CIGRE C4 Colloquium on
Lightning and Power System,
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# MISCONCEPTIONS ABOUT LIGHTNING AND ITS RELATION TO AIR TERMINAL DESIGN ERRORS
**(Invited paper)**

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# Introduction

- A survey reveals that more than 90% of the conventional air terminal designs in Malaysia failed to fully comply with the lightning protection standards
- This resulted in many buildings that use the conventional air terminals to be struck and damaged by lightning
- It was found that a significant number of engineers had gross misconceptions about lightning and these misconceptions had been translated to the design errors in the field
- This paper will look at the common misconceptions about lightning and the need to eradicate them in basic engineering education.

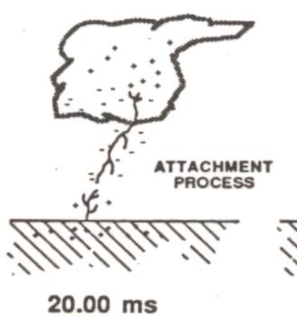
# Topics to cover

- Review of lightning attachment processes
- Review of air termination design methods
- Misconceptions in lightning and their impact on air termination design errors in the field
- Status of non-conventional air terminal technologies
- Summary



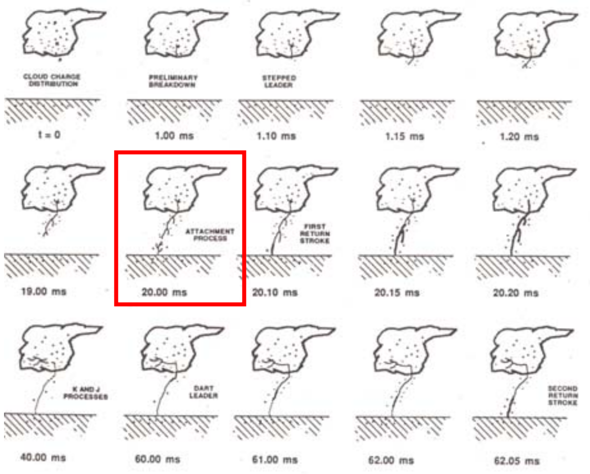
# Review of lightning attachment process

- Lightning attachment occurs when a discharge from a thundercloud attaches itself to an object on the ground
- Part of the overall lightning discharge process



# Lightning discharge process

Rakov and Uman (2003)






# Lightning attachment process

Darveniza et al (1997)

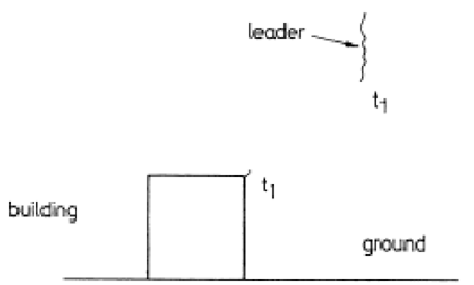



**Fig. 1** *Stages in lightning attachment process: commencement of connecting streamer*
At time $t_1$ a connecting streamer commences from building

# Lightning attachment process
Darveniza et al (1997)

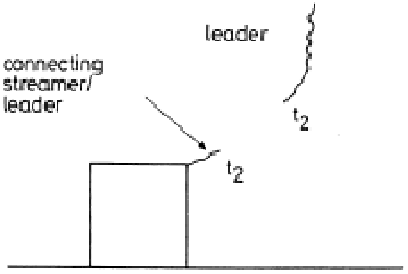



**Fig. 2** *Stages in lightning attachment process: connecting streamer approaching leader*
At time $t_2$ connecting streamer and leader approach each other



# Lightning attachment process
Darveniza et al (1997)

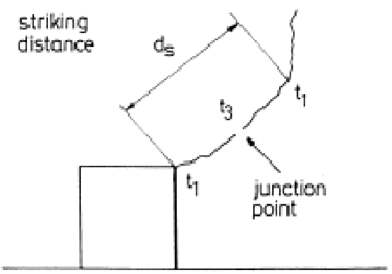



**Fig. 3** *Stages in lightning attachment process: connecting streamer meeting leader*
At time $t_3$ connecting streamer and downward leader meet at junction point. Striking distance $d_s$ is defined as shown

# Lightning attachment to structures

- Lightning strikes thousands of structures on the ground annually
- In most cases, they attach themselves to the corners and edges
- Sometimes it strikes the highest point of a structure

[Photo: The Star Publications]



# Lightning attachment to structures

- On rare occasions, lightning can also strike the sides of tall structures

- [Photo: K. Ambrose]

# Lightning attachment to structures

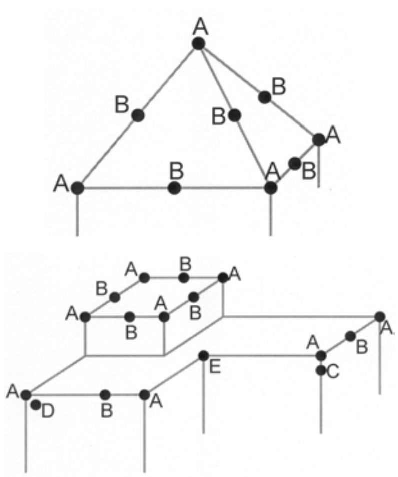
- Until 1990, lightning attachment used to be regarded as random, unpredictable
- However, studies on high-rise buildings with lightning attachment points in Kuala Lumpur and Singapore revealed a regular pattern of occurrence
- Lightning attachment points seemed to accumulate at corners, exposed points and edges
- This data provides a method to predict location of future attachment points on structures



# Lightning attachment on structures

(Hartono & Robiah 1995, 2000)

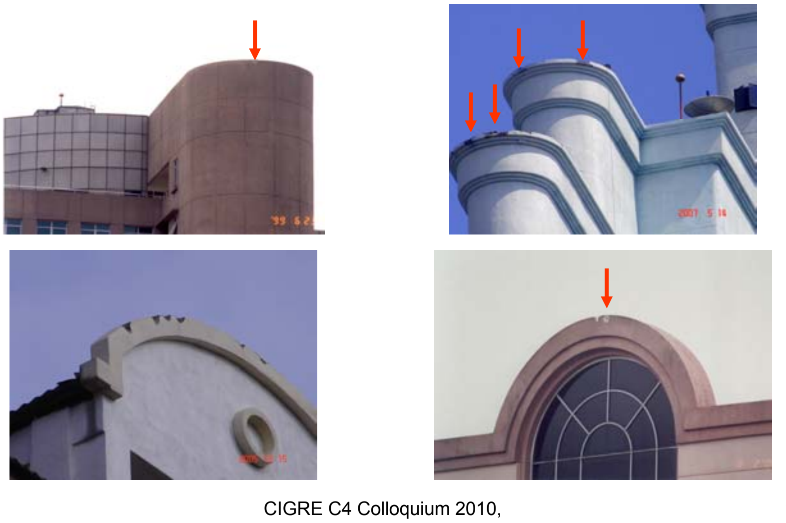
- A: Exposed corners and points (>>90%)
- B: Straight or curved horizontal edges (<5%)
- C: Vertical edges near A (<2%)
- D: Flat surfaces near A (<1%)
- E: Included corners, etc. (0%)



# Exposed corners and points



# Exposed edges



## Size of lightning damage (bypass)

- More than 90% of these bypasses seemed to be small in size
- Some vendors used this fact to downplay the seriousness of lightning incidents
- Factors contributing to the small bypass size include
  - Presence of metallic rebar underneath masonry
  - Strength of material used eg. concrete
  - Small lightning current magnitude



## Lightning current distribution

- Lightning current magnitude shown to have a wide variation
  - From 2,000A to more than 350,000A
- Lightning current distribution
  - 1% strokes exceed 200,000 A
  - 10% strokes exceed 80,000 A
  - 50% strokes exceed 28,000 A
  - 90% strokes exceed 8,000 A
  - 99% strokes exceed 3,000 A
- Severity of bypasses can be related to magnitude of lightning current

# Severity of bypasses

- Less than 5% of bypasses resulted in
  - Structural damages
  - Fire outbreaks

[Photo: The Sun]

## Tenant hurt in lightning strike on house

**Petaling Jaya**, Wed: A tenant was injured when lightning struck the roof of a double-storey town-house in Taman Megah Emas last evening during a violent thunderstorm, ripping off tiles and masonry.

Roof tiles shattered by the impact of the lightning fell into the three rooms, injuring a woman in her 30s. She is warded in University Hospital and the other five tenants have vacated the house.

Contractor Foong Wai Loong, 24, who stays in the ground floor unit, said he had just returned home about 5.30pm yesterday when a passer-by alerted him to the tenant who was screaming for help.

They summoned an ambulance which sent the woman to hospital.

The storm also uprooted several trees in Kelana Jaya, damaging passing vehicles. There were no reports of injury.

**Raining masonry ... damage wreaked by the lighting on No 268, Jalan 8, Taman Megah Emas.** – SUNpix by AHMAD YUSNI

25/1/96



# Severity of bypasses

- Lightning attachment on ballast concrete can result in large bypasses
  - Concrete material is very light and fragile
  - No rebars were used

# Severity of bypasses

- Lightning attachment to brick structures have similar effect
  - No rebar were used

[Photos: Flickr.com]



# Severity of bypasses

- Lightning attachment to combustible structures can lead to fire outbreaks
- Rooftop fires normally caused by lightning current entering the wooden rafters

# Severity of bypasses

- In nature, similar ratio of damages to trees can also be seen
- Most trees struck by lightning only have parts of their bark stripped
- Some have their branches broken off
- Very few have been completely demolished

[Photos: Flickr.com]



# Severity of bypasses

- Lightning attachment to metallic objects usually leave a small bypass
- Metallic roofing and structures normally require no air termination

[Bottom photo: Flickr.com]

# Review of air termination design

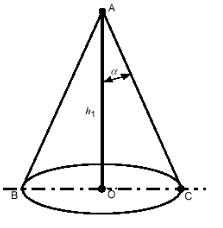
- Several air termination design methods developed in 19th century still in use today
- This enables lightning protection engineers to design air termination systems that are effective against lightning strokes
- These methods are described in current lightning protection standards eg. IEC62305
  - Protection angle method
  - Mesh method
  - Rolling sphere method
  - Collection surface method

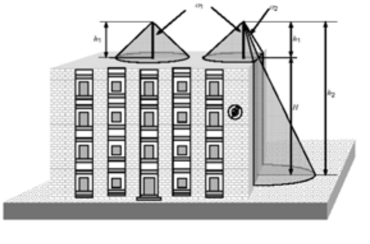


# Protection Angle Method (PAM)

- Developed by Gay Lussac in 1823
- Air terminal provide a protection zone in the shape of an imaginary cone
- Lightning either attach on the tip of the cone or somewhere else
- Objects within the imaginary cone is protected from lightning strokes
- Method was found to be unsuitable for highrise structures

[ Note: Diagrams from IEC62305]

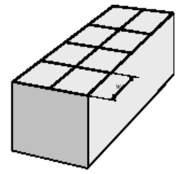


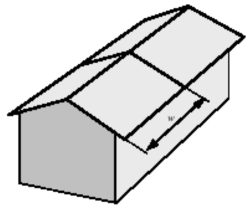



# Mesh Method (MM)

- Developed by J.C. Maxwell in 1876
- Air terminals are positioned in a grid form on surfaces that are exposed to lightning strokes
- Lightning will attach to the grid instead of the structure beneath it
- Method was found to be very costly and degrade the aesthetics of the structure

[ Note: Diagrams from IEC62305]



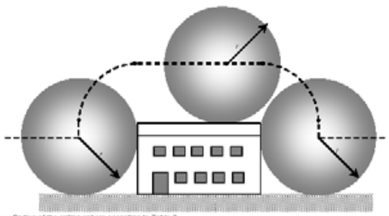




# Rolling Sphere Method (RSM)

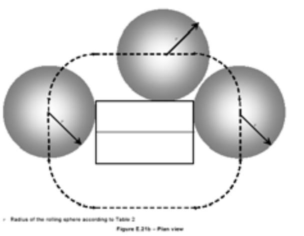
- Developed by Dr. Tibor Horvath in 1950s
- An imaginary sphere is rolled over and around the structure to be protected
- Radius of sphere equal to striking distance
- Parts of structure touched by imaginary sphere are at risk of being struck by lightning
- First applied in Hungarian standard in 1962
- Then applied in other national and international standards since 1970s

[Note: Diagrams from IEC62305]



r Radius of the rolling sphere according to Table 2

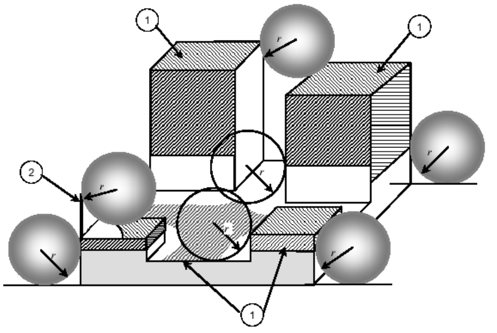
Figure E.21a – Side view



r Radius of the rolling sphere according to Table 2

Figure E.21b – Plan view

# Rolling Sphere Method (RSM)



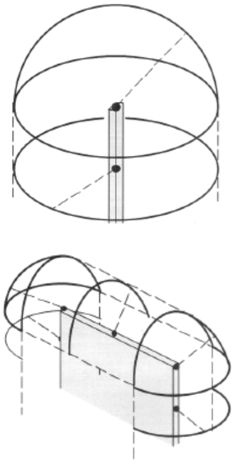
- Parts of the structure touched by the sphere require protection
- However, the method makes no differentiation between high and low risk parts

[ Note: Diagrams from IEC62305]

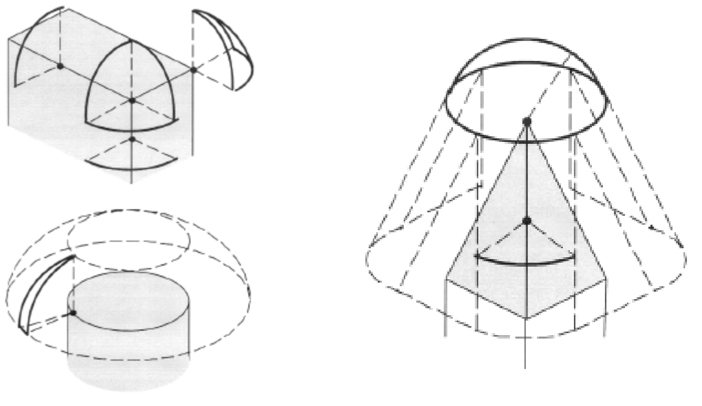


# Collection Surface Method (CSM)

- Developed by Hartono & Robiah in 1995
- Based on the RSM
- Center of sphere create a unique collection surface for every part of exposed structure
- Method can determine the high risk parts of structure to lightning stroke
- First applied in Australian standards in 2003
- Then in IEC standards in 2006



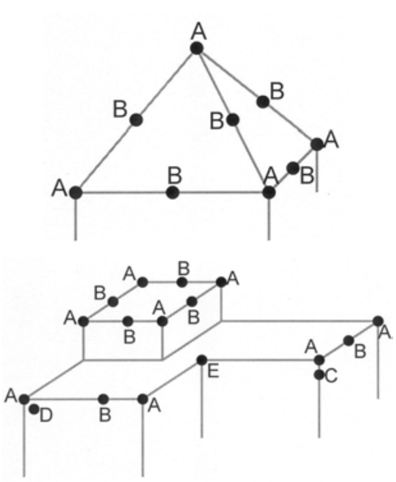
# Collection Surface Method (CSM)





# Collection Surface Method (CSM)

- Statistical analysis of bypass photographic data revealed high risk locations on structures
  - A: >>90%
  - B: <5%
  - C: <2%
  - D: <1%
  - E: 0%



# Air terminal positioning according to AS/NZS1768:2003

AS/NZS 1768(Int):2003 32

Field data of damage caused by lightning flashes terminating on structures (See Appendix G, Refs 2 & 3) identify the parts that are vulnerable to strikes. The most vulnerable, associated with over 90% of observed lightning damage, are nearly always located on upper parts of structure, such as—

(a) pointed apex roofs, spires and protrusions;

(b) gable roof ridge ends; and

(c) outer roof corners.

Other areas of vulnerability, in decreasing order, are—

(d) the exposed edges of horizontal roofs, and the slanting and horizontal edge of gable roofs (<10%);

(e) lower horizontal edges and vertical edges on outer-sides just below corners (<5%);

(f) flat surfaces near points and corners (<3%); and

(g) intruding surfaces and other surfaces, particularly flat surfaces (<1%).

- Air terminals (lightning rods) to be positioned on top of the designated locations mentioned above



# Air terminal positioning according to IEC62305:2006

**5.2.2 Positioning**

Air-termination components installed on a structure shall be located at corners, exposed points and edges (especially on the upper level of any facades) in accordance with one or more of the following methods.

Acceptable methods to be used in determining the position of the air-termination system include:

- the protection angle method;
- the rolling sphere method;
- the mesh method.

- Since 2006 engineers have the means to design air termination systems that can effectively intercept the lightning strokes using conventional air terminals
- Up to 98% protection level can be achieved using above methods (Dudas and Dudas, 2008)

# Misconceptions about lightning

- Some misconceptions about lightning have been in existence for decades, origin could not be traced
- Usually believed by the general populace
- Same misconceptions also found in many other countries
- Unfortunately, lightning protection not a subject in many tertiary engineering courses
- Majority of engineers and technicians subconsciously retained these misconceptions
- Not a problem as long as misconceptions are not applied
- When applied these misconceptions directly cause errors in the air termination designs



# Common misconceptions about lightning

- Two most common misconceptions are
  - "Lightning always strike the highest part of a structure"
  - "Air terminals always attract lightning"
- Impact on air termination design
  - Air terminal positioned on the highest point of structure
  - Air terminals arbitrary positioned on the structure, avoiding the high risk locations
- Consequence
  - Lightning attachments occur at the usual high risk locations, resulting in bypasses
  - Air termination system rendered practically useless

## Impact of applying misconceptions on air termination design


- Single air terminal positioned on the highest point of structure
- High risk locations left exposed to lightning



## Impact of applying misconceptions on air termination design



- Air terminals arbitrary positioned on the structure, avoiding the high risk locations
- High risk locations left exposed to lightning

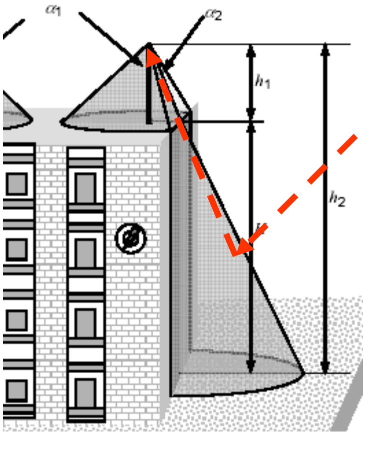
# Additional misconceptions about lightning in engineering education

- Textbook on lightning protection (Ahmad, 1998) introduced new misconceptions
  - Air terminal can bend the lightning path upwards
  - Metal rebars in structures attract lightning and cause more damages to structures
  - Lightning protection standards will be obsolete
  - Air terminals must be positioned away from corners and edges
  - Non-conventional air terminal technologies are new and effective
- Dire consequences
  - More engineers believed that air terminals can attract lightning
  - More engineers disregard the use of lightning protection standards
  - More engineers look for solutions among DAS and ESE air terminal technologies



# Impact of additional misconceptions about lightning

- Misconception: “A stepped leader entering the cone will be attracted to the air terminal”
- Students and engineers were taught to believe that air terminals have “attractive” powers



# Impact of additional misconceptions about lightning

- Misconception: “Air terminals must be positioned away from corners and edges”

- Lightning attachments still occur at the usual high risk locations even though there is an air terminal nearby

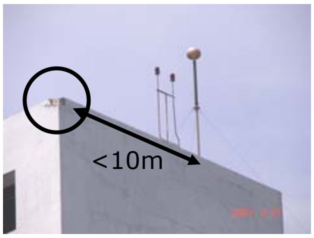


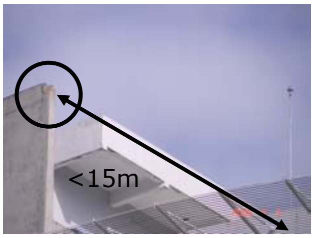
# Impact of additional misconceptions about lightning

- Misconception: “Non-conventional air terminal technologies are new and effective”
- Two specific technologies were mentioned in the book
  - Dissipation array system (DAS)
  - Early streamer emission (ESE)
- Graduate engineers from the university are more prone to apply the DAS and ESE in projects
- Note: Both the above technologies have been discredited by CIGRE and NFPA in 1995, and regarded as dangerous to use by the International Conference on Lightning Protection (ICLP) in 2005
  - http://www.iclp-centre.org/warning.html

# Early streamer emission technology

- Since 1991, failures of various makes of ESE air terminals have been photographed
- Significant number of bypasses occurred within ESE claimed zone of protection
- Photos submitted to CIGRE in 1995
- CIGRE 33.01 have rejected the ESE in May 1995, followed by IEC and NFPA a few months later






# STATEMENT OF CIGRE TASK FORCE 33.01.03 "LIGHTNING INTERCEPTION"

- The components of the Task Force during the meeting held in Milano on May 18th 1995, have examined the problem related with the use of non conventional lightning air terminals (e.g. Early Streamer Emission).
- From the discussion it arise that up to now there is neither sufficient theoretical analysis, nor substantial field data which support conclusive improvement in interception efficiency of these kinds of devices with respect to the conventional ones (metallic air terminals).
- Main technical reasons
  - 1 – Even if a streamer from a non conventional active terminal can be launched at an earlier time than a streamer from a conventional air terminal, once launched, it will require the same conditions of field strength to propagate as for a leader from a conventional air terminal.
  - 2 - The assumed constant velocity of $10^6$ m/s for upward leader propagation is in contrast with the field records which show an initial channel speed of about 0.04 to 0.2 $10^6$ m/s and it increases as the gap between the upward and downward leaders diminishes.

# Statement of CIGRE Working Group 33.01 “Lightning”

- CIGRE 95 SC 33 (WG 01) 17 IWD, 24th May 1995
- The members of the Working Group during the meeting held in South Africa on 23rd and 24th of May 1995, have examined the problems related to the use of non-conventional lightning air terminals (e.g. Early Streamer Emission, ESE, terminals).
- From the discussion it was concluded that up to now there is neither sufficient theoretical analysis nor substantial field data which support claims of significant improvement in interception efficiency of these kinds of devices, with respect to the conventional ones (metallic air terminals).



# Statement of CIGRE Working Group 33.01 “Lightning” …contd.

- Furthermore, the theoretical basis for the Early Streamer Emission technology appears technically incorrect for the following reasons:
  - 1 - Even if a streamer from a non-conventional terminal can be initiated at an earlier time than a streamer from a conventional air terminal, once initiated it will require the same field strength to propagate as a leader from a conventional terminal.
  - 2 - The assumed constant velocity of $10^6$ m/s for the upward leader propagation is in contradiction with the available data for both natural lightning and long laboratory sparks which show an average velocity of one order of magnitude lower.
- Therefore the early initiation of streamers cannot be translated into an increased length of the ESE terminal as compared with the conventional one.
- In conclusion, at this time, any use of such non-conventional lightning protection technology cannot be supported by CIGRE WG 33.01 “Lightning”.

# ESE vendors still defy the CIGRE, NFPA and ICLP stand

- ESE vendors worldwide still claim that ESE air terminals can attract lightning better than Franklin rods
- They still use the streamer speed ($V_s$) of $10^6$ m/s in brochures even though they have no proof to show after more than 20 years of “research”
- During ESE forum in Kuala Lumpur in December 2009, ESE patent holder Dr. Djermoune repeated the discredited streamer speed claim
- In the USA, it is now illegal to claim that ESE technology is better than Franklin rods



# Prominent ESE failure in France

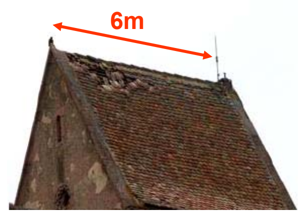
- On May 21, 2009, lightning struck the bell tower of a 12th century Saint Pierre and Paul church in Sigolsheim, France
  - http://www.gs-ing.com/gest/gest/up/1245414572_Un%20clocher%20foudroye%20a%20Sigolsheim..pdf
- Bell tower is only about 30m high and was installed with an ESE air terminal

[Photos: Flickr.com]

# Prominent ESE failure in France

- The lightning struck the stone cross and demolished it
- The ESE air terminal was installed about 6m from the stone cross
- News report stated that the ESE air terminal was inspected annually and was functioning at the time of the strike

[Photos: Flickr.com and Dernières Nouvelles D'alsace]






# Prominent ESE failure in France

CHAMBRE DES EXPERTS AGREES, COMMUNAUTE EUROPEENNE
Enregistrées auprès de la commission Européenne sous le n° 8024213399-59

**A.1 Dossier photographique**

Position initiale d'une croix en pierre d'une hauteur de 0,80m

Impact de la foudre, la croix a été brisée,

Paratonnerre à dispositif d'amorçage Helita pulsar 25 d'une hauteur de 1,70 m par rapport au faîtage

La longueur hors tout du faîtage est de 7 mètre
L'impact à été évalué à moins de 6 mètres du paratonnerre

Il n'y a aucune autre trace d'impact sur la ligne faîtière du clocher

- Lightning struck a small low structure protected by ESE technology
- Bypass occurred just 6m away from ESE air terminal

# Prominent ESE failure in France


- Inspection of the ESE air terminal showed no impact from lightning
- This is clear evidence that ESE technology cannot protect even a small structure from lightning



# Summary

- The lightning interception and attachment phenomena is better understood after decades of research
- Lighting attachment and bypass locations are not random events and can be predicted with confidence
- Positioning the air terminals right on top of the predicted lightning attachment location is the best method to intercept the lightning stroke successfully
- Air termination designs must be in full compliance with standards to achieve high level of protection
- Common misconceptions about lightning exist but they are relatively harmless until applied

# Summary

- Lightning protection in engineering education can eradicate these common misconceptions and prevent engineers from falling prey to false lightning protection technologies
- Promoting misconceptions in engineering education is a contributing factor to the high percentage of erroneous air termination designs and should be stopped
- Non-conventional air terminal technologies have already been discredited for more than a decade and dangerous to public safety
- More field data are emerging to show that the ESE air terminal technology is ineffective



# References

- Ahmad, H., “Kilat dan Perlindungan”, Penerbitan UTM, 1998
- Darveniza, M., Mackerras, D., and Liew, A. C., “Review of Claimed Enhanced Lightning Protection of Buildings by Early Streamer Emission Air Terminals”, IEE Proceedings – Science Measurement Technology, Vol. 44, No. 1, January 1997
- Dudas, J. and Dudas, M., “Software for Lightning Protection System Diagnosis according to IEC 62305”, 29th ICLP, Uppsala, June 2008

  http://www.svodice.cz/docs/ICLP2008Paper10-3.pdf
- Hartono, Z.A. and Robiah, I., “A method of identifying the lightning strike location on a structure”, ICEMC, Kuala Lumpur, April 1995
- Rakov, V. and Uman, M., “Lightning: Physics and Effects”, Cambridge University Press, 2003

# Thank You

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