Traslado del barco solar del faraón Keops de 4.600 años de antigüedad en el Cairo – Egipto

4.600 years old ancient pharaoh Khufu's solar boat transfer at Cairo - Egypt

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RESUMEN

Durante la construcción del nuevo Gran Museo Egipcio (GEM) de El Cairo - Egipto, el traslado de elementos antiguos planteó desafíos importantes. Una de las tareas más importantes fue trasladar el Barco Solar de Keops, el barco funerario del faraón de 2.500 años de antigüedad, descubierto y reensamblado en 1954 a partir de 1.224 piezas de cedro. Sarens fue el encargado de extraer el barco del museo donde se encontraba al pie de la Gran Pirámide, transportarlo diez kilómetros e instalarlo en su nueva ubicación dentro del GEM.

ABSTRACT

During the construction of the new Grand Egyptian Museum in Cairo (GEM) – Egypt, moving ancient artifacts posed significant challenges. One major task was transferring the Solar Boat of Khufu, the 2,500-year-old funerary boat of the pharaoh, discovered and reassembled from 1,224 cedar elements in 1954. Sarens was tasked with extracting the boat from its museum at the foot of the Great Pyramid, transporting it ten kilometers, and installing it in its new location at the GEM.

PALABRAS CLAVE: Ingeniería y sociedad, SPMT equipos de transporte modulares, grúa cadenas 800t.
KEYWORDS: Engineering & society, transport, Self Propelled Modular Trailer, 800t crawler crane.

1. Introduction

Sarens was engaged by the joint venture responsible for the construction of the Grand Egyptian Museum (GEM), which comprises the Belgian company Besix and the Egyptian company Orascom. The task involved extracting, transporting, and installing the solar boat at its new dedicated museum within the GEM. The primary objective of this delicate operation was to ensure the boat's protection from any potential damage, including fluctuations in temperature and humidity levels, as well as forces from inclinations, acceleration, or deceleration during the process.

The joint venture assumed responsibility for designing, constructing, and installing the protective boat sarcophagus. This sarcophagus included a system to regulate both temperature and humidity levels as well as an internal support structure.

In addition to these rather specific technical constraints, a key critical piece of data

was missing to define the means of transport and lifting weight. No weight information was available on the artifact and the design of the sarcophagus had not yet begun.

Sarens focus was then to find the best technical solution to perform the following three operations under strict constraints without weight information:

- Extraction from the current museum
- Transport to the GEM (see Figure 1).
- Installation in the new building.

Date for the transport operation was already fixed with international media coverage for the operation meaning sarcophagus design and handling solution were developed at the same time to avoid planning jeopardy.

Figure 1: 10km route up to the GEM

2. Artefact key data

Sarens based its technical approach and studies taking into account the below preliminary information considering that sarcophagus detailed design was not even started:

- Length: approx. 44m
- Width: approx. 6m
- Height: unknown as it was also unknown if the oars would be removed or not
- Weight: unknown – 100t estimated including sarcophagus

Picture 1: Kufu Solar Boat

3. Transfer Operation

3.1 Extraction

The former Solar Boat Museum was situated at the base of the Pyramid of Cheops (see Figure 1), within a specialized facility that maintained a controlled climate.

During the initial phase, two primary solutions were analyzed and proposed. The first solution was an extraction of the sarcophagus through an opening created in the roof of the existing museum. Two potential crane positions were considered (see Figure 2): one at the shortest radius near the base of the pyramid, and the other along the access road to the site. The latter position is intended to minimize ground pressure in areas of significant archaeological interest.

Figure 2: Possible crane locations

The cranes proposed for the two positions were:

- 750t crawler crane type Liebherr LR1750 with 42m main boom and 49m flying job at a radius of 57m
- 1.600t crawler crane type Demag CC8800-1 with 132m main boom at a radius of 107m

This first solution was dismissed primarily due to safety concerns associated with demolishing the roof directly above the sarcophagus, which posed high risks of falling debris and potential damage.

The second proposed solution involved using Self-Propelled Modular Trailers (SPMTs) positioned on a temporary bridge, facilitating the extraction of the structure from the side wall of the museum, which would be demolished beforehand. This approach addressed several issues:

Firstly, by utilizing 15 lines of Kamag K24 SPMTs, a transport capacity of over 500 tons was achieved.

Secondly, it eliminated all activity above the sarcophagus.

Additionally, the extreme maneuverability of the SPMTs provided maximum precision and smoother execution than use of a crawler crane.

Furthermore, ground pressure was controlled and evenly distributed across all axles, not exceeding 10 tons per square meter.

Inside the building, a temporary bridge of 52m long was built below sarcophagus. To ease the installation of the steel structure, a special device was attached to the head of the SPMTs converting it as lifting and installation device (see Figure 3). This enabled Sarens to work in safe conditions, below sarcophagus to erect the full structure.

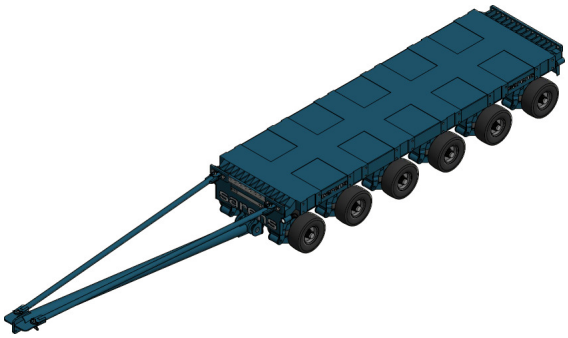


Figure 3: SPMT lifting device

However, this solution presented another challenge: lowering the sarcophagus from a height of approximately 5 meters once it exited the museum to ground level, before commencing transport to the new GEM.

Picture 2: Height difference between solar boat and ground

A lifting tower solution with a jacking system was evaluated but deemed too complex to implement by the client.

It was determined that an access ramp approximately 130 meters in length would be constructed to compensate for the 5-meter

elevation difference. However, utilizing an access ramp instead of a jacking system introduces the issue of the sarcophagus's inclination. The ramp's slope was calculated to be 3 degrees.

The internal hydraulic system of the SPMTs enables adjustment of an inclination by maximizing the stroke of the first line of axles and minimizing the stroke of the last line. However, in a configuration with 15 lines, the hydraulic system could not correct the inclination sufficiently to ensure the sarcophagus remained straight during transport. Extending the access ramp was not feasible due to site constraints and the proximity of other archaeological sites. Likewise, reducing the number of axles to enhance correction was impractical due to stability and rigidity requirements for the sarcophagus during transport.

To address this challenge, we proposed using two sets of SPMTs arranged one atop the other (see Figure 4 and Pictures 3 & 6). This approach effectively increased the inclination correction capacity, allowing us to manage slopes of up to 3 degrees while ensuring the sarcophagus remained perfectly levelled.

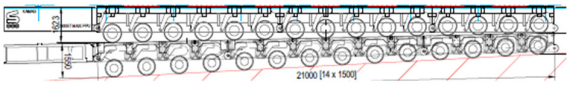


Figure 4: Inclination compensation with SPMT

Picture 3: Inclination compensation with SPMT

3.2 Transport operation

The extraction operation was the most complex aspect of the project. The route from the base of the pyramid to the GEM spanned approximately 10 km (see Figure 1).

After exiting the ramp, we needed to navigate the pyramid complex carefully, avoiding various pyramids and terrain irregularities before reaching the main road.

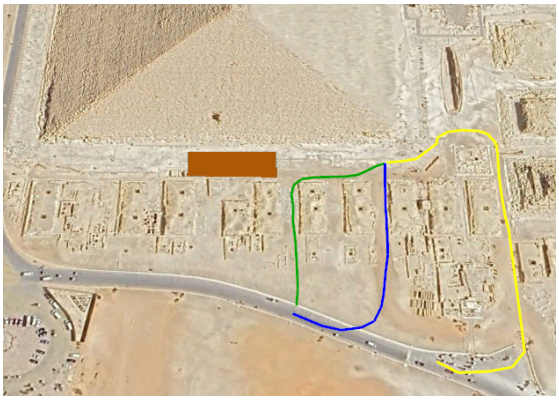


Figure 5: Current location and possible extraction routes in different colors

Prior to the final operation, which was to be held in front of the international press and broadcast live on Egyptian television, a general repetition was conducted using a specially constructed replica with dimensions identical to those of the sarcophagus.

The grand procession through the city streets proceeded smoothly at a speed of 1 km/h, allowing for precise control of

acceleration and deceleration forces and the adjustment of the axles strokes to manage the boat's inclination according to the road's gradients.

Picture 4: Solar boat live inclination monitoring

3.3 Installation operation

The new solar boat museum was under construction when the solar bot was installed. Since the roof was not yet completed, it was decided to carry out this final operation using a crane and lift over the complete sarcophagus to its final location using local available equipment.

An 800-ton capacity crawler crane, the Demag CC4800 with a 90m main boom and maximum superlift, was mobilized from the Sarens Egypt fleet to the new GEM to execute this critical lifting operation. The primary challenge of this operation was the tackle arrangement.

The combined weight of the sarcophagus and the artefact could not exceed the crane's capacity. This implied that the sarcophagus was not strong enough to be lifted using only four lifting points. Consequently, a total of 12 lifting points were necessary, and a special tackle three arrangement was designed for the operation.

In SSL/LSL configuration and 90m boom, the crane offered a capacity of 150t at 56m radius, sufficient to erect in safe condition the solar boat which final weight was 105t.

4. Conclusions

In collaboration with the joint venture, we had only 8 months to establish a preliminary solution, develop detailed engineering for both the sarcophagus and handling means simultaneously, mobilise all the equipment from overseas to the job site and perform the three operations described above.

This project involved significant operational interdependencies in a highly specific environment, with a non-negotiable deadline mandated by the Egyptian authorities.

Several innovative solutions were implemented in conjunction with the client to address the unique specifics of the project.

We would have been pleased to provide additional technical and detailed information; however, the preparation and execution of this iconic operation are bound by a strict non-disclosure agreement.

We take great pride in our involvement in the transfer of this iconic artefact, which will soon be accessible to the public at the new GEM in Cairo.

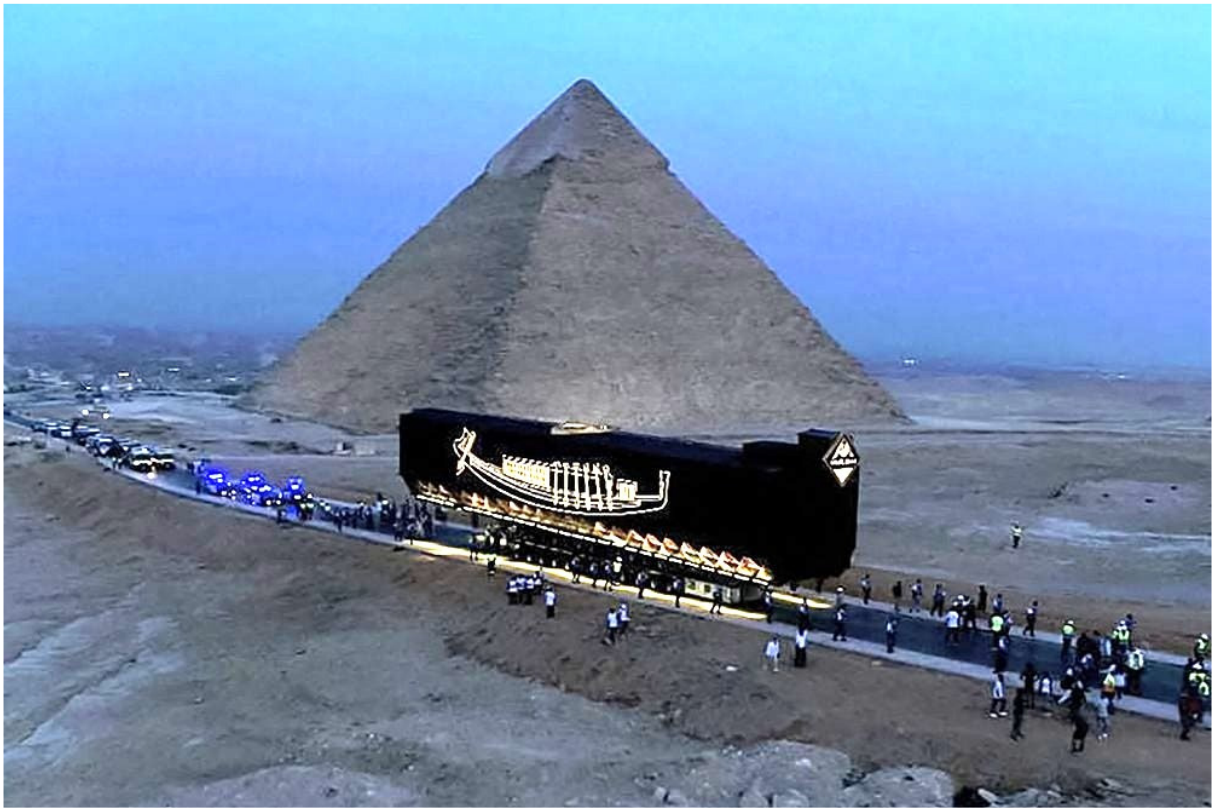
Picture 5: Solar boat wooden support inside sarcophagus

Picture 6: 15 lines of Kamag K24 SPMTs placed on Kamag K25 SPMTs

Picture 7: Installation of temporary bridge under solar boat sarcophagus using SPMTs

Picture 8: Test drive with Solar Boat Sarcophagus replica

Picture 9: Final transport from Pyramids area to GEM



Picture 10: Final transport from Pyramids area to GEM

Picture 11: Lifting operation inside new dedicated museum within GEM complex