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Factors Influencing the Performance of Porous Wind Shields

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Abstract. Porosity, porosity distribution, porous shape, porous size, thickness of shield, shield height &width, and shield orientation are the factors that influence the performance of porous wind shields. Among them, porosity is the most important factor in determining the performance of porous shields. However shield height & width have major impacts on the performance of shields. The remaining factors play less significant influences on the performance of the shield, but they remain researching interests to be further studied.

1 Introductions

Porous wind shield (or commonly known as porous wind fence) is one of the artificial devices used to improve windy and snowy climatic conditions to serve human needs. It has been widely applied in costal, arid, and cold areas to fend wind and to check blown particles. In cold regions, porous wind shielding systems are used to effectively reduce the damages caused by wind and transported sediments (i.e. windblown snow).

Although considerable researches have been studied on how to evaluate the performance of porous wind shields since the 1970's,a comprehensive understanding of the factors that influence the relationship between shelter efficiency and the flow regime characteristics behind porous wind shields is yet satisfied.

In the paper, the factors affecting the performance of porous shields are discussed in details. The most influential factors in determining the performance of porous shields are highlighted. Factors affecting operational issues such as visibility, ventilation, sound-proof and fire resistance have been pointed out but have not fully covered in the study.

2 Structure of porous shield

Porous wind shields as artificial shields are always constructed to have optical porosities greater than zero, so that they produce artificial windbreaks and block particles intrusions. Porous wind shields can be classified as upright, horizontal, gridded, holed-plank and wind screen, etc. Materials can be metal, plastics, or wood, etc. Fig. 1 shows the porous wind shield produced by IKM DSC AS in Norway.

A wind shielding system serves as windbreaks to effectively reduce the damages caused by wind and sediments transported over a greatest shelter distance. Standard Norway is one of the organizations who have set up the standard requirements to wind shield system[1].

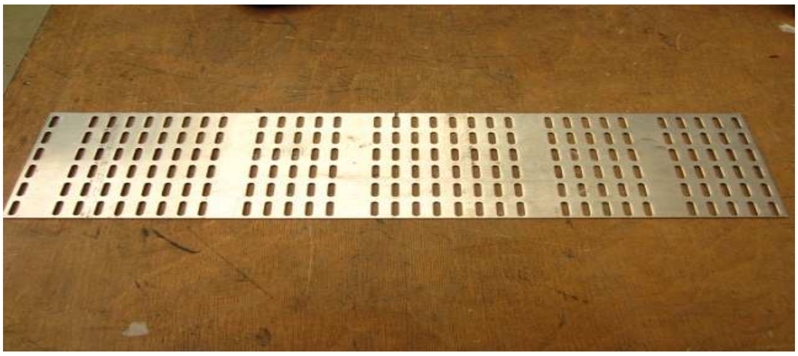

Fig.1: A flat porous wind shield

3 Factors influenced on the performance of a porous shield

Shield porosity, porosity distribution, porous shape, shield height, shield width, spacing, free wind-velocity and the surface roughness of the surrounding area all influence the performance of a porous shield. Among them, the main factors influenced on the performance of a porous shield are: shield height and width, overall porosity, porosity distribution and orientation[2].

3.1 Porosity

Porosity can be defined as the ratio between the open area of the barrier and its total area[3]. Considerable researchers concluded that porosity is the most important structural feature in designing a porous shield[2][3][4][5][6].

Porosity is generally considered to have the highest influence on the distribution of wind velocity and turbulence intensity. An ideal wind shield is required to create the greatest wind reduction over the longest shelter distance[7]. Both wind reduction and effective shelter distance are related to porosity. A low porosity shield tends to create high turbulence downwind, which may have a good wind reduction but a poor effective shelter distance, as the recovery of mean horizontal wind velocities occurs at a distance closer to the shield. Hence there should be a shield porosity that provides the optimal shelter effect by balancing the reduction in wind speed (pressure) with the effects on the shelter distance caused by the changes in turbulence and other factors.

In general, shield porosity between 0.20-0.50 is considered to give noticeable changes in the flow characteristics[3][8][9][10][11]. The optimal porosity for a porous shield ranges between 0.3-0.4 by the majority of published results[6][11][12].

It is worth noting the concept of the critical porosity which is defined as the maximum fence porosity below which flow separation and reversal occurs[13]. It can be concluded that the optimal shield porosity should correspond to the critical porosity above which bleeding flow is dominant.

The threshold velocity is the minimum wind velocity required to initiate wind erosion. Some researchers[6][14][15]proposed it as a key variable in wind erosion studies. The magnitude of the shelter effect provided by porous wind shields in terms of reducing wind erosion can be directly defined by measuring the effects of the shields on the threshold velocity. For this purpose, wind shields with different porosities are simulated in wind tunnels. The measured threshold velocity is usually normalized to the dimensionless relative threshold as simplification.

3.2 Porosity distribution

The issue of optimum porosity distribution remains debatable among researchers. Rosenberg[16] suggests that the porosity should decrease with height in proportion to the logarithmic nature of the wind-velocity profile. Hagen et al.[12]report that a porosity less than 0.4 near the fence top causes excess shear and turbulence, while low porosity near the bottom creates low pressure which induces a recirculation zone in the leeward area. Raine et al.[9]recommendthat the porosity of a shield should be increased from 0.0 at the base to 1.0 at the top, with an overall porosity of 0.2-0.3.However it is questionable that either the top or the bottom of an optimum wind shield should be of very low porosity.

3.3 Pore size, shape design and thickness of the shield

There are relatively few experimental results about detailed investigations of the above factors influencingthe effectiveness of porous shields, although most researchers have mentioned that they will affect the performance of the shield[2][9][12][13].

Davide et al.[17]experimented round holed and square holed fences respectively. The testing results revealed that the effects of the porous shape are negligible, because the discrepancies between the data for round and square shapes are irrelevant. It seems possible choose arbitrarily porous shapes.

Davide et al. alsostudied the role played by the thickness of the shield. They investigated 11 different typologies of screens, with different thicknesses (1-6mm) and diameters of holes (2-10mm) but at the same level of porosity (0.4) and the shape of holes (round). The results revealed that the loss coefficient is higher for the grid samples with smaller values of thickness and larger diameters of holes.

Davide et al.'s testing results reveal that the factors might have insignificant impacts on the performance of porous shield. However, the experiments have been conducted at the porosity of 0.4, which lies at the higher edge of the reported most effective porosity range (0.3-0.4). Therefore, further investigations regarding these issues need to be undertaken.

3.4 Shield height and width

Reynolds number based on step height:

$$R_{eh} = U_{\infty}\, h/v \tag{1}$$

Reynolds number based on body width:

$$R_{ed} = U_{\infty}\, D/v \tag{2}$$

where$U_{\infty}$is the free-stream velocity,$h$is step height,$D$is width of the body, and$v$is the kinematic viscosity of the wind flow.

Based on the above equations, it is evidently that the height and width of a shield are crucial in determining the value of Reynolds numbers. It is widely acknowledged that the Reynolds number affects the characteristics of wind flow, including velocity profile, flow region, turbulence intensity, Reynolds stress and vorticity.

Sang-Joon et al. [18]performed wind tunnel tests of various fences with different porosities and heights. The results show that the mean pressure coefficient decreases when the fence height is greater than the reference height. The pressure value at the center of the low-pressure area downwind of the fence decreases with increasing fence height.

Mulati et al.[19]proposed a relationship between the bulk drag coefficientC_d, the width$W$and the height$H$as the following:

$$C_d = K_d \left(\frac{W}{H}\right)^{-b} \tag{3}$$

whereK_d and$b$are constants and depend on the frictional volume of the flow domain.

From this argument, it is concluded that the drag force increases with increasing the width, but the increase is not linear because of the sheltering effect.

3.5 Shield orientation (wind loads)

When a porous shield is not perpendicular to the wind flow, the forces acting on the structure may be split into a normal force due to the pressure difference, and a frictional drag parallel to the plane of the structure. The frictional drag force may be accounted for using a friction drag force coefficient in the range of 0.01-0.04 depending on the surface roughness[20].

The normal force coefficientC_n, which equals to the drag coefficient when$\theta = 0^{\circ}$, can be expressed as the following[21]:

$$C_n(\theta) = \frac{k\cos^2(\theta)}{(1+k\cos^2(\theta)/4)^2} \quad (4)$$

where$k$is the loss coefficient which is related to the pressure drop across the structure, $\theta$is the angle between the onset wind flow and a normal to the structure.
It is worth noticing that the effective loss coefficient is reduced by a$\cos^2(\theta)$factor, when a porous shield is at an angle to the wind flow.

4 Conclusions

Basically the performance of a porous shield is evaluated by the reduction of the wind velocity and the effective shelter distance at minimum costs. The paper reviews the above factors that influence the performance of a porous shield. Among them, the porosity is the most influential factor in determining the performance of porous shields, and the optimal porosity of shield is between 0.3-0.4. Shield height and its width also have major impacts on the performance of porous shields as they are important variables todetermine the Reynolds number.
Comparatively fewer researches studied on the rest factors. Further investigation of these factors remains a recommended research interest, as many issues are still in debate, in particular, how to balance other issues such as visibility, ventilation, sound-proof and fire resistance etc.

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