Numerical Investigation of Sliding Motion and Flow Field Changes in Snow Accretion on Wire Using Particle-Based Method

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Abstract

Snow accretion on electrical wires occurs due to the adhesive force between the snow crystal and the wire surface. Heavy snow accretion can threat electric infrastructure. To understand this phenomena, numerical simulations have been conducted to reproduce snow accretion. Shimura et al. employed a particle-based method to predict snow accretion on electrical wires, achieving good agreement at snow height. However, the previous model did not account for snow body motion, leading to non-physical long-term snow growth. In this study, we modeled the sliding motion of the snow body and conducted a long-term simulation. We also computed the flow field around the electric wire to investigate the impact of the snow body on the flow field. Our results showed that considering the sliding motion model increased the mass of accreted snow. In addition, the force exerted by airflow on the wires differed with and without the sliding motion model.

Keyword: *Computer Fluid Dynamics, Snow Accretion, Particle-Based Method, Sliding Motion*

1. Introduction

Snow accretion is a phenomenon where snow stick to the surface of an object. On electrical wires, snow accretion occurs due to the surface tension of melted snow and the ice bonds between snow crystals and the wire surface. According to experiments by Wakahama et al. [1], under conditions of relatively high temperatures and strong winds, the accreted snow can develop into cylindrical bodies as large as 10 to 20 cm in diameter. This accumulation can lead to wire breakage or transmission tower collapse. Additionally, asymmetrical snow accretion can cause lift imbalance, leading to galloping. Galloping increases the risk of electrical wires contacting each other, potentially resulting in short circuits. As mentioned above, snow accretion on wires is a significant problem that severely impacts social infrastructure. To quantitatively understand these phenomena, numerical simulations have been conducted to reproduce snow accretion. Nakamura et al. [2] developed a physical model for snow accretion and conducted simulations for snow accretion on wire. The results showed good agreement with the observed data in snow mass on the wires due to the parameter study, but they didn't discuss about the shape of the snow body. Shimura et al. [3] employed a particle-based method to predict snow accretion on electrical wires, achieving good agreement between predicted and experimental snow height. However, the previous model did not account for the motion of snow body, leading to non-physical snow growth. Since the shape of snow body is a crucial factor in predicting galloping phenomena, accurate prediction of snow body is essential. In this study, we modeled the sliding motion of the snow body on the wire surface and conducted simulations to assess long-term snow accretion. We also computed the flow field around the electric wire to investigate the impact of the snow body on the flow field.

2. Numerical method

2.1 Simulation of snow accretion

In this study, snow accretion was simulated by describing each snowflake as a single computational particle. Although snow crystals have complex shapes, we simplified the snowflakes as spherical particles and did not consider rotation, merging, or breakup of snow particles during their movement. Snow accretion

was computed when snow particles approached the wire surface. Experiments by Mizuno et al. [4] and Hefny et al. [5] demonstrated that the adhesive force of wet snow is proportional to the contact area, evaluated as force per unit area [N/m^2]. The contact area depends on distance between snow particles; as particles come closer, the contact area increases. Furthermore, Nakamura et al. [2] showed that the adhesive force between snowflakes is larger than that between a snowflake and wire. To reproduce these behaviours, we employed particle number density from particle-based method. In this study, snow particles were considered accreted into snow body particles when the following conditions were met:
(1) The ratio of the computational particle diameter to the distance between the blowing snow particle and the particle constituting the wall or snow body is less than or equal to the threshold parameter r_{th}.
(2) The particle number density computed using snow body particles is greater than or equal to the threshold parameter $n_{th.}$

2.2 Sliding motion model

This study considered the sliding motion of the snow body. Aso et al. [6] clarified the shear adhesive stress of snow. The shear adhesive force F [N] was calculated as follows:

$$F = N_s d S_a \tag{1}$$

where N_s is the number of surface particles of the wire, d is the diameter of a snow particle [m], and S_a is the shear adhesive stress [Pa]. When the torque due to gravity acting on the snow body exceeds the torque due to the shear adhesive force, the snow body begins to rotate. Rotation was computed using the following equation:

$$T = I\alpha \tag{2}$$

where T is the Torque [N·m], I is the moment of inertia [kg·m^2], α is the angular acceleration [rad/s^2]. The shear adhesive stress during rotation was assumed to be 0.8 times that of the stationary state.

2.3 Flow field computation methods

The flow field around the snow-accreted wire was computed using the Eulerian method, assuming a two-dimensional, compressible, and turbulent flow. The governing equations were the Reynolds-averaged continuity equation, the Navier-Stokes equation, and the energy equation. The LU-ADI method [7] was applied for time integration, and the Kato-Launder k-ε model [8] (a high Reynolds number model) was employed for turbulence model.

3. Computational conditions

Based on the observational data by Árni et al. [9], the target for the computation was a 0.5-inch diameter wire. In the numerical domain, particles were arranged in a circle to represent the wire’s cross-sectional shape. To ensure that the blowing snow particles could adhere to the wire surface, dummy particles were placed within the effective radius from the outer edge of the wire. The computational conditions were also based on observational data. To investigate the differences in accreted snow shape and flow field with and without sliding motion model, we conducted two simulation cases: Case 1 included the sliding motion model, and Case 2 did not. The computational conditions are shown in Table 1. The time step Δt was set to Δt = 1.0×10^{-5} s when a snow particle approached within 10 mm of the computational particles of the snow body or wall particles on the wire surface; otherwise, Δt was set to Δt = 1.0×10^{-3} s. Snow particles were injected from random locations 0.2 m ahead of the wire based on the Snow Content (SC) [g/m3], which represents the mass of snow per unit volume, and the velocity of the snow particles. The thresholds r_{th} and n_{th} used for determining accretion were set to r_{th} = 0.90 and n_{th} = 1.10, based on the previous study by Shimura et al.

Table.1 Computational Conditions

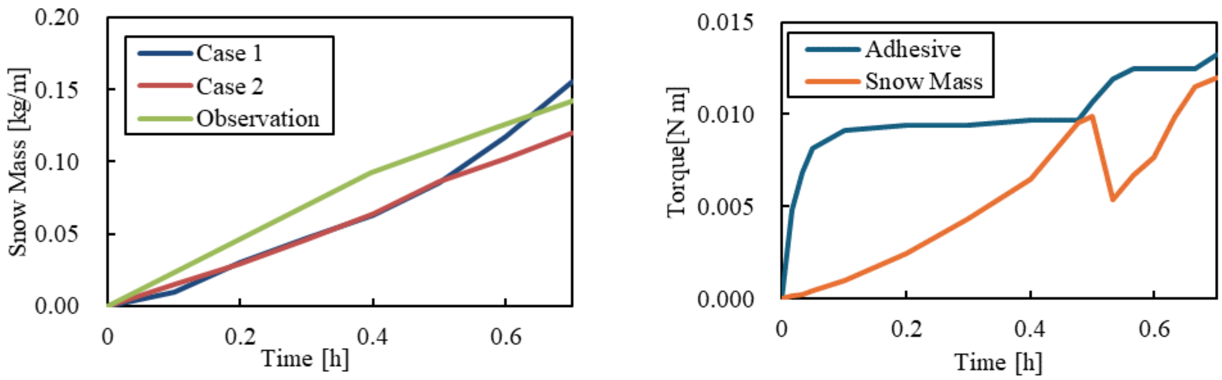
		Case 1	Case 2
Wire Diameter	[mm]	12.7	
Initial Velocity of Snowflake	[m/s]	23.5	
Snow Content (SC)	[g/m^3]	0.40	
Sliding Motion Model		w/	w/o

4. Result and discussion

4.1 Influence of the sliding motion model

Fig. 1(a) shows the time variation of snow mass per unit length. Blue, red, and green solid lines represent the snow mass in Case 1, Case 2, and the observed data, respectively. Fig. 1(b) shows the time variation of the adhesive force and the torque due to gravity acting on the accreted snow mass in Case 1, where the blue and orange lines indicate the torque due to the adhesive force and the torque due to gravity, respectively. In Fig. 1(b), the snow mass begins to slip at t = 0.48 h. Fig. 1(a) shows a significant difference in snow mass between Case 1 and Case 2 after the sliding motion; specifically, the snow mass in Case 1 was 22% larger than in Case 2 at t = 0.7 h. This difference is attributed to the sliding motion increasing the projected area in the upstream direction by 70%, resulting in more snow particles impacting the surface of the snow body. The snow mass in Case 1 approaches the observed results, suggesting that reproducing the sliding motion of the accreted snow body allows for more accurate snow mass prediction.

Fig. 1(b) also shows that the torque due to gravity decreases immediately after sliding occurs but increases again hereafter. This is because the center of gravity of the snow body moves vertically downward as a result of the sliding motion. On the other hand, the torque caused by the adhesion force increases due to the expansion of the contact area on the snow body, caused by the sliding motion. Through this iterative process, the accreted snow body will develop into a cylindrical shape.



(a) Comparison of accreted snow mass (b) Torque of adhesive force and snow mass in Case 1

Fig. 1 Comparison of accreted snow mass and torque over time

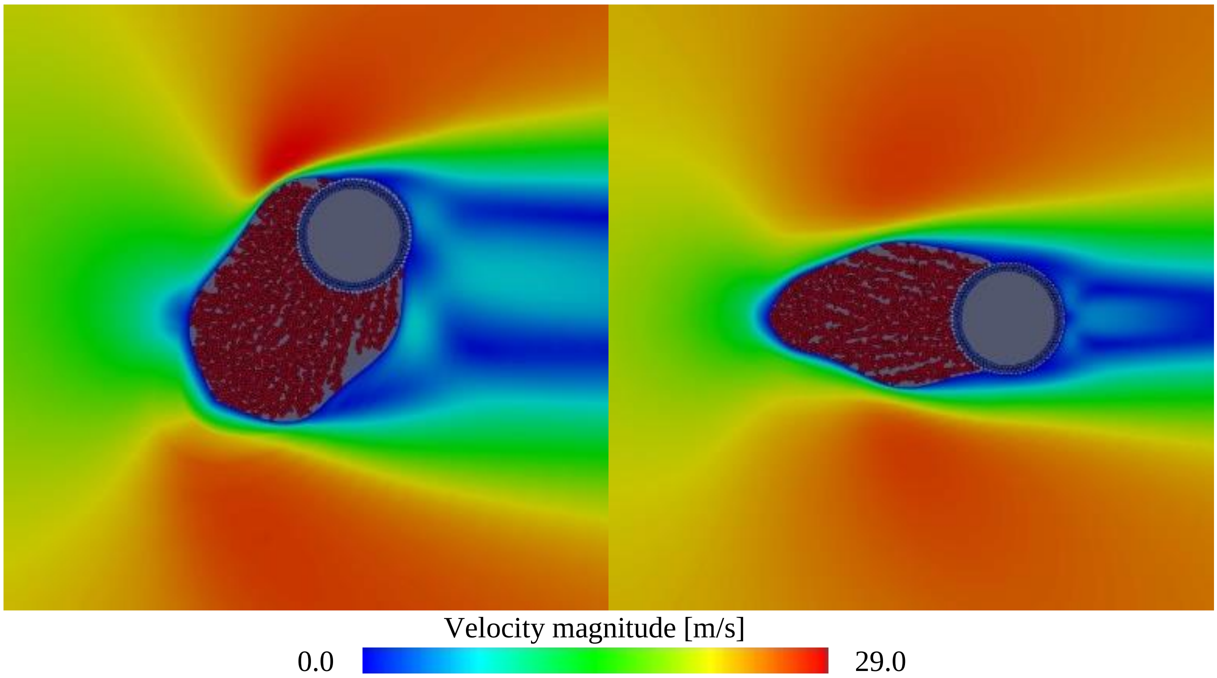
4.2 Change of flow field

Fig. 2 shows the drag (Fig. 2(a)) and lift (Fig. 2(b)) for Case 1 (blue plot) and Case 2 (red plot). After the sliding motion occurs at t = 0.5 h, there are significant changes in both drag and lift, indicating an increase in drag and the onset of downward lift. Fig. 3 shows the shape of the snow body and the surrounding velocity field at t = 0.7 h. Fig. 3(a) and (b) correspond to Case 1 and Case 2, respectively. At t = 0.7 h, the drag in Case 1 is found to be 2.2 times greater than in Case 2. On the other hand, the drag in Case 1 peaks at t = 0.5 h, immediately after the sliding motion, and then decreases gradually. This behavior is due to the snow body initially having a linear shape in the upwind direction when sliding occurs, which gradually transitions to an almost streamlined shape as additional snow accretes, as shown in Fig. 4. At t = 0.7 h, the magnitude of the lift in Case 1 is approximately 4.9 times greater than in Case 2, and the lift direction is downward. Therefore, the change in the shape of the snow body caused by its sliding has a significant effect on the aerodynamic characteristics of the surrounding fluid and the electric wire.

5. Conclusion

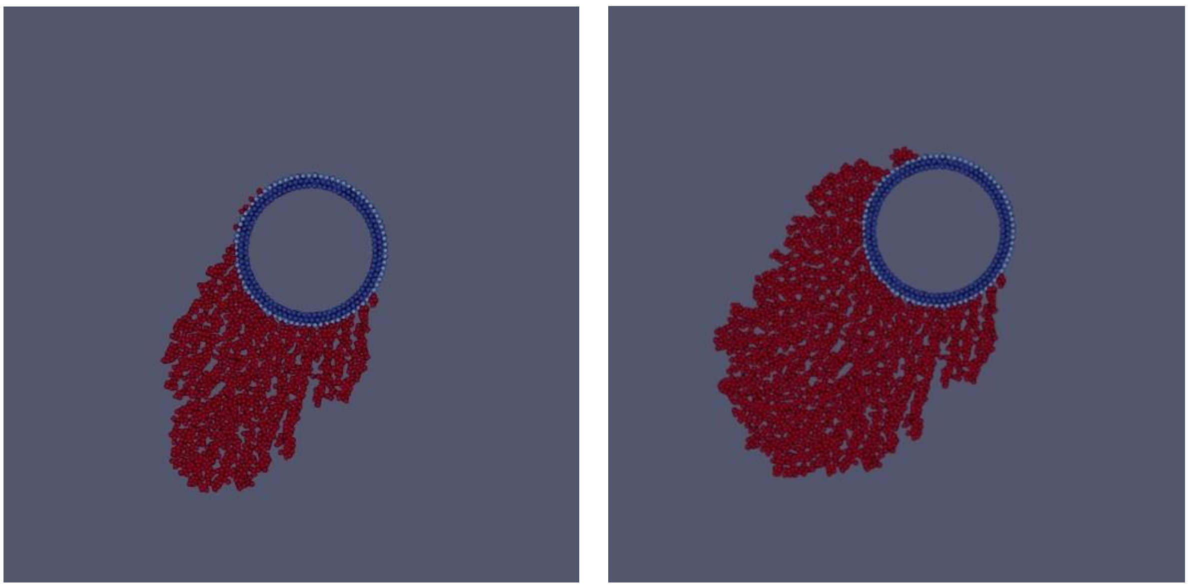
In this study, we proposed a sliding motion model for snow accretion and conducted particle-based simulations of snow accretion on electric wires. We also investigated the changes in the flow field and aerodynamic characteristics of the accreted snow on the wire based on predicted snow body shape.

With the sliding motion model, the increase in the projected area in the upstream direction led to a higher accreted snow mass, showing a trend similar to the observed results. The velocity field around the snow body changed significantly after the snow body slipped, resulting in a significant increase in the drag acting on the wire. Furthermore, the lift force, which is an important factor in prediction the galloping phenomenon, increased in the negative direction. These findings will contribute to more accurate predictions of snow accretion and will be useful for predicting the galloping phenomenon.



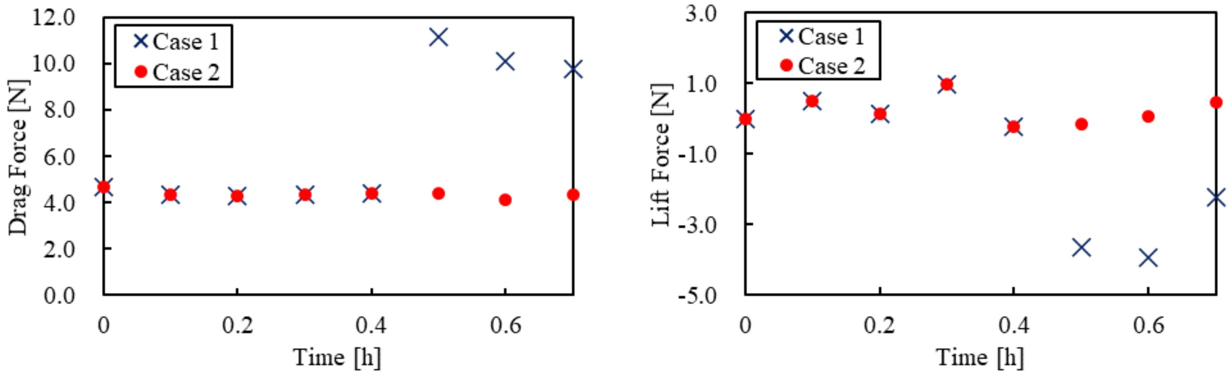
(a) Velocity field for Case 1 (b) Velocity field for Case 2

Fig. 3 Velocity field at t = 0.7 h in present simulation



(a) Snow shape immediately after sliding (b) Snow shape at t = 0.7 h

Fig.4 The comparison of snow shape between before and after sliding



(a) Drag Force (b) Lift Force

Fig.2 Comparison of drag and lift over time in cases with and without sliding motion model

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