2016 24th International Lightning Detection Conference & 6th International Lightning Meteorology Conference
18 - 21 April | San Diego, California, USA

Lightning attachment process to common buildings

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***Abstract*— In this paper we analyze upward connecting leaders induced by some downward negative lightning flashes that struck an ordinary residential building located in São Paulo City, Brazil. Most of what is known about the current of downward flashes comes from information gathered on towers. There are no observational data of lightning attachment to common structures or buildings (under 60 m) that are present in almost every city. For the first time, the attachment process was analyzed by a high-speed camera running at 10,000 images per second. The striking distance observed was larger for return strokes with higher peak currents. The ratios of speeds of the downward leader and the upward connecting leader varied from 1 to 9. The final jump discharge initiated from the positive upward connecting leader**

Keywords*— Upward connecting leader, cloud-to-ground flash, lightning rod, lightning protection systems

I. INTRODUCTION

The effectiveness of a lightning protection system (LPS) depends on its efficiency to intercept the down coming lightning leader. The interception is usually done by an upward connecting leader (UCL) launched from the LPS installed on the structure or building to be protected. This interception prevents a lightning strike to a critical part of the structure being protected.

The understanding of the characteristics of an UCL and of the attachment process with the downward leader plays an important role in the determination of the volume or zone of protection of the air-termination system of a LPS and in the improvement of LPS designs.

However, a good observation of a lightning attachment to a structure may require a very long observation time. Tall structures are more likely to be struck by lightning, however if their height is over 100 m they will almost always initiate upward lightning flashes. Therefore, the common attachment process that affects the majority of structures and buildings is not observed.

Although there are some data on lightning attachment to tall towers (height over 60 m), there are no observational data of lightning attachment to common structures or buildings that are present in almost every city (under 60 m). Research on lightning attachment to these common structures is therefore mostly theoretical and based on laboratory observations of electrical discharges. This research is often done assuming that some parameters observed in laboratory can be used in models.

This work provides some preliminary results obtained from high-speed video observations of lightning attachment to buildings. These observations can provide some parameters that are crucial in lightning protection studies like: (a) striking distance, (b) the length and speed of the downward leader, (c) the length and speed of the UCL.

II. THE BUILDINGS

The present study presents results from measurements of cloud-to-ground lightning flashes that struck a pair of common identical 14-story apartment buildings (Figure 1) in São Paulo City (southeastern Brazil). The tip of their lightning rods is at a height of 52 m. Their steel reinforced concrete structures are used as natural LPS. The flash density Ng for the region is about 11 flashes/km².year [ELAT, 2015].

Fig. 1. Identical buildings (P2 on the left, P1 on the right), both have the same LPS installed.

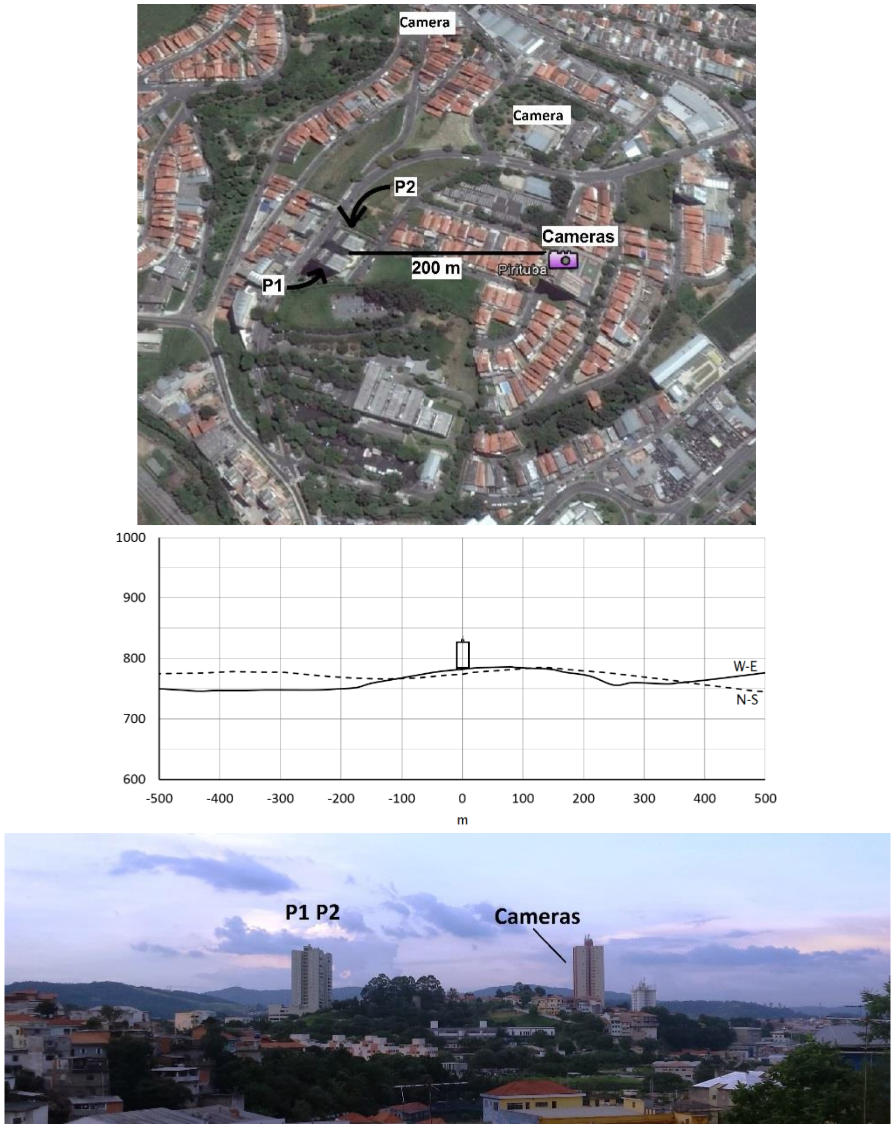


Fig. 2. a) Location of the twin buildings P1, P2 and cameras; b) approximate elevations (m) of the terrain along two directions: West to East (solid line) and North to South (dashed line), taken from Google Earth. The building is drawn on W-E elevation curve in scale; c) a side view of buildings P1 and P2 and the building where most cameras are placed.

Figure 2 shows the locations of the two buildings and cameras, the topography of the terrain within 500 m of the buildings, and a side view of P1 and P2 together with the place where high-speed cameras are located. It can be seen that the buildings are on relatively flat terrain in terms of lightning attraction.

III. Instrumentation

A. Video cameras

In preparation to a study of lightning attachment, several cameras were placed around the buildings. Images from different angles are available (Figure 3). A high-speed digital video camera (Vision Research's Phantom v711) with time-resolution and exposure times of 50 and 100 microseconds (20,000 and 10,000 images per second) was used to record the images of the lightning attachments. For more details about the measuring systems and about the use of high-speed camera for lightning observations, see the works by Saba et al. [2013]. In this work, all distances and speeds reported were measure in 2D and therefore will be underestimated.

IV. Data

Since January 2012, a total of 15 (UCL) from buildings and other tall structures (mobile phone and water towers) were observed with high-speed cameras. In the same period, 12 unconnected upward leaders (UUL) were observed. The twin buildings (P1 and P2) produced 6 UCL and 6 UUL.

Fig. 3. Images of the same lightning strike from different angles.

In this paper we will present discussions about three lightning attachment cases observed on lightning rods of the twin buildings P1 and P2. In all cases we observed that the UCL was always accompanied by an UUL from the other building, as shown in Figure 4.

V. RESULTS

The cases of lightning attachment to lightning rods that will be described and analyzed are: case A on February 9th, 2014; case B on March 1st, 2014 and case C on February 25th, 2015.

The analysis of displacement and speed of the downward leader and the corresponding UCL and UUL are presented in Figures 5 and 6. Time 0 is set at the beginning of the return stroke.

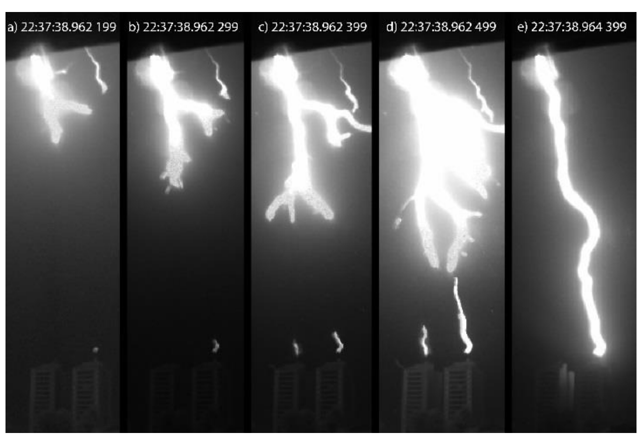
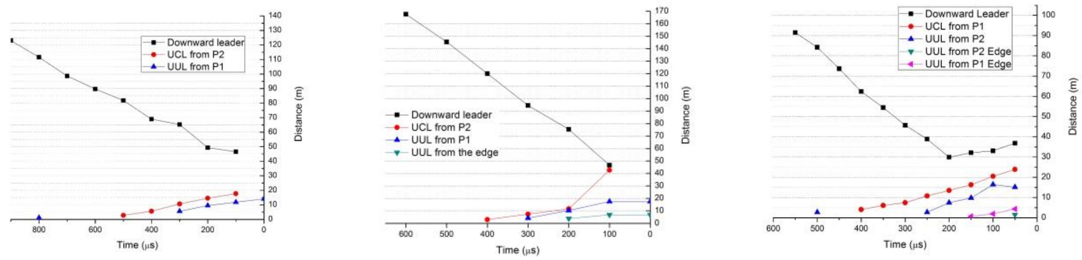
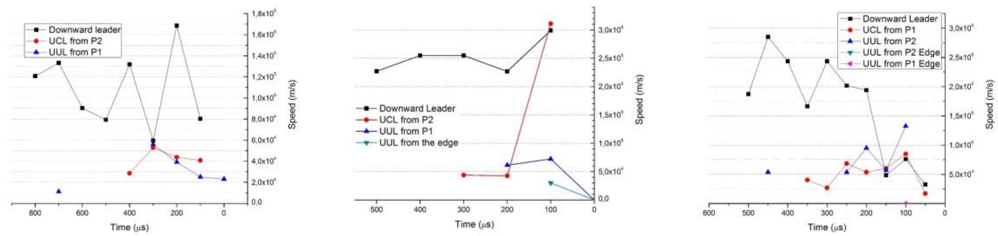


Fig. 4. *Sequence of video images showing the initiation and development of an UCL and two UUL on February 9th, 2014. The UT time of each video frame (stamped at the end of the frame integration) is given as hh:mm:ss.xxx yyy (xxx digits are milliseconds and yyy are microseconds).*



Case A Case B Case C

Fig. 5. *Distance travelled by each leader as a function of time in 100-µs intervals.*



Case A Case B Case C

Fig. 6. *Average speed for each leader in 100-µs intervals.*

The striking distance, a concept that has been widely used in lightning protection studies, was defined by Golde [1973], as the separation between the tip of the stepped leader and the tip of a grounded structure when a stable upward connecting leader is initiated from the tip of the structure (Figure 7). According to this definition, the striking distances for the cases are shown in Table 1.

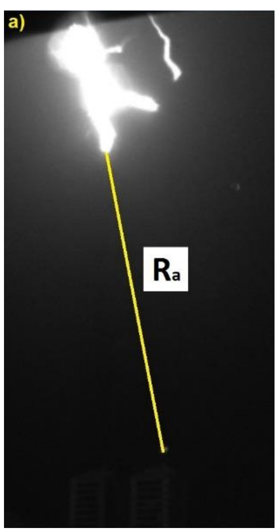


Fig. 7. *Striking distance for case B (120 meters).*

As the striking distance depends on the critical breakdown electric field needed across the final gap, and it is assumed that the return-stroke peak current is proportional do the charge on the leader, several analytical expressions for the striking distances are found in the literature and used by the electro-geometric model (EGM). They are represented by the general equation:

$$R = aI^b$$

Where R is the striking distance in meters, I is the peak current in kA, and a and b are constants. Table 1 shows the estimated values of peak current for each case. All estimates are based on values given by the lightning location system that covers the region. The constants a = 10, b = 0.65, given by the model created by Love [1973], are the ones, among others given by different models (e.g. IEC 62305 [2010], Brown and Whitehead [1969]), that give a striking distance value closest to the observed values. However, all striking distances given by this model are underestimated (see Table 1).

VI. Discussions

The physical mechanism of leader attachment to ground together with the characteristics of upward connecting leaders is one of the most important issues in lightning physics research according to Dwyer and Uman [2014]. Recent studies on the subject have analyzed this mechanism for negative CG flashes on tall structures (e.g. Lu et al.,[2013]; Saba et al., [2015]) and for triggered lightning [Wang et al., 2014]

The cases studied here (contrary to past observational studies on lightning attachment) occurred on a type of building that is extremely common in cities. The proximity of the camera and the high frame rate used allowed us to see some interesting details that may improve the understanding of the attachment process and, consequently, the lightning protection studies.

TABLE 1- VALUES OF STRIKING DISTANCES AND ESTIMATED RETURN STROKE PEAK CURRENT FOR EACH CASE.

	CASE A	**CASE B**	**CASE C**
Speed ratio range	1.1 – 4.6	1.0 – 5.8	2.9 – 9.1
Striking distance	82 m	120 m	62 m
Estimated Ip	17 kA	21 kA	14 kA
Striking distance from Love's model	63.1 m	72.4 m	55.6 m

This case study allows us to conclude that:

a) the ratios of speeds of the downward leader and the UCL varied from 1 to 9;

b) the striking distances vary from 62 to 120 m and vary with the value of the peak current as expected in past models described by the literature;

c) the striking distance values given by model elaborated by Love (1973), although underestimated, are the ones closest to the observed values.

ACKNOWLEDGMENT

The authors would like to thank Raphael B. Guedes da Silva, Lie Liong Bie (Benny), Hugh Hunt, Guilherme Aminger and Christopher do Prado Sato for all support in data acquisition, Dr Vernon Cooray for some fruitful discussions and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for supporting the research through the Project 2012/15375-7. The authors would also like to thank Luiz Fernando Gonçalves, Domênico Benenati and Eduardo Bochicchio for all the information regarding the twin buildings P1 and P2 , and to the dwellers as well, for giving permission for this research to take place in their buildings.

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