THE IMPACT OF A LIGHTNING STROKE ON A FLAT ROOF WHEN THE BUILDING IS FILLED WITH WATER

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ABSTRACT

The flat roof of an exhibition hall was hit by a flash during a thunderstorm with strong rain and partially destroyed. This case can be explained by the Electro Hydraulic Effect. A laboratory simulation in the **BET** confirmed this damage mechanism with a model of the flat roof. As a conclusion of this case, guidelines for lightning protection should be elaborated so that future damages can be avoided.

1 INTRODUCTION.

Up to now three cases of damaged buildings which are to be traced back to a flash into a water overcast flat roof were reported.

Case 1: Photo1-4. In the Dutch municipality Markelo (N 52,29,056; E 6,57,312), a car exhibition hall was damaged at 25th of July 1994 at 8 p.m. /1/. The cost for repair were app. 280.000 $. The building had no lightning protection system. In the evening a thunderstorm occurred that first diverted and returned relatively through meteorological circumstances where it overlaid themselves with a further approaching thunderstorm. Heavy rainfall began 10-15 min before the first thunderstorm. In the village, up to 30 cm of water were measured. In this area, numerous flashes were registered by the Dutch flash measuring system. In this paper, some hypotheses are examined to the explanation of this case. Some effects could be confirmed by experiments. As a previous result of this work, recommendations for protection are given for buildings with flat roofs so that future damages on buildings and persons can be avoided.
Case 2: Photograph 5. The flat roof of a factory was destroyed in Belgium /2/.
Case 3: Photograph 6. In Austria the roof of a paper factory was destroyed /3/.

2 DETAILED DESCRIPTION OF THE CASE IN THE NETHERLANDS.

Photo 1 shows the roof of the damaged building (30m x 30m x 3,3m). The roof consists of a sheet construction of trapezoidal sheet steels (Fig. 1). Insulating boards are attached on the trapezoidal sheet steels. Roofing paper covers the hard foam plates. The height of the roof frame is app. 9 cm. Photos 2-4 show the damaged parts of the building. At the time of the event, only one person in the bordering office section of the building was present. According to the statement of this person, the first flash hit the flat roof. The second flash occurred approximately 3 minutes later and damaged the house telephone. As a result of the first stroke, a strong blast wave shook the whole building. Some cars were moved by the blast wave and ran through the pane of glass. As shown in Fig. 2, there are two punctures, where the parts of the roof touched the ground in the hall, in the flagstones. A coloured crack on both sides which looks like a discharge figure comes from a puncture. Within the radius of some meters, further small spots with similar features have been found. In Photo 2, the hanging down roofing paper can be recognised. The roofing paper was burned according to the statements of the witness on a surface of 3-4 m of diameter and crumbled during touch. A carbonised channel was found at the place of the roof opening through the hard foam plate. The Dutch flash navigation system of the KEMA was used to confirm lightning as a root cause /4/.

A: 20.02 Distance of approximately 2 km: Consecutive two flashes directly (-52 and -10kA)
B: 20.09 Distance of round 1km: Consecutive two flashes directly (-53 and -24kA)
C: 20.11 Distance of round 1,5 km: A flash (-81kA)
The values B and C are plausible since two flashes were reported at intervals of 3 min. The position of the building in relation to the observed flashes shows Fig. 3. The location area of the system /4/ is also registered there. The observed flashes correspond well within the location boundaries.

3 POSSIBLE CAUSES OF DAMAGE.

Starting from the present damage pictures, a direct lightning strike into the roof is considered as a cause. Possible explanations for the effect of a lightning strike are:

- Action of force by the current in the trapezoidal sheet steel.
- Lightning stroke into the water surface with Electro Hydraulic Effect.
- Evaporating water.

3.1 Action of force.

In the trapezoidal shaped sheet steels of the roof construction, an action of force can originate due to a lightning strike by the partial lightning currents which flow in same direction. However, a construction of this type achieves a very high mechanical firmness because of the trapezoidal shaped structure of sheet steels. Experiments on a model of the sheet steel structure using impulse currents of 50 kA 10/350 µs did not confirm this hypothesis.

3.2 Lightning stroke into the water surface with Electro Hydraulic Effect.

At the date of the damage the roof was covered with water. During heavy rainfall, the water drain with its few drain apertures was not capable to carry off the huge amount of water completely. In the area where the roof was destructed, a water level of some cm can be assumed. On account of the damage picture, the question about the lightning strike into a water surface arises. Starting from the observations confessed up to now and the present facts of the case, the following hypotheses result:

- In a thunderstorm field, corona occurs in several places by spraying water droplets.
- When the stepped leader propagates to earth, the field strength on the water surface increases rapidly. It is possible that already available corona builds up a channel through the water surface and the isolating roofing paper.
- The return stroke starts from the water surface to the stepped leader. The return stroke heats up the pre-discharge channel in the water.
- The return stroke connects with the already existing stepped leader and current will flow through the water surface. In this case, the flash channel develops itself under water.
- The energy dissipation during thermo ionisation of the arc channel creates a blast wave. The coupled energy in the blast wave is sufficient to smash the roof through the Electro Hydraulic Effect inwards.
- The movement of the cars is possibly also to explain by the Electro Hydraulic Effect.

3.2.1 Corona on the water surface.

Corona can result from falling raindrops, collision of raindrops and blistering. This effect requires a field strength of 180kV/m. Falling raindrops hit the water surface and they splash high small water drops which are further accelerated by the available electrical field. At the top of the splashed water a corona discharge occurs /5/. In a similar way several other corona discharges take place. The field strength increases in a wide range due to the downward running stepped leader resulting in an increased corona intensity. By these corona, it is conceivable that water is heated up at the bases of the water gauges and as a result increases the conductivity of the water strongly.

3.2.2 Return stoke.

At a field strength of 500 kV/m, the first return stroke starts. It is possible that several parallel discharges start on the water surface and connect themselves to a return stroke. At the moment of the union of the two flash channels, the actual flash discharge starts.
None are metallically leading subjects on roofing paper. Surface discharges /6/ occur when the normal component electrical field strength stresses the surface of an insulating material. Underneath of the insulating material the trapezoidal sheet steel forms the earth electrode. A distortion of this sliding discharge surface occurs through the bolts. The ions generated by the sliding discharges of the surface discharge cannot flow off through the insulating material. They create a strong current in the rapidly changing electrical field and a creepage spark occurs. It is likely that a creepage spark connected through the roofing paper to a bolt.

3.2.3 The Electro Hydraulic Effect.

If an electrical discharge takes place below a water surface, a blast wave is formed by the expansion of the arc channel. This mechanism is known /7/, /8/. as the Electro Hydraulic Effect. A blast wave propagates with supersonic speed concentrically to the discharge channel. Fig. 4 shows an analysis of the physical courses of events of a run-off water spark after calculations from Martin/ 9/. Fig.4a shows the injected impulse current. Fig.2b shows the charge injected into the arc channel versus time. The channel diameter of the arc is enlarged within some micro seconds from zero to some mm. As a result, a shock wave is generated. The pressure distribution at the surface of the arc versus time is represented in Fig. 1c. The generated pressure at the boundary of the arc decreases from a value of 35000 atm to 3500 atm within a few micro seconds. This Effect is reverse proportional to the rise time of the current. The velocity decreases to a value of app 100 m/s.

3.2.4 Movement of the cars.

It is conceivable that a partial current of the second return stroke or the reported third stroke reached the building in Markelo and that a surface discharge developed itself on the water overcast floor of the building. References on it find themselves in the numerous surface discharge figures on the floor. A tile with discharge figures was opened. No indications of a direct current flow were found included through the soil. Lengths of surface discharges of some meters up to 10 m may be applied here. If the ground is already filled with water, the Electro Hydraulic Effect also becomes effective here. A simulation of surface discharges of app. 10 m with current intensity of some 10 to 100 kA, as they occur during a lightning strike, are unrealisable in the lab because of the high arc voltage.

4 EXPERIMENTAL PROOF OF THE ELECTRO HYDRAULIC EFFECT.

The hypothesis described in the former chapter is based on an Electro Hydraulic Effect caused by a flash channel below the water surface. Therefore it must be proven that the shock wave created in this case was capable to damage a roof. For the experiments, the model of the roof represented in Fig.5 was constructed and loaded with a discharge. An exploding wire with a length of 1 cm was employed to simulate the spark channel of the return stroke. A current impulse 10/350 µs was then injected into this wire. Without water, however also with exploding wire, a focal spot is only left during a discharge injection on sheet steel where little metal only evaporates. However, the experimental result varies clearly with a water filling: The effect of this discharge on the metal plate is represented in Fig.6.The sheet steel shows an aperture from approx. 350 cm^2. Therefore, this mechanism, known as the Electro Hydraulic Effect, can be applied to the damage case in question. In this case and the further carried out experiments, the energy input was between 5 and 10kWs.

A further experiment was carried out with a trapezoidal sheet steel with the identical dimensions of the destroyed roof. The exploding wire was connected Y-shaped to the steel sheet to two points, each of a length of 12 cm. The result of the experiment with trapezoidal steel sheet is shown in Fig.7.

One can assume easily that destruction becomes more vehement, the longer the arc is burning freely under water. A further explanation for metal shaping is the in /10/ specified presumption that the lattice structure of metal is cancelled for the duration of shock waves in the ultra short-term field, so that a steel sheet can be formed virtually smoothly.

5 CONCLUSION

3 years after the event the precise processes could not be reconstructed precisely. Based on the reported facts, the findings at the site of the garage and the results of the described experiments the following possible cause can be concluded:

- ♦ The discoloration of the roofing paper indicates a surface discharge at the boundary surface between roofing paper and water.
- ♦ The experiment showed that a conductive channel occurs through the water surface at switching impulse voltage.
- ♦ Due to a lightning stroke into the water, a surface discharge arises on the boundary surface between roofing paper and water. The conductive channel follows into a bolt through roofing paper. In this case, the energy in the flash channel becomes Electro Hydraulically effective under water. The effective area of the surface discharge under water lies in the range of some meters of diameters according to the information of the witness. The energy in an arc channel in normal air is indicated in literature with 230kWs per meter length. From the fact we can assume a energy dissipation of some 100 to 1000kWs.
- ♦ The lattice structure of metal is cancelled for the duration of shock waves in the ultra short-term field, so that a steel sheet can be formed virtually smoothly.
- ♦ The movement of the cars can not be clarified in the lab for the mentioned reasons.

6 RECOMMENDATIONS.

The present case concerns a building with flat roof. It is meanwhile very popular to grass over flat roofs or cover them with grit. It remains to examine how a such engaged flat roof behaves during a lightning strike. For avoidance of damages and injuries to persons in buildings with flat roofs, the following propositions should be discussed in the associated working groups:

- ***Guaranteeing a sufficient water drain to prevent pools of water on a flat roof during a heavy rain fall. However, the danger consists in the malfunction of the rainwater gutters by pollution.***
- ***Sufficient slope, so that the water only occurs at the outer zones.***
- ***Building a lightning protection system on the flat roof with a collecting electrode and conductors which must be arranged above the maximally possible water level.***

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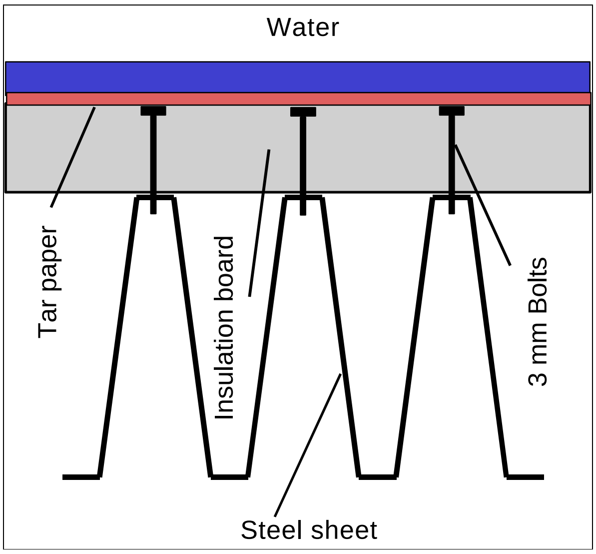

Fig 1: Construction of the roof

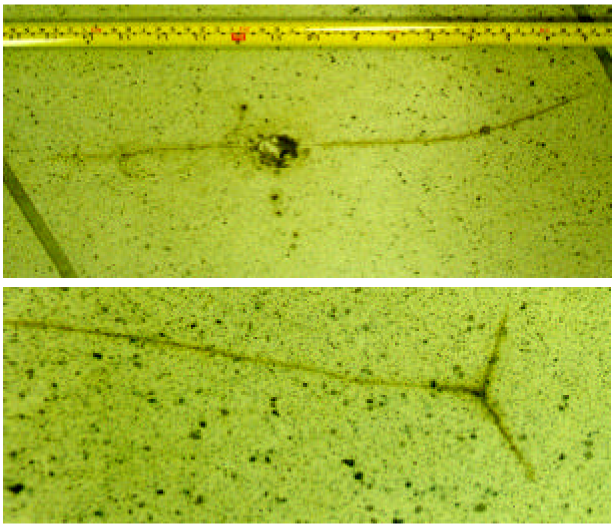

Fig.2: Punctures where parts of the roof are connected to ground in the hall, in the flagstones.

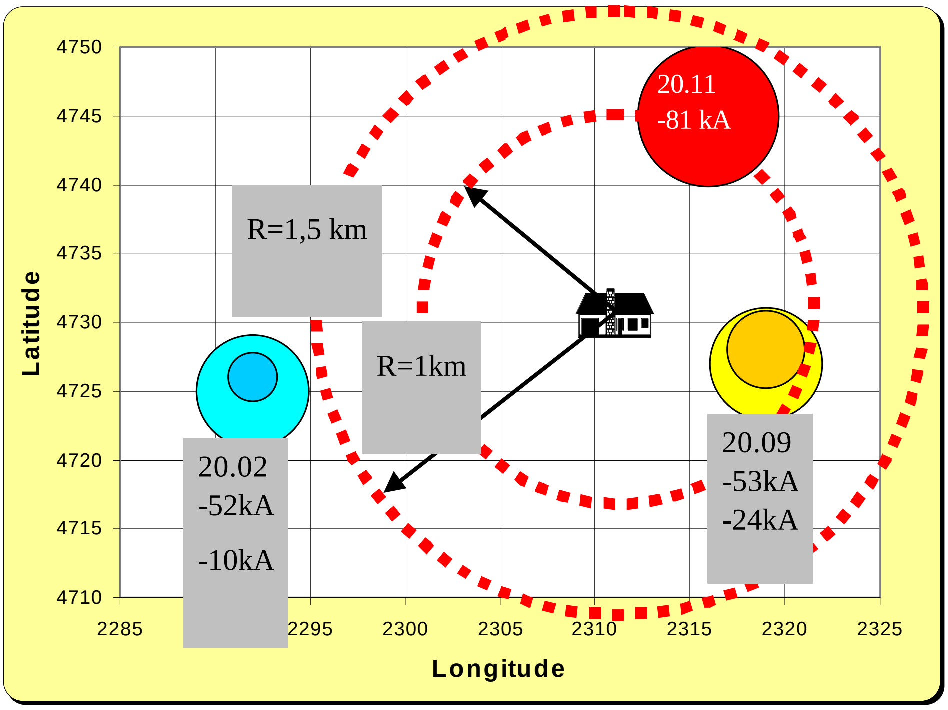

Fig.3: The position of the building in relation to the observed flashes. Amersfortse Coordinates, Latitude and Longitude. The diameter of the circles indicates the peak of the registered current. Time and current values are indicated in the diagram.

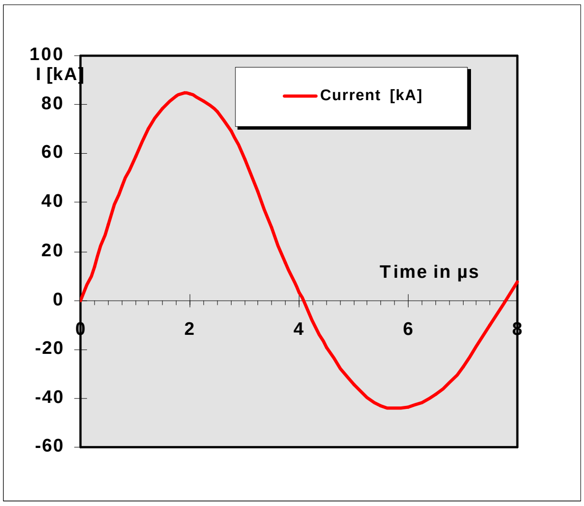

Fig. 4 a The shape of the injected current.

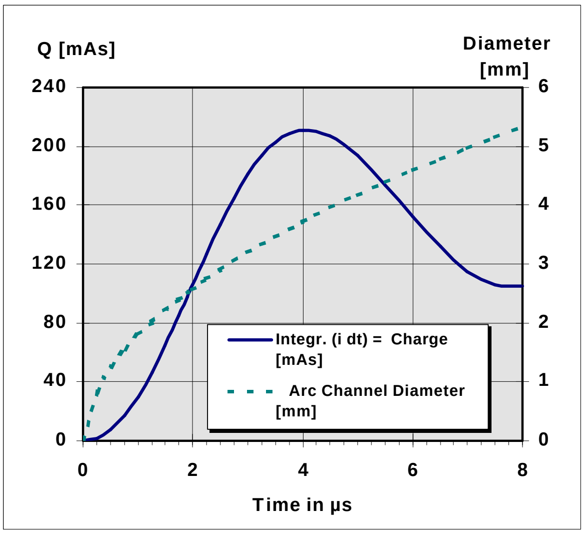

Fig. 4b The Charge and the arc channal diameter versus time.

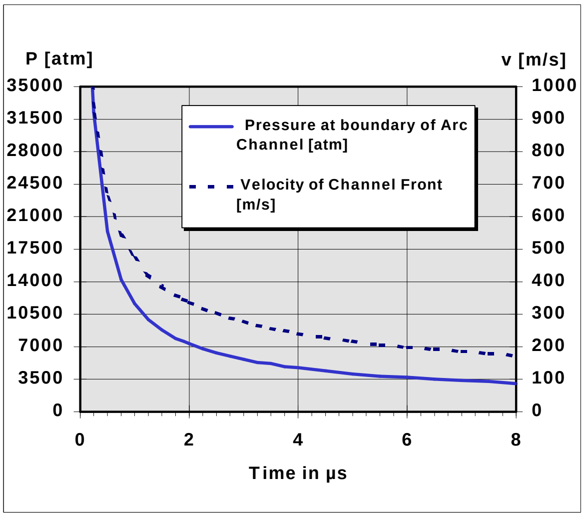

Fig. 4c:
The pressure at the boundary between arc and water as well as the velocity of the propagating front wave versus time.

Fig. 4: Results of calculations of the effect of a current flow through water under impulse conditions according to Martin,E.A.: The underwater spark, an example of gaseous conduction at about 10000 atmospheres. Dissertation University of Michigan

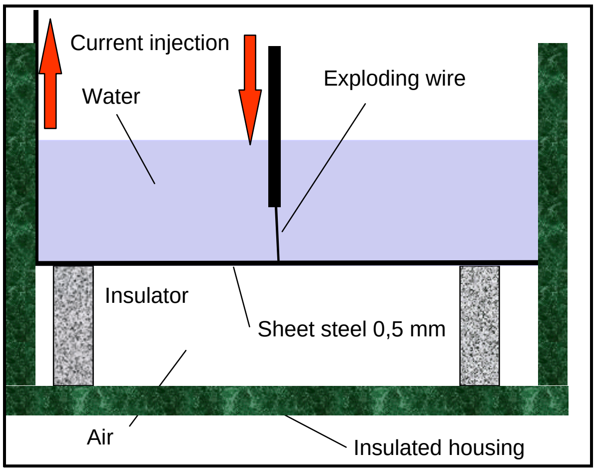

Fig.5 Model used in laboratory experiments to investigate the effect of an under water spark to a sheet steel.

Fig.6 Result of the test with impulse current. Steel Sheet after the dis-charge. Arc length under water: 1cm; Water level 4 cm. Impulse current: 10/350µs; Peak=54 kA; Charge:=10As;
Specific Energy=291kA^{2}s.

Fig.7 Trapezoidal steel sheet after the experiment.
Arc length under water: 2x12cm.
Impulse Current : 10/350µs; Peak= 49,6 kA; Char-

Photo 1
View of the destroyed roof of the building in the Netherlands.

Photo 2
Detailed view of the roof opening. This is the place where the flash hit the roof.

Photo 3
Smashed roof and twisted T-steel girder.

Photo 4
Front view of the building.   Some cars were moved by the blast wave and ran through the pa-ne of glass

Photo 5
The roof of a Factory in Belgium after a lightning strike.The roof shows two big holes.

Photo 6
The roof of a paper factory in Austria after a lightning strike.