Archaeological sites in Nepal and India: Concerns of lightning risks

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Abstract— **This study investigates the present-day lightning risks of a large number of archaeological sites in Asia, with special attention to religious monuments in South Asia with invaluable historical value. The study reveals that in most cases, no lightning protection measures (LPM) have been adopted and in several structures, LPM have been adopted but without conducting a methodical risk assessment or standard system design under experts' advice. In a majority of archaeological buildings in Nepal, appropriate lightning protection systems have not been installed, though an apparent air termination system could be observed in the form of a metallic spire or a metallic roof component. However, a system of down conductors and earth terminations has not been properly installed or not installed at all. Both the Department of archaeology and the Department of Urban Development and Building Construction (DUDBC) have not taken adequate steps to install LPS in archaeological sites fearing losing the aesthetic appearance and historical values of the structures. Appropriate LPM has not been adopted even on the structures that have been rebuilt after they were partly or fully damaged by the 2015 earthquake. In many historical structures in the southern part of India, on the other hand, partial LPM has been adopted. Even those that are designed up to the knowledge and standards that existed at the time of design, have not been maintained, and as a result, the components are most often loosely hanging or partially destroyed. Many authorities argue that concerned monuments have survived for several centuries or even over a millennium thus they do not need lightning protection. However, the environment of many such monuments is now modified with rain shelters, lighting systems, CCTVs etc., without having any LPM, thus their exposure level has been increased. However, there are no attempts made in estimating the new risk with modifications that have been done. Also, in the South Indian region, several highly significant monuments and structures have been observed to have Early Streamer Emission (ESE) devices with single down conductors. Most often, these down conductors have multiple acute bends due to the architectural topography of the building. In many such cases, the earthing system is obscured and impossible to be inspected. On such a backdrop, we propose new compulsory international or national standards or an annexure to existing standards for risk assessment, design, implementation and maintenance of LPS of archaeological structures.**

Keywords—Archeological sites, lightning damage, non-standard LPS, South Asia

I. INTRODUCTION

Lightning is one of the most prevalent atmospherically originated threats to the well-being of structures in tropics and Oceans where the ground flash density is relatively high. The damage to an ordinary building by a lightning strike may cause financial losses as well as human life threats. On the other hand, the impact of a lightning strike on an ancient structure may be beyond financial loss due to the irreparable nature of these structures. A recent publication [1] reported a list of incidents of lightning damage to archaeological sites in South Asia. Apart from the incidents, reported in this publication the following key accidents in South Asia have also been reported in mass media

.In September 2021 the 14th Century built Lankatilaka temple, in Kandy, Sri Lanka has been damaged by lightning. Several layers of bricks of the ancient temple have been damaged by the strike, according to the Archaeology Department, Sri Lanka. There were no lightning protection measures (LPM) given to the building by the time the incident took place.

The 5th Century built Pratapur Temple in the Swayambhu Monument Zone of the Kathmandu Valley, Nepal, which is listed as a UNESCO World Heritage site, was struck by lightning on February 13, 2011, causing serious damage to several structures and monuments. Nepalese Department of Archaeology stated that there could be two separate lightning strikes on the ancient temple within a difference of a short period. A brief description of this incident has been given in the published literature as well [2].

Sigiriya Rock Fortress, another 5th century built on-rock palace in the North Central Province Sri Lanka, a UNESCO World Heritage Site, experienced a lightning impact in October 2012. A large part of the so-called Lion's Paw" was damaged. The Archeology Department of Sri Lanka, however, have not provided a detailed investigation report in the public domain regarding the exact cause of the damage. The authors have analyzed the photographs released at the time of the incident. The special spread of damaged bricks may be an indication of outward force. There may be a possibility of lightning attachment to the upper parts of the rock and the current has passed into the surrounding through Lion's paw.

Only a few studies can be found in the literature on the systematic study of lightning protection measures and concerns on the archaeological structures [1-5] despite the immense economic and historical values that these structures possess. We envisage that this lack of information on the current situation concerning lightning threats on archaeological sites leads to the lack of interest among the standards committees to develop guidelines in this regard.

Hence, in this project, an attempt has been made to understand the prevailing situation concerning the LPM scenarios of archaeological sites by conducting a field assessment of various archaeological sites in Kathmandu Nepal and south India. We develop a suitable guideline that can be used by relevant authorities in the archaeological sector.

II. Methodology and Field assessment

A. *Mythological and superstitious believes*

We conducted field assessments of the various archaeological sites in Kathmandu Nepal and India, during which we made visual inspections of the sites and also conducted informal interviews with locals in the vicinity of the archaeological sites. The main purpose of interviewing the locals was to understand the complexity of adopting LPM and adhering to international standards. Some excerpts of the interaction are as follows:

i) In South India, the major myth was related to the warlord of the gods known as "Murgan" also known as the son of Lord Shiva. According to some of the locals, it is believed that "Murgan" being the saviour and warlord of the gods, the gods of thunder and lightning would not dare strike the temples, and if so occurred "Murgan" would protect the people.

ii) In Changu Narayan, "A UNESCO world heritage site, located on a small hill at Bhaktapur, within the Kathmandu valley, the main priest of the temple and locals explained the mythological beliefs of lightning. According to them, the cockerel is the most powerful type of lightning and the one that symbolizes good luck. It is said that the cockerel jumps down from the clouds in the form of lightning and attacks the evil spirits. To not get struck by the cockerel, people have ridges replicating cockerel at the edges of their homes and temples. Yet another belief is that there are two other types of lightning being perceived as white Bajra and black axe. These are said to be the types that are not very dangerous to humans as they come down to earth to leave stones in the form of axes and bajras. They are said to have medicinal healing properties and are hence considered god's gift. Whereas, fire lightning (locally called 'Mala') is one of the fierce lightning that is believed to instantly cause a fire once it strikes any structure or individual. The locals claimed that they witnessed the Mala when a school in the vicinity of Changu Narayan temple was set on fire after lightning struck the school, a few decades back (they don't remember the exact date though).

iii) In Swoyambhunath Mahachaitya, the local priest inferred lightning as a dragon. The dragon is said to have four legs with a very long hind tail that latches on whatever it has come to strike. The Dragon is said to create destruction once it leaves the object, and ascends. A local also claimed that he saw the 4 paws of the dragon attached to the Pratapur temple at different heights on the day of the strike, and also saw the dragon leave towards the sky.

B. *Field Assessment of various sites*

The assessments of the sites were all conducted similarly both in India and Nepal. The Assessment carried out involved the participation of the concerned authorities of the sites. The priest or the head caretakers of each temple were also inquired about the records and data collection.

During the survey the various Archeological Structures that were surveyed were mostly of national and historical significance, the perspective of the locals, the authorities and caretakers have added a different dimension to the requirement of Standard LPM measures.

The major objective of the assessment was to investigate the condition, quality and practice of LPM taken at each site. The assessment checked if the LPM was adopted following standards (if present) otherwise, why it was not present and what the perception of LPM was for the locals and the authorities.

The LPM situation was assessed visually and some measurements were done where possible, and the adequacy of the LPM measures was thus determined at each site.

Sites Observed:

1.Patan Durbar Square (Lalitpur, Nepal)

2.Basantapur Durbar Square (Kathmandu, Nepal)

3.Swoyambhunath Mahachaitya (Kathmandu, Nepal)

4.Changu Narayan Temple (Bhaktapur, Nepal)

5.Pashupatinath Temple (Kathmandu, Nepal)

6.Brihadeeshwara Temple (Thanjavur, India)

7.Meenakshi Amman (Madurai, India)

8.Palani Murgan Temple (Tamil Nadu, India)

9.Tiruvanakoil Temple (Trichy, India)

10.Samaypuram Temple (Trichy India)

11.Srirangam Temple (Trichy, India)

C. *Observation of protection practices*

Infield survey in south India, Specifically Thanjavur, the temple authorities revealed that multiple strikes caused damage to the temple even after LPM were adopted. Upon closer inspection, it was observed that the single down conductor, has multiple acute bends, and there is no proper earth termination system to be seen. A single air terminal has been installed to cover the entire premises with an area of 180,895 m^2.

A majority of temples had early streamer emission (ESE) type Arresters to which the temple authorities are rather oblivious of the situation and are more than happy to have an ESE rod which, according to them, is a "recent technological advancement".

On many such occasions, it is evident that the authorities make attempts to downplay the incidents, most probably to avoid blemishes of not taking proper actions to provide appropriate LPM to the site beforehand. However, it has been revealed through informal surveys that most authorities do not have the required expertise or resources in making a risk assessment, selecting appropriate LPM, assessing the condition of existing LPM or maintaining the LPM.

III. Observation and Discussion

A. *Patan Durbar Square(Lalitpur, Nepal)*

The Patan durbar square itself is a constituency of multiple archaeological structures among which the famous Krishna mandir and Patan museum are also present. None of the Structures built in the Durbar Square Premise has any form of

LPS, but some do have down conductor-style metallic strips hanging atop the structure (Figure 1).

Figure 1: Krishna Mandir (Lord Krishna's temple) built on the premise of Patan Durbar square that has an air termination steeple on the top that is not connected to a down conductor system or an earth termination (to be witnessed).

B. *Basantapur Durbar Square (Kathmandu, Nepal)*

The Basantapur Durbar area is also a constituency of multiple archaeological structures, among which the famous Shiva Parvati temple and Hanuman Dhoka are also present. None of the Structures Present in the Durbar Square Premise has any form of LPS, but some do have a down conductor style metallic plate hanging atop the structure, except for one of the structures in the Patan durbar square. However, a lightning arrester followed by a single down conductor can be seen on Basantpur tower- a nine-storied structure that is being reconstructed after it was destroyed by the massive 2015 earthquake (Figure 2). Although a multinational company has been rebuilding the tower, none of the workers could explain the LPM being adopted. The Basantapur Durbar Square is located at the heart of Kathmandu, where there are dozens of archaeological structures but none of them seems to have proper LPM installed.

Figure 2: Basantapur tower that is being recently rebuilt after it was demolished by the 2015 massive earthquake. It can be seen on the tower that a single lightning air termination system followed by a single down conductor is installed on it. We were not allowed to assess the base of the structure citing security reasons.

C. *Swoyambhunath Mahachaitya (Kathmandu, Nepal)*

The Swayambhunath Mahachaitya is one of the UNESCO world heritage sites, located in the western part of Kathmandu. Although there are several structures atop a hill called Swoyambhunath, there are three tall structures namely,

1. Main Chaitya 2. Pratappur Temple 3. Anantapur Temple

Among them, the Pratappur temple was struck and destroyed by lightning on 13th February 2011. Shown in figure 3 is a photograph of a damaged temple taken on the next day it was struck. Pratappur temple was destroyed by lightning sparing the taller structure since it did not have proper lightning protective measures. No appropriate lightning protection measures can be seen on the structure even though it was recently built (Figure 4).

Instead, it is claimed by the local priest that LPM was done within the building after it was erected. Whereas,

- There was no visible air terminal on any of the structures.
- No available down conductors on either of the temple.
- No earth termination system could be observed.

Figure 3: The damaged Pratappur temple at Swyambhunath along with the main stupa and Anantapur temple. Also, shown in the inset is the damaged stone statue that was placed on one side of the main entrance door of the damaged temple.

Figure 4: The newly constructed Pratappur temple after it was destroyed by lightning in 2011.

D. Changu Narayan Temple (Bhaktapur , Nepal)

No protective measures against lightning have been taken as it is believed that the gajur (steeple) of the temple itself protects it from lightning. This temple is also a UNESCO world heritage site that is located atop a small hill to the north of Bhaktapur (Figure 5).

Figure 5: Changunarayan temple located atop a small hill at Bhaktapur. The photograph on the left depicts an air termination system whereas the photograph on the right depicts the down conductor dangling towards the bottom edge of the roof.

E. Pashupatinath Temple(Kathmandu, Nepal)

This temple is a sacred Hindu temple classified as a UNESCO world heritage site in 1979 that is believed to have been built in 400 BCE. Despite its historical and religious importance, no appropriate protective measures have been taken. It is believed that the metal steeple and the gold-plated metallic roof protect the temple from lightning (Figure 6). In this temple too, there is a trailing metallic strip that runs from the steeple and dangling below the roof.

Figure 6: Pashupatinath temple located at the bank of Bagmati river in Kathmandu. The steeple and the metallic roof are seen in the photograph.

F. Brihadeeshwara Temple (Thanjavur, India)

The Brihadeeshwara kovil is a Hindu Dravidian-styled temple located on the south bank of the Cauvery river at Thanjavur Tamilnadu, India. The temple premise has two major structures, one structure is the main entrance gate, and the other is the main temple (Figure 7).

The air termination system is not visible on the main gate although there are down conductors running down both sides to three earth pits. The Down conductors have directly been clamped to the wall and have multiple steep bends. The Earth pit consisted of a GI pipe as an earth electrode.

Whereas, on the main temple building an air Termination System has been installed which is a conventional type that was clamped to the steeple of the temple. There is a lamp on a stand that was placed higher than the tip of the air termination. Two down conductors are taken almost together (at a few centimetre separation). A large number of acute bends on the down conductors can be observed. The copper strip has directly been brought into the ground and no earth pits were observed.

Figure 7: A Photograph of Brihadeeshwara temple located at the bank of the Cauvery river in Tamilnadu India. Shown in the inset is the edge of the temple that was struck by lightning.

G. Meenakshi Amman (Madurai , India)

The Meenakshi Amman Temple is located in Madurai Tamilnadu India. It has four large gates in four geographic directions and the main temple building at the middle of the four gates. Each of the 5 structures has an air termination system and all of which are ESE types (Figure 8). However, no down conductor was visibly attached to the ESE air terminals. As these structures are built centuries ago, there is no possibility that they have a steel reinforcement structure to which the air termination could be connected. No earth termination system could also be seen in the vicinity of the structures.

Figure 8: Meenakshi Amman temple located at Madurai Tamilnadu India. An air termination system can be seen on the top of the building.

H. Palani Murugan Temple (Tamil Nadu, India)

The Palani Murugan temple is located atop a hill in the Dindigul district in the western part of Tamilnadu India.

A lightning protection system has been installed on the temple. A single ESE was present on the top of the temple, however, no down conductors were observed Figure 9). No earth termination system could also be seen around the temple.

An ESE type air terminal was also present close to the entry point of the temple which is at the height of the foot of the temple, with one down conductor touching the ground.

Figure 9: A Photograph of the ESE air termination system installed close to the entrance gate and well below the top of the structures in the close vicinity.

I. Thiruvanaikaval Temple (Trichy , India)

Thiruvanaikaval temple is a famous Shiva temple located in Trichy Tamil Nadu India. This is a large temple in terms of Area, with quite a few Structures. Out of the Temples inside Thiruvanaikaval, 4 temples have ESE type air termination systems (Figure 10). The remaining Temples did not have any type of LPM. The down conductors were mostly run down on two sides. The down conductors were Either single core cable or Copper Strip. The single-core cables were cut off halfway to the earthing. The Earthing System is a tripod earthing system or G.I pipe, which is completely non-functional in 3 places since down conductors have been cut off in between.

Figure 10: The ESE air termination system installed on the top of the building of Thiruvanaikaval temple.

J. Samaypuram Temple (Trichy India)

Arulmigu Mariamman Temple, Samayampuram is one of the most important religious sites in Trichy, South India. The temple has two tall entrance gates namely the front gate and back gate (Figure 11).

An alternative air termination rod, apparently an ESE device, is installed on the Front gate, whereas the down conductors were not visible nor were the earth termination visible.

Similarly, a conventional type of air termination system is seen to have been installed on the back gate of the temple, whereas, only one down conductor was seen to have been installed. Interestingly, on the down conductor CCTV camera is seen to be fitted (Figure 11).

On the other hand, there was no additional earth termination system instead and the down conductor strip itself has been earthed.

Figure 11: The down conductor system, on which CCTV was installed on the building of Samaypuram temple.

K. Srirangam Temple (Trichy , India)

Srirangam Kovil is a Hindu temple dedicated to Ranganatha and is located in Srirangam, Tiruchirapalli, Tamil Nadu. It is the largest site among all the other temples in terms of area, covering 155 acres of area, with 21 gopurams (temples) inside itself.

Out of the 21 temples, 12 have been installed with ESE air terminals (Figure 12), whereas, the remaining 9 temples do not have LPM.

Each of the 12 air terminals had a single down conductor each running directly into the earth without proper pits or earth termination system.

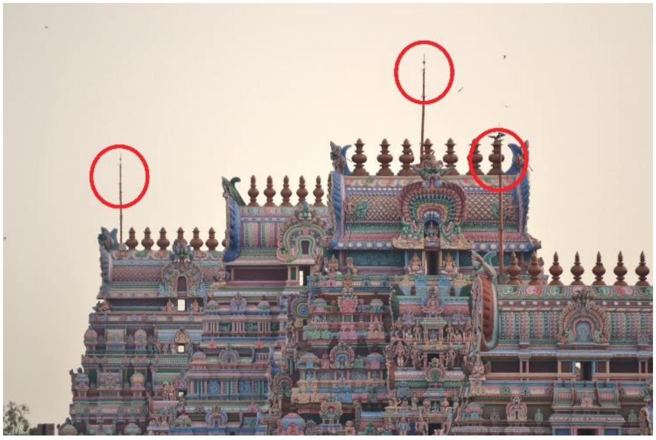

Figure 12: Three ESE air termination systems installed on the top of the buildings at Srirangam temple.

IV. Discussion

It is of prime importance to understand the recommended practices of lightning protection, as per the specifications given in IEC Standards, which now have been adopted by a large number of countries as their national standards. Considering the potential of this paper being read by non-experts in the field, we herewith include an outline of the IEC 62305 series.

IEC 62305-1 [8] provides very useful information on the lightning characteristics and parameters of engineering significance. It also provides the possible test waveforms that could represent lightning currents and lightning current generated/induced voltages that can be produced under laboratory conditions.

IEC 62305-2 [9] presents a comprehensive risk assessment procedure for most general buildings. The information in [8], is essential in the computations specified in [9]. Notably, the risk assessment described in [9] is restricted to the protection of buildings and their occupants. It does not cover the safety of people outside such structures. There are some specific cases such as the risk assessment of high-risk installations [10], roof-mounted PV systems [11], twin towers and adjacent structures of a building complex [12] etc. which have not been covered in [9] and addressed elsewhere.

As per the specified method of risk assessment given in [9], once a building of concern is decided to be provided with lightning protection measures (LPM), it should first be assessed for the lightning risk. The risk assessment needs a list of input parameters such as ground flash density of the region, building dimensions, building occupation (number of human beings and types of storage), service lines connected to the building, its neighbouring environment, fire and surge protection that has already been provided to the building etc. Once the first round of computations is done, the outcome will be risk factors (R_x) for the following cases.

R1: risk of loss of human life (or permanent injury)

R2: risk of loss of service to the public,

R3: risk of loss of cultural heritage,

R4: risk of loss of economic value.

IEC 62305-2[9] specifies tolerable risks for R_1 to R_3. If any calculated R_x exceeds the relevant tolerable risk index, then the building needs LPM. The whole procedure of risk calculation is repeated by increasing the level of lightning protection (LPL) at which the calculated risk is lower than the tolerable risk specified in the standards. Once the LPL for a building is determined before the implementation of the relevant LP measures, another calculation is conducted to find whether the cost of LPS is acceptable in comparison with the expected losses under lightning threats. R4 comes to play its role at this stage.

After the level of protection for a given building is determined and justified by the risk assessment, IEC 62305-3 [13] provides a comprehensive guideline on how to design and implement the structural protection system. This guideline specifies the positioning, dimensions, materials and other concerns of air termination, down conductor and earthing systems. It also guides the designer in determining how much the separation between the LPS and other metal parts of the building should be maintained. Alternatively, it recommends electrically connecting such parts to the LPS provided that it will not increase the risk of injury or damage.

IEC 62305-4 [14] specifies the transient bonding that should be done between the live/neutral wires and earthing system to prevent dangerous arching or transfer of voltage due to high currents. This is also known as surge protection. Surge protective devices play a role in the risk assessment as well (so does fire protection).

Non-conventional LPMs such as ESE technology do not adhere to the above IEC Standards. Instead, they follow either French standards (NF C 17-102 [15]) or Spanish standards (UNE 21186 [16]). These standards assume the rods have 100-200 times longer virtual heights over their physical height. Thus, most buildings where several air terminations and down conductors are needed for reasonable protection against lightning under IEC standards, require only a single air termination and a single down conductor under ESE technology-related standards. The technology has not been proven theoretically, experimentally or statistically [17, 18]. Studies done in several countries with high lightning ground flash density have clearly shown that the damage to structures with ESE devices is significantly higher than those with conventional LPM [3, 19].

The majority of the archaeological sites under this investigation in India were found to have adopted the alternative air terminal system mostly ESE type, largely overlooking the standards set by the national building code of India. Five out of Six of the temples visited in India (Tamil

Nadu) were fitted with ESE arresters on the top of various structures. None of the installations was observed to have adopted any national or international standards. Neither LPS comprising conventional air terminals have followed any national or international standards. For example, in Thanjavur, although the materials of the arrester and down conductors were as per conventional systems the installations have not followed the standards as the down conductors have many acute bends and they do not terminate at proper earthing systems.

Many archaeological sites in the Kathmandu Valley, Nepal, on the other hand, under investigation, were found to have no lightning protection systems at all. Although the remnants of the once protective measures on most of these structures are still in place, they do not protect against lightning to any level set by the international electrotechnical commission (IEC) 62305. The lack of a proper lightning protection system could partly be due to the unavailability of the national standard that has incorporated a lightning protection system and partly due to the ignorance of the concerned authorities towards the values of these structures. In this context, none of the archaeological sites is safe from lightning threats.

Considering the lightning threats in Nepal [6] and India [7], the lack of proper LPM in these structures may not only pose property damage but human risk as well. Most of these temples are visited by thousands of pilgrims and tourists a day, thus, methodically designed and implemented LPS will be of utmost importance due to multiple reasons.

V. Conclusion

In this study, we have investigated 11 archaeological sites in Nepal and India which contain over 50 structures. The structures under investigation were found to have either no protective measures or have LPM that do not follow any standards. Consequently, almost all the structures that were taken into account for the investigation are vulnerable to lightning hazards. In a majority of these sites, authorities were found to be ignorant of the protective measures either due to lack of knowledge or due to the local myths about the protective measures. Further, the installations of non-conventional air terminal systems in Indian sites under consideration are mainly due to the lack of knowledge of the concerned authorities and fraudulent marketing of the vendors. We therefore strongly recommend the concerned authorities take LP measures seriously to prevent the immeasurable economic loss and retain the historical & religious values of the structures.

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