



Effect of Direct Lightning Strike in the Down Conductors Embedded into the Reinforcement

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Abstract-- The foundation earthing is generally accepted as the best lightning protection earthing system combining the advantages of a low DC resistance and a low impedance but also minimizing step and touch voltages. Down conductors may also be embedded into the reinforced columns of a structure as described in IEC/EN 62305 – 3. However the installation of LPS conductor into the reinforcement must be very carefully implemented since it was proved that a poor equipotential bonding between the LPS conductor and the reinforcement bars can easily cause serious cracking of the concrete even at a low current of 35kA, 10/350 μ s. In this paper an experimental procedure will be presented simulating the effect of a direct lightning strike with various magnitudes and waveshapes on a variety of specimens designed according to civil engineering standards, aiming to illustrate the consequence of having a poor equipotential bonding between the reinforcement bars, the down conductors and the foundation earthing tape.

Index Terms-- Bonding, Concrete, Connectors, Down Conductor, Foundation Earthing, Lightning Protection System, Reinforcement

I. INTRODUCTION

As it has been presented by previous researchers [1], [2] there are evidences of cracks on concrete structures, which have been victims of direct lightning strikes and they didn't have an external lightning protection system – LPS to protect them.

The explanation was given by Professor Leite [3], who proved that the concrete may trap humidity, which due to the passage of the lightning current may vaporize very fast causing high pressure leading to possible cracks on the concrete.

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As described in IEC/EN 62305 – 3 [4], [5] the down conductors may be bonded with the reinforcement. Figure 1 represents part of the foundation earthing and the down conductor driven through the reinforced concrete of a structure. As shown in Figure 1 specific connectors are used to bond the LPS conductors with the reinforcement bars. Figure 2 and 3 show appropriate connectors that fulfill the requirements of EN 50164 – 1 [6] and provide an approved electrical and mechanical connection between the LPS conductors and the reinforcement bars.

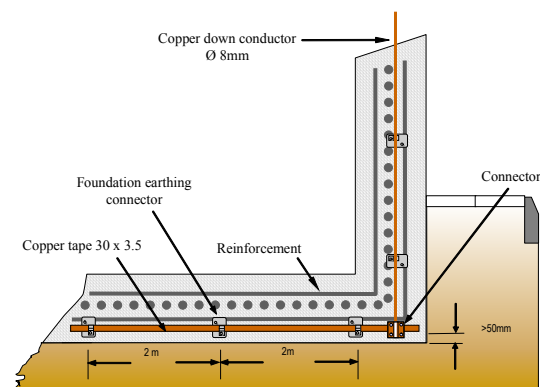


Fig. 1: Foundation earthing and down conductors bonded with the reinforcement



Fig 2: Down conductor installed through the reinforcement



Fig. 3: Approved connectors for connecting LPS conductors with the reinforcement

In contrast Figure 4 and 5 shows a non approved connection between the LPS conductors and the reinforcement bars. Many believe that the reinforcement may also be used as an extension of the LPS conductors and they don't use down conductors to connect the air terminals with the earthing system but only the reinforcement bars. However the reinforcement bars may have voids between them, which will generate an arc causing serious cracks in the concrete.

Additionally if the down conductor is bonded with the reinforcement with wire only, then part of the lightning current will also pass through the reinforcement. The wire as mentioned earlier will not be able to withstand the lightning current causing explosion and cracks on the concrete.

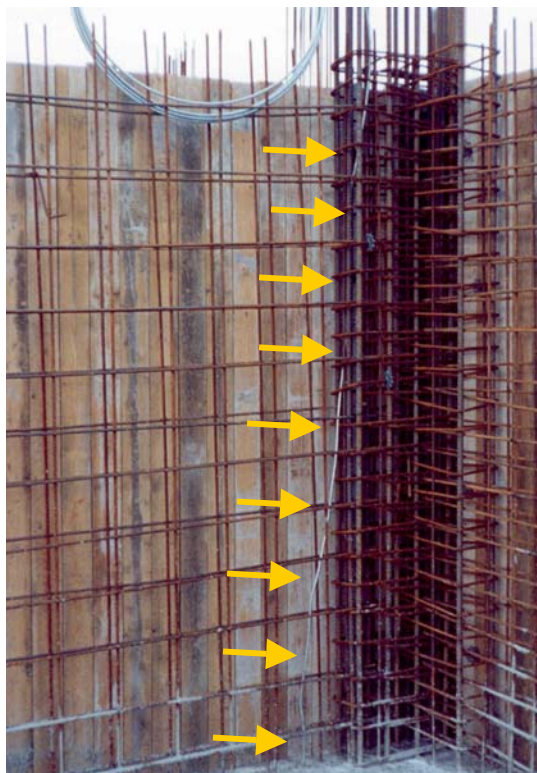


Fig. 4: Down conductor is driven through the reinforcement without having any bonding with it.



Fig. 5: Non approved connection between earthing tape and reinforcement

The purpose of this paper is to investigate the mechanical strength of the concrete performing tests on various connections and configurations, which are then, build with concrete and set them to discharge lightning current with a waveshape of 10/350 μ s of various magnitudes.

The work presented in this paper is only based on experimental results but it is currently verified by mathematical calculations in order to estimate the resultant forces and stress values that are generated between the reinforcement and the LPS conductors during the passage of the lightning current.

Two types of tests were performed. In the preliminary tests only one connection was tested having a block of concrete around it with dimensions of 20 x 20 x 20 cm. In the final tests a more complicated block was tested investigating the performance of an entire part of the reinforcement either with appropriate and non appropriate connections between the reinforcement bars and the LPS conductors.

II. PREPARATION OF PRELIMINARY TESTS

The arrangement that was tested in the preliminary phase was a B1 cross connection according to EN 50164 – 1 connecting a 16mm reinforcement bar with a hot deep galvanized steel tape 30 x 3,5mm. Four different B1 connections were tested. In the three the connection between the LPS tape and reinforcement bar was with wire only and one was with an appropriate connector commonly used in the foundation earthing. All specimens were then embedded into concrete and left for 20 days for the concrete to dry.

As shown in Figure 6, specimen A was with the appropriate connector, which is similar to the one described in Figure 3, the tightening torque was set at 12Nm for both screws. Specimen B was with wire but the wire was very tight around the LPS tape and the reinforcement bar. In specimens C and D the wire was not so tight, which was allowing a small void to be formed between the LPS tape and the steel bar. In specimen C was 1mm and in specimen D was 10mm. The contact resistance in all the specimens was less than 1mOhm.

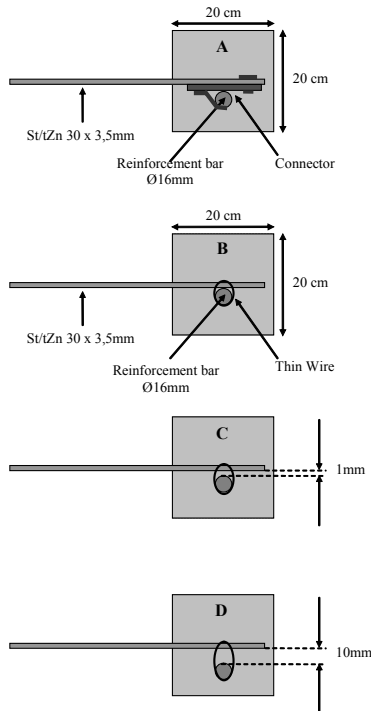


Fig. 6: Preliminary test specimens – top view

The quality of the concrete in this test is very important. This is why samples were sent to accredited laboratories to perform tests regarding the strength of it. In total three samples were sent and all of them had a tension compression more than 20N/mm^2 , which is an accepted concrete quality widely used for domestic multifloor structures.

For safety issues the specimens were sealed in a wooden box. The two terminals of each specimen were then connected to the output of the 100kA, 10/350 μs generator as shown in Figure 7.



Fig. 7: Experimental set-up of the preliminary tests

III. PRELIMINARY TESTS RESULTS

Each specimen was individually tested with lightning currents starting from 35kA, 10/350 μs up to 100kA, 10/350 μs in order to investigate the maximum lightning current that can pass through connection without causing the concrete to break.

Specimen A was tested first, which had an appropriate connector to provide an electrical and mechanical connection between the LPS tape and the reinforcement bar. Table 1 summarizes the results, which have proven that specimen A has successfully discharged five lightning impulses with a 10/350 μs up to 98kA without causing any visual damage to the concrete surface.

TABLE 1: SUMMARY OF PRELIMINARY TESTS FOR SPECIMEN A

Lightning current 10/350 μs	Result
35kA	No Visual damage
58kA	No Visual damage
81kA	No Visual damage
98kA	No Visual damage
98kA	No Visual damage

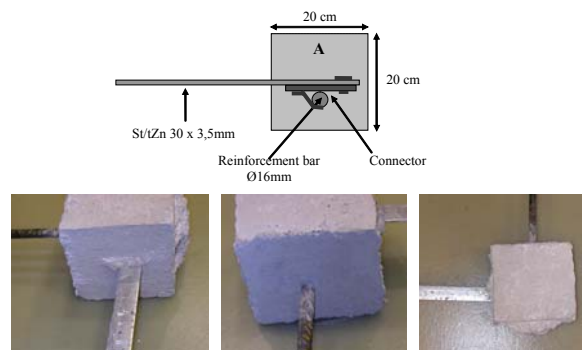


Fig. 8: Results after five lightning impulses for specimen A

Specimen B was tested second, which had a tight wire to provide an electrical and mechanical connection between the LPS tape and the reinforcement bar. Table 2 summarizes the results, which have proven that specimen B has successfully discharged three lightning impulses with a 10/350 μs up to 57kA without causing any visual damage to the concrete surface. The third impulse at 79 has caused an explosion and the concrete was broken.

TABLE 2: SUMMARY OF PRELIMINARY TESTS FOR SPECIMEN B

Lightning current 10/350 μs	Result
35kA	No Visual damage
57kA	No Visual damage
79kA	Concrete was broken

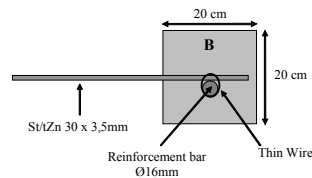




Fig 9: Results after three lightning impulses for specimen B
Specimen C was tested third, which had a loose wire to provide an electrical and mechanical connection between the LPS tape and the reinforcement bar. Table 3 summarizes the results, which have proven that specimen C has successfully discharged one lightning impulse with a 10/350 μ s of 35kA without causing any visual damage to the concrete surface. The second impulse at 57kA has caused an explosion and the concrete was broken.

TABLE 3: SUMMARY OF PRELIMINARY TESTS FOR SPECIMEN C

Lightning current 10/350 μ s	Result
35kA	No Visual damage
57kA	Concrete was broken

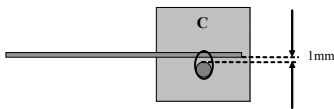


Fig 10: Results after two lightning impulses for specimen C

Specimen D was tested last, which had a very loose wire to provide an electrical and mechanical connection between the LPS tape and the reinforcement bar. Table 4 summarizes the results, which have proven that specimen D could not discharge any lightning impulses since the concrete was broken with the first impulse at 35kA, 10/350 μ s.

TABLE 4: SUMMARY OF PRELIMINARY TESTS FOR SPECIMEN D

Lightning current 10/350 μ s	Result
35kA	Concrete was broken

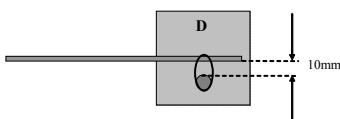


Fig 11: Results after one lightning impulses for specimen D

IV. PREPARATION OF FINAL TESTS

In these tests a more detailed block of reinforced concrete was prepared in order to investigate not only a single connection between the LPS conductor and the reinforced bars but to examine the path of injected lightning current in a reinforced concrete block.

The reinforcement block is shown in Figures 12 and 13. It was composed out of six horizontal reinforcement bars having a diameter of 16mm bonded with each other by using three reinforcement bonding rings with diameter of 10mm. At every cross point between two reinforcement bars there was a tight wire bond. Two LPS conductors (hot deep galvanized steel tape 30 x 3,5mm) were connected in either side of the block as shown in the Figure 12 and 13. One was bonded with the reinforcement with the same connector as in the preliminary tests in specimen A and the other was bonded with the reinforcement only with one tight wire (see Figure 14).



Fig 12: Reinforcement block with various connections



Fig 13: Reinforcement block with various connections – top view

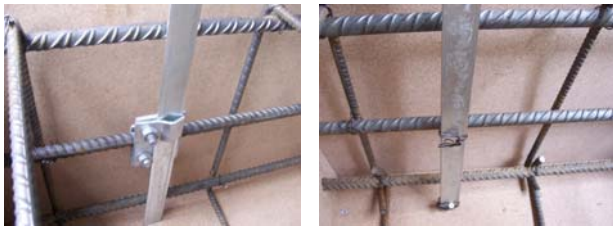


Fig 14: Detail of connections between the LPS conductors and the reinforced bars on both sides of the specimen

The reinforcement block was then embedded in concrete having the same quality as in the preliminary tests. Figure 15 shows the reinforced concrete block, which had the following dimensions: Length 80cm, height 60cm, width 30cm.

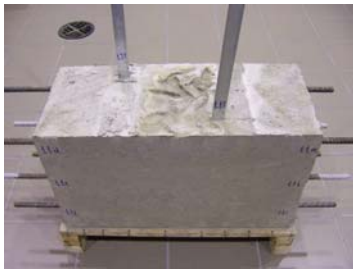


Fig 15: Reinforced concrete block with various connections

V. FINAL TESTS RESULTS

The generator output was connected on various configurations as summarized in Table 5. Figure 16 shows the numbering, which was given on each reinforced bar and LPS conductor for identification purposes.

The only configuration, which did not show any visual damage of the concrete block, was the one that had the appropriate connector and allowed a safe discharge of the lightning current. All the rest at some point have shown serious damage and cracks on the block as illustrated in the following figures. Table 5 with the notes below it summarizes the results.

Further investigation is currently under development for more detailed analysis and further tests so as to have a more complete understanding.

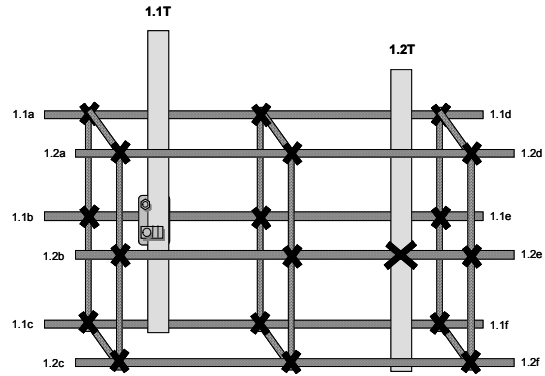


Fig 16: Numbering of reinforcement bars and LPS conductors for identification during the testing procedures

TABLE 5: SUMMARY OF FINAL TEST RESULTS

Combinations		Lightning current 10/350 μ s			Notes
1.1T	1.1e	-	-	90kA	(1)
1.1T	1.1f	34.9kA	63.6kA	-	(2)
1.1T	1.2f	30kA	63.2kA	-	(3)
1.1T	1.2T	32.9kA	59.2kA	-	(4)

- (1) Concrete block did not show any visual damage or cracks
- (2) After the second impulse at 63.6kA the block presented cracks and serious damage on the 1.1e point – Figure 18
- (3) After the second impulse at 63.6kA the block presented cracks and serious damage on the 1.1b, 1.1c and 1.2c – Figure 19
- (4) After the second impulse at 59.2kA the block presented cracks and serious damage on the 1.2d, 1.2e and 1.2f – Figure 20 and 21



Fig 17: Experimental set-up of the final tests

VI. CONCLUSIONS AND DISCUSSIONS

From the previously described results it has been illustrated that if connection between the LPS conductor and the reinforcement bars are done only with wire and the wire is loose, then the concrete may present damage either due to the arc formed at the void between the LPS conductor and the reinforcement bar or due to the explosion of the wire, which can not withstand the energy of a lightning current impulse even at low level of 35kA.

For a more complicated reinforced concrete block the results have also proven that bonding between LPS conductors and reinforcement bars shall be carefully considered since depending on the discharge path of the lightning current through the reinforcement damages may be caused if only wires are used as connectors.

Further tests and calculations are currently in process for additional information on this matter.



Fig 18: Results after two lightning impulses between 1.1T and 1.1e



Fig 19: Results after two lightning impulses between 1.1T and 1.2c



Fig 20: Results after two lightning impulses between 1.1T and 1.2T



Fig 21: Results after two lightning impulses between 1.1T and 1.2T

VII. ACKNOWLEDGEMENTS

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