



The Technology of Qomi-poosh Vaults in Iranian Traditional Architecture

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ABSTRACT: Arches and vaults are of the most important parts of traditional buildings of Iranian architecture. In the traditional architecture of Iran, before oil was discovered, fuel (such as wood) was one of the high-ranking issues. Therefore, Iranian traditional architects did their best to reduce the use of wood. There was however, a revival of the use of brick in construction. Qomi-poosh technology is one of the most impressive and admirable achievements of traditional architecture of Iran, which was invented by Ostad Hassan Qomi. This paper aims to study Qomi-poosh vaults and its execution techniques. Our investigation shows that Qomi-poosh technology could span nearly 6 metres with only 5 cm thickness (the width of a brick), which is equal to one a hundred and twentieth.

Keywords: *Qomi-poosh* technology, traditional architecture of Iran, indigenous construction technologies, brick.

REVIEW OF ARCHITECTURAL VAULTS IN IRAN

The variety of different types of Iranian vaults, considering their shape and direct correlation between the geometrical shape and the way the forces are applied to the vaults, causes the need for an independent review. The review must define vault types that encompasses all items from the viewpoint of geometrical shape. A vault of geometrical shape arises from the rotation of a straight line around a parallel axis with a transitional form of theoretical geometry.

The literature review of the research shows that new horizons of Islamic architecture (Mahdavinejad, 2003, pp. 23-32) lie in the wisdom of Islamic architecture (Mahdavinejad, 2004, pp. 57-66) and its emphasis on architectural construction. This is more evident in the principles of mosque design (Mahdavinejad

& Mashayekhy, 2011, pp. 65-78) especially in light-openings in Iranian mosque domes (Mahdavinejad et al., 2011, pp. 61-68). Moreover, it can be implied that vault construction plays a significant role in defining the traditional architecture of Iran. In addition, due to the availability of the materials namely water and soil, brick vault is a common type among all the Iranian architectural styles. However, it has to be noted that implementation and keeping the simplest vault up in Iran needs diligence and extra-sensory perception.

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Arrangement of Building Materials in Iranian Vaults

From this viewpoint, the Iranian vaults fall into the two following categories:

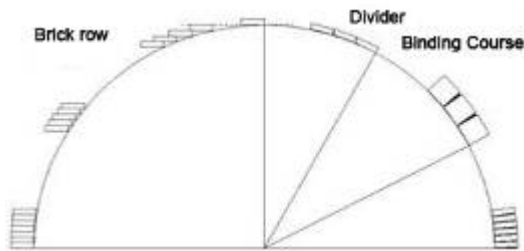


Fig. 1. Arrangement of construction materials in different types of vaults. (Source: class notes of Farhad Tehrani)

Building the Vault by the Method of the Brick Row¹

In this method, the pre-made building materials like brick or stone are placed slightly forward of the previous line of brick or stone. However, all the brick layers are parallel to the ground. This projection causes the span

to become narrow and therefore the back of the vault becomes heavy. In this method, each part of the vault is stable on its own and when the two parts meet, the stability increased. The builders start the construction process from the top and back of the vault. The brick layers stick out a little to tighten the span, which has a direct effect on the height of space created. The builder controls the vault's degree of curvature. In this way, the seam is not based on the longitude, but rather the latitude of the vault.

Building the Vault by the Method of the Binding Course²

In this method, the brick angle varies to the horizontal level, the bricks point towards the arc radius and the brick seam is coordinated in both latitude and longitude. The brick arrangement in the Binding Course method has different styles like Roman, Plentiful, Dividing Wall, Regular Course or a combination of them. The method of construction, development, formability and load bearing strengths is different in each style. The main rib of the load bearing is carried out by the Roman or Plentiful method or even by a combination of both. In this method, the vaults are symmetrical, so there is a better opportunity for controlling and reducing asymmetrical pressure.

Table 1. Comparison of Some Parameters in Different Types of Binding Course Vaults (Roman, Plentiful and Lapoosh)

	Roman Vault	Plentiful	Lapoosh Vault
Brick usage in a specific span	The highest level of brick usage for covering a specific span	The brick usage is equal to Roman vault for covering a specific span.	The lowest level of brick usage for covering a specific span.
Vault development direction	This vault is built only perpendicular to the seam.	This vault can also be built in layers that are not perpendicular to the seam.	This vault is built only perpendicular to the seam.
Load bearing ability	It has great load bearing ability without deformation.	It has lower load bearing ability compared to the Roman vault and is deformed under heavy loads.	Not only it has no load bearing ability, but also belt strips are used to strengthen it. Plaster and grout is used to increase width.
Brick arrangement	The brick is placed in the arc plane from the smaller side of the brick. This causes the shape of a curve to be easily executed.	The curve of this vault is in the shape of a set of broken lines because the brick is placed in the arc plane from the bigger side.	Formability is difficult so the mortar is used to alleviate this problem.
Vault weight per area unit	This vault has the highest weight.	The weight of this vault per area unit is less than the Roman vault and more than the Lapoosh vault.	This vault has the lowest weight.



LAPOOSH OR DIVIDER WALL



Fig. 2. Brick arrangement in the *Lapoosh* vault (Source: the authors).

The Divider Wall is the *Lapoosh* vault, built as wide as the width of one *Precieux* brick. Divider walls exert low weight to the load bearing pillars and seams. The construction is difficult and needs great skill. The expert

could build these vaults with a combination of practical skill and great knowledge of the principles of theoretical geometry.



Fig. 3. Construction of the *Lapoosh*, The House of *Borujerdis*, *Kashan*, (Source: Tehrani & Koosheshgaran, 2003, p. 143).

This vault is vulnerable and has never been used for load bearing units because of the position of the adobe bricks.



Fig. 4, 5. In *Kashan* and *Tehran*, houses the belts are clearly evident in the *Lapoosh* vaults (Source: The document centre archive of the architecture faculty of *Shahid Beheshti University* and the paper “Above the Geometry of Vault and Dome”).



The mettle of the mortar used in this vault is important. It should be pure swelling mortar plaster. Only by paying attention to this matter the progress will be done rapidly. To build this vault, it is enough that one of the walls has a vault to use as a buttress wall, and then the general form of the vault curve can be drawn and the construction can begin. The base is always Roman and in the same direction as the seam. This vault is usually built in a barrelled-arch form and a Persian arch has not been seen yet.

The other practical point about this vault is the control of length and curvature, which is performed at the start

of the construction of the *Lapoosh* vault, by making use of two or three roman brick layers. A belt including at least two vault strips is applied for each one metre, if the length exceeds the limit. These belts that are extra sized, stick out from the one side of the roof, also considered as control tools for the plaster used in the roof. These belts prevent the vault from vibrating and therefore increase its stability. Since the vault is not so stable, especially for heavy loads, it is compulsory to cover the vault surface with Finishing plaster and then *Palaneh* with mud and clay mortar (Fig.7).

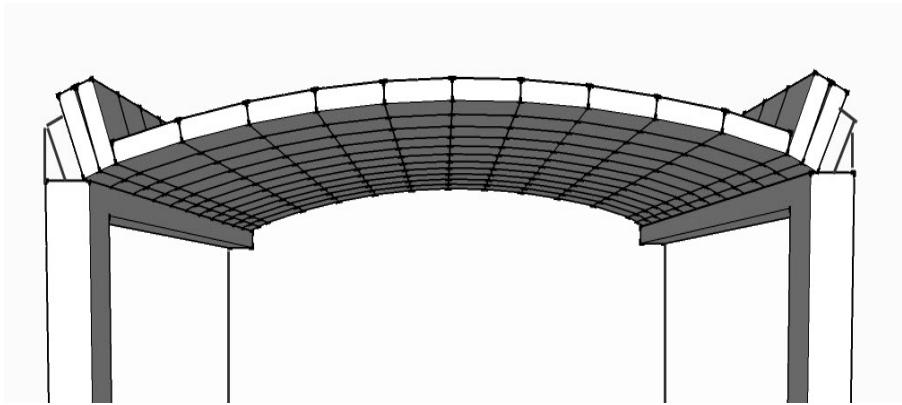


Fig. 6. Several rows of brick in the Roman arrangement is used for the supports, stability and connection of the vault (Source: the authors).

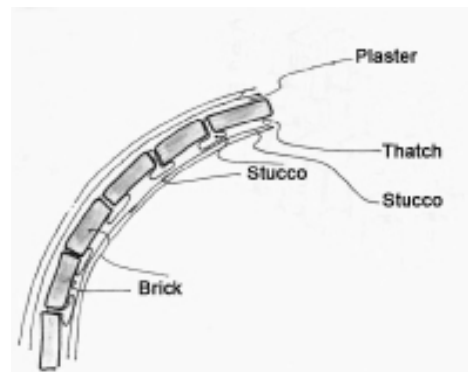
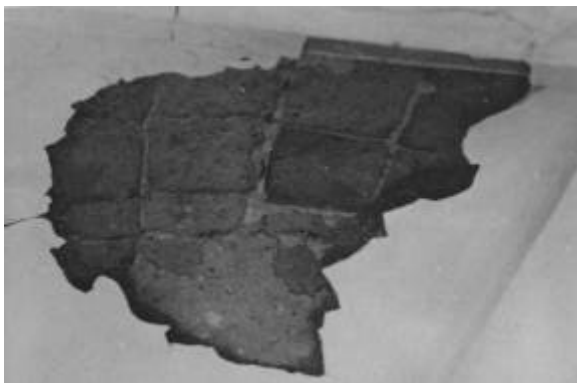


Fig. 7, 8. Construction details of the *Lapoosh* vault and a Plentiful vault showing the brick binding, The House of Attars, Kashan

Sometimes when the craftsman is binding the bricks of vaults, he spreads the gypsum mortar just like a plaster mesh. This is a trivial work but the result is stability.



Fig. 9, 10. Two vaults built by the *Lapoosh* method.

THE PERFORMANCE & DEVELOPMENT OF THE *LAPOOSH* VAULT METHOD

What the master builder does in the construction of a *Lapoosh* divider wall vault is presented in this section. As well general considerations, he takes special cases into account depending on the form of construction. All point to the insight and knowledge of the builder about how the forces apply and their effects, especially for setting up a *Lapoosh* divider wall vault (Mahdavinejad & Tehran, 1996).

The brick arrangement (extreme thinness) does not allow the arc to be a sharp Persian arch. In no circumstances the main load bearing can be in the form of *Lapoosh*, not even multilater. This vault (the *Lapoosh*) is always used as a filler between main load bearing surfaces. In cases like the *Agha-Bozorg Mosque of Kashan*, where the facade of rib bricks has been damaged and it has been adhesive- layer with a brick dividing wall. The dividing wall vault mortar (with brick and adobe as construction materials) is pure swelling mortar plaster to allow the continuation of the work. It is performed in this way so that the divider wall vault curve is drawn on the *Esvault* vault which is upright to the seam. In the base one or several Roman rows are built in coordination with the vault curve. (The slope degree is controlled and the base of two vaults must be in the same direction.) Then the vault is using the wall, the *Esvault* vault and arch base and the mason's trainees. Two trainees of the mason hold the brick while the plaster hardens. The bricks are arranged symmetrically from both sides until the work is done. After every several binds, the expert uses his technical know-how to make sure that geometrical shape of the vault is correct, which is a section of a cylinder, compiled. In case the span is big, a belt is set up in every

one metre.

Then a layer of plaster Timous grout is added. The water is poured into the mortar container, then a specific amount of plaster is made and stirred and then quickly poured onto the ceiling. A layer of brick, adobe, thatched mud mortar and a thatch mortar is poured on it. In this way, the whole vault becomes resistant enough to take concentrated loads. The surplus plaster mortar between two bricks is evened out by the back of the hand. It is like the approach of covering brick surface in t vault. The result is stability and hardening. In these *Lapoosh* vaults, the form has a significant role in bearing loads, while the material is not so important, considering their low efficiency and the thinness of the vault.

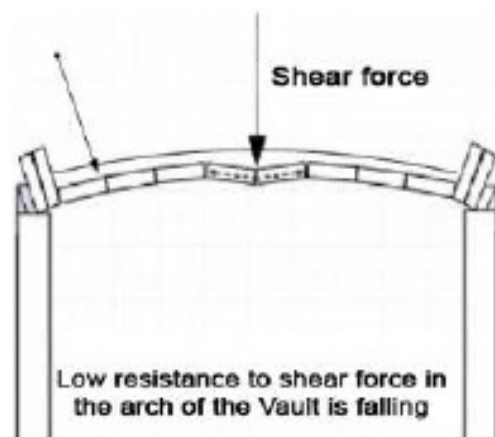


Fig. 11. Analysing the structural behaviour of the *Qomi-Poosh* vault when exposed to forces (Source: the author).

The evolution of the vault and development of the span of the *Qomi-poosh* vault by Master *Hasan Qomi*.



Master Hassan Qomi

Mirza Mehdi Khan Shaghghi (Momtahnoddoleh), the designer and architect of Melli and Sepahsalar Mosques, wrote in his diary book about his trip to the town Qom: "That person took the pencil to his mouth and merely added a line to my plan. In fact he drew a deviated line instead of a line that I had drawn and then gave the *Bayaaz* and pencil back to me and said: Now take a look." (Shaghghi, 1975, p. 99).

I paid some attention and found out that he was right. I asked him: Who has taught you the science of *Manazer* and *Maraya* that you could correct my error so well? He said: I have no idea about this science. I am even illiterate. My eye ordered me to do something, so your work and your plan arranged well. I was delighted by the intelligence and art in some of the Iranian people. This person was Master Hassan the architect. He has an innate natural view in this art and industry. He is the expert of his own time. He has great techniques in engineering and building different bridges and minarets with rising and descending stairs from both sides. It was a great surprise for me how much wit and talent God had granted him (personal correspondence with the author).

Master Hassan Qomi is an experimental master in Iranian traditional architecture. He lived in the 13th and 14th centuries of the lunar calendar. He was a writer, designer and composer. He has left two works; there are different opinions about the date of their construction. One is The Mirror Porch of *Hazrat Masoumeh*. The porch was constructed out in cooperation with famous master builders of that time. The other work is the courtyard of the tomb of *Ali Asghar Khan Atabak* in Qom. The first one was built in the year 1225 lunar calendar and second one in the year 1303. He also took part in the construction of the great divider wall of *Qom* and the great *Timche* of *Kashan*. (Quoted by architect master *Reza Helli*, personal correspondence with the author). When master Hassan entered the field of architecture and building vaults, it coincided with the arrival of Iron into the construction industry. Iron was for the first time used in Iran in the reconstruction of the dome of *Tekyeh Dolat* back in the year 1280 solar calendar. He made use of the physical property of iron, namely high-tensile property, to develop the span and increase the load bearing of the *Lapoosh* vault, which later became known as *Qomi-Poosh*. He could develop the span of these vaults using a method nowadays called pre-stress in concrete fabrics.

Definition of Pre-Stress

Pre-stress is a method of reinforcing concrete with high strength steel, which causes the concrete vault to have more strength against loads. The use of pre-stress dates back to 440 B.C., when the Greeks reduced tension and bending stresses in the body of their warships by using strained ropes. However, specific technical knowledge was needed to build and install pre-stress structures. The two following examples can explain this term.



Fig. 12. Renovation of Dolat Masque ceiling using metal structures (Source: <http://www.vista.ir/?view=context&id=296133>)

An example which stands for the simplicity of its construction, is the old wooden barrel. The tension created in the metal rings presses the wooden vaults together effectively to increase their strength and stability. Another example is an effort to pick up a row of books. We need to apply some force from both sides to the row of books to increase the strength against slippage between the books, so lifting becomes possible. This example also explains one of the most common principles in pre-stress applications. In a more comprehensive definition of pre-stress, the pressure inserted on the construction has a great role on the design and even improvements on load bearing capacity. Concrete has a low tensile strength, but it is strong against compression. Through pre-stressing a concrete vault, it remains under stress even after bending caused by the load. Therefore, a more effective design is presented. Two common types of pre-stress are as follows:

1. Pre-stress pre-tension: this method is mostly used in factories. In this method, the concrete is poured around the sheath containing the unstressed cables. When the concrete reaches enough strength, the cables are pulled



and they are fixed using special clamps.

2. pre-stress post-tension: It is practical at the site of the building. pre-stress concrete innovation introduced by *Eugene Freyssinet* who makes use of the post-tension for the first time in the year 1939. Most of the instances of its early application were in the design and construction of bridges. pre-stress post-tension developed by using multi-string cables in big sheaths which placed in the concrete section and fixed in both ends. The cables pulled by a jack from one side or both sides and then grout poured into the sheaths. This approach known as the bonded method, grout sticks to the cable all along the section.

Finally, pre-stress is creating an extra force in the concrete in such a way that a t vault of the tensile stress caused by the foiled load. In a pre-stress used a cable (tendon) with high-tensile strength instead of ordinary armatures. Under great tension, these cables pulled by special hydraulic jacks and with a certain force (which calculated by the design crew) and fixed in the two ends of the beam by special nodes. Thus, the pre-stress cables contracted and got back to their original state and therefore a great compressive force created beneath the

neutral axis of the concrete. Naturally this force is against the tensile force created in the concrete by gravitational loads. Therefore, these cables frustrated the forces caused by gravitational loads and the section would be able to withstand more loads. As a result, the cracks controlled by this method and the building units could be thinner.

Master Hassan Qomi's Approach

There are two important differences between building *Qomi-poosh* vaults and *Lapoosh* vaults:

1. In *Lapoosh* vaults, the architect builds the vault from two sides. It means that vault development direction is linear and is in one span of the vault. However, in the existing samples of *Qomi-poosh* building direction is simultaneously in two spans. This approach unable the architect in using ropes for levelling and the result is accuracy down to work. So it depends on the expert and his skill to coordinate the principles of geometry with his hands and eyes.

2. Using wire (*Kesh*) in *Qomi-poosh* vaults: Two or four layers of six-millimetre-thick wire used in this type of vault.

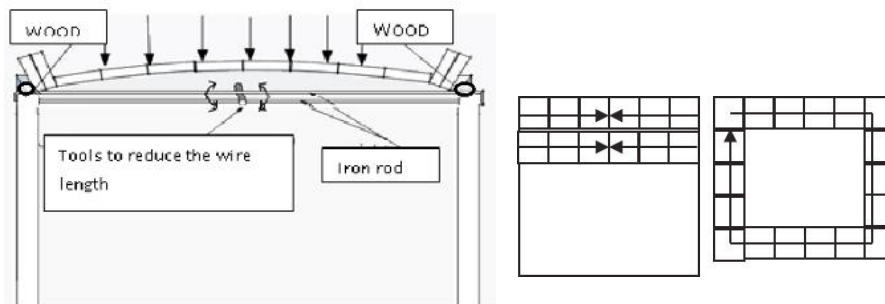


Fig. 13. The details of the vault invented by Master *Hasan Ghomi* (Source: the authors).

Entering Iron to the construction industry in Iran and its coincidence with Master Hassan *Qomi's* era helped him in improvement of *Lappish* vaults. He could make use of the tensile property of this new material in developing the vault span. Wood was the only material whose tensile property used by architects. Metal obviously has much higher tensile strength and durability. Master Hassan built the *Qomi-poosh* vaults the way his forefathers used to. The only difference with his masters was the use of iron wire while building the vault. After building the supports he would damp the destructive tensile force in them by placing a wood made of van. This wood also used to place and connect the iron wire (*Kesh*) to the vault construction.

He would twist the iron wires around the wooden

vaults (in one span) and he would then connect the wooden t vault as a supporter (Fig. 10). Having built almost half of the vault, He would shorten wires by twisting them in the middle. He did it at the middle point of construction. So it caused a pre-stress in these vaults. This pre-stress created a force in the opposite sense of the X part (Buoyancy force of the vault) and foiled this destructive force. The only reason was extra load bearing force (Fig.11).

In another method, the wire placed in four sides of the base. This led to uniformity of the vault. The pre-stress theory was not present in this method and the four sides' correlation prevents it from Buoyancy and destruction. So the vault could act uniformly against lateral forces.



Fig. 14. The stages of building the *Qomi-poosh* vault (Source: architect *Helli's* personal archive).

Pre-Stress in Qomi-poosh Vaults

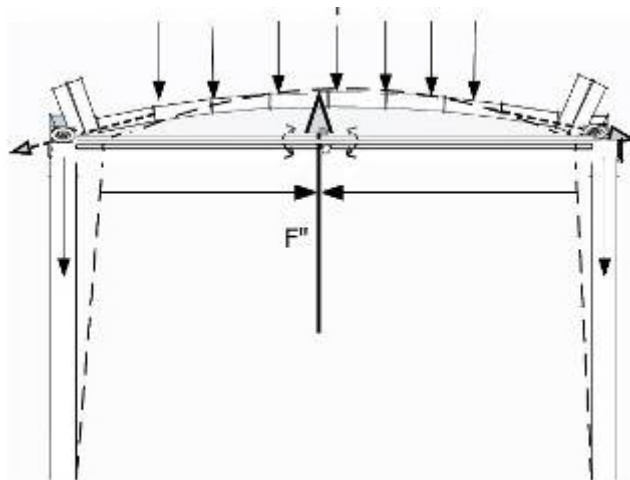


Fig. 15. Force analysis in the vault (Source: the authors).

As it mentioned, the architect has created extra forces in the construction after building the vault .It is in the opposite direction of the destructive tensile force, which leads to ruining the vault. This method falls into the pre-stress category, because of extra force. That is the tension has applied after the construction built. The extra force in the construction caused the load bearing capacity improvement and the same width of one brick

preserved. This fact led to an increase in the vault span (Fig. 11). This pre-stress post-tension property has used in contemporary technological architecture, to cover extensive spans in concrete constructions.



Fig. 16. A few *Qomi-poosh* vault samples with different deflection (Source: architect *Helli's* personal archive).

CONCLUDING COMMENTS

Master *Hassan Qomi* could build six-meter-long spans as wide as one brick using the post-tension property. In other words he achieved a width to SPAN ratio of 1/120 which is a good ratio for today's technology and the great breakthroughs in the construction science. A better ratio can only obtain in Membranes. All the evidence and the vaults remaining from this master point to that he had an experimental view of the pre-stress property and put it to practical use in building the vaults. By investigating the present pre-stress concrete structures and their construction technology with the *Qomi-poosh* vaults, we can conclude that pre-stress is used in both cases and each of them has made use of this idea and this technology with regard to the time period.

This is an implicit verification to the richness of Iranian traditional architecture, which has been obtained by a case study. A review of *Qomi-poosh* vaults and their structural properties implies that common native patterns

of Iranian architecture are easily able to meet numerous requirements of the architecture society, through making proper use of modern technology and advanced construction techniques. The application of these patterns will not only be a great help in present architecture, but also it is considered as the continuance of achievements in the history of Iranian and Islamic architecture.



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ENDNOTES

1. *Ragchin*
2. *Dorchin*