Technical Guidelines

For

HERITAGE BUILDINGS

Lightning Protection Survey and Design

September 2011

Contents

FOREWORD

These Technical Guidelines intend to propose value-added technical solutions for Architects, engineers and contractors.

It is based on the existing lightning protection standards. It must be remembered here that lightning protection design is based on statistical studies and it intends to limit as much as possible the damages due to lightning to human beings and structures:

"As in the case with anything related to the natural elements, a lightning protection system, designed and installed in accordance with this standard, cannot guarantee absolute protection to structures, persons or objects; however, applying this standard will significantly reduce the risk of protected structures being damaged by lightning." NF C 17-102 standard 2011.

"There are no devices nor methods capable of modifying the natural weather phenomena to the extent that they can prevent lightning discharges. Lightning flashes to, or nearby, structures are hazardous to people, to the structures themselves, their contents and installations as well as to services. This is why the application of lightning protection measures is essential." IEC 62 305 Part 3 : 2006

The responsibility of Indelec shall not be engaged in case of damages caused by lightning after implementing lightning warning systems and lightning protection systems installation, based on this survey recommendation. INDELEC shall not be liable for any financial compensation.

INTRODUCTION

Historical heritage is important to a city's identity and character. When a historical building is demolished, the loss is irrevocable. Natural and cultural heritage is one such invaluable public asset that belongs to society and posterity. It is part of the "social capital" of a country. We preserve heritage buildings not just for their architectural merits, but for the character and substance of the society which they embody. In many ways, heritage conservation is also a matter of sustainable development and cross-generational equity. The streets and buildings of cities and villages are part of the historic character of a country. Each townscape tells the story of its unique development, and gives a sense of place, continuity and cultural identity.

Conservation areas vary greatly in their nature and character. They range from the centres of our historic villages, towns and cities to model housing estates, houses set in their historic parks, 19^{th} century industrial buildings etc... Where these places are of special architectural or historic interest or deserve to receive careful protection, they are designated as conservation areas by planning authorities according to local and regional criteria.

The conservation of these historic buildings is not only a political or "specialized architects" concern. It is widely shared by the population and the Heritage Open Days in UK or the "Journees du patrimoine" in France are extremely successful, with millions of visitors to "national treasures".

In his book "Conservation of Historic Buildings", the author Bernard M. Feilden is mentioning: *"Perhaps, the most frequent of natural causes of violent damages is lightning (...). Lightning has a tendency to strike the tops of tall objects standing up above the general ground level. When there is a substantial electrical resistance in the path between the point of striking and the mass of the earth, damage will generally be caused"*

This document intends to propose economically-sounded engineering solutions for the lightning protection of historic buildings based on the latest standards requirements.

LIGHTNING PHYSICS

1. Storm conditions

Certain atmospheric conditions, such as high temperature or humidity, lead to storm clouds being formed. These huge, anvil-shaped cloud masses are usually of the cumulonimbus variety, the lower part being made up of water droplets while at higher altitude are found ice crystals.

Strong up currents within this type of cloud cause the electric charge on the water droplets to be separated resulting in high levels of positive charge at the top and high levels of negative charge at the bottom of the cloud.

A storm cloud forms overhead creating a vast dipole with the ground and, under the influence of the negatively charged cloud base, the ever present electric field in the atmosphere at ground level suddenly inverts and builds up rapidly reaching between 10 to 15 kilovolts per meter. An electrical discharge to the ground is then imminent.

2. The build up to a lightning strike

The first stage of a lightning strike involves an initial discharge of low luminosity and intensity known as a downward leader. It forms at the cloud centre and moves down toward the ground in steps of several dozen meters at a time. At the same time, the electric charge in the atmosphere at ground level increases as the downward leader gets closer.

Any high point in the vicinity immediately gives rise to natural ionization in the form of a series of electrical discharges which are blue in color. This is the point effect or corona effect. As soon as the downward leader is close enough to the ground, the ionization due to the corona effect intensifies, especially near any high point, and eventually turns into an upward discharge: this discharge is the upward leader that develops toward the cloud.

When one of these upward leaders comes into contact with the downward leader, a conductive path is created allowing a powerful current to flow. This is what we call a lightning strike which is characterized by its bright flash and the deafening sound of thunder. The lightning strike may in fact be made up of a number of successive return strokes, only a few hundredths of a second apart, all following the same highly ionized and conductive path.

Lightning Facts	
Peak Current	2 to 500 kA
99%	≤ 200kA
50%	≈30 kA
Polarity	90% Negative
Time between flashes	>10 sec
Return strokes	Usually 5 to 9
Duration	30 to 200 µs

LIGHTNING HAZARDS

1- Historic building dated structural engineering

"When there is a substantial electrical resistance in the path between the point of striking and the mass of the earth, damage will generally be caused". This is probably the main reason for heavy damages caused by lightning to Historic Building.

For modern structure, engineering companies will design usually reinforced concrete or metal frame structures. Both the metal frames and the rebars are providing the lightning current with conductive paths through the structure to the ground. The damages are usually visible with pieces of concrete falling apart: this is due to the lightning current forcing its way to the metallic structural components below the concrete surface. There are more electrical and networks damages than structural damages in case of modern buildings, even though a proper lightning protection system is widely required to minimize the risks.

Historic buildings are often built soundly, but due to the age of the building materials, the structure is unsafe in the event of a lightning discharge. The structure is mainly using masonry and wood construction materials. The masonry is made of stones or bricks assembled with mortar (lime or cement). Wood beams are used either as structural elements together with mortar or masonry or for complete wooden structure.

***Kukulkan stepped pyramid - Mexico**: Built by the pre-Columbian Maya between the 9th and 12th centuries AD*

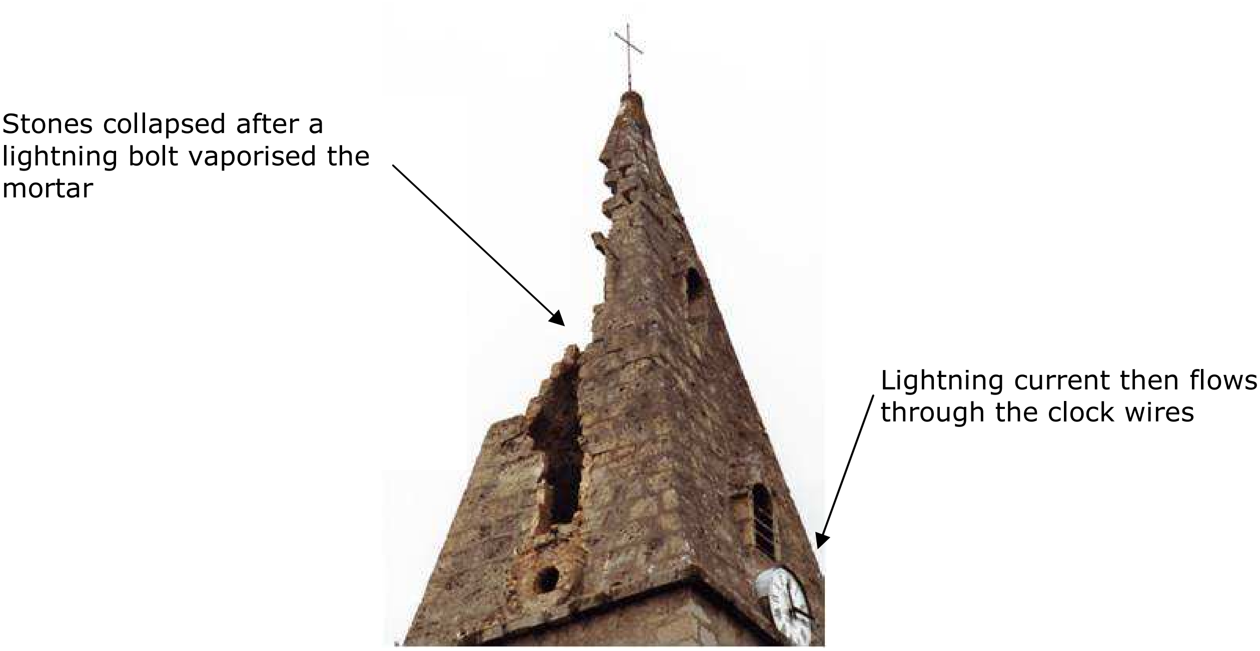
The main specificities of these materials, as far as lightning is concerned, are:

- Their very poor conductivity;

- Their poor insulation of these materials leading to moisture and humidity with diffusion and condensation phenomena

Besides, the lack of knowledge of the electricity and the lightning phenomenon obviously leads to the absence of any type of lightning protection (to appear at the end of the 18th century only). Lightning is widely associated with the Gods anger.

Therefore, lightning damages are extremely important: the current is usually moving through the most conductive paths (mortar or wood), destroying these consolidating materials. Stones are then collapsing with no more mortar maintaining them, such as this example of church tower (in this specific case, the lightning current destroyed the stone roof before connecting to the church clock wires):



2- Height of the Heritage buildings

Building height has always been associated with power and wealth: a King castle must be built with the highest keep. A temple or a church must also be higher than any surrounding buildings, illustrating the power of God(s):

Vincennes castle keep

Indian temple

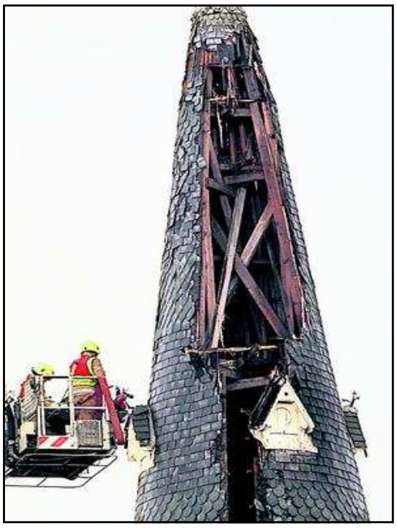
So majority of Heritage Buildings is also facing "high rise structures" lightning issues:

a- The first specificity of high-rise buildings as far as lightning is concerned, is the high frequency of discharges on the structure. This is due to the high electro-magnetic field concentrated at the top of the structure compared to the ground level, which ease the development of corona effect and then upward leaders.

b- The second specificity also deals with the height of these structures: the length of the lightning current path between the connection point (usually the top of the structure) and the ground is such that the surge and electrical arcing risk inside the structure is increased.

c- A very limited risk of "side flashes" also exists for these higher structures (please refer to INDELEC Technical Guidelines for High Rise Building lightning protection systems design).

Due to their usually high and isolated positions, Heritage Buildings are therefore especially prone to lightning discharges with increased risks of heavy damages and fire:


3- Budget and aesthetic constraints

It is today widely accepted that Heritage buildings are part of the “social capital” of a country and that they must be restored and preserved. Restoration constraints are dealing with budget and aesthetic issues:

a- The Heritage Buildings restoration is usually conducted by Conservation authorities or associations, both with limited budgets. Therefore the restoration and maintenance of these buildings must be extremely cost-effective ... and unfortunately many buildings are just left without any proper Lightning Protection Systems, whereas these buildings should benefit from such systems due to the risks lightning represents.

French castle destroyed by fire ignited by a lightning bolt: the municipality owing it had no budget to install a proper LPS

b- Heritage Buildings must be restored and maintained, usi
ng the most effective modern technologies for safety (including fire prevention, electrical safety, and security of the visitors...). But these "modern add-ons" must obviously be hidden not to destroy the original aesthetics.

Unfortunately, the installation of a proper Lightning protection system is commonly considers by Heritage Building architects as unacceptable since it affects the building aesthetics. But the potential loss of a "national treasure" or the huge reconstruction costs should rather be taken into account since technical solutions are available to install a LPS without affecting the building aesthetics.

4- Visitors safety

Besides the building integrity, lightning also represents a major harm to the visitors (and staff) of these monuments.

World famous Heritage Buildings attract **millions of visitors** yearly: 13 million for Notre Dame de Paris (France), 10 million for China Great Wall (China), 4 million for the Roma Coliseum (Italy), 2.5 million for the Taj Mahal (India) etc...

Evacuation of such crowd in case of lightning incident would be extremely complex with a very high risk of panic (due both to the large number of persons and the inadequacy of these historical buildings to such crowds). This important risk factor (please refer to the Lightning Risk Assessment survey: "danger for the persons = high risk of panic") must therefore be taken into account. In a few countries, a lightning protection system installation is now compulsory for such structures welcoming large number of visitors ("ERP" classification).

Visitors queuing in front of Versailles Palace (France)

Conclusion

A proper LPS design is therefore of the prime importance for Heritage buildings, to maintain these "national treasures" safe as well as ensuring the safety for staff and visitors.

Lightning damages on Heritage buildings are extremely severe due the structural engineering used centuries ago (without any metallic reinforcement that can help to dissipate the lightning current to the ground) and often their high and isolated location. Moreover, these buildings are today open to the public with millions of tourists visiting these sites. These factors are taken into account into the Lightning Risk Assessment and usually lead to the installation of LPS (according to the IEC 62 305 Part 2 or UTE Guide C 17 108 "risk assessment surveys").

Lastly, a well designed and engineered lightning protection system is almost invisible and does not affect the building aesthetics:

Example of World Heritage building with well-integrated INDELEC Lightning protection System installed (Angkor Vat – Cambodia)

1- Lightning Protection Standards

a- International Standards for Lightning Protection:

The IEC recently published a new series of standards for Lightning protection:

IEC 62-305 Part 1: General Principles
IEC 62-305 Part 2: Risks management
IEC 62-305 Part 3: Physical damage to structures and life hazard.
IEC 62-305 Part 4: Electrical and electronic systems within structures

b- National standards for Lightning Protection:

They are usually based on the IEC standards for conventional systems (single rods, meshed cage and catenary wires). For Early Streamer Emission air terminals, national standards are usually based on the French standard NF C 17-102 (1997).

This survey will consider both types of standards, for conventional lightning protection systems as well as ESE air terminals.

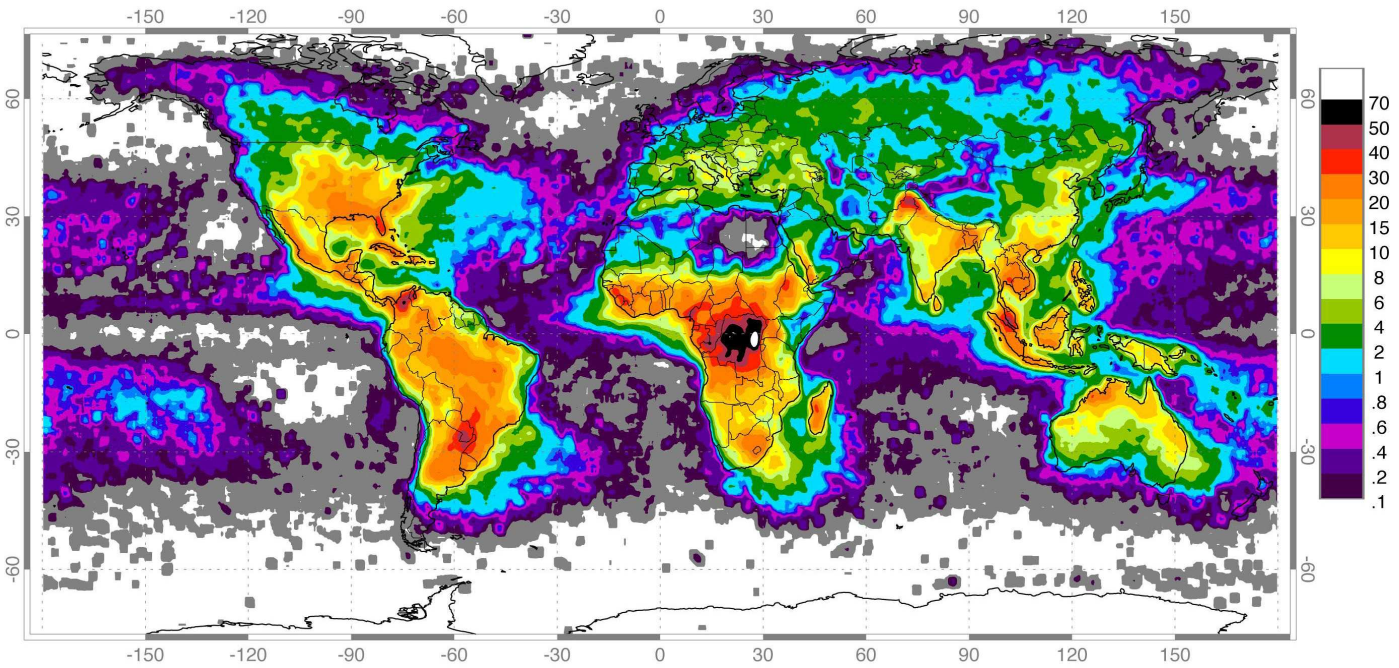
Standard	Designation
IEC 62 305 (1st edition 01-2006)	Protection against lightning
NF C 17-102 (July 1995)	Protection of structures and open areas against lightning using early streamer emission air terminals.

2- Assessment of local lightning activity

A major factor for lightning risk evaluation is the value of the lightning frequency in the area: even in a single country, the lightning density can vary tremendously (from 3.2 to 14.9 for Vietnam as an example) and therefore it is of primary importance to assess properly the local lightning density to evaluate the risks and the protective measures required.

The standards are referring to three data:

- Isokeraunic level N_k,
- Lightning Flash Density N_g,
- Maximum Lightning Density $N_{g\,max}$ (takes into account the maximum lightning density and the precision of detection).

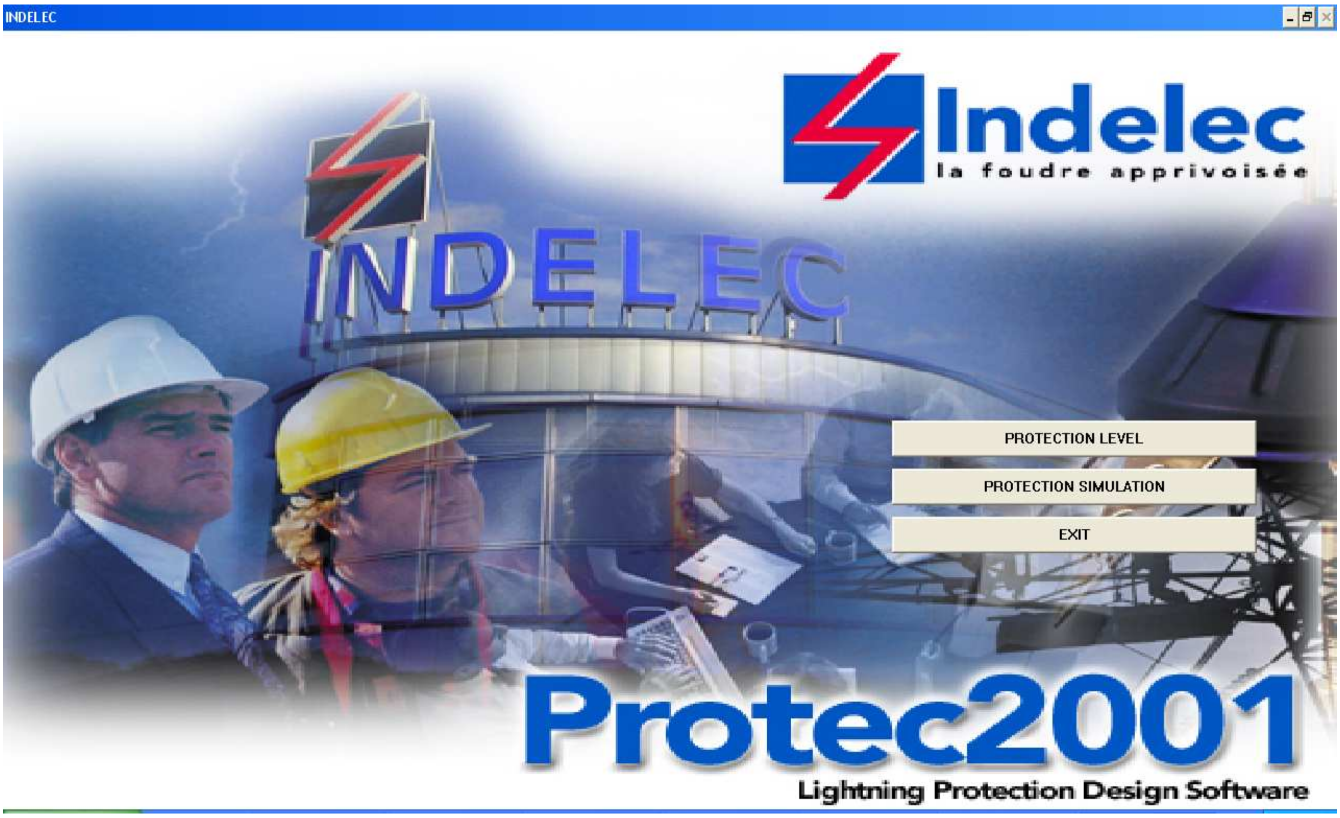


Low Resolution Full Climatology Annual Flash Rate

Global distribution of lightning April 1995-February 2003 from the combined observations of the NASA OTD (4/95-3/00) and LIS (1/98-2/03) instruments.

3- <u>Lightning risk assessment survey</u>

The survey is based on the UTE C 17 108 and results are computer generated (PROTEC 2001 software)



The following parameters are to be taken into account:

1. Lightning Activity in the area
2. Dimensions of the buildings
3. Power Supply lines
4. Relative Location of the structure
5. Danger for the persons.
6. Fire Risk
7. Occupation of the structure.
8. Building Services

The Protection Level calculated according to the Guide C 17-108 methodology and requirement, is extremely important: It is a major parameter for the Lightning Protection Design and the calculation of the **Protection Radius (R_p)** of the lightning air terminals:

$$R_p = \sqrt{h(2D - h) + \Delta L(2D + \Delta L)}$$

Where:

R_p: Protection radius

D: Striking distance/Rolling Sphere radius ($D=10 \times I^{2/3}$).
D depends on Protection Level requirement (cf Risk Assessment Survey here above).

h: Height of the air terminal above the structure. The optimal height is 5 meters above the structure to be protected.

ΔL: advance triggering distance calculated according to the formula

$$\Delta L = \Delta T(\mu s) \times V(m/\mu s).$$

.

4- Proposed Lightning Protection Design

A- Design requirements

The design of the Heritage Building Lightning Protection System must meet the following expectations:

1- Significant reduction of the risk of damages due to lightning discharges

As in the case with anything related to the natural elements, a lightning protection system, designed and installed in accordance with the standards, cannot guarantee absolute protection to structures, persons or objects; however, applying this standard will significantly reduce the risk of protected structures being damaged by lightning.

2- Economically sounded lightning protection design

The costs issue for Lightning protection system is to be consider with the sky-rocketing prices of the main LPS component: copper used for the down conductors (usually flat copper strip minimum 50mm^2) and grounding. With a price reaching 8,000 USD/ ton, the budget for lightning protection is representing an increasing burden for the investors and conservation authorities. Therefore a proper lightning protection system must be cost-efficient with a detailed study of various technical solutions before lying down and burying tons of copper.

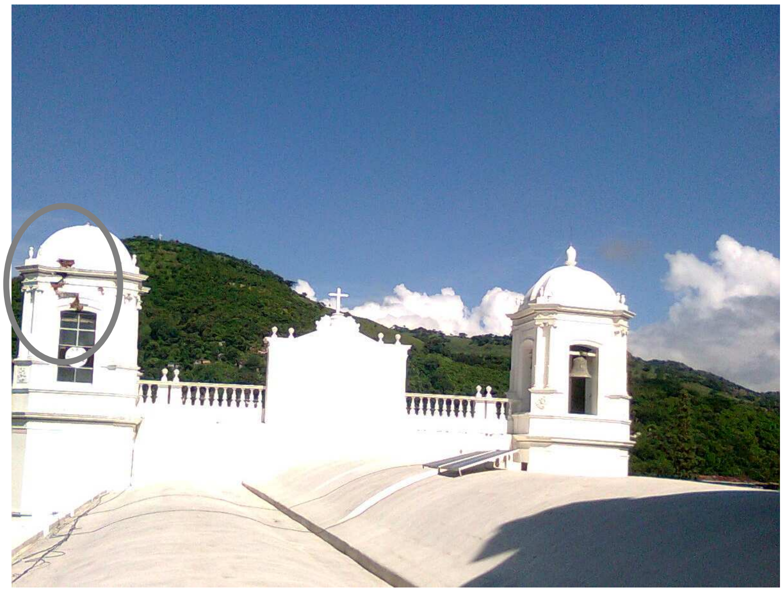
3- Aesthetically "acceptable" LPS design

Besides the safety of the building, one of the main requirements of the conservation authorities and architects is the integration of the LPS without any visible impact on the structure.

This requires a specific design using mainly bare copper accessories (that will turn to a greenish less visible colour) and specific unexposed routing. Similarly, the grounding system must be adapted to the site (in order to preserve existing terraces, access roads, pools, gardens etc...).

4- LPS design fully complying with the existing standards requirements

As mentioned here above, the design must comply with existing while being cost-effective and aesthetically acceptable. The reference to systems such as "active air terminals" or "Dissipater Array systems" is therefore excluded from the present document since these are not back up by a proper Standard.



Church (Nicaragua) protected by a conventional lightning rod and damaged by lightning. ESE air terminals are providing a larger protection radius thus an improved protection.

B- Typical design

a- Air terminal

Based on these requirements, the appropriate lightning protection design for Heritage Buildings appears to be using ESE air terminals. This solution is the preferred choice of all major (private and public) investors: Notre Dame de Paris, the Loire Valley castle in France, the Tower of London in UK, the Acropolis temple in Athens, the National Museum of Mexico, the Angkor Vat Temple in Cambodia or the Tokyo Daijingu temple in Japan...

A meshed cage conventional Lightning Protection System is extremely difficult to design and install on an Heritage building due to the number of conductors (one down conductor every 10m along the building), the costs and the aesthetic issues.

The Early Streamer Emission air terminals are commonly located on the edge of the building. But a specific location is usually designed in order for the visitors not to notice the air terminal from the main entrance of the site:

Daijingu Shrine (Japan) protected by a "hidden" INDELEC lightning air terminal

Installation of the Prevectron ESE air terminal on Notre Dame de Paris cathedral: The air terminal is not visible for visiting tourists from ground level (western facade).

The air terminal elevation pole and its fixings to the building must also be carefully designed to stay “invisible”: for example, the pole can be fixed on the roof frame beams.

b- Down conductors

The positioning of the conductors is equally crucial to the overall appearance of the building. By placing the conductors behind buttresses and out of sight lines, the whole aspect of the building remains undamaged. Similarly, conductors routing behind gutters if existing are recommended (in such cases, the gutters must be interconnected to the conductor for equipotential bonding purposes).

Typically, in a well designed installation, the down conductors are placed behind pinnacles and in returns of buttresses or other key features. They should always be straightened and installed with a string line, following the lines of the building. On rubble or pitch faced stonework they should not be dressed into each crack and contour of the stone as the conductor then looks poorly installed in profile.

Example of conductor routing along a gutter

Down-conductor fixing on Notre Dame de Paris and its famous gargoyles

c- Choice of materials

The choice of material is critical in reducing the impact of the system: The lightning protection system must strictly meet the standard requirements as well as the architects and visitors aesthetic expectations

The usual material to specify would be flat tinned copper tape and PVC clips. These are quite adequate for the purposes of protection but are ugly and detract from the overall appearance of the structure.

Perhaps the most suitable materials for a sympathetic installation are:

- Use of round bare copper conductor(50mm2 minimum cross sectional area);
- Alternately, the conductor can be sheathed with suitably coloured PVC to blend with its surroundings. In this way the conductor appears part of the building rather than contrasting with it.
- Use of copper/metallic fixings
- Specific air terminals such as the INDELEC Prevectron MH serie:

Grande Mosquée de Paris (largest mosque in France and the third largest in Europe) protected with two Prevectron MH air terminals (Paris – France)

C- Prevectron 2 ESE air terminal

- **5 main components for 5 key benefits**

1) *a lower series of electrodes* which capture the surrounding ambient energy and supply the energy to the system. Each lower electrode is connected to capacitors so the energy needed is properly stored and ready to be used. **No external power supply is needed. Fully autonomous operation**;

2) *a waterproof, stainless-steel and composite material housing* connected to the Earth: **Robust, made for extreme climatic conditions;**

3) *an electronic triggering system*. This electronic device calculates the variation of electric field and triggers a streamer (or upward leader) when the lightning is approaching: **Active at the precise time the lightning is striking. Timing emission of the streamer totally controlled;**

4) *an upper series of spark-generating electrodes* to generate a high voltage with strong intensity streamer: **Generate a powerful streamer to intercept the lightning; Intensity and Voltage of the streamer totally controlled;**

5) a central pick-up rod made of tinned copper. This rod runs right through the entire length of the lightning conductor, thereby providing an uninterrupted route down to Earth for the lightning: **Ultra-safe capture thanks to a full electrical continuity between the tip and the earth point;**

Prevectron TS2.25 MH

Prevectron TS3.40 MH

Prevectron S6.60 (large areas)

● **Description of the operation process**

1) When storm conditions are prevalent, the intensity of the electrical field increases considerably. This change is detected by the lower series of electrodes situated around the lightning conductor. The triggering device then receives the information through its housing and switches itself on.

The PREVECTRON® 2 becomes active when a storm cloud appears, it switches itself on automatically, and store energy contained in the ambient electric field in capacitors.

2) When a lightning discharge is approaching the ground, the electric field rises suddenly and very fast. At this precise moment only, the electronic device releases the energy stored in the capacitors and consequently triggers an ionisation at the upper series of electrodes: this is the triggering of the *corona* effect. These primary electrons will lead to the formation of what is known as an *upward leader* which is designed to attract the lightning towards the lightning conductor.

The PREVECTRON® 2 detects the lightning and emits a powerful streamer at the exact moment the lightning is approaching.

INDELEC **PREVECTRON®** is the only advanced lightning protection system to detect lightning and therefore generate an upward leader at the precise time the lightning is approaching the ground. Not too early, not too late, only at the right moment. Consequently, it does not attract more lightning on the building.

3) Once the upward leader has intercepted the lightning, a conductive path is thus created between the storm cloud and the tip of the **PREVECTRON®**. This tip is directly connected to the ground via a down-conductor (full electrical continuity). The energy within the lightning can then be channelled safely down to Earth through the down conductor.

The lightning current is captured and dissipated safely thanks to a full electrical continuity between the tip of the PREVECTRON® 2 and the Earth point.

● **Proven efficiency and reliability**

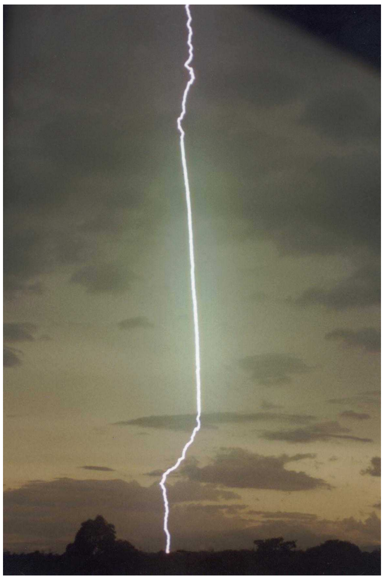
The **PREVECTRON® 2** is regularly subjected to on-site tests (i.e. tests in real-life lightning conditions). **INDELEC** conducts these tests in different countries such as Brazil, France, Japan US (Florida) and soon in Indonesia (reports available). The last series of on-site tests on the **PREVECTRON® 2**, in collaboration with a team from the French Atomic Energy Commission (C.E.A.) in Brazil demonstrated the following:

→ the real performance figures for the electrical activity at the tip of the lightning conductor;

→ details of the operational effectiveness of the **PREVECTRON**'s triggering system;

→ the **PREVECTRON**'s ability to withstand lightning strikes after being subjected to more than 30 strikes, each one measuring over 200 kA.

Further testing in major high-voltage laboratories in France (the *Electricité de France* power station at Renardières or the Cediver laboratory at Bazet) in China and in India (Central Power Research Institute –CPRI at Bangalore) also enabled the product's ability to withstand repeated strikes and its overall effectiveness to be constantly tested and checked throughout its development phase.



D-Installation specifications

Installation procedures of the entire lightning protection system shall be governed by the IEC 62305 and the NF C 17-102 standards. The manufacturer of the air-termination shall provide designs and instructions for the installation as per these standards.

To ensure an effective system and satisfactory long-term performance, all fittings need to be mechanically robust and provide good corrosion resistance in conditions of 50°C and 95% relative humidity.

All conductive materials used should be suitable for lightning protection installations and meet IEC 62305 Part 3 Table 6 and 7 requirements (ref Annex).

AIR TERMINAL

- ✓ Manufacturing process of the air-terminal shall be ISO: 9001 certified.

- ✓ The air terminal shall have been tested in an independent High-Voltage laboratory with a standardized waveform: 8/20µs in accordance with the NF C 17-102 - Annex C "ESE Lightning Conductor Assessment Procedure" to assess its advanced triggering time Δt.

- ✓ The maximum Δt value used for calculation of the Protection Radius Rp should not exceed 60 µs (NF C 17-102 F2)

- ✓ In addition, the air-terminal shall be able to withstand both positive and negative discharges of 100kA current and more.

- ✓ The protection area of the air-terminal shall be determined using the normative rolling sphere method from the IEC 62305 and NF C 17-102.

- ✓ The air-terminal shall guarantee a full electrical continuity between the tip and the down-conductor.

- ✓ The air-terminal shall be active only during a thunderstorm. It shall ensure the emission of a streamer (ionization of the air around the tip) when a lightning strike is occurring in the claimed protection area.

- ✓ Performances and working principle of the air-terminal shall not be affected by non lightning related climatic conditions (wind, rain, pollution, temperature variations, frost…).

AIR TERMINAL INSTALLATION

The air terminal should be fixed at the top of an elevation pole so as to be at 5 meters minimum from roof (reference height: highest point of the structure or any protruding element such as chimneys, statues, decorative masonry etc... located on the roof).

The air termination support shall be fixed securely on the structure to enable the air termination and mast system to withstand maximum locally recorded wind velocities. Guy wires might be necessary to secure the system properly.

DOWN CONDUCTOR

- ✓ Number of down-conductors: for non-isolated ESESystem, each ESEAT shall be connected to at least two downconductors. For a better current distribution, the two paths to ground should, be situated on two different facades unless in case of force majeure.

- ✓ The down conductors materials, configuration and minimal cross-sectional areas should comply with IEC 62305 Part 3 table 6. They should be fixed to the building / poles by means of 3 fasteners per meter.

- ✓ The use of insulated coaxial cables is not permitted according to NF C 17-102 §2.3.4.

- ✓ The down conductors should be connected to the air terminal by means of a metallic adapter located on the E.S.E. air terminal.

- ✓ The down conductors should run down the elevation pole and take the shortest direct route down the outside of the structure to the earth termination system, avoiding any sharp corners, thereby providing a low impedance path from the air terminal to its earth termination system. Preferably, they will be located on different sides of the structure.

- ✓ Any metallic object located at a distance from the down conductor inferior to the defined Separation Distance should be bonded to the said conductor (refer to IEC 62305 Part 3 §6.3).

✓ A test clamp should be installed on the lower part of each down conductor (generally 2 meters above ground level) so that these down conductors may be disconnected from the earth termination system for regular checks of the earth termination resistance value.

✓ The base of each down conductor should be protected from accidental knocks and other damage by means of a 2 meters stainless-steel protection sheath fixed to the building.

EARTH TERMINATION SYSTEM

General

All earthing system for a same structure should be interconnected. One earth termination will be provided for each down conductor based on at least on two electrodes per earth termination.
Due to the impulsional nature of lightning current and in order to enhance the current draining to earth thus minimizing the risk of dangerous surges inside the protected volume, it is important to consider the shape and dimensions of the earth termination system as well as the value of its resistance.
A certain contact surface with the soil shall be assured in order to facilitate the lightning current dispersion in a short time.
Earth termination systems should meet the following requirements:

- the resistance value measured using a conventional equipment should be the lowest possible (less than 10Ω). This resistance should be measured on the earthing termination insulated from any other conductive component.

- earth termination systems having a single excessively long horizontal or vertical component (> 20 m) should be avoided in order to minimize the inductive voltage drop.

The use of a single vertical termination system deeply buried to reach a humid layer of soil is thus not advantageous unless the surface resistivity is particularly high and there a high conductivity layer far below.
However it should be noted that such drilled earth termination systems have a high wave impedance when the depth exceeds 20 metres. Then a greater number of horizontal conductors or vertical rods should be used, always perfectly electrically interconnected.
Earth termination systems should be made and laid out as stated above.
Unless there is a real impossibility, earth termination systems should always be directed outward from the buildings

Earth termination system types

The earth termination dimensions depend on the soil resistivity in which the earth termination systems are installed. The resistivity may vary, to a considerable extent depending on the soil material (clay, sand, rock…).

The resistivity can be assessed from the table 6 or measured using a suitable method with an earth meter.

For each down-conductor, the earth termination systems may consist of:

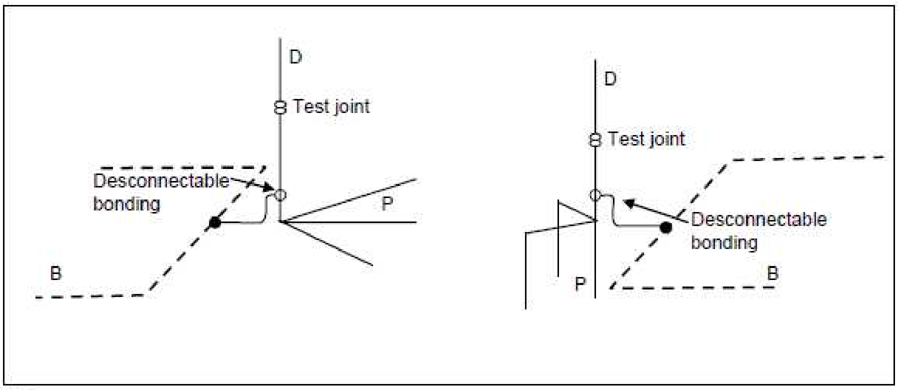
Type A: divised in:

A1. conductors of the same nature and cross-sectional area as the down-conductors, except for aluminium, arranged in the shape of goose-foot of large dimensions and buried at a minimum depth of 50 cm.
Example: three 7-8 meter long conductors, buried horizontally at a minimum depth of 50 cm.

and:

A2. set of several vertical rods with a minimum length of 6 metres at a minimum depth of 50 cm.
- arranged linearly or as a triangle and separated from each other by a distance equal to at least the buried length;
- interconnected by a buried conductor which is identical to or has compatible characteristics compatible with the down-conductor.
Note: the recommended arrangement is the triangle

Type B: Ring earth electrode
This type of arrangement comprises either a ring conductor external to the structure, in contact with the soil for at least 80% of its total length or a fundation earth electrode provided it is based on a 50 mm² conductor. The bottom of each downconductor should at least additionnaly be connected to either a 4 m minimum radial or a 2 m minimum rod.



D: down-conductors
B: ring at the foundations of the building
P: ESESystem earthing

Earthing equipotentiality

When the building or the protected volume has a foundation earth termination system for the electrical system, the ESESystem earth termination systems should be connected to it with a standardized conductor (see EN 50164-2).

For new installations, this measure should be taken into account since the initial design stage, and the interconnection to the foundation earth circuit should be made right in front of each down-conductor by a device which can be disconnected and located in front of an inspection pit with the symbol ⏚.

For existing buildings and installations, the connections should be preferably made to the buried parts and it should be possible to disconnect them for inspection purposes.In case of interconnections inside a building, the routing of the bonding cable should avoid inductions on cables and objects in the surroundings.

When several separate structures are included in the protected volume, the earth termination system of the ESEAT should be bonded to the buried equipotential earth network that interconnects all the structures"

PERFORMANCE RECORDING EQUIPMENT

- ✓ For maintenance purposes, the Lightning Protection System can be equipped with a digital lightning flash counter.
- ✓ The lightning flash counter shall have been tested and certified in a high-voltage laboratory with an 8/20µs waveform in accordance with EN 50-164–6:2009 and UTE C 17-106 standard.
- ✓ The lightning flash counter must be testable on site using a specific tester provided by the counter manufacturer.
- ✓ The lightning flash counter shall be fixed on the down-conductor without affecting the electrical continuity of the conductor and as per the manufacturer instructions.

MAINTENANCE

- ✓ As per the standards (IEC 62305 Part 3 §7 and NFC 17-102), the lightning protection system shall be inspected at least every 2 years and/or after any lightning impact recorded on the lightning flash counters.

- ✓ A visual inspection shall be performed to ensure that:
  a) No extension or modification of the protected structure calls for the modification of lightning protection system or installation of additional one.
  b) the electrical continuity of visible conductors is correct,
  c) all components fasteners and mechanical protectors are in good condition,
  d) no parts have been weakened by corrosion

- ✓ Air termination system shall be checked to ensure that:
  a) It is still properly connected to the down conductors,
  b) The system is still in operating conditions (tester to be used),
  c) It is still properly installed on the support and it can withstand high wind velocities (relatively to the local conditions).

- ✓ Measure of the earth termination resistance shall be realized to ensure it is still below 10 ohms.

ANNEX 1

Some examples of Heritage Buildings equipped with INDELEC PREVECTRON ESE Lightning Conductors.

Alexander Nevski
Bulgaria

Basilica Cartago
Costa Rica

Angkor Wat
Siem Reap, Cambodia

Acropolis
Athens, Greece

Denver Cathedral
Colorado, USA

Tower of London
London, UK

Notre Dame Church
Paris, France

National Assembly
Paris, France

Eglise de la Madeleine
Paris, France

Kandy Temple
Kandy, Sri Lanka

The Banqueting House
Whitehall – UK

The Balmoral Hotel
Edinburgh, UK

Hampton Court Palace
UK

La Concorde Obelisk
Paris, France

Palacio National
Mexico

Kalishta Monastery
Struga, Macedona

Chao Tian Temple
Taiwan

Fo Guang Shan Temple
Taiwan

Tivoli Brewery
Colorado, USA

National Museum
Bangkok, Thailand

Red Fort
Delhi, India

Dosan Seowon temple
Korea

Phu Phing Ratchaniwet
Thailand

St John's College
NSW - Australia

Mylapore Temple
India

Santa Cruz do Sul
Brazil

Rajcica Monastery
Debar, Macedonia

ANNEX 2

LIGHTNING PROTECTION SYSTEMS COMPONENTS SPECIFICATIONS (IEC 62-305 – Part 3)

Table 6 – Material, configuration and minimum cross-sectional area of air-termination conductors, air-termination rods and down-conductors

Material	Configuration	Minimum cross-sectional area mm²	Comments 10)
Copper	Solid tape	50 8)	2 mm min. thickness
	Solid round 7)	50 8)	8 mm diameter
	Stranded	50 8)	1,7 mm min. diameter of each strand
	Solid round 3), 4)	200 8)	16 mm diameter
Tin plated copper 1)	Solid tape	50 8)	2 mm min. thickness
	Solid round 7)	50 8)	8 mm diameter
	Stranded	50 8)	1,7 mm min. diameter of each strand
Aluminium	Solid tape	70	3 mm min. thickness
	Solid round	50 8)	8 mm diameter
	Stranded	50 8)	1,7 mm min. diameter of each strand
Aluminium alloy	Solid tape	50 8)	2,5 mm min. thickness
	Solid round	50	8 mm diameter
	Stranded	50 8)	1,7 mm min. diameter of each strand
	Solid round 3)	200 8)	16 mm diameter
Hot dipped galvanized steel 2)	Solid tape	50 8)	2,5 mm min. thickness
	Solid round 9)	50	8 mm diameter
	Stranded	50 8)	1,7 mm min. diameter of each strand
	Solid round 3), 4), 9)	200 8)	16 mm diameter
Stainless steel 5)	Solid tape 6)	50 8)	2 mm min. thickness
	Solid round 6)	50	8 mm diameter
	Stranded	70 8)	1,7 mm min. diameter of each strand
	Solid round 3), 4)	200 8)	16 mm diameter

1) Hot dipped or electroplated minimum thickness coating of 1 µm.

2) The coating should be smooth, continuous and free from flux stains with a minimum thickness coating of 50 µm.

3) Applicable for air-termination rods only. For applications where mechanical stress such as wind loading is not critical, a 10 mm diameter, 1 m long maximum air-termination rod with an additional fixing may be used.

4) Applicable to earth lead-in rods only.

5) Chromium ≥ 16 %, nickel ≥ 8 %, carbon ≤ 0,07 %.

6) For stainless steel embedded in concrete, and/or in direct contact with flammable material, the minimum sizes should be increased to 78 mm² (10 mm diameter) for solid round and 75 mm² (3 mm minimum thickness) for solid tape.

7) 50 mm² (8 mm diameter) may be reduced to 28 mm² (6 mm diameter) in certain applications where mechanical strength is not an essential requirement. Consideration should, in this case, be given to reducing the spacing of the fasteners.

8) If thermal and mechanical considerations are important, these dimensions can be increased to 60 mm² for solid tape and to 78 mm² for solid round.

9) The minimum cross-section to avoid melting is 16 mm² (copper), 25 mm² (aluminium), 50 mm² (steel) and 50 mm² (stainless steel) for a specific energy of 10 000 kJ/Ω. For further information see Annex E.

10) Thickness, width and diameter are defined at ±10 %.

ANNEX 3

EARTH ELECTRODES SPECIFICATIONS
(IEC 62-305 – Part 3)

Table 7 – Material, configuration and minimum dimensions of earth electrodes

Material	Configuration	Minimum dimensions			Comments
		Earth rod ∅ mm	Earth conductor	Earth plate mm	
Copper	Stranded [3]		50 mm^2		1,7 mm min. diameter of each strand
	Solid round [3]		50 mm^2		8 mm diameter
	Solid tape [3]		50 mm^2		2 mm min. thickness
	Solid round	15 [8]			
	Pipe	20			2 mm min. wall thickness
	Solid plate			500 x 500	2 mm min. thickness
	Lattice plate			600 x 600	25 mm x 2 mm section Minimum length of lattice configuration: 4,8 m
Steel	Galvanized solid round [1] [2]	16 [9]	10 mm diameter		
	Galvanized pipe [1] [2]	25			2 mm min. wall thickness
	Galvanized solid tape [1]		90 mm^2		3 mm min. thickness
	Galvanized solid plate [1]			500 x 500	3 mm min. thickness
	Galvanized lattice plate [1]			600 x 600	30 mm x 3 mm section
	Copper coated solid round [4]	14			250 µm minimum radial Copper coating 99,9 % copper content
	Bare solid round [5]		10 mm diameter		
	Bare or galvanized solid tape [5] [6]		75 mm^2		3 mm min. thickness
	Galvanized stranded [5] [6]		70 mm^2		1,7 mm min. diameter of each strand
	Galvanized cross profile [1]	50 x 50 x 3			
Stainless steel [7]	Solid round	15	10 mm diameter		
	Solid tape		100 mm^2		2 mm min. thick

1) The coating shall be smooth, continuous and free from flux stains with a minimum thickness of 50 µm for round and 70 µm for flat material.
2) Threads shall be machined prior to galvanizing.
3) May also be tin-plated.
4) The copper should be intrinsically bonded to the steel.
5) Only allowed when completely embedded in concrete.
6) Only allowed when correctly connected together at least every 5 m with the natural reinforcement steel of the earth touching part of the foundation.
7) Chromium $\geq$ 16 %, nickel $\geq$ 5 %, molybdenum $\geq$ 2 %, carbon $\leq$ 0,08 %.
8) In some countries 12 mm is allowed.
9) Earth lead in rods are used in some countries to connect the down-conductor to the point where it enters the ground.