	1188						
		8(14-13	600	pointed	semicircular	upstream breakwater ogival	Medieval Christian
i	1188						
		9(12-11	600	ogival	semicircular	breakwater similar to Moorish construction	Medieval Christian
j	1198						
		10(10-9	550	ogival; stepped back	semicircular	upstream breakwater ogival	repairs 17th-18th Century
k	1021						
		11(8-7	500	pointed; step back pronounced	pointed	upstream breakwater ogival	repairs 17th-18th Century
l	1000						
		12(6-5	700	pointed	ogival		repairs 17th-18th Century
ll	1003						Roman/Moorish
		13(4-3	700	pointed	ogival	pointed downstream	repairs 17th-18th Century
m	1040						Roman/Moorish
		14(2-1	700	rectangular			Medieval Christian
n	1040						Roman/Moorish
		15	700				Medieval Christian
n	793						Roman/Moorish
Torre de la Calahorra (SE)							

Appendix IV

Puente sobre el Guadanuño



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