A new snow removal device and determination of for membrane structures

B S Wang, Y K Zhang, L Meng, S Li, H Zhang, Q H Song
School of Civil Engineering, Ludong University, 186 Hongqi Middle Road, Yantai 264025, China
2947@ldu.edu.cn

Abstract: In order to avoid the damage of membrane structure caused by snow load, a new type of intelligent snow removal device is proposed based on the principle of micro-spray irrigation and the dual control of pressure and temperature. The determination method of construction parameters such as pressure critical value, snow area, sprinkler size and number of the device is expounded. Finally, taking a Shanghai membrane structure project as an example, the snow area of the project was determined. Considering the size of snow area and the sprinkler spraying area, the number and construction location of the sprinklers on the membrane surface were finally determined.

1. Introduction
Since the 1970s, membrane structure, as a new type of spatial structure system, has been gradually developed. It has been widely used in canopy, sports venues, railway stations and airports, and is a common spatial structure form to bear external load[1-2].

Snow load is a common form of load. Long-span spatial structure is very sensitive to snow load and often leads to bag effect. It can be seen that the membrane area snow plays an important role in the safety of the structure, snow-removing device is extra important to consider the snow removal device to reduce the engineering accidents caused by snow load[3-5].

Traditional snow removal methods mainly include snow melting line, hot air circulation, optimizing structure and shape, but the shortcomings are significant. For example, the optimized structure shape of snow slide safety is low; Manual removal is both laborious and costly, and has great limitations. It takes a lot of time and energy to adopt heat treatment method and snow melting method of electric heaters used in Japan[6-8].

In this paper, a new type of snow removal device for membrane structure is proposed and the key construction parameters of the device are determined. Through an engineering case analysis, the number and location of the snow area and the sprinkler needed for snow removal are determined.

2. Working principle of new snow removal devices
The upper structure of the new snow removal device is composed of sprinkler, water pipe and pressure detection device. The lower structure is composed of snow melting agent storage box, control valve, self-priming booster pump and temperature detection device. Figure 1 shows below.
Figure 1 Composition of snow removal device

It adopts snow-melting agent, uses temperature identification technology and pressure detection technology to realize intelligent control, and achieves the goal of rapid snow-melting on film surface. When the two conditions of temperature and pressure are met at the same time, the snow removal device starts to work. The snow-melting agent is sucked out and mixed with tap water in a certain proportion to form a snow-melting liquid, which is pumped to the sprinkler for spraying. The snow removing device includes two modes: snow removal mode and cleaning mode. After the snow removal mode was completed, the film snow removal device automatically entered the cleaning mode. The working principle of snow removal device is shown in Figure 2.

Figure 2 Working Principle of Snow Removal Device

In addition, the snow removal device needs to determine the critical pressure value $P$ and structural snow area and other key parameters in the construction operation. Comprehensive pressure critical value and snow area location and size to determine the sprinkler layout and specifications.

3. Determine construction parameters

3.1. Pressure threshold $P$
For the snow removal device, the critical pressure required for the start-up of the snow removal device should be reasonable. Too high may lead to delayed snow removal, which may lead to a series of engineering accidents. Too low cause waste of resources and increase costs. According to China “Load
code for design of building structures” (GB 50009 - 2012), the basic formula of standard value of membrane snow load is:

\[ S_k = \mu S_0 \left[ \text{kN/m}^2 \right] \]  

(1)

In the formula: \( S_0 \) is Basic snow pressure(\text{kN/m}^2), \( \mu \) is distribution coefficient of snow load.

The snow distribution coefficient \( \mu \) can be calculated according to the specification. Different from other roof different from other roof materials. Japanese scholars Hidenaru Yamaguchi and Tsukasu Tomabechi [9] found that in general dry areas, the critical angle of skiing can be 21.8° with low humidity and high wind speed, while in areas with high humidity and low wind speed, the critical angle of skiing can be 28°. When the film slope is greater than the critical skiing slope, the film is difficult to snow, but also considering a certain snow load, snow distribution coefficient \( \mu \) can be 0.25-0.5.

In this paper, the bag effect of snow load and the process snow removal effect are considered, and 0.8 times of the safety factor is given. At the same time, 0.4 times of the standard value of snow load is used as the critical value \( P_1 \) of the initial operation of the snow removal device.

\[ P_1 = 0.8 \times 0.4 \mu S_k \]  

(2)

The snow load standard value of 0.2 times is used as the critical value of the end operation of the snow removal device \( P_2 \)

\[ P_2 = 0.8 \times 0.2 \mu S_k \]  

(3)

3.2. Determination of snow area

In this paper, according to the slope of each point on the membrane structure surface, the cloud image of the membrane surface slope is plotted to determine the snow area. The calculation formula of film slope is as follows:

\[ r = |Z_i - Z_j| \left\{ \left[ \left( X_i - X_j \right)^2 + \left( Y_i - Y_j \right)^2 \right]^{1/2} \right\} \]  

(4)

In the formula: \( X_i \) and \( Y_i \) and \( Z_i \) are coordinate values of membrane structure in space coordinate system. Combined with the critical angle of skiing proposed in the literature, the critical slope value of the snow area is determined. According to wind speed and direction, the critical slope of snow area is determined as follows:

\[
\begin{align*}
0 \leq \gamma \leq \tan 30^\circ (0.577) & \quad \text{Low wind speed areas} \\
0 \leq \gamma \leq \tan 15^\circ (0.268) & \quad \text{Windward side in high wind speed areas} \\
0 \leq \gamma \leq \tan 45^\circ (0.707) & \quad \text{Leeward side in high wind speed areas}
\end{align*}
\]  

(5)

3.3. Specification and layout of sprinkler

The determination of the number of sprayer mainly considers the snow area, sprinkler specifications and spraying area. Number of sprayer \( n \) estimated by formula (6):

\[ n = \frac{A}{A_0} \]  

(6)

In the formula: \( A \) - Snow area  
\( A_0 \) - Effective spray area of sprinkler

In order to determine the effective spray area of sprayer, several common sprayer in the market are used in this paper, as shown in Figure 3. The working parameters are shown in Table 1.
4. Engineering case analysis

Taking a Shanghai membrane structure project as an example (Figure 3), the determination process of construction parameters of snow removal device is described. The project is a skeleton membrane structure, steel structure as a rigid boundary, can be installed on the sprinkler.

Shanghai is a region with high humidity and low wind. The critical angle of skiing is 30°. The basic snow pressure of 50-year return period in Shanghai is selected as 0.2 according to the specification. The snow distribution coefficient is 0.85 according to the critical angle of skiing. The critical pressure $P_1$ is 0.0544 and $P_2$ is 0.0272 according to the formula (3) and (4).

| Sprayer Type              | Working Pressure (kg/cm²) | Water Injection Volume (m³/h) | Spray Diameter (m) | $S_0$ (m²) |
|---------------------------|---------------------------|-------------------------------|--------------------|------------|
| Adjustable bullet         | 2-4                       | 0.82                          | 2-5                | 1-8        |
| 360 degree rotary         | 2-4                       | 0.86                          | 8-10               | 16-25      |
| Single direction          | 2-3                       | 0.14                          | 1.5                | 1-4        |
Figure 5. Taking a structural unit, in order to truly reflect the snow area, this paper takes the formed surface after splicing and stretching of the cutting piece as the construction surface, the layout of the cutting line and the shape of the formed surface.

Figure 6. The slope of each point on the surface is determined by forming the node coordinates of the surface. The blue area below the slope critical value accounts for 3/4 of the structural unit, belonging to the snow area, indicating that the structure is easy to snow.

For the sprinkler arrangement of the membrane structure with regular shape, it is arranged in the rigid or flexible boundary of the membrane structure according to the spray radius of the sprinkler. Considering that the longitudinal film boundary spacing is short, the sprinkler can only be arranged on the longitudinal film boundary. Because the change of the longitudinal boundary $x$ is negligible relative to the change of $y$, the sprinkler number can be calculated according to the following formula:

$$L = \left( \frac{cH}{n} \right)^2 + \left( \frac{cH}{n} \right)^{3/2}$$  \hspace{1cm} (7)

In the formula; $H$ is the total number of longitudinal fixed boundaries; $n/H$ is the number of columns to be arranged; $c$ is the projection distance of the longitudinal membrane boundary in the snow area on the horizontal plane; $cH/n$ is the spacing of the longitudinal sprayer on the plane; $r$ is the average slope of the two adjacent sprayer can be obtained by the membrane node coordinate $m_2$; $A_0 = 16–25$ m$^2$ can be obtained by selecting 360-degree rotary sprayer; $n = 4$ can be obtained by Formula (6); $c$ can be obtained by the node coordinate; $r$ and $L$ can be obtained by Formula (4) and (7)

$$c = \sqrt{9000^2 + 2400^2} = 9314\text{mm}$$

$$r = |Z_1 - Z_2| \left[ \left( (X_1 - X_3)^2 + (Y_1 - Y_2)^2 \right)^{1/2} \right]^{1/2} = \frac{1}{2} \times \frac{1200}{4500} = 0.135$$

$$L = \left( \frac{cH}{n} \right)^2 + \left( \frac{cH}{n} \right)^{3/2} = \sqrt{0.5^2 r^2 + 0.5^2} = 4685\text{mm}$$

5. conclusion

In order to avoid the engineering accidents of membrane structure caused by snow load, a new intelligent snow removal device is proposed in this paper. Based on the critical angle of skiing and film slope, the key construction parameters of the device are determined, and the method is simple. Taking a membrane structure project in Shanghai as an example, this paper expounds the specific determination process of the construction parameters of the device, and finally finds that only a small number of sprayer can be arranged to achieve the purpose of snow removal. The following work will carry out the snow removal device test to further verify its feasibility.
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