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Modified FAE method based on CFD simulation for predicting snowdrift on gable roofs

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SUMMARY:
This study modifies the finite area element (FAE) method by considering the influence of transport distance on snow transport rate. And the accuracy of the modified FAE method is verified through the wind tunnel test. Then, the influence of slope on the snow load of gable roofs is studied by the modified FAE method. Comparing the results of the wind tunnel test and the modified FAE method, it is found that the two results are consistent. The simulation results of the modified FAE method show that both the erosion on the windward roof and the deposition on the leeward roof increase with the roof slope. Moreover, with the increase of roof slope, the friction velocity difference between the windward and leeward roof will increase, resulting in the drift coefficient increasing with the roof slope.

Keywords: FAE method, CFD simulation, roof snow load

1. INTRODUCTION

At present, the research methods of snow load on gable roofs mainly include field measurement, wind tunnel or water flume test, and numerical simulation. Combined with the wind tunnel test and simulation, Irwin and Gamble (1989) created the FAE method and used it to simulate the wind and snow flow around complex building structures to evaluate the snow load. However, the original FAE method used the saturated snow transport rate formula to calculate snow erosion and deposition, ignoring the impact of transport distance on snow transport development. In this paper, the FAE method is modified for use on small-span roofs by considering the effect of transport distance on snow transport development. And the modified FAE method is compared and verified by wind tunnel test. Finally, the modified FAE method is used to study the influence of slope on gable roofs' snow distribution.

2. MODIFIED FAE METHOD BASED ON CFD SIMULATION

2.1. Research object

The research object is a gable roof with a span L of 20 m, a width B of 15 m, and a height H of 10 m. The initial snow depth S_0 is 0.5m, and the snow repose angle β 50 °, roof slope α =10 °, 20 °, 30 °, and 40 °, as shown in Fig. 1.

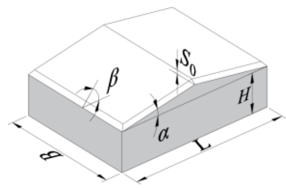

Figure 1. Research object.

2.2. Calculation principle

The FAE method divides the roof snow into a large number of "finite area elements", as shown in Fig. 2(a). By calculating the mass transport rate of each element, the snow mass change of the element in a given time interval can be calculated. Take a finite area element (*i*, *j*) as an example shown in Fig. 2(b). If the snow can drift and there are enough snow sources in the windward element, the inflow mass transport rate of the element (*i*, *j*) in the *x* direction and *y* direction are Q_{x-in} and Q_{y-in}, the outflow mass transport rate are Q_{x-out} and Q_{y-out}. According to the principle of mass balance, the mass change of snow dm in element (*i*, *j*) during the *T* period is:

$$\mathrm{d}m = (Q_{x-in} - Q_{x-out} + Q_{y-in} - Q_{y-out})lT \quad (1)$$

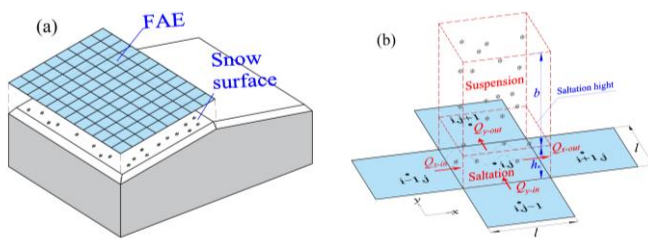

Figure 2. FAE method calculation principle.

2.3. Friction velocity calculation of FAE

This paper uses CFD to calculate the flow field around the research object. The boundary conditions and grid division scheme of the computational domain are shown in Fig. 3(a) and (b). The friction velocity U_* on the snow surface can be calculated by surface shear stress τ_w of CFD numerical simulation.

$$U_* = \sqrt{\tau_w / \rho_a} \quad (2)$$

The friction velocity u_* of each element in the FAE method is the mean value of the friction velocity U_* of the CFD grid contained in the FAE method element, as shown in Fig. 3(c).

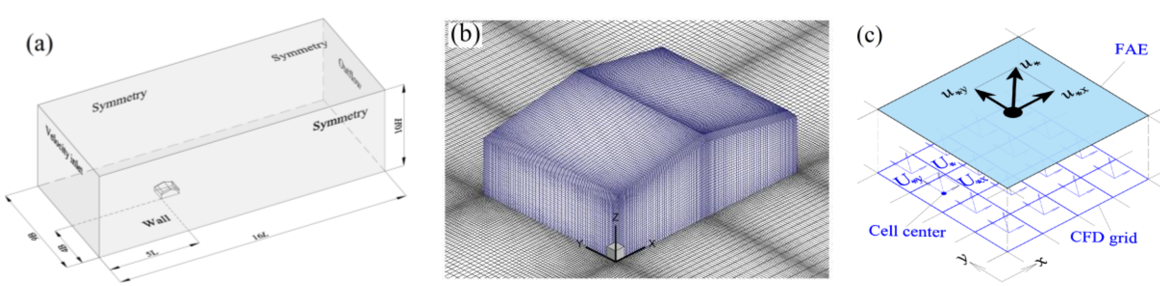

Figure 3. Friction velocity of FAE method.

2.4 Snow transport rate

Owen (1964) assumed the self-equilibrium mechanism of particle saltation, and the atmosphere imposed a constant shear stress on the particle surface to maintain the particle saltation. The saturated saltation transport rate $Q_{sat\text{-}salt}$ is defined as Eq. (3). The suspension transport rate of snow particles can be determined by integrating the mass flux of suspended snow particles. The mass flux is the product of the mass concentration and the velocity of particles moving along the wind. Pomeroy and Male (1992) believed that the velocity of particles moving along the wind is equal to the wind speed, so the suspension transport rate of snow particles is represented as Eq. (4). For unsaturated snow transport development conditions, O'Rourke et al. (2005) proposed development rule to describe the relationship between transport distance and saturated transport rate. The Unsaturated snow transport rate at X position can be expressed as Eq. (6), L_{sat} is the saturated transport distance. Table 1 summarizes the snow transport formulas used in the modified FAE method.

Table 1. Summary of modified FAE method formula.

Parameter name	Describe	Equation number	Reference
Saturated saltation transport rate $Q_{sat\text{-}salt}$	$Q_{sat\text{-}salt} = \alpha \frac{\rho_a}{g} u_*^3 \left(1 - \frac{u_{*t}^2}{u_*^2}\right)$	(3)	Owen (1964)
Saturated suspension transport rate $Q_{sat\text{-}susp}$	$Q_{sat\text{-}susp} = \int_{h*}^{h*+b} U(z)\phi(z)\,\mathrm{d}z$	(4)	Schmidt (1982)
Saturated total transport rate Q_{sat}	$Q_{sat} = Q_{sat\text{-}salt} + Q_{sat\text{-}susp}$	(5)	-
Unsaturated snow transport rate $Q(X)$	$Q(X) = Q_{sat}\sqrt{X/L_{sat}}$	(6)	O'Rourke et al. (2005)

3. VERIFICATION OF MODIFIED FAE METHOD

To test the prediction results of the modified FAE method, the snow re-distribution test of 10 ° gable roof is conducted in the wind tunnel. The geometric scale ratio of the wind tunnel model is 1:50. In the wind tunnel test, high-density silica sand is selected as the substitute particle. The initial depth S_0 of silica sand on the roof is 20mm. The silicon sand re-distribution on the roof centreline is measured with a laser displacement meter. The eave height H is defined as the reference height, and the reference wind speed $U(H)$ is 5.0m/s. The test time is 4 minutes, 6 minutes and 8 minutes respectively. The wind tunnel test results and the simulation results of the modified FAE method at different test times are shown in Fig. 4. It can be seen from Fig. 4 that the modified FAE method is consistent with the results obtained from wind tunnel tests. Snow erosion occurs on the windward roof and deposition occurs on the leeward roof.

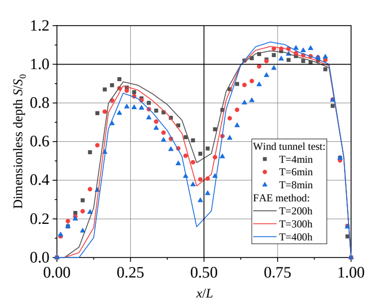

Figure 4. Comparison between wind tunnel test and modified FAE method

4. RESULTS AND ANALYSIS

When $U(H)$=5.0m/s, the distribution of friction velocity of roofs with different slopes is shown in Fig. 5(a). The streamline distribution in Fig. 5(a) shows that the airflow produces obvious separation at the ridge and forms a recirculation region behind the building. With the increase of the roof slope, the recirculation region behind the building is increasing. Affected by the wind speed on the snow surface, the friction velocity is greater than the threshold value (u_{*t}=0.15m/s) on the windward side and less than the threshold value on the leeward side. This phenomenon will lead to snow erosion on the windward roof and deposition on the leeward roof, as shown in Fig. 5(b). And Fig. 5(b) shows that the erosion on the windward and the deposition on the leeward are both increasing with the roof slope. Fig. 5(c) shows that as the roof slope increases, the difference between the friction velocity on the windward and the leeward also increases, resulting in the drift coefficient (C_d) increasing along with the roof slope.

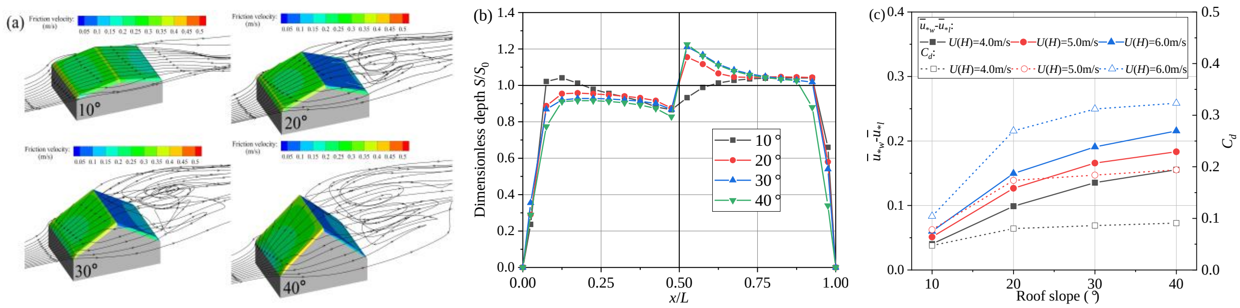

Figure 5. Simulation results by FAE method with different slopes.

5. CONCLUSIONS

In this paper, the FAE method is modified by considering the influence of transport distance on snow transport rate. Then, the influence of slope on the snow load of the gable roof is studied by using the modified FAE method. The wind tunnel test results show that the modified FAE method is consistent with the wind tunnel test results. The simulation results of the FAE method show that both the erosion on the windward face and the deposition on the leeward face increase with the increase of the slope of the roof. Moreover, with the increase of roof slope, the friction velocity difference between the windward and leeward roof will also increase, resulting in the drift coefficient increasing with the roof slope.

ACKNOWLEDGEMENTS

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