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Lightning Overvoltage of Rails and Signalling Cables in Electrified / Non-electrified Section

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***Abstract*— Effective and economical lightning protection measures are necessary for the railway signalling systems because suspended operation or train delays due to lightning damage may cause social disturbance. Railway signalling systems are mainly composed of signalling cables laid on the ground surface, rails and overhead power lines. The authors have measured lightning overvoltage of these components of railway signalling systems in the field. The measurement in a non-electrified section was conducted from 2010 to 2013, and the measurement in an electrified section has just started from 2015. This paper describes the measurement results in the electrified section and the correlation between lightning overvoltages of the components and lightning conditions, such as the stroke current and the strike position. Moreover, this paper indicates the difference of lightning overvoltages of signalling cables and rails between the electrified section and the non-electrified one.**

Keywords- railway signalling system; lightning overvoltage; stroke current; strike position; rail; signalling cable

I. INTRODUCTION

Railway signalling systems have made remarkable progress in recent years with their components becoming increasingly compact and multi-functional due to the adoption of microcomputers and other electronic devices in wide ranges. However, lightning damages such as circuit burnout, system failure and others frequently occur in railway signalling systems because the electronic devices are easily damaged by lightning surges. Fig. 1 shows the proportion of troubles of the railway signalling systems to the total transportation troubles and the proportion of troubles of the signalling systems due to lightning damages to the total troubles of the signalling systems from 2010 to 2012 in Japan. As shown in Fig. 1, the troubles of the signalling systems account for about 10 % of the total transportation troubles, and the troubles of the signalling systems due to lightning damages account for about 10 ~ 20 % of the total troubles of the signalling systems.

Effective and economical lightning protection measures are therefore necessary for the railway signalling systems because suspended operation or train delays due to lightning damage may cause social disturbance. Then it is important to understand characteristics of lightning overvoltages of the railway signalling systems quantitatively.

Railway signalling systems are mainly composed of signalling cables laid on the ground surface, rails and overhead power lines. The authors therefore have measured lightning overvoltage of these components of the railway signalling systems in the field to enable quantitative analysis of the frequency of lightning overvoltage occurrence. The measurement in a non-electrified section was conducted from 2010 to 2013. The authors investigated the correlation between lightning overvoltages of the signalling cables, rails and overhead power lines and lightning conditions, such as the stroke current and the strike position (distance from the measurement position), and derived the equations for estimation of the lightning overvoltages according to the lightning conditions [1], [2].

The authors have just started the measurement of lightning overvoltages of signalling cables laid on the ground surface, rails and overhead distributed lines for the signalling systems in an electrified section from 2015.

This paper describes the measurement results in the electrified section. We investigated the correlation between lightning overvoltages of signalling cables, rails and overhead distributed lines for signalling systems and lightning conditions, and derived the equations for estimation of the lightning overvoltages according to the lightning conditions in the electrified section as well as in the non-electrified section. Moreover, this paper indicates the difference in lightning

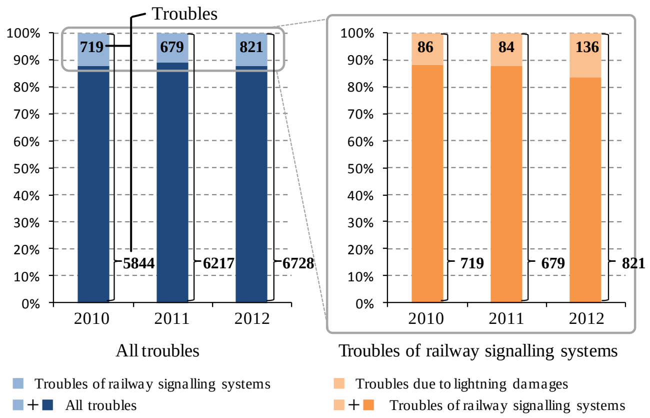


Figure 1. Troubles of railway signalling systems due to lightning damages.

overvoltages of signalling cables and rails between the electrified section and the non-electrified one.

II. Field Test for Observation of Lightning Overvoltages of Railway Signalling Systems in Electrified Section

A. Field test site

It is necessary to obtain the magnitude and frequency of lightning overvoltages that are generated in signalling cables, rails and overhead distributed lines for railway signalling systems in the event of actual lightning in order to consider the countermeasures against lightning damage. The measurement of overvoltages of the components of the signalling systems was therefore carried out in the field.

The field test was conducted on “A line” (Quadruple track and electrified section) located in the Kansai area. Fig. 2 shows the overview of the test site. The ground resistivity of this site was measured as approximately 300 Ω·m by Wenner’s 4 electrodes method.

B. Measurement periods

Measurements of lightning overvoltages were carried out from 22 May to 22 October 2015. Summer lightings were subjects of the measurement.

C. Measurement system

Fig. 3 shows a diagram of the measurement set-up at the field test site. We measured lightning overvoltages of signalling cables laid on the ground surface, rails and overhead distributed lines used for signalling systems against the ground.

The observation system such as 16ch high speed A/D converter was installed in a measurement hut constructed temporarily at the wayside.

A railway signalling cable, which has the length of 434 m, was temporarily laid on the ground surface for the field test. SVV cable (1.25 mm^2 × 4 cores) was used. SVV cable has no metal sheath and is the most popular for a railway signalling cable. As shown in Fig. 3, the resistances of 1 kΩ simulating signalling equipment load were provided at both the ends of

Figure 2. Overview of the field test site (electrified section).

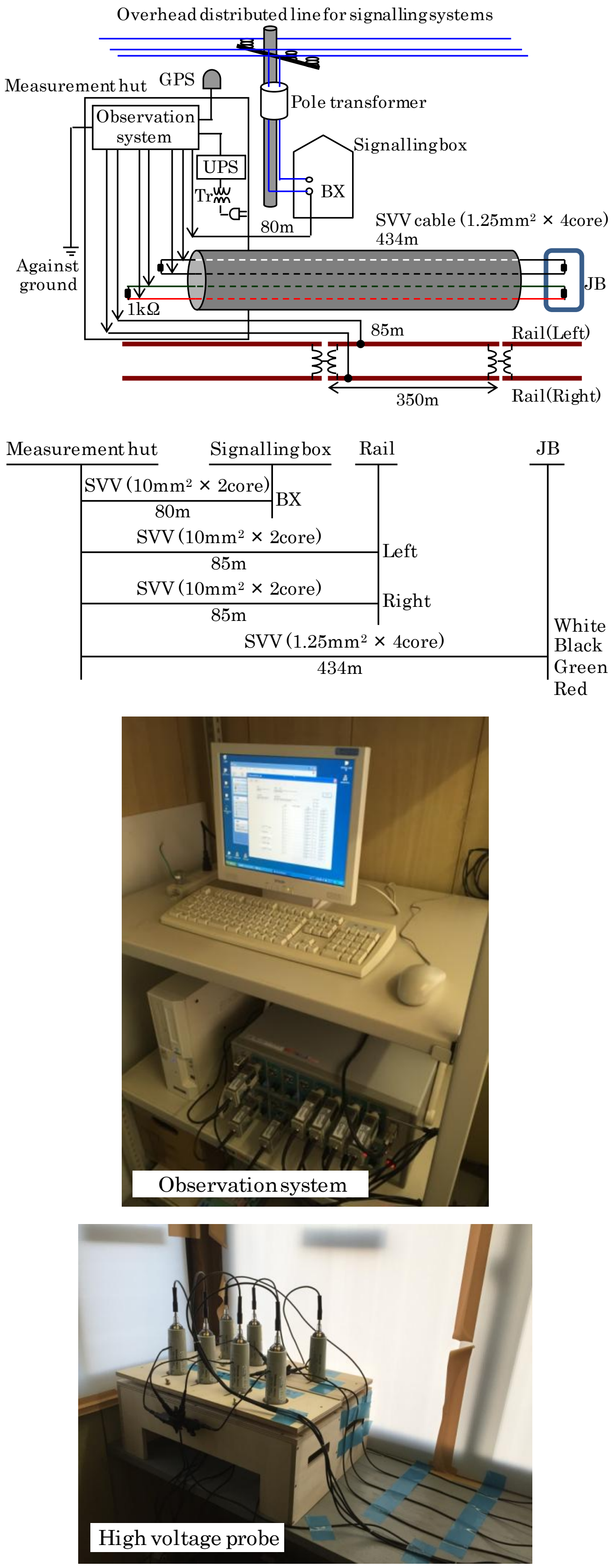


Figure 3. Diagram of measurement set-up.

signalling cables. One resistance was provided between “White” core and “Black” core, and another one was provided between “Red” core and “Green” core. 4 cores of SVV cable are insulated from the ground, as they are normally done.

On the other hand, rails used for measuring lightning overvoltages were the ones under operation. They have the length of 350 m. Measuring wires were jointed to the left side and the right side of rail, respectively. Measuring wires are SVV cables (10 mm^2 × 2 cores) and have the length of 85 m extending from the rail to the measurement hut.

Moreover, the lightning overvoltages of power lines extending from overhead distributed lines used for railway signalling systems were also measured. The voltage of overhead distributed lines used for railway signalling systems is AC 6.6 kV. AC 110 V power lines are led to a signalling box via a pole transformer for transforming from AC 6.6 kV to AC 110 V. Measuring wire is SVV cable (10 mm^2 × 2 cores) and has the length of 80 m extending from the signalling box to the measurement hut.

The triggered level to register waveform data of lightning overvoltages is ±156 V for signalling cables, ±313 V for rails and ±625 V for power lines, respectively. The high voltage probes used for measurement are Tektronix P6015A.

Waveform data of lightning overvoltages were registered when overvoltages at any measurement points exceeded the triggered level. The record length of waveform data is 102.4 μs/ch (50 ns × 2,048 samples/ch). Waveform data files were recorded in a PC, with inclusion of the triggered time identified by use of GPS (Global Positioning System).

On the other hand, data concerning lightning conditions such as the stroke current and the strike position are based on the data obtained by JLDN (Japanese Lightning Detection Network) [3]. The striking time is also the time by GPS. We can specify the lightning generating overvoltages of signalling cables, rails and overhead distributed lines used for signalling systems by comparing the time of lightning occurrence by GPS with the time of overvoltages occurrence also by GPS.

III. MEASUREMENT RESULTS

A. *Characteristics of Lightning Stroke during the Measurement Periods*

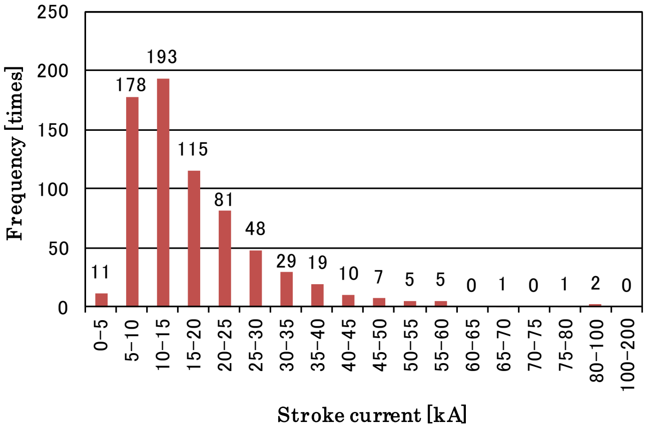
Table I shows the numbers of lightning stroke during the measurement periods. The numbers in Table I refer to those occurring in the area within a radius of 10 km from the center of the measurement hut. The number of lightning overvoltages having exceeded the triggered level is also shown in Table I.

Figs. 4 (a) and 4 (b) show the distribution of lightning stroke current and the distribution of the distance between the measurement hut and the lightning strike position during the measurement periods, respectively. The vertical axis of Fig. 4 (b) indicates frequency per km^2. From Fig. 4 (a), there are no noticeable peculiarities about the characteristics of lightning current. On the other hand, Fig. 4 (b) indicates that there are many lightning stroke at the positions 6 km and over distant from the measurement hut during the measurement periods.

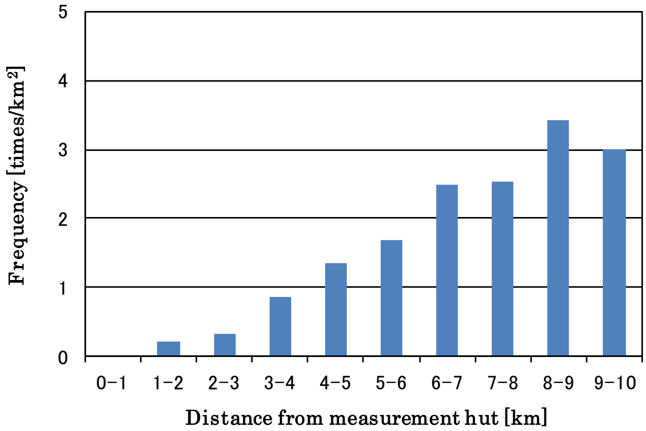
TABLE I. NUMBER OF LIGHTNING STROKE AND LIGHTNING OVERVOLTAGES HAVING EXCEEDED TRIGGERED LEVEL DURING MEASUREMENT PERIODS

Date	Number of stroke	Number of lightning overvoltages
06/08/2015	72	0
07/08/2015	11	0
08/08/2015	587	52
09/08/2015	28	5
01/09/2015	6	0
10/09/2015	1	0
Total	705	57

*Within a radius of 10 km from the center of the measurement hut.



(a) Distribution of stroke current.



(b) Distribution of strike position.

Figure 4. Distribution of stroke current and strike position during the measurement periods.

B. *Lightning Overvoltage Wave Form*

By way of example, Fig. 5 shows a map of locations of lightning strikes occurring on 8 August 2015. The ‘×’ plotted in the figure indicates the position of strikes. These lightning strike locations are based on JLDN data.

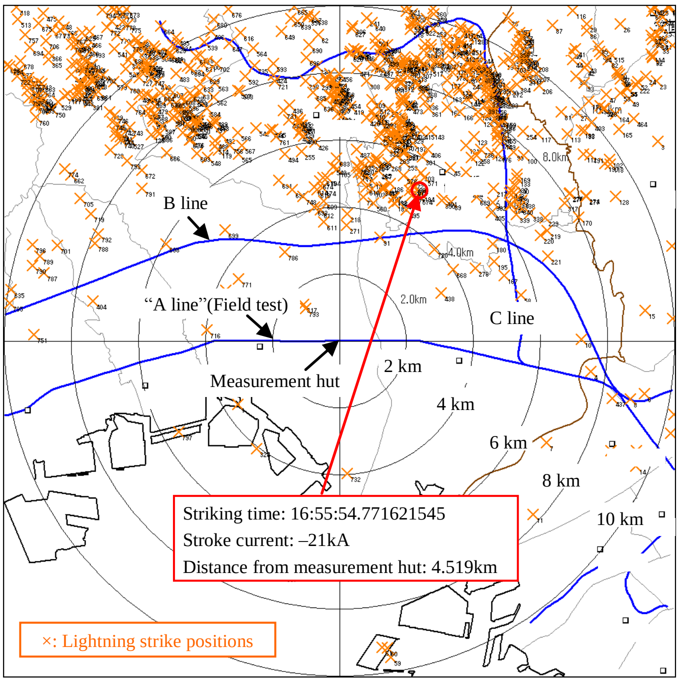


Figure 5. Lightning strike location map on 8 August 2015.

Fig. 6 shows the waveform data of lightning overvoltages of signalling cables ("White" core), right rail and overhead distributed lines used for signalling systems against the ground generated by the lightning stroke enclosed with '○' in Fig. 5. This lightning struck at 16:55:54.771621545 on 8 August 2015. The stroke current was −21.0 kA and the distance from the measurement position to the lightning strike position was 4.519 km. On the other hand, the triggered time of lightning overvoltages was 16:55:54.771636722. The lightning stroke generating the lightning overvoltages can be identified by comparing the time of lightning occurrence by GPS with the time of overvoltages occurrence also by GPS.

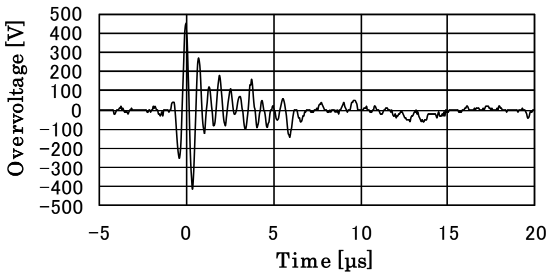
As shown in Fig. 6 (b) and (c), there is the AC bias component due to track circuit and power lines at electrified section in lightning overvoltage wave forms. However, the bias component can be seen in lightning overvoltage wave forms measured at non-electrified section.

IV. Estimation of Lightning Overvoltages of Railway Signalling Systems in Electrified Section according to Lightning Conditions

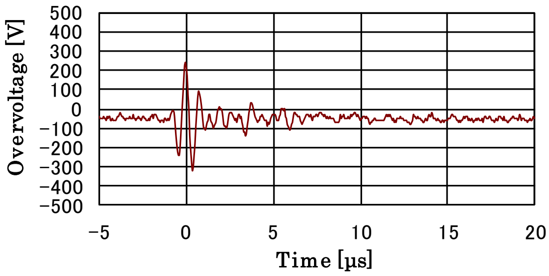
A. Generation Mechanism of Lightning Overvoltage

The lightning strokes radiate strongly impulsive electric-magnetic fields. Electrical fields E [V/m] generated at this time are expressed by (1) [4].

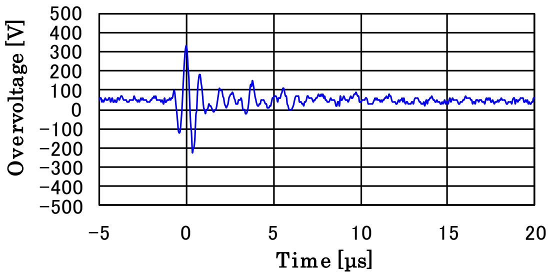
$$E = A \cdot \frac{I}{r} \tag{1}$$



(a) Lightning overvoltages of SVV cable ("White" core).



(b) Lightning overvoltages of right rail.



(c) Lightning overvoltages of overhead distributed line.

Figure 6. Waveform of lightning overvoltages generated by the lightning stroke enclosed with '○' in Fig. 5.

where I is the lightning stroke current [A]. r is the distance from the measurement position to the lightning strike position [m]. A is the factor of proportionality.

From (1), the lightning overvoltages are proportional to the lightning stroke current and inversely proportional to the distance from the measurement position to the lightning strike position.

We therefore investigated the correlation between lightning overvoltages (V) of signalling cables, rails and overhead distribution lines used for signalling systems and lightning conditions, which are defined by the stroke current divided by the distance to the strike position (I/r).

B. Correlation between Lightning Overvoltages and Lightning Conditions in Electrified Section

Fig. 7 shows the correlation between lightning overvoltages of signalling cables, rails and overhead distribution lines used for signalling systems which are main components of railway signalling systems and lightning conditions, such as the stroke current and the strike position (distance from the measurement position), in the electrified section. The horizontal axis indicates the lightning conditions expressed by *I/r*, and the vertical axis indicates the lightning overvoltages generated by the lightnings. Regarding signalling cables, plotted data indicate the lightning overvoltages between “White” core and the ground. In the case of rails, plotted data indicate lightning overvoltages between the right rail and the ground.

The dispersion of lightning overvoltages proceeds from the error of the lightning strike location positioning and stroke current estimation. Moreover, the front duration of lightning current waveform is not considered. Further as one more thing, lightning strokes to the ground and the ones to the structures are mixed.

Equations (2) − (4) can be derived from Fig. 7. These equations are the equations for estimation of the lightning overvoltages according to the lightning conditions in the electrified section. The regression lines by (2) − (4) in Fig. 7 cover 97 % of plotted data of lightning overvoltages.

- The lightning overvoltages of signalling cables.

$$V = 0.043 \times \left(\frac{I}{r}\right) + 0.28 \tag{2}$$

- The lightning overvoltages of rails.

$$V = 0.033 \times \left(\frac{I}{r}\right) + 0.21 \tag{3}$$

- The lightning overvoltages of overhead distribution lines for signalling systems.

$$V = 0.034 \times \left(\frac{I}{r}\right) + 0.20 \tag{4}$$

where V is the lightning overvoltages of signalling cables, rails and overhead distribution lines [kV]. I is the lightning stroke current [kA]. r is the distance to the lightning strike position [km].

We can estimate the lightning overvoltages generated in the components of railway signalling system which is installed in an electrified section according to the lightning conditions by (2) − (4). We can therefore estimate the lightning conditions leading to lightning damage in the case where the withstand voltages of railway signalling systems is exceeded, by (2) − (4) in the same way.

Fig. 8 is shown for reference only. Fig. 8 shows the correlation between lightning overvoltages of signalling cables, rails and power lines for customer and lightning conditions. The data of Fig. 8 are the measurement results in the non-electrified section from 2010 to 2013 [2].

The number of data included in Fig. 7 which were measured in the electrified section is 57. In short, the number of lightning overvoltages which exceeded the triggered level is 57 times. On the other hand, the number of data included in Fig. 8 which were measured in the non-electrified section is 578. From Fig. 7, lightning overvoltages of signalling cables according to lightning conditions are higher than those of rails. However, there is no difference regarding with lightning overvoltages between the signalling cables and the rails in the non-electrified section as shown in Fig. 8. The measurement points of signalling cables are considered the reason. The measurement points of signalling cables are the end of cable in the electrified section. On the other hand, the measurement

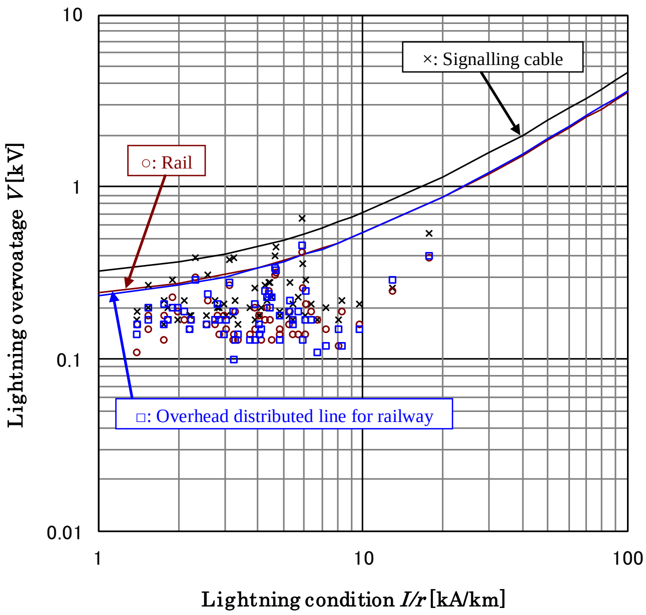


Figure 7. Correlation between lightning overvoltages and lightning conditions (electrified section).

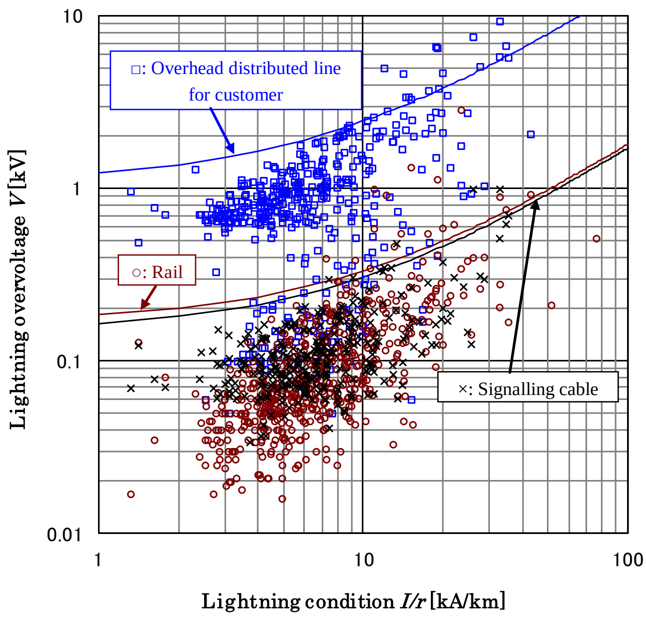


Figure 8. Correlation between lightning overvoltages and lightning conditions (non-electrified section).

points of the signalling cables are the middle of cables in the non-electrified section.

We have a schedule to continue the measurement of lightning overvoltages in 2016 to increase the data in the electrified section.

V. Comparison between Lightning Overvoltages in the Electrified Section and Those in the Non-Electrified Section

A. Signalling Cables

Fig. 9 shows the comparison of the correlation between lightning overvoltage of signalling cables laid on the ground surface and lightning conditions in the electrified section with that in the non-electrified section. The approximating linear lines are indicated in Fig. 9.

As a result of calculation of the t-test, it is confirmed that the lightning overvoltages of signalling cables according to lightning conditions in the electrified section are significantly higher than those in the non-electrified section.

B. Rails

Fig. 10 also shows the comparison of the correlation between lightning overvoltage of rails and lightning conditions in the electrified section with that in the non-electrified section. The approximating linear lines are indicated in Fig. 10.

As a result of calculation of the t-test, it is confirmed that the lightning overvoltages of rails according to lightning conditions in the electrified section are significantly higher than those in the non-electrified section in the same way as the case of the signalling cables.

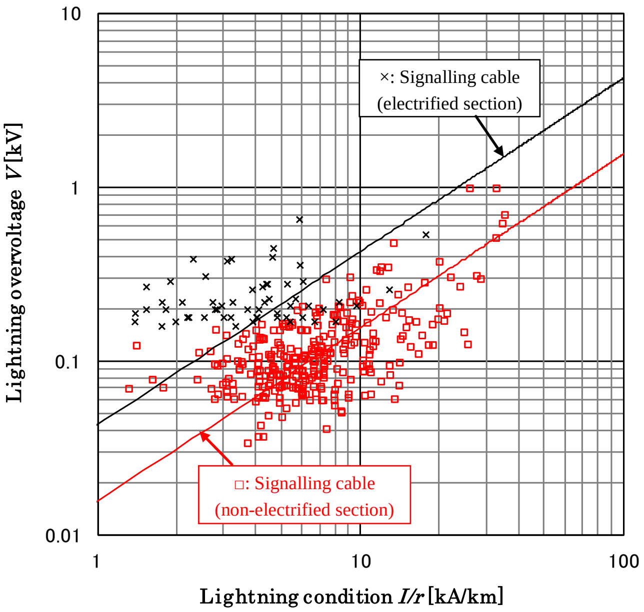


Figure 9. Comparison of the correlation between lightning overvoltages of signalling cables and lightning conditions in the electrified section with that in the non-electrified section.

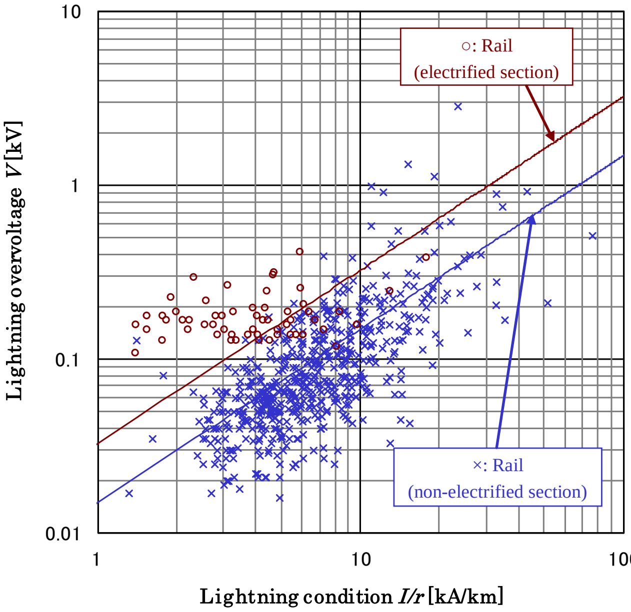


Figure 10. Comparison of the correlation between lightning overvoltages of rails and lightning conditions in the electrified section with that in the non-electrified section.

VI. Conclusions

This paper describes the observation results of lightning overvoltages of railway signalling cables laid on the ground surface, rails and overhead distribution lines which are main components of railway signalling systems in the electrified section in 2015 and indicates the equations for estimation of the lightning overvoltages according to the lightning conditions, such as the stroke current and the strike position. We can therefore estimate lightning conditions leading to lightning damage in the case where the withstand voltages of railway signalling systems are exceeded by the equations.

Moreover, as a result of calculation of the t-test, it is confirmed that the lightning overvoltages of signalling cables and rails according to lightning conditions in the electrified section are significantly higher than those in the non-electrified section.

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