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Study of Snowdrift around Buildings of Antarctica using Numerical Analysis

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1. INTRODUCTION

The removal of the snowdrifts resulting from snowstorms is often physically intensive work. Therefore, it is important to consider snowdrift around buildings in construction planning. The snow cover around a cube model resulting from a snowstorm was calculated through numerical analysis. The validity of the numerical analysis was verified by comparison with Oikawa's experimental results[1][2]. Snow coverage around buildings of an Antarctic base due to a snowstorm was then predicted.

2. NUMERICAL ANALYSIS

2.1 Snow coverage around a cube model

Multi-phase flow analysis of air and snow particles was conducted using general-purpose heat fluid analysis software (FLUENT6.3). The depth of snow cover was expressed as a volume fraction; i.e., the volume ratio of snow particles to air. Analysis conditions were the same as Oikawa's field observation conditions[1][2].

2.2 Snow cover around an Antarctic base building

Curved-roof and flat-roof models were taken as analytical models. The analysis method is the same as that for the cube model. Analysis conditions were determined from observational data for Mizuho base.

3. RESULTS AND DISCUSSION

3.1 Snow cover around the cube model

The depth of the snow coverage describes the ratio of the volume fraction of snow particles at the base of a cube model obtained from numerical analysis to the average volume fraction of the snow particles dispersed in air. The depth of the snow coverage increases as the volume fraction of snow particles increases. As shown in Fig.1, the results of numerical analysis and field observation have the same distribution of snow coverage.

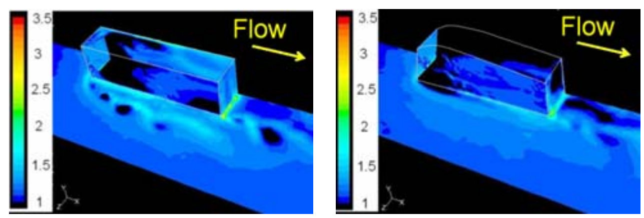
3.2 Snow coverage around an Antarctic base building

The numerical analysis result was able to reproduce the snow coverage of the field observation. Therefore, the snow coverage around the base of an Antarctic base building due to a snowstorm was calculated.

As shown in Fig.2, there is less snow coverage on the roof and leeward side of the curved-roof model compared with the case for the flat-roof model.

(a)Numerical analysis (b) Field observation

Figure 1: Snow coverage distribution around the cube



(a) Flat-roof model (b) Curved roof model

Figure 2: Snow coverage around the Antarctic base building

4. CONCLUSION

Using versatile fluid analysis software, a snowstorm was treated as solid–gas two-phase flow of air and snow particles, and the snow cover around a cube model was calculated by converting the volume fraction into snow depth. Strong wind decreases the depth of snow cover along each side wall and the windward side. The snow cover distributions around a cube model determined in numerical analysis and field observations are almost the same. Furthermore, calculation results show that snow cover around models curved-roof model of an Antarctic base building is much less than that around flat-roof model, and curved-roof model have walls suitable for entrances, such as the entrance for a snow vehicle. The snow depth on the leeward side of model curved-roof model is the smallest among models in numerical analysis. Therefore, reduction of the surrounding snow cover in the case of model curved-roof model will make the job of snow removal much easier.

5. REFERENCES

[1] S.Oiwka, T. Sato, K. Kosugi, "Wind tunnel similarity of snowdrift with artificial snow," 2001 COLD REGION TECHNOLOGY CONFERENCE, pp.129-132, 2002

[2] S. Oikawa, T. Tomabechi, T. Ishihara, "Study of wind tunnel similarity on snowdrift around buildings," J. of Snow Eng. Of Japan, Vol23 No.2, pp.13-32, April 2007.

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***Abstract*—The removal of snowdrifts resulting from snowstorms is often physically intensive work in Antarctica. Therefore, it is important to consider snowdrift around buildings in construction planning. Snowdrift has been visualized in large-scale wind tunnels using walnut powder and activated earth as imitation snow. In this study, however, we predicted snowdrift using a small experimental facility and existing numerical-analysis software that can be easily implemented. First, the snow cover around a cube model resulting from a snowstorm was calculated through numerical analysis. The numerical analysis was verified by comparison with observations. To consider the effect of the form of a proposed Antarctic building on snowdrift, the snowdrift around buildings of an Antarctic base was then predicted by numerical analysis. It is thus expected that work involved in removing snowdrifts can be reduced through the appropriate design of curved-roof buildings employing numerical analysis.**

Keywords-Visualization of snowdrift, Antarctic base, Construction planning, Snow removal, Numerical analysis.

I. INTRODUCTION

The removal of snowdrifts resulting from snowstorms in Antarctica is often physically intensive work. Therefore, it is important to consider snowdrift around buildings in construction planning. Snowdrift has been visualized in large-scale wind tunnel tests that use walnut powder and activated clay as imitation snow, and many research results have been published [1,2,3]. In this work, however, we predict snowdrift using a small experimental facility and existing numerical-analysis software that is easy to implement. First, the snow cover around a cube model resulting from a snowstorm is calculated through numerical analysis. The numerical analysis results are then verified by comparison with observations.

It is planned that the Japanese observation party at the Showa base in Antarctica will construct a compound building that includes control rooms and a large space for the maintenance of snow vehicles and has natural energy systems, such as systems for wind power generation, photovoltaics, and solar thermal conversion. To consider the form of the building and the effect of snowdrift, the snowdrift around buildings of an Antarctic base due to a snowstorm is predicted by numerical analysis. Three types of flat roof and a curved roof are taken as building models. As a result, it is thus expected that the work involved in removing snowdrifts can be reduced by designing appropriately curved roofs employing numerical analysis.

II. NUMERICAL ANALYSIS

A. Analytical Model

Figure 1 shows the cube model used in this study for comparisons with field observations [1,2].; the cube is 1000 mm on each side. Figure 2 shows the Antarctic base building model. Figure 2(a) shows a flat-roof model of a rectangular parallelepiped (Model A). Figure 2(b) shows a flat-roof model (Model B) for which the wall on the windward side is inclined. Figure 2(c) shows a curved-roof model (Model C) for which the wall on the windward side is inclined.

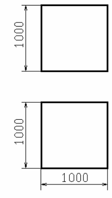
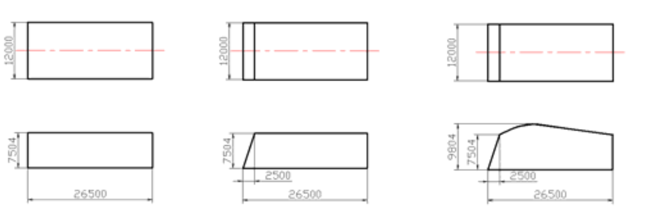


Figure 1. Cube model (Unit:mm)

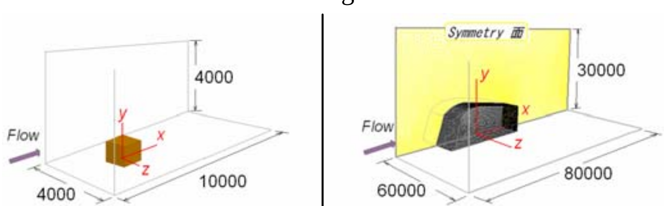


(a) Model A (b) Model B (c) Model C

Figure 2. Antarctic building model (Unit:mm)

B. Amslytical Method

The snowdrift for the cube model and Antarctic base building was analyzed using the versatile fluid analysis software package Fluent 6.3. The method of analysis was the same for the Antarctic base building model and cube model, and analysis was performed for unsteady three-dimensional turbulent flow. The RNG (Re-Normalisation Group method) k–ε model was used for multi-phase flow analysis of air and snow particles. The depth of snow cover was expressed as a volume fraction; i.e., the volume ratio of snow particles to air. Analysis conditions for the cube model were determined from data for the observation site in Hokkaido [1,2]. and those for the Antarctic base building were determined from observational data recorded at the Mizuho base in Antarctica. Since the wind direction of the snowstorm was dominant in one direction, this wind direction was set as the orientation of the X-axis in the numerical analysis. Wind blows against a gabled wall. Figure 3 shows the analysis region and conditions for the cube and Antarctic base building.



Analysis conditions (a)	Analysis conditions (b)
Velocity of wind: 5 m/s	Velocity of wind: 18 m/s
Turbulence intensity: 10%	Turbulence intensity: 10%
Air temperature: –6 degrees C	Air temperature: –10 degrees C
Snow conditions	**Snow conditions**
Real density: 920 kg/m^3	Real density: 900 kg/m^3
Particle diameter: 0.2 mm	Particle diameter: 0.07 mm
Average volume fraction: 3.744×10^{-8}	Average volume fraction: 1.84×10^{-7}

(a)Cube model (b) Antarctic model

Figure 3. Analysis region and conditions (Unit:mm)

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III. Results and Discussion

A. Snow coverage around the cube model

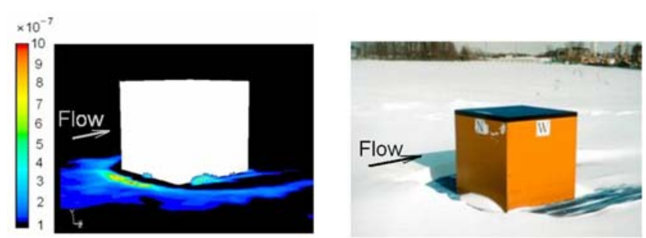
Figure 4 (a) shows the volume fraction V_f of snow particles around the cube model determined by numerical analysis. The wind direction is from left to right. An increase in the volume fraction of snow particles indicates an increase in snow cover. Figure 4(b) is a photograph of snow cover around the cube in the field observation [1,2]. The snow cover was reduced by strong wind at the windward face and the two side faces. The numerical analysis and field observation clearly show the same distribution of snow coverage.

The coordinate origin is taken as the center of the contact area of the cube and a snow surface. The X-axis is parallel to the wind direction, the Y-axis is perpendicular to the snow surface, and the Z-axis is perpendicular to the wind direction. The cube has length H. Figures 5–7 present the ratio of the volume fraction V_f of snow particles around the cube model in numerical analysis to the average volume fraction V_{af} of the snow particles dispersed in air. The ratio of V_{af} to V_a gives the snow depth. The ordinate of the numerical-analysis result is the ratio of V_f to V_{af}, and that of the field observation result is the ratio of snow depth (D) to H. The abscissa is the ratio of the position on the X-axis to H.

Figure5 shows the snow depth on the windward side of the cube. The position $x/H = -0.5$ corresponds to the wall surface on the windward side of the cube. The snow depth is smallest at about $x/H = -0.7$ in both the numerical analysis and field observation, and the tendency of the snow coverage in the numerical analysis agrees with that of the field observation.

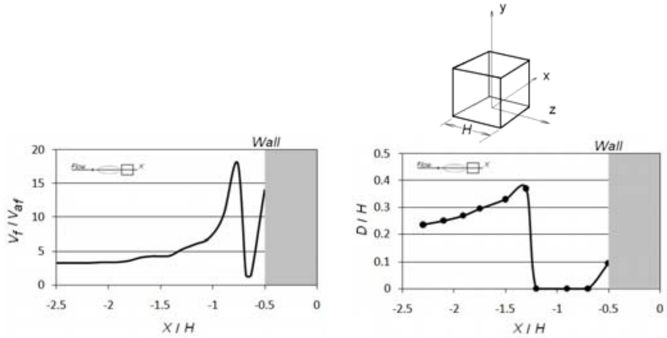
However, numerical analysis shows a small region where snow is removed by wind in contrast to a larger region in the field observation.

Figure 6 shows the snow depth distribution on the leeward side of the cube. The position $x/H = 0.5$ corresponds to the wall surface on the leeward side. In numerical analysis and field observations, there is snow drift up against the leeward wall. The snow depth distribution in the numerical analysis agrees well with that in the field observation.



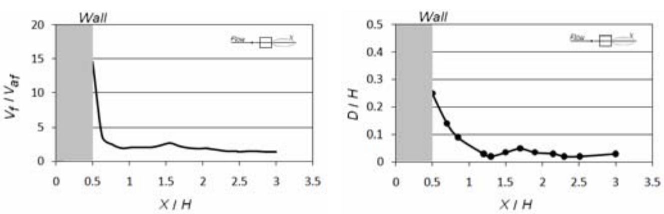
(a) Numerical analysis (b) Field observation

Figure 4. Snow coverage distribution around the cube



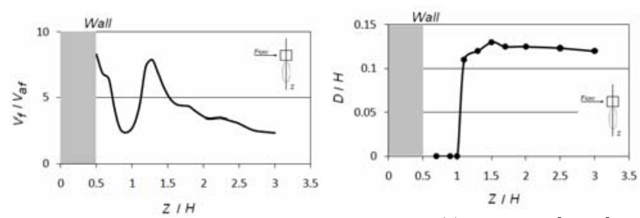
(a)Numerical analysis (b)Field observation

Figure 5. Windward snow depth



(a) Numerical analysis (b) Field observation

Figure 6. Leeward snow depth

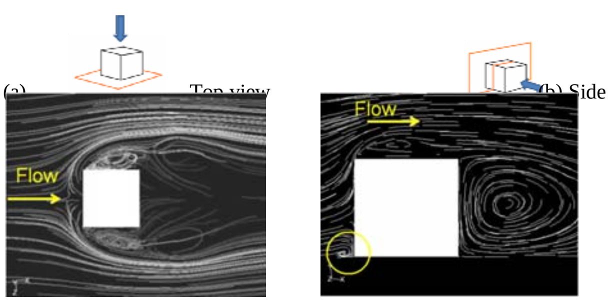


(a) Numerical analysis

(b) Field observation

Figure 7. Side snow depth

(a) Top view (b) Side



view

Figure 8. Trajectories of snow partiSide snow depth

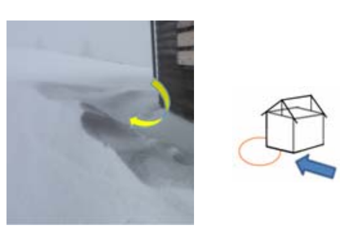


Figure 9. Photograph of actual snow cover near the winward gabled wall

Figure 7 shows the snow depth distribution along the *Z*-axis of the cube. The position z/H = 0.5 corresponds to the side-wall surface. The snow depth is smallest at about z/H = 1 in the numerical analysis and field observations, and the tendency of the snow coverage in numerical analysis agrees with that in the field observation.

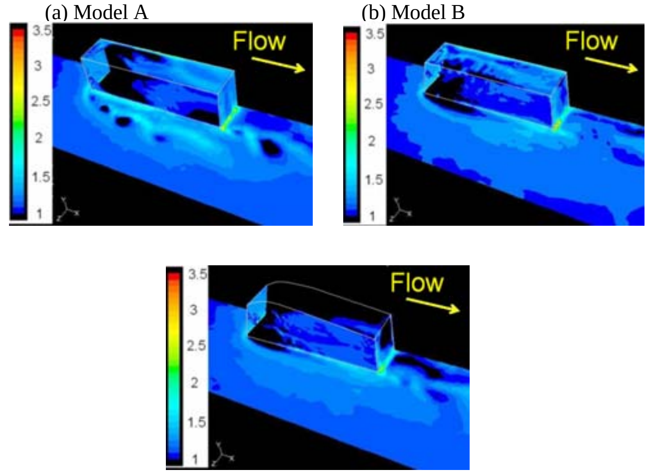
Figure 8 shows the trajectories of snow particles in the numerical analysis with the cube model viewed from the top and side. The direction of flow is from left to right. The wind produces horseshoe-shaped vortices along the two side walls and the windward face, and there is inflow of snow particles on the leeward side. Figure 9 is a photograph of the actual snow cover near the gabled windward wall. The reduction of snow cover by wind near the gabled wall is the same as that in the region marked by the circle in Fig. 8(b).

B. Snow cover around the Antarctic base building

Figure 10 presents the volume fraction distribution of snow particles around the Antarctic base building determined in numerical analysis. The ratio of V_{af} to V_a gives the snow depth. The figure shows the building model from the leeward side. The flow direction is from upper left to lower right. There is snow coverage near the side wall for model A. But, there is less snow coverage (black color space) near the side wall for model B and C.

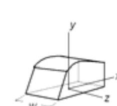
Figure 11 (a) shows the snow depth against the side wall, near the windward wall, parallel to the *Z*-axis. The depth of building has length *w*. The position z/w = 0.5 corresponds to the surface of the side wall. There is little snow coverage against the side wall for models B and C compared with model A, and thus, this position would be suitable for entrances of models B and C, such as an entrance for a snow vehicle. Figure 11(b) shows the leeward snow depth parallel to the *X*-axis. There is snow drift against the leeward wall, which is least for model C.

(a) Model A (b) Model B



(c) Model C

Figure 10. Snow coverage around the Antarctic base building



(a) Side wall (b)Leeward wall

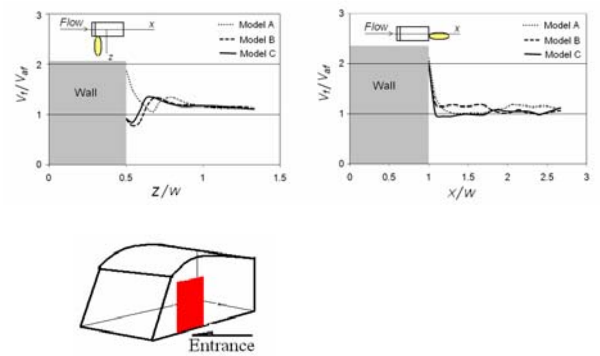


Figure 11. Snow depth around the Antarctic base building

Figure 12 shows the trajectories of snow particles in numerical analysis viewing the Antarctic base building model from above. The flow direction is from left to right. A vortex forms along the side wall; the vortex of model A is larger than that of models B and C.

Figure 13 shows the trajectories of snow particles in numerical analysis viewing the Antarctic base building model from the side. The direction of flow is from left to right. There are many intricate vortices above the roofs of models A and B and a large vortex on the leeward side. The snow particles for model C flow along the roof and form a vortex on the leeward side.

(a) Model A (b) Model B (c) Model C

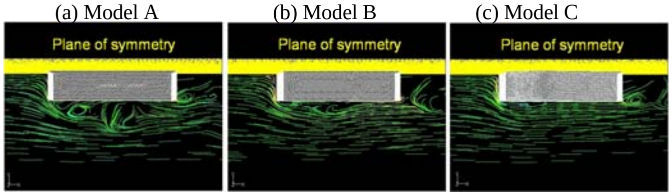


Figure 12. Trajectories of snow particles in numerical analysis viewing the Antarctic base building model from above

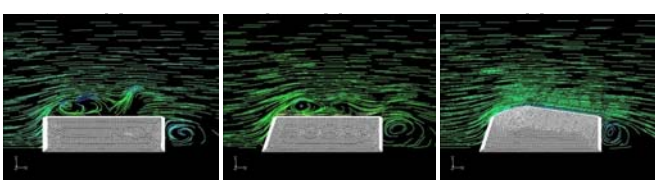
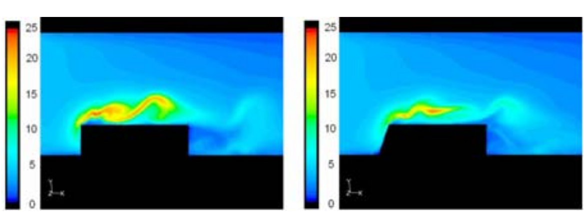
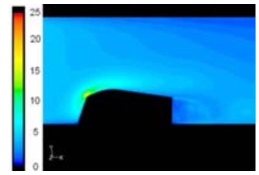


Figure 13. Trajectories of snow particles in numerical analysis viewing the Antarctic base building model from the side



(a) Model A (b) Model B



(c) Model C

Figure 14. Turbulent kinetic energy distributions around the Antarctic base building model

The computational results of the turbulent kinetic energy distributions around the Antarctic base building model are shown in Fig. 14. The turbulent energy above the roof of model A is more complicated than for models B and C.

IV. Conclusions

Using versatile fluid analysis software, a snowstorm was treated as solid–gas two-phase flow of air and snow particles, and the snow cover around a cube model was calculated by converting the volume fraction into snow depth.

Strong wind decreases the depth of snow cover along each side wall and the windward side. The snow cover distributions around a cube model determined in numerical analysis and field observations are almost the same.

Furthermore, calculation results show that snow cover around models B and C of an Antarctic base building is much less than that around model A, and models B and C have walls suitable for entrances, such as the entrance for a snow vehicle. The snow depth on the leeward side of model C is the smallest among models in numerical analysis. Therefore, reduction of the surrounding snow cover in the case of model C will make the job of snow removal much easier.

- References

[1] S.Oiwka, T. Sato, K. Kosugi, "Wind tunnel similarity of snowdrift with artificial snow," 2001 COLD REGION TECHNOLOGY CONFERENCE, pp.129-132, 2002

[2] S. Oikawa, T. Tomabechi, T. Ishihara, "Study of wind tunnel similarity on snowdrift around buildings," J. of Snow Eng. Of Japan, Vol23 No.2, pp.13-32, April 2007.

[3] Y. Sato, T. Hannuki, O. Abe, "Fundamental study on snowdrift control by design of building shape," 2009 COLD REGION TECHNOLOGY CONFERENCE, pp.52-56, 2009