Field Observation of Wet Snow Accretion and Galloping on a Single Conductor Transmission Line

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Abstract— **This paper presents the field observation results of wet snow accretion and galloping on a single conductor transmission line in eastern Hokkaido, Japan. Twenty-one wet snow accretion events were observed during the winter seasons from 2008 to 2015. The observed results indicate that the combination of air temperature and relative humidity during wet snow accretion agrees well with the results predicted by the precipitation type classification method. The amount of snow accretion was significantly reduced for the lines with the counterweight and interphase spacer, which suppressed the rotation of the conductor. Furthermore, galloping occurred when wind speed exceeded 7 m/s, and galloping with a large amplitude was known to occur even if the amount of snow accretion was low. The amplitude of galloping for the line with the interphase spacer was suppressed by approximately 40% compared with the line on which the counterweight was installed.**

Keywords—***Wet snow accretion, Galloping, Field observation, Single conductor, Overhead transmission line***

I. Introduction

Snow accretion on overhead transmission lines sometimes causes significant damage to facilities and leads to massive power outages [1, 2]. Snow accretion on overhead lines is classified as precipitation icing. Many cases of large-scale snow damage in Japan have been caused by wet snow accretion on overhead lines [3, 4]. Wet snowflakes, which precipitate at a temperature of approximately 0 °C, contain some liquid water and easily accrete to the conductor. In serious cases, transmission tower collapse might be induced by the weight of the heavily accreted snow and increased wind load due to the increase in the wind projected area with snow accretion. In some instances, ground faults occur due to conductors drooping under the weight of the accreted snow, while in others, the conductor short circuits due to jumping upwards as a result of the accreted snow suddenly falling off. The later phenomenon is called sleet jumping.

On the other hand, galloping of overhead transmission lines is occasionally observed when the lines are subjected to snow accretion under strong wind [5]. This phenomenon involves significant vertical oscillation accompanied by horizontal and torsional oscillations at low frequency. An increase in the amplitude of oscillation has the potential to cause interphase short circuits and fatigue on the crossarm of the tower and insulator.

To prevent or reduce wet snow accretion on the overhead lines, snow resistance (SR) rings and counterweights have been used in Japan [6]. Excessive snow accretion forms a cylindrical sleeve around the conductor. Cylindrical snow sleeves develop via two different mechanisms. In the first, the accreted snow slides along the strands of the wire. In the second, the wire rotates due to the moment caused by the snow accretion weight. The SR ring is a plastic ring that prevents accumulated snow from sliding along the twists in the conductor surface, thus preventing excessive cylindrical snow accretion. A counterweight is an eccentric weight that discourages conductor rotation, thus preventing excessive cylindrical snow accretion. Interphase spacers have been used to prevent short circuits due to galloping. They maintain a safe distance between conductors during galloping and suppress conductor rotation.

Field observations of full-scale transmission lines have been conducted to investigate the actual characteristics of snow accretion [7] and analyse the dynamic response of the lines to galloping [8–10]. However, not much data have been collected because the climate conditions that induce heavy snow accretion have rarely occurred during the observation periods. Obtaining data related to galloping is quite difficult because galloping occurs only under specific conditions of snow accretion shape and wind speed. Furthermore, limited data are available to validate the effect of countermeasures in the actual environment. Therefore, further research and detailed data are required.

Accordingly, we conducted field observations of wet snow accretion and galloping on a single conductor transmission line in eastern Hokkaido, Japan [11]. We compared the amounts of snow accretion and oscillation amplitudes of lines with different countermeasures, including combinations of SR rings, counterweights, and interphase spacers. During the winter seasons from 2008 to 2015, a total of 21 wet snow accretion events were observed. In this paper, we analyse the observation results and discuss the conditions of wet snow accretion and galloping incidence. Furthermore, the effects of the countermeasures on single conductor transmission lines are discussed.

II. Observation Site

The observation target is a 66 kV single conductor transmission line in eastern Hokkaido, as shown in Fig. 1. The targeted spans of the line are 1L and 2L between tower Nos. 1 and 3. These towers are located in a flat pasture (Fig. 2), and the line extends at 104° in the azimuthal direction. The target line consists of ACSR240 conductors (aluminium conductor steel-reinforced with a nominal cross-sectional area of 240 mm^2). The span lengths between tower Nos. 1 and 2 and Nos. 2 and 3 are 332 m and 281 m respectively. Tower No. 2 is a

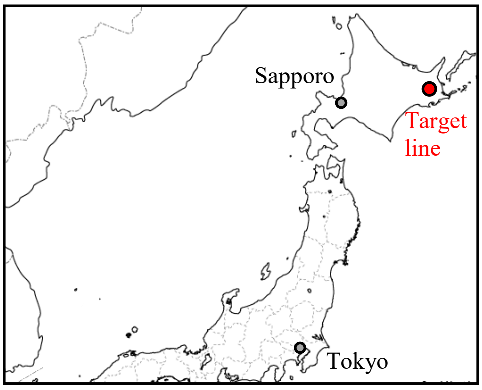


Fig. 1 Location of target line in Japan

Fig. 2 View around the target spans

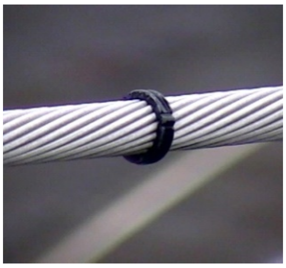
tension type support, whereas tower Nos. 1 and 3 are suspension type supports. The closest tension type towers before and after tower No. 2 are five spans apart; each group of five spans between the tension type towers constitutes a suspension.

The countermeasures for snow damage are installed in the spans in three combinations. The first includes only SR rings (i.e. Ring), the second includes SR rings and counterweights (i.e. Ring+CW), and third includes SR rings and interphase spacers (i.e. Ring+SP). Each countermeasure is shown in Fig. 3. The amount of snow accretion and oscillation amplitude of the lines with different countermeasures were compared.

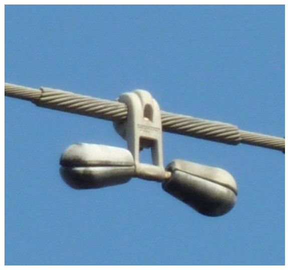
Anemometers, a thermometer, a hygrometer, a barometer, and tension meters for the conductors are installed in tower No. 2. The amount of snow accretion is calculated analytically using the tension and wind speed. Furthermore, WEB cameras are installed in tower No. 2. Infrared LED lamp markers are installed in the 1/4, 1/2, and 3/4 positions of the span. Therefore, displacements of the line at the markers can be obtained by analysing the images taken by the WEB cameras.

III. Observation Results

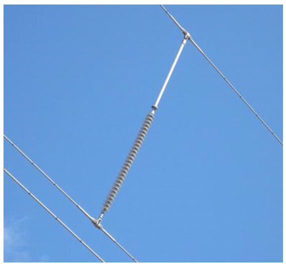
Field observations were conducted from 2008 to 2015, and a total of 21 wet snow accretion events were observed. Table I shows the number of wet snow accretion events in each wind speed class and maximum amount of snow accretion. Except for those events with a very small snow accretion amount (not included in Table I), the snow accretion type for all events was classified as wet type. Wind speed was classified as either moderate or strong for many events. In particular, high amounts of snow accretion occurred under strong wind conditions.



(a) Snow-resistance ring



(b) Counterweight



(c) Interphase spacer

Fig. 3 Countermeasures installed in spans

Table I. Number of wet snow accretion events in each wind speed class and maximum amount of snow accretion

Class of mean wind speed	Maximum amount of snow accretion		
	~0.3 kg/m	0.3~0.8 kg/m	~0.8 kg/m
Weak (1–3 m/s)	0	1	0
Moderate (3–8 m/s)	6	1	0
Strong (8 m/s)	6	4	3

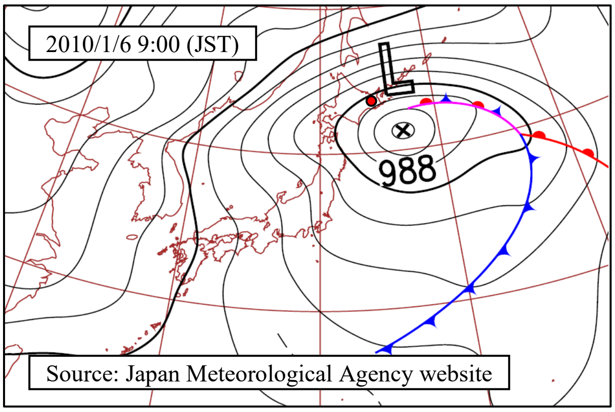


Fig. 4 Typical weather chart of snow event

Fig. 4 shows an example weather chart for a snow event. For most severe snowfall events at this site, low pressure developed on the southern shore of Hokkaido and approached the study site, and the precipitation at approximately 0 °C, which is conducive to snow accretion, continued under strong winds. In this manner, abundant data on electric wire oscillation, including galloping with wet snow accretion, could be obtained.

Figs. 5 and 6 show examples of the time series variations in the metrological conditions, average amount of snow accretion, and maximum vertical total amplitude of the line, as 10-min statistical values. Note that the amounts of precipitation noted in these figures are analysed radar rainfall data rather than data observed at this site. The amounts of snow accretion were analytically calculated using the tension and wind speed, assuming that the snow accretion shape was cylindrical and the density of snow accretion was 300 kg/m^3. The total amplitude of vertical displacement was defined as the difference between the maximum and minimum values of

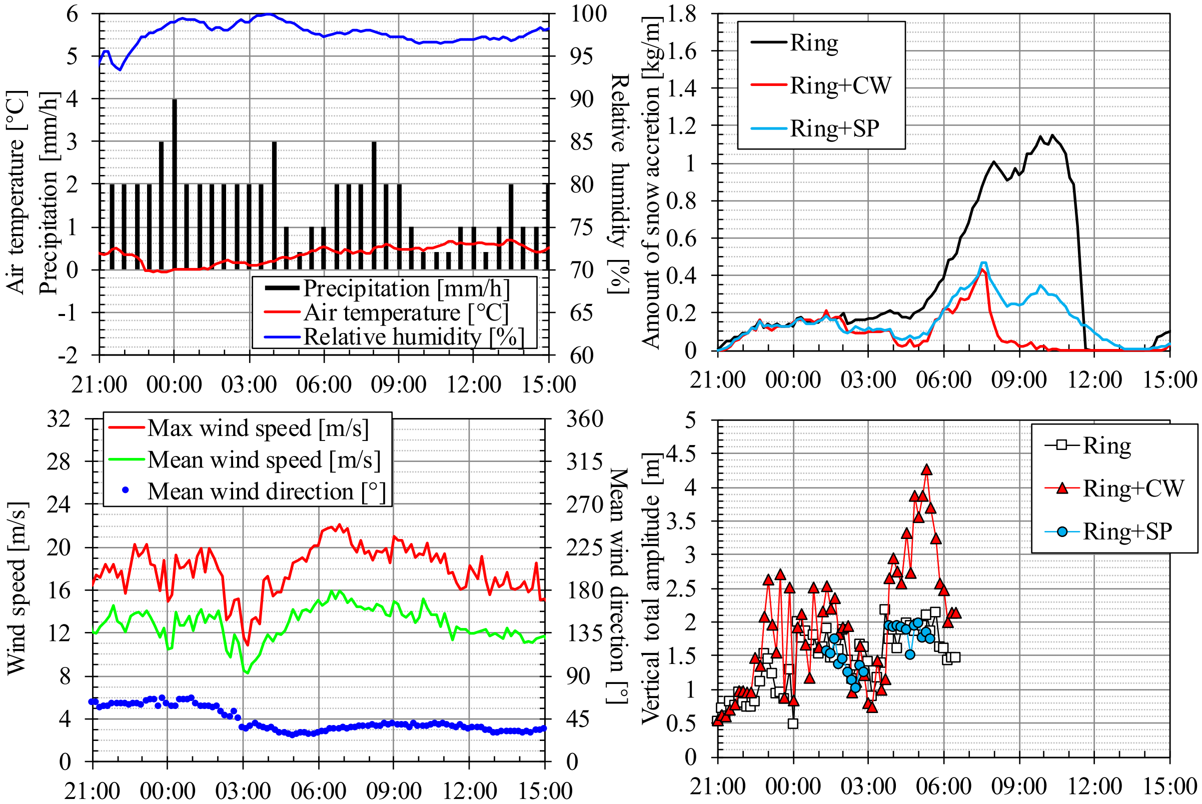


Fig. 5 Time series of statistical values in an event with remarkable “snow accretion” and “galloping” (2010/1/5–6)

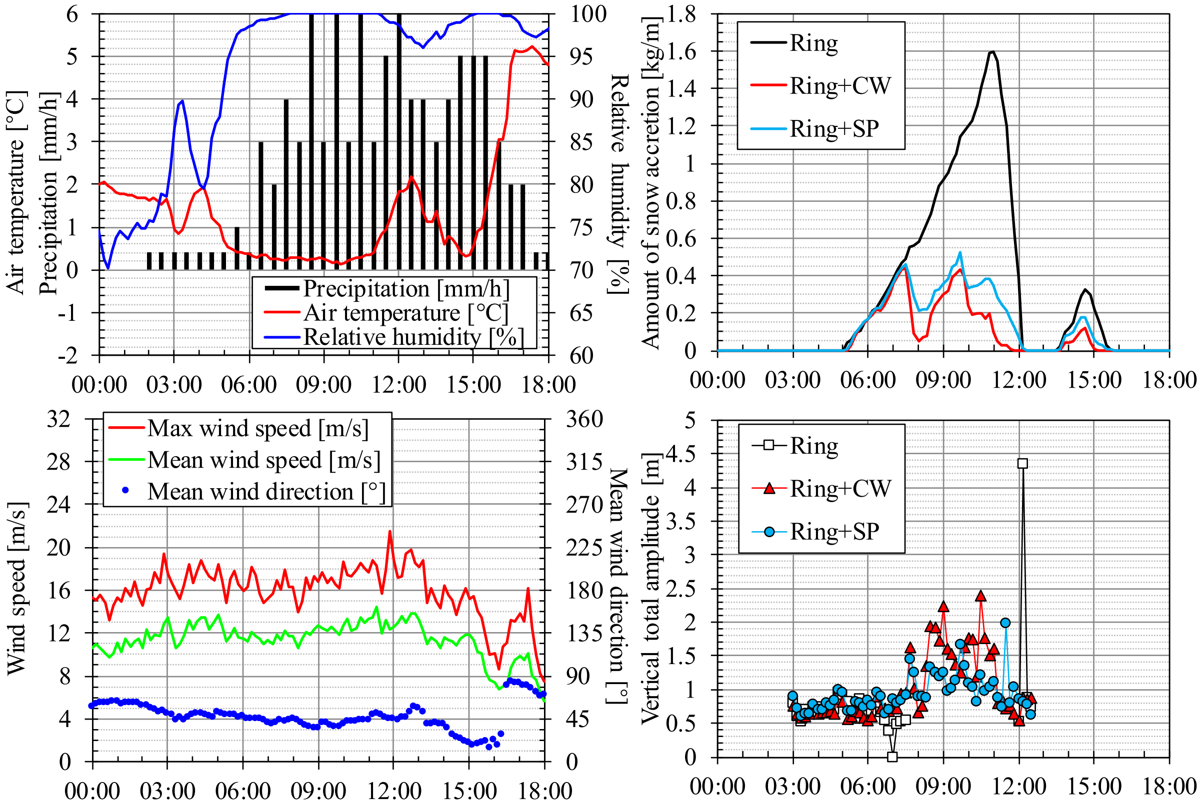


Fig. 6 Time series of statistical values in an event with remarkable “snow accretion” and “sleet jump” (2010/12/23)

the vertical displacement in a 10-min window. These figures show that larger values compared to the target were observed at the 1/4 and 1/2 spans. The average amount of snow accretion and maximum vertical amplitude for multiple observation spans with the same countermeasures are shown in these figures.

The countermeasure effect is thought to be the weakest in the line with the SR rings only. The amount of snow accretion for this line increased due to precipitation at approximately 0 °C, as shown in Figs. 5 and 6. However, it can be seen that snow accretion is quite sensitive to air temperature and that the accreted snow begins to fall off when the temperature approaches 1 °C, such as at approximately 11:00 on 2010/12/23, as shown in Fig. 6. Conversely, for the lines with counterweights or interphase spacers, which suppress the rotation of the conductor, snow accretion does not occur beyond a certain amount and the accreted snow continues to fall off, either wholly or partially. Additional information on the effect of countermeasures appears in Section VI.

As shown in Fig. 5, the response amplitude changed depending on the amount of snow accretion (or strictly speaking, the shape of the snow) and wind speed. High amplitude was observed on the line with SR rings and counterweights, such as at approximately 3:00 to 6:00 on 2010/1/6, as shown in Fig. 5. Images taken by the WEB cameras indicate that vertical oscillation was caused mainly by galloping. The cause of galloping along the line with the counterweights is also described in Section VI.

Furthermore, sleet jump, which is caused by the accreted snow suddenly falling off the conductor, was observed along the line with SR rings only, such as at approximately 12:00 on 2010/12/23, as shown in Fig. 6. Since the observed spans consisted of multiple successive spans, the difference in the timings of accreted snow falling between the continuous spans generated a large vertical amplitude.

IV. Snow Accretion Conditions

Clarification regarding the meteorological conditions favouring snow accretion involves an important factor, namely whether the snowflakes are wet or dry. In other words, it is important to know to what extent the snowflakes contain liquid water. Though wet snowflakes easily accrete to the conductor and adhere to the surface even under moderate and strong wind conditions, dry snowflakes adhere only under calm and weak wind conditions. Fig. 7 shows the temperature and relative humidity when the amount of snow accretion increased for the line with the SR ring only. Fig. 7 also shows the discrimination line between rain and other precipitation particle types and the discrimination line between snow and other precipitation particle types. These discrimination lines were obtained using the precipitation type clarification analysis [12]. The type of precipitation was analysed by using the meteorological surface data (including precipitation particle types) of the past 40 years collected by the weather station located in eastern Hokkaido. A past study proposed that wet snowflakes, which contain moderate amounts of liquid water and easily accrete, are frequently observed in the central zone between two discrimination lines [13].

The observed results indicate that the combination of air temperature and relative humidity during wet snow accretion agree well with those predicted by the precipitation type classification method.

V. Galloping Characteristics of Line with Counterweights

Based on displacement data obtained through image analysis for the winters from 2008 to 2015 (8 events, 10-min × 371 data), Fig. 8 shows the relation between the mean orthogonal wind speed and vertical total amplitude (10-min statistical values) for the line with the SR rings and counterweights. Galloping occurred when wind speed was more than 7 m/s, and the amplitude increased with wind speed. The maximum vertical oscillation amplitude did not exceed

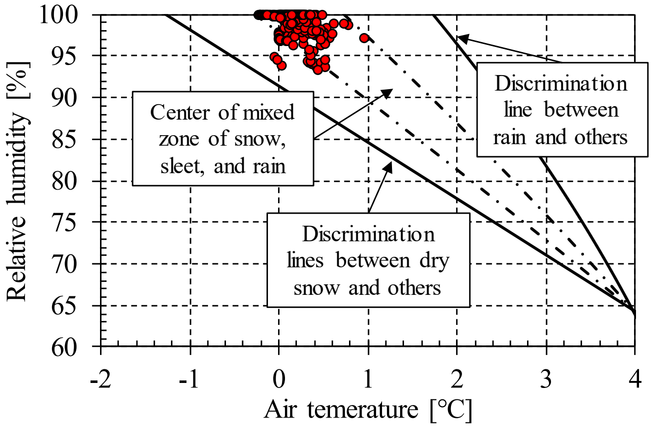


Fig. 7 Temperature and relative humidity when the amount of snow accretion increases (line with SR rings only)

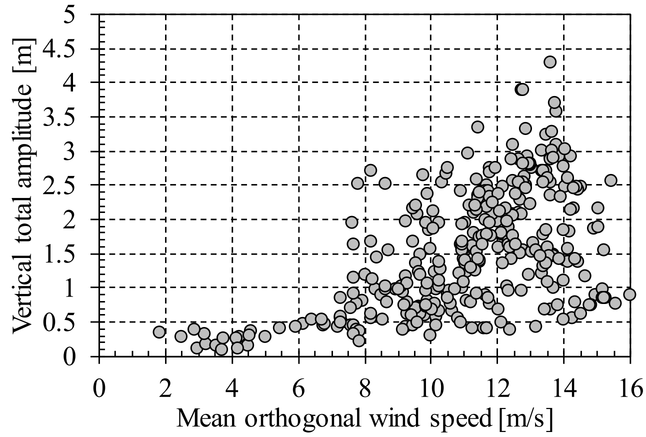


Fig. 8 Vertical total amplitude characteristics of the line with SR rings and counterweights under snow accretion

4.3 m. In addition, most high amplitude galloping was observed even with low amounts of snow accretion, such as at approximately 5:00 on 2010/1/6, as shown in Fig. 5. In other words, the slight snow accretion has the potential to transform into galloping with a large amplitude if the specific condition pertaining to snow accretion shape (namely, angle of attack) and wind speed are met.

VI. Effect of Countermeasures

Fig. 9 compares the maximum amount of snow accretion in each event for the lines with three different combinations of countermeasures. The amount of snow accretion was significantly reduced in the lines with the counterweight and interphase spacer, which suppressed the rotation of the conductor, compared to the line without these countermeasures (i.e. only the SR rings). Because the wire does not rotate easily, snow accretion tends to develop in one direction only. As a result, snow is likely to fall off during accretion.

However, suppressing the conductor rotation increases the incidence of galloping. The reason for this is thought to be as follows: snow accretion development in a single direction forms sharp snow shapes (i.e. triangle- and crescent-shaped accretions) that are likely to introduce galloping. These snow accretions might introduce fluctuations in lift force along with motion. The oscillation amplitude of the line with counterweights was larger than that without them (i.e. only the SR rings), as shown in Fig. 5.

Fig. 10 compares the vertical total amplitude of the line with the SR rings and interphase spacers with those of the line with the SR rings and counterweights for each 10-min statistical value. The maximum amplitude of galloping for the line with the interphase spacer was 2.6 m, which was suppressed by approximately 40% compared to the line with the counterweight. Thus, installation of a phase spacer is the simplest option for suppressing both the amount of snow accretion and amplitude of galloping. However, the most effective method involves selecting countermeasure devices to suit the weather conditions of each region and specific features of the transmission facilities. For example, if there is no possibility for galloping, that is, the wind speed is low, counterweights would be the ideal choice to suppress snow accretion. If snow accretion is not expected to be excessive but galloping might occur, then using a snow ring alone will suffice.

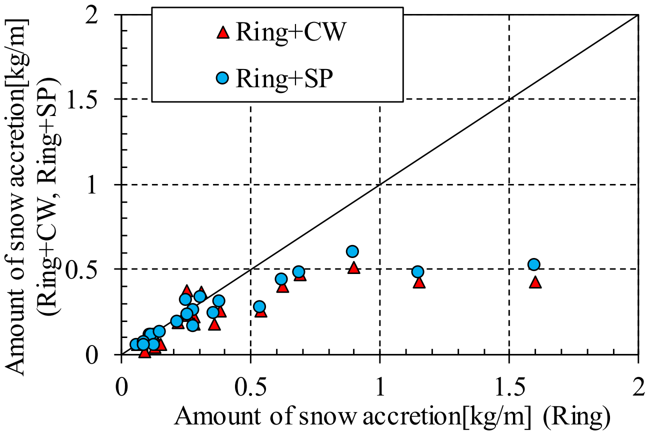


Fig. 9 Comparison of maximum amount of snow accretion in each event

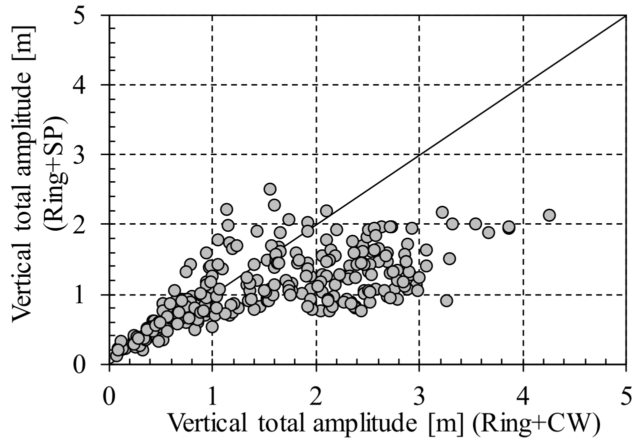


Fig. 10 Comparison of total vertical amplitude for each 10-min statistical value.

VII. Conclusion

Field observations on a single conductor transmission line in eastern Hokkaido in Japan were conducted as part of this study. Twenty-one wet snow accretion events and galloping events associated with snow accretion were observed. These events included snow accretion of amounts up to 1.6 kg/m, galloping with a vertical oscillation amplitude of up to 4.3 m, and sleet jump with heights of up to 3.5 m. The observations indicate that the combination of air temperature and relative humidity during wet snow accretion agrees well with the results predicted by the precipitation type classification method. Furthermore, galloping occurs when wind speed exceeds 7 m/s, and the amplitude of the response increases with wind speed. Galloping with a large amplitude can occur even if the amount of snow accretion is low. The effect of each countermeasure was also investigated. The amount of snow accretion was significantly reduced for the lines with the counterweight and interphase spacer, which suppressed the rotation of the conductor. The amplitude of galloping for the line with the interphase spacer was suppressed by approximately 40% compared with that of the line with the counterweight.

Acknowledgment

The authors would like to thank the members of the Research Committee of Snow Damage of Electric Power Transmission Facilities (chaired by Professor Emeritus Takeshi Ohkuma, Kanagawa University, and organized by CRIEPI) for their direction and advice regarding this study. The observations were conducted with the cooperation of Hokkaido Electric Power Co., Inc. We express our gratitude for their assistance.

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