CHANGING PARADIGMS IN STRUCTURAL CONSERVATION: A CENTURY OF INTERVENTIONS IN THE SUN TEMPLE, KONARAK

Saptarshi Sanyal

ABSTRACT

This paper discusses an aspect of ongoing endeavour for structural conservation of the Sun Temple, Konararak – a pinnacle of Indian monumental architecture and an inscribed UNESCO World Heritage Site. Through this case study, critical analysis of history of this structure as well as the history of interventions on it is seen to have an influence on conservation priorities today. The project, where the author has been involved in technical capacity over the last two years, is a useful case to highlight how it is essential to view conservation of monumental structures as a continuous process, not just in theory but also in practice. The paper would elaborate on the architectural and material aspects of the Sun Temple, and in this context, enumerate possible critical stresses that this thirteenth century monument sustains today, in its partially ruined state. It highlights how the permanent intervention in the past, resulting in peculiar site conditions, makes the process of collecting data to quantify these stresses numerically quite difficult. However, by combining some crucial site observations with experts’ recommendations made over time, it has been possible to anticipate likely nature of these threats and pressures on the temple’s superstructure. Such an approach helped to prepare definite proposals for investigation and conservation with regard to the Sun Temple, Konarak, to guide future treatment, thus becoming a suitable case to substantiate how certain theoretical principles can be applied in the practice of conservation.

Keywords: Sun Temple, Konarak, Conservation process, Permanent interventions

1. INTRODUCTION

In contemporary conservation practice, it is considered essential to critically evaluate the history of a structure and information sources on prior works. This exercise must be carried out before any decisions regarding current or future course of structural and material treatments can be made. The analysis is both qualitative and quantitative. The qualitative studies, which comprise research and visual inspection, inform experimental studies and more specific quantitative investigations. The Sun Temple, Konarak situated in Orissa, India is considered a pinnacle of the Kalingan architectural typology of temples. Recognition of its outstanding architectural and artistic attributes has also elevated this monument to World Heritage status. Therefore, along with a national responsibility, its conservation and preservation form an international obligation. At the time of inscription of the monument on the World Heritage List in 1984, the structure was already in partially ruinous state. Several decades of repair works and conservation measures had already been carried out. The recent most task of the Archaeological Survey of India (ASI)’s technical team, comprising conservators, archaeologists, engineers and conservators has been to study certain interventions critically in order to ascertain the current approach for structural conservation. Since the past two years, from 2010, assimilation of vast sources of information found through literature, and evaluation of recommendations by external experts has comprised this important exercise. More significantly, combining such research with the team’s detailed visual inspection of the structure itself provides
direction for quantitative analyses and brings forth complex and challenging problems of structural conservation.

This paper identifies once such serious problem, which may have serious implications on the safety of this monument, and contributes to the uncertainty in approaching conservation treatments at current date. This challenge regarding the conservation of the Sun Temple forms an important discourse in advancing knowledge on conservation theory and its practical application. This can be appreciated by an exposition into its historical, architectural, technical and material aspects. Furthermore, our discussion highlights the crucial observations that help us estimate the factors that endanger its safety and the ways in which further investigation can be carried out. The analyses presented below are a combination of historical survey, material and structural studies as well as current inspection of the structure and its comparison with similar structures.

2. ARCHITECTURAL AND MATERIAL OVERVIEW

The Sun Temple merited inscription on the World Heritage List based on its representation of a unique artistic achievement (criterion I), an outstanding testimony to the 13th century kingdom of Orissa (criterion III) and as a link in the diffusion of the Tantric cult of Surya (Sun) Worship (Criterion VI).[1] Its Outstanding Universal Value (OUV) is embodied predominantly in formal rendition of concept in architecture and sculpture. The attributes that make Sun Temple significant as heritage are predominantly physical – its structure and fabric. This makes it necessary to dedicate this section to outlining some of these aspects along with their technical implications.

2.1. Architectural form, design and artistic value

The Sun Temple is an anthropomorphic embodiment in architectural form. It represents culmination of Kalingan temple architecture in complete and perfect form of a chariot of the Sun God. This represents movement of the Sun God mounted on 12 pairs of wheels driven by seven horses with all iconographical features and paraphernalia.

Its architecture is unique by virtue of creative deviation from ongoing construction trend, while also conforming to elements from the Silpa Sastras [2] and other texts that formed the ancient design canon. For example, placement of independent Natamandira (dance hall) at a considerable distance from Jagamohana (prayer or audience hall) and Rekha deula (sanctuary), to accommodate Aruna sthamba or pillar as integral architectural component of its overall design, with Surya’s (Sun God) charioteer surmounted on it [3].

Fig. 1 Conjectural reconstruction of the complete temple complex (left) and aerial view (right)

This monument also represents perfection in classical Indian art as evident in its sculptural representation. Contemporary society is depicted throughout prominently on exterior of the temple, besides celestial creatures. These artistic narratives in sculptural manifestations are of high degree of excellence in workmanship and widest assortment of themes and subjects, representing contemporary secular, courtly and religious life of the time, thus qualifying it as a masterpiece of human creative genius. Apart from what remains today, the architectural and artistic excellence of the Sun Temple has
been uncovered through several historical textual records at various stages dating since the 16th century. These also indicate the descriptions of the temple in its complete state as well as the many stages of its ruin [4]. These are supplemented by visual records in the form of paintings and later, as photographs from the 19th century onwards.

Presently, the remains of the original temple that survive are its audience hall or Jagamohana: the most imposing standing structure amongst the surviving ruins, the base of its sanctuary and the roofless remains of the dance hall. Several historical and material causes have been assigned for the ruin and destruction of the temple [5] and, in following subsections, shall be referred to when discussing structural stability. Today, the Jagamohana, measures 30 m a side externally, square in plan, and is 37 m high from the plinth level, which is another 4.6 m in height. The roof forms a square hollow stepped pyramid in three stages (called piddha) that is 36 m across and 18 m in height. Its circular crowning element, the Amlaka, is 13 m in diameter and 8 m high.

![Fig. 2 Carvings on the plinth of the Sun Temple (left) and its comparison in scale with similar temples](image)

### 2.2. Construction and material properties

#### 2.2.1. Description of materials and construction

The chief conservation issues within the scope of this paper are with respect to those of the Jagamohana. The wall construction is of three-leaved dry constructed masonry with laterite stone for core and khondalite stone for external and sculptural surfaces. Its foundation is primarily of laterite and important carved elements like doorway jambs and deities are constructed in chlorite stone. Iron is an important structural element and is used for cramps and dowels to hold the masonry as well as in tensile structural members like lintels. Apart from those insitu over doorways, several large iron beams resting on stone columns were also used for supporting the corbelling of the superstructure but are now dislodged.

#### 2.2.2. Structural attributes and inherent stresses of original design

From studies on the approximate density of stones used, Prof. B.M. Feilden in his report on the structure in 1987 had estimated it’s mass to be 46,000 T above the plinth with a pressure of 460 KN/m² on its foundations. He states that this could be considered high for a rapidly constructed modern building, although for the Sun Temple, which was built over at least 12 years, gradual consolidation of the soil, which is granular laterite, would have taken place over its construction period [6]. Further modeling of the structure has been done with the Finite Element (FE) analysis. This was based on the assumption of a homogenous and elastic material of the building structure. Though anisotropic in reality, Prof. (Ing.) G. Croci’s team (1997) considered this for computational purposes and analysed the structure in terms of its dead load as well as step-by-step building phases.

It was found through this study that compressive stresses reach the maximum value at the internal corners, which are of the order of 1.0 N/mm². Tensile stresses are much lower and are around 0.25 N/mm² over the doors and 0.125 N/mm² in the inside of the roof. Overall, the roof’s behaviour is domical i.e. likened to the “arch effect”. The stresses below this arch line are vertical compressive and
horizontal tensile, which are even lower at 0.05 1.0 N/mm². This indicates that such a pattern is critical for local stability, because in corbelled dry masonry, the horizontal tensile strength is provided by shear. It depends on the vertical stresses and friction angle between individual block (stone) surfaces [7].

![Diagram of Arch effect and domical behaviour of Jagamohana roof]

**Fig. 3** “Arch effect” and domical behaviour of Jagamohana roof

3. **BEHAVIOUR AND DAMAGE DUE TO DESIGN AND NATURAL ACTION**

3.1. **Local failure of masonry**

A significant problem in the Jagamohana’s structure has been the loosening of the masonry blocks in its pyramidal form. From historical records of descriptions and structural repairs, the problem was identified even as far back as the 19th century [8]. Today, the structural behaviour of the monument, the damages it sustained and its inherent stresses help us understand the causes of such failure.

Due to the overall domical behaviour of the pyramidal roof as noted above, compressive stresses are concentrated around its corners. It may be inferred that there is a predominance of tensile stresses in the masonry while moving away from the corners of the square form. Such a condition makes it evident that sections of the corbelling that are away from the arch-effect or dome thrust-line, do not participate in the global stability, even as per original design. The resultant tensile forces cause the blocks in these areas to break loose. Rust-expansion of iron cramps due to penetration of moisture not only on the exterior but also interior (due to fissures or gaps of stone or courses), adds to above problem and cause splitting and local failure of masonry blocks. Vertical cracks observed in individual stones and loose projecting stones in the projected sections of the exterior substantiate this. Due to most of the corbelled masonry being projected stones in the interior, the problem would be significantly more serious. Though the interior is inaccessible at current date, a watercolour painting with a view of the interior dated to 1812 [9] and cross sectional drawings prepared in 1902-03 [10] are important visual records that prove the observations made above are also true for the interior of the Jagamohana.

![Images of loose stones and analysis of painting]

**Fig. 4** Loose stones on exterior of southern face (left) and analysis of a painting (right): 1812 –W.G. Stephen, showing the interior

2779
3.2. Hypotheses on global stability of Jagamohana
From FE modelling studies, it was understood that in the original structure, supported by iron beams, the inner corbeling masonry does not contribute to the global stability. The collapse of the supporting columns and beams, however, make the local masonry vulnerable to disjoining [11].

While the local failures have been occurring, the delineated structural behaviour indicates that due to the thickness of the pyramidal form of the roof, a large inner volume of masonry does not participate in its overall stability. This dome or arch effect, in three and two dimensions respectively, is sustained along its thrust line irrespective of the loosening of masonry blocks.

With the knowledge from available historical records, verified with current observations from Kalingan temples of a similar scale, such as the Lingaraja temple in Bhubaneswar and Jagannath Temple in Puri, it is expected that the iron beams that have collapsed would have played a decisive role in upholding both the global and local stability. These conditions lead us to believe that while the overall structure of the Jagamohana may be stable today, this can only be confirmed after detailed investigations of the interior. However, such inspection is prevented by the fact that the interior is currently inaccessible. This brings us to evaluate this major structural intervention that led to the current conditions with regard to this monument.

4. FILLING OF STRUCTURE AND RESULTING ISSUES

As regards structural stability, the most significant intervention that may have an impact on the Sun Temple Jagamohana’s safety is the filling of its interior in beginning of the twentieth century. Some recent observations in monitoring of continuous vertical cracks on its northern and western faces cause us to question this intervention critically. The forthcoming subsections here will describe the actual intervention, and analyse to what extent it serves its intended purpose; with above knowledge on the inherent pressures in the structure.

4.1. Brief description of work and its justification
Between 1903-08, the interior of the Jagamohana structure was filled up with sand. This was contained within a dry stone casing; about 5 m in thickness and 15m in height from the bottom to the top. Historical records on this repair work indicate that the total volume of stone weighs about 2000 T. [12] The dry stonework was extended to all doorways, blocking any openings from which this filling could slide out. The remaining portion of the interior was filled with sand by means of drilling a hole from the top of the crown and each of the sides of the vertical walls. As stated earlier, the collapse of masonry from the internal portions of the roof of the Jagamohana was perceived as a threat to safety. The splitting and falling of stones due to local stresses and chemical action would have, in turn transferred the load to neighbouring blocks and this catenation of stresses may have eventually caused the supporting iron beams and stone pillars to collapse, as evidenced in its latest visual records.

4.2. Implications on structural safety today
The sand filling as described above was intended to support the masonry that was vulnerable to failure and dislocations. In this sub-section, we shall examine the resulting outcomes of this repair work based on structural understanding of Jagamohana and detailed inspection of its exterior:
4.2.1. Support to collapsing stones

The inspection of the structure has indicated that the sand-filling intended to originally support the inner corbelling has sunk. This was observed at the vents that were left after closing openings used to originally load sand. At current date, there is passage of air through these openings, which indicate a differential pressure in the interior and exterior. Moreover, the passage of air is only possible because the space at this level of the structure is hollow from the inside. This suggests that the sand filling today rests below this level.

There are two very plausible explanations for the sand being depressed. Firstly, at the time of filling, in spite of the best measures being taken at the time the sand could not have been compacted fully since the Jagamohana was already a covered space. Secondly, with a combination of time and moisture ingress, the self-load of sand filling would have increased. Both these situations caused the sand to sink, therefore compaction occurred under its own weight.

From available architectural documentation showing the soffit of the structure and an assumption of the angle of repose of sand ~30°-32°, it was gathered that the sand now rests in a pyramidal form lower than the soffit of corbelled roof. The unsupported height of this structure is about 10 metres from the top of this sand pyramid. This implies that the sand is not serving its original purpose of supporting the falling stones in the interior.

Fig. 6 Compaction of sand as indicated by passage of air from the interior

4.2.2. Effect on global stability

Two major observations relating to global stability were made in the investigations of 1987 but their causes were unclear. The first relates to ‘dishing’ of the platform i.e. the centre being lower than the edges due to differential settlement. While the plinth did not show any cracks, the possible reason for this may be the renewal of the surface stone after their development. The second was that of continuous vertical cracks at certain locations of the lower part of the structure.

Fig. 7 Possible reasons and signs of distress on structure as an effect on global stability
It was decided in the recent investigations that the latter vertical cracks would be monitored qualitatively by the fixing of tell-tale glass markings. Over time, it was seen that the glass was developing cracks, which indicate that the cracks are expanding over time. With above understanding of the depressed condition of sand, it is quite likely that the thrust on the walls is both vertical and lateral. In addition there is a vertical added load on the plinth, which could be the most likely cause of its differential settlement. On the whole, these observations raise concerns on the masonry and sand filling’s effect on global stability due to distress observed in the structure.

4.2.3. Reversibility
The very nature of the sand filling and masonry is irreversible unless a major intervention to remove them is made. This has formed a continuous debate since the past four decades regarding whether the structure will be further affected by such a removal or will benefit from it. In either case, the irreversibility of the intervention gives rise to another important problem as noted below.

4.2.4. Access for future qualitative and numerical studies
Several significant studies on the structure have been carried out over time, but these are based only on inspection of the exterior and conjectural idea of the interior. It is important to note that the actual condition of the interior is unknown till date. This knowledge is, however, critical to inform any definitive decisions that can be based on numerical and quantitative assessments on structural stability and safety. With the interior being totally cut off from access, the studies so far have been based on earlier documentation of the interior and only, thus, based on partial information. This necessitates the access to the interior to be created as a priority. This is critical to enable the collection of photographic, graphical and numerical information that would help the analyses that are needed to inform structural conservation treatment in the future.

4.3. Inferences
The original intent of the intervention in the monument by filling it with sand was to protect the masonry stones from collapsing. But today, its behaviour has altered the overall configuration of the structure and induced new stresses. The fact that it is irreversible and prevents access to the interior only compounds the problems that already exist. In the light of this situation, the first step in the conservation approach was to facilitate access to the interior to study its exact condition and the effect of the filling on the structure. It would also enable the carrying out of structural strengthening measures using the latest available technology. In this regard, the ASI team prepared a proposal to address such an issue in 3 major stages starting with the making of a passage into its interior.

5. CONCLUSIONS AND FUTURE ACTION
The intervention that forms the focus of this paper is over a century old and was not according to contemporary conservation principles. It raises several important concerns and issues, all of which are today in favour of changing paradigms of structural conservation. Some questions will continue to remain, and some will be addressed in near future through proposed action. It is, nevertheless, very important that structural conservation related to complex problems like those of the Sun Temple be addressed very cautiously to avoid permanent damage to irreplaceable cultural heritage.

5.1. The importance of diagnostic action
The case of the Sun Temple’s Jagamohana helps us appreciate that a thorough appraisal of a structure is as important as the conservation treatment that follows from it, in contemporary practice. It shows that the factors that affect local and global stability are linked but not necessarily co-dependent. Here, the importance of creating access to the interior cannot be undermined as only after the requisite documentation and analyses with the information retrieved therein, can a definitive course of conservation action be prepared. In the planning of action itself, it is important to remember that it must not permanently alter a structure, which brings us to the next aspect – one of reversibility.

5.2. Continuity and reversibility of actions
A fundamental aspect of conservation action is that it is not final and unchanging, but is continuous. This means that at any point in time, the action is only as good as the available knowledge and technical capabilities of human and material resources respectively. It also implies that future action
could possibly address issues that cannot be addressed today. To leave scope for such continuity, treatments and physical interventions on the structure should be reversible. In repair works of Indian monuments that originated under the British colonial government, it was common to use modern construction methods such as brick or stone buttressing, shoring and construction of new elements like pillars and columns to support weakened historic masonry or structural members. Across several sites, such physical elements, while introduced to ensure stability, significantly alter the original structure as well as have impact on its global and local structural properties. This happens due to both nature of the materials used, such as modern bricks, stone blocks or even concrete, and even due to changed formal configurations that result from such intervention. The Sun Temple is just one such example, where certain irreversible previous interventions have had a considerable impact on the structure.

5.3. Authenticity versus structural safety
The most striking debate that sand filling in the Sun Temple raises is that of whether the permanent intervention of the twentieth century is a part of its history or not. If viewed in this line of argument, any change to it would mean altering the history of the structure. However, if analyses such as those comprising above discussion reveals that it a) does not serve its intended purpose of ensuring stability and b) endangers the stability of the structure today, should it be allowed to remain? This question can only be addressed by facilitating access to the interior and getting a more comprehensive and definitive understanding of the current state of conservation.

5.4. Proposal for investigation of interior
For this purpose, a proposal for penetrating into the structure with a workable sized tunnel was prepared from the first terrace of the pyramid on the western side. This proposal, which is currently under discussion, addresses the concerns for current intervention by:
1. Using a previous opening, which was made to fill sand; therefore, with minimal damage to the artistic and sculptural works
2. Application of chemical methods for dissolution of mortars to create tunnel for access, thereby reducing any risk from vibration or mechanical stresses
3. Progressive strengthening of passage by dry and reversible methods using FRP or steel portal frames

In such methods for actual action, the intervention within the structure is minimal and the conservation benefits are very high. Access to the interior is a necessary and urgent need for planning any future conservation works, and is the first step in the process.

ACKNOWLEDGEMENTS

The author would like to thank Dr. D.V. Sharma, (Director, retd.) Archaeological Survey of India (ASI) for his guidance and supervision in the project. In addition, the following members of ASI shared their valuable inputs over the course of the project work and analyses: Dr. Gautam Sengupta (Director General), Praveen Kr. Shrivastava (Addl. Director General), A.K. Patel (Superintending Arcaheologist), Subash Khamari (Dy. Superintending Archaeologist), J.K. Patnaik (Asst. Superintending Archaeologist), T. Lakshmi Priya (Conservation Architect), R.S. Jamwal (Superintending Archaeological Engineer) and Rakesh Kumar (Draughtsman). In addition, the author is indebted to the discussions and inputs from Prof. (Ing.) Giorgio Croci at the Seminar for Conservation of the Sun Temple, Konarak, Bhubaneswar (2010).

REFERENCES


