

# Lightning Protection of Stupas in Sri Lanka

Joseph Rohan Lucas

**Abstract:** Lightning is a weather-related phenomenon with dire consequences for tall structures. The lightning protection adopted in Sri Lanka in stupas in ancient times, from the third century was adequate, as no lightning damage to stupas have been recorded in early times. However, the present restoration of lightning protection may be inadequate as recent strikes have been detected due to improper new practices due to an absence of detailed recording of the lightning protection in ancient times. This paper discusses the lightning protection of stupas, especially of Ruwanwelisaya from ancient times to the present, tracing the history of lightning protection from the Mahawansa and the Culawamsa. While the bulk of the lightning energy probably went through the stupa in ancient times, the modern protection tends to bring the energy to earth through the surface of the stupa and the compound at the bottom which can cause disastrous effects. Monitoring is recommended to be undertaken to see whether the dissipation of bulk of the lightning energy is through the stupa itself, even in the present day, or along the surface of the stupa and through the compound at the bottom.

**Keywords:** Lightning protection, stupa, dagaba, Sri Lanka, Mahawansa, Culawamsa

## 1. Introduction

In ancient times, as early as 465BC, the advisor Artemis of King of Persia wrote how lightning bolts always struck the “highest houses and tallest trees” [1]. Thus, even in very early times, lightning would have been of concern in both land and at sea. On land, the tallest man-made objects at that time would have been the pyramids in Egypt (Figure 1) which had been constructed over two thousand years earlier. There is no mention of lightning protection being installed in these early structures.

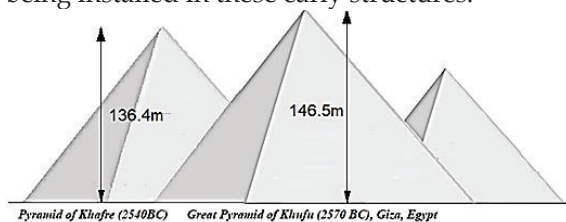


Figure 1 - Early Pyramids in Giza, Egypt

The next largest of ancient structures in the world are the stupas in Sri Lanka [2] shown in figure 2.

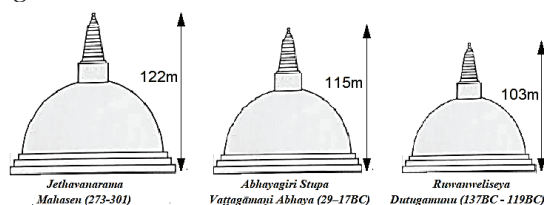


Figure 2 - Heights of Ancient Stupas in Sri Lanka

Figure 3 shows a sailing ship, which were the tallest objects in the ocean. These ships are known to have showed a glow at the sharp points in the masts during thunderstorms


known as St. Elmo's fire [3]. St. Elmo's fire is a form of corona, giving a bright bluish violet visible glow.



Figure 3 - St. Elmo's Fire

This corona occurs during thunderstorms from tall, sharp pointed objects such as lightning rods, masts on ships, and spires. It is thus reasonable to assume that protection from lightning would have been foremost in the minds of early kings who built tall structures to the Gods and those sailors caught at sea during thunderstorms.

Records show that there have been many damages to stupas, other than in Sri Lanka and described as follows.

Eng. (Prof.) J.R. Lucas, C. Eng., HLFIE(SL), FIEE, B.Sc. Eng. (Hons) (Cey), MSc (Manch), PhD (Manch), Senior Professor, Department of Electrical and Electronic Engineering, General Sir John Kotelawala Defence University, Ratmalana. Email: [lucas@kdu.ac.lk](mailto:lucas@kdu.ac.lk)  
 <https://orcid.org/0000-0001-7215-0815>

The Kanishka Stupa (120m, ~127AD) in Pakistan, considered the tallest building in the world at the time of construction, had been struck by lightning, destroyed, and repaired several times [4]. The Golden Stupa at the Chiang Rai temple in Thailand was destroyed by lightning in 1434AD [5]. The Borobudur stupa in central Java was struck by lightning [6] in 19AD and its summit was destroyed. Most recently, the Boudhanath Stupa in Nepal was struck by lightning [7] in 1969 and suffered damages. Thus, there is a lot of evidence that stupas were actually the target of lightning with major consequences.

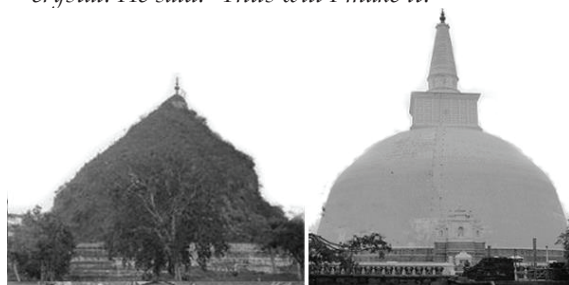
However, the largest and tallest stupas are found in Sri Lanka and no damages have been recorded in the past due to lightning [6]. It is to be noted that a single lightning bolt [9] can deliver between one to ten giga-joule of energy (~1000 units of household electricity), with corresponding currents of the order of hundreds of kiloampere with temperatures in the lightning channel rising to around 15,000°C, hotter than the Sun. This amount of energy and temperature can destroy virtually anything, including stupas, if not harmlessly dissipated.

## 2. Lightning Protection of Ancient Stupas Sri Lanka

Ruwanwelisaya is the third largest ancient stupa in Sri Lanka. It was constructed around 140 BC by King Dutugemunu and is recorded in detail. Mahawansa Chapter 29: clauses 5-12 [10, 11] describes the preparation for the foundation for the stupa as follows. *"The fine clay that is to be found on the spot, forever moist, where the heavenly Ganga falls down .... is called because of its fineness, 'butter-clay..... The king commanded that the clay be spread over the layer of stones and that bricks then be laid over the clay, over these a rough cement and over this cinnabar, and over this a network of iron, and over this sweet-scented marumba that was brought by the samaneras from the Himalaya. Over this did the lord of the land command them to lay mountain-crystal. Over the layer of mountain-crystal he had stones spread; everywhere throughout the work did the clay called butter-clay serve (as cement). With resin of the kapittha-tree,' dissolved in sweetened water, the lord of chariots laid over the stones a sheet of copper eight inches thick, and over this, with arsenic dissolved in sesamum-oil, (he laid) a sheet of silver seven inches thick."*

King Dutugemunu, who built the Ruwanwelisaya, was very conscious of the quality desired and made sure that material for the stupa was carefully screened and the master builder carefully selected. Chapter 30 clauses 5-13 of the Mahavamsa records it as follows.

*"Thereupon commanding that the drums be beaten he called the master-builders together with all speed; in number they were five hundred". And one of them answered the king, on his asking: 'How wilt thou make (the thupa)?' 'Taking a hundred workmen I will use one wagonload of sand in one day.' The king rejected him. Thereon they offered (to work with) one half less and yet one half less again, and (at last with) two ammanas of sand. These four master-builders also did the king reject. Then an experienced and shrewd master builder said to the king: 'I shall pound (the sand) in a mortar, and then, when it is sifted, have it crushed in the mill and (thus will use) one ammana (only) of sand.' And on these words the lord of the land, whose courage was like to Indra's, consented, with the thought: There will be no grass nor any such thing on our cetiya, and he questioned him saying: 'In what form wilt thou make the cetiya?' At that moment Vissakamma entered into (and possessed) him. When the master-builder had had a golden bowl filled with water, he took water in his hand and let it fall on the surface of the water. A great bubble rose up like unto a half-globe of crystal. He said: 'Thus will I make it.'*



**Figure 4 - Ruwanwelisaya: In 1809 and now**

Figure 4 shows a picture of the Ruwanwelisaya taken around 1809 in a somewhat dilapidated condition and a more recent picture of it after renovation, with both pictures showing the vajra chumbaka (or lightning protection) installed at the pinnacle.

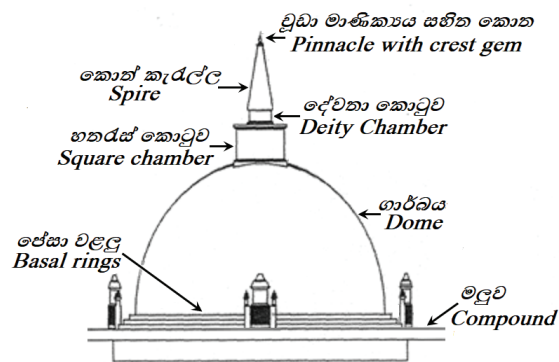


Figure 5 - Details of Ruwanweliseya

Figure 5 shows the various parts of the stupa, from the ChudaManikkya (the large gemstone placed at the pinnacle of a stupa), to the KothKeralla, the Devathakotuwa, the hatareskotuwa, the Gharbaya, the PesaValalu to the Maluwa and the base below it [12]. The corresponding Sinhala terms are also included on the figure, as those terms describe the stupa more accurately. According to the Mahawansa (Culawamsa) [13], King Sangathissa I (243 - 247 AD) has installed a Lightning Protection system "Vajra Chumbaka" to the Ruwanweliseya. The Culawamsa Chapter 36:64-65 records it as follows "Thus crowned did Sangha Tissa reign four years in stately Anuradhapura. He set up a parasol on the Great Thūpa and gilded it, and moreover the king put four great gems, each worth a hundred thousand (pieces of money), in the middle of the four suns, and put upon the spire of the thupa a precious ring of crystal (Vajra Chumbaka)". Then King Datusena (461- 478 AD) had installed the Vajra Chumbaka again to Ruwanweliseya, Jetavanaramaya and Abhyagiriya as stated in Culawamsa Chapter 38 Clauses 73-74 "Having undertaken renovations in the viharas here and there, he had some fine stucco work executed for the wall of the (Relic) house. (In the same way) he had valuable stucco work made for the three big cetiyas and put up a golden umbrella as well as a ring for protection against lightning.". It is also stated that King Mahanaga (561 - 564 AD) had also rectified the lightning protection systems of the 3 main stupas. Culawamsa Chapter 41 Clause 95 states this as follows "He decorated the three great cetiyas with stucco work and (put up) a protecting ring (against lightning). He also repaired the elephant terrace and the paintings."

The authors of Mahawansa do not give further details regarding the lightning protection. Probably the chudamanikkya at the top attracted lightning, transferred it to the dome structure through its metallic base and the energy was absorbed by the huge mass of the dome. As King Dutugemunu was very

particular in quality and used butter-clay and finely grounded sand, the transfer of load and of energy was by direct contact from brick to brick. Analysis done by Ranaweera and Munasinghe [14] has stated that the Mahastupa had effectively a reinforced concrete foundation, and that the very thin layer of cement made the brickwork stronger. Further they state that "A thick plaster layer was used to waterproof the surface and prevent the deterioration of the stupa under the action of elements."

The Vajra Chumbaka installed at the pinnacle of a stupa is a large ring or block of quartz crystal supported from the bottom by a gilded metallic container fixed to the dome structure. Being a semiconductor at the very top of the structure, it is fair to expect the quartz crystal to send the first answering leader, before the other parts of the structure [15]. Quartz has a specific heat capacity almost twice as that of copper (about  $780 \text{ J kg}^{-1} \text{ K}^{-1}$ ) and a melting point ( $1720^\circ\text{C}$ ) about  $400^\circ\text{C}$  more than that of copper. Therefore, the quartz block will withstand more heat dissipation than a copper rod does. It is thus likely that although the energy could have been as high as giga-joules, it was perhaps dissipated in a volume of millions of cubic meters having a negligible adverse consequence. Thus, no damage would have occurred to the crystal or the stupas in ancient times. This is confirmed by the fact that there are no historical records of lightning damage to any of these large stupas during the Anuradhapura kingdom [6] that stretches over 1000 years during which any such incident, if occurred, would have been well documented. At present, every year, several lightning casualties are reported from this area [16], which indicates that the lightning density in the area is not that low.

## 2.1. Recent Protection of the Sri Lankan Stupas from Lightning

Even in recent history, there is no mention of lightning strikes to any of the stupas in Sri Lanka, except for perhaps the Mihintale Stupa built in 7AD which was struck on 23 April 2010 (Figure 6) which has undergone restoration in 1979 with the addition of lightning protection as well [17, 18].





**Figure 6 - Damage to Mihintale Stupa by Lightning [18]**

In this instance, the stupa's crest gem, terrace and the pinnacle have been severely damaged. It has been stated that the lightning protection system has been in a faulty condition during the damage. The copper tape of lightning down conductor had been cut and removed by thieves in the stretch from the basal rings to the grounding point. Thus, lightning which struck the pinnacle, not only damaged the unprotected components at the top, but brought the lightning discharge down to the basal rings where it got dissipated due to the lack of a path to proceed. This tells us a lesson that, in interfering with existing systems, due care must be taken to understand concepts and ensure that stresses are not transferred elsewhere.



**Figure 7 - Jetavanaramaya Stupa Showing Cable**

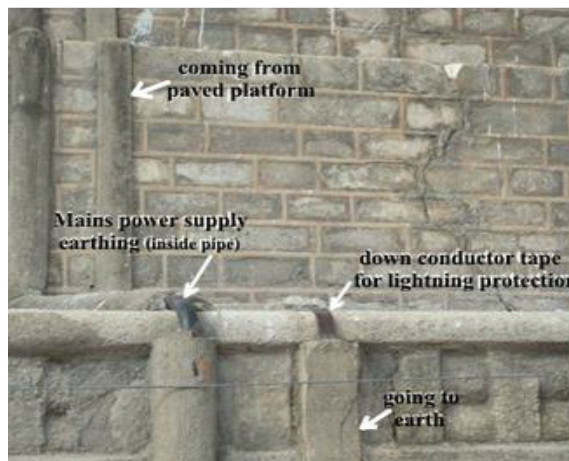
Figure 7 shows the Jetavanaramaya stupa, constructed between 273 and 301 AD, which was originally 122 m in height. With ravages of time, it now stands at 71 m with part of the pinnacle missing. In August 2011, lightning struck the remaining top of the Kothkerrella, and grounded through the electrical cable installed to illuminate the Stupa damaging the electrical panel at the base. Why did this happen? Probably because those who installed the wiring, and the lighting did not consider the possibilities of induced effects from a direct lightning strike. This too tells us to be careful in additions that may affect the lightning protection of the stupa.

Mahawansa does not record of any lightning strike to the Maha Stupa (Ruwanwelisaya) during a period of 1000 years, although it speaks about Vajra Chumbaka being used for lightning protection and maintained by subsequent kings. The system in use, is to get the lightning to strike the Vajra Chumbaka as the preferred point of discharge and harmlessly carry the energy to the earth through the central axis of the Stupa to perhaps the silver, copper and steel used in the foundation of the base of the Stupa.

Around 1956, during a restoration of the Maha Stupa, a lightning conductor had been installed at the very top and a single copper down conductor had been taken along the surface of spire, deity chamber, square chamber, the dome, the basal rings and the paved platform (Figure 8) and the elephant wall.



**Figure 8 - Path of Lightning along Down-Conductor and Paved Platform**



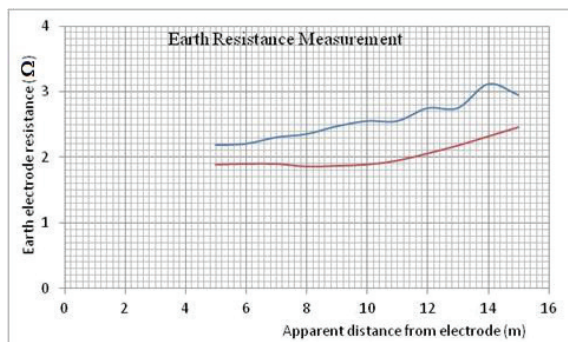
**Figure 9 - Earthing Points Coming out of the Elephant Wall**

Due to the strikes to stupas in 2010 and 2011, in May 2012, an investigation was carried out regarding the lightning protection of the Maha Stupa under the control of the Telecom Regulatory Commission of Sri Lanka.

Outside the elephant wall, the point where the down-conductor comes out was visible and accessible (Figure 9). However, it appears to go well into the ground soon afterwards and the position of the earthing could not be located even through a reasonable amount of digging.

Although the earth electrodes for lightning protection could not be physically located, the general area in which these had to be installed was identified. The measurements were made in two different directions in the land outside the elephant wall, with the current electrode placed approximately 23 m from the assumed position of burial of the earth electrode, and the potential electrode being moved around the half-way position of 11.5 m where a single measurement would normally be taken.

The maximum position of the potential electrode was limited by the length of the wire provided with the instrument. In order to ascertain the validity of the measurements, additional readings were taken along the path of measurement at 1 m intervals. A plot of this is given in Figure 10.



**Figure 10 – Resistance Measurements on the Lightning Earth Electrode**

According to normal theory, the measured value of earth electrode resistance would be zero towards the electrode being measured, rising to a flat value in the mid region, corresponding to the actual earth electrode resistance of the measured electrode, and finally rising up again to a relatively high value near the driven current electrode (in this case at 23 m). It must be realised that the distances shown in Figure 10 are not exact distances from the electrode as the exact position of the electrode could not be accurately determined. However, the flat region at a distance of 10 m to 12 m seems to indicate that the value at this distance would be the actual reading of the earth electrode resistance and seems to have a value of around 2 to 2.5  $\Omega$ , and the exact location of the earth electrode is not of much concern to the measurement.

## 2.2. Effectiveness of Lightning Protection System

It is a common belief among the public that placing any lightning conductor on top of a tall structure and connecting it to an earth electrode via a down conductor (copper tape) will remove all the risks associated with lightning, independently of whether it is designed properly or not, provided the earth electrode resistance is sufficiently low. Thus, in testing lightning protection installations, it is common practice to measure the earth electrode resistance and get a value of less than 10  $\Omega$ . However, it needs to be remembered that copper down conductors and earthing tapes also have inherent inductances of the order of 1  $\mu\text{H}/\text{m}$  [6], which may be insignificant when the length of conductor is low and at power frequency but very significant at lightning related frequencies and rates of change.

Sreedhar and Srinivasan [19] have undertaken a detailed perspective of traditional and scientific methods of lightning protection systems, lightning strokes and their effects on historical monuments, heritage properties and important landmarks. Srinivasan et al. [20] have also modelled and assessed lightning hazards to humans in heritage monuments in India and Sri Lanka. Bandara et al. [21] have undertaken a Lightning Risk Analysis on Protected Sri Lankan Heritage Stupas.

Lightning currents in vulnerable places can have magnitudes of the order of 200 kA, with the rate of rise having values of the order of 100 kA/ $\mu\text{s}$  [9]. With short lengths of down conductor, the total impedance from the lightning conductor to the earth could be taken as approximately the earth electrode resistance. Hence the measure of the earth electrode resistance, as is commonly done, may be adequate to maintain the developed voltages at acceptable levels. For example, the developed voltage at the lightning conductor location would be 400 kV for a 2  $\Omega$  resistance of earth path at a lightning current of 200 kA, provided lengths of all connecting tapes are negligible.

In the case of a single down conductor, from the top of the spire of the Ruwanwelisaya (height 103 m) to the probable location of the earth electrode, the length is estimated to be around 150 m. With a typical internal inductance of 1  $\mu\text{H}/\text{m}$  for a flat copper tape, this would result in a total copper tape inductance of 150  $\mu\text{H}$ . This would generate

15,000 kV for the inductance of path at a lightning rate of rise of 100 kA/ $\mu$ s.

It is thus seen that for a tall structure, measuring the effectiveness of the lightning protection based purely on the earth electrode resistance has little significance. While the voltage at the spire may build up to 15 million volts, the voltage across the earthing tape in the compound, where people gather, will only build to a value dictated by the earth electrode resistance and any inductance of the earthing tape between the bottom of the dome and the grounding point.

### 2.3. Generation of Step Potential due to Lightning

When a high current flows into the earth due to lightning, a rise in the ground potential in the immediate neighbourhood occurs. The lightning down conductor of the Ruwanwelimahastupa is taken across the stone paved platform (Figure 8), where large numbers of persons congregate to pay homage to the Ruwanweliseya. Having large lightning currents flowing along this single path could cause excessive potentials to be developed across the stretched feet of persons standing in the vicinity (step potential) [22]. Rajapaksha et al.[23] have also presented possible lightning hazards to humans near giant ancient stupa. Fortunately, due to the low earth electrode resistance, the buildup of voltage at the compound is low and no incidents of injury due to step-potentials have been reported.

### 2.4. Rolling Sphere Method of External Lightning Protection

IEC standard 62305 on Protection against lightning - Part 3: Physical damage to structures and life hazard[24] deals with the protection of structures such as stupas. For structures which are not very high, less than about 60 m, a simple conical method of determining the required external lightning protection is generally considered adequate [Figure 11].

However, for structures which are more than this height, it must be realised that not only can lightning directly strike the top of the structure, but it can even strike the side of the structure as the flashover distance for a lightning strike is unlikely to exceed 60m.

Thus, the usual method of determining the protection for such structures is to use the rolling sphere method (Figure 12) of

determining the required protection [24]. This is based on the fact that lightning comes down from cumulonimbus clouds in steps of around 50m dependant on the charge on the down-coming leader.

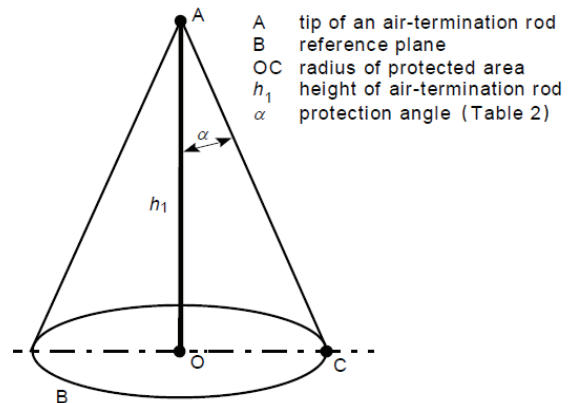


Figure 11 - Volume Protected by Air Termination Rod [24]

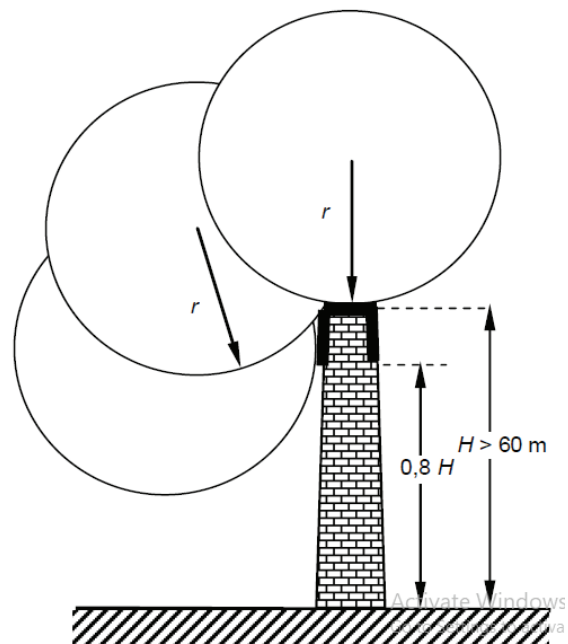


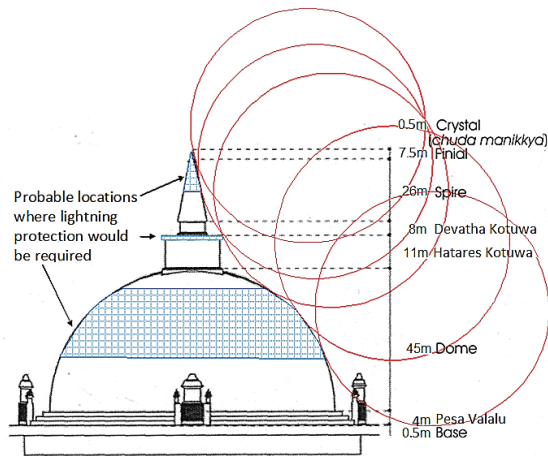
Figure 12 - Protection According to Rolling Sphere Method [24]

Thus, when the tip of the down-coming leader is around 50 m from the ground, it can virtually strike any object within a radius of 50 m. This gives rise to a 50 m radius rolling sphere. Depending on the class of lightning protection required, rolling sphere radii of 20 m, 30 m, 45 m and 60 m may be selected as specified in Table 2 of the standard.

Since the Ruwanweliseya stupa is obviously the highest structure in the neighbourhood (around 103 m), if lightning protection is to be provided, it should correspond to class I with a rolling sphere radius of 20 m. The rolling sphere



method requires that a sphere of radius 20 m (for class I) be rolled all over the surface of the structure to be protected, and where the sphere touches the surface of the structure, protection needs to be provided (Figure 13).

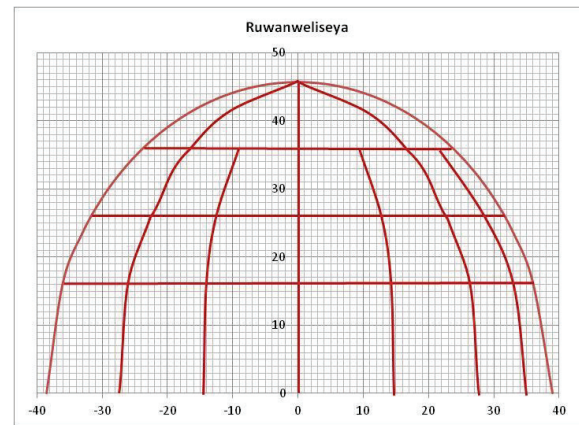


**Figure 13 - Determination of Areas to be Protected using the Rolling Sphere Method**

Further, for class I protection, there is also a requirement that down-conductors be provided all around the structure to be protected at horizontal spacings of approximately 5 to 10m. The circumference of the dome of Ruwanweliseya being around 242 m, a total of over 24 down conductors would be required. The locations of the horizontal tapes to form the required meshes of approximate size less than 10 m×10 m would be determined by the rolling sphere method.

Based on the rolling sphere method, it is seen that, not only the top portion of the spire would need protection, but so would be the perimeter of the top of the square four-sided tee, and a part of the dome would all need to be protected. If the protection of the dome area is considered, the protective copper tapes would probably take the form shown in Figure 14.

IEC62305-3 further states that the observation data show that the probability of flashes to the sides decreases rapidly when approaching ground. It thus recommends installing a lateral air-termination system only on the upper 20% of tall structures.



**Figure 14 - Location of Copper Tape Mesh on Dome**

This would be very unlikely to be the best form of protection of the Ruwanweliseya from a lightning strike.

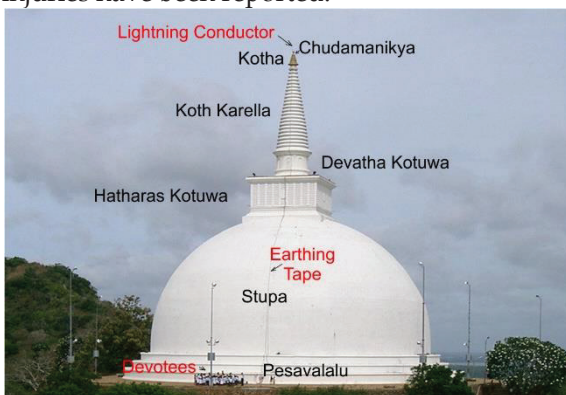
### 3. Analysis and Discussion

Ruwanweliseya stupa has existed for over two thousand years, and although there are records in the Mahavamsa that lightning protection has been provided, there are no records that lightning has ever struck and damaged this Stupa. It appears that early lightning protection for the Stupa has probably been provided through the Vajra Chumbaka at the top of the Stupa and being finally earthed at the copper plate, silver plate and the iron mesh at the base of the Stupa. The material of the bricks used and the butter clay that held the bricks together would have possibly provided the effective distributed down-conductor from the Vajra Chumbaka to the earth electrodes at the base. When lightning actually struck the pinnacle, it would have been harmlessly dissipated to the interior of the stupa structure with no physical damage whatsoever.

At the time of the finding of the Ruwanweliseya, and recorded by Smither in 1894 [25], the height to the top of the existing ruin was only around 54m, and to the copper finial present was around 60m. The height of the original Stupa appears to have been around 85m according to the Mahavamsa. Thus, extensive reconstruction has taken place since then to bring it to its present height of 103m. It should be noted that the material used in the reconstruction may have been different to that originally used nearly two thousand years before [14]. Thus, the properties of earthing could also have been different. Even so, no lightning strikes damaging the Ruwanweliseya structure has been recorded even since then even before the present lightning protection

consisting of a copper lightning conductor and a single down conductor has been installed.

Studies on lightning protection have shown that earthing tapes beyond about 50m in length are ineffective in earthing a lightning installation on account of the high inductance. Thus, the present method of earthing using a single lightning down conductor on the surface of the Ruwanwelisaya Stupa would probably dissipate only a small fraction of the energy to the external earthing point. It could also be prone to cause harm to persons in the neighbourhood of the tape across the stone paved platform than providing useful earthing as seen by devotees gathered near the down conductor (Figure 15). Fortunately, no such injuries have been reported.



**Figure 15 - Ruwanwelisaya with Devotees Standing next to Down Conductor**

Although the rolling sphere analysis shows that part of the dome is theoretically vulnerable, standards state that it is usually only the top 80% of a structure that is really vulnerable, other than any sharp edges that may be present. As the height of the Ruwanwelisaya to the top of the finial is around 103 m, only the top 20% (21 m) needs to be protected based on the determination of the rolling sphere. As the spire and finial together account for 34m, providing protection to the spire and the top edge of the square just below the DevathaKotuwa is also vulnerable due to its sharp corners and would need lightning protection along its top edge.

For earthing to be effective and for as low a voltage as possible to be generated, and not bring down to the stone paved platform at the bottom of the dome, earthing should be done as close as possible to the lightning conductor and earth tapes.

In ancient times, effectively the earthing went right through the central axis of the Ruwanwelisaya from the finial vertically

downwards. Gomes [22] has analysed the structure of the Stupa as a collection of lumped circuit elements using software to show that the thinly distributed current, driven into the deeply laid foundation of the structure, prevents development of significant step potentials in the vicinity that could pose danger to the devotees.

It is now not feasible for a down conductor to go through the spire, the Devathakotuwa, the vedika and the dome, right down to the silver plate, copper plate and the iron mesh. However, this may not be necessary as the very low thickness of cement between the bricks ensure the transfer of energy directly from brick to brick, and a good contact with the top portion would perhaps be adequate.

What may be feasible would be to provide adequate metallic down-path along the surface of the Spire and the Devathakotuwa, and to make several earthing connections to the body of the dome.

This suggestion needs further study before implementation, as this too may be an act of going overboard, as the dome is fully symmetrical, and the currents would naturally get distributed over the very large area of the stupa.

Although lightning protection and its earthing have been provided for the Ruwanwelisaya in around 1956, there is no evidence to show whether any lightning currents actually flow through this path, or along the surface of the dome, or through the centre of the structure itself. It is thus necessary, before any extensive changes are made to the earthing of the Stupa, lightning recorders be installed both at the top of the Stupa (near the finial) and at the bottom (where the earth tape comes out from the elephant wall). This study would inform what effect the present protection has, or whether it is just a misleading device giving false security to the persons in the neighbourhood in the event of a lightning fault.

#### **4. Conclusions and Recommendations**

The ancient stupas in Sri Lanka are among the tallest man-made structures in the world. While many stupas in other countries have been struck and damaged by lightning strikes, the stupas in Sri Lanka, before the addition of recent lightning protection, have not been damaged by lightning.



Lightning protection for the Ruwanweliseya has presently been provided using a single copper lightning rod and a single copper tape down conductor, without considering the requirements of the relevant standards.

The exact location of the burial of the earth electrode/s for the lightning protection is unknown. What is known is the point at which the tape comes out from the elephant wall. There is also no removable connection to permit regular measurement of the earth electrode resistance. The location of the earth electrode/s should be exactly determined, probably using metal detectors available, perhaps with the armed forces.

The length of the down conductor and earth tape should be kept to a minimum to prevent high voltages developing across the inherent inductance of the tape, due to the high rate of rise of the lightning current waveforms.

Since the structure (Ruwanweliseya) is 103m in overall height and is the highest structure in the immediate neighbourhood, the rolling sphere method (radius 20 m) of designing the lightning protection must be used as per standards. The rolling sphere design, taken as a whole, suggests that the spire and the edges of the vedika need protection against lightning.

A single lightning conductor installed does not completely serve the purpose of protecting the Stupa.

In doing restoration of lightning protection of any stupas in the future, not only care should be taken to preserve the original brick, soil, or clay structure in order that the earthing properties of the original structure are not lost, but also to examine the possibility of earthing the chudamanikya through the dome itself.

In ancient times, the lightning energy probably went through the structure without harming the stupa due to the flexible nature of the butterclay that bonded the bricks. The modern external copper tape on the surface of the stupa, may not actually be transmitting the major portion of the lightning energy to earth so that it might be desirable to undertake a study, by installing suitable lightning counters or other devices at both the top of the lightning conductor as well as towards bottom, to determine what fraction of the lightning actually passes on the copper tape to ground.

## Acknowledgement

Author wishes to acknowledge the assistance given by the TRCSL in undertaking the original visit to study the lightning protection at Ruwanweliseya.

## References

1. "The History of Lightning Protection", Lightning Strike Ltd., [Online]. Available: <https://www.lightningstrikeltd.co.uk/blog/the-history-of-lightning-protection/>.
2. "10 Tallest Man-Made Architectural Triumphs from our Ancient World". [Online] Available: <https://www.realmofhistory.com/2015/11/13/10-tallest-man-made-architectural-triumphs-from-our-ancient-world/>.
3. Paslow, S., "The Eerie Saint Elmo's Fire", November 2016. [Online] Available: <https://mysticsciences.com/2016/11/17/the-eerie-saint-elmos-fire/>
4. Shah, S. Q. A., "Medieval Peshawar (1000-1526 AD)," Ph.D. Dissertation, Area Study Center, University of Peshawar, Pakistan, 2013. Available <http://pr.hec.gov.pk/jspui/bitstream/123456789/2530/1/3086S.pdf> Accessed: 20 June 2023.
5. Diskul, M. C. S., "The History of the Temple of the Emerald Buddha." <http://www.cs.ait.ac.th/wutt/wat.html> Accessed: 20 June 2023]
6. Susantha Goonatilake, "Tech History - Sri Lankan", [Online]. Available: [https://www.academia.edu/38325027/Tech\\_history\\_doc](https://www.academia.edu/38325027/Tech_history_doc).
7. "Boudhanath" [http://www.khandro.net/stupa\\_Boudhnath\\_KD.htm](http://www.khandro.net/stupa_Boudhnath_KD.htm) Accessed: 20 June 2023.
8. Susantha Goonatilake, "Sri Lankan Lightning Conductors in Comparative Perspective", [Online] Available: [https://www.academia.edu/38324958/history\\_science\\_article\\_doc](https://www.academia.edu/38324958/history_science_article_doc).
9. Lucas, J. R., "High Voltage Engineering", Chapter 3, University of Moratuwa, 2001, [Online] Available: [http://prof.rohan.lucas.lk/images/notes/HV%20Voltage/HV\\_Chap3.pdf](http://prof.rohan.lucas.lk/images/notes/HV%20Voltage/HV_Chap3.pdf).
10. Wilhelm Geiger, "The Mahavamsa or The Great Chronicle of Ceylon", English Translation, Oxford University Press, 1932.



11. "The Mahavamsa: The Great Chronicle of Lanka from 6<sup>th</sup> Century BC to 4<sup>th</sup> Century AD", Translated from Pali by Wilhelm Geiger, Web version by Rhajiv Ratnatunga, Pittsburgh, PA, USA, August 2002. [Online] Available: <https://www.budsas.org/ebud/mahavamsa/index.htm>.
12. Sherren. Amendra, "Beyond the seeing eye: The Mahathupa of Lanka", Sarvodaya VishvaLekha Publishers, First Edition, 2006.
13. Wilhelm Geiger, "Culawamsa being the more Recent Part of the Mahavamsa, Part I, German Translation. English Translation by Rickmers, C.M., The Ceylon Government Information Department, Colombo, 1953.
14. Ranaweera, M., and Helarisi Abeyruwan, "Materials Used in the Construction, Conservation, and Restoration of Ancient Stupas in Sri Lanka", University of Cambridge, Available: <https://www.arct.cam.ac.uk/system/files/documents/vol-3-2573-2586-ranaweera.pdf>.
15. Gomes, C., "Historical View of Lightning", Chapter 1, [Online] Available: <http://llampeinternational.com/downloads/LightningInSriLanka/Historical View of Lightning.pdf>.
16. Edirisinghe, M., and Maduranga, U.G.D., "Distribution of Lightning Accidents in Sri Lanka from 1974 to 2019 Using the DesInventar Database," ISPRS International Journal of Geo-Information, Vol.10, No.3, p.117, Feb.2021. Available: <http://dx.doi.org/10.3390/ijgi10030117>.
17. "Lightning Damages Sri Lanka's Historic Mihintale Dagoba", [Online] Available: <http://mingkok.buddhistdoor.com/en/news/d/9053>.
18. "Lightning Strikes Mihinthale Stupa", Sunday Times, Sri Lanka, April 25, 2000. [Online] Available: [https://www.sundaytimes.lk/100425/News/nws\\_12.html](https://www.sundaytimes.lk/100425/News/nws_12.html).
19. Sreedhar, S., and Srinivasan, V., "Lightning Strokes and its Effects on Historical Monuments, Heritage Properties and Important Landmarks a Detailed Perspective of Traditional and Scientific Methods of Lightning Protection Systems," Int. J. Eng. Technol., Vol. 7, No. 2, p. 784, 2018. DOI: 10.14419/ijet.v7i2.12421.
20. Srinivasan, V., Fernando, M., Cooray, V., "Modelling and Assessment of Lightning Hazards to Humans in Heritage Monuments in India and Sri Lanka," IEEE Access, Vol. 8, pp. 228032-228048, 2020. doi: 10.1109/ACCESS.2020.3046100.
21. Bandara et al., A., "Lightning Risk Analyses on Protected Sri Lankan Heritage Stupas," 2018 IEEE 13th International Conference on Industrial and Information Systems (ICIIS), Rupnagar, India, 2018, pp. 322-327, doi: 10.1109/ICIINFS.2018.8721399.
22. Gomes, C., Kadir, M.A.A., Izadi, M., and Gomes, A., "Lightning Current and Voltage Distribution of Large Axially Symmetric Buddhist Stupa in Sri Lanka", 2014 International Conference on Lightning Protection (ICLP), Shanghai, China, 2014, pp. 1637-1651.
23. Rajapaksha, U.K.R.M.H., Kumara, J.R.S.S., Fernando, M.A.R.M., Susantha, K.A.S., Venkatesh, S., and Jayaratne, D.K., "Possible Lightning Hazards to Humans Near Giant Ancient Stupa," in 2019 14th Conference on Industrial and Information Systems (ICIIS), 2019. DOI:10.1109/ICIIS47346.2019.9063283.
24. Protection against Lightning - Part 3: Physical Damage to Structures and Life Hazard, IEC 62305-3, 2010.
25. J.G. Smither, J.G., "Architectural Remains, Anuradhapura, Ceylon", Asian Educational Services, 1994, (first published 1894, London).