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Lightning Incident with Multiple Natives Injured in the Sierra Nevada de Santa Marta - Colombia

Description of Scenario

Jorge Alejandro Cristancho C.*, Jorge Enrique Rodríguez M., Carlos Andrés Rivera G., Francisco Román+
Electromagnetic Compatibility Research Group EMC-UN
Universidad Nacional de Colombia
Bogotá D.C., Colombia
* jacristanchoc@unal.edu.co, + fjromanc@unal.edu.co

***Abstract*— This paper reports the lightning-caused tragedy on October 5th, 2014, when 11 Colombian Indigenous inhabitants died and 15 were seriously injured inside an Unguma, a ceremonial house constructed with traditional methods. The accident scenario and the possible interaction mechanism that produced several traumata in the indigenous men are described. The ground potential rise inside the Unguma and the energy absorbed by a simulated human body placed on the floor surface at eleven different positions and distance spans from the possible lightning impact point are calculated. The calculation was performed through electromagnetic numerical simulations of a lightning direct impact on a simplified model. A parametric analysis was performed with four soil resistivities.**

Keywords—Lightning, accident, Lightning-caused injuries, multiple struck people, large group

I. INTRODUCTION

When lightning interacts with humans could have significant physical, psychological and economic effects. Even more, if a lightning event affects, injures or kills multiple people at once, it could also have a strong social impact. Despite of multiple casualty incidents are uncommon, there are some available reports in specialized publications and many in the public media about multiple persons injured by a single lightning strike event. Places of this type of incidents are sport fields, parks, open areas and outdoor or remote wilderness settings with several adult and children casualties [1] even including dogs [2]. A lightning incident involving a large group of injured people in Colombia, occurred in 2010, at the rural district of *El Bizcocho*, Municipality of San Rafael in the Department of Antioquia. On the afternoon of May 3rd, during a religious procession, a lightning incident left more than 60 casualties with 3 fatalities. Similarly, in Nyaruguru, Rwanda, during a Saturday religious service in March 11th, 2018, a single lightning event left 16 fatalities and 140 people injured [3].

Currently, the lightning safety standards are focused in protection of structures but, with respect to human and living being's protection against lightning, there are very few references. The technical report IEC/TR 62713 "Safety procedures for reduction of risk outside a structure" is an introduction to the lightning strike prevention that give some information about adequate actions that should be taken by people when exists lightning-caused risks [4]. IEC 62305 "Protection against lightning" addresses the principles of lightning protection of structures, risk management and damages to structures and life hazard [5]–[7]. On the other hand, IEC 60479 "Effects of current on human beings and livestock" focuses on the effects of AC and DC power line currents on the human body, considering the source parameters, some current paths and a body constant impedance [8]. Since the problem of lightning-caused injuries which affects mainly rural or less developed countries in areas with high lightning activity is not decreasing, there are few publications addressing the issue of lightning protection of living beings. The lack of instruction and education, weak and vulnerable housing, working outdoors, intensive traditional agriculture and other socioeconomic factors contributes to this conspicuous panorama [9]. Gomes have had presented some lightning protection proposals for low income communities and small structures [10], [11]. Additionally, the team of ACLENet (African Centres for Lightning and Electromagnetics Network) with the help of communities, governments and private initiatives is implementing several lightning protection system for vulnerable small buildings and homes in Africa [9].

In this work, we are reporting retrospectively, the lightning-caused tragedy on October 5th, 2014, when 11 Colombian Indigenous inhabitants died and 15 were seriously injured. Moreover, to estimate the earth potential rise at eleven points on the floor surface of the ceremonial house constructed with traditional methods, a simplified model was used.

II. BACKGROUND

A. *Some Geographical Aspects of the Sierra Nevada de Santa Marta*

The *Sierra Nevada de Santa Marta* is an isolated mountain range formation located in the northern part of Colombia, nearby to the Caribbean coast. It is placed in the Intertropical Convergence Zone, with an area of 3830 km^2 reaching altitudes of 5700 m above mean sea level. It is the world's highest coastal mountain range and due to the different altitudes, it has a large variety of climates, ranged from tropical coastal and lowland rain forest to permanent snows. The soils from 0 to 1000 m.a.s.l. are mainly clays of very high plasticity with a fine layer of organic material. From 1000 to 2000 m.a.s.l. the soils are mainly gravelly silts of moderate fertility.

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The Sierra Nevada de Santa Marta is considered a high-performance hydrographic factory, feeding 35 rivers with a flow rate which irrigates the lands of the coastal flood plains and valleys of rivers Ariguaní and Cesar. It has an average precipitation between 1000 to 4000 mm/year suppling water to aqueducts of several cities, settlements, farms, livestock and mining around the mountain range [12].

The rainfall seasonality in the area is bimodal with the highest amount of rainy days in May and June, and September and October. The high peak is in October, month with average records of around 15 rainy days [13].

B. *Kemakumake village*

The *Sierra* (Sierra Nevada de Santa Marta) is the cradle of the Tairona pre-Columbian culture. Currently, there are still descendants of that culture with around 70,000 indigenous people of four ethnic groups, placed in the jurisdiction of the Departments of Cesar, Magdalena and La Guajira. It was declared by UNESCO as a Biosphere Reserve of Man and Humanity for its variety of ecosystems, biodiversity, history and culture. This area is considered a sacred site for the four indigenous peoples of the Sierra: the Kogui, Arhuaco, Kankuamo and Wiwa [14]. These Tairona Culture descendants, live in *Resguardos Indigenas* (Indian reserves) located in the mid-highlands, delimited by the ancestral territory of the *Sierra*.

Wiwa people are placed in the foothills of the mountain range of the Sierra. Kemakumake is a Wiwa's settlement at northwest of the Sierra, placed in a valley of the Guachaca River Basin, at 314 m.a.s.l., near to the small town of Guachaca, a rural suburb of Santa Marta City municipality. The location coordinates of Kemakumake are 11°10'41.09" N 73°54'27.42" W as shown in the map of Fig. 1. This area is part of the indigenous reserve *Resguardo Indígena Kogui-Malayo-Arhuaco*. Such as other Wiwa's villages, the structure of Kemakumake had a traditional ceremonial main house in the middle called *Unguma*, site from which the settlement was growing.

C. *The Unguma: the Wiwa's ceremonial house*

The *Unguma* is the territorial reference, the dominant structure and the core of a Wiwa´s villages, surrounded by the other houses of their residents. As said by Wiwas themselves, an *Unguma* is a sacred traditional building dedicated to ceremonial rituals where is allowed only the men entrance, for important discussion meetings and to talk about the community concerns. It is also the house temple used as Centre of guidance, formation and learning where is received advise of the spiritual leader known as *Mamo*. The *Unguma* base could be of rectangular or round shape. It uses local materials of the nature such as thatch-roofed mixed with palm leaves; adobe, woven palm and wood walls; and earthen floor. This ceremonial house has only two small entries oriented from east to west. Do not have windows or any other evident type of ventilation or illumination. Sometimes for special meetings, inside are used up to four controlled campfires. This architecture and characteristics reveal the Wiwa ideology and have a meaning of thought and knowledge, of authority, human beings, spirit and communication [15].

Fig. 1. Map of Colombia and Wiwa's settlement place of Kemakumake on Sierra Nevada de Santa Marta, indicated by the arrow in the right side. Source: adapted from Wikipedia, ESRI and OpenStreetMap.

The sacred house of Kemakumake was placed in a small valley surrounding by low height hills and close to some palm trees of similar height than the ceremonial house. It had 11,0 m x 8,5 m approximately, supported by two central bulk columns of about 6 m height, made of trunk trees bring from different places. Fig. 2 shows the location of 40 men inside the Unguma.

D. *The lightning risk*

Every year the Sierra Nevada de Santa Marta is stroke by thousands of lightning flashes. The base and hillside of the mountain have average variations on lightning strike density between 8 to more than 64 strokes per square kilometer per year, as shown in a lightning map of Fig. 3. The higher lands of the mountain have less than 2 strokes per square kilometer per year.

In the base of this mountain range are placed two hotspots of high lightning activity, in Barrancas-Guajira and El Retén-Magdalena, ranked as the 46th and the 343rd of the world, with flash rate densities of 95,38 and 57,75 flashes/km^{2}year respectively [16]. These data of the Tropical Rainfall Measuring Mission TRMM, a joint mission of NASA and the Japan Aerospace Exploration Agency, also record maximums hourly and daily average flash rates at 17 h local time and at the beginning of October, with up to 50 flashes/day for the 1998-2013 period [16].

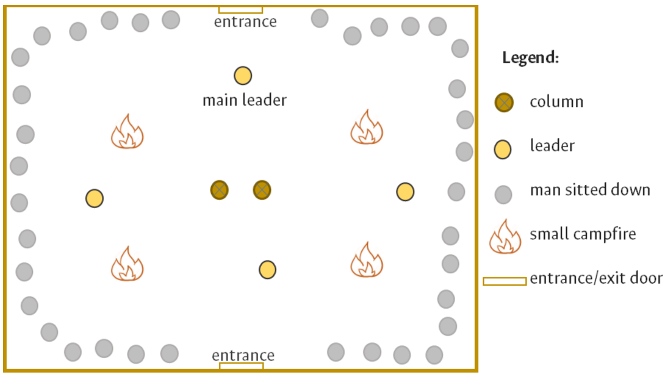

Fig. 2. Representation of the 40 men gathered inside the Unguma surrounding their leaders in the middle of the ceremonial house.

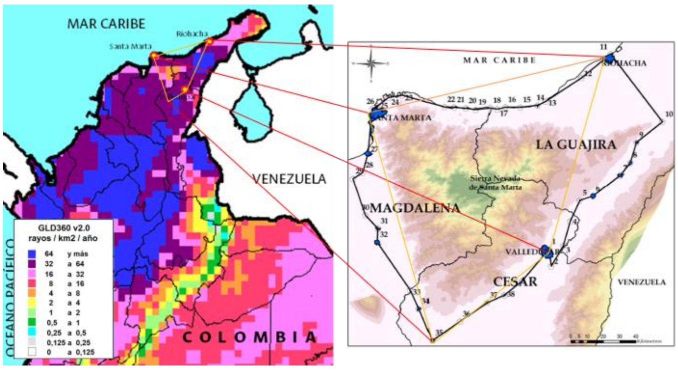

Fig. 3. Lightning strokes density map of the north of Colombia (left) showing the influence area of Sierra Nevada de Santa Marta inside the Black Line (right) of the Reserve Kogui-Malayo-Arhuaco. Source: authors from, *left:* Ron Holle (personal communication) from Vaisala GLD360 v2.0 data for 2012-2016 and *right*: [17].

Kemakumake village, with a population of about 900 people for 2014, was placed in an area of 28125 m^2, with a lightning density of 32 strokes/km^2·year. The materials used in their homes, extracted from nature, are practically totally flammable. Additionally, due to the building's small entries and the village location in the backcountry with complicated access, it becomes very difficult any attempt to evacuate the people from their houses and from the village.

Due to the high lightning activity, the presence of combustible materials and high occupancy, for the presented scenario it can be expected that the risks of human losses and loss of cultural heritage is not tolerable, according to IEC 62305-2 "Protection against lightning – Part 2: Risk management" [6]. Then, the installation of an adequate lightning protection system is mandatory, as it should be for all this type of constructions, even in very low lightning activity places (Ng > 0,02).

III. The Lightning-Caused Tragedy

A. *Possible mechanisms of lightning injuries*

The possible lightning mechanisms that can interact with humans or animal to cause injures can be electrical, non-electrical or a combination of them. The electrical are those caused by the coupling of electrical currents with the body such as: direct strike, ground currents (also known as earth potential rise – EPR or step potential), contact potential, side flash (or side splash) and upward streamers (or connecting leaders). The non-electrical injures can be those caused by mechanical effects of the lightning channel, heat or fire, such as: barotrauma due to the overpressure by the blast wave, blunt force [9], [18]–[20], shrapnel or missile injury [9], the secondary fall of other materials such as tree branches, façade slabs and tiles, or subsequent fires. Moreover, beside the electrical current, lightning channel is a very strong source of ultraviolet radiation and it has been shown that it gives rise to X-ray and gamma radiation [20]–[22]. Despite the very rapid phenomenon, these radiations of high energy could lead to eye injuries or brain cortex stimulation.

The ground currents appears as the most lethal and traumatic lightning mechanism, accounting for about 50% of all lightning injuries in a developed country [9], [19], possibly much more in developing countries. This mechanism can cause dangerous step voltages and grounding arcs [19], [23].

B. *Types of lightning injuries to humans*

The different coupling mechanism between lightning and humans, or the combination of these, can lead to many injuries. For this reason, lightning-strike victims may be both trauma and medical patients. The most related injury to lightning, in popular knowledge, are the burns. However, there are many other lightning-caused injuries, some of which could cause death. Cardiopulmonary arrest is considered the most common fatal consequence of a lightning strike [19], [22]. Lightning related injuries could affect: respiratory and cardiovascular system, muscular and skin, eyes, ear, nervous system, endocrine and sexual system, that can produce neurologic, neurocognitive and psychological dysfunction, myalgia and keraunopalysis (temporary paralysis of the arms or legs) particularly in lower extremities, weakness, numbness and tingling in muscles and tissues [19], [22]. Some stimulation of visual cortex that lead the experience of hallucinations and phosphenes also has been related to lightning, probably due to the strong electromagnetic fields associated to the electric discharges [24].

C. *Case scenario of the tragedy*

On the night of October 5th, 2014 at the *Unguma* ceremonial house in the middle of Kemakumake in the Sierra Nevada de Santa Marta, a meeting was held for the leadership transfer of the community Wiwa and to discuss some problems between their families. There was a heavy electrical storm in the meanwhile the meeting prolonged until the wee hours of the next day's morning. The GLD360 data from the Vaisala lightning detection network registered on a 15 km radius around Kemakumake site, 2301 strokes for the period between Oct 5, 2014 23:30 h and Oct 6, 2014 1:00 h local time, as shown in Fig. 4.

Inside the house about 40 men were gathered around the small indoor campfires, as represented in Fig 2, many of them squatting or sitting on the ground and others in short bench seats of wood [15]. Around 12:20 AM (Oct 6th) the *Unguma* was struck by a lightning, possibly on a tip of one of the two columns that support the roof and the house structure. According to the Mamo leader of the meeting, the lightning strike caused an explosion of a main central column, throwing splinters into the air, one of which reach his face. Fig. 5 shows a representation in a non-scaled drawing of two people sitting around a column struck by a lightning.

It is no so clear, but probably the stroke starts a fire in the upper part of the roof. Mamo said that immediately after the lightning strike, he saw the image of a small person going out of the *Unguma* and then persecuted it until the image vanished below the rain. The Mamo reacted and return to the house when saw the people inside, paralyzed lay on the floor seeming like they were dead.

With the help of women of the community, they took everyone out of the ceremonial house. The advance force of the fire on the roof, finally incinerated entirely the sacred house and other two smaller huts close to the former [25].

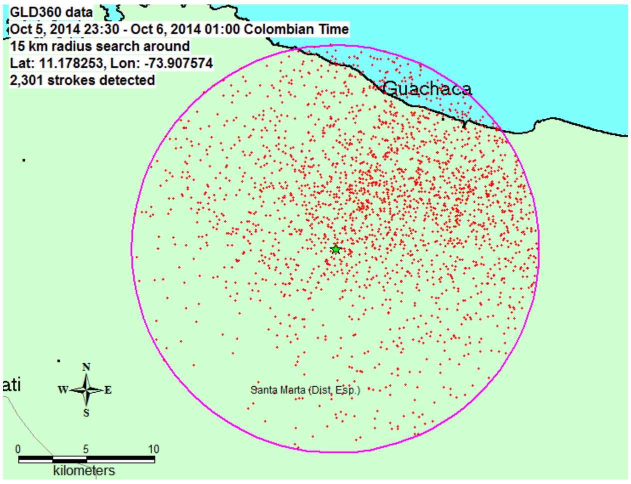

Fig. 4. Lightning detection map of 15 km radius around Kemakumake for Colombian time between Oct 5, 2014 23:30 h and Oct 6, 2014 01:00 h. For that 90 minutes were detected 2301 strokes with an average of 26 strokes per minute. Source: Ron Holle (personal communication) from Vaisala GLD360 v2.0 data.

All the victims were taken out after the fire starts. The lightning currents led partial-thickness and full-thickness burns in the lower extremities and the buttocks, mostly in 8 injured victims. Due to the location of the Kemakumake village in the backcountry and lack of communications, only after 6 hours the specialized medical help arrived, by military helicopter, for care and evacuation of the injured people to regional trauma centers of the city of Santa Marta.

The lightning-caused incident ended in the tragedy that left 26 casualties, 11 people dead and 15 injured. Among the fatal victims were 7 men of the same family of the Mamo who was leading the meeting and their son, also a leadership of the village. After the lightning tragedy, the village of Kemamumake was totally abandoned as shown in Fig. 6.

According to IDEAM (Institute of Hydrology, Meteorology and Environmental Studies of Colombia), for that Oct 5, 2014 was reported a particular hot weather due to a "tropical wave effect", causing an excess of energy in the northern Colombia, resulting in a so slowly cloudiness and stormy night [26].

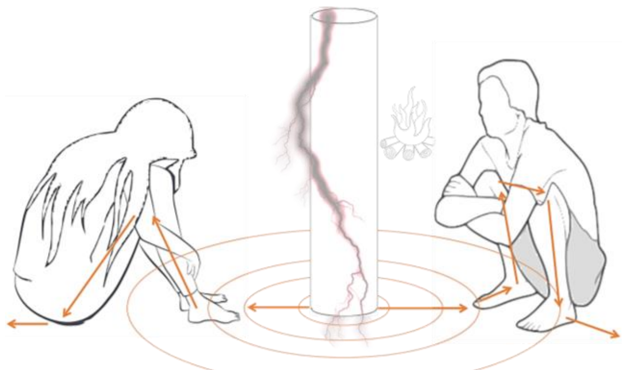

Fig. 5. Representation of a lightning stroking a wooden column with two people sitting around it, on the ground and in squatting position. The grounding currents can cross inside the human bodies from the feet to buttocks and from foot to foot. The worst case of the two represented is sitting on the ground.

Fig. 6. Satellite images from Kemakumake before (12/28/2013) and after tragedy (1/10/2017). The circle encloses the *Unguma* location. Source: adapted from Google Earth.

IV. Discussion

Lightning incidents with multiple casualties are very uncommon. This case scenario of the lightning-caused tragedy shows that the most probable mechanism that injure the men inside the *Unguma* were ground currents. When the lightning struck the house, the general position of the man inside were squatting, sitting on the floor or in short wood benches. Then, the burn marks in the lower extremities and buttocks of the victims could were the effect of the ground currents let on their path. Additionally, the father Mamo report the wooden shrapnel by the splinter hit in his face due to the explosion of a main wooden column. It is less probable a side flash discharge from the struck column due to the places of each gathered man, but if the lightning path crossed over the roof, a side flash could connect from the walls through a victim body. Despite of this hazardous scenario and the first lightning cause, the lack of emergence medical assistance is estimated as the main reason of the multiple dead. It is very likely that some of the fatal victims would have needed cardiopulmonary resuscitation, procedure with a high success rate in this type of incidents [19], [27]. Without immediate cardiac or respiratory support it is more likely to die after a lightning strike [27]. In the less developed countries, the main cause of death from lightning is cardiac arrest at the time of the injury [9].

Multiple lightning-caused injuries, as the reported case, have strong social, cultural and economic implications [19]. The lightning-caused loss of 11 men, leaders of the Wiwas' community, left the social and cultural structures confused and disoriented. Much knowledge of the Wiwas' advisors was lost forever. The reconstruction of the social fabric and families has been taken much time and efforts. Obviously, this tragedy left indelible marks and the fear in the people that see in this incident an advice of the nature, for not continuing mistreating and destroy it.

Despite of the risk assessment of IEC 62305-2, is obvious the obligatory implementation of a Lightning Protection System (LPS) for the main construction and the village of Kemakumake and for other places in similar risk.

To assess the potential rise between some points in the surface inside the ceremonial house was made a computer simulation of a simplified model of an *Unguma*. The results of this numerical approach are shown below.

A. Computer simulations

The numerical simulation of a simplified model of an *Unguma* with rondavel shape of 11 m diameter and 6 m height is performed in CST Microwave Studio (Fig. 7). In the simulation a 50 kA, 10/350 µs current source is used, following the methodology described in [23]. It is assumed a lightning channel of 10 cm diameter that attaches and buries 50 cm into the ground. To assess the potential rise, eleven voltage probes are placed on the surface floor of the ceremonial house model with different locations as shown in Fig. 8. Considering a homogeneous soil, it is assumed that the Superficial Current (SC) spreads radial homogeneously from the attachment point, at the base of the central pole, to outside. Then, voltage probes have three types of orientations (A, B and C). The first type (A) is perpendicular to the direction of the SC, the second (B) is parallel to the direction of the SC and the third (C) is forming an acute angle to the SC (~ 45° to the current flow).

Moreover, to estimate the effect of the soil resistivity four resistivity values common to sandy-clay type soils of the accident region are taken: 70 Ω·m, 100 Ω·m, 200 Ω·m and 300 Ω·m to perform a parametric analysis of the scenario. The maximum voltage values obtained after running simulations for each probe at each resistivity value are tabulated in Table 1.

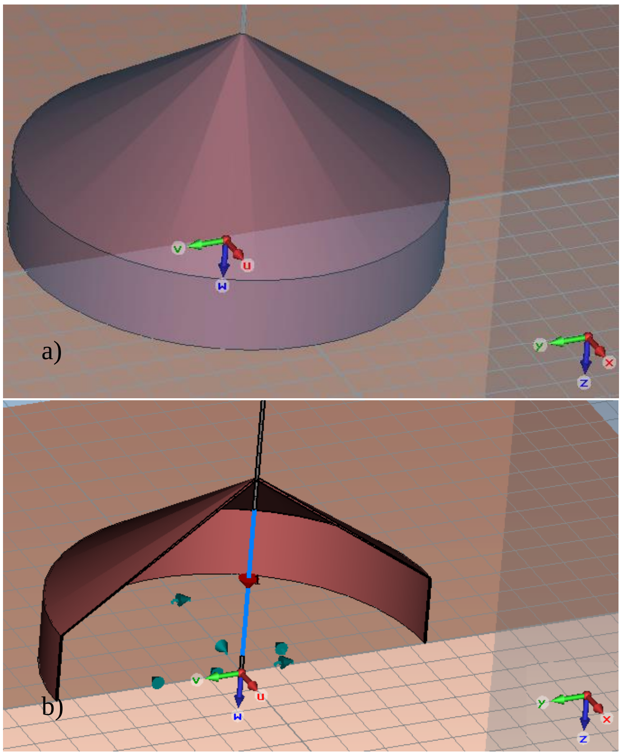

Fig. 7. Implementation of the Unguma model (rondavel shelter of 11 m diameter and 6 m height) in CST Microwave Studio® (a) and cross section, channel and location of some voltage probes on the floor surface (b).

B. Energy calculation for each point

For the estimation of energy through the human body at the eleven points, was assumed a resistance (R) of 1000 Ω for different paths, as used in the IEEE Std 80-2013 in the section 7.1 "Resistance of the human body" [28].

The following expressions (1) and (2) were used to perform the calculations,

$$P(t) = V_p(t)I = V_p(t)\frac{V_p(t)}{R} = \frac{V_p(t)^2}{R} \qquad (1)$$

$$E = \int_{t=0}^{T} P(t)dt \qquad (2)$$

where $P(t)$ is the power, $V_p(t)$ is the voltage measured at the probe and R is the resistance of 1000 Ω of the human body. The energy values after the calculations are presented in Table 1.

Results summarized in Table 1 show energy levels below 20 J for configurations of type A, with a distance span of 1 m and placed at more than 1 m away from the surface strike point.

The value of 20 J is suggested as safe limit tolerability for the human body by some publications according to the Dalziel's experiments [28]–[30]. Configurations B and C, and those A so close to the strike point, exceed the tolerance limit of energy absorbance for the human body.

C. Final remarks

Prevention is the first measure to take for reduce the lightning risks. However, despite of positive effect, awareness alone is not enough to reduce the risks of lighting to humans [9], [11]. Awareness and warnings are useless unless there are safe places to reach in time [9]. Unfortunately, many people in Africa, Asia and Latin America dwell permanently in very vulnerable structures to lightning strikes [10] and attention to the risk commonly is not taken into account by governments and population [11] or only after a tragedy. Nevertheless, even in developed countries, in some circumstances is not easy to access a safe shelter [10].

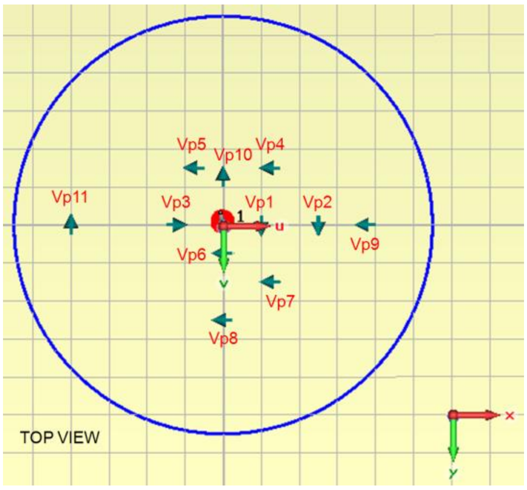

Fig. 8. Top view showing the location of the eleven voltage probes on the floor surface. The grid is 1 meter between the squares.

TABLE I. MAXIMUM VOLTAGE AND ENERGY FOR THE ELEVEN EVALUATED POINTS.

Probe	**Orientation**	**Distance to strike point** [m]	**ρ₁=70Ω/m**		**ρ₂=100Ω/m**		**ρ₃=200Ω/m**		**ρ₄=300Ω/m**	
			Voltage [V]	**Energy** [J]	**Voltage** [V]	**Energy** [J]	**Voltage** [V]	**Energy** [J]	**Voltage** [V]	**Energy** [J]
Vp1	A	1,0	3557,73	3,21	5082,46	6,5568	10163,67	26,22	15398,69	60,20
Vp2	A	2,5	191,86	0,01	272,94	0,018	543,56	0,07	822,23	0,16
Vp3	B	1,0	133723,66	4516,32	191031,13	9216,96	382055,13	36867,81	578868,25	84636,74
Vp4	C	1,8	35369,91	315,23	50526,04	643,32	101045,56	2573,25	153095,56	5907,29
Vp5	C	1,6	34366,82	298,29	49093,64	608,75	98183,92	2435,03	148762,06	5590,07
Vp6	A	0,8	8520,59	18,37	12171,69	37,54	24343,82	150,18	36884,89	344,79
Vp7	C	1,8	35369,91	315,23	50526,04	643,32	101045,56	2573,25	153095,56	5907,29
Vp8	A	2,5	191,86	0,01	272,94	0,018	543,56	0,07	822,23	0,16
Vp9	B	3,5	19708,55	97,02	28148,97	197,99	56278,29	791,92	85260,35	1817,90
Vp10	B	1,0	144518,39	5272,52	206449,88	10760,25	412894,53	43040,93	625594,63	98808,47
Vp11	A	4,0	75,89	< 0,01	107,11	< 0,01	211,92	0,01	319,49	0,02

Note: Probe refers to monitor of voltage for each of the eleven location as shown in Fig. 8.; Orientation refers to each of the relative three direction (lengthwise, crosswise and diagonal) of probes from the center to outside; Distance to strike point is the distance from the lightning impact point to the probe; ρ_n= is the soil resistivity.

As thatched roof huts do not offer any protection against lightning, in places with cloud to ground lightning activity is mandatory the implementation of some lightning protection system. However, there are various practical difficulties of implementing recognized lightning protection standards on those type of constructions and other places in remote locations the majority going through financial and educational constraints [11].

From the scenario reported and numerical simulation outcome, it can be considered that the worst trauma effect occurs on victims that were sitting on the ground close to the base of the struck pole, particularly oriented as type B, lengthwise to the current flow, when the energy levels are much higher than the permissible in the whole inner area of the *Unguma*. As it is represented in Fig. 5, when lightning strikes a column or other tall object, the worst-case position that can produce more trauma is sitting on the ground. In squatting position with feet together, the lower distance span between each foot reduce the potential rise mitigating the lightning risk. Moreover, reducing the soil resistivity, the potential rise decreases and therefore the energy absorbed by the body.

V. CONCLUSION

In this paper was reported the lightning-caused tragedy inside a ceremonial house, placed in Kemakumake village at the Sierra Nevada de Santa Marta in north Colombia. The single lightning strike tragedy left 11 fatalities and 15 injured of a Wiwas' people community. It was discussed the accident scenario and some geographical and cultural aspects, showing the ground current as the most probable interaction mechanism that produced much of the traumata. Traditional buildings made with natural materials are very prone to facilitate tragedies such as was reported. The outcomes of computer electromagnetic simulations of a simplified model of the scenario show that the potential rise can lead to death. Reducing the surface soil resistivity and taking a squat position can help to reduce the risk. However, lightning protection system is mandatory in that style of construction, even more if gather much people.

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