Lightning Protection System for PC Buildings

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I. INTRODUCTION

Reinforced concrete (RC) structure buildings constructed using precast concrete (PC) employ mechanical joints to connect the main reinforcing bars within columns. In such buildings, there is generally a void space between the mechanical joints and the main reinforcing bars, or between each reinforcing bar, where no electrical connection exists. Obayashi Corporation have therefore exploited the lattice-shape or grid-like structure of the reinforcing bars to develop lightning connectors, thereby making effective use of the building's characteristics to enable protection from lightning. The main reinforcing bars are electrically connected to joints using an intermediary between the connections, thus creating a number of routes for the lightning current to flow and ultimately delivering a highly reliable lightning protection system. The lightning connector was evaluated by "the Investigation and Research Committee on the Performance Requirements of Down-Conductors Made of Rebar for Lightning Protection" of the Institute of Electrical Installation Engineers of Japan [3]. And the lightning connector meets the requirements for the IEC standard, connection components [5].

II. CONVENTIONAL DOWN CONDUCTORS USED IN PC CONSTRUCTION METHOD

A. PC construction method and mechanical joints

RC structured high-rise apartment buildings in Japan, in recent years, have been constructed using PC construction methods. This method of building enables a shorter construction period and is thus labor-saving. In PC construction methods, the columns and beam members are manufactured at factories, and are then delivered to the site where they are assembled (Fig. 1). As no concrete placement occurs on site, this method uses mechanical joints to connect the reinforcing bars to each other.

Of all the various types of mechanical joints, the mortar-grouted joint (Fig. 2) and the threaded-rebar joint (Fig. 3) are more frequently utilized. The mortar-grouted joint involves the insertion of a rebar from and into both sides of a sleeve joint; the void space between the sleeve and rebar is then filled with a high-strength grout to connect both bars using the hardened grout material as an intermediary. Therefore, no electrical connectivity is established between the rebar and sleeve, or between each rebar. The inner diameters at both ends of the joint are different from each other; the smaller end is known as the narrow-end side and the larger end the wide-end side. The rebar on the narrow-end side is fixed by a rubber seal and that on the wide-end side is inserted into the sleeve on site. In addition, the threaded-rebar joint fastens the thread knot of the rebar to the screw thread of the coupler using a torque fixation method or grout fixation method.

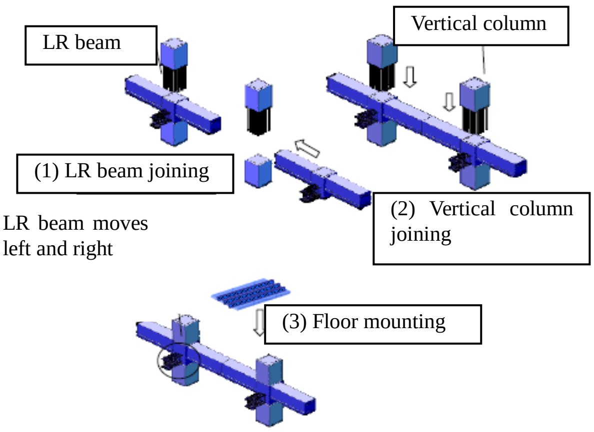

Fig. 1. PC construction method (LRV method [1])

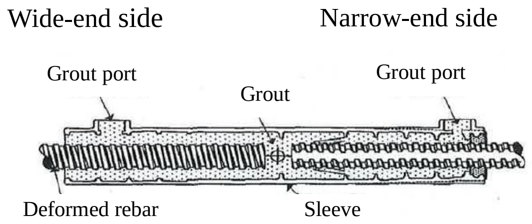

Fig. 2. Mortar-grouted joint

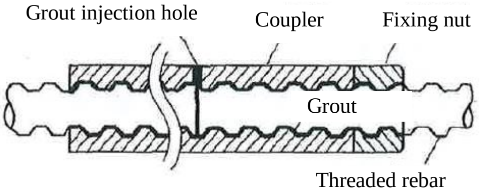

Fig. 3. Threaded-rebar joint

B. Conventional method used in installation of down-conductors

In the PC construction method using mortar-grouted joints, it is generally not permitted to utilize the main reinforcing bars of columns as down-conductors because they are not deemed to be electrically connected. Therefore, the conventional installation method embeds a vinyl chloride pipe in a PC column in advance at the factory, and the down-conductor wire is then passed down through the column (Fig. 4). However, as the down-conductor is independent of the building's structure, the lightning protection performance is significantly inferior to that within steel-framed or conventional reinforced concrete buildings. In addition, this method is more costly because it requires the work of both PC construction workers and electricians, in accordance with the built-up structure of PC construction.

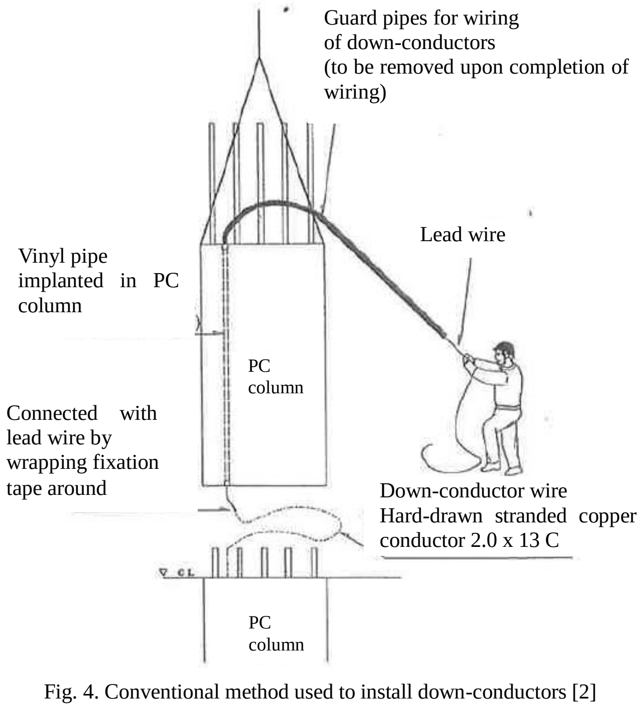

Fig. 4. Conventional method used to install down-conductors [2]

III LIGHTNING PROTECTION SYSTEM USING LIGHTNING CONNECTORS

Hard-drawn stranded copper conductors are not connected to the reinforcing bars of the building, and therefore, the conventional method of installing down-conductors cannot utilize the building structure as a down-conductor nor can the structure be used to build a system for internal lightning protection. Therefore, to address this, Obayashi Corporation has devised a system whereby lightning connectors electrically connect the main reinforcing bars with each other.

A. Structure of lightning connectors

There are two types of lightning connectors as follows: one is used with the wide-end side of the joint and the other with the narrow-end side. The wide-end connector (Fig. 5) is installed on site and is structured so that a metal piece is placed against the inside of a sleeve-shaped joint, which extends to the center and holds the rebar. The narrow-end connector (Fig. 6), which is installed in the factory, is structured to be placed on the outside of the sleeve-shaped joint; it uses a bolt to tighten the center of the metal piece to hold the rebar. These connectors enable the lightning current to flow from reinforcing bars to joints and vice versa.

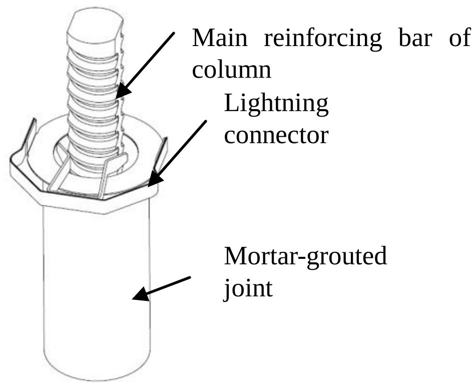

Fig. 5. Lightning connector (wide-end side)

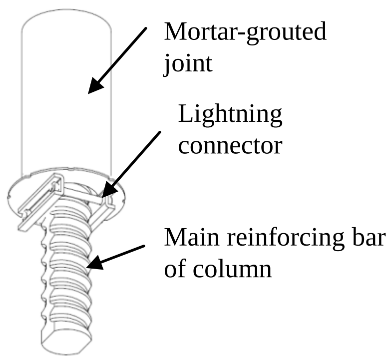

Fig. 6. Lightning connector (narrow-end side)

B. Performance of lightning connectors

A metal structure used to hold a sleeve-shaped joint or rebar will inevitably produce greater contact resistance than a bolt tightening such as that on the narrow end side. However, in actual PC construction work it is extremely difficult to use the bolt-tightening style to connect the upper and lower main reinforcing bars with each other during the process when the main reinforcing bar (that protrudes from the upper column) is inserted into the joint embedded in the lower column. Another disadvantage is that an oxide film forms on the surface of a rebar after it has been exposed to high temperatures during the manufacturing process, and because of its high contact resistance, the oxide film can generally not attain electrical connectivity. To address this, Obayashi Corporation has succeeded, through various trial-and-error efforts, in reducing the contact resistance of lightning connectors to that of the milliohm level, which is comparable to that of commercially-available joint metals. Although the contact resistance of each connector is relatively high, this can be resolved by using main reinforcing bars of multiple columns to reduce the electric resistance of the whole building.

C. Lightning protection system using lightning connectors

The design of the system has a similar structure to that of a bird cage, and the reinforcing bars are connected to each other by the intermediary lightning connectors (Fig. 7). This system is mainly for use in RC structures that employ the PC construction method, and it delivers both external and internal lightning protection. The appropriate number of main reinforcing bars that need to be equipped with lightning connectors varies depending on the grade of each building.

In addition, the concept of external lightning protection is extended to include lightning protection on the sidewall of high-rise PC buildings. Furthermore, handrails (Fig. 8) or projection rods on apartment buildings can be utilized as lightning-receiving parts (Fig. 9); if lightning strikes the handrail or projection rod it then flows into the main reinforcing bars of the columns through lightning connectors and finally flows out through the foundation of the building to the ground.

For internal lightning protection, equalization of electric potential between the floors can be achieved by drawing out a grounding wire from a rebar clamp connected to the main reinforcing bar of the column, which is then connected to slab reinforcement (Fig. 10). This works effectively to protect electronic appliances from secondary induced lightning or acts as a grounding point for surge protective devices (SPDs).

D. Effects on joint structure performance

In Japan, structure methods of rebar joints are specified in a public notice issued by the Ministry of Land, Infrastructure, Transport, and Tourism. It is thus essential to satisfy the requirements of these methods in a building where a lightning current will flow through joints. It is imperative that there is no change in the mechanical property of joints and that no mechanical damage would occur to joints in the event of a lightning current flow. These requirements are reported by the “Investigation and Research Committee on the Performance Requirements of Down-Conductors Made of Rebar for Lightning Protection” of the Institute of Electrical Installation Engineers of Japan [3]. According to the Committee’s evaluation, it is only permissible for rebars and joints that conform to such requirements to allow a lightning current to pass through them.

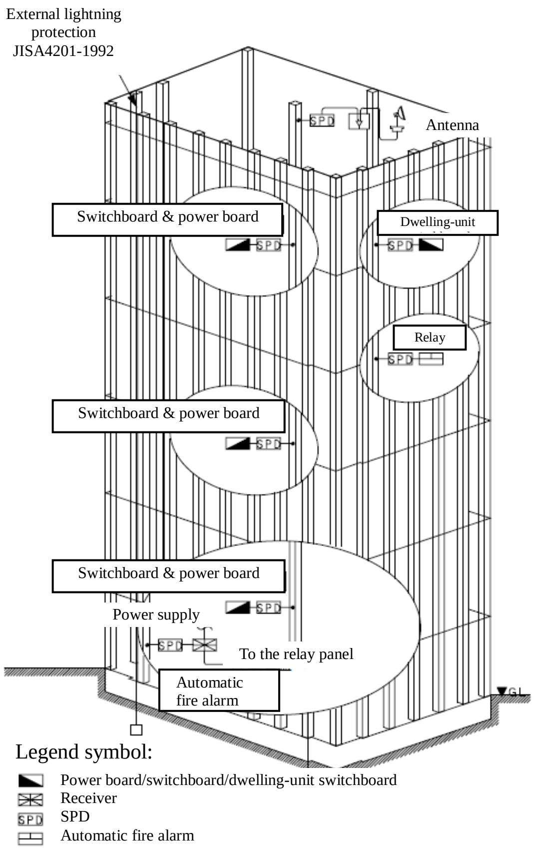

Fig. 7. Lightning protection system using lightning connectors

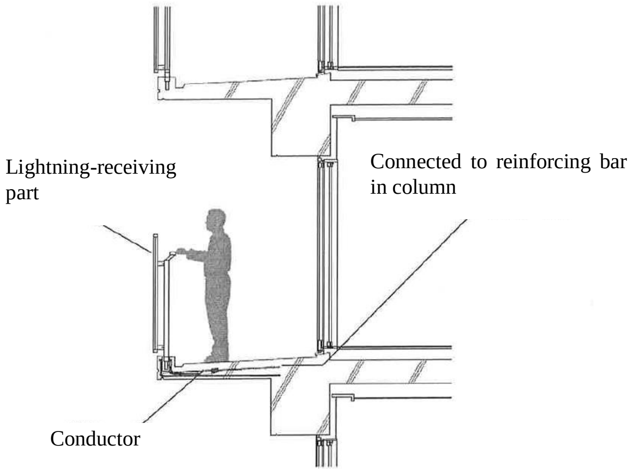

Fig. 8. Conceptual figure for lightening protection on sidewall (using handrail)

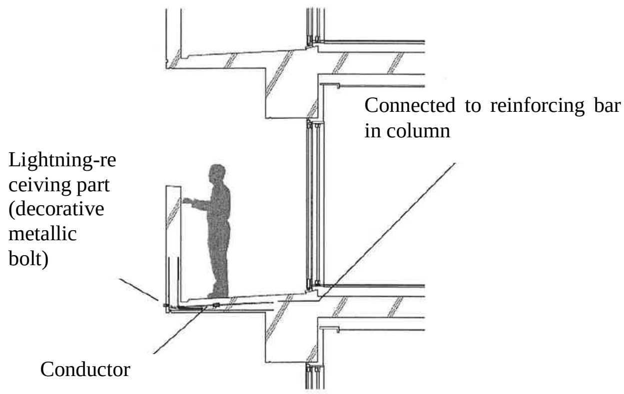

Fig. 9. Conceptual figure for lightening protection on sidewall (using projection rod)

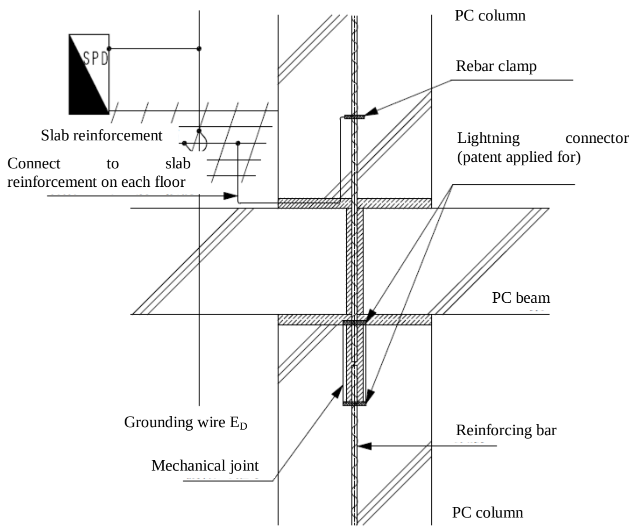

Fig. 10. Equalization of electric potential between floors

IV. RESISTANCE OF DOWN-CONDUCTORS USING LIGHTNING CONNECTORS

To verify the performance of lightning connectors, we measured the electrical resistance of columns used as down-conductors in Building B, where the main reinforcing bars of the columns are connected to each other by lightning connectors.

A. Measurement method

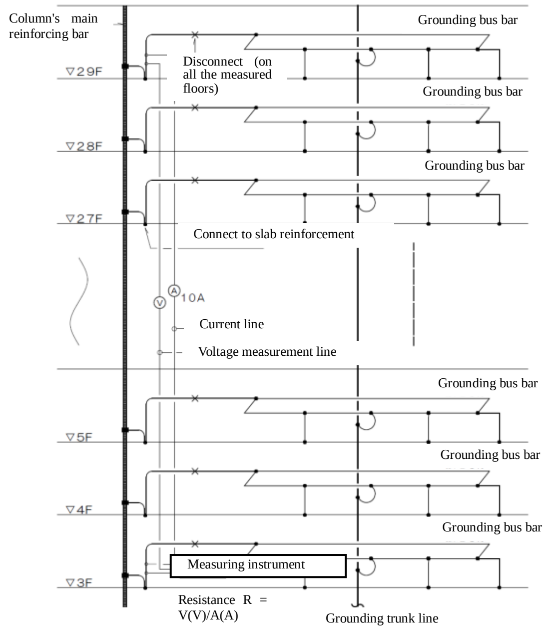

Fig. 11. Schematic diagram of obtaining measurements (Building B)

We measured the electrical resistance of the columns in Building B using the four-terminal method, which employs a low-resistance measuring instrument (Fig. 11 and Fig. 12). Electrical resistance can be determined by transmitting 10A (10 amperes) of direct-current electricity between the third floor (3F) and the twenty-ninth floor (29F) and measuring the voltage between these floors.

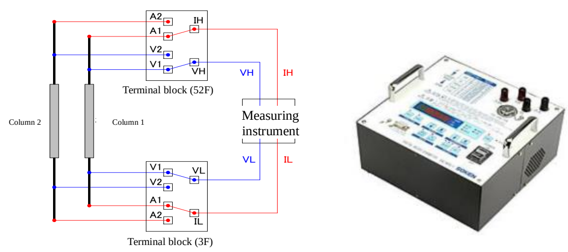

Fig. 12. Measurement circuit and low-resistance measuring instrument

B. Results of measurement

Table I shows the results of electrical resistance measurements recorded on columns between the 3F and 29F of Building B. The calculated values show results determined on the assumption that a parallel circuit is working effectively between each pair of columns.

TABLE I. ELECTRICAL RESISTANCE MEASUREMENT RESULTS
(Building B: 29-storey building)

Measured Column	**Measurement Value**	**Calculated Value**
Column 1	28.300 mΩ (1)	
Column 2	33.420 mΩ (2)	
Column 3	39.950 mΩ (3)	
Column 4	34.170 mΩ (4)	
Columns 1 & 2 parallel	20.160 mΩ	15.430 mΩ
Columns 1 & 3 parallel	17.350 mΩ	17.063 mΩ
Columns 1 & 4 parallel	17.186 mΩ	15.618 mΩ
Columns 2 & 3 parallel	25.619 mΩ	18.343 mΩ
Columns 2 & 4 parallel	25.955 mΩ	16.898 mΩ
Columns 3 & 4 parallel	18.901 mΩ	18.530 mΩ

C. Discussion

In this section, we first attempt to calculate the electrical resistance of one reinforcing bar of Column 1. The electrical resistance per bar on floors from 3F to 29F is

Reinforcing bar 56.32 m x 0.193 mΩ + joint part (including the bar) 26 locations x 1.363 mΩ + measuring wire 6.0 m x 0.824 mΩ/m = 51.3 mΩ. (7),

where 56.32 m = 85.7 m–26 x 1.13 m.

Calculation conditions:

- Total length of the reinforcing bar D41 is 85.7 m
- Resistance of the reinforcing bar D41 is 0.193 mΩ/m
- Resistance of joint part (bar + joint) is 1.363 mΩ/1.13 m, which is the resistance value of a test object connected by the connector
- Resistance of IV5.5 measuring wire is 0.824 mΩ/m

Table 1 shows that the measured resistance values of single reinforcing bars from (1) to (4) are all small, ranging from 55 to 80% of the calculation value in Eq. (7), which is 51.3 mΩ. We presume that this result was reached because the columns have a large number of reinforcing bars connected by hoops. However, the parallel-circuit values between two columns in Table 1 are between one third (1/3) and one half (1/2) of the calculation value shown in Eq. (7). Such differences are caused by resistance of the measuring wires; lengths of the wires differ between the measuring instrument and each column.

We then attempt to estimate the total resistance between the third floor (3F) and the twenty-ninth floor (29F) , where, in the case of Building B, which has 42 columns,

{(1) + (2) + (3) + (4)}/4/42 = 0.80 mΩ.

Therefore, assuming a safety factor of 10, the resistance is 8.0 mΩ. This result is considerably lower than 0.2 Ω (200 mΩ), which is the target value for the overall resistance of a building that is defined in the International Electrotechnical Commission (IEC) standard 62305-3 [4] as applicable for use as a down-conductor. This result therefore means that the building itself can be utilized as a down-conductor for lightning protection, even if it is constructed by the PC construction method, as long as the main reinforcing bars in the columns are connected to each other securely using connectors or other appropriate means.

V. CONCLUSION

It is possible to utilize the main reinforcing bars of RC structures constructed using the PC construction method as down-conductors in an external lightning protection system, if electrical connectivity can be established between the main reinforcing bars. In addition, by structuring the reinforcing bars within the building in the shape of a bird cage, with the aim of equalizing electric potential throughout the building, the actual structure of the building can also be utilized as an internal lightning protection system.

VI. FUTURE CHALLENGES

It is not possible to gain measurements of the electrical resistance of a high-rise building during construction, because when the concrete is being placed on the upper floors the interior finishing work has already begun on the lower floors. Therefore, to measure resistance it is necessary to install measuring wires in advance, and this needs to occur before the finishing work is begun in relevant areas. In projects with a tight time schedule, it would thus be necessary to allow for sufficient preparation and setup, in addition to gaining prior consent from the building constructors. We therefore hope for the emergence or development of an estimation method that enables the omission of measurements, or of a simplified method for use in measuring a building's resistance.

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