Advanced Materials Research Vols. 133-134 (2010) pp 349-354

doi:10.4028/www.scientific.net/AMR.133-134.349

The Role of Solid Springer in Masonry Vault

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Abstract During a scientific research, directed to understand the structural role of some particular masonry elements, noticeable in covering structures like vault and dome, we searched the technical rules and function of these elements. We verified that in literature there is no specific documentation about these elements and its mechanic purposes. The study was directed to recognize the most representatives architectures in different ages, and to identify the construction technique's evolution process of this particular arc-double or thickening of arc that we arrived to identify as a necessary building component to give balance in particular structural configuration. This process put down roots from the roman ancient age, until baroque age, where the most original applications of this regulation were placed. From Pantheon to the limit case of St. Filippo Neri chapel, the covers' structures springer angle studied was analyzed together with its relation to plan, sections and elevation of all buildings. Therefore, if these elements are well-performed, they follow precise constructive patterns that this article would like to identify and show.

Keywords: Rule of art, abutment, springer angle, formal relationship, arch outline, masonry dome

Introduction

Leon Battisti Alberti described the temple as the most complex of structural building and underlined the difficult but necessary union between building and decorative art, where the latter is not only an embellishment of wall face and insides, but a place where *"[...] incoming visitors are struck by so praiseworthy things [...]"* and then "*[...] Strabone told Milesiis built a so big temple that it remained without covering structure: an example not to imitate. Samis boasted of having the biggest temple in their land. We recommend, as far as possible, to give the bigger proportions to the building; but allowing its decoration. [...]" (L. B. Alberti, De re aedificatoria)*

We can understand that, according to Alberti, the covering structure was a building element able to give magnificence and greatness to the whole building, not forgetting the exigency of not exceeding in presumption and dimension. Impudent works are not advised. In the following quotation, he analyzes the different building systems, exalting their merits and lacks; he emphasizes catastrophic events' defence, particularly dwelling on the close relationship between structural elements' choice and their function: "*[...] it was ascertained that the structure of basilica covered with beams was able to better spread the priest's preaching voice than the vaulted temple [...]".(L. B. Alberti, De re aedificatoria)* Therefore, according to Alberti, the temple must be well-proportioned, well-decorated with a worthy covering structure as *house of gods*, suitable for its destination and resistant as *the greatest defence against catastrophic events*. He pointed out that in nature "*[...] prevails circular shape, as it is evident in what endures, begets and changes in the universe. It's pointless to remember globe, stars, trees, animals and their hatches, ect..., which are all circular things by nature [...]".*We just want to start from this shape.

Historical Periods and Building Elements: the arch and the space's conquest

"*[...] we must try to lighten masonry weight by means of arch [...]firstly the wood lightened from load will not bend, and then, will be easy to replace it without the employ of props [...]" (Vitruvio)*

Vitruvio points out two aspects: the first one is the problem of materials' decline, particularly of wood, and the second one is the great discover of arch as building element.

In monumental art, *space's conquest* is essentially due to the introduction of this element, employed by Etruscans, Greeks and Romans. The latter increased its use in complex systems known all over the world with the name of *vault*.

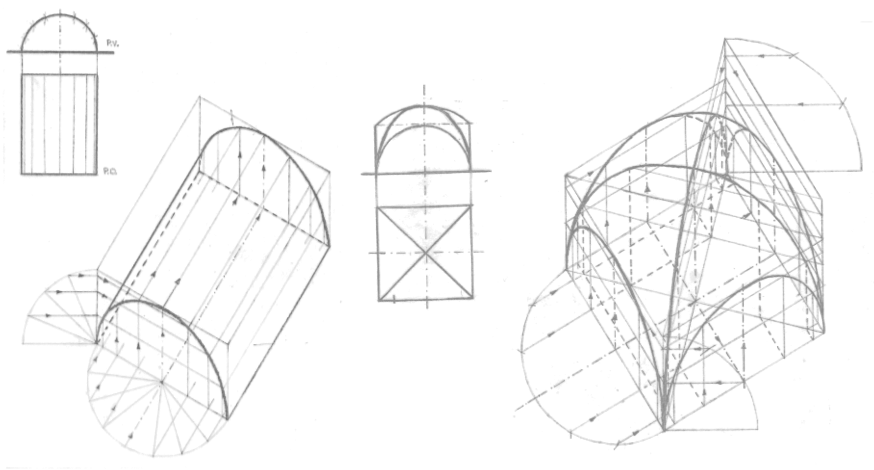

Figure 1: vaults, draw

Romans created different systems in order to obtain the *equilibrium* in the different building typologies they wanted to build up. But what is the element of stability in these structures? It is possible to notice that this thrust is greater in the springer and lower in the key, and that it is set in a polygon of forces. According to these considerations, it is clear that a satisfactory answer to this question will only result from an attentive study on the springer angle.

Romans carried out *co-operate abutment* able, with their weight, of giving a necessary and sufficient contribute for the stabilization of the pier, without compressing and crushing it.

Figure 2-3: Solid springer built in vaults extrados like co-operate abutment, photos

They surpassed this concept; greater was the area to cover more ingenious had to be the solution employed in order to satisfy the global equilibrium.

However, extending the above-mentioned concept to a serious of monumental buildings, divided for typology and structure according to their different planned systems, they will give us an exhaustive answer on the *rule of art* that ties *formal relationships* of *rise and diameter and height of springer and section of resistant element, with the necessary stiffenings to carry out the work.*

We could start with a first distinction between different kinds of stiffenings employed in historical masonry building with bend axis, built up for covering big span; which are:

- *structures with abutments;*
- *structures with masonry solid springers;*
- *structures with extradoses.*

In the latter case, with reference to *dome's typology* we can distinguish three possible typologies of stiffenings:

- *extradosed;*
- *with ribs inside the resistant section of the dome;*
- *with ribs built up in the intradoses(in the arris).*

Figure 4-6: Different stiffenings examples, from the left to the right: Mausoleum of Theodoric, Ravenna (extradosed); Minerva Medica's temple, Rome,(inside); Bib Mardum' Mosque in Toledo,(intradoses)

Considering important historical periods for architecture, from Pantheon to Baroque, it is possible to observe admirable examples related to this building technique, that found its accomplishment in the late Baroque shapes, where mathematic instrument joined to a long experience in the field created more impudent patterns.

The Historical Case

The *Pantheon* Pantheon's dome is the most extraordinary example of dome ever carried out, and it is well-known that this structure was stiffened by means of a rigid scaffold in coffers, observable from the intrados of the dome. Instead, it is not known very well that in its extrados it presents a thickening of the springer area with a stairs' outline, which give a fundamental contributes to the dome stability by means of extradoses concentric rings. The presence of *continuous rings* is set up in the section as an *increase of traditional springer angle*, of around *twenty degrees*. It is a fundamental building device able to stabilize the whole organism in order to avoid buttresses in springer's walls, that will have notably modified the temple view and its planned articulation.

This interaction between planned system, springer angle and cover stiffening can be considered a valid observation for other cases, as the following ones.

Figure 7: Pantheon's covering photo

***St. Sophia*'s Church** St. Sophia's Church in Istanbul presents a central planned system, of quadrangular typology with a serious of domes and minor semi-domes, placed in succession and all set up in order to buttress the big dome. But what is the secret of this colossus? It had many collapses because of strong horizontal strain due to seismic events, that compromised the static equilibrium of the structure. But what is changed during these demolitions and reconstructions? Certainly, *bending outline*!

Formal data must be interpreted according to these terms. Examining the different cases, we can notice that greater is the drop of the form of the underside of the arch, greater will be the correspondent degrees' increase of springer angle. This last will increase on the basis of a *linear law*, according to which its reduction will occur only in presence of contrasting elements of masonry wall that carry the weight of dome.

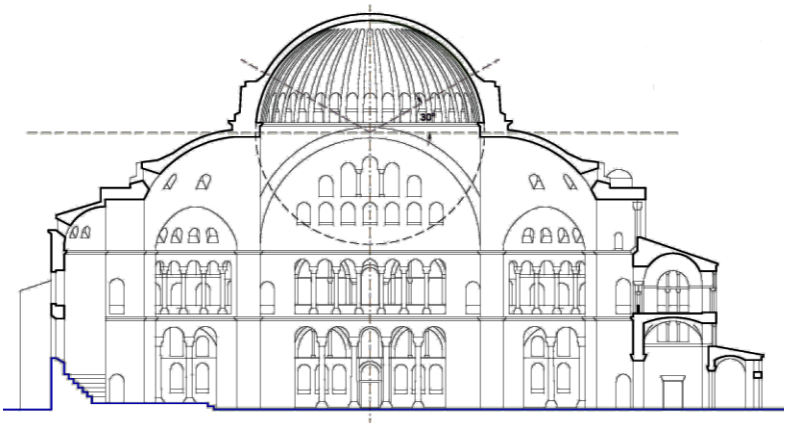

Figure 8: St. Sophia's Church, cross section with springer angle' increasing

This is the case of St. Sophia, where the ring is set in extrados position instead of being continuous, as in the Pantheon, is spaced out by a regular sequence of filled and no filled spaces with a progression of springer angle of traditional typology.
It was noticed that all analyzed cases followed this simple rule, according to which:
an increase or reduction of springer angle in relation to the planned organization of the structural organism and to the thinness of the structure in elevation;
an increase or reduction of springer angle in relation to rise-bay relationship of the covering outline.

Comparing the three structures with round arch outline: *Pantheon* - semicircular arch shape; *St. Sophia* in Istanbul – arch shape a little bit more low than a semicircular form; and *St. Vitale* in Ravenna - arch shape a little bit more high than a semicircular form; all three with a central system plane but articulated in different ways.

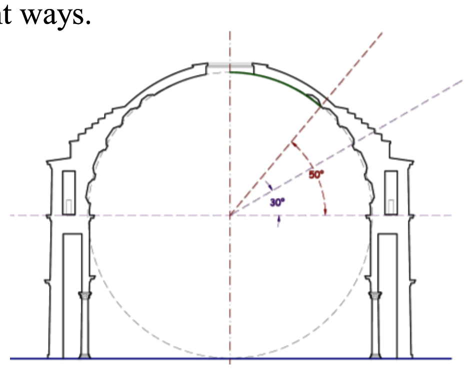

Figure 9: Pantheon, cross section with springer angle' increasing

Therefore, they undergo different increases of the springer angle in relation to the different planned relationships and its technical solutions in order to carry out stiffening extradoses:

- concentric circles with stairs' sections; (Pantheon)
- unique ring with plate and right angle' sections; (St. Sophia in Istanbul)
- dome cladding with bent tile covering. (St. Vitale)

According to the rule, in gothic structures or with *lancet arch* we should have a reduction of springer angle for the increase of the underside's form of the arch but, because of the building thinness in elevation of these monumental works, the increase of springer angle results inevitable; that becomes part of the same Pantheon's case history.

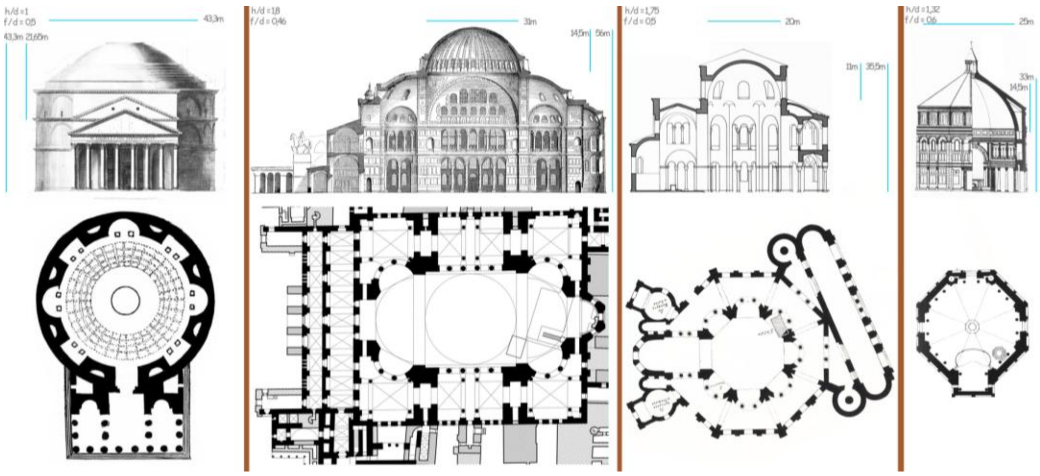

Figure 10: Different plan and cross section

Following this rule, the structure with *segmental arch very low,* close to flat arch, can be considered limit cases with extrados elements that are placed one on top of the other like over-and-under arches. So, these structures stiffening the whole section, avoid its deformation also in case of horizontal actions, like seismic actions. An historical example tested in different natural disasters, such as the terrible earthquake occurred in Parma in 1983, is St. Annunziata's Church. In spite of its 10m of span and its very thin structural section, it has maintained all its stability in case of static loads and dynamic strain too.

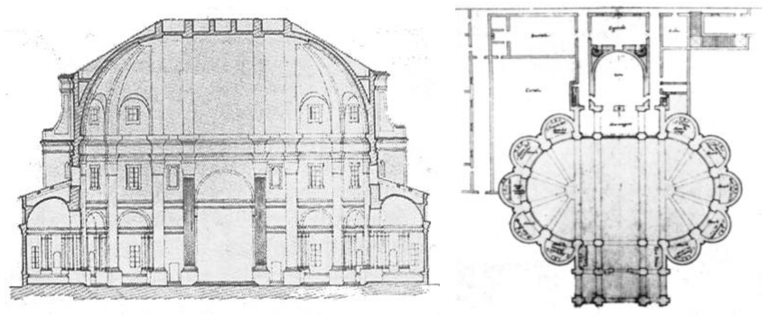

Figure 11-12: S.S. Annunciate church, plan and cross section

Conclusions

In the preceding paragraphs, by analyzing real cases, we have demonstrated the existence of a masonry art's rule, that checks the conditions of structure's global equilibrium, the variability of structure's springer angle with bend axis in function of the relationships that characterized the fundamental geometric dimensions such as rise, span, section, planned system. This statement will need a case history more extended to be absolute sure.

However, we consider there are already important answers in cases of remarkable importance studied in literature but never analyzed in these terms.

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