International Journal of Trend in Research and Development, Volume 4(5), ISSN: 2394-9333
www.ijtrd.com

Historical Indications of Architectural Aspects Effect in Seismic Behavior

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Abstract— in the study of futuristic imagery of seismic design, we would benefit, educationally, to explore some of the famous historical monuments in structural and architectural terms, especially on the traditional dilemma of lateral forces. In some cases, such as pyramids, Parthenon and Pantheon, the seismic resistance shaped part of the architectural history. This search aims to clarify the influential degree of the architectural aspects effect in seismic behavior, by studying three historical architectural civilizations, choosing the most popular standing building in each. The paper shows that, in the standing historic buildings, the architectural configuration was the most influential seismic tool. There were no strong materials, steel and reinforced concrete in these times that can strengthen the building and fasten its tie, thus Architecture Configuration played the most important role against earthquakes in these times.

Keywords—*Configuration; siesmic; lateral pressure; Earthquake Architecture.*

I. INTRODUCTION

While the history is the mirror of the nations, reflecting their past, translating their present and inspiring their future, it was very important to take care of it, maintain it and transfer it properly to the next generations to be a light at the end of the tunnel of their present and future. The nations with no history don't exist, as the history is the basis of the nations, live with it and die without it.

The relation between the earthquakes and architecture is a historic relation started with the dawn of the history, as the ancient man tended to build a shelter for himself to protect him from nature. This shelter developed historically and architecturally to become a house for himself and his family, then a temple to pray in, a market to sell and buy and many other forms of buildings. With technology advances, the building became houses with multiple stories with more than one family, or vast expanse buildings to serve different purposes. With earthquakes' occurrence, and the damage of the buildings due to them through history, emerged the historical dilemma of how to protect the buildings from destruction, and man from dying because of that destruction. So, the man embarked a historical journey to establish a set of architectural concepts to protect the buildings of seismic threat, and to achieve the concept of their eternity and to deliver the required message of them for as long as he can. These concepts developed through history and became architecturally reflective of the architectural and philosophical goal of their original structure. We referred to that in this paper as the methodology of architecture and earthquakes.

The earthquakes were considered occasional events that don't subject to the designing control. However, the structural basis if the design can't be denied, as the one can summarize the most part of the architecture history, till the end of the 19th century, as a struggle to establish proper areas in light of the limited materials that were effective at that time against pressure forces. As the buildings grew higher and weaker, the responses of the designers to the nature of lateral wind and seismic forces, emerged. The wonderful Gothic architecture is a good example of that (1) .

II. ANCIENT EGYPTIAN ARCHITECTURE:

The ancient Egyptian civilization was found around the river Nile in the northern eastern corner of the African continent. When studying this region using seismic threat map, we will find that it's a medium prone area as we move towards Sinai and Suez Gulf. The threat decreases as we move south towards Luxor, Aswan and Nubba.

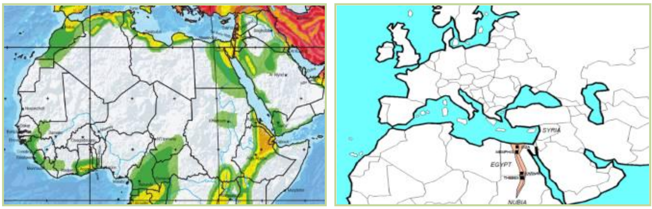

Fig 1: The original area of the Egyptian Civilization and its location in seismic threat map.(8)(9)

When studying and researching the indicators of structural design response of the religious buildings in the ancient Egyptian architecture concerning the requirements of seismic structure, and the extent of the architectural expression of the aspects of structural seismic resistance, we witnessed that the ancient Egyptian architect was eager to make his buildings eternal in face of the natural catastrophes based on the afterlife philosophy.

The ancient Egyptian architects decided the aesthetic rules of the Egyptian forms of the stone architecture. So, the method of clarity, direction alignment, reducing bindings and complexity was the dominating method in that age. The Egyptian temples characterized with direction alignment, segment symmetry and using the rectangular shapes that are divided into smaller rectangles. Due to what the Egyptian climate is characterized of clear sky and hot air, the architects didn't need to use large openings, so, the walls appeared as large expansions free from openings. Also, the Egyptian architect made the columns tied laterally with botanical materials, then the gabs are filled and exteriors are covered with mud. Then the columns that are of the shapes of plants are developed. The ancient Egyptians used also palm trees trunks in building the roofs. The studies revealed that the ancient Egyptians has the credit of presenting the technological triangle of architecture to the world: building unit, measuring unit and formation unit(10). Many of these points participated in enhancing the seismic performance of the Egyptian structures. For example, the researchers considered the stone bases of the obelisks and columns, which were consisted of many layers without ties, the basis of the concept of base isolation (2), which were used to protect the rest of the obelisk or the column from transferring the forces of earthquakes. Also, the roofs were built of light materials participated in reducing the impacts of inertia forces of different seismic activities. There are many studies that dealt with seismic resistance patterns in the ancient Egyptian architecture.

Fig 2: The base of an Egyptian obelisk that illustrating the stone layers of the base as a method of base isolation.

III. THE PYRAMIDS

The pyramids are the most famous examples of the Egyptian tombs, that are located in Giza not far away of the Nile coast. They were built since 25 centuries B.C. between 2480 and 2550 B.C. in a medium seismic prone area, and had experienced many seismic activities along the centuries.

The historic symbol of the pyramid shape was the expression of one of the most ancient civilizations in history. There were a lot of explanations about why the Egyptians chose the pyramid shape in building their tombs. The architectural symbol of the pyramid is religious as the mass decreases gradually and ends with a dot as indication to the sky or the God. There are another philosophical views that see the pyramids were founded to indicate the location of the ancient civilization if there was a flood. Others said that they were built to protect the earth of the stars falling on earth. However, they all agreed upon that they were built to defy all forms of natural threats based on the principal of the eternal life and to protect the Egyptian civilization.

When seismically studying the architectural shape of the Pyramids, we found that the pyramid shape is the best structural formations in resisting the earthquakes, as the biggest portion of the mass is near the ground and decreases as we move upwards. Also, the symmetry of the structural shape presents balancing and centralism of the mass. All these factors participate in the huge solidity in bearing the lateral seismic loads.

Many explanations appeared that deal with the relation between the pyramid shape and the seismic activities. Some directed their explanation towards that the pyramids are some form of transmitters that transmit the earth movement resulted from the earthquakes into electric energy used by the ancient Egyptians in their daily life. This concept relied on the position of burial chamber, the corridors that lead to it and the huge sizes of lime stones of the exterior that serve as an outer isolator of the Pyramids which resembles the modern concept of generating energy.

Fig 3: Giza Pyramids.

There are other hypothesis that consider the Pyramids as centers of absorbing the earthquakes by reducing the kinetic energy resulted from the seismic motion and transforming it to another form of energy, therefor increasing the stability of the Nile area that is vulnerable to the seismic activities.

The Egyptian Pyramids are considered as a historic icon of the relation between architecture and earthquakes, as the Egyptian architect combined the famous structural and philosophical formation of the Pyramids and related them with several variables, most importantly, the structural dimension of dealing with earthquakes, as the pyramid shape is the strongest shape in resisting the earthquakes. this didn’t happen by chance, but was achieved after thorough studies and researches. If we asked ourselves, what if the Pyramids were cubes or slender? Would they have the same structural and form strength they have now? The Pyramids, as the researchers and experts confirm: are the best architectural expression of the strongest architectural formation to resist earthquakes.

IV. THE GREEK ARCHITECTURE:

The Greek civilization existed from Greece in the west, through Egypt and the Levant to Iran and the borders of Afghanistan in the east. While studying this area using seismic threat map, we found that the area from Greece in the west to Iran in the east is seismically high, and the seismic threat reduces to medium and low in Levant and Egypt.

Most of the scientists and architects found that the design of the religious Greek buildings was meant to protect them from earthquakes. The professor Kiriazis Bitilakis, the professor of structural engineering in Aristotle University in Thessaloniki, the Greek architecture in Acropolis as:

“wonderful building, used keen solutions to architectural problems that thought to be unsolvable”.

The Greeks introduced to us some of the most wonderful and seismically powerful buildings in the old world, that became the foundation and the bible of many of the architects, ancient and contemporary. We can see clearly in most of the Greek temples different levels of the architectural expression of seismic resistance.

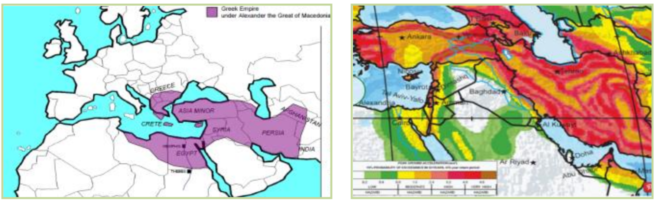

Fig 4: The Greek civilization under the rule of Alexander the Great, and its location on seismic threat map.

V. THE PARTHENON IN ATHENS

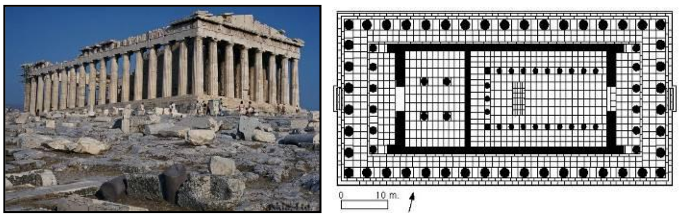

Fig 5: Parthenon layout and plan.

One of the most famous examples on the Greek temples, the Parthenon in Athens, 5 B.C., that was built on the Acropolis in Athens, which is a high seismic area, and has experienced many earthquakes through time.

The Parthenon survived along 24 centuries in a medium seismic threat area. The plan of the temple is symmetric on both axis. Also, it has a parameter colonnade around strong shear walls, and the inside parameters there are more columns(3).

The changes that would be made to this design to increase its earthquake resistance were it built in its generic form today, would involve changes of material (changing the unreinforced stone walls into homogeneous shear walls; using a stronger, stiffer roof diaphragm; and changing the stone columns into an earthquake resistant material), an alternative structural system (to transform the post and beam into a rigid frame), and better structural details (connections between walls and roof, anchorage of any appendages, etc.). However, the configuration - where the resistant elements are rather than what they are - is admirably well-suited for earthquake forces. If one wished to build a building of this size out of blocks of marble without the aid of modern earthquake resistant practices, the Parthenon's configuration could scarcely be bettered (4).

VI. THE ROMAN ARCHITECTURE

The Romans traveled from eastern Europe or from Asia to the Italian islands since the 12th century B.C., and established the ancient city of Rome. The Romans started to organize and develop their political, military and social institutions. Then started to gradually expand their influence and established a state that dominated initially the whole Italian Peninsula, then the most parts of the ancient world with vast borders from the British Islands and the Atlantic European coast in the west, to Mesopotamia and the coast of Caspian Sea in the east, and from the central Europe to the northern Alps and the African Sahara and the Red Sea in the south. By that, it was an example on the Universal State with colonizing bias that lasted to the 5th century A.D. when the German tribes managed to dominate the Roman state provinces in 476 A.D.

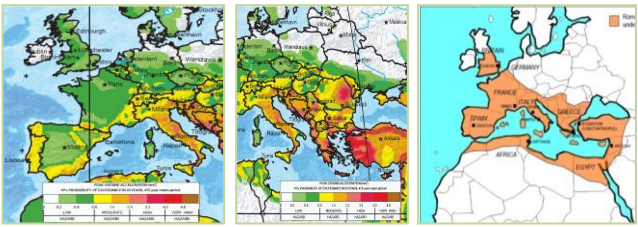

Fig 6: The roman civilization and Its location on seismic threat map.

When studied this region using the seismic threat map, we found that the most parts of the civilization were in medium threat regions, except for the region from central Europe from Turkey in the east to the borders of Italy in the west, which is highly active.

The geographic nature of the Roman state helped to use different kinds of building materials, on the contrary to the Greeks, who depended on the marble. Also, the volcanoes participated in the availability of the masonry, that resembles the modern cement, that helped them to build the vast expanded roofs. Due to the vast area of the Roman state, this helped them to tap into the different regions they conquered and learnt many building methods. Therefore, they managed to overcome the implementation problems they faced during buildings' implementation. While the religion has no relation to the architecture, this helped that the religious buildings were not the dominant factor as many buildings and functions were built. These buildings were stiff enough, and the experts said that this was achieved thanks to the stiffness of the materials that the Romans used. It was noticed that the Romans used Arched extensively, that helped to increasing the seismic resistance, due to their ability to transfer the lateral loads and resisting the lateral pressure(5).

VII. THE PANTHEON

The Pantheon was completed in 125 A.D. in the ancient city of Rome, highly seismic activity area, and experienced many earthquakes along the time. The building is located on a base is higher than the ground by 1.3 meters, and consisted in two main parts: the terrace and the circular main structure. The dimensions of the terrace are 33.10 meters and 13.60 meters. There are 8 Corinthian colonnades with height of 11.80 meters, covered with white marble. The circular structure was 43.20 meters high, which is the highest point of the dome. In the upper part, there's a circular sky hatch with diameter of 8.80 meters. The dome was built with a light mix of concrete and gypsum. It has also 5 main diagonal panels and other panels that stem from the center, that meant to reduce the weight of the plastic dome. There also are a lot of the classic architectural details, as each part of the building is considered a reference to the following classic architectures.

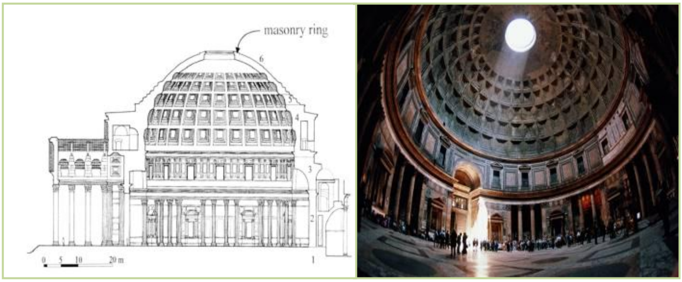

Fig 8: The internal design of the dome and cross section.

Since the grand scale of Roman interior spaces is one of the characteristics which differentiates Roman from Greek classical architecture, it is instructive to study the Pantheon: at one hundred and forty three feet, the largest span building of antiquity, and a record for the world which it maintained for the seventeen centuries following its construction.

Though historically notable for its height and span, the tremendous mass of the Pantheon is also a prominent structural feature. Unlike the strategic point-for-point buttressing of lateral thrusts in some Gothic buildings, the Pantheon's walls resist the thrust through sheer mass. Although it is true that mass is generally a seismic liability, extremely thick masonry walls can be more stable than this truism might lead one to believe. The vertical gravity force of the Pantheon's mass is so great, relative to any lateral forces, that the entire structure is kept firmly in compression at all times (6).

This strategy represents a simple form of the pre-stressing in which today we induce very high compressive forces (by use of a highly stressed tensile component) which has the effect of greatly diminishing the tensile forces in that member.

Friction, which is typically neglected in the design of structures today, is significant in such a massive masonry structure. Friction between the large surface areas of masonry elements provides the connections which would today be made with positive mechanical fastenings, and though one would not wish to count on friction to provide reliable connecting force values, it is part of the explanation for the stability and strength of massive, well built, unreinforced masonry buildings.

The dome is completely solid except for the oculus at the top, and the walls are punctured by only the one monumental doorway, Coffers and hollow spaces are uniformly distributed around the building. This solidity provides unbroken stress paths for lateral forces. Though the walls are built of unreinforced concrete, brick, and stone, and hence can sustain only small shear stresses, their tremendous horizontal cross-sectional areas make up for the deficiencies of the material properties.

As for the massive development, in that time, of the vast expansion domes that reinforced with asset of frames and panels, and their role in reducing the total weight of the roof and therefore reducing the inertia forces upon it. Also it played a big role in distributing the vertical forces and bearing the horizontal forces(7). With bearing in mind covering a vast area functionally and aesthetically without any internal structural elements.

Next table shows the seismic points of each previous ancient building, and its Architecture characteristics which related to its seismic performance. (No weights just existence).

Table 1: Architecture and Seismic issue in the pyramids, Parthenon and Pantheon.

S	Seismic issue	Pyramid	Parthenon	Pantheon
1	Inertia force dist.	√	√	√
2	Torsion effect	√	√	√
3	Stiffness	√	-	√
4	Ductility	-	√	√
5	Period and Resonance	√	-	√
6	Damping	√	√	√
A	Architecture issue	Pyramid	Parthenon	Pantheon
1	Scale	√	√	√
2	Proportion	√	√	√
3	Symmetry	√	√	-
4	Height	√	√	√
5	Plan Density	√	√	√
6	Corners	√	-	√
7	Perimeter Resistance	√	-	√
8	Redundancy	-	√	-

CONCLUSION

We may find that how it's amazing that many of the fragile historical monuments survived although lacking the strong materials, steel and reinforced concrete that can strengthen the building and fasten its ties. As they were built before the emergence of all the analytical and quantitative tools of the seismic designs, so the answers relate to the buildings' configurations, using simple and symmetrical shapes that reduce the seismic loads, and the occasional use of the stressing materials in a way that reduces the forces of elasticity, shear and bending. The perfect result here is:

“In the historic buildings, the architectural configuration was the most influential seismic tool”.

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