The Great Pyramid At Long Last - We know how it was built !

The Great Pyramid must have been an awesome sight immediately following its completion some 4500 years ago. Its four faces were covered in gleaming white Tura limestone outer-casing-blocks, which must have glistened like a gigantic beacon under the fiery Egyptian sun.

Although the ancient monument is still an impressive sight, the majority of its outer-casing-blocks have been removed over the ensuing centuries since its construction — mainly for building purposes involved in the expansion of the nearby city of Cairo.

However, these acts of vandalism have, in a way which could never have been envisaged, provided the key to solving the mystery of how the Great Pyramid was constructed.

During more recent times, numerous surveys have revealed that all four exposed faces display a slight, but discernible, concavity. This concavity is apparent only where the packing blocks are exposed; where they are still covered by the casing blocks the surface is perfectly flat.

There have been numerous attempts to explain the concavity in the exposed outer-packing-blocks, but the conclusions had always been the same: - "The purpose of the concavity of the Great Pyramid remains a mystery, and no satisfactory explanation for this feature has been offered. The indentation is so slight that any practical function is difficult to imagine."

In 2003, James Frederick Edwards proposed a construction methodology which challenged the previous theories of Egyptologists and historians, which mainly focussed on ramps or levers for elevating the stone blocks used in the construction process.

In his article of 2003, Edwards points out that the sides of a pyramid constitute a set of inclined planes, and makes a convincing case that the ancient engineers could well have taken advantage of this fact and simply hauled the block and-sledge assemblies up the faces of the pyramid into place. This methodology is very efficient, whereas using ramps and levers is far more time-consuming.

Although this first article was generally well-received, it lacked, as did every other proposed construction methodology up till then, any archaeological evidence to support it.

In 2016, Edwards published a second article, in which he argues convincingly that the concavity in the outer-packing blocks provides meaningful archaeological evidence to add weight to his proposed construction methodology.

Let us examine the second article in some detail:-

Although there is common agreement that the concave indentations are only very slight, they can be accounted for using a building methodology in which the block-and-sledge assemblies are transported on the faces of the pyramid. Hauling the assemblies up the pyramid's faces would produce a lateral force as shown in Figure 1.

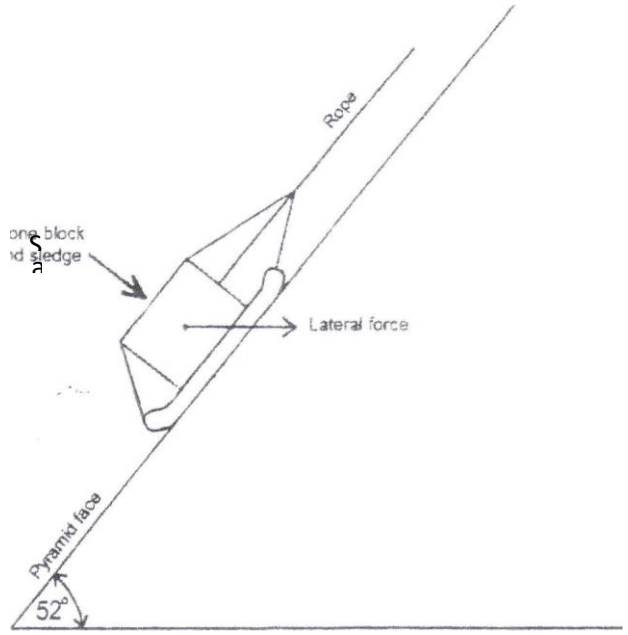


Fig. 1. Graphic representation of lateral force.

The lateral force would be transferred, via the hard outer-casing-blocks, directly onto the softer outer-packing-block — and Figure 2 shows one particular course during the hauling process.

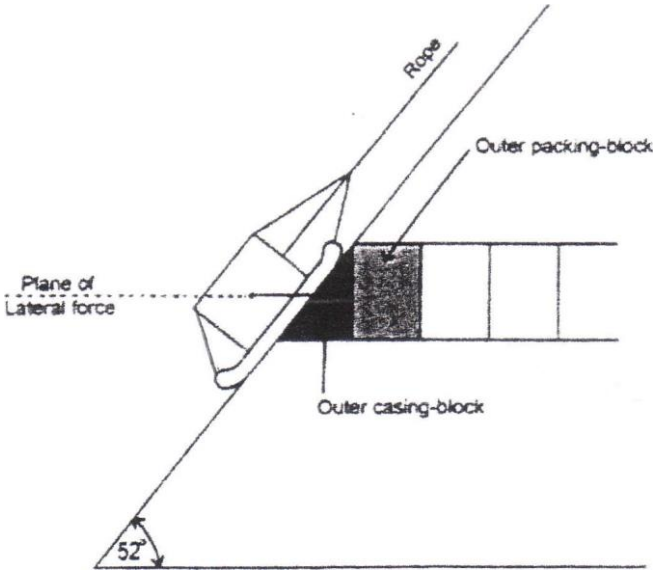


Fig 2. Graphic representation of lateral force acting on one particular course.

It has been estimated that 2,300,000 separate blocks of stone, the majority weighing between 2 and 3 tonnes, were used during the course of building the Great Pyramid. Assuming that all four faces were utilized to the same degree, we can estimate the number of lifts per face as 2,300 000/4 = 575,000 lifts per face.

Since there are numerous variables, it is impossible to be one hundred per-cent accurate regarding the value of the lateral forces. Did the construction teams lubricate the pyramid's faces, or were the block-and-sledge assemblies hoisted up dry? If water from the nearby

harbour complex was used as lubrication, the resulting coefficient of friction between the sledges and the pyramid's faces would have been around 0.2. Perhaps the ancient builders avoided the intricacies associated with lubrication and just hauled the block-and-sledge assemblies up the faces of the pyramid This would result in a higher coefficient of friction and lateral force plus increased wear on the faces — but their earlier experiments on the Red Pyramid at Dahshur would have indicated how much excess material to leave on the faces of the outer-casing-blocks of Tura limestone.

Whatever the exact values of the lateral forces, the important indicator is that their "pattern spread" across each face of the pyramid mimics the "pattern spread" of concavity observed in each separate face of the Great Pyramid.

The "pattern spread" of lifts is depicted in Figure 3.

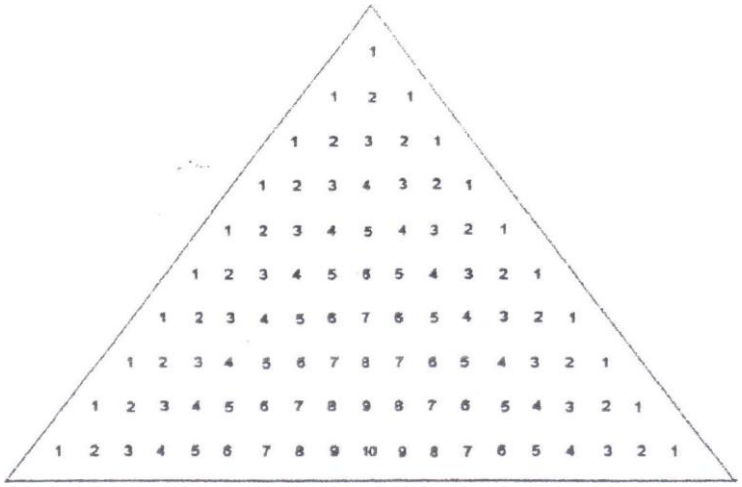


Fig. 3. Distribution of lifts across one face of the pyramid.

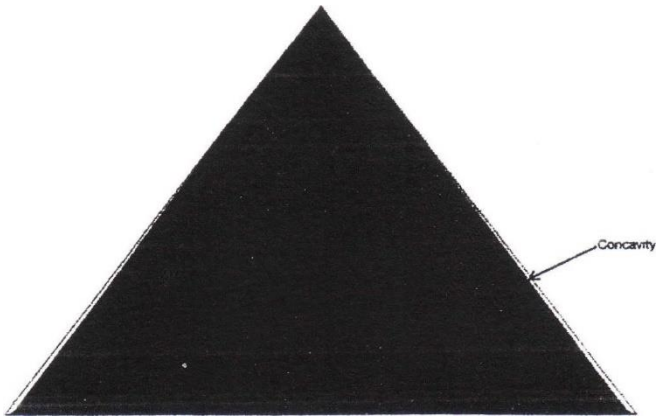
10 = Area of highest number of lifts

1 = Area of lowest number of lifts.

It is reasonable to conclude that the transfer of lateral force through the hard outer-casing-blocks onto the softer packing-blocks, would over many thousands of lifts, cause the packing blocks to compact, and to move very slightly in the direction of the lateral force — towards the core of the pyramid. This movement would be miniscule, but over a period of numerous lifts, become discernible, resulting in the observed concavity,

The number of lifts, and hence forces, was, as expected, at a maximum at the bottom of each face, and reduced progressively towards the outer edges of each face and towards the apex, as the pyramid gained height as it was built.

These effects are shown in Figures 4 and 5.



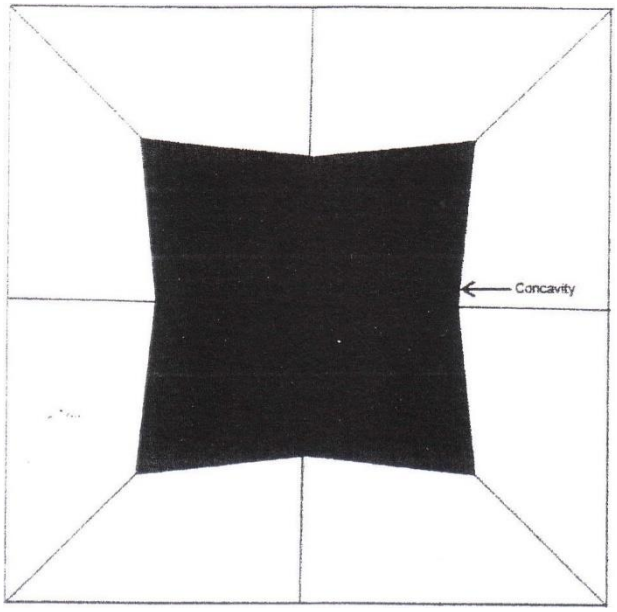


Fig. 4. Center cross-section depicting concavity (exaggerated).

Fig. 5. Plan-view cross-section at pyramid half-height depicting concavity (exaggerated),

The exposed core blocks of the Great Pyramid suggest that it was constructed as a "coursed" pyramid, as it consists of level courses of stones. As the pyramid gained height each course would, very gradually, reduce in thickness, and hence mass. A set of force maps was drawn up for each face of the pyramid.

The amount of concavity in the pyramid's faces shows that the number of 'passes' across each face was similar. This was probably to even out wear on the outer-casing-blocks due to the action of lifting. It is also highly likely that an "alternate course building methodology/' was employed.

Designated slipways, perhaps around 5 metres wide, would have been utilized — all under the watchful eyes of "overseers", to ensure that each was progressively utilized, in sequence, across its full width during each lifting sequence. Such an approach would guarantee an even distribution of lifts across each face of the pyramid during the construction process.

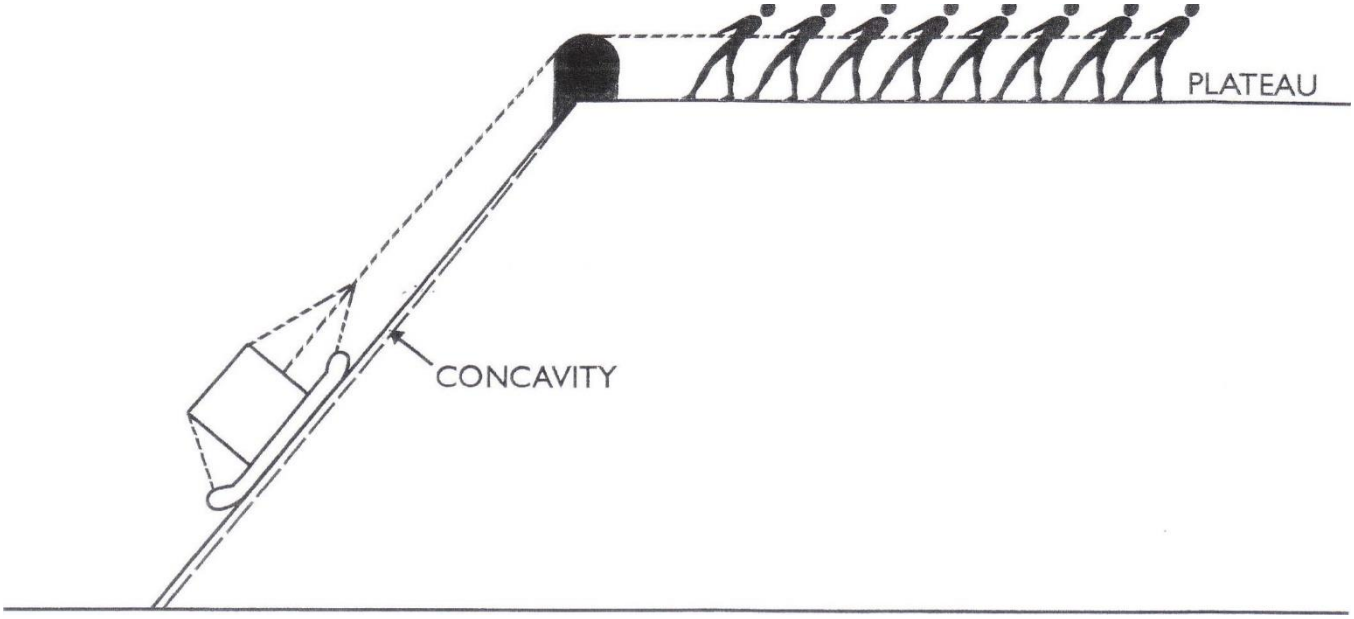
Once all the building blocks had been positioned, the outer-casing-blocks would have required dressing. Because we know that a generous amount of material was left on the faces of the outer, and harder, Tura limestone outer-casing blocks prior to final dressing, it would have been a more straightforward task to achieve a "flat" surface across the four faces of the pyramid. Hence, no concavity across the finished faces would be observed, as it was obscured by the outercasing-blocks.

It is granted that it is impossible to calculate the exact amount of indentation caused by the compressive effects of the lateral forces for a specific number of passes across a particular area of the pyramid's face, as there are too many variables involved. However, an estimation can be made for the number of passes over a particular area of the pyramid's face and compared with an approximation of the actual amount of indentation at the same point.

Although there are some fine examples of very closely blocks fitted within its structure, it is important to note that the Great Pyramid is not, in the technical sense, a solid mass, The majority of the core blocks can be described as "loosely set" - which makes the packing-blocks more susceptible to compressive forces. Because of its shape, the downward constraining forces experienced by each separate course of blocks increase progressively with distance from the angled faces towards the core of the pyramid. Hence, the angled faces of the pyramid, unlike a structure with vertical faces allow a higher degree of lateral compression to take place in the vicinity of the outer-casing-blocks and outer-packing-blocks. This is true for every course of blocks from ground level to the apex of the pyramid.

If the Great Pyramid had not been vandalised over the centuries, we would probably still be in the dark regarding its method of construction.

THE METHODOLOGY - IN SIMPLE TERMS



The stone blocks are hoisted up the faces of the Great Pyramid whilst mounted on wooden sledges — which had been delivered to the base of the pyramid from the nearby stone quarry.

The total number of hoists per face is around 575,000 — which accounts for the concavity observed in each face.

Following completion of the lifting, each outside face of Tura Limestone was trimmed in order to remove the scars of construction. This action would hide the concavity — which was only revealed following the removal of the majority of Tura Limestone outer casing blocks.

Conclusion

What do lames Frederick Edwards' two articles tell us about the construction of the Great Pyramid?

The first article clearly demonstrates that, with respect to the speed and efficiency of operation, his proposed methodology has strong advantages over alternate proposals,

The second article demonstrates that the external lateral forces, induced by hauling block-and-sledge assemblies up the angled faces of the pyramid, account for the concavity observed in the exposed outer-packing-blocks. This resolves the question of the purpose of the concavity: there was no purpose. It was, rather, a side-effect of the construction process.

Finally, it can be stated beyond reasonable doubt, that the construction process first described in the article of 2003 is totally supported by the archaeological evidence presented in 2016, No other proposed methodology can make such a claim.

Article 1- Edwards, James Frederick, 'Building the Great Pyramid: Probable Construction Method Employed at Giza.
Technology and Culture 44, no 2 (April 2003) 340-54.

Article 2- Edwards, James Frederick, "The Concave Faces of the Great Pyramid. An Explanation".
Technology and Culture 57, no 4 (October 2016) 909-25

Dr. Edwards is a retired chartered consultant engineer and physicist He has published several books and articles dealing with topics as diverse as pure and applied physics and the transportation system of medieval England and Wales, He is an avid walker and has written numerous walking guide books covering Cheshire, Shropshire and the North Welsh Borders..

Any questions relating to the aforementioned overview cannot be answered through this website.

If you do have any questions relating to the overview, it is recommended that you examine the original papers published in 2003 and 2016

Some Final Thoughts Relating to the Construction of the Great Pyramid.

Having completed two articles (2003 & 2016) relating to the construction of the Great Pyramid — there is only one outstanding question: Were the hauling lifts carried out '”dry" or ”lubricated"?

The lubricated coefficient of friction, μ, between the wooden sledge and the stone surfaces of the pyramid's faces was estimated to be around 0.2 in the first article of 2003. This was deduced from recent experiments carried out at Karnak Temple. The validity of this result was checked against the wall painting of the hauling of-the large statue of Djehetu-hotep in his twelfth dynasty tomb at Deir el Bersha. Although this was useful for estimating the hauling power of an individual, it does not necessarily follow that lubricated faces were employed during the building of the Great Pyramid,

At the halfway stage of construction, in terms of height, it would take less than three minutes to raise a block and sledge assembly up the outside faces of the Great Pyramid using teams of fifty haulers.

Compared with hauling the statue, this type of hauling can be described as a ('sprint". It's akin to comparing a 400 metre runner with someone running 10,000 metres. The 400 metre runner can put a lot more energy into a much shorter time. Also, the Great Pyramid haulers only carried out one lift per hour, on average, so had plenty of time for rest between hauls.

The intricacy associated with “lubricated" hauling results in heavier block and sledge assemblies than when hauling up "dry". The weight of the lubricator, lubricant, containers and a strengthened sledge would all add to the weight — compared with a "dry" block and sledge assembly. Also, in order to provide complete "lubricated" coverage to the pyramid's faces, more care would be required when dispersing the lubricant. Furthermore, because of the overall increase in weight, when compared to a "dry" assembly, there would be neither a significant gain in terms of hauling capacity, nor any reduction in lateral force.

Considering all the above mentioned factors, it is my own opinion that the actual construction lifts were carried out "dry" — where the coefficient of friction, μ , between the wooden sledges and the Tura limestone faces of the pyramid — would be approximately O.5.

As previously stated, in both articles, the builders of the Great Pyramid would have known how much extra material to leave on the faces of the Tura limestone outer-packing-blocks following their experiences when constructing the Red Pyramid at Dahshur.