Arch Construction in Palmyra (Syria)

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Abstract. Palmyra is an important ancient site famous of its architectural monuments. Analysis of numerous monuments exposed an intriguing situation, until the IIIrd century arches and arched vaults were constructed in a specific manner based on a corbeled system. Such system was adopted even in construction of a famous Monumental Arch of Palmyra. Situation completely changed in the IIIrd century AD. Author discusses the problem analysing development of the building construction and technique in Palmyra comparing it with other sites of ancient Syria.

1. Introduction

Palmyra an oasis on the Syrian Desert became an important center and partner of Roman Empire. The town was famous because of its richness built on the control of trade between Rome and Orient. Since it had been discovered in the end of the XVII century there were a great interest to its architectural monuments. Palmyra architecture is described as a perfect example of Greco-Roman style and building technique with some oriental changes in decoration. Their temples, tower tombs and the Great Colonnade with the Monumental Arch became famous ancient monuments. [1] Building the Bel Temple in the I-st century caused a considerable change in the building technique. Opening of the new quarry of a hard white limestone caused introduction of an ashlar masonry. Due to a better recognition of local limestone properties it was possible to invent in the IIIrd century AD a new building technique called opus palmyrenum, where walls were constructed of a long and thin slabs (1 x 3 x 0,35 m). [2] In general opinion the Monumental Arch constructed in the beginning of the IIIrd century AD is a type of building construction that represents the Roman influence in Palmyra. The local situation seems slight different.

2. Arch construction at an early stage.

In general opinion, the early building technique in ancient Palmyra is rooted in Mesopotamian tradition with mudbrick walls and vaults. However except for only one mud brick corbeled vault spanning 1 m discovered in an underground tomb dated to the middle of the II-nd century BC, [3] the are no other examples of vault of arch construction until the I-st century AD, and most buildings were constructed by applying the simple technique of pilling together field stones with a mud and clay mortars. Decorative elements and wall facing were performed in a soft stone. In the Ist century AD arches built in that time were constructed using a very unusual system. In the monumental architecture of towers tombs and hypogeae tombs, the architectural forms of arches, vaults and domes were adopted not as structural, but as decorative elements. Figure 1. This can be observed in the Kithot tower dated to the 44 year and other tower tombs of this period. For example, the in the underground tomb of Bulha son of Nabushuri dated to the 89AD. Here in the northern exedra there is an arch constructed of six elements with rebatted joints set symmetrically but without a key stone. At this time, we have also evidence of vaults and domes...
built of thin stone slabs. Being carved to an arch form, such slabs constituted a decorative shuttering for the use of mortar – not so as to create a load-bearing structure, but for joining and stabilizing vault elements.

![Decorative arches and vaults in tower and underground tombs; A – of stone voussoires, B – of stone slabs. (up to 3 m span)](image1)

Such construction system was adopted for the underground tombs. [4] After digging out the compacted earth to form an underground tomb chamber, builders constructed vault of thin slabs to protect the chamber against falling particles of earth. In such construction stone slabs of edges with rebated joints were set in rows one after another, with their joints being mortared from behind. A thin top stone then locked up the arch, but such a key-stone had not structural meaning. Vaults of this kind simply had not been able to protect the chamber of ca. 2.5 m span against the weight of more than 2 m compacted earth hanging over the chamber. Interiors of underground tombs with stone vaults looked more distinctive than tombs of walls rendered with a plaster, even it had been painted. Moreover, with such a construction system, it was possible to build in a tower tomb no. A, a dome spanning 3 m, [5] Figure 2.

![Tower tomb A. The remnants of a dome built of mortared stone slab](image2)
3. Arch construction in the IInd century AD

In the underground tombs of the IInd century AD tradition of decorative arches and vaults still continues. For example, in the Yarhai tomb dated to the year 108 AD, there is an arch constructed of 11 voussoirs with rebated joints. In the underground tomb of Artaban dated to the late IInd century the arch of the main exedra was constructed of 8 voussoires with rebated joints. The gathered experience was helpful in building vaults as a load bearing fabrications, but still their applications was rooted in the corbelled system. The number of buildings applying arches and vaults as a construction system is not great. At that period stone arches did not exceed 2.5 m and despite their semicircular form, they were built as a corbelled structures using specially shaped voussoirs with rebated joints and protruded arms, Figure 3. Their size and setting demonstrated the application of keeping gravity centered within each specially shaped stone. Such construction presumably was used in Elahbel tower dated to the 102 AD, [6]. Other constructions of this type are decorative archivolts in the exedras of the underground tombs. In underground tombs vaults are still constructed as a decorated structure built of a thin slabs, as was introduced in the second half of the I century AD.

Figure 3. Arches in the Theatre (ca. 3.5 m). A - Aditus Maximus, B - Versurae

The constructions built in the end of the IInd century AD as entrances to the Theatre continue the previous solutions but in a bigger scale. Figure 3. The difference in construction of the Aditus Maximus entrances to the Orchestra and the Versurae entrances to the stage can be explained by a time difference. The Herein, the Palmyrene builders decided to construct the arches out of non regular voussoires, and despite the fact that building the arches of regular voussoires would be an easier task, their construction was built of elements individually shaped with protruded arms. Interesting here are the large key stones keeping a size of a lintel. These construction have 3.5 m span. Presumably, objections to arch structure durability engendered such an individual approach.

4. Construction of the Monumental Arch in Palmyra

The Monumental Arch, a prestigious structure erected at the beginning of the IIIrd century is an important example proving continuity of the traditional technique. In Syria, since the beginning of the IInd century there were many constructions of this kind and size built by Romans. As we see in Palmyra, their experience had not been used. The Monumental Arch set at the Great Colonnade is a unique building because of its triangular plan and of its construction system. [7] Its span is twice bigger than previous constructions built in Palmyra. A structural analysis of this building pointed out some peculiar solutions. Again there is no regularly shaped voussoires. Arch stones are individually shaped stone blocks with rebated joints, the arch is locked not by a regular key-stone, but double lintels of a huge 2.5 m span. In Palmyra since the end of the 1st century AD, a system of double lintels was commonly used as an architraves in colonnades and porticoes of a bigger span. It proves that Monumental Arch builders trusted more in a traditional solution, than a new revolutionary construction
of an arch built of regular voussoirs. A careful study of remaining Monumental Arch archivolt brings
to light more interesting features related to its construction process.

There are two publications wherein differences had been noted, but their explanation are not
satisfactory. It was Josef Durm, who firstly published in the 1885 year a structural scheme of the
Monumental Arch explaining the differences by a three-centre arch system. [8] Unfortunately Durm
never had been in Palmyra, therefore his analysis was not complex. But it should be noticed by Durm
that irregular, not radial system of joinery, being characteristic for a three-centre arch should result in
flattish arch. The Monumental Arch in Palmyra has the main archivolt semi-circular. Architect Robert
Amy who was in charge to restore the monument in the 1932 year completed its perfect architectural
documentation confirming regular shape of the main Arch. [9] He also noted an interesting feature of
arch stones setting in the Arch. However reassembling voussoires they were shape differently with
rebated joints and considerable protrusion on inner side. Moreover their setting were accordingly to a
principle to keep gravity center within the lower block. Amy being focused on monument restoration
did not research the Monumental Arch building system.

![Figure 4. The Monumental Arch. Building stages](image)

The present study on the Monumental Arch has brought to the light several more interesting facts. The
general difference between the true arch system and the corbeled structure consists in the load bearing
transfer. In a true arch, the weight is transferred directly on imposts according to the geometry of a semi-
circular structure. A load transfer in a corbeled structure is performed vertically according to the
balanced gravity forces in the successive elements. The slight projection of each horizontal element,
respectively, to not exceed their center of gravity, secures the structural safety of the construction. By
cutting out the edges of the protruded ashlers it is possible to make the intrados convex. Such action also
diminishes the weight of individual stone in the corbeled structure – which considerably enlarges the
span. Still in general practice, corbelled arches cannot achieve a semicircular form, yet in the case of the
Monumental Arch it was achieved. It was possible by setting as a key-stone a large span lintels
measuring 1/3 of the Arch span. Figure 4. This was possible because its construction system adopts not
only corbelling and a post and lintel system, but also specially shaped stone voussoires with a protruded
arm that assures a better counter balance. Those arms serve not only to keep balance of an individual
stone block, but also to extent its centre of gravity by providing possibility to put more weight on
opposite site. Such system is secured by the upper masonry blocks pressing upon the protruded arms of
the lower arch elements. There is also another feature providing securing the safety of construction.
Each course of so called voussoires with protruded arms are set as a pair of stone blocks. Figure 5.
However such system creates more difficulty in execution but higher stones provide better durability than a narrower ones. One can say that system of voussoires with protrude arms was commonly known and often used when arch was erected without centring and doweling, it being helpful in the building process. In general, we could agree, but the situation in Palmyra is different.

Figure 5. The Monumental Arch. The Intrados with double voussoires and double lintel as a key stone

In the I-st and the IInd century, all arch constructions, no matter whether big or small, were built this way. Building a centering for the Monumental Arch would not have been a problem, because of need for a great volume of wood to be imported to the town for constructing timber roofs and ceilings of a great spans now barren. Moreover, re-usable supportive centering would be a helpful measure in building both the regular or the corbelled arch. We could even agree and accept such solution as a sustaining and supportive construction when building a regular, but the extremely large linteled key-stone argues against it. From the structural point of view, a key-stone in a regular arch construction responds to the compressing stress, but a lintel responds to the breaking one. Apart of the structural issues we should not omit the aesthetical ones. The Monumental Arch façade and the Archivolt intrados are so well executed that nothing can spoil the impression of it being of a regular arch construction. Furthermore, the protruded collar separates the Archivolt from the background wall creating a false impression voussoires of an arch are not protruded, and they have nothing to do with wall ashlars. Only a double lintel of a large span in the Monumental Arch significantly points out that its construction was differently than were the regular arch structures common in Roman architecture. A perfect joinery limited to the minimum any doubts on the arch construction

5. Arch constructions in the III-rd century AD
Any study of the building techniques at Palmyra reveals a strange situation, that until the IIIrd century, there was no regular arch construction, however, there are plenty of constructions resembling an arch form. The I-st and the IInd century corbelled arches confirms that Palmyrene masons seemingly were not
fully acquainted with arch construction and presumably were afraid of the durability of a heavy stone arch. [10] This suggestion can be confirmed by a comparison of two archers constructed in the passage to the Bel Temple temenos, are thought to have been fabricated at the beginning of the III-rd century.

The arches have the same span of 3.65m, Figure 6, although both are constructed differently, depending on their load bearing. The inner arch between columns of the great portico in the Bel Temple temenos was constructed regular voussoires and plain joints. The second arch constructed beneath the high temenos wall has voussoires with rebated joints. The comparison of both structures constructed differentially points out that centering was not a problem. This difference might be explained by Palmyrene masons being afraid of a load bearing. In such context, it is easier to understand why in the IIInd century there was no regular arch construction in Palmyra. For more than a hundred years, they must have been testing and attempting the mastering of a solution based on a corbeled structure with crossetted voussoires. Unfortunately, this approach was not good enough to construct the vaults of a larger span. Finally, with a great deal of effort, a solution was derived, resulting in a perfect semicircular arched corbelled structure, as the Monumental Arch is. The IIIrd century brought to Palmyra new ideas and technique perfectly elaborated by Romans. Having a solution at hand at least eight large arches with spans 5 to 6 m and constructed of 9 to 11 regularly shaped voussoires of the same size were then built in Palmyra. Figure 7. Beside these, the largest arch that of a span 6,4 m and utilizing 13 regular voussoires was built in the middle part of the Great Colonnade to the north of the Theatre. There are also evidence of other big arches, but they were dismantled in antiquity to decorate buildings constructed in the hall of Principia in the Diocletian Camp to the West of the Palmyra town. [11] It is worth of mention that in Palmyra at that time there is also evidence of semi domes constructed of mortared rubble.

6. Arch Construction in Ancient Syria
Dramatic change in Palmyra significantly points out that until the beginning of the III-rd century there was a limited knowledge on arch building. The great expectation to construct a great span arches finally was solved with a help of Roman engineers. This particular situation in Palmyra should be discussed in a broader context. Comparison of Palmyra with the situation in Mesopotamia in the East and Levantine Syria and Judea in the West shows a significant difference. In Mesopotamia, in the Parthian kingdom, there are many examples of stone arches and vaults of great span built in Hatra and Assur. Such
practices can be explained by improvement of the long lasting local traditional technique involved in building a mud brick arches and vaults. Indeed, in Hatra among others, there are stone arches of spans of 10 m and vaults of spans of 14 m [12] In contrast, the development of arch building in Judea and Syria is the result of Roman presence. In an early Ist century AD Judea, there are many examples of arch constructions built by Herod the Great. Due to close contacts with Rome, it was, hence, possible to import new construction system well practiced in Italy. The most famous is the arched aqueduct in Caesarea Maritima. A similar situation occurred in the neighbouring Nabatean kingdom. Here, the first arch was erected at the entrance of the main temple in Petra (“Qasr al Bint”) built in the 1st century AD [13] At this time, a great arch of such a span (ca. 6 m), could easily be fabricated by an experienced master-builder being, brought to Petra. In the IInd century AD, in the greater area of Syria, similar constructions were erected in the towns of Decapolis and Hauran. Moreover, there are many monumental buildings built at this time in Bostra, Jerash and Shahba. Furthermore, in the greater Huran region, the arch became a basic construction in the local building trade. Indeed, the Hauranean construction system of roofing supported on successive sets of arches, became a hallmark of the architectural prowess of Antiquity [14] The differing situation in Palmyra in the beginning of the IIIrd century looks inexplicable. Palmyra was a wealthy town, and Palmyrenians could easily spend large amounts of money to advertise their success by building monuments similar to those erected in other important towns. Roman mason or an architect could solve the problem, as we see a situation was different. However, there were plenty of intercultural contracts with Romans, the art and science of building in Palmyra was self-developed. The situation dramatically changed in the IIInd century when Palmyra became a needed partner in the Eastern limes defence. Thus friendly and close contacts with a Roman partner at that time presumably were encouraged and resulted in technological transfer. Thus, new building knowledge caused abandonment of a local construction system in a favour to a new one, where construction of arches was a simple and an easy task. Number of arches constructed in a short period until the 273 year significantly confirms the situation. Study on the arch construction in Palmyra brought to the light a problem of a know how transfer. As we see, it was not an easy task to reproduce

Figure 7. The Arch in the Great Colonnade of regular voussoires
in a local conditions a commonly known construction type. Spectacular situation of arch building in Palmyra give us an interesting knowledge on technology transfer in antiquity.

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