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Techniques, designs and terminology of elevation of stonework bridges during modern age

Begoña Arrúe Ugarte

The analysis of handwritten sources related to the construction of bridges during the Modern Age, which began during the elaboration of the catalogue of bridges in La Rioja (Arrúe and Moya, coord., 1998), let me present to the First National Congress of Construction History (Arrúe 1996), a preliminary study on the system of foundation under the water used in their building. The paper I present today aims at completing the findings those sources add to the knowledge of implementation of elevation of bridges and at establishing some conclusions about the models, techniques and terminology generalized during that period in the context of Castilla, connecting them with the ones defined in the contemporary construction of bridges in other Spanish regions and in France, the nearest references, as well as to the ones proposed by the theorists of architecture.

Legalized written documents of contracts for the building of a bridge go with full constructive conditions which, very often, focus upon the types of foundation to follow. Their relevance for the survival of the building is shown in the presentation of the layouts or detailed plans on the grillage or pile foundation must be carried out, especially in repairing projects. This is the case in, for example, Manuel del Olmo's for the bridge of Viveros upon the Jarama, Madrid, around 1686 (Corella 1992, 166), or Juan Martínez's and Martín de Urtázar's 1694 for the repairs of the bridge in Nájera upon the Najerilla along St. Jacques Way through La Rioja (Arrúe and Moya, coord., 1998, 1:423). But, at the present time, we are interested in highlighting the methods used for the elevation of the fabric after the conclusion of the works of foundation and the previous disposition of caissons, in the way they are documented in the projects of the work contracts.

The foundation done, they go ahead with the building of piers. The use of this term was not common until the XIX c. being more general in the revised documental sources from the XVI to XVIII c. the terms *cepa* or *machón*. The term *pilar* was also used preferably along the XVI and the first half of XVII c.[1]. The author of Tratado de Arquitectura, preserved in the National Library, in the middle of XVI c., mentions *pilares* (Anonymous, c 119, 225), and also Simón García in *Compendio de architectvra y simetría de los templos* . . . . 1681, which copies part of the treatise written by Rodrigo Gil de Hontañón in the XVI c. and, also, the *Arte y Uso de Architectura*, by fray Lorenzo de San Nicolás, 1639 and 1664, who uses *cepa* (Huerta 2000, 521). On the other hand, in *Los veinte y un Libros de los Ingenios y Máquinas*, written for Felipe II between 1564 and 1575, attributed first to the king's engineer Juanelo Turriano and then to Pedro Juan de Lastanosa (Pseudo Juanelo Turriano 1983; García 1989, 33- 39; García 1990, 74–137), the book 18 is dedicated to the implementation of the *pilas* of the bridges, which would have cutwaters up and down the stream as *proa* and *popa*. The anonymous treatise will also mention them during the elevation of the work: «que el pilar a de tener figura de barca con proa y popa, en la proa se rrecibe la corriente del agua y en la popa se despide, y sobre cada una dellas se lebantan dos estribos aplicados a los lados de la puente para la firmeza della» (Anonymous, c. 119, 227). Consequently, piers with their cutwaters on the bed of the river and buttress on both banks are differentiated. But this terminological distinction is not always so clear cut in the prescriptions of the projects. Fray Lorenzo de San Nicolás himself talks about buttress or cutwater to refer to the strengthening of the *cepas* up or down the stream (San Nicolás, c. LXI, 170), and Simón García uses cutwater for both sides of the pier even with different form. Written sources, which use generally both terms, tend to name cutwater to the part against the stream and buttress to the one with the stream. Since Middle Age, the term *cuchillo*[2] is also used, as in the author of *Los veinte y un Libros*. The tip of the upstream cutwater is usually referred to as *nariz* like in fray Lorenzo de San Nicolás, and previously documented in handwritten sources in La Rioja.[3] Less frequent in Castilla seems to be the term *espolón*, taken by Covarrubias in his Dictionary, 1611, as a synonym of *nariz* or tip in the *cepas* and *pilares* in the bridges. Its use is recorded in La Rioja in written form not before the XVIII c.[4]

These notions on terminology, apart from their lexicographical interest, can also be of use when planning the calculation of the thickness of the piers related to their height and the span of the arches, and the necessity, or not, of having the same dimension for those which support the strength of two arches and for the buttress in the banks which support only one. Spanish theorists and builders don't seem to differentiate between the central piers of the bridge and the lateral buttress in the work because their naming is indistinct. This distinction is stated by Mesqui for whom the *Traité des Ponts* by Henri Gautier, 1714, is the first one to differentiate between *piles et culées* in the laws of proportion for the stability of the work (Mesqui 1986, 181). Generally, in historical bridges the same laws are applied for piers and buttress but it has to be taken into account that these usually depend on the thickness the work gets when it emerges from the level of the water because the construction masters strengthen the base with a bigger platform. Let's go over the work of the piers they propose to comment later on the dimensions and forms they design for cutwaters.

On the founding they proceed to the elevation of the pier with the best quality stone, well squared and worked with mattock, settled in plumb line and leveling. The construction takes two systems depending on the preferences of the master of the project: 1 complete solid ashlar in the whole thickness of the pier, in the first courses or up to the spring of the arches; 2. Ashlar work with headers and through stones[5] in the first courses and continuation of the elevation with ashlar to the outside and filled with rubble and gallet or *médula*. The first system is less frequent but it is sometimes a requisite as in the conditions of 1588 for the rebuilding of the bridge in Cuzcurrita upon the Tirón.[6] Figure 1, or in the project of nine piers for two bridges of wooden board upon the Leza and Jubera in 1629.[7] The second system is the common one with variations in the placement of headers and through stones in the first courses. For instance, Juan Raón in the project of 1657 for a bridge in Alberite upon the Iregua, Figure 2, proposes to harness the ashlar work with headers, 5 to 6 feet long —castellan foot—, and 4 to 5 base in each course and in stretches of 6 for 6 in a height of 4 feet, and with two courses of through stones which would cross the whole interior of the pier (Arrúe and Moya, coord., 1998, 1: 499–503, 2: 870).[8] The relevance of the good joining of the work of the piers stated in these examples, can also be seen in the contracts in other regions like in the constructive conditions in Lerma, Burgos, upon the Arlanza, signed around 1573 by very well known architects like Miguel de Nates, Juan de Naveda, Juan del Río Alvarado, Pedro de la Torre o Diego de Sisniega, among others (Cadiñanos

Figure 1
Bridge of Cuzcurrita del Río Tirón, La Rioja

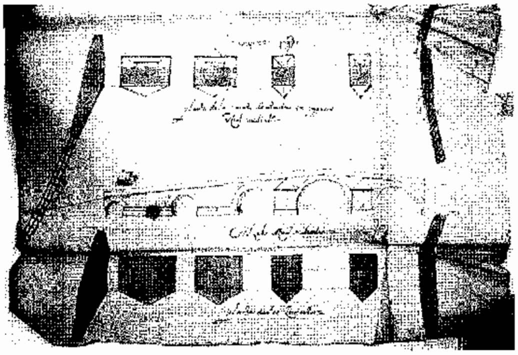

Figure 2
Plan by Juan Raón for the bridge of Alberite upon the Iregua, La Rioja. 1657 (Archivo Municipal de Logroño)

1996, 42), Juan Gómez de Mora in 1619 for a bridge upon brook Abroñigal in Madrid (Corella 1994, 21), and in other ones from the XVIII c. like those in Álava (Azkarate and Palacios 1994, 266–267), or Vélez, Málaga, designed by Domingo Tomás (Camacho 1992, 350). This practice shown in the contracts is advised in the treatises although without specification of small details of construction. In this way, the author of Tratado de Arquitectura XVI c. proposes the use of big stones and a great number of through stones or crossbeams in the base of the piers: «Pero asi la proa como la popa conviene que sean de piedra muy rrecia y que la agua no la gaste y lo de dentro del cuerpo del pilar debe ser hedificado de grandes pieças o muchas atrabiesas porque con muchas firmezas sustiente los conbates del agua» (Anonymous, c. 119, 228–229). In the work by Simón García we find «grandes y fuertes piedras bien travadas y grapadas» (García 1681, fol. 41 v.). Fray Lorenzo de San Nicolás proposes to fill the piers with the biggest stone possible and the heart with good mortar and smaller stones (San Nicolás, c. LXI, 170).

The settling of the ashlar work was made with good lime mortar, usually a mixture of lime and sand fifty fifty which, occasionally, was reinforced with double the lime in the rubble work of the foundation.[9] It is also documented the use of iron staples specially in repairing works like in the ones projected by Juan Ochoa de Arranotegui on the bridge of Santo Domingo de la Calzada upon the Oja, in 1562 (Moya 1980, 2: nº 360), Gaspar de Vega for the bridge in Viveros, c. 1569, with six pounds weight each staple (Corella 1992, 158), and the masters Olate, Pérez de Obieta and Rodrigo de la Cantera in the rebuilding of the bridge in Logroño upon the Ebro, in 1587, where we find staples of one ounce thick, two ounces and a half width and four ounces spigot (Arrúe and Moya, coord., 1998, 2: 853).

The base of the piers is built on a bigger surface than the elevation when it emerges from the water, like in fray Lorenzo de San Nicolás when he remarks that to the piers it should be given good baseboards or *zarpas* «para que queden bien bañadas» (San Nicolás, c. LXI, 170). In the practice of the studied constructions the section of the pier can reach in the base up to four feet wider along the perimeter (1,12 m). In the Treatise by Simón García it is stated, following the rule of Alberti, that the inferior thickness in the pier is double the superior part (García 1681, fol. 41 v.), but it doesn't seem to have reached that proportion in practice. This thickness decreases gradually by means of *dejas*[10] or footing, half foot in each course. This reduction is done usually in plumb line, not being the slope documented in La Rioja until the XIX c. although it was in Álava in the repairs of 1736 of the bridge Marubay in Catadiano (Azkarate and Palacios 1994, 262). As far as the relation between the height and the width of the piers, we can see, with exceptions the preference of extending the pier with its cutwaters once and a half the thickness during the XVI and XVII c., then becoming into twice and a half in the XVIII. Nevertheless, in the project of 1562 for the bridge of Santo Domingo de la Calzada, a length of triple the thickness is proposed although the parameter of the width of the vaults must be consider as well as the measure given to the span of the arch. Related to this, Simón García advices in his work to give for the area of the pier half the surface resulting of the multiplication of the span of the arch for the width of the vault. Of this result, three parts would be given to the upstream cutwater and two to the one downstream (García, fol. 40 v.). In the examples analyzed by Mesqui, French builders tend to the proportion 1/4 for the thickness of the pier in relation to the span of the arch rejecting the extreme 1/6 proposed by Alberti, and avoiding the possible risks in the work (Mesqui 1986, 182). The builders working in La Rioja, as well as the authors of the projects, seem to know the advice of the writers of the treatises, because in the preserved bridges or in the documented which have been researched, the trend during the Modern Age is to a thickness of 1/3 or 1/4 of the span of the arch. The anonymous treatise on architecture will follow the proposal of Alberti between 1/3 and 1/6, or a thickness of a quarter of the height of the bridge (Anonymous, c. 120, 232), but fray Lorenzo de San Nicolás will take fewer risks when suggesting for the pier a thickness of half the span, proportion we can see in the examples in La Rioja in the XVI c. but in the base or area under the water. The written sources we study do corroborate the implementation of geometrical rules in the constructive practice (Heyman 1995; Huerta 2000), although the knowledge could come from oral sources as the Comissioner of War Marcos de Vierna remarked when supervising some projects for bridges of the XVIII c., and not all the masters would be acquainted to the same extent with the works of the theorists.

The elevation of the piers follows two models used along the three centuries of the Modern Age: 1. lengthening of cutwaters to the grade line forming lay by in the causeway up and down the water; 2. the top in the wall face of the bridge from the beginning of the arches or in different levels in the spandrel areas. The first one is considered as a follow up of the medieval designs but the fact is that the contribution to the safety of the construction, and the space it provided to the causeway and the seat to the passers by, and even the availability for war, commercial, religious or commemorative building, made of it a great success as shown in the constructive practice. This one will be the common model in the north of Castilla and, specifically, in La Rioja, a region of intense activity of building of bridges having the privilege of the passing of the river Ebro and six tributaries to it in spite of the small geography of the area, Figure 3. This model, however, could be ascribed to the practice of masters from Cantabria, around 50% coming from Trasmiera during the XVI c. are documented as active in the region. It went on being used preferably in the following centuries in works done or supervised by specialists from very diverse origin brought in by the contract part or by the Consejo de Castilla. From the XVIII c. on it was kept by local masters, some of them like Francisco Alejo de Aranguren sanctioned by the Academia, which will send other members for the control of the projects to carry out the order by Carlos III in 1777, like Diego Ochoa or Manuel Ángel de Chavarri. In spite of the fact that more erudite models are not unknown, this system is kept in works of certain relevance and new planning up to the end of the XVIII c. like in the bridge of Torremontalbo upon the Najerilla. This was a work carried out between 1790 and 1794 with an intention of modernity, protected by the Real Sociedad Económica de la Rioja Castellana, in the way from Logroño towards the border of La Rioja which would link with the one in Santander and would benefit the exportation of wines, Figure 4.[11]

Figure 3
Bridge of Briñas upon the Ebro in Haro, La Rioja

The second model used in the classic period and proposed by the Italian theorists from Aberti, can take different forms in the top. The most simple is the crown by means of a perpendicular plane to the line of wall faces used by Alonso de Covarrubias, c. 1543,

Figure 4
Bridge upon the Najerilla in Torremontalbo, La Rioja

and Gaspar de Vega, c. 1569, in their designs for the bridge of Viveros. But the most widespread from the XVI on will be the one with two planes in double slope following the triangular section of the cutwater as in Juan de Herrera in the Puente Nuevo upon the Guadarrama, Figure 5. The end in conic *chaperon* shape with graded courses which will become general in the designs of the XVIII c., Figure 6, will also be used. It has not been preserved in bridges in La Rioja before the XVIII c., Figure 7, but a triangular cutwater design was presented by, probably, Juan de la Portilla for the Bridge-aqueduct of Zamora in Cervera del Río Alhama, in 1653, later on modified so as to lengthen it to the grade line (Arrúe and Moya 1998, 1: 653–654). In the same way, Juan Raón would use this type of pier in his design of 1657 of the bridge in Alberite, the cutwaters crowned in double slope under the parapets to the level of the extrados in the arches in two of them and to the spring in other two. The down stream cutwaters, on the other hand, are crowned with a hood bell shaped and a ball in the top, Figure 2 (Arrúe and Moya 1998, 1: 500–501). The placement of the ball in that area, element related to the architecture in El Escorial, is found in France in the Bridge Charraud upon the Sedelle in Crozant, not finished until 1695, and in the Bridge Wilson upon the Loira in Tours, at the end of the c. XVIII, Figure 8 (Prade 1986, 229, 151). In Spain, from the designs by Herrera on, the balls are placed in the crown of the parapets in plumb line with the cutwaters, as intended for La Rioja in 1639 Domingo de Urruela y Velasco in the bridge of Calahorra, where the balls themselves would be of weight and constructive function, as suggested in fray Lorenzo de San Nicolás (Arrúe 1998, 145).

Figure 7
Bridge upon the Tirón in Leiva, La Rioja

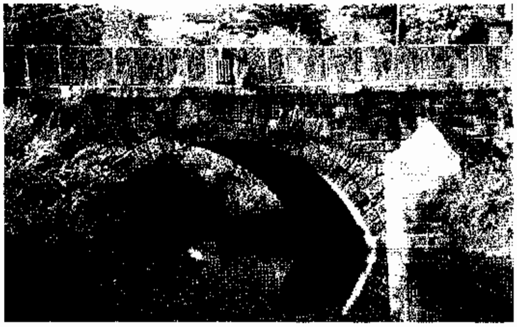

Figure 5
Bridge Nuevo upon the Guadarrama between Galapagar and Torrelodones, Madrid

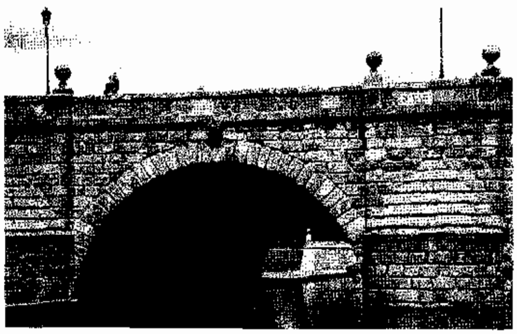

Figure 6
Detail of the bridge of Segovia in Madrid

Figure 8
Bridge Wilson upon the Loira in Tours

It seems that historiography shows more attention to the dimensions or height of the piers than to the form of the section of cutwaters. Along the Modern Age we'll see triangular, semicircular, trapezoidal and ogival up and down cutwaters independently of the continuation or not to the grade line as well as the use of mixed forms combining one and the others in the cutwaters themselves, or different in one or the other. The most frequent and «classic» is the triangular or angled for the tip and the rectangular for the down stream cutwater. The researched bridges with this typology in La Rioja have a variable angle for the tip from the right one (bridges in Ribafrecha, Villanueva y Brieva), the 80° or 82° (Igea, Cornago, Viguera), the 75° (Igea, Cornago) and the 65° (Leza). It seems that the proportion proposed by Alberti, 3/4 of the right angle or, if less salient is preferred, 2/3 of the right angle, is never reached (Alberti, l. IV, c. VII, 188). Fray Lorenzo de San Nicolás prefers the right angle and, however, a not too pointed angle to avoid deterioration as Alberti states (San Nicolás, c. LXI, 170 y 172). The author of *Los veintiún Libros* will prefer the obtuse angle to separate better the waters (Pseudo-Juanelo Turriano 1983, lib. 18: 486–528). The same variability of angles, always inferior to the right one, observes Mesqui in France (Mesqui 1986, 196–198).

Ogival form, also known by Spanish historiography *en huso* and the French *en amande*, is placed by Mesqui in France the area of Limoussin for the upstream cutwaters being the bridges of Saint-Marcial y Saint-Etienne de Limoges, XIII c., the main examples, Figure 9. He relates this form to the military architecture of the same period because it can be observed in towers of ogival section like in the Poiteau, Parthenay or Coudray-Salbart. For him, the hydrodynamic superiority of this typology has not been proved and he understands that this fashion is forgotten and then back in the bridge of Moulins, work by Jules Hardouin-Mansart in 1704 (Mesqui 1986, 197; Lombois 1993, 40–44). Also Prade coincides in signaling the rare use of the ogival cutwater in France, only upstream, during the c. XIII and XIV, and the frequent adoption of the form in the c. XVIII, when it is also used downstream (Prade 1986, 32). If this is the fact in the constructive history of bridges in France, it is not the one in the Spanish practice as we can not locate here contemporary parallels of the medieval French while in the XVI c. bridges of this cutwater

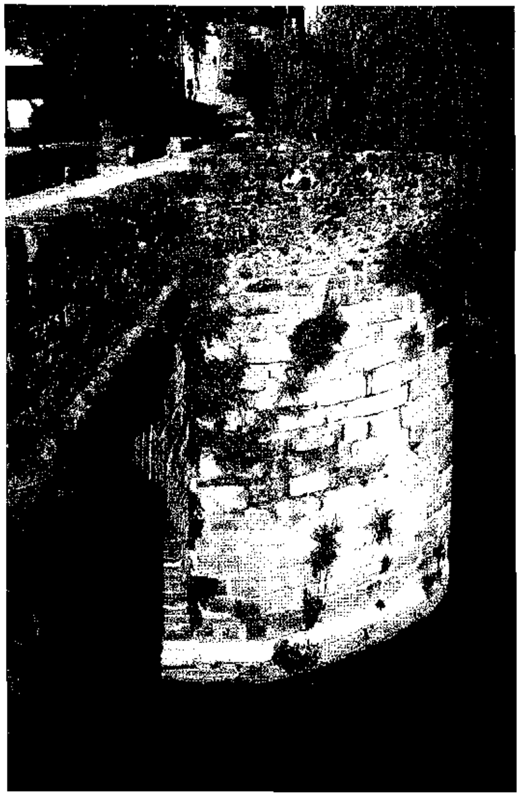

Figure 9
Detail of a cutwater in the bridge Saint Etienne upon the Vienne in Limoges

form were built. Because of this, its use during the Renaissance more than an answer to tradition can be considered as a novelty. As mentioned by Mesqui, it is probable that Alberti refers to this form when he accepts the semicircular cutwater excepts when it is not so obtuse or blunt to interfere with the speed of the stream (Alberti, l. IV, c. VII, 188). The anonymous treatise on architecture follows closely these rules: «Las popas y propas, si fueren rredondas, saldrán de la obra en figura de medio círculo y si son agudas em punta, saldrán quato la mitad de la anchura de la puente; o según otros, hácense en ángulo que sean dos terçias de rreto» (Anonymous, c. 120, 232). This relation of similarity between the round and the pointed cutwaters, or the ogival form, and the difference with the triangular, angled or acute manifested in treatises, is stated and clarified in the constructive conditions that Juan Pérez de Obieta, Rodrigo de la Cantera, Juan de Olate and Pedro de la Torre Bueras present in 1587 for the rebuilding of the bridge in Logroño upon the river Ebro. According to these masters, it was necessary to substitute some medieval piers with triangular cutwaters for others in ogival form because it was considered that these ones expelled better the water and undermined less: «los taxamares y ángulos dellos se arán como se muestra en la planta que son obrados apuntados para más fortaleça y perpetuidad, porque los que son agudos no son tan fuertes y seguros porque los ofende mucho más el agua quando los yere, ya que el agua no les dane los árboles y maderas que bienen los descalabran por ser delgados y en los rredondos se despiden mexor» (Arrúe 1998, 139–140).[12] A similar reform is undertaken in the bridge of San Vicente de la Sonsierra in 1594, Figure 10, with participation of, also, Diego de Sisniega, and in the bridge of Cuzcurrita, Figure 1. Pedro de la Torre Bueras uses it in his designs for La Rioja (Ezcaray, Torrecilla de Cameros, Viguera), Burgos (Buniel) or Cantabria (Arce), the latter one with Siniega himself and other masters from Cantabria, in 1585. A year before it had been chosen for the Puente Mayor of Palencia by Francisco del Río, Alonso de Tolosa, Juan del Ribero and Francisco de la Puente (González et al. 1991, 633 and 575), with piers of 14 and 15 feet thickness for spans of about 35 feet, which confirm the proportions mentioned above and used in contemporary bridges in La Rioja (Arrúe 1995, 167). But there are examples of ogival cutwater from the end of the XV c., like in Montoro (Córdoba), Figure 11, and its use during the three first quarters of the XVI c. in Castilla and León have been related to the military design by Francesco Di Giorgio Martini (Aramburu 1992, 62–63). It is not surprising then that the ground plane and the elevation of the bridge drawn by Simón García in his treatise contains ogival upstream cutwaters and rectangular downstream ones (García, fol. 41), although its elevation is crowned at the height of the spring of the arches as opposed to the continuation to the grade line preferred by the masters from Cantabria. It is likely that he would introduce in this way the proposals by Herrera, combining both typologies. During the XVII c. the preference for the ogival cutwater is confirmed in some projects in La Rioja —Murillo, 1629; Calahorra, 1637—, and it will be the common one in the projects of the XVIII c. like in those one by Diego

Figure 10
Bridge upon the Ebro in San Vicente de la Sonsierra, La Rioja

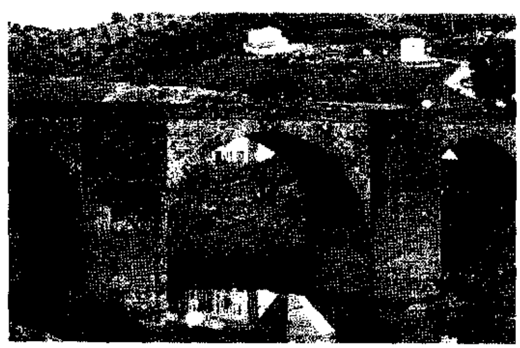

Figure 11
Bridge of Montoro upon the Guadalquivir, Córdoba

de la Riva for the bridge in Agoncillo in 1765 and Francisco Alejo de Aranguren for the bridges in Leiva in 1772, Figure 7, Pedroso in 1775 and Miranda de Ebro in 1786. These projects are revised by the Comissioner of War Marcos de Vierna, who designed in 1761 the bridge of Aranjuez upon the Jarama with ogival cutwater up and downstream, crowned with conic chaperon (Andrés 1989, 97–101). They will also be used by, for example, José García Martínez, captain of engineers, in 1770 for the bridge of Vélez-Málaga (Camacho 1992, 348), and we can see them in the bridges of Herreño and Retamar upon the Guadarrama in Madrid (Navascués 1985, 106–107), Figure 12. In the same way, they are designed by Perronet in the bridge of Chateau-Thierry, and with semicircular cutwaters in the ones in Mantes and Orleans (Perronet 1987, 169–171, 121–151, 194–236).

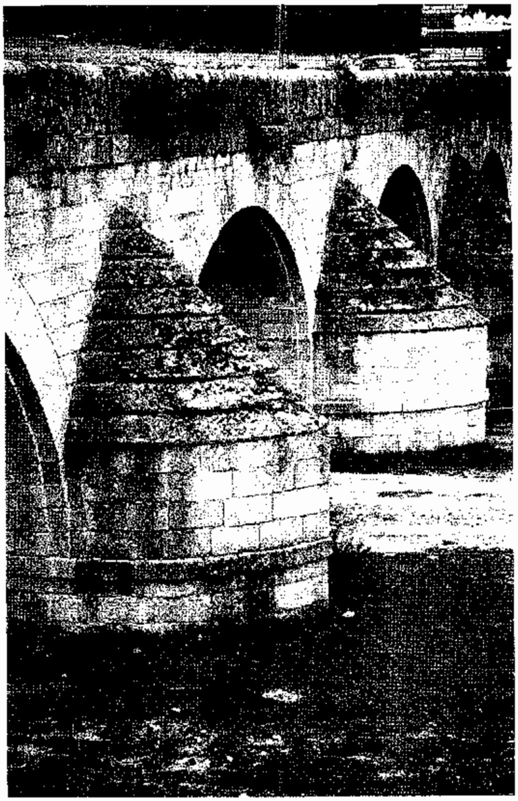

Figure 12
Bridge of Retamar upon the Guadarrama, Madrid

Semicircular shape will be frequent in Spanish bridges under the kingdom of Felipe II, like in Almaraz upon the Tajo in Cáceres, the one designed by Andrés de Vandelvira for Ariza in Jaén or Hernán Ruiz el Joven for Benamejí in Córdoba (González 1998, 124–133).[13] Its use down the stream is found in the mentioned bridge of Montoro, around 1500, and in the projects of the XVII c. by Gómez de Mora and José del Olmo for the bridge of Toledo in Madrid. In this bridge, Pedro de Rivera, in the beginning of the XVIII c., will lengthen the triangular cutwaters with semicircular buttress to the causeway so as to form lay by in it, against the opinion of Teodoro Ardemans (Navascués 1968, 54; Verdú 1993, 59). This combination of forms had already been previously used and one example is the bridge of San Marcos in León, work of the end of the c. XVI by Felipe and Leonardo de la Cajiga, in which cutwaters up and downstream are lengthened with semicircular headers up to the causeway (Fernández, Abad and Chías 1988, 212–217). Less frequent will be the use of the trapezoidal form, planned in 1578 for the Puente Nuevo in París, containing more mannerism than function according to Mesqui (Mesqui 1986, 197). It was used by Lucas Gutiérrez de Bargas for the cutwaters he planned in the Puente de Toledo (Navascués 1968, 55) and can be found in those ones in the bridge of Cornago upon the Río Linares, built at the end of the XVI c. (Arrúe and Moya, coord., 1998, 1: 670–473), or in the unique and contemporary bridge of Vilanova upon the Arnoia in Alariz, Orense (Alvarado, Durán and Nárdiz 1989, 231–237). All the mentioned examples show the variety of opinion hydrodynamics involved, but it must be remembered that repairs on a bridge along history are frequent becoming usual the modification of the elevation of cutwaters, like in the bridges upon the river Ebro en La Rioja. Because of this fact, documentary revision of the implementation of designs and conditions is always open (Arrúe 2000, 28–30).[14]

In the works of the elevation of the piers, the accommodation of the centerings to go round the arches is foreseen by means of corbel or short timbers (González 1998, 122), Figure 13. The contracts of construction do not specify the features of the centerings as it is a work usually sponsored by the council, as well as with the rest of the timbering and the nailing. However, we can find in them the necessity of the good joining of the springers and

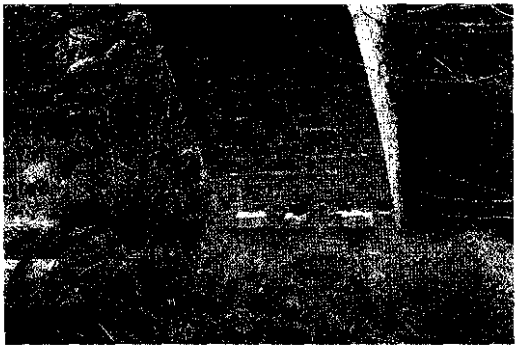

Figure 13
Central vault in one of the bridges upon the river Iregua in Viguera (km 313, N-111), La Rioja

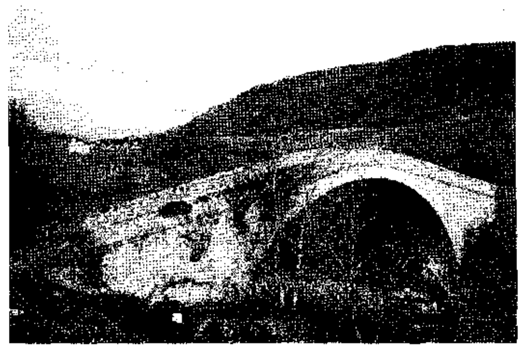

Figure 14
Bridge upon the Iregua in Pradillo, La Rioja. 1771

voussoirs with the ahslar of the cutwaters and buttress, even mentioning sometimes the seat of the voussoir without lime mortar, wedges, grouts or fillers. The action of vaulting of the arches is called *retumbar* or *retumbear*, the spring, *arrancamiento*, *retumba* or *retumbla*, and the arches *tumbas* (Anonymous, c.119, 229). In the Modern Age the most widely spread arch is the round one sometimes segmental, but it was kept along the XVI c. the pointed arch, of rise always inferior to 2/3 of span, and the basket and elliptic became frequent by the end of the XVIII c. For the thickness of the ring called *anillo*, *cabeza* or *batalla*, a measure of beds between foot and a half and four feet and a half is the usual one in the studied contracts (between 0,42 and 1. 26 m). We find differentiation also between the groins, with bigger size, and the voussoir of the rest of the vault.[15] These are usually of 0,56 × 0,84 m, with beds between 0,84 and 0,91 m. In specific examples like in the bridge of Pradillo upon the Iregua, designed in 1765 by Hilario Alonso de Jorganes, director architect of the royal way from Santander to Burgos, it is proposed to give to the bed or trasdos to the voussoirs a minimum of three feet —0,84 m—, four feet and a half for the groins —1,26 m —, split in two, and that in case those large pieces were impossible to find, a new ring was built (Arrúe 1998, 178–181). This bridge finished in 1771 as shown in the inscription, has only one arch of 27,20 m span and it is a clear example of the maintenance of sloped causeways during the Modern Age especially in mountainous areas, Figure 14 (Arrúe and Moya, coord., 1998, I: 462–470). But in general the trend is the flat causeway and an odd number of arches as indicated in the Italian treatises.

The master builders try to avoid the stress on the rings of the arches with a layer of rubble work, and they project the close of spandrels with another of ashlar of a course or a foot height, and two fingers or two inches of pad projection, as a uniform base in the causeway, marking in this way the grade line sometimes with outstanding rubble work. The author of the treatise on architecture of middle XVI c. devises a similar system: first medium stone with lime and above it thick and big stones (Anonymous, c. 119, 230). Over this layer of stone, the drainage system was settled to the height of the key stone of the arches or in cutwaters up and down stream, rising to the grade line. Marcos de Vierna will asign for these channels a measure of 0,42 m high, 0,56 m wide y 0,42 m pad projection, and the introduction in one impost of 0,42 m high and four fingers pad projection, in the additions Aranguren plans for the project for the bridge of Logroño in 1779. The contracts of construction used to give details of the implementation of the ledges for a good fixing of the work due to the frequent repairs and reforms they went through. Juan Raón will propose the use of iron staples in his project for the bridge of Alberite in 1657, but Diego de la Riva in the one in Agoncillo in 1765 or Aranguren in the one in Torremontalbo in 1778, propose to reinforce the joint by the opening of a hollow, parallel to the vertical of the parapet, later filled with lime and pebbles. The measures of the ledges are projected accordingly with the height of the bridge varying from 0,70 and 1,12 m high and 0,28 and 0,36 m wide. Fray Lorenzo de San Nicolás recommends the bigger possible thickness for the ledges because they do not only serve to the passers by but to the bridge itself, and points to the form of pedestal, with its base and entablature, and the balls on top of it. For the pavement he advises the paving with hard slab and moderately thick and cobblestone for very used bridges (San Nicolás, c. LXI, p. 171). In the bridges studied in La Rioja, the paving of the causeway, where the slope or convexity would be kept for the best drainage of waters, the characteristic medieval work is maintained: cobblestone pavement. The task is asigned to a professional stone paver, once the spaces are filled with grougs of lime and stone. In general, this pavement was organized in streets or cross streets signaled by lines of stone very big in the center and other smaller ones crossing forming boxes filled with pebbles. This system seems to be common to other regions —for example those ones proposed by Francisco de Arcilla for the bridge in Cacabelos in 1524–1525 (González 1987, 26), or Juan Gómez de Mora in 1619 for the bridge of Ventas (Corella 1994, 21–22)—, although it differs in the measures of the boxes of stone pavement, Figure 15 (Arrúe 1998, 182–187). The width of the causeway tends to vary between the 2,75 m and 5,5 m, dimensions to oblige during the XIX c. to the widening of the boards and the resulting modification of the aspect of the historical bridges.

figFinally, with no time to pose other questions related to the nature of the materials or the decorations of the works,[16] it is worth mentioning the condition expressed in the constructive prescriptions of plastering with lime the wall faces, finishing that has not reached our days. It is documented in La Rioja, for example in the bridge of Nájera in 1694, in the one of The Penitencia in Logroño in 1743, or in the one in Leiva of 1772, and it is confirmed in the conditions of Bartolomé Hurtado of 1668 for the bridge of Ventas, who, among others, proposes to plaster everything with good white lime and good sand (Corella 1994, 27).

All the data above mentioned show clearly the variety of typologies in the elements of the bridge during the Modern Age. Practical experience evolves into a progressive safety in the dimensions of the structure, validated by a theory that even proposes models looking at examples from classic Rome. But, apart from them and from peculiar realizations, those designs which solve the necessities the work presents within geographical contexts in the daily construction, are the ones adopted. That is the reason of the survival of sloped boards or of the lengthening of the piers up to the causeway. Symmetry among the parts and regularity of bonds is the tendency doting with uniformity and weight to the appearance of bridges. Decorations are «modernized» be the bridges from the Renaissance, the Mannerism or the Baroque periods but the inherent dynamic to this type of work does not allow to establish categorical changes in typology during the Modern Age. These changes would materialize and generalize clearly along the XIX c.

Figure 15
Detail of the road in the bridge upon the river Iregua in Villoslada de Cameros, La Rioja

Notes

1. For reference of terminology to handwritten sources, chronology and dictionaries, see the Glossary of terms included in *Catálogo de puentes anteriores a 1800, La Rioja* (Arrúe and Moya, coord., 1998, 2: 936–979).
2. The term is used in the document of obligation of 1377 signed by Mateo Gil for the repair of the bridge of Viveros upon the Jarama en Madrid (Corella 1992, 155). In the repairs of the bridge of Logroño upon the Ebro in 1587 it is planned to take seven courses apart «por la parte del cuchillo» and four «por la parte del estribo». The signature of the archive and the transcription of handwritten sources referred to La Rioja are found in the Catalogue mentioned above. I will refer to it so as to avoid long documentary quotes (Arrúe and Moya, coord., 1998, 2: 855).

3. In the conditions of 1562 for the repairs of the bridge in Santo Domingo de la Calzada, proposed by Ochoa de Arranotegui (Moya 1980, 2: nº 360). García Salinero does not locate it in the *Léxico de Alarifes* until the translation by Miguel de Urrea of the treatise by Vitruvio in 1569 (García 1968, 163). The use of *nariz* is common in the documentary sources in XVII and XVIII c.
4. In the constructive conditions of the bridge of one arch to be built in Tirgo upon Tirón, in 1741, they name cutwater to the ones built upstream and buttress to the ones placed downstream. In the contract of construction of the bridge upon the river Viejo in San Vicente de la Sonsierra, signed by José de Landa in 1751, the term buttress seems to refer to the work of the piers up and down the stream indistinctively (Arrúe and Moya, coord., 1998, 2: 891, 895).
5. In La Rioja, the stone *perpiaño*, the one which crosses completely a wall, is generally called *pasadera* and also the variations *prepiaño*, *pripiaña* and *pripiaño*. The term *pripiaño* is collected by Benito Bails in his Diccionario de Arquitectura, posthumous work in 1802, as *mediana* stone.
6. Signed by Pérez de Obieta, Rivas and Sisniega: «Otrosí serán fabricados los dichos pilares en la manera siguiente todo, ansi en los estremos de la parte de fuera como en las médulas y cuerpos de dentro, de buenas pieças bien esquadradas y galgadas a picón, y con buenas juntas que tengan las pieças de largo a tres y a quatro y cinco pies de largo, y ancho dos pies y dos pies en quadrado, con el alto que tubieren, tenyendo en quenta de guardar sus buenas ligazones, ansí en la parte de dentro como en la de fuera, y echar buenos tizones para que bayan ligando la obra y fábrica de manera que quede con perpetuidad y firmeça, y subirán fabricados de esta manera hasta donde an de començar a nibel los arcos y de allí arriba, subirán por la parte de fuera con sus muy buenas pieças y por la parte de dentro, de froga y buena ripiaçón» (Arrúe and Moya, coord., 1998, 2: 234–243, 859).
7. Following the conditions of the work that the Council of Murillo de Río Leza alloted to Juan de Setién Venero: «toda de piedras lavradas y galgadas para que asiente y aga eleción sobre el enpotrado, asentadas en la dicha primer ylada sovre vuena froa de cal, y su mezcla della a de ser tanta cal como arena» (Arrúe and Moya, coord., 1998, 1: 559–563, 2: 865).
8. The use of through stones in the first course is an expressed requisite in the contract of the construction of the bridge of Prado in San Vicente de la Sonsierra, which José de Landa was obliged to build in 1751: «Y con condizión que la primera ylada de zepas y espolones ha de ser de pasaderas enteras y, en lo restante de todo lo exterior, un sillar entre dos pasaderas» (Arrúe and Moya, coord., 1998, 2: 895).
9. It is condition in the rebuilding of the bridge in Torremontalbo upon the Najerilla by Ignacio Elejalde and Mateo de Retes, contract of 1735 (Arrúe and Moya, coord., 1998, 2: 887).
10. The term *deja*, common in carpentry, is not found in dictionaries of construction until the XIX c. But it is very usual in stoneworks in the previous centuries. With the same meaning of baseboard to reduce the thickness in height we find *retallo* or *restallo*, *grada*, *retreta*, *zapata* and *zócalo*.
11. It was projected by Manuel Echanove with seven eliptic arches between 14,70 y 8,30 m. spand, on piers with triangular upstream cutwater piers and rectangular downstream ones which go up to the causeway (Arrúe and Moya, coord., 1998, 1: 396–404).
12. Confirmation of this rebuilding with ogival cutwaters and the remaining of medieval triangular ones in the bridge in Logroño is shown in the plan Palomares projected in 1849, after the severe damages in the flood in 1775 and before the definitive substitution for the one designed in 1882 by the engineer Fermín Manso de Zúñiga (Arrúe and Moya, coord., 1998, 784–807).
13. There are no rests in La Rioja of examples of piers with upstream cutwaters or semicircular downstream (Arrúe 1995)
14. For example, related to the above mentioned medieval bridges in Limoges, one of the cutwaters in the bridge Saint Etienne presents the inscription 1577, which is not collected by Guibert (1904, 233–234), but it is by Perrier and Bonnaud (1977, 187–188), and it is well known that it went through a very important reconstruction finished in 1619, according to the commemorative inscription. I could not tell if handwritten sources have recently come up with data on the specific works carried out at the end of the XVI c., which clarify the alterations the medieval work could have endured.
15. See the analysis on proportions of arches proposed in the treatises of the time in the work by Santiago Huerta (Huerta 2000, 513–526).
16. It is not preserved in the bridges in La Rioja but in the one in Logroño it was designed a rustic main front with the arms of Felipe II in 1587, and two big stone lions in 1682; pilasters in the one designed in 1735 for Torremontalbo and, in the one in Haro upon the Tirón, they installed two statues with saints on pedestals in 1741 (Arrúe 1998, 188).

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