Theoretical reconstruction of the Solar Altar in the Hatshepsut Temple at Deir el-Bahari

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Abstract: In a recent article Andrzej Ćwiek (2015) criticized on ideological grounds one of the hypotheses concerning the reconstruction of the Solar Altar in the Complex of the Sun Cult of the Temple of Hatshepsut in Deir el-Bahari. The theoretical reconstruction in question, presented as one of the possibilities in an earlier text by the present author (Dziedzic 2013), called for two obelisks and a sacrificial table standing on the Solar Altar located in the open courtyard of the complex. Ćwiek also pointed to the practical difficulties associated with transportation and placement of stone obelisks. This article describes the technical aspects of transporting and placing obelisks in two different locations. It also contains calculations concerning the weight impact of the altar elements (obelisks) on the altar structure.

Keywords: Deir el-Bahari, Hatshepsut, temple, Sun cult, Solar Altar, obelisks

Modern research has shown that stone obelisks were extremely varied and were erected as solar symbols from the time of the Old Kingdom (from the mid 3rd millennium BC at least). These slender tapering pillars capped with a pyramidion, easily covered with inscriptions, have also been the subject of investigations by architects and engineers exploring the artistic and technical aspects of these extraordinary objects. The first to discuss the issue was Reginald Engelbach in his book *The problem of the obelisks, from a study of the unfinished obelisk at Aswan*, published in 1923. Other important contributions to the discussion of technical problems involved in the construction, transport and raising of obelisks were made by Martin Isler (1976) and Labib Habachi (1984). A number of publications have dealt with the tallest and heaviest obelisks, between 19.60 m and 32.18 m long and weighing between 143 and 455 tonnes (Arnold 2003: 166). These required a large expenditure of labor and manpower, as well as near perfect logistic solutions for their transport and positioning in a desired place. The present article discusses issues related to the hypothetical raising of obelisks in the Complex of the Sun Cult in the Temple of Hatshepsut at Deir el-Bahari in Luxor. These obelisks are admittedly much smaller compared to their counterparts in the Karnak or Luxor temples.

MODERN METHODS OF DOCUMENTATION

Modern non-invasive testing methods, such as 3D scanning and digital photography, aided by artificial lighting of the examined area, allow hitherto undetected traces and marks to be identified and documented. Cuts made by the builders of the altar in the Sun Cult Complex in Deir el-Bahari, known already from the first documentation by Édouard Naville's team and from a study by Janusz Karkowski (2003: 126), were presented by the author in a previous article in the form of drawings and photographs, along with evidence of wear caused by frequent walking on the stone surfaces (Dziedzic 2013). The latter observations could hardly be ignored in an architectural study of the altar, which would have been neither complete nor reliable were it to be based only on earlier extant documentation.

DIMENSIONS AND WEIGHT OF THE PROPOSED OBELISKS

The parameters of the proposed obelisks and their bases were given in numbers and illustrated with clear linear scales in the drawings, although no information on the kind of stone was put forward by the author (Dziedzic 2013: 645). It can be assumed that it was either granite or limestone. The granite could have come from the Aswan region, from the area of the First Cataract, where rich deposits of that stone were located and extracted from the earliest times. The granite has a phanerocrystalline and fine-grained structure (Klemm and Klemm 2008: 233). Its specific gravity ranges from 2.60 to 3.20 kg/dm^3 (kg/l) (Arnold 1991: 28).

Limestone, the principal building stone used in the construction of the Temple of Hatshepsut in Deir el-Bahari, may have come from a local quarry located 3 km away from the town of Gurna, on the western bank of the Nile River. Rajmund Gazda has shown that there were two kinds of limestone, soft and hard, in use at the temple. The hard limestone contains quartz crystals, dolomite and iron oxides, the soft one is a marly limestone bonded with clay (Gazda 2000: 167). The specific gravity value of the limestone from the Hatshepsut Temple, as tested by Stanisław Wojdon in 1970, is 2.2 T/m^3 (2.2 kg/l) which based on a classification employed by Janusz Dembek in his unpublished supplementary paper defines the stone as soft (1.72–2.80 T/m^3). According to Wojdon's calculations, the limestone has a compressive strength of 700 kg/cm^2 (68.65 MPa)[1]: 1 -2). Dieter Arnold classified this type of limestone as porous: 1.70–2.60 kg/dm^3 (kg/l) (Arnold 1991: 28). Based on the data on the obelisk dimensions (Dziedzic 2013: 645), the volume of each of the obelisks was calculated as not exceeding 2.50 m^3.

Assuming that the specific gravity of limestone is 2.80 kg/l, the weight of each of the obelisks can be estimated as 7 tonnes. Had the obelisks been made of granite, each of them would have weighed 8 tonnes, given the same volume as above and a specific gravity of 3.20 kg/l.

[1] Data based on tests performed by Stanisław Wojdon in 1970. Similar values for limestone were given by Dieter Arnold (1991: 28).

TRANSPORTING OBELISKS

Once an obelisk had been carved from bedrock, it had to be transported to the temple for which it was destined. Detaching the obelisk from bedrock prior to transportation was a major difficulty according to Engelbach and he described two hypothetical methods that could have been used with regard to the unfinished obelisk from the quarry in Aswan (Engelbach 1923: 53). The Aswan obelisk is 41.75 m long and weighs 1,168 tonnes (Arnold 2003: 166). The obelisks discussed in this paper would not have exceeded 8 tonnes in weight had they been of Aswan granite and 5 m in length, hence the extraction of an appropriate block from bedrock would not have been an issue. In terms of size, the envisioned obelisks would not have differed from the other decorative elements used in the Temple.[2]

The obelisks could have been transported to the temple on a wooden sledge hauled by a team of men. Engelbach calculated a labor force of 6,000 men needed to move the Aswan obelisk (Engelbach 1923: 56). Referring to a scene painted inside the tomb of governor Djehutihotep at Deir el-Bersha (Middle Kingdom, 19th century BC), Habachi estimated the weight of the statue depicted in the painting as about 60 tonnes and the number of men pulling it at 172 men. However, he also pointed out that no log rollers were used under the sledge, although the technique was known to contemporaries as a way of reducing the manpower needed for transport. Several thousand men carrying out the task would not have been an effective measure (Habachi 1984: 24). Upon comparing the weight of the monuments with that of the two obelisks from the Hatshepsut Temple, one easily concludes that no more than 40 men would have been needed to transport each of the blocks to Deir el-Bahari. Engelbach also suggested Spanish windlass for securing the obelisks to the sledge, referring to the scene of transportation of obelisks depicted in the Temple of Hatshepsut (Engelbach 1932: 57).

At this point, one should ask how the obelisks could have been brought into the courtyard of the Sun Cult Complex. There are three possibilities. The obelisks may have been delivered before the walls of the northern part of the temple were completed. It would mean that the courtyard arrangement was determined already at the onset of construction and no technical

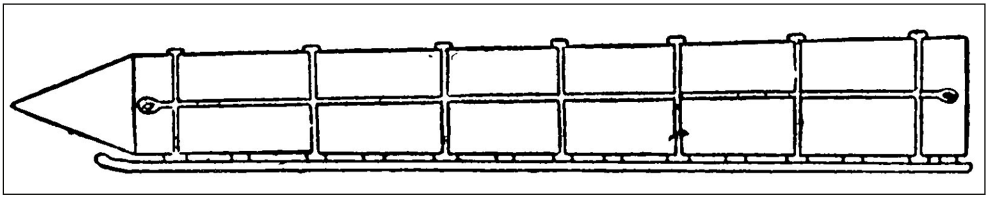

Fig. 1. The Hatshepsut obelisk secured on a sledge with Spanish windlass (After Engelbach 1923: 57)

[2] The granite false door in the Chapel of Hatshepsut with a cubic volume of 2.80 m^3 also weighs about 8 tonnes (author's observation).

or logistical problems occurred. However, let us assume that the decision to bring in the obelisks and place them in front of the altar was made when the Sun Cult Complex with the Small Altar was already in operation and the northern part of the upper terrace was already standing. Changes of the courtyard design and the construction of the Great Altar would have simply required the obelisks to be moved to a higher level. Navigating these massive blocks into a complex that differed little from the present known plan would have constituted a major task. Obstacles would have included not only walls constructed to their full height, but also columns in the Ra-Horakhty Vestibule, but neither the spacing of the columns in the vestibule nor the arrangement of the entrance leading into the Complex and further to the courtyard, and the walls standing to full height would have hindered the transport of the obelisks into the courtyard [*Fig. 3* top].

After being brought into the courtyard, the obelisk would have to be placed on an already prepared pedestal. To compensate for the difference in height between the pedestals and the level on which the transportation took place, there would have to be an embankment inclined up to 2%, that is, 1°. Marks incised into the surface of the pedestal would have specified the precise location of the monument. Engelbach noted that one of the methods of erecting an obelisk, assuming its weight did not exceed 35 tonnes, was to use a lever. Examination of the base of the Hatshepsut obelisk at Karnak by the present author has suggested that an obelisk, while still in horizontal position, should have been positioned with its edge resting on a groove marked on the pedestal (see Engelbach 1923: 67) [*Fig. 2*]. This method of raising obelisks was described in greater detail by Isler (1976: 33–34). A simple lever consisted of a beam, ropes tied around the obelisk and a container with sand. As sand was fed into the container, the container went down, while the obelisk moved upwards until it was standing in vertical position (Isler 1976: 33) [*Fig. 3* bottom]. Had such works been carried out in the courtyard of the Sun Cult Complex, the lever would have been placed in a way enabling the container with sand to come to a rest on the courtyard pavement on the northern and southern sides of an already standing altar. The obelisk raised to the vertical had to be stabilised in its ultimate position. Undoubtedly, the success of this operation would depend on the use of a qualified workforce, of which there must have obviously been an abundance on site during the construction of the Temple of Hatshepsut.

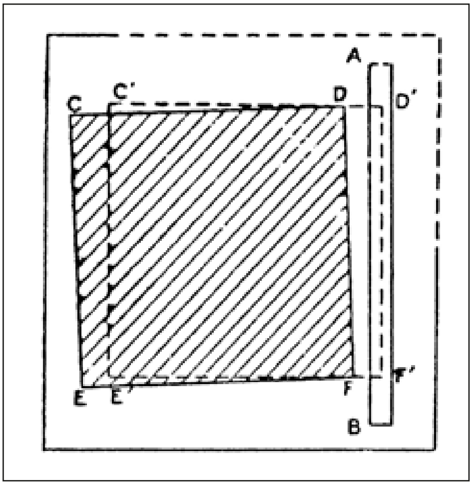

Fig. 2. Pedestal with the site for mounting an obelisk (After Engelbach 1923: 68)

The other possibility is that the courtyard arrangement was changed when the Great Solar Altar already existed in the

Complex of the Sun Cult. It was decided that obelisks would be placed on the already modified altar. The logistical and technological process for bringing in and raising the obelisks would have been the same as in the previously described scenario, the sole difference concerning the height at which the pedestals for mounting the obelisks were placed [*Fig. 4* top]. An embankment would have been needed to achieve a height of about 190 cm (the height of the altar with the pedestal for mounting the obelisk). It would have had to start at the entrance to the Complex, and in the area of the Ra-Horakhty Vestibule it would rise towards the courtyard

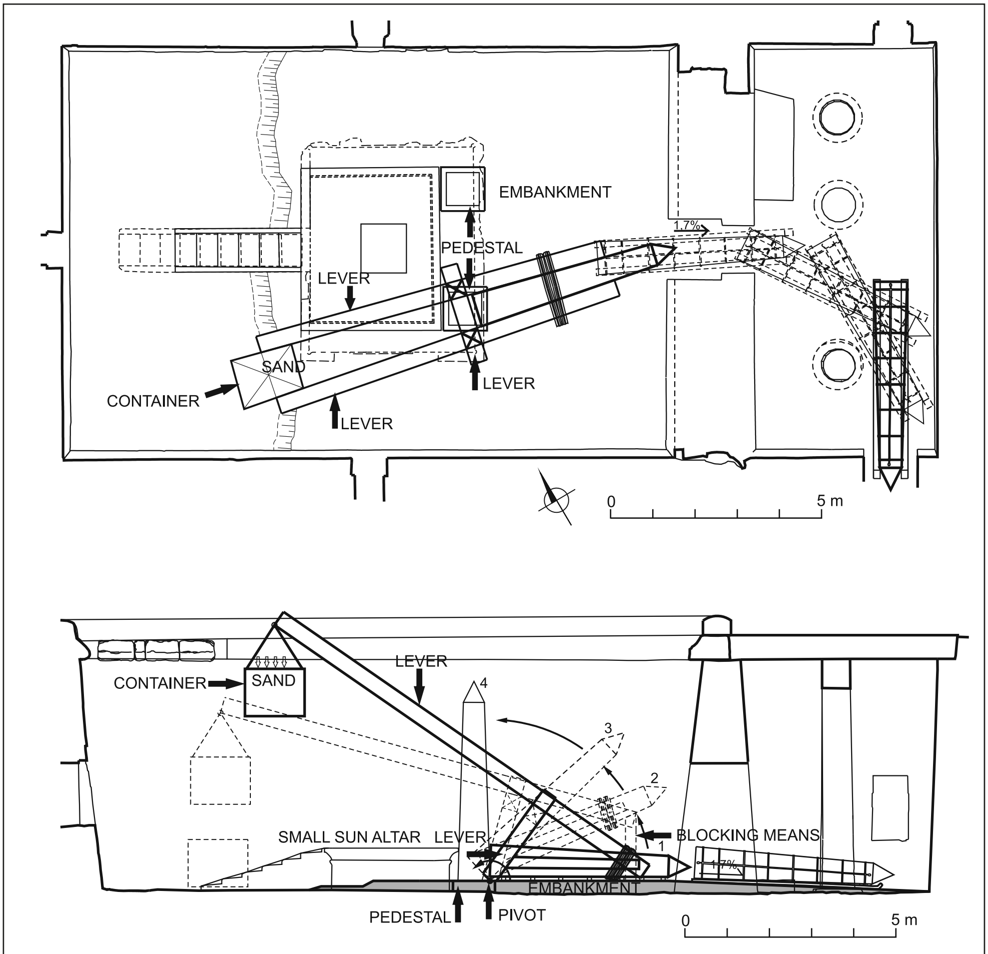

Fig. 3. Theoretical reconstruction of the raising process assuming that the obelisks were placed in front of the Small Altar: top, stages of introducing the obelisk into the courtyard on a sledge and preparing it for raising on the pedestal; bottom, raising of an obelisk using a lever (PCMA Temple of Hatshepsut Project/drawing T. Dziedzic; bottom image, after Isler 1976: 39–40)

by 8.5%, that is, 5°. From the courtyard entrance to the destined location, the slope of the embankment would need to rise by up to 14%, that is, 8°. An embankment of such slope would have decreased the height of the passage from the vestibule into the courtyard, but it would have still been more than 200 cm and would have not constrained transport of the obelisks by human labor. Another important step in the process was to support the obelisk with a blocking means made of wooden beams when it was raised 45° from the ground [*Fig. 4* bottom]. This gave the laborers some breathing space before the next phase of the raising process.

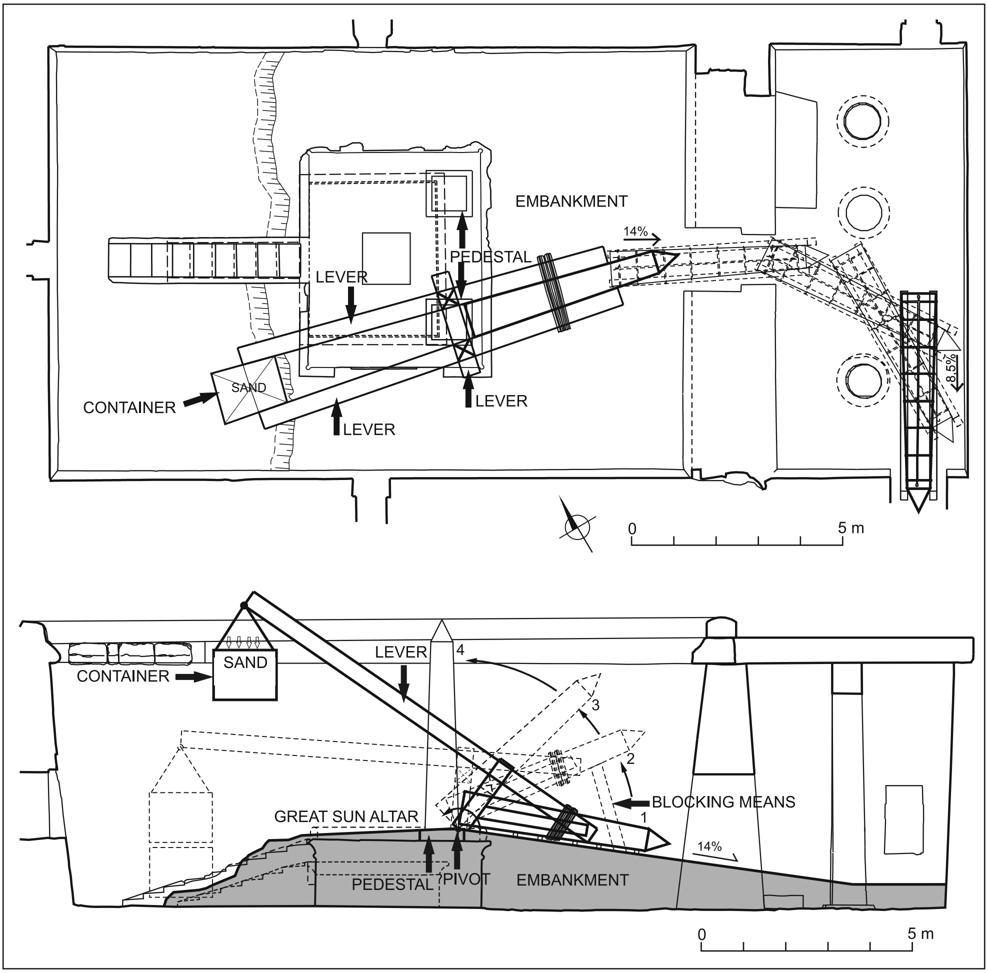

Fig. 4. Theoretical reconstruction of the raising process assuming that the obelisks were placed directly on the Great Altar: top, stages of introducing the obelisk into the courtyard on a sledge and preparing it for erection on the pedestal; bottom, raising of an obelisk using a lever (PCMA Temple of Hatshepsut Project/drawing T. Dziedzic; bottom image, after Isler 1976: 39–40)

DETERMINING ALTAR RESISTANCE TO THE LOAD OF THE OBELISKS

The design compressive strength of the limestone slab altar from the Sun Cult Complex in the Hatshepsut Temple at Deir el-Bahari was calculated by engineer Anna Caban. For the purpose of the calculations, an assumption was made that the obelisks were constructed from a compact limestone, that is, the hard limestone described above.

The mean value of local compressive stresses should satisfy the condition:

$$\sigma_d = \frac{N_{i.d}}{A_b} \leq \frac{f_k}{\gamma_m}$$

$N_{i,d}$ – design concentrated load (specific gravity of the obelisk) = $V \cdot F_k \cdot \gamma_{f\,[\mathrm{kN}]}$,
V – volume of the obelisk [m^3],
F_k – specific gravity of compact limestone 28.0 [kN/m^3],
γ_f – load coefficient 1.1 (for permanent loads according to Polish norm PN-82/B-02001),
A_b – load impact area [m^2],
f_k – characteristic compressive strength 70.0 [MPa],
γ_m – partial safety factor 2.5 (for category B of conducted construction works and category I of brick wall components according to Polish norm PN-B-03002:1999);

$N_{i,d} = 2{,}49 \cdot 28{,}0 \cdot 1{,}1 = 76{,}69[kN]$
$A_b = 1{,}05 \cdot 1{,}05 = 1{,}10[m^2]$
$\delta_d = 69{,}72\ [kN/m^2] \approx 0{,}07[MPa]$

Design compressive strength of the altar

$$\frac{f_k}{\gamma_m} = \frac{70,0}{2,5} = 28,0[MPa] \geq \sigma_d = 0,07[MPa]$$

The condition concerning the mean value of local compressive stresses has been satisfied.

Calculation results show that the altar loaded with the obelisks uses only 0.25% of its bearing capacity. According to calculations by engineer constructor Mieczysław Michiewicz, the stone pavement compressed by an obelisk being raised used only 2–3% of its design compressive strength. The small dimensions of the blocks making up the Great Altar did not significantly reduce the load capacity of the entire structure, and the structure itself was placed on a stone surface.

CONCLUSION

The study revealed that it was technically and logistically feasible to transport and place the obelisks on the Solar Altar in the Temple of Hatshepsut at Deir el-Bahari. The entire transport and placement process could have taken place at any stage of modification of the architectural layout of the courtyard in the Complex of the Sun Cult. The presented analyses indicate that the loads placed on the altar structure by the obelisks would have had no effect on its resistance, and Andrzej Ćwiek's suggestion that the altar would have been crushed is inaccurate.

Any further discussion of the hypothetical altar arrangement should be based on documented evidence: an inventory of the historic site including all identified marks and traces, and knowledge of worship and religion in ancient Egypt of the relevant period.

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