Journal of Applied Mechanical Engineering
ISSN: 2168-9873

Shiells, J Appl Mech Eng 2015, 4:4
DOI: 10.4172/2168-9873.1000174

Research Article Open Access

Mechanical Technique for Raising an Obelisk

Shiells JE*

US Government, 1401 Clearview rd, Edgewood MD, USA

Abstract

A simple technique is outlined which may answer the mystery of how the Egyptian obelisks were raised to their upright position. This technique relies on a mechanical ram which is characterized by equations that are derived in this article. The mechanical ram is basically a leverage device which would enable the ancients to apply a very large force with only a minimal input force. A paper analysis is developed to show how this technique may have raised the heavy 130,000 kg Thutmose obelisk upright, although the procedure would have been painstakingly slow. Note however, that no case is made here that the Egyptians actually used this technique.

Keywords: Mechanics; Obelisks; Archaeology

Introduction

A paper analysis is presented of a proposal to erect the moderate size Thutmose obelisk. This paper compares the turning moment to set Thutmose upright with the theoretical available force that could be obtained from the force multiplier method described. This technique depends on an unusual lever arrangement which will hereafter be referred to as a mechanical ram. The hydraulic ram could be considered as the modern functional equivalent of this mechanical ram. However, an important disadvantage of the mechanical ram is the minute working stroke as compared to a hydraulic ram. Therefore such a mechanical ram would have to be repositioned (reset) many times in order to ratchet the obelisk centimetre by centimetre to the final upright position.

First, some background material is presented which motivated this study including a brief description of the current thinking about this problem. Then the mechanical ram is described in detail, followed by an estimate of force required to raise Thutmose. Finally, some practical considerations are explored including the application of a finite element analysis Bathe [1] to establish the practically of the theoretical proposal.

Background

The PBS television program NOVA in "Secrets of Lost Empires: Obelisks" Barnes [2] made the public aware of the mystery of how the Egyptians raised the massive obelisks to the upright position. Levers could raise the obelisks to a certain height but eventually the raising height limits the availability of pivot points as well as the amount of force that can be applied to the end of the lever. Archeologists Englebach [3] were well aware of this problem many years ago. Later Chevrier [4] a method was proposed by which an earthen (sand) ramp was used. The idea was to shove the obelisk (backwards) up the gradual sloping end of the ramp and then have the base of the obelisk go over the steep end of the ramp under control of ropes until it settled on the pedestal rock. This method is sometimes referred to as the "sand funnel" method which is said to be unproven Arnold [5].

A very interesting discovery was made during the production of the PBS video Barnes [2]. When the crew went to the "obelisk graveyard" in Tanis, Egypt, they found pedestal stones with a turning groove along with associated abandoned obelisks. Figure 8 shows a drawing of such a stone supporting the edge of the obelisk base. This kind of stone would be absolutely necessary to prevent slipping or twisting if a method were known for pushing the obelisk upright from the horizontal position like the technique described here. The "sand funnel" technique envisions that the obelisk is set down at a high angle in which slipping would be unlikely, hence no need for a turning groove. In chapter 3 of his book, Wirsching [6] present a number of mechanical proposals for solving this erection problem. None of these methods are remotely similar to the technique outlined in this paper. Most of these methods depend on brute force with little attention to mechanical advantage except for one. This one is similar to the "sand pit" method which represents the latest thinking. This idea Cort [7] is that the obelisk is slowly lowered while turning into the upright position by allowing the supporting sand under the obelisk base to escape in a controlled manner. This technique however requires the obelisk to be contained in a giant sand box and is not universally accepted.

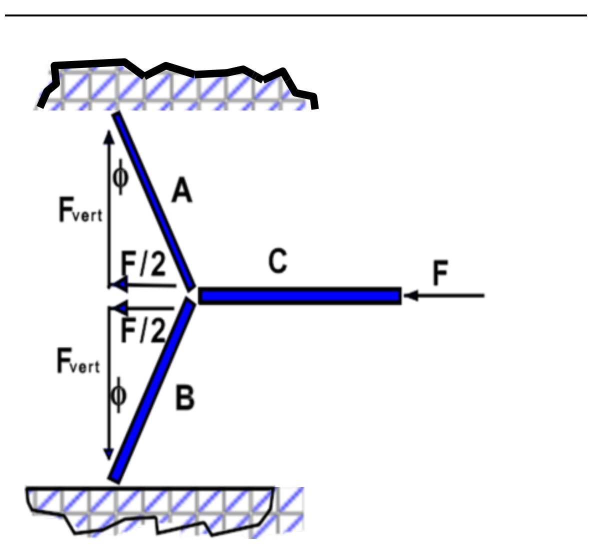

Figure 1: Force vector diagram for mechanical ram

***Corresponding author:** James E Shiells, US Government, 1401 Clearview rd, Edgewood MD, USA, Tel: 410 676 0640; E-mail: jespd109@gmail.com

Received June 09, 2015; **Accepted** July 29, 2015; **Published** August 02, 2015

Citation: Shiells JE (2015) Mechanical Technique for Raising an Obelisk. J Appl Mech Eng 4: 174. doi:10.4172/2168-9873.1000174

Citation: Shiells JE (2015) Mechanical Technique for Raising an Obelisk. J Appl Mech Eng 4: 174. doi:10.4172/2168-9873.1000174

Mechanical ram description

Figure 1 show the essential features of the mechanical ram along with the associated force vectors. Two rigid beams (A and B) are situated between two stationary surfaces about which they are free to rotate but not slide (pivot only). The beams are oriented at the angle (phi) ϕ off the vertical as shown. Where these beams meet is the point where beam C is used to apply the force F. This force F compresses both beams A and B equally. From an examination of the force diagram it follows that each of these beams must resist with a horizontal force component of magnitude F/2. With further analysis of the force diagram it also follows that the vertical force component is given by equation.

$$\mathbf{Fvert=(\ F/2\ )\ cot}\ (\phi) \quad (1)$$

The mechanical advantage (MA) of the system is defined as the ratio of the vertical force component to the applied force F as shown by equation 2.

$$\mathbf{MA=Fvert/F} \quad (2)$$

Combining equation 1 with equation 2 yields equation 3 which defines the mechanical advantage in terms of the angle ϕ.

$$\mathbf{MA=.5}\ \cot\ (\phi) \quad (3)$$

From equation 3 it becomes apparent that very high values of mechanical advantage (MA) may be obtained with this system if small values of angle ϕ are used. However, the lower value of the starting angle ϕ implies that the useful working stroke (WS) becomes smaller. Figure 2 illustrates how the working stroke for a unity length beam is calculated.

Since two beams are involved in the mechanical ram, the maximum working stroke is given by equation 4.

$$WS=2\ \{1.0-\cos\ (\phi)\} \quad (4)$$

Table 1 list several values of mechanical advantage (MA) and working stroke (WS) as a function of the angle phi.

For example, if two 6.1 m beams are set at the initial angle of ϕ=4 degrees it follows from Table 1, that a mechanical advantage of 7.1 with a working stroke of (6.1×100× .00488) or 3 cm is available. Referring to Figure 1, this means that a force F of 10000 N will result in a vertical force Fvert of 71000 N with a maximum lift of 3 cm. When the ram advances the value of phi decreases which means the MA becomes higher and the required input force for a constant load drops accordingly. While moderately impressive for a force multiplier it clearly falls short of the task of raising Thutmose which is approximately 130,000 kg. However, the situation changes dramatically when consideration is directed toward a serial mechanical ram configuration. Figure 3 show two mechanical rams placed in series.

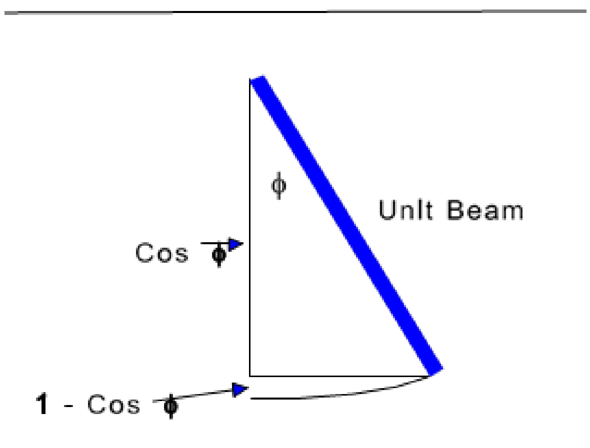

Figure 2: Unit beam working stroke (WS).

In this arrangement a force F on the first ram (beams C and D) is magnified by MA before being applied to the second ram (beams A and B) where it is magnified again by MA. In order for the second ram to complete its full working stroke it is necessary for the first ram to be used several times. The advance of the second ram must be locked temporarily else it would snap back when resetting the first ram. In raising an obelisk, this would mean locking each incremental increase of elevation with a temporary support or "follower" beam.

Table 2 is a repeat of Table 1 except that the values of MA are squared to describe the features of the serial mechanical ram.

As an example of the capability of the serial mechanical ram, consider the case of four 5 m beams (A, B, C, D) in Figure 3 with a starting angle ϕ equal to 5 degrees. From Table 2 the mechanical advantage (MA) is now 32.5 and the working stroke (WS) is (5× 100× .00762) or 3.8 cm. Referring to Figure 3, this means that if a force (F) of 5000 N is applied, then a lift Fvert of 162,500 N can be expected. The first ram (C/D) would have to be reset several times so that the second ram (A/B) could complete the 3.8 cm working stroke. The order of magnitude of force available from such a device suggests it may be up to the challenge of raising Thutmose.

Obelisk force estimations

The analysis of the force required to turn the obelisk to the upright position follows: The Thutmose I obelisk Wirsching [6] is approximately 20 m long and a mass estimated at 130,000 kg. Clearly, the force required to upright the obelisk depends on where the force is applied as well as the angle of inclination theta (θ) of the obelisk. The angle θ being 0 degrees when the obelisk is on its side and θ is 90 degrees when it is upright. In order to make these estimates it is first necessary to calculate the turning moment (Mo) of the obelisk as a function of the inclination angle θ. Figure 4, represents the obelisk at some intermediate angle θ. For modelling purposes, a simplifying assumption is made that the 130,000 kg mass is distributed uniformly along the 20 m length. In reality, the actual obelisk tapers slightly toward

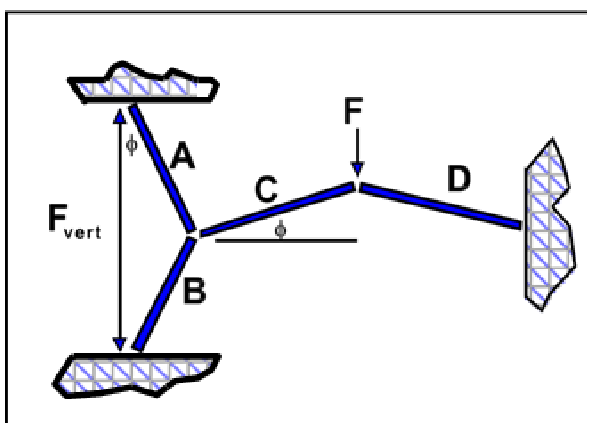

Figure 3: Serial mechanical ram configuration

Citation: Shiells JE (2015) Mechanical Technique for Raising an Obelisk. J Appl Mech Eng 4: 174. doi:10.4172/2168-9873.1000174

phi (degrees)	mechanical advantage (MA)	(WS) working stroke (m)
2	14.3	0.00122
3	9.5	0.00274
4	7.1	0.00488
6	4.7	0.01096
8	3.55	0.01946

Table 1: Mechanical ram parameters.

phi (degrees)	mechanical advantage (MA)	(WS) working stroke (m)
2	204.5	0.00122
3	90.2	0.00274
4	50.4	0.00488
6	22.1	0.01096
8	12.6	0.01946

Table 2: Serial mechanical ram parameters.

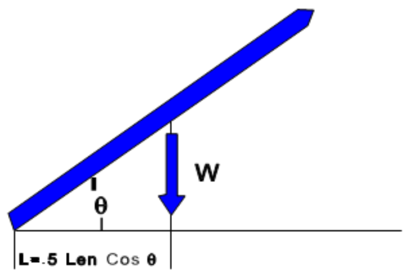

Figure 4: Obelisk turning moment arm.

its top and its centre of gravity would therefore be closer to its base. This assumption of uniform density would make the modelled obelisk more difficult to turn upright than the actual Thutmose I. Figure 4 illustrates the moment arm length L about which the weight W acts hence the turning moment Mo is given by equation 5 where Len is the length and W is the weight of the obelisk.

$$\mathbf{Mo} = \mathbf{.5} \text{ Len W Cos } \theta \qquad (5)$$

Table 3 list the turning moments as calculated by equation 5 for various values of the inclination angle However, or very high angles, (i.e. 75 degrees or greater) the turning moment is overstated by equation 5. This is because an increasing fraction of the obelisk mass acts to counter-balance the mass on the other side of the pivot point.

Once the turning moment (Mo) is established, it becomes convenient to calculate the single force (F) required to balance the obelisk weight depending on the location where the force is applied. This force (F) is calculated by dividing the turning moment (Mo) by the turning arm (L) length. Figure 5 show the relationship between the arm length (L), the point of force application (x) and the angle of inclination θ.

Table 4 list the results obtained for the case of single force acting at a point 19-1/6 m from the base of the obelisk. Ideally, the force should be applied, as nearly as possible, perpendicular to the side of the obelisk. In practice, the point of force application would likely have to be lowered as the obelisk rises. This would allow for shorter and more reasonable length beams.

Single serial ram application

The above tables show the order of magnitude of force (600,000 N) required by a mechanical device to upright Thutmose. The serial mechanical ram example Figure 3 described earlier would be capable of about 487,500 N lift with only 15,000 N of input force. Figure 8 illustrates how the serial mechanical ram might be employed to upright the obelisk. The obelisk is shown pivoting on its turning block at an angle of 20 degrees. The rigid beams (A,B,C,D) which make up this serial mechanical ram are shown at an exaggerated starting angle (ϕ=10) for clarity. Likely some initial obelisk angle of perhaps 10 degrees or so could have been achieved through the use of regular lever beams. This is because a number of levers could be operated at the same time given the obelisks near horizontal position. For the postulated obelisk it is seen from Table 4 that a force of 625,033 N would be required to lift the obelisk when it is at 20 degrees. From Table 2 if the mechanical ram were set up with a starting angle (ϕ) of 4 degrees, then a mechanical advantage (MA) of 50.4 could be expected. This means that an input force of (625,033/50.4) or 12,400 N need be applied manually by a group of men pulling on a rope. In this example the beams shown to scale are about 4 m long. The working stroke (WS) may be calculated by using Table 2 and is found to be (4 × 100 × 0.00488) or only about 2 cm.

Multiple serial ram application

When multiple mechanical rams are used in parallel then a substantially longer stroke is possible. For example, if four mechanical rams replaced the single ram then each ram would require a mechanical advantage (MA) of one fourth of that of the single ram. In this case that would be a mechanical advantage of 50.4/4 or 12.6. From Table 2 or thru the use of equation 3 the starting angle would now be 8 degrees rather than the original 4 degree starting angle for the single ram. From Table 2 the new working stroke (WS) for the unit beam is found to be 0.01946. Therefore the working stroke for the quad system is (4 × 100 × 0.01946) or about 8 cm. This quad system would require four separate

Theta(degrees)	Turning Moment(Mo)N-m
0	12,748,640
20	11,979,803
40	9,766,025
60	6,374,320
80	2,213,778

Table 3: Obelisk turning moments for various inclination angles.

Theta(degrees)	Force (F) N at x = 19-1/6 m
0	665,146
20	625,033
40	509,532
60	332,573
80	115,501

Table 4: Force to lift obelisk at 19-1/6 meters from base.

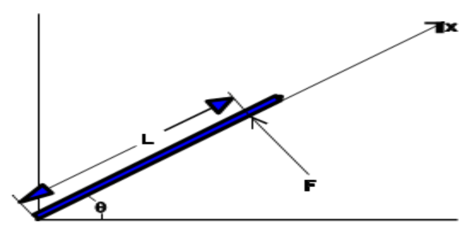

Figure 5: Obelisk lifting force.

Citation: Shiells JE (2015) Mechanical Technique for Raising an Obelisk. J Appl Mech Eng 4: 174. doi:10.4172/2168-9873.1000174

applications of the 12,400 N force. The width of Thutmose would easily accommodate such a quad system of parallel serial rams.

Finite Element (FE) Simulation

One of the rams in the quad system is examined with the finite element program ADINA in order to check the above theory. The purpose of the FE analysis is not only to verify the predicted force against the obelisk but also to assess the stress on the beam. In the FE simulation it was assumed that cedar beams make up the mechanical ram. This is because in Arnold [5] it was stated that cedar beams were used to prop up a wall in a pyramid during ancient construction. The mechanical properties of yellow cedar (12% moisture) were taken from ref. 8. In Figure 8 beam A (like beam B) is overwhelmingly subjected to the most stress when lifting the obelisk. The FE analysis was therefore directed to beam A. Figure 6, shows (not scaled for clarity) the physical configuration for the analysis of beam A. The load is one half of the input force (12400 N) times the mechanical advantage of the first mechanical ram (C/D). This works out to be $(0.5\times12400\times\sqrt{12.6})$ or 22010 N. The cedar beam has a square cross-section of 30×30 cm and is 4 m long. The boundary conditions are the same that were assumed for Figure 1.

In the earlier development of the ram equations, it was assumed that rigid beams connected the contact points. The red line in Figure 6 represents such a one dimensional beam between the peak pressure points. The configuration was designed so that the angle of this equivalent beam was 8 degrees above the horizon, although the cedar beam is only 4 degrees.

FE Simulation Results

The color coded stress results of the FE simulation are shown in Figure 7a. This confirms that the maximum contact force (color light green) occurs as indicated by the red arrow heads in Figure 6. It also shows that the cedar beam is not at all over stressed. The maximum stress is listed as 8,375 kPa while the maximum compression limit for cedar is more than 5 times greater at 43,500 kPa.

The FE program also provided the nodal contact forces between the end of the cedar beam and the obelisk surface i.e.CS1. Figure 7b is a listing of these nodal forces which resulted from the 22010N load. The non-zero nodal forces were, as expected, on the lower face of the beam end as depicted by the red arrow head in Figure 6. The sum of these nodal forces added up to 15.4 E04 N. The mechanical advantage (MA) readily follows by dividing this force by twice the input load of 22010 N. This value of 3.49 compares favorably with Table 1 (phi=8), which predicted 3.55 based on the elementary vector analysis (Figure 7c).

Conclusion

In conclusion, it has been demonstrated through the use of vector analysis and computer simulation how the ancients may have brought to bear the tremendous force necessary to upright the 130,000 kg obelisk. The technique outlined in this paper required only a direct force of approximately 12,400 N. Figure 8 shows the basic serial ram set-up although the required "follower" beam which locks each elemental increase in elevation of the obelisk is not shown. An advantage of this

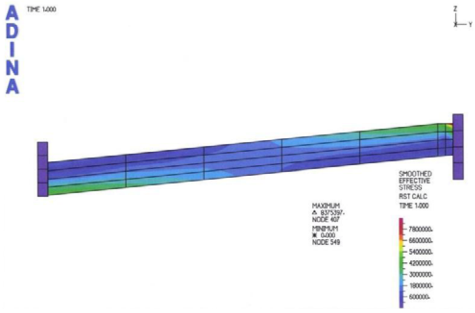

Figure 7a: AFE results for beam A.

ADINA: AUI version 8.8.1, 1 April 2013: SOLID-RAM-101 yellow cedar
Licensed from ADINA R&D, Inc.
Finite element program ADINA, response range type load-step:
Listing for zone CS1:

POINT	CONTACT_FORCE-Y
Node 6	0.00000E+00
Node 12	0.00000E+00
Node 18	0.00000E+00
Node 24	0.00000E+00
Node 30	0.00000E+00
Node 36	0.00000E+00
Node 42	0.00000E+00
Node 48	0.00000E+00
Node 54	0.00000E+00
Node 60	0.00000E+00
Node 66	0.00000E+00
Node 72	0.00000E+00
Node 78	1.49403E+03
Node 84	2.98805E+03
Node 90	2.98805E+03
Node 96	1.49403E+03
Node 102	1.85176E+03
Node 108	3.70351E+03
Node 114	3.70351E+03
Node 120	1.85176E+03
Node 236	0.00000E+00
Node 237	0.00000E+00
Node 238	0.00000E+00
Node 254	0.00000E+00
Node 255	0.00000E+00
Node 256	0.00000E+00
Node 272	0.00000E+00
Node 273	0.00000E+00
Node 274	0.00000E+00
Node 290	5.97611E+03
Node 291	5.97611E+03
Node 292	5.97611E+03
Node 308	7.40703E+03
Node 309	7.40703E+03
Node 310	7.40703E+03
Node 331	0.00000E+00
Node 332	0.00000E+00
Node 333	1.52244E+03
Node 334	3.66903E+03
Node 355	0.00000E+00
Node 356	0.00000E+00
Node 357	3.04489E+03
Node 358	7.33806E+03
Node 379	0.00000E+00
Node 380	0.00000E+00
Node 381	3.04489E+03
Node 382	7.33806E+03
Node 403	0.00000E+00
Node 404	0.00000E+00
Node 405	1.52244E+03
Node 406	3.66903E+03
Node 622	0.00000E+00
Node 623	0.00000E+00
Node 624	0.00000E+00
Node 625	0.00000E+00
Node 626	0.00000E+00
Node 627	0.00000E+00
Node 628	6.08977E+03
Node 629	6.08977E+03
Node 630	6.08977E+03
Node 631	1.46761E+04
Node 632	1.46761E+04
Node 633	1.46761E+04

Figure 7b: ADINA (R) FE output; **R:** ADINA is a registered trademark of K.J. Bathe/Adina R & D Inc.

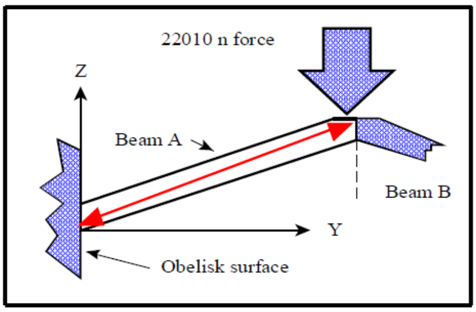

Figure 6: FE problem set-up.

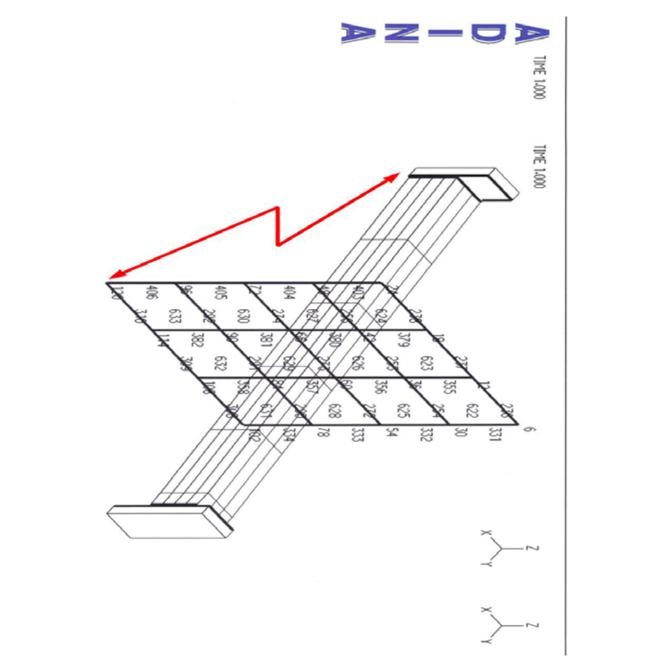

Figure 7c: FE Contact Surface (CS1) Node Identification.

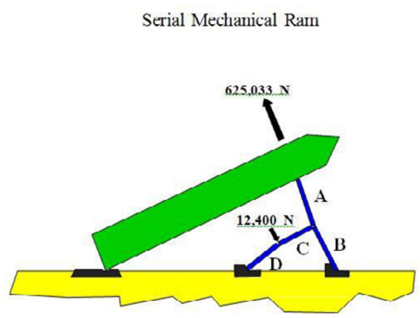

Figure 8: Serial ram set-up for raising the obelisk.

slow gradual procedure is that it allows time for care that the obelisk does not flip to either side during erection. When the obelisk is nearly upright, a team controlling ropes Cort [7] attached to the top has proven effective in the final stage of the ascent. The technique outlined in this paper may also have been used by the ancients to move massive building blocks. While this technique required incredible patience, this task would pale by comparison to the job of shaping the obelisk from solid granite with only primitive tools.

References

1. Bathe K (2006) Finite Element Procedures, Prentice Hall, New Jersy.
2. Barnes M (1997) Secrets of Lost Empires: Obelisks VGBH Video, Boston.
3. Englebach R, George HD (1923) Problem of the Obelisks. NewYork.
4. Chevrier H (1952) Note on Lerection of Obelisks. Annals of the Department of Antiquities, Kairo.
5. Arnold D (2003) Encyclopaedia of Ancient Egyptian Architecture, Tauris, London.
6. Wirsching (2007) Obelisks transporting and erecting in Egypt and in Rome. Production and Publishing, Norderstedt.
7. Cort J. Secrets of Lost Empires II: Pharaoh's Obelisk, VGBH Video, Boston.
8. Green D,Winandy J, Kretschmann D (2007) The Encyclopedia of Wood Skyhorse Publishing Inc New York NY: 4-7.