Analytical survey of structural engineering and long-term resistive environmental elements in an Iranian magnificent palace

Omid Reza Baghchesaraei1, Alireza Baghchesaraei2
1- Department of Civil Engineering, Azad University, Parand, Iran
2- Master of Science student, Department of Architecture, Bahcesehir University, Istanbul, Turkey
omidrezabaghchesaraei@yahoo.com
doi:10.6088/ijcsen.201304010036

ABSTRACT

In Iranian Architecture especially in a mason which was built more than 2500 years ago (Persepolis), Convergence structure, architecture and decoration are defined based on systematic harmony Using slim columns in this structure, along with special structural and architectural arrangements for column headers to compensate for long spans between columns, are among the main features of this structure. In addition to that, Iranian architects have beautifully blended decoration and structure and by using bull-shaped column headers in whose bowl beams get placed, prohibiting displacement of beams, and concurrently harmonizing between form, architectural decoration, and structural functions. By investigating and analyzing the columns of Persepolis, comparing their sizes and the accuracy in calculation of their sizes using Pi, and comparing the density of the stones that were used in the construction of the stone columns with sizes of similar concrete columns and the required reinforcement, the quality and durability of a similar concrete structure is compared with the stone-made Persepolis.

Keywords: Ancient high-tech structure, Iranian architecture, Technology of construction, Persepolis, Historic structure, Apadana.

1. Introduction

Iran’s profound and ancient engineering background during its ancient era is evident, considering what is left from the Achaemenid Persia empire time. The Achaemenids built on a grand scale. The artists and materials they used were brought in from practically all territories of what was then the largest state in the world. The astonishing Perpolis complex (the great construction) in which space and structure have combined to create a unique piece is significant in several aspects; firstly, the idea behind the stability of the structure is the fact that a mixture of stone wood and adobe is used while considering the features of each material, moreover, the precise size of the structural components is the result of the builders’ technical knowledge of the material features for carrying load and critical structural points, the use of weight for stabilization of the structure, creating balance through connections based on the material’s nature, etc.

According to this, Iranian architects were aware of the compressive stress of adobe and stone, and used these materials in the vertical elements, such as walls and columns, and wood, due to its useful tensile, compressive and bending stresses has been used in making horizontal load carrying elements like posts. (Abolghasemi L., 1978). The use of the right material, as well as applying new construction methods, have turned Persepolis into a structure which has maintained its magnificence through the centuries. Today, the new materials which have
improved since the industrial revolution owing to the advancement in technology create new space features. For instance, by using compressive and tensile strength over reinforced concrete, the size of columns and their spans have changed and they create spectacular space. However, architecture is not achieved only by the construction materials and various functions. Architecture is the changing spirit of each historical period that influences the social life, religion, science and art of that period. The new architecture was not created when there were metal and concrete buildings, but these innovations appeared when a new spirit required their appearance. Calculating the size of the columns in Persepolis by using materials such as reinforced concrete is indicative of this point at which the creative mind of the Iranian architects, who have used the materials in the best possible way, have brought lots of innovative achievements to improve the structural systems.

Figure1: Image showing Persepolis 3d plan

1.1 Structure

Setting up a structure is not a simple task, but it means solving the stability problem regarding available materials and their functional limits and their space characteristics. Iranian architects paid specific attention to structure and did not regard that separately from beauty. They were trying to innovating new methods of construction to provide stability of buildings. In Persepolis, the method of stabilizing the structure is a combination of using available materials, such as stone, wood and adobe, regarding their behavioral characteristics and their role in structural systems regarding dimensions, technical knowledge of critical structural points, such as capitals, proper use of dead load (weight) to achieve stability and balance of structure due to resistance against applied loads. Therefore, they used northern Iranian local architecture, which uses a timber skeleton and central Iranian's architecture to cover the building, and more use of local materials simultaneously. The awareness and experience of builders from compressive strength of adobe and stone resulted in the use of these materials in vertical elements, such as walls and columns and were used in the construction of load carrying beams from wood, which has better tensile and bending strength. Precision and delicacy in construction of the conic columns of Persepolis is so high that researchers believe that they had been aware of $\pi$ ratio and the calculation of height and method of construction of columns and the pressure that they bear and load distributing in columns sections is a result of this discovery.

The comparison of vertical and horizontal dimensions shows some specific relations between the columns’ height and their sectional sizes. The result of dimensioning different parts
shows that they had measuring tools with precision of up to a few millimeters. Also, there are some signs that might have been used to show the axes of columns and walls. As said, apart from using specific measuring units in the plan, columns and walls are designed as a specific module, in addition to numerical proportions and metric relations governing the complex’s elements.

1.2 Design process; elements and relation with other elements

To better understanding the structural role in Persepolis, we take into account the structure in relation with material, function, form and the geography of the site as the most important influencing factors.

2. Material and structure

Structural form is highly influenced from the material specifications, the physical characteristics of the materials, and the type of internal forces that they bear and, as a determining result, the type of structural element (Alpago A.,1986) .Thus choosing the material usually happens before choosing structural systems. This choosing is relative to how these materials should be set up more than everything and is evaluated on bias of different properties, such as lightness, heaviness, hardness and elasticity. The abundance of specific materials in one region has great effects in usage of those materials and as a result plenty of usage of specific structural systems in that region. In Persepolis, they used stones, wood, clay and bricks in the buildings. As described, the methods of setting up structures in northern Iran and the awareness of architects of compressive, tensile and bending strength of wood resulted in usage of these materials in beams and some columns. From existing grave-stones, which are about the construction procedure of the building, we conclude that they used Lebanese Cedar wood to satisfy the required strength of the wood. This wood has a specific weight of 0.46 (BaghchesaraeiA) and before that, they had used wood to cover spans of 2.5 to 3.5 meters in length, but in Persepolis, the ambition of architecture overcome that era and led to spans of more than 6.5 meters in the 100 columns hall and also 9 meters in the Apadana hall. Weakness of wood in bearing loads (which are vertical to fiber directions) lead to low shear capacity, especially in cases where there are bending loads on wooden elements (such as load bearing beams); also the weakness of wood in bearing concentrated stresses, which happens
in mechanical connections, increases the need to design detailed connections. In the construction of doors and windows they used engraved stones, although the form of lintels has been extracted from Egyptian architecture, against Egyptian architecture they had not consisted of usual shapes. They had engraved the stones artistically and used that as a decorative element. (Besenval R., 2000) The outer layer of walls consisted of stone and the inner parts are made from glazed bricks. In the construction of walls and the covering of ceilings, they used adobe. Adobe consists of clay as an element that provides adhesiveness after drying and some other combinational elements (depending on which mine was used), which has a role in reducing the thickness of the ceiling, such as sand, gravel, etc. Clay bricks, more than covering spans, work as an insulator. The main problem in construction is shrinkage of clay after drying (equal to 10 percent of initial length); clay does not have enough strength against deformation and movement of buildings, thus sometimes they used brick, which is more expensive than adobe, having more strength. They found a kiln near Persepolis, which is said to be used to kiln bricks as there was no suitable clay near Persepolis. They carried suitable clay from Isfahan.

2.2 Function and structure

Architecture is not an aesthetic shape but it is a dynamic fact that can be proved only by human activity. In fact, function is the effect of architectural space on human kind. The main aim of the structure is to set up a stable skeleton that could satisfy the functional needs of building and space ambitions. In fact the structure is in close relation with the building’s function. In other words, the needs always stimulate engineers to innovate and use new structural systems. (Abolghasemi L., 1978) As mentioned before, Persepolis Palace was a palace for religious functions and ceremonies, The Persian empire wanted to show their power to the world by its greatness. Thus they needed a vast and high hall, which can welcome more than 10,000 people to show their deep willingness to greatness. Structural systems that had been used up to that time could provide spans of up to 3.5 meters. Therefore, an architect should have had some innovations to build his new forms, to overcome their functional needs and because of lack of knowledge and technology to create materials, he tried to improve the existing material specification and some innovations in structural systems and he created a masterpiece which is called Persepolis.

2.3 Form and structure

Form is a pursuit of multidimensional living, what an architect does more than everything is an answer to humans’ nature. In fact, every constructed space could not be realized if it did not have any idea to have any adaptation with human living. Form is not the purpose, but only a reason to describe function. We can conclude the relation between form and structure in relation with the structural system and form of the building as a final result. On the basis of this relation, we can predict different structural systems for various forms of building. In this condition, we should not get it wrong by looking at outer decorative parts of the building. In Persepolis, the architecture form is full of beauty, a pure geometry which is based on simple geometric shapes that head the plans, views and perspectives. Direct lines connect the columns and develop major axes of the building; we also have their lines in the third dimension, and in surrounding walls. Iranian architecture relies on purity and simplicity of buildings and omitting on every exaggerated decoration leads to a combination of structure and form that we cannot separate from each other, which is clearly seen in the capitals of Apadana Palace and the 100-Columns Palace. Thus the pure structure heads the overall building (Ghobadian, V., 2005). Architecture designs the connections details artistically such
that there is no need to hide the structure in thick walls. Architecture and structure combined together make great halls, which are based on stone trees and which should be admired by every visitor.

2.4 Geography and structure

The structural system is in close relation with natural factors, especially weather. In Iran, with diverse natural specifications and different weather, each part has its own special architecture[8]. As described, in the north of Iran with humid and rainy weather wooden material is used, in the central mountainous part of Iran stone and clay materials are used and in some parts a combination of two materials have been used. In Persepolis, as they regarded load carrying in large spans and insulation of building against cold weather in winter and hot weather in summer, both construction methods were applied. The compressive tensile and bending stress of wood made it suitable to use for load carrying in large spans and certain. Capitals, and some specifications of clay material, such as being an insulator, made it appropriate for covering roofs and the central pore of walls, which are covered outside by stones and inside by glazed bricks.

3. Stability system of beam covering

In this system, applied force (which is usually weight) is transferred with elements such as columns. This force adds to the weight of vertical elements (columns) and transfers to supporting parts. As a point of view in this system, there is not enough rigidity in the connection between beams and columns, the deformation of the beam does not transfer to the column completely. Although they used this system in Persepolis, we can see an amazing innovation to improve quality and mechanical specifications of materials and to increase the efficiency of the structural system. As described, until the construction of Persepolis, using wood to cover spans of up to 3.5 meter was usual. Iranian architects used different methods to increase the length of spans such as:

1. Using beams in both perpendicular dimensions. Persepolis’s architects used this method to prevent exerting extreme loads in beams of unique directions. Thus they used a special connection at each end of every beam to have a uniform distribution of load.

2. Designing the capitals of columns. As they used ropes to assemble two beams together in local Iranian architecture and then used wood on them as small pillow, this kind of connection has been modified to connections in Persepolis. It seems that the idea of the capital of Persepolis came from Iranian local architecture. The capitals of the Persepolis columns are important from some aspects.
Figure 3: Image showing capitals of Persepolis that came from Iranian local architecture

3.1 Persepolis: a high-tech building in an ancient time

Architecture is not the achievement of construction materials and various functions and social conditions. It is the changing spirit of its time. New achievement of architecture is not a result of new materials made by technological progress, but is the result of the human need for new spaces; then, a new spirit makes their existence necessary. All of modern architectural progress is a kind of growth in which many historical limitations and restrictions have been replaced by discovery, awareness and a tendency towards developments. General principles of modern architecture are based on purity of building, using basic geometrical shapes in designing buildings and eliminating redundant. (Khakpour, M., 2005) Viollet-le-Duc (1814-1879), a French architect who was an important theorist in modern architecture, regards the structure of gothic building dynamics and believed that the relation between structure and function is an underlying principle in renaissance architecture and should be a guide as an important principle for modern artists. (Memarian, G.H., 1998)

Iranian architects paid special attention through construction methods and did not regard that separate from beauty. Therefore, making a beautiful structure omitted the need to cover the structure in wide walls and showed the beauty and power that was in structural elements built with emphasis on stability and satisfying the sense of security. Therefore, the space’s quality and structure of building are bonded together with omitting columns, not only the structure destroys, but also the spaces specification is disrupted, because the mutual relation of space’s nature and construction system and materials is destroyed completely (Alpago A., 1986). This mixture of space and structure is combined in designing some parts, such as connections of beams to columns with decorations and precision and delicacy, which is used in designing, displays the details of a building as a sculpture in a building. Using bricks with fixed dimensions in walls, cutting and polishing stone pieces of columns in extract site and engraving some holes to put some steel pins to connect pieces together and installing these pieces on site, the balance of dimensions in plan and sections of Persepolis can be regarded as prefabrication of building. Therefore, many principles of high-tech, such as displaying the structure inside and outside of the building, avoiding unnecessary decorations, showing the construction process and load transfer from beam to column and finally to foundation, the exact design of structural details and showing the structure as beautiful, prefabrications and innovation in construction methods with available materials, all are used in the construction of Persepolis. (Pirnia, K., 2007)

Figure 4: Image showing joins between stones, some holes were designed in the pieces
The architecture of Persepolis is based on space values, based on geometric shapes and free configuration, frequently without symmetry of plan and view, the appearance of architecture and decoration in structure and display of elements and structural details as general characteristic of space is stable and lasting because of the complete adaptation of construction methods on the function and homogeneity of structure. (Pirnya K., 2005)

4. Comparison between columns and foundation of Apadana hall and 100 columns

Regarding the spans, density of wood and clays that are used in Apadana Palace’s roof covering and Persepolis, in modeling the structure we conclude that they had used the maximum capacity of material in construction of that era. (Taghizadeh k., 2011)

Table 1: Table showing Comparison between columns and foundation

<table>
<thead>
<tr>
<th>Comparison between columns and foundation</th>
<th>Apadana hall</th>
<th>100Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column’s size</td>
<td>Foundati on’s size</td>
<td>Column’s size</td>
</tr>
<tr>
<td>1.25</td>
<td>5x5x0.7</td>
<td>1.05</td>
</tr>
</tbody>
</table>

In spite of the insistence of Iranian architecture to use local materials in construction, they used some woods for beams from Lebanon and some soils for adobe from Isfahan; this accuracy and obsession for choosing material shows its importance more clearly.

5. Conclusion

The main idea of the construction of Persepolis as a palace is the existence of halls with high columns; therefore, the architect needed some innovations to gain his ideas of space and function. Because of not having modern materials, they tried to improve the characteristics of existed materials and innovation in structural systems. Therefore, providing functional needs in Persepolis led to creating a magnificent structure that was bonded with architecture. According to researchers, in ideas based on the creation of a new method in the world’s architecture that were inspired by the idea of columns that are looking and stretching towards sky and unique space specification of halls with column in this buildings, Persepolis is the pioneer of the other buildings in that era in using the best technologies available in that time. The Persepolis complex is a building that is ruled by the tendency towards progress and freedom of restrictions, using the best specification of materials and improving them (due to technical knowledge of their behavior under loads), relying on principal geometric forms, displaying the structure, omitting decoration, prefabrication, innovation in construction methods and covering spans with precise design and details, stability of the space specification on structural system and therefore can be regarded as a high-tech building in its era. Comparing the construction facilities of existed materials at the time of the construction of Persepolis with modern materials, such as reinforced concrete, insisting on the structural innovations of Persepolis and the methods of using materials in that complex in situation and clarifying that if such a building with space ideas and reasonable discipline was built with modern materials, there would not be a salient change in space specification as column dimensions are the same. Thus we can assert that the durability of a structural masterpiece is not only the reason for progress in construction methods, but during history, the buildings.
Analytical survey of structural engineering and long-term resistive environmental elements in an Iranian magnificent palace

Omid Reza Baghchesaraei and Alireza Baghchesaraei

that were made by using the least equipment of that specific era were solid and stable due to their innovative methods of construction and insistence on creating dramatic spaces.

6. References


Analytical survey of structural engineering and long-term resistive environmental elements in an Iranian magnificent palace

Omid Reza Baghchesaraei and Alireza Baghchesaraei