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The study of lightning strikes to common buildings in Brazil

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***Abstract*—Most of what is known about the electric current of downward flashes and striking distance of lightning protection systems come from information gathered on tall towers. There are no observational data of lightning attachment to common structures or buildings (under 60 m) that are present in almost every city. In order to study lightning strikes to common buildings, several instruments were installed in and around two identical buildings located in São Paulo city, Brazil. This paper describes the setup of electric field sensors, current transformers, X-ray sensors, high-speed video and standard video cameras. Some of the data already obtained in its first two months of operation are also shown.**

Keywords- Upward connecting leader, cloud-to-ground flash, lightning rod, lightning protection systems, X-ray

I. INTRODUCTION

A good observation of 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. Similarly, the study of the electric current that flows through the lightning channel is mostly based on measurements obtained in tall towers and from rocket triggered lightning and again, the majority of electric current data obtained so far is from upward flashes.

This work describes the setup of the instrumentation and reports some preliminary data from high-speed video and still photographic cameras, electric field and current sensors. These observations can provide some parameters that are useful for the study of lightning attachment to grounded structures, which is crucial for the improvement of lightning protection standards.

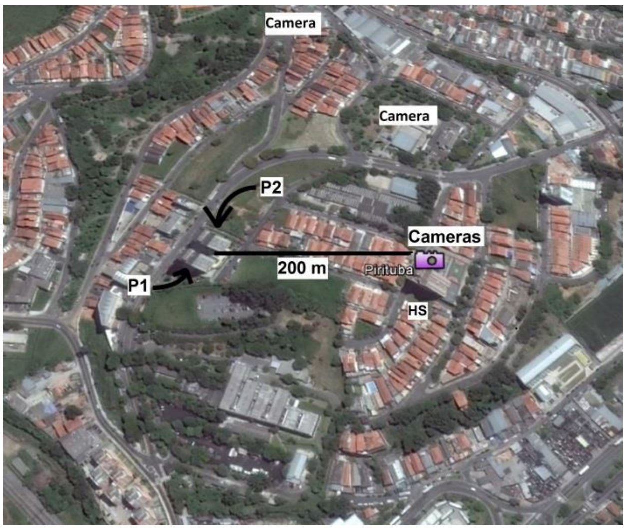
II. THE BUILDINGS

The present study presents results from measurements of cloud-to-ground lightning flashes that struck two 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 lightning protection system (LPS). The flash density Ng for the region is about 11 flashes/km².year [1].

Figures 2a to 2c show 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. The high speed camera is located on the 4th floor of the building on the right (named HS).

Figure 1. Identical buildings (P2 on the left, P1 on the right) with the same LPS installed.

a)



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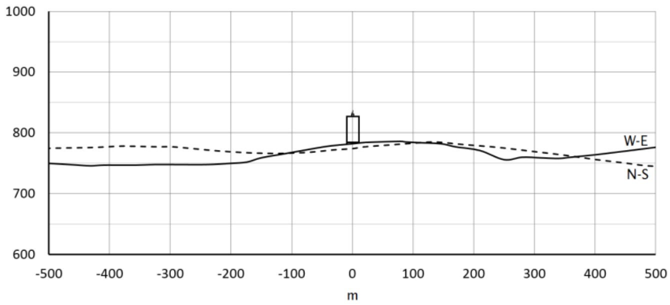

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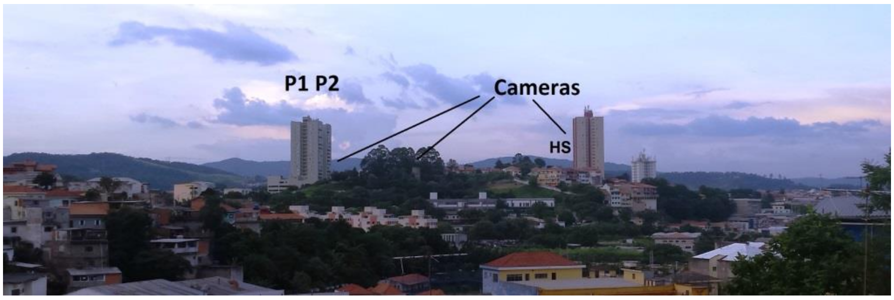

Figure 2. . a) Location of the twin buildings P1, P2 and cameras; b) approximate elevations (m) of the terrain along two directions: West to East (solid line) and North to South (dashed line), taken from Google Earth. The building is drawn on W-E elevation curve in scale; c) a side view of buildings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

Figure 3. Images of the same lightning strike from different angles. This lightning flash that occurred on January 27, 2016 was composed of 6 return strokes.

Figure 4. Image from a high-speed video of a downward leader and upward connecting leaders a few microseconds before attachment (recorded on February 9, 2014).

III. INSTRUMENTATION

A. Video cameras

In preparation for a study of lightning attachment, several cameras were placed in 3 different locations around the buildings. Images from different angles will help to estimate the distances of different lightning processes to the lightning rods (Figure 3). A high-speed digital video camera (Vision Research's Phantom v711) with time-resolution and exposure times of 12.5 and 100 microseconds (80,000 and 10,000 images per second) was used to record the images of the lightning attachments (Figure 4). 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. [2]. All distances and speeds reported in this work are still in 2D and therefore will be underestimated.

B. Current sensors

One Pearson current sensor model 310-X was installed on the lightning rod of each building (see Figure 5). This current sensor is capable of recoding current up to 50,000 A with an useable rise time of 200 nanoseconds, a low frequency 3dB cut-off of 5 Hz (approximate) and a high frequency 3dB cut-off of 2 MHz (approximate). The output of the sensor is split in two channels (20 dB and 50 dB attenuation over 50Ω), and sent to a data acquisition system through a pair of fiber optic links. Before installation, both sensors were tested and calibrated in the high voltage facility at IEE/USP.

Figure 6 shows the current waveform of one return stroke and an M-component that struck the lightning rod of building P1 on January 27, 2016 (shown in Figure 3).

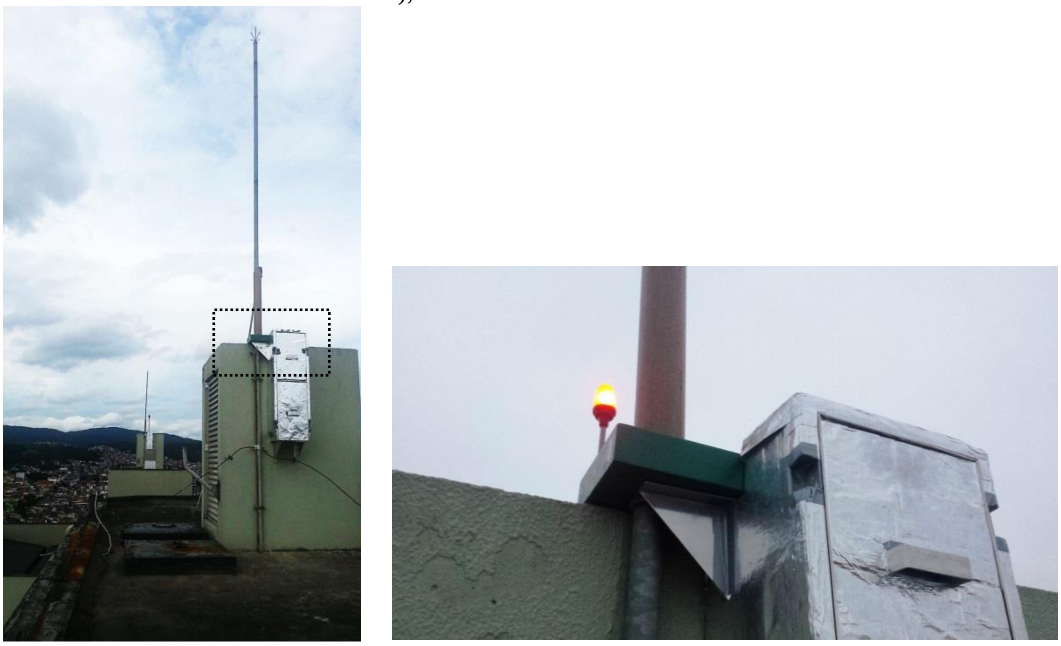

Figure 5. Current sensor installed on the lightning rods (left) and detail of the installation (right).

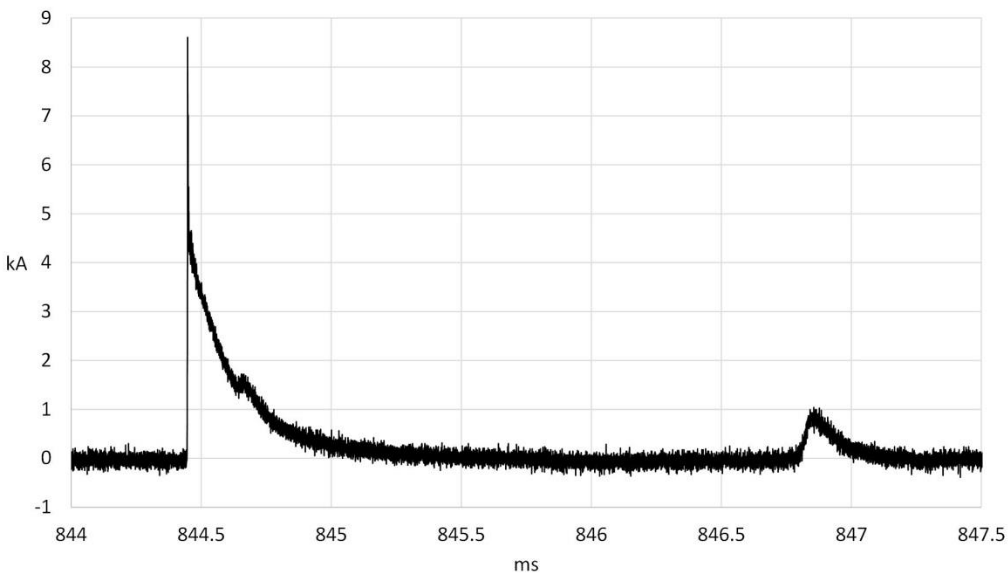

Figure 6. Current waveform of the second return stroke and following M-component the flash discharge that struck one of the lightning rods.

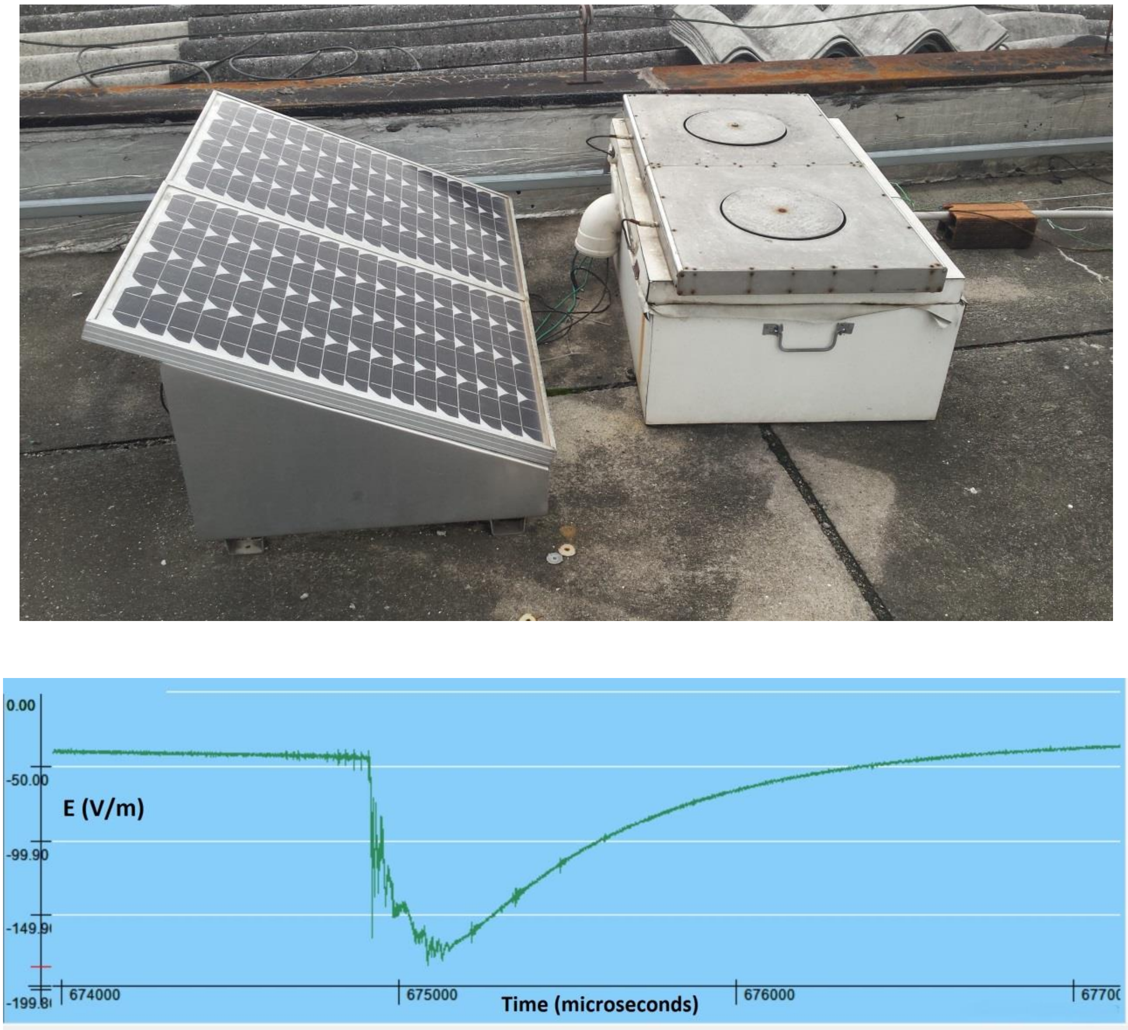

Figure 7. Electric field sensor and the signature of a lightning stroke.

C. *Electric field sensor*

The measuring system for the electric field sensor consisted of a flat plate antenna with an integrator and amplifier. Fiber-optic links were used to transmit the signal from the integrator/amplifier to the digitizer. For time synchronization a GPS receiver is connected to a PC. The sampling rate of the waveform recording system is 5 MS/s on each channel. The lower frequency and the upper frequency limits of the electric field measuring system is 306 Hz and 1.5 MHz, respectively. Four independent systems were installed. One sensor is placed on top of building P2 (at a distance of 3 and 21 meters from P2 and P1 lightning rods). The distances of the other electric field sensors to the P1-P2 buildings are: 8.5 km, 93 km and 178 km. Figure 7 shows the setup of the sensor and an example of the signature of a stroke recorded at a distance of 8.5 km from the buildings.

D. *X-Ray*

A crystal of NaI (Tl) coupled to a photomultiplier and a pre-amplifier are used as X-ray detector. They are enclosed in a heavy aluminum box with an optical fiber transmitter, both powered by batteries. This system is similar to the one used in several other works [3-6]. The X-ray detector is located on top of the building P2 (7.5 and 16.5 meters away from lightning rod of P2 and P1) in order to measure X-rays associated with the lightning discharge. Figure 8 shows the location of the X-ray sensor and other sensors placed at the top of the buildings. No measurements of X-rays were obtained so far.

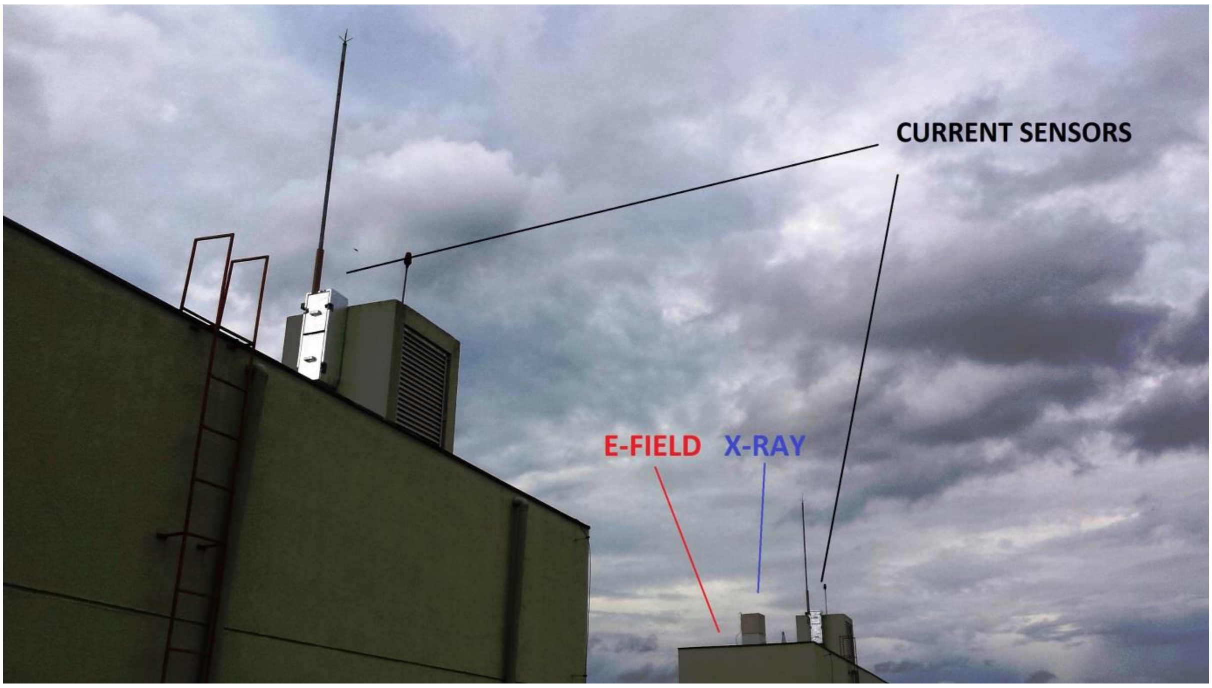

Figure 8. Location of the sensors on top of buildings P1 (left) and P2 (right).

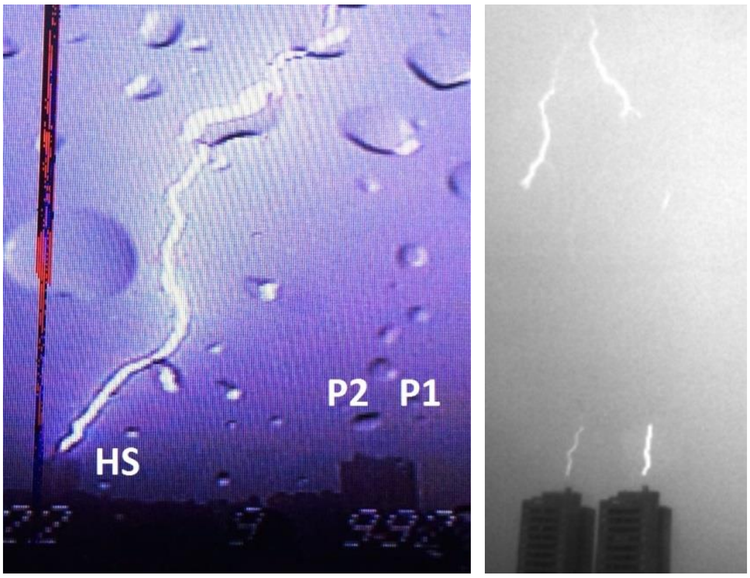

Figure 9. Negative cloud-to-ground flash striking building HS (image from standard video on left) and producing UUL from P1 and P2 on February 2nd, 2016 (image from high speed video on right).

TABLE I. MEASUREMENTS OBTAINED SINCE THE END OF INSTALLATION.

Date	CG striking location	Leader from P1	Leader from P2	Measurements	Videos
January 27, 2016	P1 building	UCL	UUL	Current, E-field	30, 120 and 3200 ips
February 2, 2016	HS building	UUL	UUL	Current, E-field	30 and 56,000 ips
February 24, 2016	HS building	UUL	UUL	Current, E-field	30 and 80,000 ips

IV. DATA AND COMMENTS

Three events were recorded since the conclusion of the installation of the sensors on the buildings, at the end of December 2015. Three negative cloud-to-ground flashes produced upward connecting leaders (UCL) and unconnected upward leaders (UUL) from the lightning rods on buildings P1 and P2. One struck building P1 (Figure 3) and the other two struck the building where the high-speed camera is located (marked as HS in Figure 9). Table 1 summarizes the obtained measurements.

Although this data is very recent and still under analysis, several interesting characteristics have already been found. The proximity of the sensors, especially of the high-speed camera and the high frame rate used allow us to see some interesting details that may improve the understanding of the lightning discharge, the attachment process and, consequently, the lightning protection studies. Hopefully, enough data will be soon gathered to study topics like:

Leader characteristics:	speed of the downward leader the length and speed of the UCL electric field changes due to leader propagation
Attachment process:	striking distance final jump
Return stroke:	peak current intensity di/dt charge transfer
Continuing current and M-components:	amplitude duration charge transfer
X-rays:	processes that produce them intensity

Contrary to past observational studies performed on tall structures (towers, wind turbines, skyscrapers, power lines, etc.) the information to be obtained from this facility will shed light on how lightning interacts with a type of building that is extremely common in cities. Note that laboratory long sparks, rocket triggered lightning and lightning initiated on very tall structures have different characteristics than the typical lightning that hits most structures worldwide.

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