*'Atiqot* 92, 2018

# Anastylosis of the Obelisk in the Eastern Circus at Caesarea Maritima[1]

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## Introduction

In the second century CE, a large facility was built for chariot racing in the eastern part of Roman Caesarea. This structure (Greek: hippodrome; Latin: circus) replaced 'Herod's Circus,' which had been built in the southwestern part of the city. In the center of the eastern facility, a fallen obelisk was found along with three conical columns made of red (Aswan) granite. The obelisk was found broken, in three parts (see Porath, this volume: Figs. 4–6, 19, 20). In light of the importance and special nature of the obelisk, it was decided to raise it on its original location.[2]

### *Conservation Committee*

The obelisk is unique in Israel, and raising it was considered a precedent. The Israel Antiquities Authority (IAA) therefore established a consulting committee consisting of experts and public figures to formulate the conservation principles of the project. The committee members included historians, archaeologists, architects, engineers and conservators. They were presented with various alternatives and with the preliminary architectural-engineering aspects of the project and discussed the professional ethics involved in the project's implementation.

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[1] This article is based on the implementation report filed in the IAA archives. The anastylosis project took place between May 2000 and August 2001 and the coating of the base was completed during January–February 2004. The project leader was engineer Yaakov Schaffer; the project director, Yoram Sa'ad; engineering planning and overseeing, engineer Lily Sohanov; architectural planning: architect I. Keidar and Shahar Puni; surveyors: Vadim Essman, Avraham Hajian and A. Levit; assistance in surveying: A. Yamim and P. Mark. Participating in implementation were: Y. Marom; S. Akiva; S. Sabadini; V. Beckman; A. Janakh; H. Abramov; L. Hanukayev; Raleb Abudiab; Jacques Neguer; Y. Kotler; H. Yazayev; T. Woody; A. Mabert; A. Gelber; A. Kuperstein; D. Siboni; L. Matatov; M. Goash. Logistical coordination: M. Deutcher and Z. Ginat. The article was edited by Lori Lender.

[2] Anastylosis was made possible thanks to a generous contribution by the Stoll and Feldman families, with the assistance of Kibbutz Sedot-Yam. Also participating in funding were the Caesarea Development Corporation, the Israel Government Tourist Corporation and the Israel Antiquities Authority.

Fig. 1. The obelisk shaft before it was moved, ahead of anastylosis, looking north.

A landslide majority of the conservation committee approved the anastylosis of the obelisk as proposed by the IAA. The members arrived at the following conclusions:
1) The cultural, conservational and historical value of raising the obelisk in its original location and the possibility of subsequent comprehensive development of the site outweighed considerations supporting leaving it in its current prone and broken state;
2) The obelisk in its current state was exposed to erosion and physical-mechanical damage.
To implement the work, the IAA appointed the Caesarea conservation team at that time, headed by conservator Y. Sa‘ad and engineer L. Sohanov.

## THE MONUMENT AND ITS CONSERVATION

The anastylosis project began with an archaeological probe led by Y. Porath in the area of the fallen obelisk (Porath 2003:34–35; this volume). The IAA excavation continued and expanded the excavation conducted at the site by the Joint Expedition to Caesarea Maritima (Humphrey 1986:477–491). The probe revealed that the obelisk had originally been installed on a foundation approximately at the center of the arena, atop the *spina*. The foundation was made of rubble (*debesh*) bonded with lime-based mortar that was thickened in the area that bore the obelisk. Northeast of the fallen obelisk in the arena, a granite block was found, measuring c. 1.2 × 2.2 × 2.2 m. Parallels indicate that obelisks were set upon a large, box-shaped pedestal. Scholars suggested that this granite block was such a pedestal, although this could not be proven. The obelisk fell, or was pulled down, into the arena west of the *spina* (Fig. 1). The findings from the archeological excavation indicate that the shaft of the obelisk remained where it had first fallen, apparently because of its great weight. Signs of sawing detected on the upper side of the fallen obelisk (the eastern side of the obelisk after anastylosis) support this conclusion.

The shaft of the obelisk is square in section, narrowing upward by an average of 2.3 cm per meter along its entire length. The top, called the *pyramidion*, was in the form of a square pyramid whose sides were at nearly 60-degree angles. When the obelisk fell, the shaft broke into two major parts, which remained *in situ*. Later, still in antiquity, the *pryamidion*, which was attached to the upper part, was cut off (see Porath, this volume: Fig. 21).

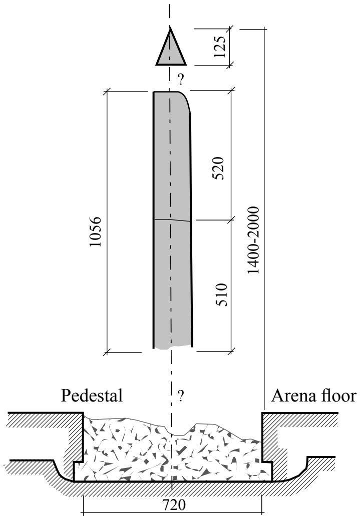


Fig. 2. Diagram of the surviving parts of the obelisk.

The cumulative length of the two parts of the shaft found *in situ* was 10.56 m; the width was 1.71 m at the bottom and 1.47 m at the top. The fracture points of the two parts of the shaft fit together. The third part, with the *pyramidion*, measured 1.49 m high and the width at the bottom was 1.2 m (see Humphrey 1986:486, Fig. 240). Its fracture point did not conform to the fractures of either of the other two pieces. Parts were broken off and missing from both the bottom and top of the obelisk's shaft. The size of the missing parts is unknown, but the length in each case was estimated at no less than 1 m each. The apex of the pyramid is truncated, and the bottom was broken off above the point where it was connected to the shaft of the obelisk. A calculation of the angles of the *pyramidion*'s sides revealed that the length of the missing section between it and the shaft was to be no less than 0.5 m and no more than 10 m long. The total length with the missing parts was estimated as a minimum of c. 12.5 m and a maximum of c. 25 m (Fig. 2). The parts of the obelisk's shaft were weighed by the crane that lifted them; the lower part weighed c. 45 tons and the upper part, c. 36 tons. With the addition of the *pyramidion* and the missing segments, the total weight of the obelisk was estimated at c. 100 tons.

Slight depressions and protrusions were found on the sides of the obelisk. The sides are slightly convex and the lines undulate at the corners formed by the shaft. A slight deformation was also found in the long axis of the shaft. Signs of sawing and carving were found on the upward-facing side of the fallen obelisk and on one edge of the *pyramidion*.

*Proposal for Reconstruction—Architectural Planning*

The principles for the final appearance of the obelisk and its immediate surroundings were offered by the architectural plan. The plan called for a reconstruction of the foundation (the *spina*), followed by a pedestal and a base (the latter with measurements similar to the granite base found at the site), above which the shaft would be raised. The bottom of the obelisk's shaft would be minimally reconstructed to straighten its faces. The two broken parts of the shaft would be reattached, and the missing part between the top of the upper segment of the shaft and the *pyramidion* would be reconstructed to the minimum extent required so the shaft could be properly attached to the *pyramidion*. The base and the reconstructed parts of the obelisk would be coated with a material resembling granite but in a way that would allow the reconstruction to be easily differentiated from the original.

*Engineering Program*

The size and state of preservation of the obelisk presented a dual challenge in terms of the engineering program. On the one hand, the need to ensure its stability after anastylosis meant significant intervention in the original materials. On the other hand, the precedent-setting nature of the work and the desire to adhere to the principles of conservation led us repeatedly to seek solutions as we proceeded that would meet the conservation and construction requirements. The use of existing technologies would have abbreviated the process but the costs would have exceeded the project's budget.

We planned all the engineering aspects in detail, such as special support constructions and calculations of weight, earthquake resistance, winds and vertical load. The program also included the development of complex methods of measurement and calculation of the suitability of materials (adhesives, metals, cements, materials to be injected, etc.)

The assembly process included numerous variables, mostly of an engineering nature. Some of the variables were known from the outset, while others emerged only as we progressed. We therefore could not plan a solution to every problem in advance, although the principles had been determined ahead of time. Additional difficulties arose when we realized that no Israeli standard existed for construction in bodies of stone, and because of the unusual schematics of the obelisk, we had to develop our own methods as we worked.

*Implementation*

The first stage involved studying methods of assembling the parts of the obelisk in order to decide which method was preferable. Two possible alternatives emerged, each of which dictated a different implementation:

1) Assembly on the ground with the obelisk prone and raising it as a single block;
2) Assembly in stages—raising the lower segment, then placing the second segment on top.

The lack of symmetry of the shaft, its weight and other factors led to doubt as to whether we could ensure a precise fit of the pieces in a prone position. Moreover, the state of preservation of the segments led us to realize the complexities involved in that method. We therefore opted for the second method, which left us control over most of the stages of implementation, including the possibility of making changes and corrections as we worked. The pieces were moved to a work area near the fallen obelisk and placed on concrete blocks.

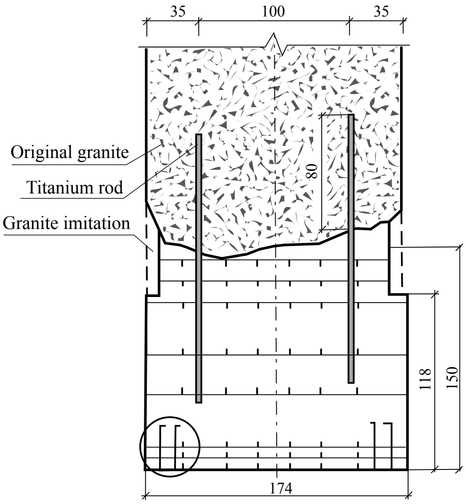


Fig. 3. Details of the reinforcement of the reconstructed lower segment.

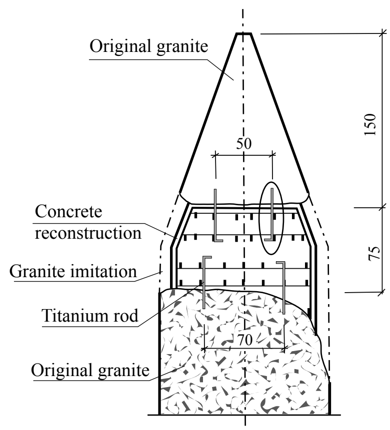


Fig. 4. Details of the reinforcement of the reconstructed upper segment.

*Measuring, Marking and Drilling*

During the planning phase, we decided to reconstruct the missing parts of the obelisk with reinforced concrete. Testing to discover the extent to which the reinforced concrete would adhere to the granite revealed that it adhered poorly due to the crystalline structure of the granite. It was then decided to insert titanium rods (which are rust-resistant) between the two segments of the obelisk's shaft, between the bottom segment of the obelisk's shaft and the pedestal (Fig. 3), and between the top segment and the *pryamidion* (Fig. 4). After consultation with experts, we decided that special nylon fibers would be added to the reinforced concrete to prevent cracking and contraction.

Precise measurements were needed to determine the location and angle of drilling the holes for the rods. Distortions and irregularities in the shaft meant that we could not take these measurements accurately in the usual way. However, a simple cord provided the solution. We divided the width of each face of each section into two equal parts at a number of points (the underside, which had been raised on concrete blocks, was inaccessible.) We then extended the cord along these midpoints to determine the central axis of the shaft.

The drilling of the holes for the titanium rods that would connect the reconstructed portions of the shaft did not require particular precision. However, the drilling on the sides of the central fracture point between the two segments had to be done very accurately so the location, angle and axis of the hole drilled on one face of the fracture would be identical to the one drilled on the other side. A special mount for the drill was built for this purpose, consisting of a square metal frame with a metal plate, to which a tabletop drill was attached. The plate was designed to move along straight lines, both vertical and horizontal, within the frame.

This equipment obviated the need to take measurements each time a hole was drilled. After the location of the first drilling spot was determined, the plate was moved a calculated distance to the next point where a hole was to be drilled. The frame was supported and stabilized by L-beams attached to its corners. The depth of drilling at the bottom of the shaft of the obelisk was c. 0.8 m, at the top, c. 0.3 m, and at the base of the *pyramidion*—c. 0.15 m.

We found that we were able to drill the first 10 cm into the granite with relative ease; however, subsequent drilling was much more difficult and slower. The initial ease of drilling might have been due to erosion of the surface over the years.

The manufacturer's instructions called for special treatment of the titanium rods to ensure better adhesion. First, their ends were sandblasted to remove fatty or other organic material. They were then immersed in complex chemical solutions for specified periods of time.

Before selecting an adhesive, the technical specifications of several leading products were tested. The main criterion was that the ability of the adhesive to withstand the passage of time. The secondary criterion was the adhesive's strength, considering that although most types of epoxy adhesives are stronger than the shear strength of the granite, they tend to 'age' quickly. No standards were found for the strength of adhesive to be used both for granite and titanium (two different realms in terms of standards), and therefore, we had to conduct a series of experiments on small models and tests at various laboratories (including at the Technion and a private laboratory at the Isotop firm). Following the tests, a product manufactured by 3M—Scotch Weld Epoxy Adhesive 1838 B/A—was selected. This adhesive can withstand the rigors of the Israeli climate because it uses a polyamide epoxy and bonds titanium to titanium well. It is also used by the Israel Aircraft Industry and the aerospace industry.

After drilling was completed, the boreholes were cleaned and the adhesive was injected, followed by the titanium rods. A pre-calculated space of 1.5 cm was left between the end of the rod and the end of the borehole to allow for the differential thermal expansion of the titanium and the granite. The rods intended to connect the two parts of the obelisk's shaft were then inserted into the bottom of the upper part.

*Casting the Foundation and the Pedestal*

The obelisk's original foundation was made of *debesh* and lime-based mortar, as noted, and was found in poor condition and incomplete. To rebuild the foundation, a hollow was dug in the center of the original pedestal measuring c. 2 × 4 × 4 m. The sides were coated with modern lime mortar to insulate it from the concrete. The casting of the foundation contains 35 cu m of B200 concrete. After the concrete hardened, the pedestal, measuring 1.5 × 4.0 × 4.0 m, was cast above it using 27 cu m of B400 concrete. Both sections were reinforced with galvanized steel rods containing nylon fibers to prevent contraction and cracking. A 'vibrating needle' was used to attain maximum distribution of the concrete components in the space. Two channels were left in the center of the upper surface of the pedestal between stainless steel plates (below) so that the bands to be used in raising the obelisk could be removed.

Fig. 5. The connection point of the pryamidion to the upper part of the shaft.

*The Lower Part: Casting the Reconstructed Portion*

To ensure the stability of the obelisk it was decided to cast the reconstructed missing bottom part of the shaft as part of the pedestal. After the lower segment of the obelisk was placed on the pedestal, the plan was to create a casing resembling the original base, around the reconstructed parts. This would hold the pedestal in place and ‘cup’ the obelisk.

To solve the problem of vertically adjusting the lower segment of the obelisk after it was raised, plates of stainless steel, a material chosen because of its rust resistance, were inserted in the corners of the cast reconstruction of the lower part of the obelisk. After the obelisk was raised, the stainless steel plate in the lower part would come to rest over a parallel plate on the pedestal. The idea was to allow additional plates to be inserted between the two plates at whatever thickness was required to attain verticality.

*The Upper Part: Casting of Reconstruction*

The *pyramidion* and the upper part of the obelisk were to be connected by casting a reconstruction of the missing part (Fig. 5). This required a decision, the result of which could only be appraised after the obelisk was standing and the scaffolding and other constructions removed. The first question was how to ensure that the face of the *pyramidion* and the face of the top segment of the shaft of the obelisk were in the same positions as they were originally, before they were cut apart in antiquity. The issue was resolved when we discovered a saw mark at the edge of one of the faces of the *pyramidion*. The saw mark was on the side facing upward and therefore would have been made after the obelisk fell. Thus, we could tell which face of the *pyramidion* was the upper, i.e., the eastern, side before the obelisk’s fall.

In light of the lack of symmetry between the shaft of the *pyramidion* and its irregularly broken edges, it was difficult to ensure its precise placement in terms of angles and axes. We based our calculations on the same method we used to determine the middle of the long axis of the obelisk's shaft. We adjusted the segments in keeping with the horizontal joining of the axes of the pyramidion to the axes of the shaft. The *pyramidion* was placed c. 0.7 m from the end of the edge of the upper segment of the shaft—after checking to see whether it would fit together smoothly to avoid creating a step when connecting the *pyramidion* to the upper segment. In the space between the *pyramidion* and the upper segment, a form was created that would conform to the meeting point between the sides of the *pyramidion* and the obelisk's shaft. The reconstruction was then cast using B400 cement, and reinforced with stainless steel rods. The reconstruction was cast a few centimeters shy of the real outlines to leave space for coating at the end of the process. To prevent galvanic corrosion that could result from contact between the two types of metal (titanium and stainless steel) in the reconstruction, the rods were insulated with two layers of nylon.

At the end of the preparatory phase, when the parts of the obelisk were ready for assembly, they weighed a total of c. 98 tons, consisting of the original bottom segment of the shaft (45 tons), the reconstructed portion of the bottom segment (minimum 11 tons), the original top segment of the shaft (36 tons), the reconstructed portion of the top segment (minimum 3.8 tons) and the original *pyramidion* (1.8 tons).

*Temporary Stabilizing Supports*

The concrete's inability to bond with the granite led to concern that pressure exerted during the lifting of the obelisk might cause the reconstructed concrete elements to detach from the granite. To prevent this, a number of steps were taken. The two segments of the obelisk were 'embraced' with temporary stabilizing supports consisting of steel L-beams laid on the corners of the segments, and metal bars were welded to the L-beams. To prevent movement of the components of the stabilizing supports, they were 'locked' to the reconstructed concrete by means of anchors. To improve the hold of the supports on the shaft of the obelisk, cement grout was injected between the L-beams and the reconstructed sections. Wooden pegs were also inserted between the granite and the L-beams. In addition, a temporary concrete and stone stabilizing support was created on which the center of gravity of the concrete reconstructions would rest. Piles of sand were prepared at the lower end of the two segments to reduce friction and the risk that the obelisk would shatter when raised (Fig. 6).

*Raising of the Bottom Segment and Casting of the Concrete Base*

To raise the segments of the obelisk, a special steel carrying frame was constructed that when raised would bear the weight and size of the obelisk shaft. The frame (Figs. 6–8)[3] which was square, was placed on the obelisk from the side, while it was still prone. The

[3] Planned by the Kaban firm.

Fig. 6. The support for the bond between the granite and concrete before lifting.

Fig. 7. The lower segment of the shaft, ready for anastylosis; note the cord along the central horizontal axis of the side of the shaft.

frame was placed around the center of gravity of the granite part of the segment. Three of its sides were welded together, and the fourth side was connected with bolts.

The day the bottom segment of the obelisk was raised (December 5, 2000) the carrying frame was attached to it, along with iron chains from one side of the shaft to the other and around the bottom. The chains were tightened and the links were counted to ensure an equal number of links on all sides, which, if equal after raising, would mean that the shaft

Fig. 8. The lower part of the shaft, in place.

was standing vertically. The cables of the crane[4] were attached to the carrying frame. We were very concerned about matters that could go wrong during the raising of the obelisk, but ultimately, the task went well. The lower segment was placed on the stainless steel plates of the pedestal. We used the mid-point axis markings of the faces of the obelisk (Fig. 7) to determine the verticality of the shaft by means of two theodolites that were placed 10 m east and 10 m north of the pedestal. We then calibrated the theodolites again to the mid-point axes on the pedestal (which we had already marked, copied from the shaft of the obelisk). Based on the readings, we then corrected the vertical axis by inserting additional stainless steel plates of various sizes.

The last measurement of the axis in relation to the absolute vertical plane showed that north–south calibration had been precisely achieved, and that on the east–west axis, a small eastward deviation remained at the top of the bottom segment (c. 12 mm). However, in consultation with the crane operators and expert bridge-builders assisting us on site, and in view of the lack of symmetry of the shaft of the obelisk, we decided to forego further adjustment (Fig. 8).

After the lower segment was in place, the temporary stabilizing supports were dismantled. The space that was left between the lower segment and the pedestal was filled with cement grout, and subsequently, a casing consisting of B400 concrete and measuring 1.20 × 2.26 × 2.26 m was created around the bottom segment to reconstruct the bottom portion of the shaft (Fig. 9). The concrete was reinforced with stainless steel rods. Scaffolding was then constructed surrounding the now-standing bottom portion of the shaft, to a height of 9 m.

*Preparation for Raising the Upper Segment*

The most difficult part of the assembly process was the raising of the upper segment. Various methods were considered and rejected because of budgetary constraints and risk of damage to the obelisk, among other reasons. The optimal solution was to surround the obelisk with temporary stabilizing supports that would avoid additional damage to the original shaft.

[4] A 450-ton crane operated by the Palgor crane company.

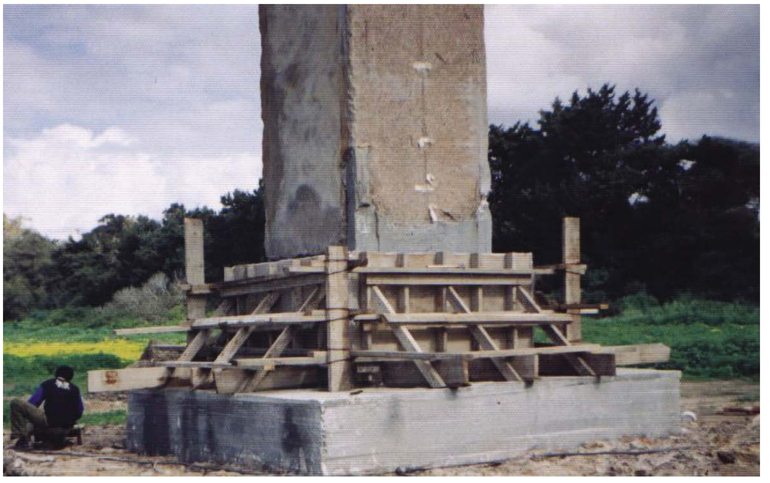

Fig. 9. Casting the casing around the base, looking southwest.

According to our calculations, to raise a body weighing 50 tons, lateral pressure of 100 tons would have to be applied (with a friction coefficient of 0.5). Every detail of the temporary stabilizing supports was planned, including the materials.

At this stage, we had already become aware of the weakness of the outer layer of the granite, and we were concerned that while raising it, that layer would be crushed by the pressure of the temporary stabilizing supports. We consulted on the matter with numerous experts from various fields. One solution we considered was to enclose the upper segment with bands connected to the carrying frame, in the same way we had done with the lower segment, and to place it on the plates affixed to the lower fracture face, filling the space between the bottom fracture line of the upper segment, and the top fracture line of the lower segment with adhesive. To determine where to place those plates, we needed to take exact measurements of the faces of the fracture on both segments. A deviation of one centimeter in affixing one of the plates could mean a deviation of the vertical axis of the obelisk by c. 8 cm at the top. However, the cost of electronic and optical equipment to take measurements of this type exceeded our budget.

Another major problem with which we had to deal was how to ensure that the upper part of the obelisk would be horizontally and vertically level. To avoid the obstacle of having to take precise measurements of the two parts of the fracture, and at the same time to solve the problem of verticality, we considered placing the upper segment of the obelisk on a single, central foundation made of reinforced Elastomer with a diameter of 25 cm. Such a foundation can bear a vertical weight of c. 60 tons and is used in bridge construction. Placing it at the center of the fracture face—at the center of gravity—would allow us to correct the verticality using minimal horizontal force. This solution did not require the faces of the fractures on the two segments to be tested for the precision of their fit.

As a solution for the horizontal level, a steel frame was devised to be installed at the top of the bottom segment, into which the upper part would be lowered. The force to level it horizontally would be exerted by means of bolts at a point 1.5 m above the fracture. During this process, the upper segment of the obelisk would remain suspended from the crane, and we would not release the bands attaching the upper part to the crane before we had ensured that the upper segment was stable.

To stabilize that segment after it was determined to be horizontally level, we sought a suitable material that would harden very quickly, have high pressure strength and be simple to apply. This material we found was cement rock,[5] which is easily applied and hardens within two or three hours after preparation. We had intended to inject the material into the area around the fracture (except for the places where the lifting bands were inserted), to create a form. The cement and the steel frame were to have held the upper segment in a vertical position, still suspended from the crane. The plan was that after the bands of the crane were released, and the cement rock was also applied to the spaces where the bands had been, grout epoxy would be injected to adhere the two parts. After the grout hardened, the cement would be removed and another layer of grout would be added.

After repeated testing, the idea of using a central support was abandoned because of concern that the flexibility of the steel beams of the horizontal leveling frame and the flexibility of the suspension system would not maintain the upper segment firmly in position for the amount of time it would take for the cement to harden. The horizontal leveling frame was therefore used only to ‘lead’ the upper segment into the proper position prior to attaching it to the lower segment.

We therefore returned to the idea of creating a number of support plates. To calculate the required height for these support plates, we once again had to determine the extent to which the fractured faces of the two parts fit together. In the area of the fracture, the cross-section of the obelisk measured c. 1.6 × 1.6 m. The incline of the fracture was c. 0.4 m from the highest to the lowest point and its face was irregular. The height of each support plate would depend on the extent of the mismatch between the two faces of the fracture due to the irregularities and the inclines of the fractures.

We had to measure manually using a wooden frame whose outside measurements were the same as the face of the fracture. The frame was placed on top of the already-standing bottom segment so that the frame’s underside was horizontally level. This side was marked off into a network of 100 squares. The upper face of the lower segment of the obelisk was marked with 100 points that would face the network of squares. The frame was then placed on the bottom of the upper segment (that was still prone at this point), perpendicular to the axis of the shaft. Measurements were then taken of the space between the face of the fracture on the parts of the obelisk, the minimum—where the two faces of the fractures actually did meet—was determined as 0.0. The height of the support plates was calculated

[5] A special product manufactured by the firm of Retard.

Fig. 10. The grooves (channels), sawed into the bottom of the upper part of the shaft and the support plates.

according to the spaces at each point created by the irregularities. We added 1.5 cm to each of these, so we could control the amount of grout epoxy injected to achieve high-quality adhesive strength over the entire face of the fracture.

The places for the supports were marked at parallel points on the two faces of the fracture. The supports consisted of stainless steel plates measuring 2 × 12 × 12 cm. A layer of grout epoxy was inserted below each plate to prevent excessive pressure on any one point. We estimated that when the upper segment was set in place, it would stabilize on three of the four plates, and define a level surface. We therefore placed two support plates along the center of gravity of the upper and lower faces, and two other support plates diagonal to the first ones, across from each other toward the outside of the fracture surface.

*Setting the Upper Segment in Place*

Now that a means had been decided for placing the upper segment on the lower segment, the question remained as to how we would ensure that the silk bands used to lift the upper segment into place would not become caught in the space between the two segments of the obelisk. The shape of the fracture meant we had to leave a space between the two parts in order to pull out the bands after placement. But because the obelisk narrowed toward its top, this space would have created a 'step' between the faces after the bands were removed. Moreover, a large space would reduce the constructive stability of the obelisk and impair the quality of the bonding between the two segments.

We therefore had no choice but to saw grooves (channels) at the bottom of the upper segment at the point where the lifting bands would be inserted (Fig. 10), in order to reduce the protrusion of the bands in the space between the two faces of the fracture. Preparation of the face of the fracture for this phase involved cleaning the stone with sandblasting, removal of oils using chemicals, and determining by examination whether the granite had ‘peeled’ to an extent that would allow good bonding.

To insert the titanium rods (diam. 45 mm), we drilled holes with a diameter of 50 mm to ensure the adhesion of the rods within the holes to a precision within millimeters when putting the upper segment in place. Manual measurement of the fit between the fracture faces was reasonable under the circumstances, but its precision was uncertain. Thus, we had to prepare for a situation in which the rods would not fit into the holes. We were also concerned that due to the small space between the rod and the hole (2.5 mm on each side) we would not be able to correct the verticality of the obelisk as needed. We therefore decided to expand the size of the holes drilled at the top of the lower segment. This decision required us to ensure maximum adhesion between the two segments of the obelisk.

We had anticipated the possibility that the upper segment would not be precisely vertical when first raised, and we estimated that if the pitch was no more than 5–6 cm to one side or the other, we could still lower the upper part into the frame. If the pitch was greater, we had other solutions ready so we could attain the required balance—by adding weights as needed, and by tightening the cables that were attached to the crane.

The same concerns we had over the raising of the lower section applied to the upper segment. But here, additional issues arose. The slightest wind would make placement of the upper section impossible and the rods protruding from the lower segment could break if struck by the upper section while it was suspended from the crane. There was also the question of the safety of the people who would be standing on the scaffolding while assisting in ‘leading’ the upper segment into place. Therefore, it was decided that placement would be postponed in case of wind, and that no one would be on the scaffolding during the lifting of the upper segment.

We raised the upper segment on June 18, 2001. We then measured the long axes to determine the verticality of the shaft, which revealed a pitch of c. 12 cm. A number of attempts were made to correct the situation, which included using weights, stretching the lifting cables and adding or subtracting links to the cable’s suspension system. To make these adjustments, the upper part was laid back on the ground a number of times, but we were unable to significantly reduce the pitch. At that point, we decided to raise the upper segment and attempt to set it in place and adjust it without the use of the weights or the chains (Fig. 11). The upper part of the shaft was lowered into the frame and with the help of wooden wedges placed between the shaft and the frame (Fig. 12), we were able to fit the outer faces of the fracture together. The shaft was stabilized on the three support points, as expected (west, north and south), and the titanium rods were inserted into the drill holes. With the release of 35% of the weight, as had been pre-determined, we stopped lowering the segment to take measurements by means of two theodolites, which were placed in the same positions as during the raising of the lower segment.

Our measurements showed that the shaft of the obelisk tilted c. 40 mm northward and did not tilt east–west. Considering the manual method of measurement and calculation, this preliminary result, before adjustment, was quite reasonable. A space of 5 mm was found on

Fig. 11. Raising the upper portion.

Fig. 12. Horizontal adjustment of the upper part using wooden wedges.

the eastern support point. A calculation was made of the correction necessary, based on a formula we had developed. For the adjustment we added a stainless steel plate 9.5 mm thick to the northern support point, a 10 mm plate at the eastern point and a 5 mm point at the western point. The final measurement showed that the obelisk was precisely vertical (Fig. 13).

*Injection of Adhesive into the Fracture Space, Removal of the Scaffolding and Conservation of the Stone*

The application of the cement rock on the edges of the fracture was accomplished quickly (Fig. 14). We then waited the required three hours before releasing the silk bands. By this time it was afternoon, and so the injection of the adhesive was postponed until the next day. During the night, the upper segment remained suspended from the crane, which supported 65% of its weight. The next morning, after checking that no cracks or crushing had developed in the cement rock, the bands were released. The frame was slipped off from above and the obelisk stood for the first time without support. At this point we completed the sealing of the edges of the fracture with cement rock, at the same time inserting the pipe for injection of the adhesive.

The elements of the fracture dictated technical demands for the adhesive to be injected that could not be met by an off-the-shelf product. The adhesive, Sikador 42,[6] was selected

[6] Manufactured by the Sika firm.

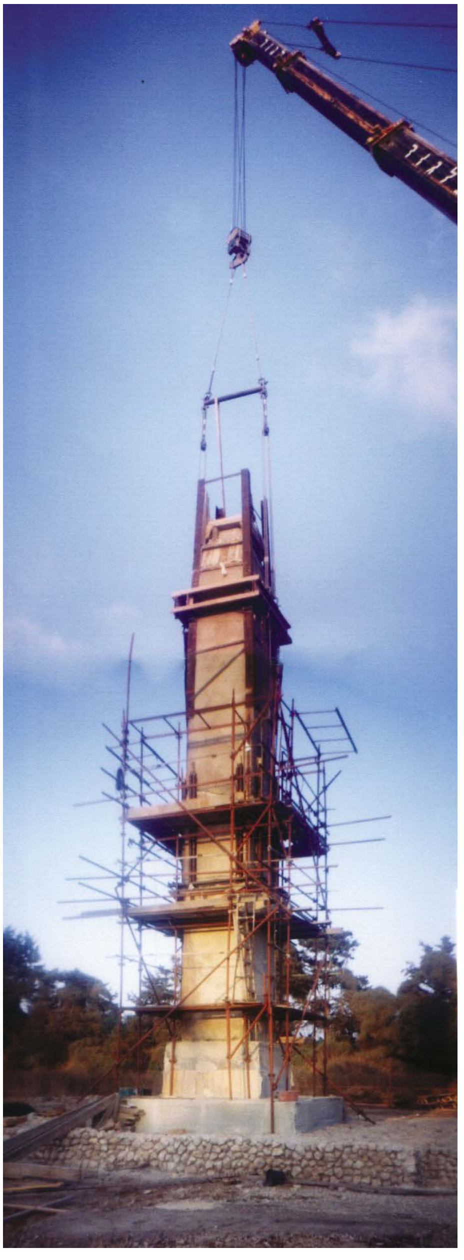

Fig. 13. The upper part of the obelisk in place, still suspended from the crane.

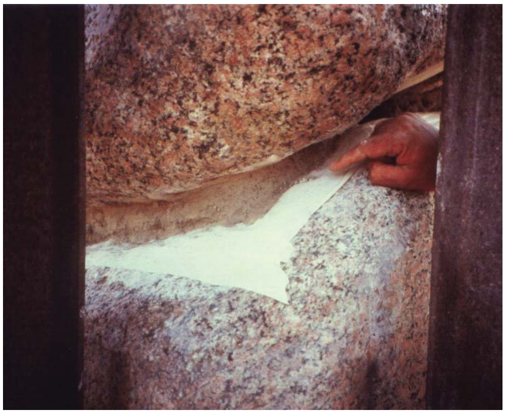

Fig. 14. Applying the cement rock at the edges of the fracture.

Fig. 15. Injecting the adhesive into the fracture space.

after study and testing. Because adhesion had a constructive function, it was important to ensure its quality. Due to the slant of the fracture, we needed an adhesive that could flow without its aggregates sinking and could penetrate narrow spaces (micro-fissures), with suitable elasticity, maximum adhesion to granite and the necessary workability, hardening and proven quality over a span of years.

Various products from a number of manufacturers were examined and testing was carried out on miniature models. All types tested included two components: the resin (liquid or powder) and the hardener (liquid). The large space between the fracture faces required the addition of a filler to the resin to improve workability and the ability to withstand pressure/ pull. After consulting the manufacturer, we added sifted sand and aluminum powder as an aggregate. To ensure that the outcome of our testing on the smaller model was not random, we repeated the test on a larger model, including simulation of the slant and the restrictive conditions pertaining to the obelisk itself (Fig. 15).

The workability of the adhesive selected was short (20–25 minutes). The space had to be filled in a continuous, single attempt so that the adhesive would not harden and obstruct the pipes or the framework. Therefore, the mixing of the materials and their injection into the funnels was done quickly. When the glue emerged through the pipes we used as monitors, we knew that adhesive had spread well inside the space of the fracture. Approximately 320 kg of adhesive were prepared for injection.

We then completed the construction of the scaffolding all the way up to the top (c. 15 m). The layer of cement rock around the edges of the fracture was removed and, after the granite was cleaned to obtain good-quality bonding, additional adhesive was applied to the edges. Conservation work was then carried out on the granite face of the monument, including cleaning off remnants of cement, glue and rust, microbiological cleaning of the cracks, cleaning salt crystals, and strengthening and gluing peeling portions.

*Covering the Cast Portions*

The last stage of anastylosis was to coat the cast reconstructed portions of the shaft. We had planned to cover the base only after the scaffolding was removed. A study of the matter led to two alternatives: (1) covering with prefabricated tiles of granite or granite-like material; or (2) coating with a technique similar to plastering.

The first alternative was rejected after it was realized that the availability and cost of prefabricated granite-like plates was prohibitive. There was also concern over the sensitivity of such plates to the climate and the risk of vandalism. We therefore decided on the second alternative, which involved creating a mixture of materials that would be suitable for application. A number of samples were made to study the components, adhesives and appearance. The mixture selected consisted of crushed granite (maximum aggregate size 4 mm), crushed limestone (same maximum aggregate size) and Acrylic-33 diluted in water. The resulting mixture generally resembles the granite of the obelisk, but nevertheless can be clearly differentiated (Fig. 16). The coating was applied to a thickness a few millimeters shy of the original dimensions of the obelisk's surface. To protect the monument from sandstorms, salt crystals and

Fig. 16. The base after coating.

Fig. 17. The obelisk after anastylosis.

erosion due to environmental or climatic factors, the surface was treated with a material that is water repellent but allows the escape of water vapor. The material, Rhodia H224, was diluted with ethyl alcohol at a ratio of 1:7.

After coating was completed, the supports were removed from around the base, allowing the entire monument to be seen for the first time with no visual obstructions. Only then could we assess the outcome of the entire project. At that point, the project was halted, because unexpected delays during the process had led to the expenditure of the entire budget. Therefore, the coating of the rest of the base and the reconstruction of the *spina* were postponed until early 2004. By February of that year, the work was completed (Fig. 17).

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