Experimental and FDTD Investigation of Surge Propagation Characteristics on Steel Frames and Concrete Walls in a Building

Shunsuke. IRIE , Akihiro. AMETANI , Naoto. NAGAOKA and Yoshihiro. BABA

***Abstract*--This paper presents experimental results of surge propagation characteristics on a bare steel conductor and a conductor covered by a concrete representing a building. Measured results are simulated by a finite-difference time-domain(FDTD) method which is one of the most widely used numerical electromagnetic analysis methods. The simulation results agree satisfactorily with the measured results. The propagation velocity along a conductor covered by a concrete differs from that along a bare conductor when a fast front surge with the rise time of some nano-seconds is applied. This has indicated that the concrete permittivity influences the propagation characteristic in a high frequency range.**

***Keywords*: surge propagations, building, steel frame, concrete wall, FDTD, permittivity.**

I. INTRODUCTION

ELECTROMAGNETIC disturbances of personal computational devices and communication equipment including telephones and fax machines become a very important problem when lightning strikes a building[1]-[4]. In this respect, a surge protective devices (SPD) are typically installed in many buildings in order to limit lightning-oriented surge.

However, the SPD can not protect the PCs and the communication equipment from the electromagnetic disturbances due to a lightning surge with a very high frequency and a small amplitude. As a countermeasure, a magnetic shielding wall is under development. For this, surge propagation characteristics on steel frames and concrete walls of a building need to be made clear.

This paper presents experimental results of surge propagation characteristics on a bare steel conductor and a conductor covered by a concrete representing a steel frame and a concrete wall. Measured results are simulated by a FDTD method which is one of the most widely used numerical electromagnetic analysis methods. The simulation results are compared with the measured results, and the propagation characteristics are discussed based on the measured and simulation results.

The authors are with the Department of Electrical Engineering, Doshisha University, Kyoto 610-0321, Japan(E-mail;aametani@mail.doshisha,ac,jp;).

Paper submitted to the International Conference on Power Systems Transients (IPST2011) in Delft, the Netherlands June 14-17, 2011

II. EXPERIMENTAL CIRCUIT

A. A Single Conductor

In an experiment of which the setup is illustrated in Fig.1, an injected current, sending and receiving-end voltages and currents are measured by using the oscilloscope (Tektronix DPO 4104), the voltage probe (Tek P6139A), and the current probe (Tek CT-2 P6041). For a voltage source, a pulse generator (NoiseKen INS-4040) is used, and a 3D2V coaxial cable of 50 [m] is used for a current lead wire. By connecting a resistance of 2k [Ω] to the pulse generator, the source circuit is regarded as a current source with the peak value of 1 [A]. The other end of a test conductor is grounded through a resistance of 10 [Ω]. The height of the test conductor is set to be h = 5 [cm].

Two different conductors, steel and reinforced concrete, are used as a test conductor. The conductor length is *l*=1.82 [m]. The cross section of the test conductors is illustrated in Fig.2.

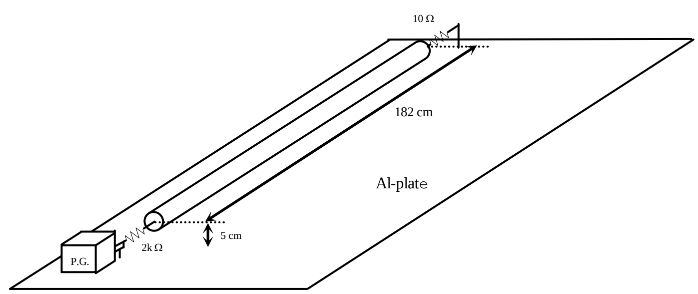
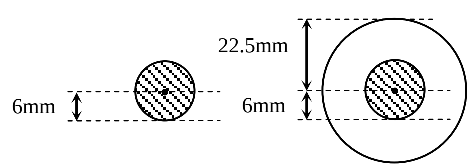


Fig. 1. A single conductor system.



(a) Steel. (b) Steel and concrete (RC).
Fig.2 Cross-section of a conductor.

B. Two Conductors

A two conductor system is illustrated in Fig.3 to measure an induced voltage between the conductors. A current source composed of a P.G. and a series resistance of 2k [Ω] is connected to an inducing circuit. The receiving-end of the inducing circuit is grounded through resistance 10 [Ω]. The both ends of an induced conductor are grounded through resistance 10 [Ω]. The induced voltage characteristic is measured by changing the separation distance between the conductors to 5 [cm], 10 [cm] and 15 [cm]. In addition, the influence of a concrete coating is measured in comparison with the steel conductor system.

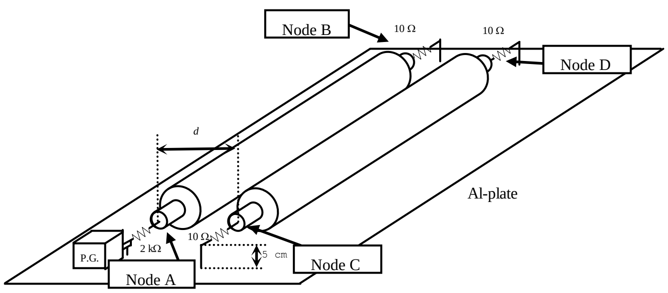


Fig.3 Two conductor system.

C. Concrete Wall

Fig.4 illustrates a concrete wall with two steel conductors with separation 10 [cm]. The wall size is 170 [cm]×20 [cm]×5 [cm].

Voltages and currents are measured at nodes A to D.

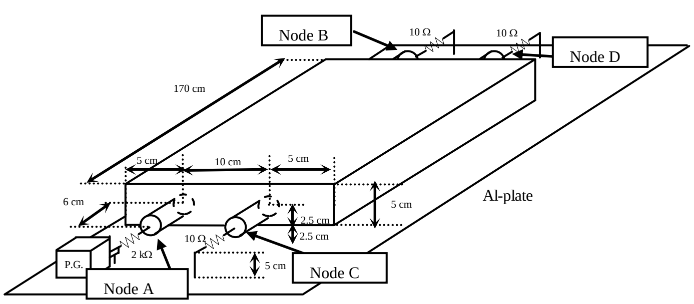


Fig.4 Concrete wall.

III. FDTD ANALYSIS MODEL

The cell size of an analytical space for an FDTD[5][6] simulation is dx = dy = dz = 9 [mm] considering the conductor radius in the experiment. The physical constants of the conductor are given in Table1. The earth is assumed to be a perfect conductor and is represented by the thickness of 5 cells. An absorbed boundary[7] is set to be 40-50 cells apart. An applied current is represented by a double exponential function. A thin wire method[8] is applied to represent a conductor. Physical parameters used in a simulation are given in TABLE I. The parameters are informed by a constructing company.

TABLE I
PHYSICAL CONSTANT

	μ_c	ε_c	σ[S/m]
Steel	200	1	1.03×10^6
Concrete	1	3	0.0024

IV. EXPERIMENTAL AND SIMULATION RESULTS

A. A Single Conductor

A measured waveform of an injected current is shown in Fig.5. Measured and simulation results of the sending-end voltage are shown in Fig.6. Because the conductor diameter of a reinforced concrete (RC) is larger than that of the steel, the surge impedance of the RC is smaller than that of the steel[9]-[11]. As a result, the peak voltage in the RC case is smaller than that of the steel. There is a difference of 3ns in the round trip time. This might come from the fact that the concrete permittivity is greater than that of the air.

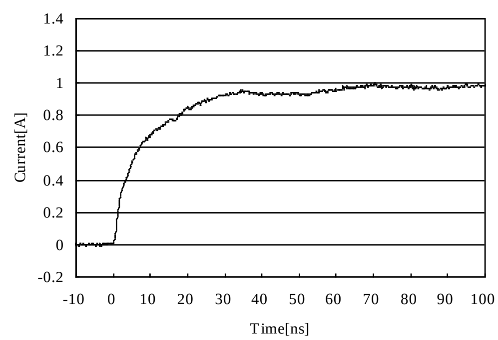


Fig.5 Injected current.

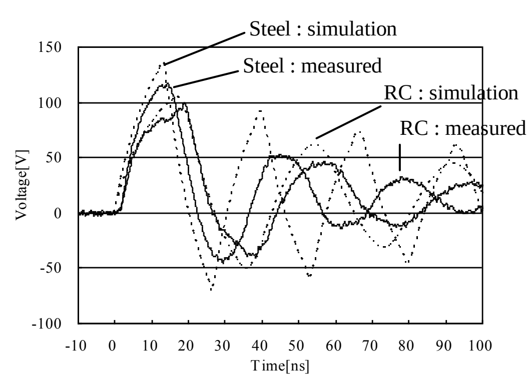


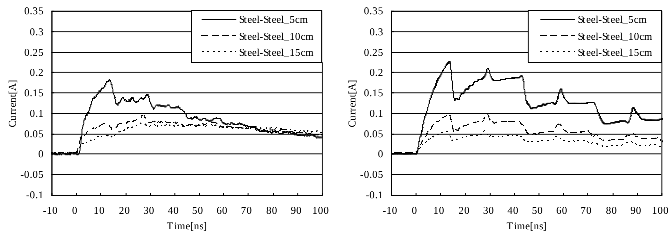
Fig.6 Sending-end voltage in the single conductor case.

B. Two Conductors

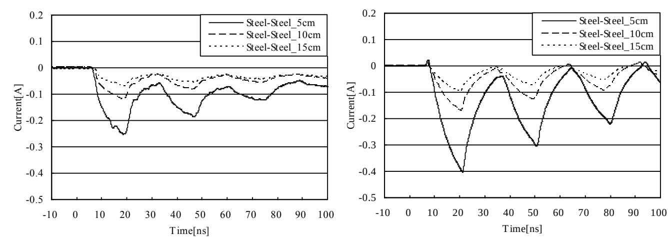
Figs.7 and 8 show the measured and simulation results of an induced current as a function of separation distance. It is clear that the induced current is proportional to the inverse of the separation distance. The current in the RC case is larger than that in the steel case, because the characteristic impedance is smaller. TABLE II shows measured and simulation results of the induced current of peak value.

C. Concrete Wall

Fig.9 shows measured and simulation results in the concrete wall case. It is observed that the current waveforms in the wall case is significantly different from those in the steel and RC cases. The current in the wall case at Node B is much smaller than those in the RC and steel cases. On the contrary, the induced currents at nodes C and D are much greater in the wall case.



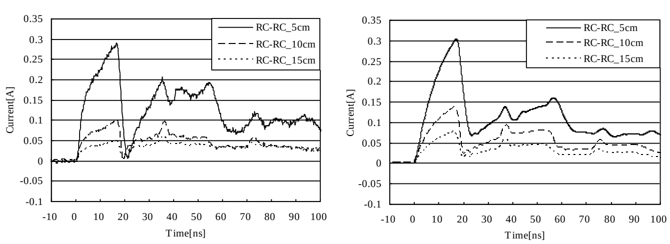
(1) Sending end.



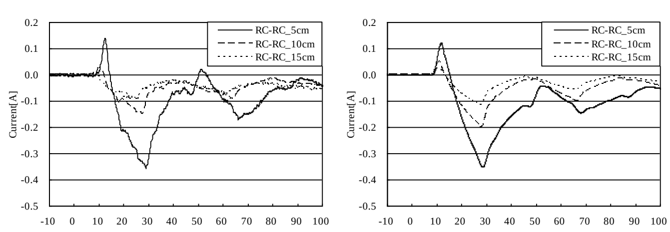
(2) Receiving end.

(a) Experiment. (b) FDTD.

Fig.7 Induced current in the steel case.



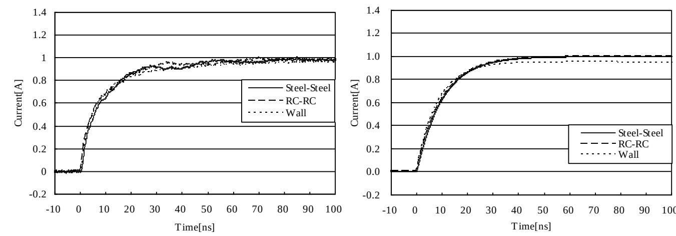
(1) Sending end.



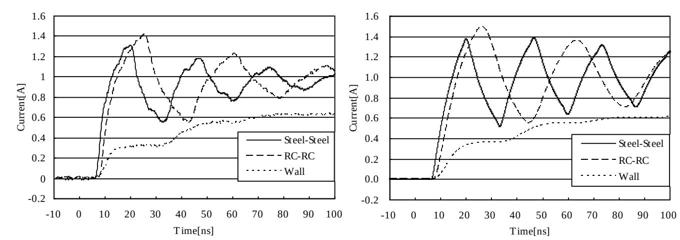
(2) Receiving end.

(a) Experiment. (b) FDTD.

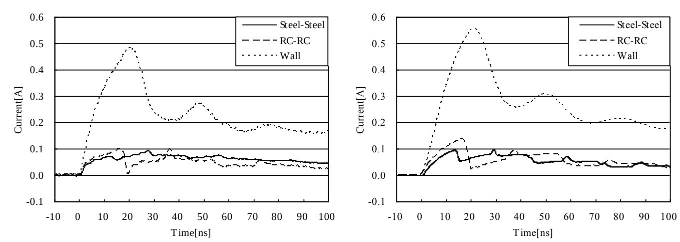
Fig.8 Induced current in the RC case.



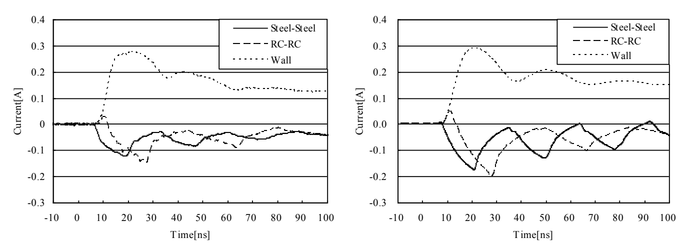
(1) Node A.



(2) Node B.



(3) Node C.



(4) Node D.

(a) Experiment. (b) FDTD.

Fig.9 Inducing and induced currents in the case of a concrete wall.

TABLE II
INDUCED CURRENT OF PEAK VALUE

Case		*d* =5 cm		*d* =10 cm		*d* =15 cm	
		Sending end	Receiving end	Sending end	Receiving end	Sending end	Receiving end
Steel-Steel	Experiment	0.1818 A	-0.2512 A	0.0720 A	-0.1196 A	0.0450 A	-0.0708 A
	FDTD	0.225 A	-0.4020 A	0.0951 A	-0.1720 A	0.0545 A	-0.0989 A
RC-RC	Experiment	0.290 A	-0.346 A	0.098 A	-0.151 A	0.039 A	-0.100 A
	FDTD	0.302 A	-0.349 A	0.134 A	-0.198 A	0.076 A	-0.112 A

V. CONCLUSIONS

This paper has investigated surge propagation characteristics on a steel, a reinforced concrete and a concrete wall, which are an element of a building, based on experiments and FDTD simulation. From the investigations in the paper, the following remarks are obtained.

(1) The propagation velocity along a conductor covered by a concrete differs from that along a bare conductor when a fast front surge with the rise time of some nano-seconds is applied. This has indicated that the concrete permittivity influences the propagation characteristic in a high frequency range.

(2) The surge impedance of a reinforced concrete is smaller than that of a steel, and thus the peak voltage in the reinforced concrete case is smaller than that in the steel case.

(3) On the contrary to the above, the induced current in the reinforced concrete case is greater than that in the steel case. Similarly, the induced current is much greater in the concrete wall case than those in the steel and the reinforced concrete cases. The above is estimated to be caused by greater electrostatic coupling in the wall case.

VI. REFERENCES

[1] M. Sato, S. Kuramoto: “A Study on Equivalent Impedance of the Building Columns and Girders against the Lightning Surges”, IEICE, Vol. J77-B-II, No.3, pp.149-158 (1994)

[2] M. Sato, S. Kuramoto: “Experimented Direct Lightning Current Distribution in a Reinforced Concrete Building”, IEICE, Vol. J80-B-II, No.9, pp.791-799 (1997)

[3] A. Ogunsola, U. Regginani, L. Sandolini : “Modeling shielding properties of concrete” , Proc. of the 17th International Zurich Symposium on Electromagnetic Compatibity, EMC-Zurich 2006, pp: 34 - 37

[4] A. Ogunsola, U. Regginani, L. Sandolini : “Shielding properties of conductive concrete against transient electromagnetic disturbances” , Proc. of the IEEE International Conference on Microwaves, Communications, Antennas and Electronics Systems, 2009. COMCAS 2009

[5] Numerical Transient Electromagnetic Analysis Method, IEE Japan (2008-3) (in Japanese)

[6] T.Uno: “FDTD method for electromagnetic field and antenna analysis”, Corona Pub. Co. (1998)(in Japanese)

[7] K. S. Yee: “Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media”, IEEE Trans. Antennas Propagat., Vol. 14, No. 4, pp. 302-307 (1966)

[8] T. Noda and S. Yokoyama: “Thin wire representation in finite difference time domain surge simulation”, IEEE Trans. Power Delivery, Vol. 17, No. 3, pp. 840-847 (2002)

[9] A.Ametani: “A General Formulation of Impedance and Admittance of Cables”, IEEE Transactions on Power Apparatus and Systems, Vol.PAS-99, No.3 (1980)

[10] A.Ametani and Y.Kasai and J.Sawada and T.Yamada: “Frequency-dependent impedance of vertical conductors and a multiconductor tower model”, IEE Proc.-Gener. Transm. Distrib, Vol.141,No.4,July 1994

[11] A.Ametani : Distributed-Parameter Circuit Theory, Corona Pub. Co. (1990) (in Japanese)