Building The Great Pyramid At Giza: Investigating Ramp Models

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"If the [internal ramp] theory is correct, it gives us a window into one of the greatest intellectual achievements of all time; it shows us just how advanced ancient Egyptian architects were in planning the pyramids, how far ahead they had to visualize to overcome incredible obstacles. Indeed, if Jean-Pierre is right about the details of construction, the Pyramid might just be the most extraordinary engineering accomplishment of all time, a monument in stone to what the human mind at its best is capable of." Bob Brier, The Secret of the Great Pyramid (21)

Abstract

How were the ancient Egyptians able to move 2.5-ton blocks to build the Great Pyramid without today's machinery? Khufu's Pyramid at Giza was a massive undertaking, requiring approximately two million stone blocks weighing an average of 2.5 tons to be set into place, five every minute during the first years of construction (Romer 2007, 197). Without any records on the construction of this ancient wonder, scholars have proposed various theories on how the Great Pyramid was built. Many scholars believe that the ancient Egyptians created ramps beside the pyramids to transport the blocks to each new level, but even they are not completely convinced by the proposed models, the most prominent being the long ramp and the spiral ramp models. Over the last fifteen years, the French architect Jean-Pierre Houdin has developed a new theory, one of an internal spiral ramp that was covered upon the Pyramid's completion, which may solve this thousands' year old mystery.

Figure 1: The Great Pyramid At Giza (Khufu's Pyramid)

Introduction

The Great Pyramid was built under the reign of the pharaoh Khufu, who ruled Egypt from around 2547 to 2524 BC. Khufu's brother, Hemienu, oversaw this pyramid's construction (Brier 2007, 23). The Greek historian Herodotus, who traveled to Egypt at around 450 BC, was told by local priests that the ancient Egyptians used "machines" to lift the blocks. Scholars believe that such "machines" were some type of crane. Another Greek historian, Diodorus of Sicily, wrote, three hundred years later, that the Egyptians used ramps to move the blocks (Brier 2007, 23). Whatever the model, one can assume that Hemienu chose the one that minimized the amount of excess material used, as well as minimized the extra manpower and time required (Smith 2004, 154).

It is reasonable to conclude that the Egyptians used ramps in the Great Pyramid's construction. There is physical evidence that supports this supposition. Texts such as the Rhind Mathematical Papyrus and the Papyrus of Anastasi I both indicate that the Egyptians were able to perform calculations involving ramps, such as determining the volume of ramps and the number of stones needed to build a ramp of various dimensions (Smith 2004, 154). Remains of ramps have been found at other sites such as Karnak (Parry 2004, 138), as well as emerging from the quarry site near the Sphinx at Giza (Smith 2004, 154-155).

Figure 2: Ramp remains at Karnak

Long Ramp Model

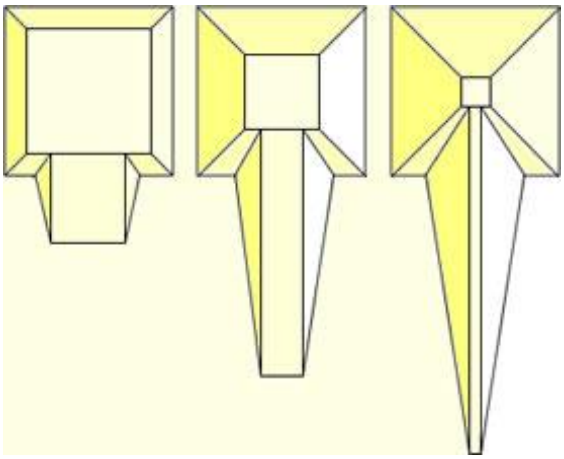

Figure 3: Long ramp model

This model proposes that there was one ramp on a single side of the pyramid. As more blocks were brought to the top, the ramp was lengthened and raised so stones could be brought higher. It is important to note that if the slope of the ramp exceeded eight percent (approximately 8 to 12 degrees), the workers would be unable to drag the stones up the ramp (Smith 2004, 164). If the ramp adhered to this incline, for the ramp to reach the top of the pyramid, which is 481 feet tall, the ramp itself would be over one mile long (Brier 2007, 23). The first issue with this proposed model is that there is simply no room on the Giza plateau for a ramp of this length. As the pyramid was being built, two cemeteries for nobility were being constructed simultaneously on the east and west sides of the pyramid (Brier and Houdin 2008, 122). On the north side, the land has a steep slope, unsuitable for a ramp, leaving the south side as the only possible face for this long ramp. To date, no remains of a ramp have been found on the south side (Brier and Houdin 2008, 122). The second problem is the amount of materials required to build this massive ramp. The volume of the stones alone would

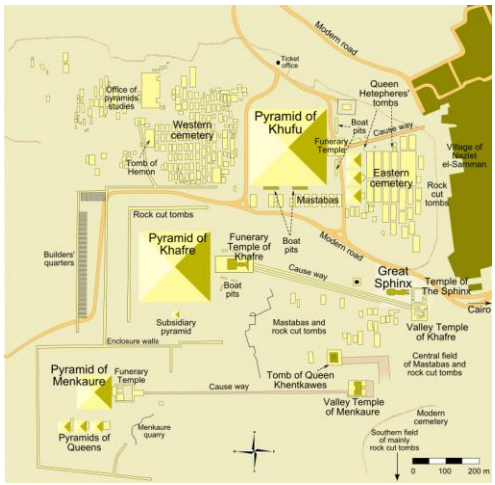

Figure 4: Giza Pyramid Complex

about equal or surpass the volume of the stones needed to build the pyramid itself (Brier 2007, 23).

Spiral Ramp Model

Figure 5: Spiral Ramp Model

In this model, the ramp would wrap around the pyramid in a spiral. This model eliminates the need for the mile long ramp required by the long ramp model, as well as explains the lack of ramp remains. However, some major issues arise. First, the corners of the pyramid would be obscured by the ramp (Brier 2007, 24). To ensure that the pyramid edges all meet at a single point, Hemienu and the architects needed to monitor the angles of the pyramid faces and constantly be making measurements. With the ramp spiraling up the pyramid on its exterior, this task would have been extremely difficult, almost impossible (Brier and Houdin 2008, 124).

The completion time would have been another problem, as the ramp would have been fairly narrow, making it difficult for two groups to use the ramp at the same time, one bringing up the stones and one bringing the sleds down (Petroski 2004, 218). The limited carrying capacity of this ramp would have led to a slower construction schedule; the pyramid took at most 23 years to build (Müller-Römer 2008, 123). The application of the limestone casing posed another problem, as it required scaffolding (Müller-Römer 2008, 123).

Internal Ramp Model

In 2003, Jean-Pierre Houdin, a French architect, presented another theory on how the Great Pyramid was built, an internal ramp, to the widely respected Egyptologist, Bob Brier (Brier and Houdin 2008, 1). Working with software from Dassault Systèmes, a French 3D software developing company (Brier 2009, 29), Houdin created 3D computer models of the Great Pyramid and its internal ramps, which Houdin believes are still in tact (Brier 2007. 24).

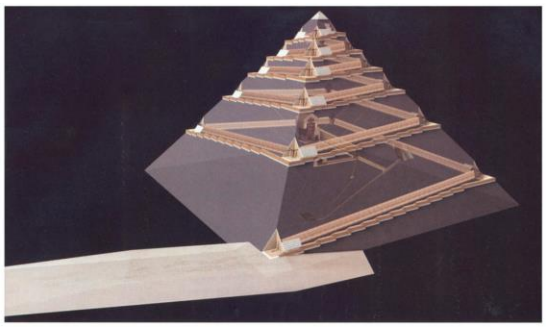

Figure 6: Houdin's 3D Model

For the bottom third of the pyramid, the long ramp model was used (Brier 2007, 24). This ramp only needed to reach a height of approximately 160 feet, so the length of the ramp did not extend as far as proposed in the long ramp model. This exterior ramp was made of small limestone blocks that, after the external ramp was dismantled, were used for the top layers of the pyramid (Brier and Houdin 2008, 139). As construction was underway at the bottom of the pyramid via this external ramp, the internal ramp was being built simultaneously (Brier 2007, 24). Starting at the bottom of the pyramid, Houdin believes that the internal ramp is around six feet wide with a grade of approximately seven percent (Brier 2007, 25).

For constructing the two of the three chambers in the Great Pyramid, the King's Chamber and the Queen's Chamber (a third chamber was carved into the bedrock beneath the pyramid for use if Khufu died before construction was completed), large granite and limestone blocks formed the roof beams and rafters. The weight of some of

these beams was over 60 tons and the beams would not have fit on the six-foot wide internal ramp, so the external ramp continued to be used (Brier 2007, 25).

After the internal chambers were completed, the external ramp was dismantled and its blocks were used in the construction of the top two-thirds of the pyramid, explaining why no remains of an external ramp have been found by field observations, stereoscopic aerial photos, or satellite images (Klemm and Klemm 2010, 83). Houdin believes that the blocks used to make the external ramp were smaller, for easier transport up the narrow internal ramp (Brier 2007, 25).

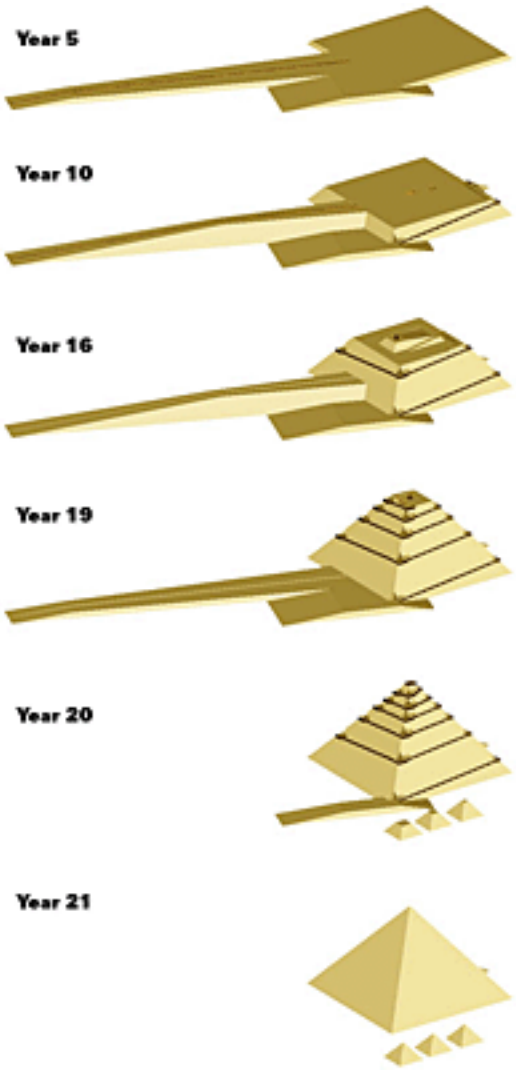

Figure 7: Year by year construction of the Great Pyramid

In building this internal ramp, Hemienu had to be careful to avoid hitting the other internal passageways and chambers. Another consideration was the ability of the workers to maneuver the stones around the corners of the pyramid. Turning the blocks 90-degrees was therefore aided, Houdin believes, by wooden cranes that were placed in openings of the ramp (Brier 2009, 28). Ancient Egyptians were familiar with the concept of cranes; they used shadoufs, devices that lifted water from the Nile. It is possible that this device was adapted for the construction of the pyramid (Brier and Houdin 2008, 130). Another mechanism for turning stones could be related to the

bearing stones found at Giza that date to the Old Kingdom. The stone was inserted into pole, and ropes were used to pull an object and change its direction from 45 to 90 degrees (Arnold 1991, 282).

While this theory may seem radical, there is evidence to support Houdin's beliefs. On the northeast corner of the pyramid, around 270 feet up, there is a notch that would have been used to turn the stones (Brier 2009, 27). Also, a member of the 1986 French surveying team noticed a desert fox entering a hole near that very notch. It is possible that there is an undiscovered hole at the base of the pyramid that leads to the internal ramp (Brier 2007, 26).

In 2008, Bob Brier climbed the north side of the Great Pyramid to have a closer look at the notch. While investigating this area, Brier noticed that the floor surrounding the notch was very uneven, measuring 18 feet wide and 20 feet high, enough room to turn the stones (Brier 2009, 27).

Behind an opening in the notch, roughly 18 inches wide and 5 feet high, was a small room. Made of rough blocks, this room had been discovered before, as evidenced by ancient graffiti dating back to 1845 (Brier 2009, 28). However, this room had not been documented before, possibly due to the difficultly in reaching this location or considered insignificance. Shaped like an L, each segment measured was roughly

Figure 8: Notch on the northeast corner

11 feet long, 5 feet by wide, and 8 feet high (Brier 2009, 28). The ceiling of this room showed some arches with keystones, which indicate that this room was purposefully constructed, not due to the removal of the limestone and stones in ancient times (Brier 2009, 29).

Once Brier relayed this information to Houdin, along with measurements, photographs, and video, Houdin analyzed the data and concluded that this room was the intersection of two sections of the internal ramp, specifically where the blocks were turned with a crane. As the pyramid's construction was nearing completion, the workmen filled in these notches, and the L-shaped room allowed the workers to bring the stones from the ramp to the notch (Brier 2009, 29). Filling the notches from the top down, the L-shaped rooms were sealed with blocks and mortar. The shape that the mortar dried in indicates that the blocks were pushed into place from somewhere below, most likely the internal ramp (Brier 2009, 29).

The members of the previously mentioned French surveying team were trying to determine whether there were any hidden chambers in the Great Pyramid. By using microgravimetry, which measures the density of various parts of the pyramid, the team found one image that showed that the edges of the pyramid were lower in density than the rest of the pyramid (Brier 2009, 29). They theorized that an exterior spiral ramp compressed the outer stones, resulting in the different densities

Figure 9: Results of the 1986 microgravimetric survey, white line indicates internal ramp, red dot indicates L-shaped room

between the two areas, but were not convinced by this explanation (Brier and Houdin 2008, 134). This image was shown to Henri Houdin, an engineer and Jean-Pierre's father, in 2000 and suggested that the internal ramp was still inside the pyramid, "running parallel to the outer face of the structure and turning 90 degrees at the corners, corkscrewing to the top" (Brier 2009, 27).

There is evidence of an internal ramp in a sun temple Abu Gurob, built in the 5th Dynasty by the pharaoh Ni-Userre. Constructed approximately 100 years after the Great Pyramid and located a few miles away, this temple was excavated in 1898 by the German Egyptologist Ludwig Borchardt (Brier and Houdin 2008, 181). This adds more physical evidence to the theory than simply the notch and the L-shaped room.

Testing The Internal Ramp Theory

Currently Jean-Pierre Houdin and Bob Brier are working on obtaining approval from the Supreme Council of Antiquities to perform a nondestructive survey of the pyramid to test the existence of an internal ramp. Nondestructive methods could include more powerful microgravimetric surveys, high-resolution infrared photography, or sonar (Brier 2007, 26). Thermal photography could also be used. If there were in fact an internal ramp, the photographs would show cool air between the hot stones (Brier and Houdin 2008. 185). If these tests yield positive results and permission is granted, archaeologists would most likely enter the ramp through the L-shaped room (Brier 2009, 29).

In 2008, Houdin and Brier experienced a setback when they failed to get a supervisor approved. Both of their initial choices, Dieter Arnold, a leading authority on

building in ancient Egypt, and Rainer Stadlemann, the former director of the German Archaeological Institute in Cairo, were rejected by Zahi Hawass, the secretary-general of the Supreme Council of Antiquities, as both were project managers of ongoing excavations at the time. Also, Bob Brier was not allowed to be the supervisor, as he specialized in mummies, not pyramids (Brier and Houdin 2008, 186-187).

Conclusion

The wait for the approval of the Supreme Council of Antiquities on the proposed nondestructive survey of the Great Pyramid is ongoing. We are, therefore, still unable to conclusively determine the ramp model used for construction. The microgravimetric survey is promising, and the internal ramp could explain the anomalies the French team found. The internal ramp at Abu Gurob strengthens the internal ramp theory, as this construction technique could have also been used at the Great Pyramid.

We can, however, reason that the long ramp and spiral ramp models were not used, due to the excess of material and lack of space on the Giza plateau in the case of the single ramp and the design flaws of the spiral model. Currently, without any records or concrete evidence of how the Great Pyramid was built, archaeologists can only speculate on the construction method used by the ancient Egyptians. Even without the approval of the Supreme Council of Antiquities, the internal ramp theory proposed by Jean-Pierre Houdin resolves the problems presented in past theories. Hopefully, the nondestructive survey will soon be approved, and this theory can either be put to rest, putting archaeologists back to square one, or be proven, solving a mystery that has puzzled scholars for thousands of years.

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Figure 2:
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Figure 3:
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Figure 4:

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Figure 5:
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Figure 6:
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Figure 7:
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Figures 8 and 9:
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