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The collapse and proposed restoration of a prehistoric megalithic structure

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Abstract

A recent partial collapse of one of the megalithic temples in Malta, dating back to 3000-3500BC, has presented an opportunity to study the structure of one of these temples in greater detail, in order to evaluate the cause of the collapse, as well as to consider the feasible limits of restoration. Since their discovery and excavation, in the middle of the last century, the limestone temple structures have been exposed to a variety of damaging environmental conditions, which have resulted in an alarming rate of deterioration. The paper summarises the structural characteristics of the temples, and the various factors that have a deleterious effect, particularly those that led to the partial collapse.

1 Introduction

The complex of prehistoric megalithic temples at Mnajdra, in Malta, consists of three distinct temples, referred to as the Upper, Middle and Lower temples, and is located close to the edge of a promontory on the south-west coast of the island, at approximately 85m above sea-level, at a latitude of 35.83^{o}N. Another major temple complex, known as Hagar Qim, lies around 500m east, at approximately 135m above sea-level; other prehistoric remains can be found within a similar distance to the north of the site. This testifies to the special significance that the site must have had for our ancestors.

The remains of the Mnajdra temples were first excavated in 1840 by C.Lenormant[1]; further excavations were carried out in 1910 by Ashby[2], before the site lapsed into obscurity up to the middle of this century. The site was then cleared and restored, and further excavations were carried out between 1952 and 1954, and then again in 1971.[1]
The complex consists of three distinct temple structures, each consisting of a number of characteristic apse-spaces. The remains of the oldest of these

structures, referred to as the Upper Temple and dated from the so-called Ggantija phase, 3600-3000BC[3], suggest a trefoil plan. The other two structures have more sophisticated forms, basically two pairs of main apses and a rear niche. The Lower Temple has been dated from the Ggantija phase, with modifications carried out during the Tarxien phase (3000-2500 BC); the Middle Temple is considered as pertaining to the Tarxien phase.

The site of the temples is situated close to the Maghlaq fault system[4], a series of north-westerly faults, the main one of which has a downthrow of about 230m. The area around Hagar Qim consists of Lower Globigerina limestone, the lowest of a Miocene sedimentary deposit essentially of debris from the shells of pelagic globigerinae. Down the hill towards Mnajdra, the outcropping rock changes to Lower Coralline limestone, a harder, more durable and more crystalline sedimentary stone, followed by a further outcrop of Lower Globigerina limestone, and, further down, another outcrop of Lower Coralline limestone, which constitutes the base of the Mnajdra temple complex. The north-westerly faulting increases to the south-west of the latter site, so that a steep cliff occurs at about 50m away, and an Upper Coralline limestone formation outcrops at the foot, close to the sea..

2 Structure

The main temples at Mnajdra have a four-apse plan, and a typical construction system. The internal perimeter of each apse is formed by a series of close-fitting upright blocks, having the approximate dimensions, in the Middle Temple, of 1200mm height, 900mm width and 200-250mm thickness. These blocks are topped by courses of horizontal blocks, approximately 350mm square in cross-section, and between 1500 and 2000mm long. In the Middle and Lower Temples, these courses of blocks corbel inwards, and suggest the beginnings of a domical structure, that may have been roofed over by other stone slabs[5], or by timber sections. The stability of these blocks was ensured by the inherent stability of ring compression structures, and was further guaranteed by the weight of the soil and rubble contained between this inner ring and an outer ring of megaliths, this time of Coralline limestone.

The current configuration of the outer perimeter of these temples is obviously the result of an extensive amount of speculative reconstruction, carried out in the first half of the century. This can be ascertained by comparing the plan and section drawn after the first excavations of 1910, and those made in 1971. The older parts of the temples, to the south, show the alternating radial and tangential massive blocks, that are also more clearly apparent in the convex parts of the external walls of the Ggantija temple complex in Gozo[6]. The construction of the outer north wall also shows the same system, albeit in more restrained form. This is partly visible in Plate 1, and clearly in Fig.1.

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Plate 1. Aerial view of the Middle Temple, Mnajdra - National Museum Archives

The stability of the structural system depends on the masonry ring in compression. The lower part of the inner wall, composed of upright panels, with a probable slight inclination inwards, locks into place as a result of the consolidation obtained by the weight of the surrounding fill. The separate layers of the overlying corbels would each be stable as long as they formed complete circular rings. The slight tendency to overturn inwards, particularly when loaded by the presumed roof structure, would serve to enhance the circumferential compressive stress that assures the stability of the ring. The plan configurations of the temple complexes do not, in fact, contain complete rings, but are based on a module of a pair of apses, on either side of the ceremonial axes. The stability of the separate parts of the ring is guaranteed by the solidity and the detailing of the masonry forming each passage between a pair of apses and another. In general, this passage is framed by two massive upright blocks, oriented with their flat "receiving" plane perpendicular to the first of the uprights forming the apse; with the lower ends slotted into appropriate depressions in a monolithic threshold, and the upper ends held in place by the massive lintel spanning between them. The passageway is thus a reinforced box against which it is possible to abut the circumferential forces from the inclined uprights, and corbelling horizontals, that form each apse. Moreover, the very pressure of the adjacent apses on to this opening would have acted as a form of pre-compression on the stone lintel, such that the limitations imposed by the low tensile strength of the material would be, to a certain extent, alleviated.

The soil infill that helps to stabilise the internal wall obviously needs to be contained by the external skin. The construction of this external wall is a succession of radial and tangential megaliths, conceived to ensure its stability against the outward pressure of the soil infill. Tampone [6,7] has led a study of the temple complexes of Hagar Qim and Ggantija, and, on the evidence collected, has identified an "entasis" in the main uprights such that the tangential blocks wedge tightly into the ring by virtue of their own weight. This wedging effect probably occurs in a vertical plane as well as in a horizontal one. The outer perimeter would thus have had sufficient solidity to withstand the outward pressures of the contained soil, and to guarantee the stability of the inner spaces.

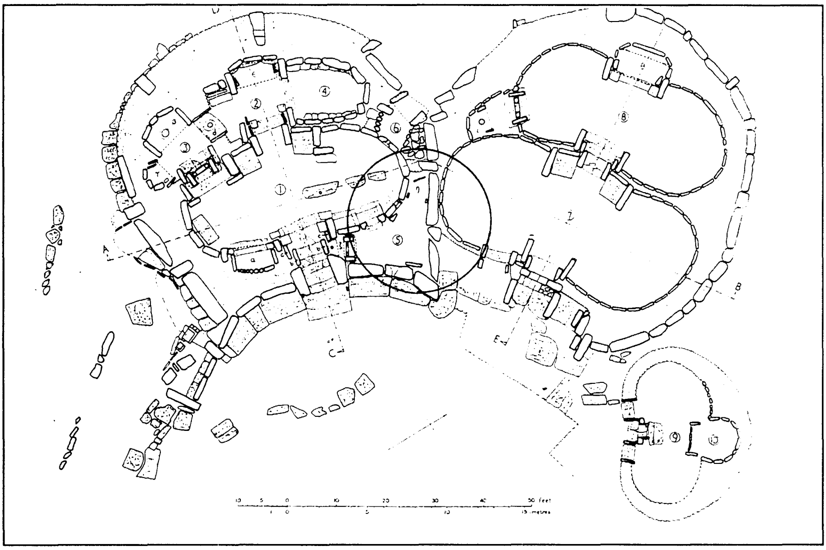

Fig. 1. Plan of the Mnajdra Temples- Evans[1]

3 Collapse

During the night of the 4 April 1995, part of the wall between the Middle and Lower Temple, collapsed. The direct cause of the collapse was attributed to the storm that occurred during the night, however it can also be seen that other factors, particularly the changes in structural configuration that had occurred as a result of the normal weathering mechanisms, as well as, what appear to be defects in the construction of the original temple, have to be considered.

The weather station at the University of Malta records that the peak rain intensity during the storm was reached at about 22.00 on the night of the 4 April. Seventy-one millimetres of rain fell over a period of eight hours, with over half of this occurring during the last two hours. A further 11mm of rain

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fell over the next three days. The average wind speed recorded at the same location for the 4 April was 8.01 m/s, from a direction 38° E of N, although, during the late afternoon and the evening, the average wind speed was closer to 11.5 m/s. The peak wind speed recorded was 19.81 m/s, at approximately 20.00. Strong winds, of a daily average between 7.3 and 4.6 m/s, from a generally north direction, persisted over the next three days.

The conditions at Mnajdra are not recorded. The site is obviously more exposed, and it is possible that the volume of rain that fell on the site was even higher. On the other hand, the site is located to the south, and to the bottom, of a relatively steep slope, so that wind conditions may have been less exposed. The wind speeds recorded, although strong, are not exceptional. Peak gusts of at least twice the 4 April peak, have been recorded at Luqa, over the past fifty years. The maximum sideways force exerted by the peak wind speed, assuming all the worst conditions, could not have been greater than 0.75 kN, which is unlikely to have sufficed to overturn the top boulder.

On the other hand, the exceptional intensity of rain, coupled with a particular water drainage pattern, within the walls of the Middle temple, probably led to a saturation of the soil, both contained within the inner and outer skins of the wall, as well as retaining, or supporting, the base of the inner skin of the Middle temple. A complete saturation of 2m of soil, which is approximately the height of the top level of the soil infill with respect to the floor level of the Lower Temple, could have achieved a side thrust of up to 10 kN.

Plate 2. Collapsed wall from first apse of Middle Temple

Plate 3. Close-up of the collapsed section

It was suggested that the blasting operations in the Coralline limestone quarries, barely 150m away at the closest point, could have contributed to the collapse. In 1993, geophone readings taken at a spot adjacent to the location of the collapse had indicated a peak particle velocity of the order of 3.5mm/s for both transverse and longitudinal waves generated with a typical blast at the quarry. The corresponding peak displacement was of the order of .003mm, and the peak acceleration of the order of 0.119g. Although it is very difficult to establish the potential effect of such seismic action on masonry constructions of this nature, it was felt that this scale of event was not sufficient to cause a collapse, although it could contribute to small displacements which reduced the degree of stability, or to the propagation of micro-cracks at the highly stressed points of contact.

It is notable that although the older temple complexes, and the Lower Temple, are founded on rock, the Middle Temple appears from the recorded excavations, and indeed from the collapsed area, to be founded on an artificial platform of stones and earth, used to level the sloping rock outcrop. This feature immediately makes the construction susceptible to the effects of rain. Subsequent studies have shown that whereas in the areas founded on Coralline rock, rain water tends to pond, as a result of the relative impermeability of the rock, in the area of the first apse, adjacent to the collapse, the water is quickly absorbed by the underlying soil. Indeed the plant growth in the floor of the Middle Temple is much more extensive than elsewhere in the complex.

Plate 4. Double-table structure propping a massive megalith - 1987

Another curious feature is the table-structure that appears in Plate 4. The structure is recorded in the excavation of 1910[2]; archaeological evidence[1] suggests, however, that, although the horizontal slabs are supported in grooves formed into the megaliths of the Lower temple, it probably was inserted at a later stage.

The construction of the Middle Temple seems to have been less carefully done than that of the older one, to the extent that the stability of the megalith which is common to the external perimeters of both temples was probably in doubt at a very early point. The table structure, intentionally or otherwise, seems to have supported the weight of the precariously balanced megalith until years of weakening, coupled by the saturation of the soil during the storm, proved too much. Plate 1, which dates back to the sixties, already shows the cracks in the table structure as it is being pinched over the pillar supports by the adjacent boulder.

The collapse of this structure is considered as having led to the collapse of the inner wall of the Middle Temple. The upper corbelled courses of the Lower Temple were also displaced by the impact with the larger blocks as they fell. These important courses have not been brought down, in this incident, but, given that the contact between the vertical faces of adjacent blocks has been completely lost, thus destroying the original compression ring, and given the substantial displacement that has occurred, the stability of this portion must be considered precarious at best.

4 Conclusions

The deleterious action of the elements on the temple structure is exhibited in other features. The action of rain is considered as the worst culprit, since, in addition to the mechanisms illustrated above, there are clear indications of the damage caused by the flow of water, falling on the soil infill, through the vertical joints of the upright tablets forming the inner walls of the apses. The lower portions of such joints are in fact much wider than the average gap, corresponding to erosion resulting from decades of flow. In many areas, the soil behind such uprights has also been leached out.

In addition, although the coralline base is considered rather impermeable to rising damp, the ponding of rain-water is providing a regular source of wetting-drying mechanisms, with consequent damage to the stone. The proximity to the salt spray from the sea is also a factor in this regard. Finally, it was also observed that the stone elevations exposed to the south and to south east are generally in a worse state of weathering than those in other directions, suggesting that the exposure to the sun is also a significant factor.

The problem that now needs to be confronted is to establish the degree of intervention that is necessary to protect the monument from further damage. The collapsed blocks will be removed during the coming summer, and a partial reconstruction of the inner wall of the Middle Temple will be attempted. However, it seems that it will be necessary to consider a more dramatic intervention so as to protect the whole temple from the ravages of rain, salt spray and sun.

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