Reinforcement in Early Medieval Hispanic Architecture

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INTRODUCTION

Unlike the architecture of classical antiquity (Adam 1996, as main reference), the architecture of the next four centuries has remained in the dark pages of the history of architectural technology. Some researchers, such as Choisy (1997), Lewcock (1978), Mainstone (1975 and 1988) or Ousterhout (1999), among others, have already shown that securing masonry structures with metal or wooden pieces had to be a wide spread technique in late antiquity and early medieval construction. In the Iberian Peninsula our long ignorance has quietly started to change thanks to recent archaeological work carried out in some of the ecclesiastical Hispanic buildings usually dated to between the fifth and the tenth centuries (Caballero 1994/95, discusses traditional chronologies and proposes alternatives for some of them). The latest facts change our traditional view of an architecture having very few structural and technological resources and knowledge compared with its Roman predecessor and these facts offer us a new field of research. The evidence for repair and reinforcement, which I shall discuss, may only be known thanks to later removal or processes of ruin, whether caused naturally or by human agency, that have affected the buildings. Therefore, the material evidence is not abundant in a class of buildings most of which are still intact and, some of them, even in current use, but the evidence that exists is highly significant.

Our work tries not only to identify all the known pieces, but also to give a probable explanation for their use and purpose in the structure of these ecclesiastical buildings. Some of the evidence was already known, as the cited references show, but some is a result of our fieldwork done with the purpose of studying the vaulting systems of the late antique and early medieval Iberian churches (Utrero 2004). We will discuss two types of reinforcement in this paper: first, reinforcements inserted in the supporting architectonic elements (walls and columns) and, second, those related to the vaults.

REINFORCEMENTS IN WALLS AND COLUMNS

Bolts, Disks and Cramps

Besides the wooden pieces collected by Caballero and Arce (1997, p. 269-270), which served mainly as lintels, doors, pavements or roofs, we can add other examples used with the aim of contributing to the stability and integrity of the architectonic elements and structures.

In the middle 1930s, the church of San Pedro de La Nave (Zamora, seventh century after Schlunk and Hauschild 1978 and Corzo 1986, ninth century according to Caballero and Arce 1997) was moved stone by stone from its original site, because a dam was to be built there, to its present site. During these lengthy removal works, the discovery was made of some wooden butterfly cramps. These cramps tie the stones of the two wall faces together, laterally through the thickness of the wall. The wall is thus held together and allowed to flex and settle without breaking. Because this was their function, these cramps were especially frequent in the lower part of the walls, where the thrust line runs out of the structure. They seemed to be positioned precisely in the fourth and seventh courses (Gómez Moreno 1966, p. 128, who shows the distribution, **fig. 1**, and Corzo 1986, p. 52). One cramp was 70 centimetres long, so this had to be used longitudinally to join at least three ashlar stones of the same wall face, rather than transversely as in the others. Although the removal works were competently led by Gómez Moreno, much information - such as the exact position of this long cramp or the total number of such pieces (only four are preserved) - were unfortunately unrecorded.

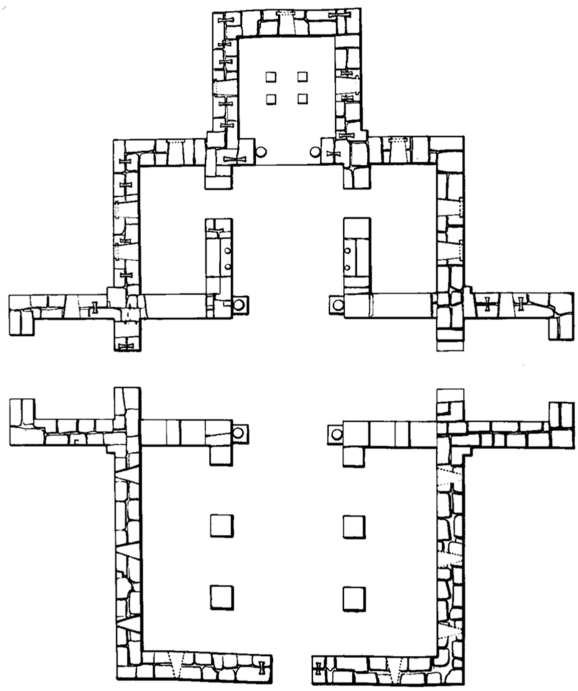

Figure 1. Wooden butterfly cramps in the walls of San Pedro de La Nave (Gómez Moreno 1966)

Adam (1996, p. 57) comes to the conclusion that in the Greek and Roman period cramps were made of iron and were fixed with cast lead. Considering the results of Durán (1990, with Roman references) and Fernández Ochoa (1997, p. 234) in the Iberian Peninsula, it seems that the use of cramps such as these were not restricted in time or place. Their typological and material diversity does not allow a single criterion for their use.

Durán (1990, pp. 94-95) thinks that the butterfly form of mortice could hold different types of cramp: wood smaller than the mortice could be made to swell by soaking with water; a wooden core covered with lead (this example is only known in the Roman Alcántara Bridge, Cáceres, thanks to a description written at the end of the nineteenth century referenced by Blanco 1997, p. 68, but of unknown location in the bridge); wrought or cast lead or bronze; an iron core covered with lead; and, finally, iron. These variations suggest the type of mortice in not dependent on the cramp material and that the presence of lead does not necessarily imply that the cramp was of wood. To those examples belonging to Iberian and Roman constructions gathered by Durán (1990, p. 96-97 and 115-117), Fernández Ochoa (1997, p. 234) adds some others discovered in Roman ashlar but reused in late antique city walls (León, Barcelona, Astorga, Tiermes and Gijón). These ashlar blocks could have been tied together with wooden or metal cramps. Fernández Ochoa quotes also the reused Roman ashlar blocks with incomplete mortices in the lower part of the walls of the church of Santianes de Pravia (Asturias, Silo 774-783, **fig. 2**). This list is completed with the reused Roman ashlar blocks with butterfly form mortice in the church of Santa María de Quintanilla de Las Viñas (Burgos, seventh century after Schlunk 1947 and Arbeiter 1990, end of the ninth century after Caballero and Arce 1997), also mentioned by Corzo (1986, p. 56), and the circular holes left by the cramp endings recorded in the archaeological excavation of the Foncalada Fountain (Asturias, Alphonso III 866-910, Ríos, 1999, p. 265).

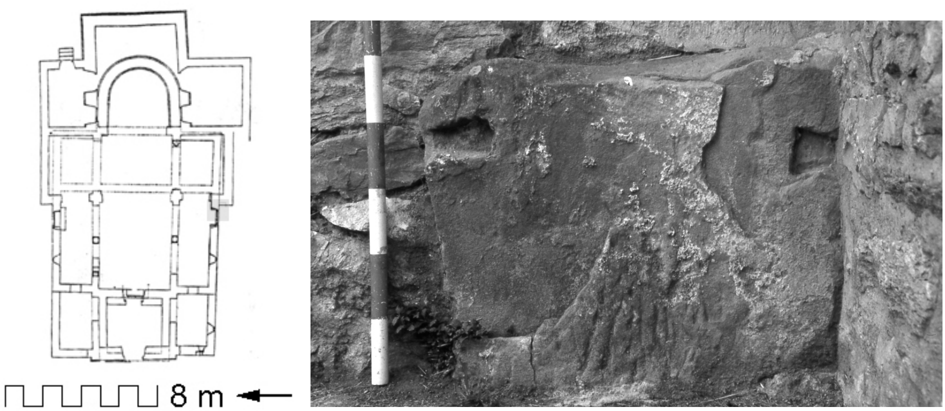

Figure 2. Santianes de Pravia (Arias 1993) and mortices of cramps in ashlar stone (shown in grey in the plan)

Although the number of cramp sockets or mortices in the Roman period is substantial, nothing can be said about the cramps and their probable relation to those found in La Nave, which must be considered hitherto a unique example not only for the early medieval time, but also for the previous one. There are no grounds to think they could have been covered by lead and they were the only way of bonding the granitic ashlar blocks, due to the complete lack of mortar between them, as the photographs taken during the removal works show. Considering the notes of Arce García (1996, p. 42), lead was used to avoid the iron rusting and to give elasticity to the joint, therefore the wooden cramps in La Nave should not have been needed. The wood is flexible enough and does not suffer from rusting. Based on this assessment, the model of wooden core cramps covered with lead (named by Durán) and based on the doubtful example of the roman Alcántara Bridge is highly improbable.

Other pieces are used to regularly distribute the load and to improve the seating or contact between stones. These were discovered, for example, by Marfil (1999, p. 181) in the archaeological excavation of the Prayer hall of the Cordova Mosque and belong to the Almanzor period (978-1002). He found a cylindrical base between the seating slab and the base of the column shaft. Between both these pieces and the upper part of the shaft and the capital, a lead disk was inserted horizontally to improve seating. Similar disks can be seen between the bases, shafts and capitals of the columns which support the two arcades in the church of San Miguel de Escalada (León, ca. 913). As a plastic material, lead helps to improve the load between columns and foundations, as noted by Choisy (1997, p. 16, who gives some Byzantine examples), and evens out the seating of the masonry (Marfil, 1999, p. 182). Disks are therefore used to lessen risk of fracture.

Finally, other kinds of reinforcement help to join those structural elements which suffer from the effects of horizontal thrust. In these cases, the masonry does not have to absorb a vertical load and the reinforcement simply connects them more securely. The supporting columns of the entrance arch to the apse of San Pedro de La Nave had leaded iron bolts or pins joining the dosserets (cubical and decorated blocks of stone tapered downwards), capitals and shafts, on one side, and bases, plinths and shafts, on the other, according to the description of Gómez Moreno (1966, p. 129). In the church of San Miguel de Lillo (Asturias, Ramiro I 842-850, **fig. 3**) the holes left by the lost bolts can still be seen in the base in situ sited at the entrance of the apse. In the archaeological works carried out at the beginning of the twentieth century, Llano (1917) discovered other similar pieces (bases, shafts and capitals) which also had holes for iron bolts. The pieces preserved in situ and also those recorded by Llano, now in the Archaeological Museum of Oviedo City, both have a small channel or groove on the upper horizontal surface which had two possible functions. According to Adam (1996, p. 58), these grooves could either have prevented the overflow of the molten lead employed to fix the iron bolts or have allowed it flow in after the upper block or drum was seated in situ.

Other examples can be found in the basilica of Bovalar (Lérida, sixth century, **fig. 4**), in the first eastern column of the northern arcade, and in the basilica of Aljezares (Murcia, seventh century) in a richly decorated base of unknown original position but probably from the apse, published by Schlunk and Hauschild (1978, Taf. 63c) and now in the Archaeological Museum of Murcia. These two examples - Bovalar and Aljezares - are not certain because they could be of Roman origin and reused in these later basilicas. The same is true of two other bases known in Casa Herrera (Mérida, sixth century) and Cegonha (Portugal, fourth century), whose date is equally unsure, as there are also many other stones of definite Roman origin in both basilicas.

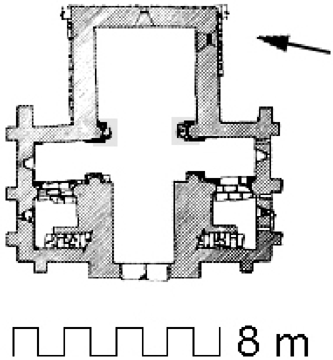

Figure 3. San Miguel de Lillo (Arias 1993) with bases at the entrance of the apse (shown in grey in the plan)

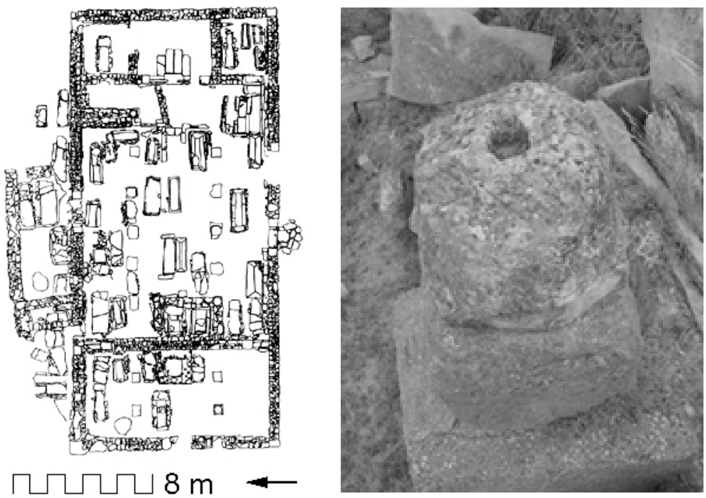

Figure 4. Bovalar (Palol 1989) and column of the northern arcade

Joining Horizontal Elements: Iron and Wooden Timbers

Closely related to these kinds of reinforcement, but with a different function, are other reinforcing elements recorded in parts of the walls directly connected to vaulting systems. These are iron or wooden beams positioned longitudinally along the load bearing masonry walls, close to the vaults.

A further example of precautionary reinforcement in La Nave was the insertion of a bonding-timber which originally ran along the masonry wall above the arched entrance to the apse. This timber had the function of tying the side walls of this narrow and high space, so reducing the effects of movement or settlement likely caused by the removal of the centring for the construction of the vault. This beam serves as a brace and was fixed to the upper part of the wall on the entrance arch with cramps of the kind described above, as the sockets preserved on one of its edges show (Matthías, Rodríguez and Pérez 2004, reconstruction p. 223, Fig. 14).

A second example is found in the complete vaulted church of San Salvador de Valdediós (Asturias, Alphonso III 866-910). The building is on two floors, both of them divided longitudinally into three long vaulted spaces, including the porch, sanctuaries and the body of the church. Each longitudinal space is barrel vaulted with tufa (Noack and Arbeiter 1994, pp. 174), a very soft type of limestone cut very thinly (thirty three centimetres thick). It has another southern porch running parallel to the main hall and two lateral perpendicular rooms - all of them brick vaults.

What makes the vaulting system in Valdediós so interesting was the discovery of iron beams in the springing of the vaults (although the published reports of this have to be analysed carefully). Fernández Menéndez (1917, p. 267 and 1919, p. 86), who led the restoration works at the beginning of the last century, says that these beams were situated in the springing of the vaults over the narthex, where they are to be seen today (**fig. 5**), and in the apses. Those in the narthex seem to be double, one in each wall face. They would then be four in number. But Schlunk (1947, p. 379) places them in the central nave and considers that they were used to distribute loads from the vaults in that location. The window openings in the haunches of the vault explain, according to him, the use of these beams and the reduced form of the vault that covers this main nave, only 2.8 metres in span. He does not give their exact position.

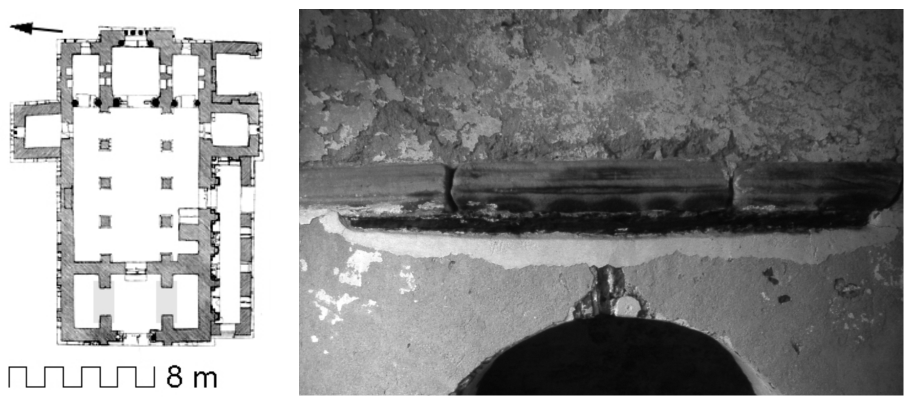

Figure 5. San Salvador de Valdediós (Arias 1993) and iron beams in the narthex (shown in grey in the plan)

We know little of the likely purposes of these iron bars. The use of such reinforcement was not unknown in Antiquity (Dinsmoor 1922 and Hoffmann 1991, who mentions some examples of iron beams in vaults, but sited transversely between the springings of the vault or above the crown of this), but it was not as frequent as we could expect. Heyman (1972) analyses some examples placed on architraves in Greek temples and denies their structural function. They could have reduced tensile stresses, but the rusting of the iron would have prevented them working in the same way later on. Heyman thinks rather that they were employed either to fasten the masonry or to work as scaffolding or as support for the flying courses. In contrast to those seen in Valdediós, the Greek examples are seen with big ashlar stones characterized by deficient tensile strength, which is an important factor making for instability in masonry buildings. Choisy (1997, pp. 119-120) notes the existence of tie-beams running across the axis of arches and vaults in some Byzantine buildings. These must therefore have had a binding or tightening purpose that cannot be related to the examples of Valdediós. Haas (1983) mentions wooden beams jointed and anchored with iron cramps in Byzantine (St. Irene, Constantinople, s. VI) and Carolingian (Aachen Chapel, 792-805) architecture, but emphasises that the use of metal was exceptional and usually wood was used. Mainstone (1988: 70) records them in the cornices of the semi-vaults in Hagia Sophia (Constantinople, 537). Although their presence in the original building cannot be confirmed, these beams could have been used to reduce the usual tensile stresses that occur in the base of this type of vaulting. The use of wooden beams is also frequent as a means of supporting walls setting until the mortar hardens (Ousterhout 1999, p. 210). This could have been the purpose of the reinforcement in the brick interior and masonry exterior faces walls in Valdediós, but in that case why were they of iron?

Valdediós is so far the only known early medieval building with iron beams. By comparison, the number of wooden beams is much bigger. Horizontal cuts in the internal wall faces of the main hall of the secular building recently discovered in Pla de Nadal (Valencia, seventh century according to Juan and Pastor 1989, eighth after Caballero 1994/95) could have held longitudinal wooden beams. Similar systems to this is known in the minaret of the Great Mosque at Cordoba where the tower belongs to the ‘Abd al-Rahmān III period (929-961, Hernández 1975, pp. 49-50), and in the apse of the church of Santa María de Arcos de Tricio (La Rioja, tenth century, Caballero 1994/95, pp. 107-112), where the ashlar masonry in only wall face used this reinforcement system (Caballero 1998). These timbers form therefore a regular grillage or continuous frame. In these two last examples, beams were fitted into holes cut in the seating surfaces of the ashlar blocks and were therefore not seen, in contrast to those of Valdediós which are visible in the narthex. It is also possible that such a system could have existed at Santa María de San Vicente del Valle (Burgos), judging by the holes preserved in some of the ashlar stones in one of the wall faces in the only nave of the church (Aparicio y De la Fuente 1996, p. 154, who date it to the seventh century, unlike Arce Sainz 1998, who does it to the ninth century). Taking these examples into account, we may affirm that iron beams could have been employed in Valdediós as a way of improving the flexibility of the walls in response to different forces, as at Pla de Nadal; a possible function as a binding element would seem to be limited as they were positioned only in the internal brick wall face, and not in the external ashlar face. In the Cordovan minaret and the apse of Tricio, the insertion of timbers in the thick wall in a framework around the square perimeter of these buildings seems to have another purpose. Beams prevent possible deformation of the walls during construction, before all settlement has occurred, and, at the same time, form a frame in the walls of the vaults. This framework serves to contain the lateral thrust of the vaults in the minaret and the outward pressure of the base of the dome in Tricio, which is localised thanks to the pendentives. Arce (1996, p. 43) quotes a similar system in La Giralda (Seville), the minaret of the mosque built at the end of the twelfth century. Tabales records (1998, p. 116) also some wooden remains which could have been part of a floor used during the construction of the lower stage of this minaret. These minarets (Cordoba and Seville) should be added to the list composed by Wilcox (1981), who records several towers mainly dating from the eleventh century, and reinforced with intra-mural timbers.

Creswell (1989) makes reference to the use of bonding-timbers in the so called omejan desert castles. Two functions can be distinguished for these pieces: some bind the masonry and others are placed as braces in the interior of arches. Among the first type, we can mention those recorded in the small castle of Qasr al-Hair ash-Sharqi (Syria, Hisham I, 724-743), where three beams are placed parallel in the ashlar walls supporting the vaults (Grabar, Holod and others 1978, p. 19), and Qasr al-Hair al-Gharbi (Syria, Hisham I, 724-727), where they are put together with sun-dried brick, baked brick and ashlar masonry (Schlumberger 1986, p. 9, Pls. 25 and 26). We could add to this group the pieces from Cordoba and Tricio. Representing the second function, we know of the coupled wooden beams tightening the arches in the Dome of the Rock (Jerusalem, 687-692), the Aqsa Mosque (Jerusalem, al-Walid I, 705-715) and Mshatta (Jordan, al-Walid II, 743-744), among others. This model is so far unrecorded in the Iberian Peninsula.

Other examples are noted by Wilcox (1981, p. 6), who identifies different examples recorded in ecclesiastical buildings dating from the ninth and tenth centuries. Their positions are not described in enough detail to allow them to be compared with those mentioned in the Hispanic churches.

All these references allow us to set in a context the beams in the walls of Valdediós, but we have to remember that these are of iron, not of wood, and are situated under the cornices of the vaults, at least in the narthex, longitudinally or in line with the axis of the vault. All these features make them unique in Hispanic architecture. It was not to resist horizontal thrust. Perhaps these beams were meant to improve the flexibility of walls, in case of uneven settlement.

As a special case, we must mention the wooden beams on the iconostasis masonry wall of the church of San Miguel de Escalada (**fig. 6**), mentioned above. These pieces could have functioned as braces, but their fragmentary state and doubtful reconstructions, and their uncertain stratigraphic relationship to the original building and the iconostasis itself, are obstacles to offering a definitive explanation for them. The iconostasis wall already functions as a brace or diaphragm arch tying together the two sides of the central nave of the church. This nave and the two side aisles are covered by a timber roof, but the lateral spaces of the transept were originally vaulted in tufa (now replaced by brick) and have suffered from lateral movement which has broken apart the surrounding horse shoe arches. The timber and the iconostasis may have prevented worse fractures, but the original presence of the former is still to be confirmed (dendrochronological analysis is currently in progress).

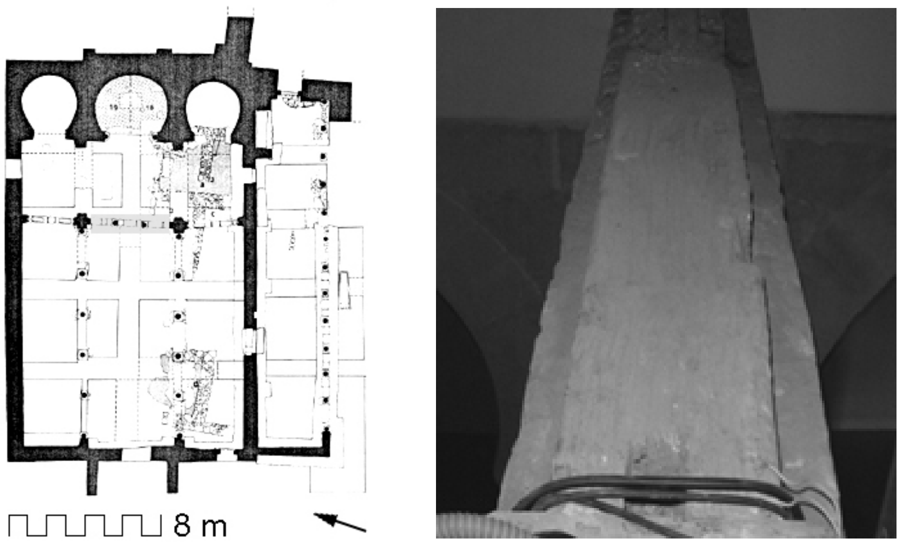

Figure 6. San Miguel de Escalada (Larrén 1986) and beam on the iconostasis (shown in grey in the plan)

JOINING AND REINFORCING ELEMENTS IN VAULTS

The elements considered above (beams, cramps and bolts) are indirectly connected to vaults but directly with walls. Cramps avoid the separation of wall faces suffering from the horizontal loads caused by vaults, beams tighten arches, and metal bolts bind shafts, bases and capitals. But few elements are inserted into vaults.

The latest archaeological work carried out in the Great Mosque of Cordoba on the exterior surface of the three ribbed domes over the square bays of the so called maqsura and the bay forming the Villaviciosa Chapel suggest a very different picture from that accepted hitherto. All these domes belong to the second enlargement carried out under the caliphate of Al-Hakam II (961-972). Marfil (1998, although we have some doubts about the Villaviciosa Chapel, which was partly removed in the fifteenth century) records a timber frame between the lower and upper stages of one of these domes. The ribs, or more properly arches, in the lower stage of the dome support this framework, creating an octagonal base for the upper stage. The frame works as a belt absorbing the loads of the upper stage umbrella dome and has a fluted form. This wooden structure transforms the behaviour of the vault by tightening it, converting the lower ribs into structures supporting the vault and freeing the surface of the vault from loads which permits windows to be opened in it. We are not told how the individual timbers in the octagonal frame are jointed together. This timber frame has therefore a double purpose: it holds together the base of the upper umbrella dome and simultaneously holds together the upper part of the arches in the lower stage of the dome. The load of the two-stage dome is thus transmitted more efficiently. The cells between the arches of the lower stage are independent surfaces. Movement can not be transmitted from the upper to the lower stage of the dome, nor vice versa, because the dome is really composed of two vaulted structures, one placed on the top of the other.

Finally, the western tribune in San Baudelio de Berlanga (Soria, second half of eleventh century) is supported by eleven domes. These are composed of five flat surfaces and their bases are tied and reinforced with square frames of wooden timbers.

Choisy (1997, p. 121) shows that wooden structures recorded in crossings and pendentives Byzantine vaults work as an inextensible belt that absorbs the vault's load. We have to mention again the wooden chainage analysed in the Cordovan minaret and in the apse of Tricio. In both examples they have to do with vaults. The above demonstrates that the use of wood as a reinforcement element during and after construction opens up a new technical field to be studied using fresh archaeological evidence.

But we have also to wonder if it is really useful to introduce such reinforcement elements in the vaults. The insertion of cramps, for example, would give stiffness to arches or vaults and would therefore reduce its capacity to respond to movement likely to be provoked by differential settlements. Flexible jointing of the different parts is a safer way of assuming stability. The more rigid a building is, the stronger it must be in order to avoid fracture. When strength is not possible, flexibility is necessary. Because of that, most of the elements that we have referred to are to be found connected to vaults, either in their bases or somewhere lower down, but never in the vaults. Wooden and iron frames around the springing of a dome combat the tensile stresses usually found in this part of a dome (Heyman 1967, p. 234). Their presence is testimony to the concern that architects have felt about the possibility of failure under these kinds of forces. At all events, we could expect joining elements between the vaults and their arched openings or end walls along the axis of the vault, but we find neither of these. Security is therefore based on the relative independence of these arches and vaults which also receive different loads. For all these reasons, we can describe the absence of joining elements in early medieval masonry vaults as normal.

Choisy, who understood masonry structures as a whole under tectonic and accidental movement, describes the same features for the Roman ashlar vaults in Western and Eastern Empire (1997, p. 21). Boyd (1978, pp. 96-97) shows the same phenomenon in earlier Greek architecture. The absence of joining elements inside the vaults may be a rule that works for every masonry vault (brick or stone) in all regions, as our examples suggest. We can also add pre-Islamic and Islamic examples, contemporary with and later than the examples already cited, in which there are no parallels with the Great Mosque of Cordoba.

CONCLUDING REMARKS

The examples described here show a new picture of late antique and early medieval Hispanic architecture. As we have emphasised at the beginning of this paper, the examples are few, but they have a great significance for the study of this period.

Apart from making the walls very thick, not very high and introducing timbers and cramps to help prevent the masonry from breaking apart, other complementary resources were employed. These have to do with the stonework: ashlar in double courses, connected by common stones which bind both faces of the same wall or two perpendicular ones, irregular joints or narrow and bonded spaces, for instance. These constructional features also help the buildings to fight against the stresses caused by settlement immediately after construction as well as later on. Frequently, many structures were built with reused masonry, which therefore had a new architectural use for it was not originally designed and could similarly be reinforced for its new purpose.

In his study of this issue, Wilcox (1981) comes to the conclusion, after considering a wide range of buildings dating from classical antiquity to gothic and in both the West and East, that Byzantium played the main role in the preservation and transmission of the employment of iron and timber reinforcements from the Roman to the early medieval periods. In Wilcox's opinion, the first European examples are found in Italy and they are no earlier than the eleventh century. This conclusion must now be reconsidered in the light of the examples preserved in Hispanic architecture. Firstly, Hispanic revised buildings are earlier than the eleventh century, whether they are seventh or tenth century in exact date. Secondly, Byzantine influence in the Iberian Peninsula has to be considered in the context of this chronological discussion. The Byzantine presence in the south-eastern Iberian region was one of the most relevant arguments for the researchers who dated churches such as San Pedro de La Nave to the Visigothic period, and inferred a later transmission to Islamic architecture, as in the Great Mosque of Cordoba. New chronology, on the other hand, focuses its attention on the Muslim conquest of Iberia at the beginning of the eighth century as a probable means of transmitting building and decorative models from the Islamic East. Some of these Hispanic buildings should therefore be dated after this documented historic event. Coming back to the reinforcement, they cannot be interpreted as exclusively a result of Byzantine influence, in so far as we do not possess the necessary buildings models or "Byzantine architecture" in the Iberian Peninsula. The examples of Islamic architecture offer a new perspective with the Cordovan models, both the mosque and the minaret. This doesn't mean we should call these architectural or structural techniques an invention exclusive to only one time or place. For example, the work of Haas (1983) on the presence of wooden beams and iron cramps in the Carolingian architecture of Aachen Chapel contradicts the thesis put forward by Wilcox, who refuted the use of such pieces at that time.

We think it is dangerous to suppose the existence of a classical tradition in the use of this technology. Resources are used as long as they serve a purpose, as with any other architectonic knowledge, and are improved thanks to empirical experience and may be transferred or codified as geometric rules which relate thickness, height and span. In this sense, modulation and metrological analysis are essential to elucidate the relationships between the different architectonic parts and elements. Masonry buildings, Roman or medieval, work the same way because of the similar resources employed to resolve same problems. Architects do not know about the structural principles of current science, but they knew how to play with dimensions and materials in an intuitive or empirical way. Mistakes also occurred as the dramatic collapse of the original church of San Pedro de La Nave shows (Caballero and Arce 1997, pp. 261-262) despite the use of reinforcement. Other factors such as the substrate or later modifications may cause unexpected problems, but architects tried to control known problems with accurate masonry work and additional reinforcement pieces.

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