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Reasons Why the Great Pyramids of Giza Remain the Only Surviving Wonder of the Ancient World: Drawing Ideas from the Structure of the Giza Pyramids to Nuclear Power Plants

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Abstract: Selecting a site for a nuclear power plant requires extensive studies to ensure its safety and stability during its operation until its decommissioning. The 4,500-year old Egyptian pyramids at Giza are buildings to learn from. This paper tries to pin down the reasons for the survival of the Giza pyramids in order to reach a criterion for choosing sites for important buildings. It argues that the site selection and the geological properties of the area, being away from seismic effects, , floods and groundwater levels, the stability of the geometric form of the pyramid, the solidity of the structural engineering and precision of execution arguably are the reasons why the Great Pyramids of Giza are the only survivors of the seven wonders of the ancient world.

Key words: Site selection, nuclear power plants, pyramids, stability of form, solidity of form, precision of execution.

1. Introduction

This paper outlines the seven wonders of the ancient world and then points out the reasons the six other wonders were destroyed and the question why the Giza pyramids survived for thousands of years. It answers the question by pointing out four reasons: (1) site selection: away from seismic effects, floods and groundwater levels; (2) the stability of the geometric form of the pyramid; (3) the solidity of the structural engineering (few voids compared to the solids inside the pyramid); (4) the perfection and precision of execution of the pyramids which also have to do with the pyramids being still standing.

This paper will examine the above factors in detail, trying to find out if they were considered before the construction of the Giza pyramids.

2. The Seven Wonders of the Ancient World

The ancient Romans and Greeks have originally initiated making the “seven wonders” list, as a kind of an ancient travel guide in their retrospective countries. Fig. 1 shows the seven wonders of the ancient world in their retrospective countries. Over time, this inventory was modified and monuments were added and then culled and was then finally completed somewhere in the middle ages. Many of the classical writers later disagreed on what was in the final list, but the following seven works of art and architecture are amongst the most commonly included monuments, and are most likely to be the final seven on the “ancient” list. It has to be noted that sketches and drawings of these wonders have vanished, so archaeologists have instead relied on ancient literary works to get a vague idea of their history and appearance. Table 1 lists the seven wonders of the ancient world according to the ascending chronological date of construction and the corresponding date of destruction for the wonders that were destroyed and shows the cause of destruction and outlines its notable feature and its modern location.

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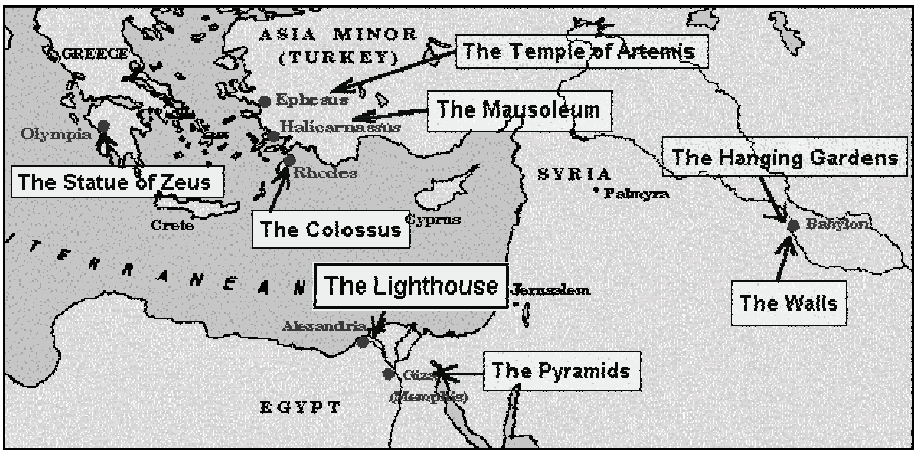


Fig. 1 The seven wonders of the ancient world in their retrospective countries.[1]

Table 1 Comparison between the seven wonders of the ancient world.

Wonder	Photo	Builder	Date of construction	Date of destruction	Cause of destruction
Great pyramid of Giza		Egyptians	2584-2561 BC	Still in existence	Still in existence
The Hanging Gardens of Babylon		Babylonians	Around 600 BC	After 1st century BC	Earthquake
Temple of Artemis at Ephesus		Lydians, Persians, Greeks	550 BC	356 BC (by Herostratus) AD 262 (by the Goths)	Arson by Herostratus, plundering
Statue of Zeus at Olympia		Greeks	466-456 BC (temple), 435 BC (statue)	5th-6th centuries AD	Fire
Mausoleum of Halicarnassus		Carians Persians, Greeks	351 BC	By AD 1494	The original structure was destroyed by flood. Then a new structure was built and was damaged by an earthquake and eventually disassembled by European crusaders
Colossus of Rhodes		Greeks	292-280 BC	AD 1303-1480	Earthquake
Lighthouse of Alexandria		Hellenistic Egypt (Greeks)	280 BC	AD 1303-1480	Earthquake

[1]http://www.scottsplanet.com/turkey/turkeyletter, accessed December 2, 2013.

Four out of six wonders were destroyed by earthquakes, i.e., 67% because of earthquakes.[2]

The Pyramid of Khufu is an Egyptian pyramid, located at Giza near Cairo, built around 2560 BC, probably designed by Hemon, part of the necropolis Memphite, according to widely accepted scientific theory so far, representing the ancient burial place of Pharoah Cheops or Khufu. The Pyramid of Khufu which stands next to the pyramid of Khafra and Menkaure is the most famous of the three. It was recognized by the ancient Greeks as one of the seven wonders of the world. The sides of the pyramid are facing due north, south, east and west. Large blocks of stones, weighing between 2.5 t (even the largest of about 15 t—the entire building is made up of more than 2.3 million such units, which makes the Pyramid of Khufu the heaviest man-made structure—has a mass of more than 6 million t), were set with great precision. The walls are covered with grain limestone from the quarries at Tura. With this case, only fragments remained in the lowest layers. Truncated apex of the pyramid meant that the amount has decreased from 146.6 m to approximately 137.0 m. Fig. 2 is a timeline of the seven wonders of the ancient world showing the length of years of the Great Pyramid survival in comparison to the rest of the ancient wonders.

3. Site Selection and Evaluation

Whether the ancient Egyptians performed site selection and evaluation studies and analyses to find out if the site is safe from the hazards of earthquakes remains an area for further studies. Fig. 3 represents the Giza complex where funerary monuments, including rock tombs, ornate mastabas, temples and pyramids were erected. The Khufu Pyramid was the centerpiece of an elaborate complex, which included several small pyramids, five boat pits, a mortuary temple, a causeway, a valley temple and many flat-roofed tombs for officials and some members of the royal family. Collins [1] maintains that the Khufu Pyramid remained the tallest man-made structure in the world (146.6 m) for over 3,870 years from year 2560 BC to AD 1300.

3.1 Seismicity of the Site

Most of the seven ancient wonders were destroyed by destructive earthquakes except the Giza pyramids. Two important questions pose themselves:

(1) What factors is the site of Giza Pyramids characterized with to make the pyramids resistant to the effects of earthquakes?

(2) How were the pyramids structured to resist aging for all those thousands of years?

The answers for those two questions require the study of the following topics: (1) location of the area; (2) seismicity of the area; (3) geomorphology of the pyramid plateau; (4) geology of the site. Each point will be discussed independently.

3.1.1 Location of the Area

The monuments of Giza Pyramids are located in the north-western part of the Giza plateau. Khufu Pyramid's tip lies between longitude 31°08′03.69 E and latitude 29°97′91.75 N which is represented in Fig. 4.

3.1.2 Seismicity of the Area

Maamoun and Ibrahim [2] correlated the earthquake data with the large scale tectonic features such as faults, folds and other geologic units. Accordingly, two main seismic dislocation zones besides three others of local activities were recognized as shown in Figs. 5 and 6 as follows: (1) Red Sea—Gulf of Suez dislocation zone; (2) Egyptian Mediterranean coastal dislocation zone; (3) Luxor-Qena dislocation zone; (4) Baharia-Fayum-Abu Rawash dislocation zone; (5) Gaghbub-Siwa Oasis dislocation zone. The instrumental seismicity map indicates that the pyramids site is characterized by very low seismicity setting. The study of historical seismicity map affecting Egypt along its geologic history, as shown in Figs. 5 and 6, shows that the area of Giza Pyramids itself is free from the

[2] http://www.buzzle.com/articles/7-wonders-of-the-ancient-world.html, accessed December 24, 2012.

effects of strong and destructive earthquakes. Most of the destructive earthquakes' epicenters are localized in the eastern bank of the River Nile. Also, the isoseismal intensity contour map reflected that the pyramid site has not been affected by intensity value more than VI on Mercalli scale. Moreover, one of three seismotectonic trends affecting Egypt passes by Fayoum province but avoid the Pyramids' site.

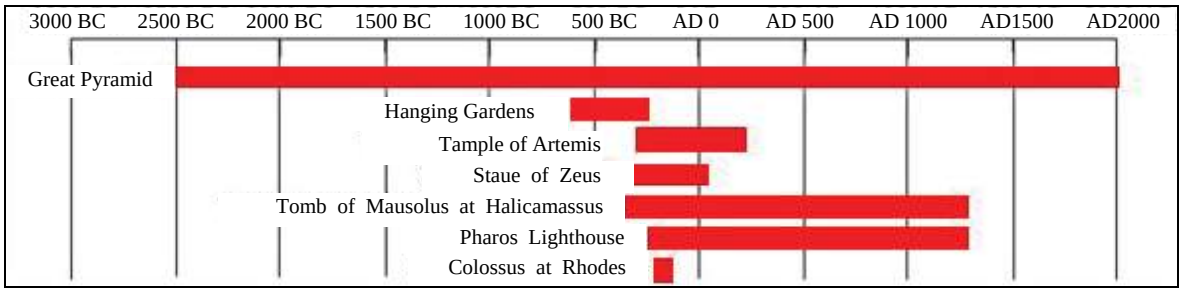


Fig. 2 A timeline of the seven wonders of the ancient world showing the length of years of the Great Pyramid survival in comparison to the rest of the ancient wonders.[3]

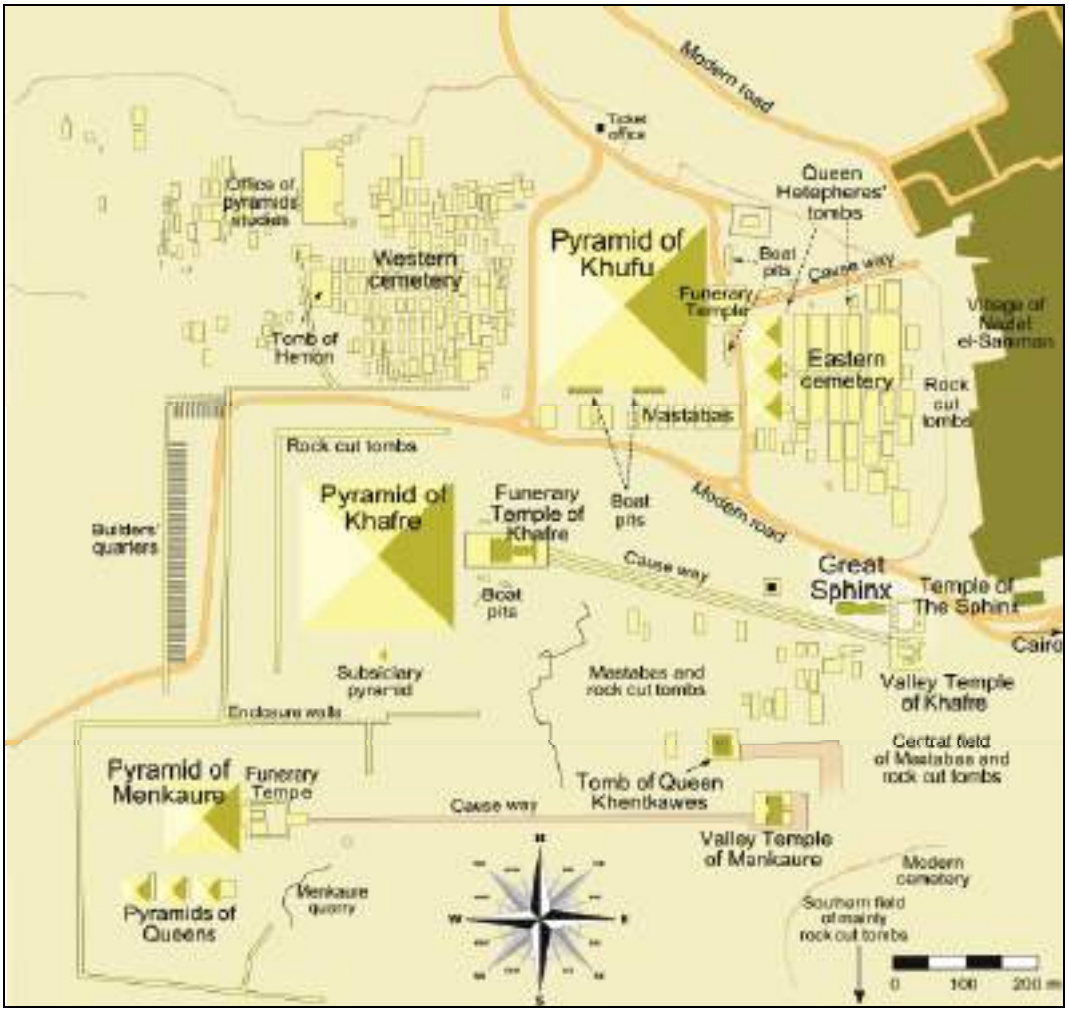


Fig. 3 Layout of Giza Pyramid complex.[4]

[3]Nicolas M. Perrault. http://www.delta7studios.com/wonders.htm, accessed August 11, 2012.
[4]Http://www.newworldencyclopedia.org/entry/Great_Pyramid_of_Giza, accessed December 24, 2012.

The only earthquake that affected the pyramids was in the 14th century on August 8, 1303. A massive earthquake (6.5 Richter) hit the Fayoum area and loosened many of the outer casing stones, some of the stones can still be seen as parts of these structures to this day. Later, explorers reported massive piles of rubble at the base of the pyramids left over from the continuing collapse of the casing stones which were subsequently cleared away during continuing excavations of the site. Nevertheless, many of the casing stones around the base of the Khufu Pyramid can be seen today in site, displaying the same workmanship and precision as has been reported for centuries. Table 2 is a catalogue showing the earthquakes in Egypt. Table 2 is a catalogue of historical earthquakes in Egypt [3].

Fig. 4 Latitude and longitude map of Egypt.[5]

Table 2 The effective earthquakes on Egypt [3].

Gregorian date	Region	Intensity	magnitude	Consequences
2200 BC	Tall Basata	VII	5.8	Deep fissures and soil cracks in Tall Basata
221 BC	Siwa Oasis	VIII	6	Destructive earthquake
24-20 BC	Alex offshore	-	-	Strong sea waves
262	Siwa-Libya	-	-	Felt at Siwa
320	Alex offshore	VII	-	Many houses destructed
553	Alex offshore	-	-	-
796	SE Mediterranean Sea	VI	-	Felt at different localities of Egypt, partial damage of Alex Light House
859	Bilbais	VI	5.5	Felt in Nile Delta and Alexandria
1111	East of Cairo	VII	5.8	Destruction of Rehachope Temple
1303	Fayoum Alexandria	VIII	6.5	Severe earthquake: many places in Cairo were destructed, affected the Nile Valley till Quoos and little damage
1326	Alex offshore	V	-	Light house was shocked, felt in many places
1687	Alex offshore	VI	-	Alexandria was vibrating for 10~12 days
1698	Rosetta	VI	5.5	Nile Valley
1754	Tanta	VIII	6	Destructive earthquake: buildings were damaged, thousands of people were killed
1870	East of Mediterranean	X	7	Severe earthquake, felt in vast area 32° N, 30° E
1879	Alex offshore	V	-	Severe earthquake felt in vast areas
1908	Alex offshore	-	-	Strongly felt earthquake
1992	Dahshour	-	5.3	-

[5]Http://www.mapsofworld.com/lat_long/egypt-lat-long.html, accessed November 3, 2012.

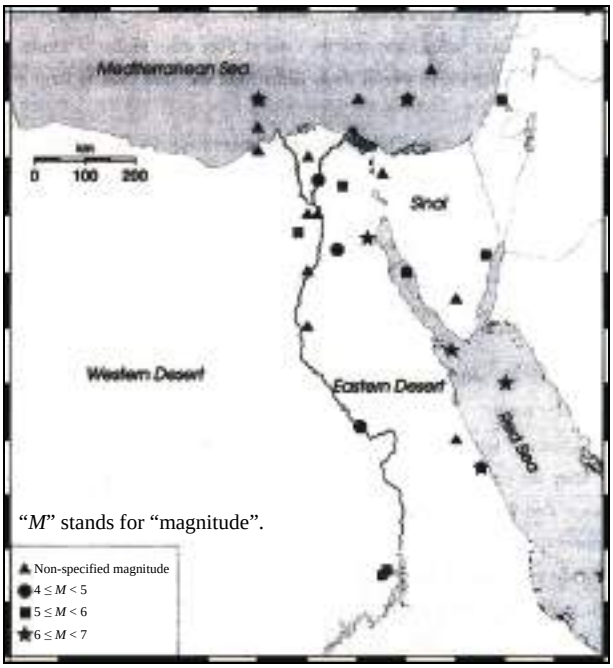


Fig. 5 Historical seismicity of Egypt.[6]

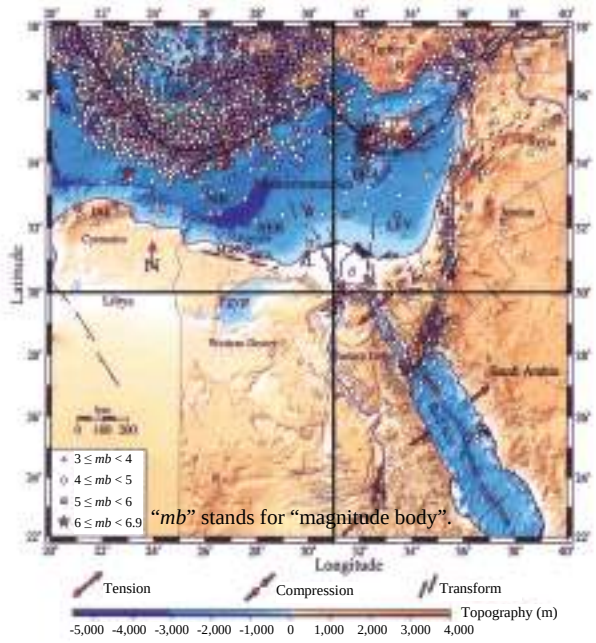


Fig. 6 Seismicity of Egypt and its surroundings.[7]

3.1.3 Geomorphology of the Pyramid Plateau

The geomorphology is the result of the interaction of three major factors: the nature of the rocks, the tectonic events which have affected the site and the effects of weathering on these formations. Regarding the type of rock, the site consists of limestone rocks which are characterized by geophysical and dynamic properties. The rock basement is visible at the base of the monuments, where the facing stones are missing. The main difficulty encountered was where the monuments were covered by their facing stones. It is noticed that the Great Pyramid was built on a carved outcrop using the existing topography at the time of its construction. The part of original hill constitutes 23% of the volume for the Khufu/Cheops Pyramid and the carved outcrop constitutes 11.5% of Khafra Pyramid. These results are deduced from direct observations and should be regarded as minimum values. The utilization of carved natural rise as a construction site seems to be general characteristics of architecture belonging to the fourth dynasty. It is difficult to speculate whether this architectural and structural choice was related to economic constraints or symbolic significations but it surely helped in securing the foundation/base of the pyramid. Fig. 7 shows the geomorphology of the pyramid plateau. The first six big steppings of the pyramid are the base of the pyramid from the rock [4].

3.1.4 Geology of the Site

The Khufu and Khafra pyramids are located in the north-western part of the Giza plateau. The Giza plateau is the subject of numerous geological studies among which are Zittel [4], Blanckenhorn [5] and Said.[8] The studies show that the monuments of the fourth dynasty of the Giza plateau were built on sedimentary sequence with dominant carbonated formations deposited in an epicontinental sea of variable depth. The age of these formations belongs to Middle to Late Eocene. Structurally, the plateau is oriented towards the NE-SW direction and dipping SE monocline, the monoclonal is affected by heterometric faults with normal dominant and weak throw oriented towards NW-SE direction which does not affect the study area site.

[6]R. Said, ed., 1990. The Geology of Egypt. Rotterdam: A. A. Balkema, p. 734.
[7]*Ibid.*
[8]*Ibid.*

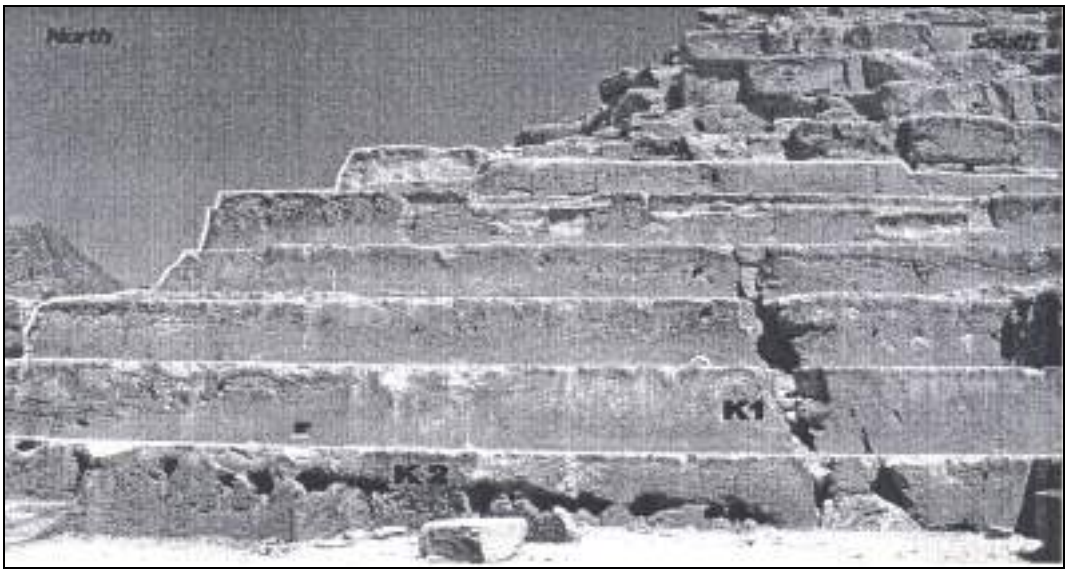


Fig. 7 Khephren Pyramid. View of the northern part of the W face. The visible part of the original hill (delimited by the white line) shows horizontal steps without horizontal or vertical block breaks (K1: Karst natural fracture; K2: discontinuities showing advanced dissolution processes along the strata surface).[9]

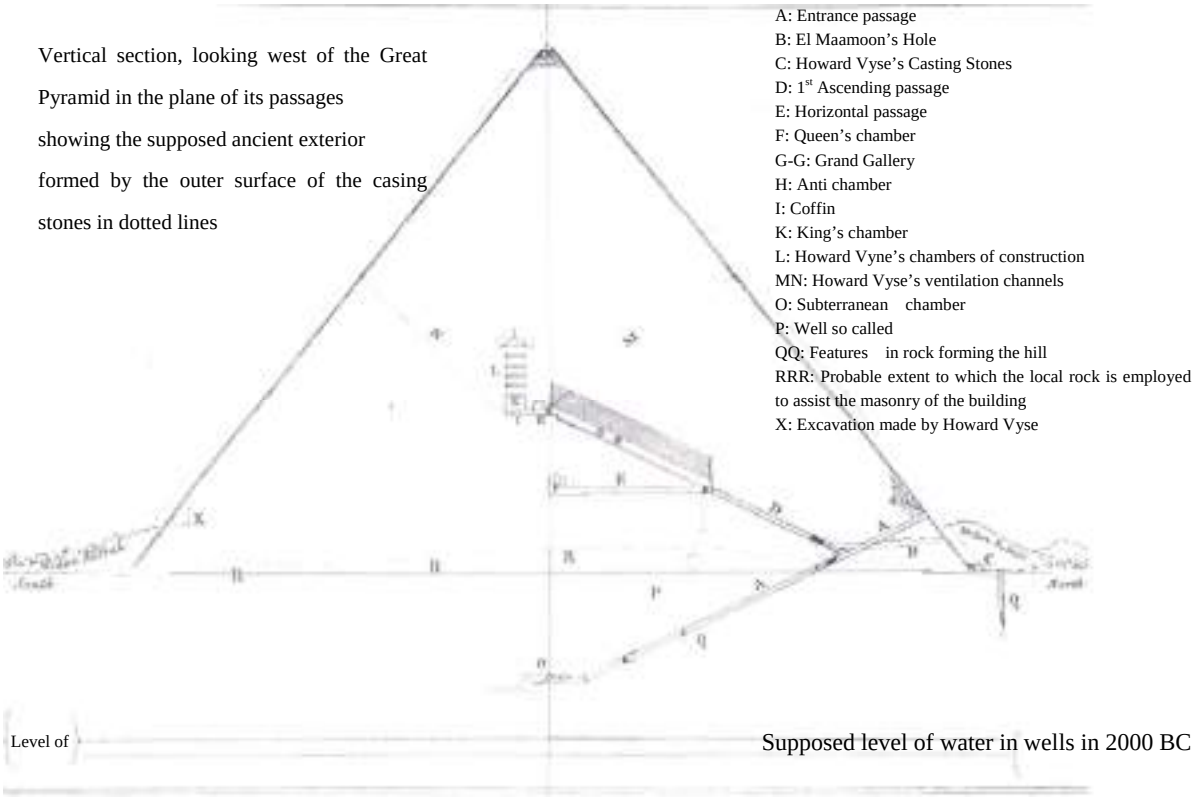


Fig. 8 The pyramid's base lies 60~66 m well above the sea level.[10]

[9]Raynaud, S., De La Boisse, H., Makroum, F. M. and Bertho, J. Geological and Geomorphological Study of the Original Hill at the Base of Fourth Dynasty Egyptian Monuments. https://hal.archives-ouvertes.fr/hal-00319586, accessed September 8, 2008.
[10]Smyth, C. P. The Initiation of the Pyramid. In The Secret Teachings of All Ages, edited by Hall, M. P. San Francisco: H.S. Crocker Company. http://www.sacred-texts.com/eso/sta/sta09.htm, accessed May 12, 2012.

3.2 Hydrology of the Site: Ground Water Level and Flooding in the Area

3.2.1 Water Table in the Area

Their altitudes above sea level of the rock base surrounding these monuments are approximately 60 m for Khufu and 66 m for Khafra pyramids, respectively. Fig. 8 shows the sea level below the pyramid.

3.2.2 Flooding in the Area

Numerous books have been written on the pyramids and the mysteries surrounding them. Only in recent years, however, some have begun to question the overall chronology of their construction and their place in the Egyptian history. As Egyptologist West [6] points out "the technology involved in the Great Pyramid is in many ways almost beyond our capacities, contradicts the belief that civilization and technology have evolved in a linear way". Yet, there is one historically recorded event that may have profound ramifications for explaining the technology utilized to build the pyramids as well as their purposes, the biblical Noah's flood. According to Berlitz [7], even though historians accept Pharaoh Cheops (Khufu) of the IV Dynasty as builder of the Great Pyramid, other Coptic traditions disagree. As Berlitz records, the Copts were the purest descendants of the ancient Egyptians stock, and the Coptic traditions maintained that the Great Pyramids existed centuries before Khufu and he may simply have repaired it. His interpreters of dreams, when queried, predicted that a great flood would come. King Sund thereupon ordered the two pyramids to be built and to be recorded through their walls all the secret sciences together with knowledge of the stars as well as their knowledge of mathematics and geometry so that, they would be a witness for those who would come after them.

3.2.3 Flash Flood in the Area

The annual flooding of the Nile had been an important natural cycle in Egypt since ancient times. The first indications of the rise of the river may be seen at the first of the cataracts of the Nile (in Aswan) as early as the beginning of June, and a steady increase goes on until the middle of July, when the increase of water becomes very great, the Nile continues to rise until the beginning of September, when the level remains stationary for a period of about three weeks, sometimes a little less. In October, it rises again and reaches its highest level. From this period on, it begins to subside, and though it rises yet once more and reaches occasionally its former highest point, it sinks steadily until the month of June when it is again at its lowest level. Flooding reached Aswan about a week earlier than Cairo, and Luxor 5-6 days earlier than Cairo. Typical heights of flood were 45 feet (13.7 m) at Aswan, 38 feet (11.6 m) at Luxor and Thebes and 25 feet (7.6 m) at Cairo (This gives the picture before the construction of the lower and high Aswan dams). And since the pyramid's base is 60~66 m higher than the water table so the pyramid was always safe from flooding and ground water. Fig. 9 shows the Nile near the pyramids in El Fayoum.

4. Stability of the Geometric Form

The pyramid is a wall bearing structure. It is all solid inside with a few voids in it which are the chambers.

Fig. 9 The Nile near the three pyramids in El Fayoum taken in October 1937.[11]

[11] Http://forgetomori.com/2007/fortean/the-pyramids-the-nile-and-the-extraterrestrials/, accessed May 16, 2012.

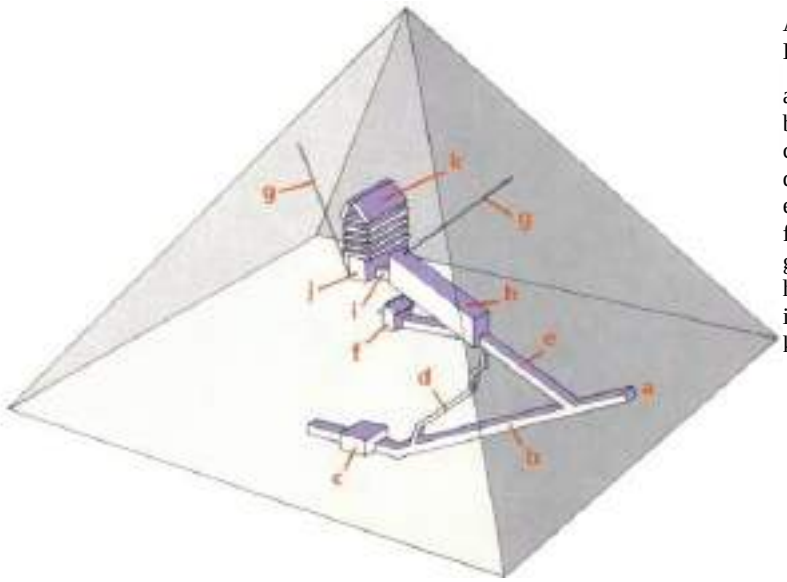
Khufu's pyramid was built entirely of limestone. It is built on a square base with sides measuring about 230 m. Its four sides face the four cardinal points precisely and it has an angle of 51°50′. Khafre's pyramid is 214.5 m^2, 143.5 m high, with a face inclination of 53.2°, and Menkaure, 110 m square, 68.8 m high, with a face inclination of 51.3° (or possibly 105 m × 65.5 m (330 ft wide × 206 ft high). For each of modelling the pyramids, it may be useful to also know the triangular face height for each as measured along the surface instead of vertically. According to trigonometry, these surface face heights are: Khufu, 195 m; Khafre, 179 m; Menkaure, 88 m (or possibly 84 m) [8].

5. Stability of the Structural Design

A pyramid is a structure where the outer surfaces are triangular and converge at a point. The base of a pyramid can be trilateral, quadrilateral, or any polygon shape, meaning that a pyramid has at least three triangular surfaces (at least four faces including the base). The square pyramid, with square base and four triangular outer surfaces, is a common version. The Giza pyramids are square pyramids. A pyramid's design, with the majority of the weight closer to the ground and with the pyramidion on top, means that less material higher up on the pyramid will be pushing down from above: This distribution of weight allowed early civilizations to create stable monumental structures. For thousands of years, the largest structures on earth were pyramids: first the Red Pyramid in the Dahshur Necropolis and then the Great Pyramid of Khufu, both of Egypt. Fig. 10 shows how the solidity in the pyramid is much more than the void, thus it is quite obvious that the form of the pyramid is a very stable 3D form with strong structural engineering. Khaled and Hays [9] compared several structures and argued that the pyramid is one of the most stable forms. Fig. 11 shows the stability of many structures in a descending order where the pyramid turned out to be the most stable structural system.

6. Precision of Execution (Egyptian Masonry Skills)

It is not surprising that the occasional eyebrow was raised in the past concerning the extent of the Egyptian masonry skills during the early dynastic period. Not only were the structures superior in a visionary capacity, but also in precision, design and execution. The dynastic period of Egypt heralded a



Axonometric view of the Pyramid of Khufu

a. Entrance
b. Descending corridor
c. Underground chamber
d. Service corridor
e. Ascending corridor
f. Queen's room
g. Air shafts
h. Great Gallery
i. King's chamber
k. Weight relief chambers

Fig. 10 Isometric drawing showing the different chambers inside the Khufu Pyramid which represents the few void parts.[12]

[12]Https://www.google.com.eg/search?q=Axonometric+view+o f+the+pyramid+of+Khufu, accessed May 18, 2012.

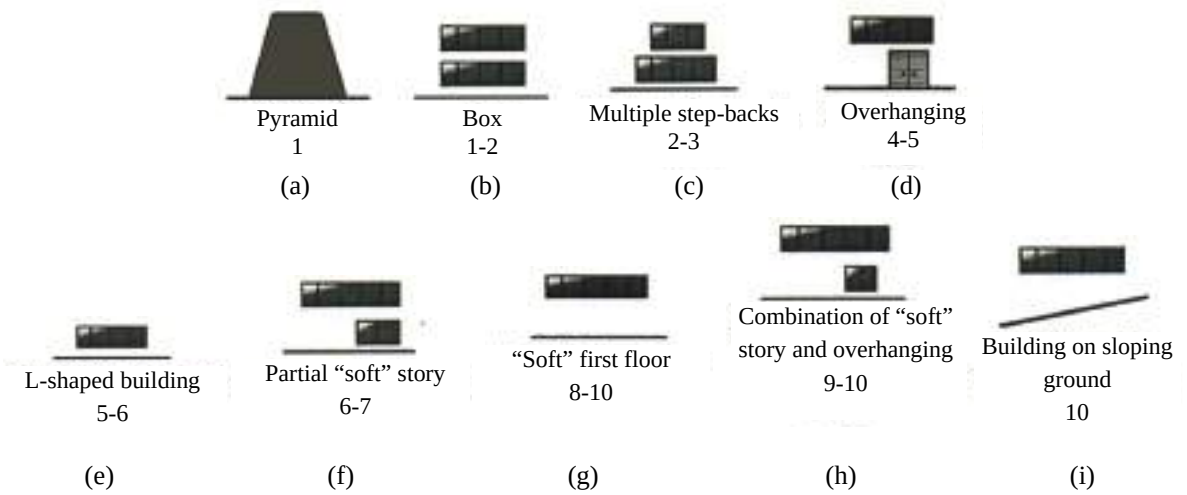


Fig. 11 Comparison of several structures showing the highest stability attributed to the pyramid form, from Khaled and Hays [9]. The numbers of "1 -10" are marking the most stable to the least stable.

time of extraordinary achievement: It was the age of the pyramid builders when some of the largest and most sophisticated structures of all time were built. Although apparently spontaneous, the technology underlying these huge constructions was built on a foundation of science and mathematics which in turn, has provided us with traces of their manufacturing processes which are proving equally astonishing. Many of the casing stones and inner chamber blocks of the Great Pyramid were fit together with extremely high precision. Based on measurements taken on the north-eastern casing stones, the mean opening of the joints is only 0.5 mm wide.

7. Summary

This research looked at the seven wonders of the ancient world and attempted to examine the only wonder that survived for 4,500 years in order to draw ideas from it to the construction of nuclear power plants and important buildings. Site selection, choice of form, structural systems and precision of execution were examined

There are several different theories about the purpose of the Great Pyramid. Along with not being able to conclude absolutely who built the Great Pyramid, it is not understood clearly why it was built. There is belief that Pharaoh Cheops (or Khufu) built the Great Pyramid for his tomb around 2500 BC, because many of the other pyramids in the area have been found to be burial chambers for the various kings of Egypt. There is also belief that the Great Pyramid monument was a time capsule left by an advanced civilization and designed to endure the times for future civilizations. The purpose of building the pyramids was to build something that would not be destroyed by the great flood. That is why they were built 60~66 m above sea level and ground water level.

Location wise, it was built on the western side of the Nile. Topographically, the site of concern was selected to be on the Giza plateau located at the border of the Nile Valley adjacent to the plain area. Tectonically, the site area is classified as a quiet tectonic area. It is located far away from all tectonic dislocations zones. Also, it reflects low seismic situation. The epicenters of strong and destructive historical earthquakes occupied the eastern part of the River Nile. In spite of all research, an earthquake affected the site in 1303 and its intensity value was VI on the Mercalli scale.

The pyramids were built on carved outcrops (a rock formation that is visible on the surface) using the existing topography at the time of construction. As mentioned above, the part of the hill used in Khufu Pyramid was 23% of the volume of the pyramid,

while for Khafra pyramid is about 11.5%. These parts of hill represent a complementary part of the whole construction of the two pyramids. These parts increase the stability of the construction and consequently their resistance to dynamic force associated with the occurrence of earthquakes.

Stratigraphically, the geological studies showed that the main stratigraphic units constituting the plateau are carbonate rocks (limestone). This kind of sedimentary rock is characterized by good physical and dynamic properties. These properties help the rock to behave like a competent rock against the dynamic force.

The selection of the pyramid site on the Giza plateau, which is raised about 66 m above sea level, protects the pyramids from the Nile flooding that takes place every year. The flood affected the Nile Delta and stooped on the foothill of the Giza plateau. Literature talks about Noah's flood and that it destroyed everything on land but the pyramids resisted its effects. This can be attributed to the genius of site selection and architectural design. Since all studies proved that the pyramid shape is characterized by low vulnerability.

The selection of the Giza pyramids site was not selected haphazardly. It was selected according to certain criteria which can be characterized by:

- low tectonic and low seismicity;
- high topography to resist the action of flooding;
- good foundation rocks to survive long times;
- stable form;
- stable structural design;
- thus the pyramid form was selected due to its high stability and its low vulnerability.

8. Conclusions

This paper looked at the seven wonders of the ancient world and argued that the reasons the great pyramids are the only remaining wonder of the ancient world is due to four factors: the brilliance of the site selection from a seismic and hydrological point of view, the stability of the geometric form, the pyramid, the stability of the structural engineering and finally the precision of its execution. Thus, choosing a site for a nuclear power plant is as important as choosing a site for a pyramid.

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