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Mechanical Engineering in Ancient Egypt, Part 88: Great Pyramid Project Management

Galal Ali Hassaan
Department of Mechanical Design & Production, Faculty of Engineering,
Cairo University, Giza, Egypt
Email: galalhassaan@ymail.com

Abstract:

The ancient Egyptians succeeded to establish an amazing civilization sustained for thousands of years and left human treasures still surviving to our present days. This included the construction of the Great pyramid of Khufu at Giza, one of the Seven Wonders of the World. This is the research paper number 88 in a series trying to explore the evolution of Mechanical Engineering in ancient Egypt. It discusses and presents how the ancient Egyptians managed the construction of the great pyramid with their available primitive tools. It presents how the ancient Egyptians could apply concepts related to project managements such as objectives, planning and design, construction, logistics, quality and documentation.

Keywords — **Mechanical Engineering history, Ancient Egypt, Great pyramid, project management.**

I. INTRODUCTION

Any one visiting Egypt will be faced by very large stone-based-structures such as the three pyramids at Giza, the colossal stone-statues in Egypt and outside Egypt, the Egyptian obelisks in Africa, Asia, Europe and America, the temples and tombs at Egypt and the huge stone-boxes in the Serapeom at Saqqara. Each item mentioned above can be considered as a great project needs to be studied in details to know how the ancient Egyptians managed to construct it with very high levels of quality control. This is what I am going to highlight in some of the research papers of this series about Mechanical Engineering in ancient Egypt.

Strudwick (1985) in his book about the administration of Egypt in the Old Kingdom presented six high administrative titles of the Old Kingdom, the Overseers of the great mansions, the Overseers of the Scribes of the King's documentation, the Overseers of Works, the Overseers of Granaries, the Overseers of Treasuries and the Viziers [1]. El-Marashly (1990) in his article about project management as perceived from ancient Egyptian projects outlined that the keys of pyramid design and construction were manpower and superior management provided by the genius architect Imhotep. He presented the opinion of Mr. Gutch that the history of project management started by the time of the ancient Egyptians during building the three Giza pyramids during the 4th Dynasty [2].

Ezzamel (2004) in his paper about work organization in the Middle Kingdom of Egypt explored the roles of accounting and administrative practices in rendering the form and functioning of work organization and labour discipline during the Middle Kingdom. He outlined also that the visible hand of administration planed a crucial role in the civilization of ancient Egypt. He mentioned that name lists were used extensively as in the papyrus of King Senusret I where 300 workers and foremen were listed for a building project [3]. Oppenheim (2005) studied the decorative programs in the pyramid complexes of the 3rd and 4th Dynasties. His study revealed interesting patterns in the decoration of the monument and showed the gradual development towards more complex iconographic and scenes with greater coverage of temple walls. He presented a number of reliefs found reused in the pyramid complex of Amenemhat I at Lisht. (which may be taken from Khufu, Khafre and Userkaf pyramid complexes) [4].

Paulson (2005) in his article about surveying in ancient Egypt outlined that Egypt was the home of the first known surveyors and surveyors also

performed construction surveys. He presented colored scenes authorizing surveying works from tomb of Menna. He outlined that ancient works for one of the Queen's pyramid adjacent to the Great Pyramid of Khufu was found. He presented the plan of Pharaoh Ramses IV tomb in a papyrus in Turin Museum where the dimensions of various shafts and chambers were listed [5]. Clarke (2009) explored the role of the 'Overseer' in the administration of Upper Egypt to the end of the Old Kingdom. He positioned the role within the Old Kingdom bureaucracy, explored the responsibility of the role and discussed the different changes in responsibilities occurred over time [6].

Holland (2011) in his paper about building the case for historical project management presented the historical project of building the Giza pyramid during the era 2550-2530 BC. He stated that the project had enormous technical challenges from the creation of a perfectly level base to building the burial chambers to completing its last third and mounting a cap stone. He outlined that this project employed a workforce of up to 20,000 at any time. The work force had to be supplied with materials, tools, food, refreshments, clothing, housing, health care and entertainment [7]. Pelletier (2013) investigated how the ancient Egyptians utilized logistics. Based on archaeological evidence he stated that ancient Egyptians were skilled in designing logistical systems. He stated also that the core goals of logistics found in ancient Egypt have largely remained the same in modern business logistics [8].

Barta (2013) described the development of the administration through the examination of Kings, Viziers, Courtiers and administrators of lower rank in ancient Egypt. He studied the administration during the 1st, 2ndand 3rd Dynasties, the 4th, 5th Dynasties down to the reign of Nyuserra, Late 5th and 6th Dynasties [9]. Brovarski (2013) in his paper about overseers of Upper Egypt in Old and Middle Kingdoms outlined that 85 overseers of Upper Egypt were known in the period from Old to Middle Kingdom. He provided an inventory of the holders of the 'Overseer' title, their dating and the significance of their titles [10]. Saatci (2014) stated that the management concept showed itself as early as thousands of years BC in the form of administration. He discussed in details the organization, human resources management and reporting examples from ancient Egypt. He stated that ancient Egypt saw the introduction of the 'Book of Dead' as the first documented quality system with detailed procedure needed to prepare the body and soul for the afterlife. He presented the attendance list of labours from Reisner I papyrus [11].

Driaux (2016) stated that the water supply of the inhabitants of ancient Egypt was completely managed by the state through the local administration charged to bring water from rural areas into towns and cities and redistribute it to the inhabitants. He referred to the stela of Pepi I, the 3rd King of the 5th Dynasty including his Decree mentioning the location and kind of installations where water was drawn from pyramid town of King Sneferu at Dahshur. He presented also a stela from the reign of Senusret I, the 2nd King of the 12th Dynasty recording that he made a watering place for his city [12]. Hassaan (2017) in his paper about farming tools in ancient Egypt presented evidences from ancient Egypt showing their great interest in planting fruit-trees, looking after different types of other trees and designing gardens with central pools. He presented also colored scenes showing how the ancient Egyptians dug water channels and planted trees and plants around them [13].

Hagen and Soliman (2018) in their chapter about archives in ancient Egypt during the period 2500 to 1000 BC studied the ancient Egyptian archiving during the mentioned period through papyri, ostraca and clay tablets. They outlined that the earliest archive of administrative papyri consisted of the papyri of an Official Merer involved in the building of the Great Pyramid of Khufu at Giza [14].

II. PROJECT OBJECTIVES

The ancient Egyptians built pyramids as a natural evolution followingpit graves and mastabas [15]. The development of pyramid tombs was simply to build a huge structure over the tomb(s) in the shape of a stone pyramid with heavy blocks and internal design that can save the body of the disease against robbers attack. Regarding the Great Pyramid of

King Khufu who ruled during the period 2589 to 2566BC during the 4th Dynasty of the Old Kingdom, We can say that the objectives of the Great Pyramid project were as follows:

- Building a burial chamber for the King above the ground level.
- Building another two chambers one above the ground level and the other under the ground level inside the rock deck may be for camouflage purposes to defend the King's body against tomb robbers.
- Reflecting Earth, mathematical and Astronomical sciences on one building structure.
- Satisfying outstanding new characteristics for the Great Pyramid of King Khufu.
-

A. Location

When the ancient Egyptians decided to build a Great Pyramid, the first question is where to locate the pyramid? They decided to locate it at the centre of the land mass of the earth such that the two lines (North-South and East-West) intersect at the capstone of the pyramid as shown in Fig.1 [16].

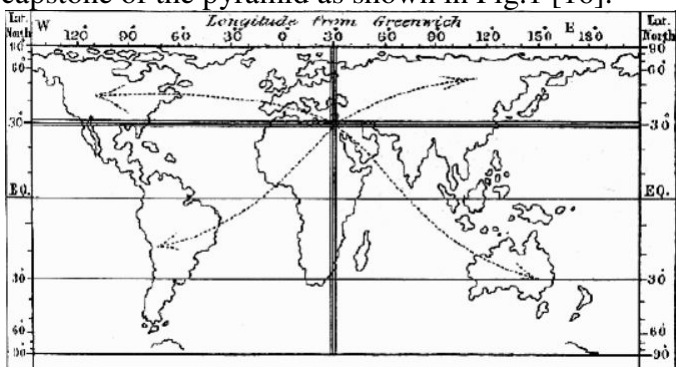

Fig.1 Location of the Great Pyramid at the centre of Earth land [16].

B. Base

The base of the pyramid was chosen to be a square base facing the four main directions: East, West, North and South with high degree of precision [17]. The length of each side of the base was chosen to be the number of days in a solar year (365.24 Royal Cubit) [18].

C. Height

The height of the Great Pyramid was assigned by its designer to equal the radius of a circle having a circumference equal to the perimeter of the pyramid base [19]. Mathematically this will lead to defining the value of pi (π).

In this context, somebody said that the Great Pyramid was intended to represent the Earth. Its height corresponds to the radius from the Earth's centre to the North Pole. While base perimeter corresponds to the Earth's circumference at the Equator [20].

D. Location of the King's Chamber

Christopher Bertlett presented an analysis leading to the location of the King's chamber inside the Great Pyramid of Khufu simulating the 'navel' location in sitting and standing human reliefs in the ancient Egyptian art as depicted in Fig.2 [19]. Using the proportions in Fig.2 reveals the following characteristics for the Great Pyramid:

- The base length /height ratio is 1.6 (approximately the Golden Ratio ϕ).
- The pyramid angle between the side and base is 51.8428 degrees.
- The offset chamber of the King is exactly in vertical alignment with the navel of the standing relief in Fig.2 [19].
- The line through the navel of the sitting relief intersects with the line through the navel of the standing relief to fix the location of the King's chamber (Fig.2).

III. GREAT PYRAMID PLANNING AND DESIGN

The Great Pyramid was a complex structure having many internal details. It was not just a tomb for King Khufu of the 4th Dynasty. Here are some of the features that had to exist in the final structure of the pyramid:

- They planned the location of the King's chamber to simulate location of the King's navel as depicted from Fig.2 [19].
- They planned the King's chamber to have 20 Royal Cubit East-West , 10 Royal Cubits North-West, 25 Royal Cubits major diagonal and 52 degrees sides inclination with base (1 Royal Cubit = 0.5234 m) [21,22,23].

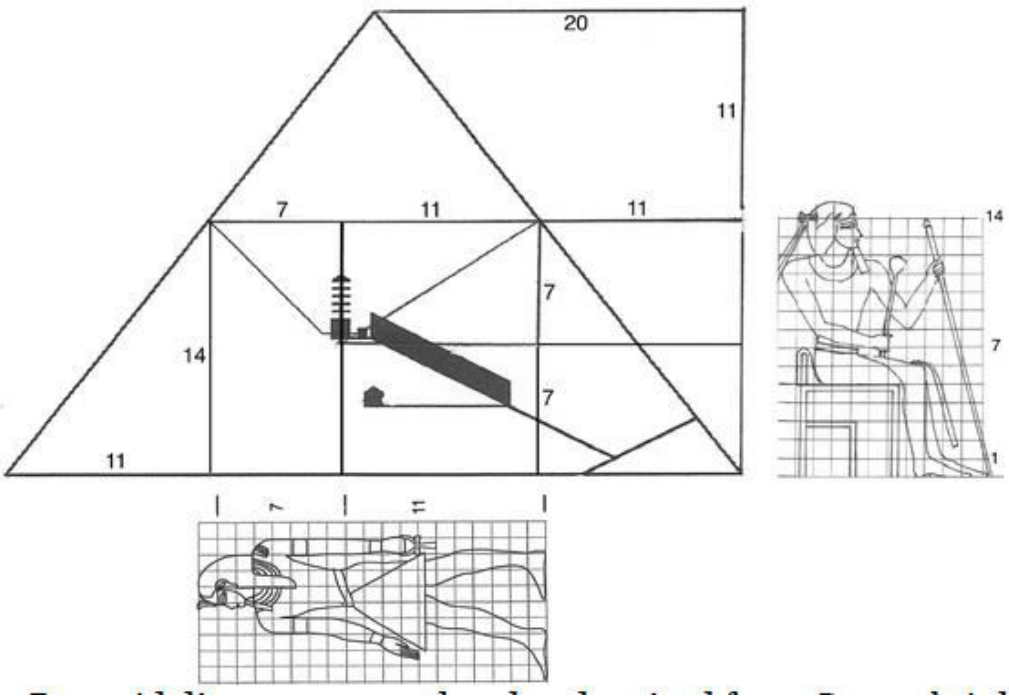

Fig. 2 Location of the King's chamber in the Great Pyramid [19].

- They planned the base to be a square with sides of 440 Royal Cubits with 90 degrees corner angles [21].
- They planned to use limestone blocks cut from Tura Quarries and transferred to the location of the Pyramid at Giza to construct most of the Pyramid structure.
- They planned to construct the King's chamber using granite blocks transferred from Aswan Quarries to the location of the pyramid.
- They planned the King's chamber to take the shape of a Djed Symbol indicating strength and stability (Fig.3 [24]).The analogy between the Djed symbol and the King's chamber design is clear.
- They planned to design the King's chamber to be failure-proof under the pyramid load above the chamber. The objective of the design in Fig.4 is to relieve the stresses over the King's chamber by distributing the compression stress to side blocks instead of direct loading the roof which may fail under bending. An innovative design idea worked for more than 4500 years.

Fig. 3 The Djed Symbol [24].

Fig. 4 The Physical design of the King's chamber [25].

- They planned the pyramid height to equal exactly the average height of land under the pyramid over the sea level [26].
- They planned to select the pyramid height and base length such that dividing the circumference of the base by twice its height gives 3.14159 which is π accurate for 6 digits [26].
- They planned to supply the King's chamber with two air passages in its southern and northern sides to point out to stars in the Constellation Orion during 2455 BC [18].

- They planned to provide two chambers inside the pyramid other than the King's chamber. One of them 41 Royal Cubits above the Pyramid base and the second is 57.4 Royal Cubits inside the ground under the Pyramid Base [23].
- They planned the manoeuvre inside the Pyramid using a number of passages leading to the three chambers inside the Pyramid as illustrated in Fig.5 [27].

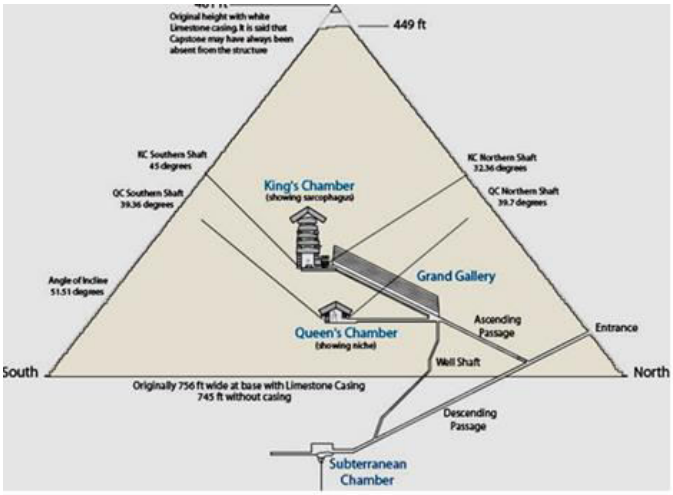

Fig.5 The passages of the Great Pyramid [27].

- A Descending Passage leading to the underground Chamber, an Ascending Passage leading the King's chamber and to what is called the Queen's Chamber, and a Horizontal Passage leading to the Queen's chamber.
- They planned the King's chamber to be lined entirely with granite blocks [28], the Queen's chamber to be constructed from highly finished limestone [29] and the Underground chamber to be unfinished [30].
- They planned to construct a huge passage known as the "Grand Gallery' as an extension to the Ascending Passage. It was intended to lead to King's and Queen's Chambers through horizontal passages. Some Egyptologists see that the Grand Gallery might served as an observation place for astronomers in the years of the Great Pyramid construction [31].
- . They planned to line all the external walls of the Great Pyramid using limestone blocks excavated from Tura and highly polished to reflect the sun light and provide shining surfaces. Fig.6 shows a part of the exterior lining of the pyramid [32].

Fig.6 The casing stones of the Great Pyramid [32].

- They planned to construct a platform under the Pyramid of highly polished and set limestone blocks. The first stone blocks course came over this platform and it was used as a reference for dimension measurements upward and downward [32].
- They planned to construct corner-block and socket joint at each corner of the Great Pyramid to protect the pyramid against earthquake and temperature effects [33].

IV. GREAT PYRAMID CONSTRUCTION MANAGEMENT

- The ancient Egyptians assigned accurately the location of the Great Pyramid Apex at the Earth's Land Centre [16].
- They assigned the orientation of the pyramid base to face the true North [22].
- They assigned the base length of the Pyramid to be 440 Royal Cubit [21]
- They assigned the Pyramid Height to be 280 Royal Cubit [21].
- They assigned the slope of the Pyramid Sides to be 51.83 degrees [35].
- They assigned the Descending Passage to have a slope of 26.5 degrees and point to the 'Pole Star'during 2170-2144 BC [18]..
- They assigned the slope of the Southern 'Air Shaft' of the King's Chamber to be 45 degrees pointing to star 'Nitak' during 2450 BC [18].
- They assigned the slope of the Northern 'Air Shaft' of the King's Chamber to be 32.47

degrees pointing to star 'Alpha Draconis' during 2450 BC [18].

- They assigned the floor of the King's Chamber to be at 82 Royal Cubit from the base of the Pyramid [23].
- They assigned the dimensions of the King's Chamber to be: 10 Royal Cubit width, 20 Royal Cubit length and 11.18 Royal Cubit height [36].
- They assigned the roof of the King's Chamber to be flat.
- For safety and strength purposes, they decided to use granite blocks as a material for the King's Chamber [21].
- They constructed the roof of the King's Chamber using 9 granite slabs of 400 ton total mass [21].
- They constructed 5 granite compartments above the King's Chamber to relief the stress of the roof due to the load above it [21]..
- They prepared a pink granite sarcophagus for King Khufu such that it was slightly larger than the 'Grand Gallery' opening to the King's Chamber. This was why the ancient and modern robberies couldn't take it away from the pyramid. They used the outside dimensions: 2.278 m length, 0.777 m width and 1.048 m height with thicknesses: 301, 300 and 176 mm respectively [37].
- They assigned the level of the Queen's Chamber Floor to be 41 Royal Cubit above the Pyramid Base [23].
- They decided to arrange the stone blocks in horizontal courses. They used a total number of 204 courses between Pyramid Base and Apex including the capstone [38].
- They made an entrance Descending Passage of 2 x 2.27 Royal Cubit cross-section and 201 Royal Cubit through masonry and 137 Royal Cubit through bedrock [39].
- They made an Ascending Passage of 74.5 Royal Cubit long and same cross-section as in the Descending Passage up to the Grand Gallery [40].
- They constructed a Grand Gallery having the same slope as the Ascending Passage with 89 Royal Cubit length and 16.4 Royal Cubit height with 3.94 Royal Cubit width at its base and 3 Royal Cubit at its top reduced in 7 steps, each step 0.145 Royal Cubit as depicted in Fig.7 [21].

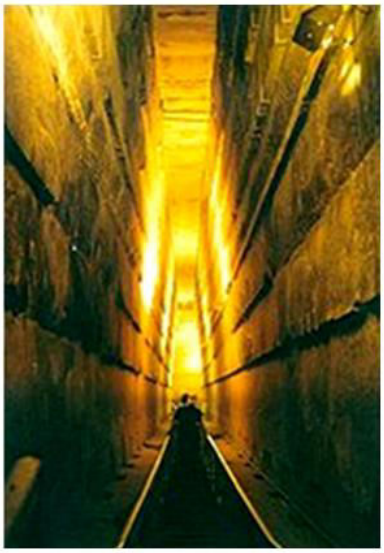

Fig. 7Grand Gallery of the Great Pyramid [21]

- To make the Great Pyramid shines day and night they lined its external whole surface with polished hard limestone cut from Tura Quarries. Each casing block had 4.85 Royal Cubit thickness and 20 tons mass [16].
- The ancient Egyptians invented a specially designed glue to cement the casing stones together and to the Pyramids wall. It had some elasticity characteristics to provide the casing with some movement without cracking or breaking [41].

V. GREAT PYRAMID LOGISTICS MANAGEMENT

- The project of the Great Pyramid was one of the huge projects during the ancient history of Egypt. The achievement of the project in a limited time (20 years) required a solid and qualified administration teams including logistics management working continuously for 20 years.
- They had to cut and transport about 2.3 million stone blocks from Tura and Masara Quarries in South Cairo (for limestone blocks) and from Aswan Quarries in South Egypt (for

granite blocks) to the location of the Great Pyramid [42,43].

- The cut stones had weight between 3 and 90 tons each [43].
- Not all the stones had the same dimensions. Each blocks stack had its pre-assigned dimensions. Therefore they had to store the blocks near the Pyramid according to stack dimensions, build the ramp leading to the stack vertical position and then pull the blocks above the ramp using mechanical devices and technology.
- To construct this huge structure, they had to recruit 4000 primary workers as quarry workers and masons and 16000 to 20000 secondary workers as ramp builders, tool makers and suppliers of food, clothes and fuels [43].
- To accommodate this large number of workers (up to 20,000 workers), they established a 'Workers Village' on the Giza Plateau with all required living facilities including bread and beer supplies needed to pay the workers [44, 45].
- I think they had to build stores for working tools, rollers, sledges, levers, wheat, bread moulds and cooking vessels to make the village independent of any other villages or nearby towns to optimize the utilization of time.
- Once the Pyramid Core was constructed, they planned to make it shining day and night through covering its external surface by white polished hard limestone blocks.
- For this purpose they prepared 115,000 – 200,000blocks of casing stones of average volume of 67,390 m^3 [46].Fig.8 shows a typical casing stone of the Great Pyramid in display in the British Museum [47].

Fig. 8 Casing stone of the Great Pyramid [47].

- Because of the decrease of the ramp width as the stack number increases from the base of the pyramid upwards they had to use stone blocks of decreasing weight as they go upward. This required preparing limestone block for the first 10 stacks of weight from 6.5 to 10 tons and after which the weight decreases to 1.3 tons [46].
- They had to prepare granite blocks cut from Aswan quarries of weight from 40 to 50 tons each for the King's Chamber [46].
- They managed to prepare a capstone in the shape of a pyramid of 1.5 * 1.5 m base and 1.3 m height to rest on the top of the Great Pyramid as the last stack [46].
- They produced about 500,000 tons of Gypsum-based mortar to join the casing stones [48].
- They had a difficult task regarding the casing stones. They had to prepare the casing stones such that they interlock with the next inner layer of the pyramid [46]. This requires extreme efforts regarding information technology about the external surface of the pyramid in the three dimensions and preparing the casing stones according to this.
- They had to manufacture two different types of mortar to join the pyramid stone blocks, one type for the inner stones and a different type for the casing stones [46].
- They had to transfer and store 5.5 million tons of local limestone blocks and 8,000 tons of granite blocks from Aswan to nearby the great pyramid [49].

- To manage scheduling work for hundred thousands of workers they grouped them in crews, each crew having 2000 workers [50]
- Each crew was divided into gangs of 200 workers each [50].
- Each gang was divided into teams of 20 workers each [50]. Most properly, each team, gang and crew would have a leader in charge in front of the High Supervisor of the project.

VI. GREAT PYRAMID QUALITY MANAGEMENT

- Did the ancient Egyptians know 'quality', 'quality management' and 'quality control'?
- To answer, we have to define the meaning of the three expressions.
- According to the Cambridge Dictionary, 'quality' means a high standard [51].
- 'Quality management' means the act of overseeing all activities and tasks that must be accomplished to maintain a desired level of excellence [52].
- 'Quality control' is a process leading to product quality maintenance or improvement [53].
- Bearing these modern definitions in mind, we ask again: did the ancient Egyptians founded the engineering management sciences and applied those definitions in their giant works?
- The answer is in the work of some experts in quality management, Mr. Hany Ismail who wrote an article with an entitle putting them as leaders of project management:

Egyptians were the first recorded project managers-planning pyramids [45].

- Others outlined the role of the pyramids builders in the evolution of project management [54].
- Mr. Ismail strengthened this meaning by stating that: 'the Egyptians became the world's best construction managers, and these skills served them well for some 2,500 years' [45].
- Now, I will present some clear evidences from the construction of the Great Pyramid indicating how the ancient Egyptians were pioneers in quality management and control:

- The dimensions of the pyramid were extremely accurate. The sides were levelled within a fraction of an inch over the entire length which are comparable with modern construction laser levelling [55].
- The four sides of the Great Pyramid base have an average error of only 58 mm in length (0.025 %) [56].
- According to the Archaeologist Flinders Petrie, many of the casing stones and inner chamber blocks of the Great Pyramid fit together with extremely high precision with mean opening of the joints of only 0.5 mm [57].
- According to Prof. Petrie, the ratio of the base perimeter of the Great Pyramid to its height was 2π with accuracy better than 0.05 % [21].
- They could align the sides of the Great Pyramid with error less than 0.1 degree [58].
- They prepared the casing stones of the pyramid flat to an error of less than or equal 1 % and placed in position with an error less than or equal to 0.5 % [17].
- The passages of the Great Pyramids were straight within an error of only 0.001 % (extreme accuracy) [59].
- The average maximum error in the King's and Queen's Chambers is only 27 mm [23].
- The Descending Passage extended down for 91 m with deviation less than 12.7 mm over the whole length [27].
- Checking the dimensions of the Air Shafts in the King's Chamber, they were extremely precise and the difference in their width was less than or equal to 5 mm and the beginning and end of the shaft were precisely online even though the shafts bent in between [27].

VII. DOCUMENTATION

- Project documentation is considered as a vital part of project management. Besides, documentation must be well arranged, easy to read and adequate [60].
- Were ancient Egyptians experts in work documentation? Did they practice

documentation 4600 years ago? .. Yes .. they were pioneers in documentation through inscription using different types of natural and artificial media available in their society.

- Some of the inscription media they used were: Papyrus [61], palettes [62], stelae [63, 64,65], ostraca [66], shabti boxes[67]. Labels and tags [68], seals [67], buttons, beads, heart amulets and finger ring bezels [70], alabaster products [71], temple structures [72], tomb structures [73], obelisks [74], coffins and sarcophagi [75] and mountain-rocks [76].
- Now, samples of Great Pyramid documentation will be presented:
  - From more than 4500 years ago a middle-ranking inspector called 'Merer' wrote a two-column papyrus about the daily lives of the construction workers of the Great Pyramid and how the limestone blocks were cut from Tura Quarries and transported by boats along the River Nile and a system of Canals [77]. The papyrus presented also some statistics and administrative details [78]. Fig.9 shows a part of Merer's papyrus as displayed in the Egyptian Museum at Cairo [78].

Fig. 9 Merer's papyrus [78]..

  - Merer's papyrus recorded financial balance sheets of revenues transferred from Egyptian Provinces in red colour and payments for food and wages in black [77].
  - It recorded also food distribution to workers including number of sheep imported for Khufu's Pyramid Project [77].
  - Some Egyptian Scribes documented their calculations for pyramids construction in mathematical papyri. They presented mathematics for the calculation of [79]:
    # Pyramid number of blocks.
    # Sides angle with ground.
    # The geometry of the overall structure.
    # Alignment of Great Pyramid to the true north.
    # The water to sand ratio (required to calculate the coefficient of friction and minimum force required to haul the building blocks).
  - One of the stones in one of the compartments above the roof of the King's Chamber had an inscription for the name of the work gang and the name of King Khufu [21].
  - The ancient Egyptians used their tombs as records for important activities of their life. Fig.10 shows a tomb relief recording the supporting activities in the Workers Village near the Great Pyramid [45]. The relief presents a lot of information about the production of bread and beer that may need too many pages to describe in writing.

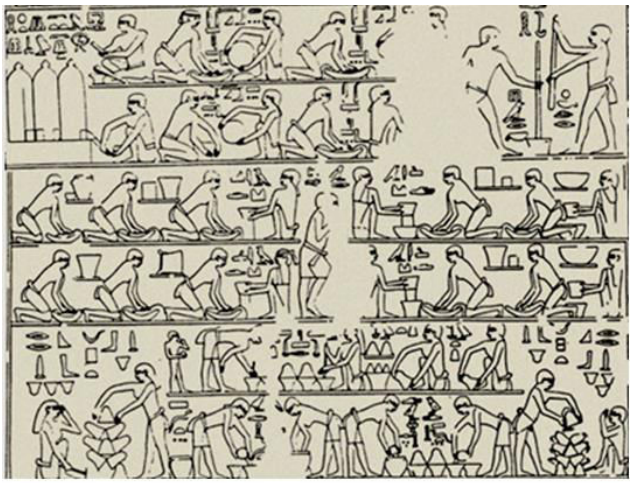

Fig. 10Workers supporting activities in the Workers Village [45]

VIII. SECURITY MANAGEMENT

- To secure the King's Chamber they blocked the lower part of the Ascending Passage leading to the Grand Gallery with three

granite slabs of 7 ton each [80]. The objective of which was to secure the King's chamber against tomb robbers [81]. .

- They supplied the Great Pyramid with a swivel door weighing 20 ton and could open by pushing out from inside with a small force. When closed it had a perfect fit to be difficult to be detected [18].
- To secure the great pyramid structure safety against failure due to expansion and contraction movements due to heat and cold, earthquakes and settling they used ball and socket design technique at the four corners of the pyramid base [16].
- To secure climbing or trying to enter the pyramid, they used hard polished limestone of 254 mm thickness and 20ton mass to cover the whole external surface of the pyramid [16].
- They plugged the lower part of the Ascending Passage with three granite slabs of seven ton each [80]. The objective of which was to secure the King's Chamber against tomb robbers [81].

IX. CONCLUSION

- The ancient Egyptians could plan, design and construct the Great Pyramid of Khufu in 20 years during the 4th Dynasty.
- They set a number of objectives to be fulfilled through the construction of the Great Pyramid.
- They assigned the location of the Great Pyramid to be exactly in the centre of earth land.
- They assigned the base of the pyramid to face the North, South, West and East directions with high degree of precision.
- They planned the length of each base side to equal the number of days in a solar year in Royal Cubits.
- They planned the height of the pyramid to equal the radius of a circle having a circumference equal to the perimeter of the pyramid base.
- They planned the King's Chamber location to simulate the 'navel' location in sitting and standing human-reliefs in ancient Egyptian art.
- They planned to use limestone blocks from Yura Quarries to construct most of the pyramid internal structure.
- They planned to use Granite blocks from Aswan Quarries toconstruct the King's Chamber.
- They planned the King's Chamber to simulate a Djed Symbol for strength and stability characteristics.
- They invented and applied a novel design for the King's Chamber Roof to relief its huge stress due to the load above it.
- They planned a number of passages inside the pyramid leading to its three chambers.
- They provided the King's Chamber with two Air Passages pointing out to two stars in the Orion Constellation.
- Because of the ultimate importance of the King's Chamber they lined it with granite blocks.
- They planned for the construction of a Grand Gallery of complex design leading to the King's Chamber.
- They planned to line the whole external surface of the pyramid with hard limestone and highly polished blocks cut from Tura Quarries.
- They planned to construct a platform under the pyramids and used it as a reference for all dimensions measured in the upper and lower directions.
- They planned to use block and socket joints at the four corners of the pyramid base to protect the pyramid against earthquake and temperature effects.
- They planned the location of the Descending Passage to point to the 'Pole Star' during 2170-2144 BC.
- They planned the location of the two Air Passages of the King's Chamber to point to 'Nitak' and 'Alpha Draconis' stars during 2450 BC.
- They used nine granite slabs of 400 ton to construct the flat roof of the King's Chamber.
- They planned for five granite compartments above the roof of the King's Chamber to relief its stresses.

- They used 204 courses of limestone blocks between the pyramid base and capstone.
- They cut and transferred 2.3 million limestone blocks from Tura Quarries to the Great Pyramid site.
- They managed to handle block stones between 3 and 90 ton each.
- They recruited 4000 primary workers as quarry workers and masons and from 16,000 to 20,000 secondary workers as ramp builders, food workers and suppliers of food, clothes and fuel.
- They built a well equipped living village on Giza plateau for the pyramid workers.
- To add a shining characteristic to the Great Pyramid, they prepared between 115,000 to 200,000 blocks of hard polished limestone.
- They planned to use block stacks holding blocks in the bottom stacks of 10 ton mass, decreased to 6.5 tons after 10 stacks. After which the block mass decreased to 1.3 ton for the upper stacks. The reason for this is well known for mechanical and civil engineers.
- They used granite blocks cut fromAswan Quarries of mass from 40 to 50 ton (or more)..
- They put a capstone in the shape of a pyramid at the top of the pyramid having dimensions of 1.5 x 1.5 m (base) and 1.3 m height.
- They produced 500,000 ton of mortar to join the casing stones.
- They succeeded to produce Pyramid Base with error within 0.025 %.
- They could finish the casing stones and the King's Chamber blocks to generate only 0.5 mm joint between the blocks.
- They could apply the pi (π) value in the pyramid dimensions with accuracy better than 0.05 %.
- They aligned the sides of the pyramid with errors less than 0.1 degrees.
- They produced inner straight passages with an error of about 0.001 %.
- They generated the Descending Passage having 91 m length with an error in dimensions less than 12.7 mm over the whole length.
- The Air Shafts of the King's Chamber has an error ≤ 5 mm.
- They documented the details of their construction logistics using papyri, block marks and tomb reliefs.
- They applied their knowledge in security management to secure the King's Chamber and the whole pyramid against tomb robbers.

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DEDICATION

I dedicate this work to Eng. AbdelRahman Hassaan, MBA Holder and Production Applications Consultant for his struggle over years to establish successful Industrial Engineering in Egypt, Saudi Arabia and UK. Good luck AbdelRahman.

BIOGRAPHY

Galal Ali Hassaan

- Emeritus Professor of System Dynamics and Automatic Control.
- Has got his B.Sc. and M.Sc. from Cairo University in 1970 and 1974.
- Has got his Ph.D. in 1979 from Bradford University, UK under the supervision of Late Prof. John Parnaby.
- Now with the Faculty of Engineering, Cairo University, EGYPT.
- Research on Automatic Control, Mechanical Vibrations , Mechanism Synthesis and History of Mechanical Engineering.
- Published more than 260 research papers in international journals and conferences.
- Author of books on Experimental Systems Control, Experimental Vibrations and Evolution of Mechanical Engineering.
- Chief Justice of the International Journal of Computer Techniques.
- Member of the Editorial Board of some international journals including IJET.
- Reviewer in some international journals.