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IMPACT AND MITIGATION OF LIGHTNING ON STRUCTURES AND INFRASTRUCTURE

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ABSTRACT

Lightning poses a dual threat to buildings through direct and indirect strikes. Damage resulting from a direct strike includes the shattering of wood, windows, masonry, and other poorly conductive materials, as well as the burnout of electrical power and distribution equipment. Energy distribution transformers may also burst due to the impact of a direct lightning strike. On the other hand, indirect strikes can affect telecommunications lines, electricity cables, instrument data cables, and even underground plumbing, potentially carrying damaging lightning surges into a building. Certain fiber-optic cables may prove inadequate in providing sufficient protection. To safeguard structures from potential harm, two prominent technologies are employed: the Stormaster Early Streamer Emission Terminal and the Benjamin Franklin Rod. The former is the more commonly adopted approach, leveraging contemporary protective system technologies. Extensive research conducted during our project indicates that damage to a structure caused by an Early Streamer Emission terminal is less severe than that which would result from traditional lightning protection methods. An innovative advancement in this realm is the Non-Electronic Lightning Terminal, considered a more promising approach than its electronic counterpart. Further research on non-electronic lightning terminals, both in conceptualization and practical application, holds the potential to provide clearer insights into their efficacy and benefits.

Keywords: Lightning, Lightning-Strike, Lightning-Rod, Light Protection System

1. INTRODUCTION

Lightning, an uncontrollable weather phenomenon, manifests as a high-energy luminous electrical discharge from thunderclouds, often accompanied by thunder. With temperatures soaring to about 30,000 degrees Celsius, a lightning discharge can wreak havoc in a matter of milliseconds—burning down buildings, melting materials, and causing structural cracks. The dangers extend to living beings, as lightning can result in electrocution, explosions, and fires within structures. Moreover, the lightning current can infiltrate buildings through various conduits, such as phone lines, analogue or digital data lines, posing a threat to electronic circuits and apparatus.

Gas piping systems, particularly those transporting combustible fuel gas, face heightened risks of fire during lightning strikes. Beyond these immediate dangers, lightning interference can disrupt air traffic control and radar systems. The atmospheric transfer of electrons to Earth during lightning is a complex process influenced by wind-induced electron rubbing and gathering, resulting in cloud charging through friction and induction.

The National Board of Fire reports that lightning is a leading cause of farm fires, contributing to over 80% of livestock losses and causing millions of dollars in damage to farm buildings and equipment annually. Lightning strikes the ground at a rate of 30 to 100 strokes per second, with the Earth experiencing about 3 billion lightning strokes each year. Lightning-related injuries and fatalities worldwide underscore the need for effective protection systems. A well-designed lightning protection system is crucial for safeguarding buildings, telecom towers, and other structures from lightning strikes.

Building structural steel inherently carries lightning, but a proper lightning protection system is necessary to facilitate the safe dissipation of the lightning's energy. Without such a system, lightning may seek alternative paths, resulting in arcing, side-flashing, and potential damage to mechanical systems like HVAC or electrical systems within a building. Notably, lightning-related incidents have caused fires, explosions, and various other damages worldwide.

1.1: Prominent Cases of Damages and Injuries Due to Lightning Worldwide:

Table 1: Lightning-Related Damages

Worldwide damages	
California 1991-1995	Due to Lightning 30,190 house were Light up & monetary loss amounting approx. $175.2 million occurred. After the 5 year period 1992-1996, govt. of Florida paid out $1.7 billion in lightning-related claims.
Denmark NJ 1926	A lightning caused blast at the Naval Air Rocket Test Station & damaged resources worth about $70 million with 13 people killed.
USA July 23, 1997	The most expensive civilian lightning loss on record is in the Denver warehouse. Damage to building & warehouses cost about$ 50 million.
Florida May to July, 1999	Lightning destroyed 126 homes, 25 business, and 86 vehicles. Suppression costs were $160 million. Damage losses amounted to $394,600,000.
India June 30, 2009 or July 18, 2011	A lightning struck in Bihar and Jharkhand killed at least 35 people at this place including eight children and also in Billeshwar town of Porbandar, Jetalsar town of Rajkot and Nagvadar town of Rajkot. There were cracks in building & 20 people killed because of lightning.
Indonesia – Cilacap October 24 1995	At 43.5°C (over the flash point), lightning struck the automatic gauging system of a 38,800 m^3 fixed-roof tank that was being filled with kerosene. The gaseous cloud over the tank exploded destroying the roof. The burning liquid spread the fire to six other tanks in the dike. The residents and staff members were evacuated. The damages are assessed at 560 MF.
United States - Baytown September 2 1997	Lightning ignited the crude oil floating on the water surface near a refinery. The refinery and the fire hall were destroyed by the ensuing fire.

2. STUDY AREA

For the study, comprehensive pre-strike photographs of buildings equipped with Early Streamer Emission (ESE) systems were captured from various angles. These structures underwent regular visual inspections every couple of months to assess any potential lightning strike damage. Whenever new points of impact were identified, photographs were taken and preserved for the purpose of this research. The subsequent case studies provide instances of both pre- and post-strike photos, illustrating structures affected by recent lightning strikes.

These case studies serve to highlight instances where lightning strikes occurred in close proximity to ESE air terminals, challenging the manufacturers' claims that the buildings are adequately protected. The visual evidence presented in the case studies questions the efficacy of the ESE systems in providing the promised level of safeguarding against lightning strikes.

3. DATA COLLECTION

3.1 SVNIT Hostel Building, Surat

The image displays a hostel building equipped with the latest Early Streamer Emission (ESE) terminals. Eight ESE terminals, at an approximate cost of 800,000 Indian rupees, have been installed on the building. Notably, there have been no reported cases of lightning damage to this structure, underscoring the effectiveness of the ESE terminals in providing protection against lightning strikes.

Figure-1 SVNIT Hostel Building.

3.2 Kuala Lumpur's Wisma Tanah Building

In 1999, a French-made Early Streamer Emission (ESE) air terminal was installed on a 5-meter guyed pole within a government administrative building. Additionally, Franklin rods were placed throughout the building, positioned approximately 0.5 meters from the corners, as illustrated. However, in 2003, it was reported that a lightning strike had occurred on the building, hitting a corner about 10 meters away and 8 meters below the depicted air terminal.

It was noted that the airport adhered to the French standard NFC 17-102, which had been formulated by the manufacturers of the ESE terminals. Criticism of this standard emerged locally from the French scientific organization INERIS [7], which asserted that the foundation of the standard was flawed. Furthermore, the INERIS report concluded that the producers of the ESE air terminals had not adequately tested their product in accordance with the specified norm. The 1999-published ESE report from the NFPA was also cited in the INERIS report.

3.3. Setapak RIA Apartment Buildings

In 1997, the photographs of these buildings were taken, showcasing the presence of already-installed French-made Early Streamer Emission (ESE) air terminals. The apartment buildings exhibit multiple levels of roofing, and the air terminals are strategically positioned at the center of the highest roof for each structure.

A recent survey highlighted that the buildings had experienced numerous lightning strikes. Upon closer examination, it becomes evident that some of the affected locations were on the roofs housing the air terminals. This observation prompts a closer scrutiny of the effectiveness of the installed ESE air terminals in preventing lightning strikes on these specific structures.

4. METHODOLOGY

4.1 Conventional method of Lightning Guarding

Given the hazardous effects of lightning on both human beings and infrastructure, a prompt and cost-effective solution is imperative. Several methods exist to shield buildings from lightning, with two primary approaches being widely employed:

1) **Lightning Protection System (LPS):** This system is designed not only for personnel safety but also for safeguarding the building. Implementing a typical LPS involves several key steps:

- An evaluation of the risk based on actual lightning exposure.
- Designing the down-conductors and the air termination network.
- Establishing the earth electrodes and earth termination network.
- Ensuring the integration of metallic services entering a structure and the metalwork inside it with the LPS.

2) **Lightning Rod:** Lightning rods, also known as air terminals or Franklin rods, are another method employed for lightning protection. These rods are strategically placed on the highest points of a structure to intercept lightning strikes, providing a controlled path for the electrical discharge to reach the ground safely.
    - These methods play a crucial role in mitigating the potential risks associated with lightning strikes, ensuring the safety of individuals and the protection of structures.

4.2 Materials used for Lightning Protection.

1) **Material Class Specification:**
    - Structures up to 75 feet tall should utilize Class I materials.
    - Structures exceeding 75 feet above grade should opt for Class II materials.
2) **Compatibility Assurance:**
    - Coordinated selection of materials for both building construction and lightning protection is essential to ensure compatibility.
3) **Material Compatibility Recommendations:**
    - Avoid placing aluminium lightning protection materials on copper surfaces, embedding them in concrete or masonry, or using them for underground systems.
    - Surfaces made of aluminium or external sheet metal should not incorporate copper lightning protection materials. Tin coating is mandated for copper system components within two feet of chimney exhausts to prevent corrosion.
4) **Strike Termination Devices:**
    - Metallic bodies with a thickness of 3/16" or more can serve as strike termination devices without the need for air terminals.
    - To be part of the lightning protection system, these bodies must be connected to conductors and bonding fittings with a surface contact area of three square inches.
5) **Cable Conductor Guidelines:**
    - Cable conductors must establish a horizontal and downward two-way channel from strike termination devices to ground system connections.
    - Prohibitions include sharp bends and excessive splices in cable conductors.
    - No conductor bend should have a radius smaller than 8 inches or a final included angle less than 90 degrees.
    - Structural components and design elements should be employed when possible to minimize the visual impact of exposed conductors.

4.3 Conventional rod.

The traditional lightning rod, invented by Benjamin Franklin in 1749, is a widely adopted method for protecting structures from lightning strikes. Also known as a lightning conductor, this metal rod is affixed to the top of a building and connected to the ground through a conductor. In case of a lightning strike, the rod provides a path for the current to safely travel to the ground, reducing the risk of fire or electrical hazards within the structure. Lightning rods are part of a broader lightning protection system, which includes a network of conductors on the roof, paths connecting the roof to the ground, bonding connections to metallic objects inside the building, and a grounding network. Typically made of copper or aluminum, the rooftop lightning rod is positioned at regular intervals on the highest parts of a building. Despite its widespread use, the effectiveness of this technology is not foolproof, and ongoing research seeks more convenient and affordable options for lightning protection. The lightning protection systems are not limited to buildings; they are also installed on trees, monuments, bridges, and watercraft to prevent damage from lightning strikes. Occasionally, individual lightning rods may be referred to as strike termination devices, air terminals, or finials.

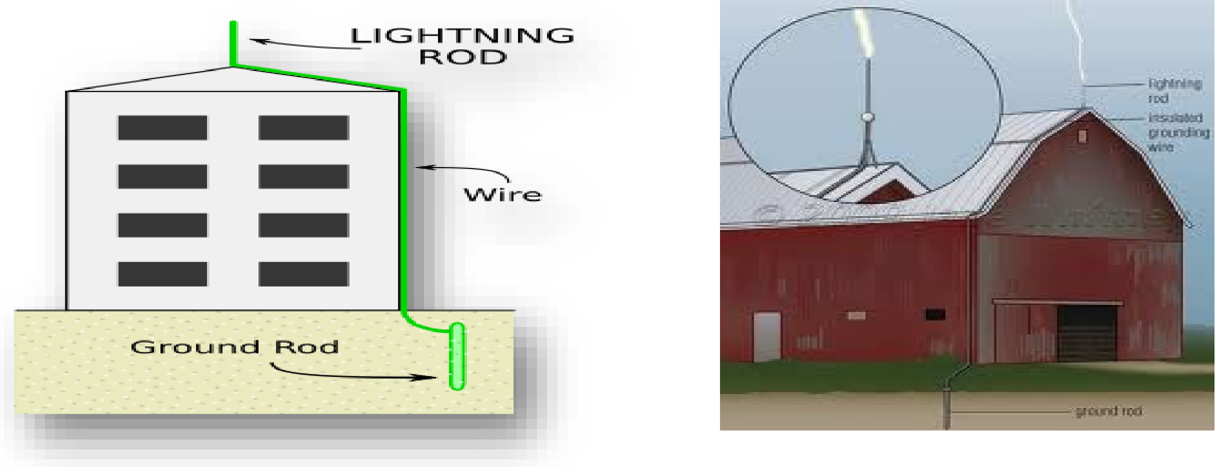

Figure-2 Conventional rod on building.

4.4 Limitation of lightning rod

The traditional lightning rod system, while effective, has certain limitations and challenges. The protective radius of a standard rod is relatively small, necessitating the installation of multiple rods and down conductors. This, in turn, requires a significant number of earth pits, leading to higher overall project costs. Moreover, the lack of available test certifications for the rods raises concerns about their performance and reliability.

Installation costs are considerably high, and the design becomes more complex. The life and effectiveness of the metal components are dependent on the discharge current, and no testing has been conducted on the rods before installation. Regular maintenance is crucial to ensure the integrity of the system due to the numerous connections involved. Loose connections or breaks in the loop can result in dangerous flashes that may harm nearby structures or equipment.

In industrial settings where charges are naturally generated, lightning currents may be drawn to metal components of factories, bypassing the lightning rod. This scenario poses a risk as the lightning current may strike active metal components rather than the inert lightning rod.

To address these challenges, alternative non-traditional methods are being explored for lightning protection. Two such methods under consideration are the Stormaster Early Streamer Emission (ESE) system from LPI and the Charge Dissipation Terminal (CDT). These alternatives are being tested to determine their efficacy in safeguarding structures, especially in situations where traditional lightning protection methods are impractical or less efficient.

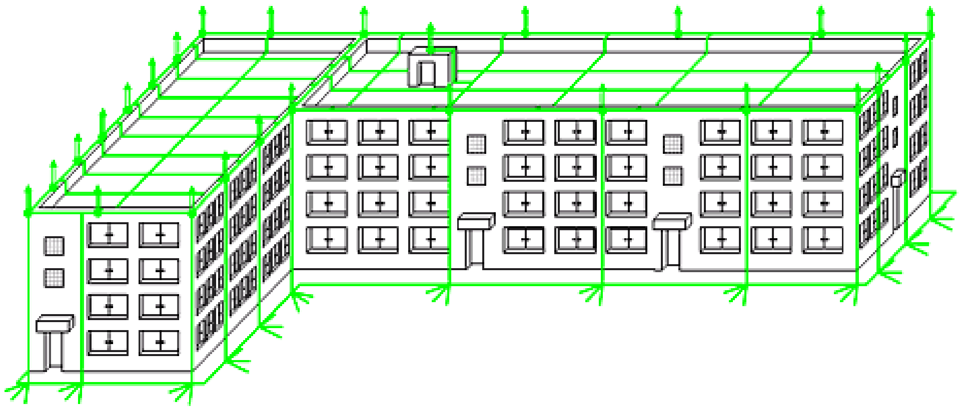

Figure-3 Lightning rods on building.

4.5 LPI's Stormaster ESE

The LPI Stormaster ESE series of terminals presents a reliable and efficient solution for safeguarding buildings from direct lightning strikes. Positioned strategically, the Stormaster ESE terminal captures lightning energy at the desired location. This energy is then conveyed through a down conductor to the ground, where it is safely dispersed without posing risks to people or property.

The primary objective of the Stormaster ESE emission air terminals is to become the preferred attachment site for lightning by emitting streamers early in the streamer-formation phase of a lightning strike. The Stormaster ESE terminal accumulates ground charge as the lightning strike builds up. Just before the impact, during the emergence of stepped leaders from the cloud, the Stormaster ESE terminal releases a sequence of ground charge pulses. This action creates a streamer from its own structure before streamers originate from other structures, reaching the stepped leaders ahead of rival broadcasters. Operated by LPI, the Stormaster ESE Air Terminal effectively manages ground charge during the lightning strike.

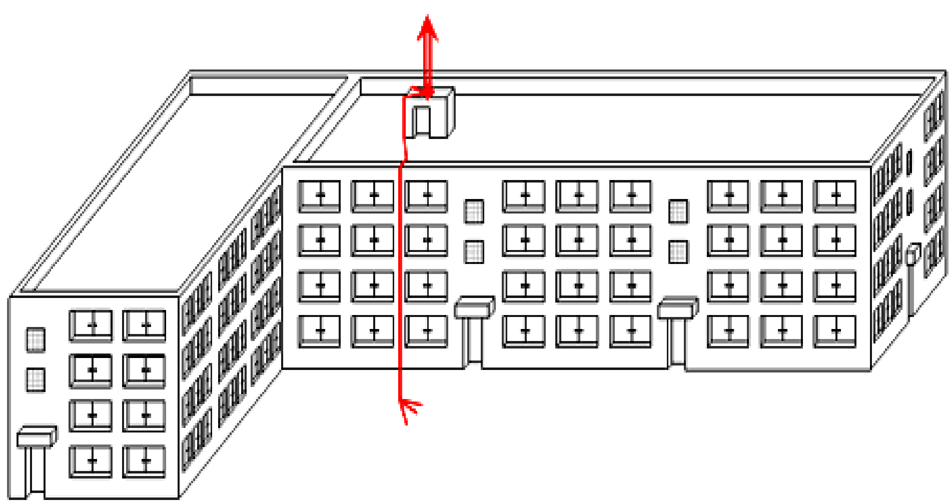

Figure-4 Stormaster ESE on building.

4.6 How does The ESE endpoint of LPI Stormaster work?

The Stormaster Early Streamer Emission (ESE) air terminal employs the natural electrical field to release an upward leader on schedule. This method provides a secure and effective means of managing potentially hazardous lightning energy at a designated location. As a thunderstorm approaches overhead, the voltage of the ambient electrical field surrounding the Stormaster ESE increases.

When a down leader approaches the shielded area, the Stormaster ESE terminal triggers an upward streamer, leading to a sudden surge in the electric field. Compared to a traditional rod, the Stormaster ESE may offer a larger or more effective protection area due to its early streamer emission concept. The ability of the Stormaster ESE terminal to release the upward streamer from the finial tip earlier gives it an advantage over other structural points in capturing lightning discharges within the protected region.

4.7 Protection Performance and Installation.

The protection radius (Rp) of a Stormaster Early Streamer Emission (ESE) terminal is calculated based on the French National Standard NF C 17-102, published in July 1995. The formula for calculating Rp is $Rp = \sqrt{h(2D-h) + \Delta T(2D+\Delta T)}$ for $h \geq 5$m. Here, the key parameters for the calculation of Rp include:

ΔT: The time interval established during the test, ranging from ΔT (μs) 15 to ΔT (μs) 60.

h: The actual height of the Stormaster terminal above the area to be protected (m).

D: The protection levels are specified in Annex B of the standard NF C17-102, with D representing the protection level chosen, depending on the desired level of protection.

4.8 Where the Stormaster ESE from LPI installed?

- Telecommunications & Broadcasting
- Petrochemical, oil & gas
- High rise buildings and hotels – all types of structures
- Stadiums, racetracks, and golf courses are examples of sports facilities.
- Military and Civil Aviation
- Mining includes bauxite, coal, gold, nickel, iron, and copper.
- All types of industrial facilities
- Defense includes arms storage, communications, and monitoring.
- Production and distribution of power
- Transportation networks, monuments, and ecological sites

4.9 The ESE Stormaster Range.

LPI's line of Early Streamer Emission air terminals includes four types.

Ordering Codes:-

1) Stormaster-ESE-15
   Stormaster-ESE-15-GI
2) Stormaster-ESE-30
   Stormaster-ESE-30-GI
3) Stormaster-ESE-50
   Stormaster-ESE-50-GI
4) Stormaster-ESE-60
   Stormaster-ESE-60-GI

Table 2 Protection Level of ESE Range

PROTECTION RADIUS (m)-(Rp)									
h=height of stormaster terminal above area to be protected	2	4	5	6	10	15	20	45	60
Protection level 1 (high protection)									
Stormaster 15	13	25	32	32	33	34	35	35	35
Stormaster 30	19	28	48	48	49	50	50	50	50
Stormaster 50	28	55	68	69	69	70	70	70	70
Stormaster 60	32	64	79	79	79	80	80	80	80
Protection level 2 **(**medium protection**)**									
Stormaster 15	18	36	45	46	49	55	55	60	60
Stormaster 30	25	50	63	64	66	71	71	75	75
Stormaster 50	35	69	86	87	88	92	92	95	95
Stormaster 60	40	78	97	97	99	102	102	105	105
Protection level 2 **(**standard protection**)**									
Stormaster 15	20	41	51	52	56	60	63	73	75
Stormaster 30	28	57	71	72	75	77	81	89	90
Stormaster 50	38	76	95	96	98	100	102	110	110
Stormaster 60	44	87	107	107	109	111	113	120	120

4.10 Technical Data of Stormaster ESE 15, 30, 50 & 60.

Stormaster-ESE15, 30 & 50

Finial Tip:- Chrome plated brass tip

Panel Material:- Anodized Aluminum

Terminal Colour:- Gold

Weight:- 1.8 kg (Approximate)

Insulation Material:- UV rated Evoprene

Down conductor Connection: - Lug connection

Stormaster-ESE-60

Finial Tip: Chrome plated brass tip

Panel Material: Anodized Aluminum

Terminal Colour: Gold

Weight: 2.8 kg (Approximate)

Insulation Material: UV rated Evoprene

Down conductor Connection: Lug connection

5. CONCLUSION

Against the conventional lightning rod (Franklin rod), CDT has potential to be an economic and effective solution to contain the harmful effects of lightning to a great extent. Feasibility of its application in general industrial and residential scenario needs to be tested, before concluding the pursuit for best solution in all respect. Initial study of the subject has led to the understanding of possible methods of tackling the adverse effects of lightning. As the damages caused by this natural phenomenon are enormous, it is required to research the issue to find out more economic and effective solution. When examining a lightning safety mechanism in its most elementary form, it is quite simple. An air terminal designed to attract and capture lightning strikes, together with a low resistance conducting cable that uses a conducting electrode to link the terminal to the earth and provide a conduit for the high energy to be dispersed into the ground. The structure is protected by this mechanism.

CONFLICT OF INTERESTS

None.

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