Lightning & Tall Structures: Problems and Solutions

by Professor Liew Ah Choy

Professor Liew Ah Choy is Professorial Fellow at the department of Electrical & Computer Engineering at National University of Singapore as well as the Director and CEO of EquiVolt Pte Lt, a consultancy company specialising in providing design and solutions to lightning protection and electrical engineering problems.

The incidence of lightning in Malaysia and Singapore is one of the highest in the world. It therefore is no surprise that we experience our share of problems associated with it.

Today, there are tall structures and buildings almost everywhere. There have been many cases of lightning strokes bypassing roof lightning protection systems on tall buildings in Singapore, resulting in dislodgement and spalling of concrete. Examples of some of these and solutions provided and/or required to prevent such damages will be discussed.

We will also discuss the mechanisms and characteristics of lightning strikes to structures for both the more common downward lightning strike and the upward lightning strike associated with very tall structures. The requirement of the Singapore Lightning Protection Code SS555:2010 to address some of these issues will also be discussed.

Other less obvious problems experienced with tall structures and systems that will be discussed include:

- Ignition of flammable gases from vent stacks under thunderstorm conditions.
- Phenomenon of "hair standing on end" on open roofs of sky-bars.

Another very important consideration in preventing lightning related problems is the requirement for equipotential bonding. We will also discuss case studies relating to injury to personnel in various operations, especially ground handling at airports, and the solutions to reduce such risks.

SOME PROBLEMS AND SOLUTIONS

Protection of corners and edges of roofs and parapet walls of tall buildings

In Singapore, there have been many cases of lightning strokes bypassing roof lightning protection systems on tall buildings, resulting in dislodgement and spalling of concrete. This effect for tall structures, where the sides of the building are struck, is well known. The lightning protection codes (IEC62305:2006 and SS555:2010) address this and require the provision of side lightning intercepting air termination systems from heights of 60m and above.

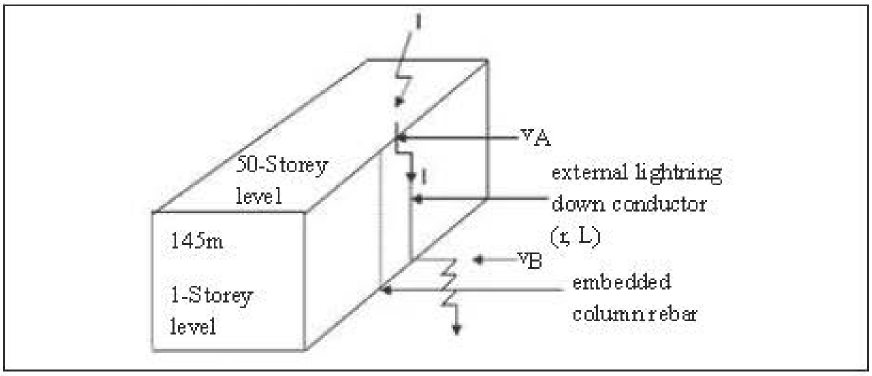
The vulnerability or exposure of the roof and sides of tall structures is seen with the application of the rolling sphere around the structure. For Lightning Protection Level LPL3, the rolling sphere radius, which represents the striking distance of the lightning leader, is taken to be 45m. This gives about 91% protection.

On the roof, the lightning protection codes recommend that roof lightning protection tapes be coursed along the outer edges of the roof perimeter or the roof parapet walls. However, in practice, due to fastening constraints, such tapes are inevitably located with some recess distance from the edges, typically along the centerline of the roof parapet walls. Herein lies the weakness, where lightning attachment is frequently at the corners and edges of the concrete, in preference to the lightning intercepting tape. When this occurs, the lightning current frequently flashes through the concrete to the rebar of the concrete structure in its path to earth. This is followed by dislodgement of the concrete, which is a hazard to persons at ground level of the structure.

A standard practical solution has been to install a finial rod at the corner of roof parapet wall to provide additional protective coverage at the sharp corner. Despite this, there have been cases whereby lightning still bypassed the protective rod to strike the corner of the concrete roof or the parapet wall. As a result, it is proposed that metal capping be provided at the outer edges of roof parapet walls and flat roofs. For roof parapet walls, this can be in the form of metal coping wrapping over the exposed top of the wall. The metal capping or coping must be bonded to the steel rebars of the structure behind it.

Case studies of some of such failures will be shown in the presentation.

NEED FOR BONDING OF LIGHTNING PROTECTION SYSTEM TO THE BUILDING REBAR SYSTEM



The voltage on a strickened lightning protection air terminal system as illustrated in the sketch above is calculated as follows:

$$v_A = L\frac{dI}{dt} + Ir + IR$$

where: I = lightning stroke current (kA)

$\frac{dI}{dt}$ = rate of change of lightning current (kA/µs)

L = inductance of lightning downconductor

r = resistance of lightning downconductor

R = resistance of earth electrode system

$$v_A = L\frac{dI}{dt} + Ir + IR$$

where: I = lightning stroke current (kA)

$\frac{dI}{dt}$ = rate of change of lightning current (kA/µs)

L = inductance of lightning downconductor

r = resistance of lightning downconductor

R = resistance of earth electrode system

The voltage drop across the downconductor = $v_A - v_B$

$$= L\frac{dI}{dt} + Ir \quad \text{------------------------} \quad (2)$$

Consider the case of a downconductor (25mm x 3mm standard Cu tape) of length = 145m from the 50^{th} to 1^{st} storey levels.

Inductance of a 25mm x 3mm tape = 1.25µH/m

Total L = 145m x 1.2µH/m = 174µH

r = 0.5Ω

Values of I and $\frac{dI}{dt}$ are distributed statistically and their values are given in the Standards.

Case (a): Take 50% of occurrence or median values of $I_{50\%}$ = 30kA,

$$\frac{dI}{dt}_{50\%} = 25\text{kA/µs}$$

$$(v_A - v_B) = L\frac{dI}{dt} + Ir = 174 \times 25 + 30 \times 0.5$$
$$= 4350 + 15 = 4365\text{kV}$$
$$= 4.4\text{MV}$$

Case (b): Take the more severe case of lightning stroke which is exceeded by 10% of occurrence of $I_{10\%}$ = 80kA, $\frac{dI}{dt}_{10\%}$ = 40kA/µs

$$(v_A - v_B) = L\frac{dI}{dt} + Ir = 174 \times 40 + 80 \times 0.5$$
$$= 6960 + 40 = 7000\text{kV}$$
$$= \mathbf{7.0MV}$$

It is seen that extremely large voltage rises and differences can occur. Assuming that the rebar and downconductor tape are fortuitously or otherwise connected at the 1st storey level (near ground), then the voltage difference between the strickened lightning downconductor and the embedded rebar behind the wall/column of the building at the 50th storey can potentially rise to 4.4MV and 7.0MV for 50% and 10% probability of occurrence lightning parameters respectively.

This large voltage difference will cause flashover to the embedded rebar with consequential effects of spalling of concrete within its flashover path. (Note: The flashover strength of air for rod gaps is approximately 1000kV/m: the flashover voltage through concrete is much lower). After this flashover, the lightning downconductor and the rebar will both carry and convey the lightning current to the earth electrode system. To prevent this from occurring, the voltage difference must be eliminated. This is achieved by bonding the lightning protection tape and downconductor to the rebar.

IGNITION OF FLAMMABLE GASES FROM VENT STACKS UNDER THUNDERSTORM CONDITIONS

Ignition of flammable gases from vent stacks during thunderstorms is not uncommon. This is usually attributed to a direct lightning strike to the stack at the time of venting. In such a situation, clearly, ignition of the gas is expected. Solutions have often been suggested and implemented to attempt to overcome such occurrences.

In an investigation by the author, it was discovered that several vent fire incidences involved more than one vent stack (typically 4) in the facility at the same time. The probability of direct lightning strikes to four vent stacks at or around the same time, causing this occurrence is indeed very remote to near impossible.

The occurrence of the phenomenon is attributed to point-discharge corona currents near metallic exhaust vent pipes caused by the high electric field on the top of the tall slender structure of the vent stack under the influence of a charged thundercloud. The onset and magnitude of point-discharge corona currents in vent stacks are likely to be more pronounced due to the presence of the hot gases which will contribute to thermal ionisation as well. With a ready stream of corona currents and oxygen in the air, venting of the flammable gases can lead to ready ignition. Such occurrences are clearly more frequent than ignition caused by a direct light to a vent stack. It also explains why fires can occur at several vent stacks at around the same time.

A case study of such a failure and possible solutions will be shown in the presentation.

PHENOMENON OF "HAIR STANDING ON END" ON OPEN ROOFS OF SKY-BARS

It was reported that during overcast skies with impending thunderstorms, customers and staff at the roof bar of a high rise hotel building, experienced strong electrostatic (ES) phenomenon with their hair standing on end. The roof bar stands at the top helipad level at an elevation level of 142m. Lightning protection masts were installed at the 4 corners of the roof bar level.

It was reported that the effect of hair standing on end was more pronounced near the lightning protection masts. At times, a hissing sound could also be heard during overcast skies conditions.

Investigations confirm that the effect is due to the high electric field caused by a charged overhead thundercloud. This electric field at the roof level is enhanced by the geometry of the tall slender building. The electric field (E) at or near the taller lightning protection masts (LPMs) above the roof helipad level is further enhanced by its distorting effect of the taller and sharper object. The head and hair of a person on the roof will also have opposite polarity charges induced on it by the layer of negative charges (-Q) at the base of the thundercloud. This means that the head and hair will have positive charges (+q) caused by induction from the cloud.

Force F due to an E field on a charge q is given by F = q x E. It is this force that causes the hair to stand on end. For the situation on the roof bar, the E fields at and near the LPMs are clearly greatest due to its enhancement. Consequently, this electrostatic (ES) force F = q x E is greatest in its vicinity.

This case study and possible solutions will be shown in the presentation.

EQUIPOTENTIAL BONDING AND EARTHING FOR REDUCTION OF DANGEROUS VOLTAGE DIFFERENCES

Another very important consideration in the prevention of lightning related problems is the requirement for equipotential bonding and earthing.

In general, during turn-around at airport parking bays, aircrafts are not solidly earthed, apart from the period of re-fueling when a static discharge cable is connected to an earth receptacle at the floor of the parking bay. Voltage rises and voltage differences can occur following direct lightning strikes to the aircraft and nearby strikes in its vicinity. There have been cases relating to injury to personnel in various operations especially in ground handling in airports. Such injury cases can be reduced with equipotential bonding between all systems which interface with the aircraft during airside operations and earthing of the parked aircraft.

This problem and some solutions will be shown in the presentation. ■