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Estimation of shelter provided by solid and porous fence

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Wind Engineering Panel. This Panel, which took over the work on wind engineering previously monitored by the Fluid Mechanics Steering Group, first met in 1979 and now has the following membership:

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ESTIMATION OF SHELTER PROVIDED BY SOLID AND POROUS FENCES

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ESTIMATION OF SHELTER PROVIDED BY SOLID AND POROUS FENCES

1. NOTATION AND UNITS

		<i>SI Units</i>
A	frontal area of fence, WH	m^2
A_0	frontal open area of porous fence	m^2
d	height above ground of effective zero-plane for site terrain, dependent on height and density of ground obstacles (see Reference 7 or 12)	m
f_s	shelter factor (see Section 4.2); $f_s = 1$ corresponds to no shelter effect	—
f_1, f_2	turbulence deficit functions (see Appendix A1.2)	—
g_u	gust peak factor (see Section 4 and Appendix A2)	—
H	height of fence	m
H_{obj}	height of sheltered object	m
k	coherence factor (see Section 4 and Appendix A2)	—
K	parameter in Equation (A1.3)	—
L_{obj}	maximum dimension of sheltered object (see Section 4.2)	m
${}^yL_u$	integral length scales of u -component of turbulence along y -direction	m
n	ratio V_{zx}/V_z	—
S_{int}	internal plan area of fence cell (Sketch 6.6)	m^2
$S_{0.33}, S_{0.5}, S_{0.83}$	sheltered areas downstream of fence for $f_s = 0.33, 0.5$ and 0.83 respectively	m^2
u, v, w	fluctuating components of wind speed along x -, y - and z - directions respectively	m/s
V_H, V_z	hourly-mean wind speeds of approach flow at heights H and z respectively at fence location in absence of fence	m/s
V_{zref}	reference hourly-mean wind speed of approach flow at height z_{ref} in absence of fence	m/s
V_{zx}	hourly-mean wind speed downstream of fence at co-ordinate (x, z) for $y = 0$	m/s
$\hat{V}_{zx}$	gust speed downstream of fence at co-ordinate (x, z) for $y = 0$	m/s

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x	longitudinal distance downstream of fence measured parallel to ground (see Sketch 1.1)	m
$x_1, x_2, x_3 \dots$	distances from point of interest to successive fences in multiple fence configuration (see Sketch 6.5)	m
W	lateral length of fence (see Sketch 1.1)	m
$(x/H)_{max}$	maximum value of x/H at which program performs calculations and displays output	—
$(x/H)_{increment}$	increment between values of x/H at which program performs calculations and displays output	—
y	lateral distance measured from fence centre-line (see Sketch 1.1)	m
z	vertical distance measured from ground level (see Sketch 1.1)	m
$(z/H)_{max}$	maximum value of z/H at which program performs calculations and displays output	—
$(z/H)_{increment}$	increment between values of z/H at which program performs calculations and displays output	—
z_{ref}	height above ground of approach-flow reference wind speed	m
z_0	surface roughness parameter for site terrain (see Reference 7 or 12)	m
$\Delta \sigma_u^2$	$\sigma_{u,zx}^2 - \sigma_{u,z}^2$	—
ΔV	$V_z - V_{zx}$	m/s
ϕ	geometric porosity ratio, A_0/A ($\phi = 0$ represents solid fence)	—
η	parameter in wind speed deficit calculation (Equation (A1.2))	—
κ	von Kármán's constant (taken as 0.4)	—
σ_u	standard deviation of u -component of turbulence	m/s
τ	averaging time for peak gust	s
ξ	non-dimensional distance, $x/(H-d)$	—

Subscripts

x	relates to value at distance x downwind of fence
z	relates to value at fence location and at height z above ground, in absence of fence
zx	relates to value downwind of fence at co-ordinate (x, z) for $y = 0$



Sketch 1.1 Co-ordinate system

2. PURPOSE, SCOPE AND APPLICABILITY

2.1 Purpose

Fences are used all over the world for the provision of favourable wind environments. Their value to agriculture and horticulture is incalculably large. It is of practical interest to predict the wind shelter in the lee of a fence in order to obtain the optimum performance for a particular application. Examples of applications are described in Section 2.4. Although there is a considerable amount of wind-tunnel and full-scale (field) research on the topic, there is a lack of agreement between various sources, implying large uncertainties in individual sets of data. This Data Item provides a coherent guide for the estimation of shelter effects behind a solid or porous fence.

2.2 Scope

This Item provides background information on the applications of fences for shelter from wind and provides methods for predicting the following flow characteristics in the flow downstream of a fence:

- (1) local hourly-mean wind speed,
- (2) local turbulence intensity,
- (3) local gust speed,
- (4) local shelter factor.

The methods for predicting these characteristics are described in Section 4, and are implemented by a computer program described in Section 5.

Guidance for predicting local mean wind speeds downwind of several fences in series is provided in Section 6.3.1.

2.3 Applicability and Limitations

The limitations of the prediction methods (described in Sections 4 and 4.2) are as follows.

- (1) The prediction methods apply directly only to a single fence. Guidance on use of the methods for multiple fences is given in Section 6.3.
- (2) The fence ($H < W/25$) is assumed to be normal to the ground (with ground slope $< 5^\circ$) and the wind shelter is predicted to a distance of $50H$ downwind of the fence and for heights up to $10H$ beyond which recovery to free-stream conditions is assumed to have occurred.
- (3) The fence is assumed to be a thin structure so that the aerodynamic porosity is equivalent to the geometric porosity. The construction of porosity is assumed to be of negligible importance after a leeward distance of about $2.5H$ downwind of the fence. The effects of porosity are validated up to $\phi = 0.5$ and extrapolated to $\phi = 1.0$.
- (4) The flow upstream of the fence is assumed to be a natural atmospheric wind that can be represented by the model described in References 7, 8 and 9. The atmospheric stability near the ground at the site is assumed to be neutral.

- (5) The prediction method is validated for windward terrain local to the fence with a surface-roughness-parameter in the range of $0.001 \text{ m} \leq z_0 \leq 0.1 \text{ m}$, *i.e.* terrains ranging from flat and open with isolated trees to the outskirts of towns. The computer program will, however, calculate predictions for rougher or smoother terrains.
- (6) The prediction methods apply when the incident wind is normal to the plane of the fence. Some guidance on the effects of wind incidence is given in Section 6.2.
- (7) Both the windward and leeward flows are assumed to be two-dimensional in the plane perpendicular to the surface of the fence and the ground. The prediction methods do not allow for three-dimensional phenomena such as end effects. End effects can be considered negligible on the flow characteristics along the centre-line when $H < W/25$. Some guidance on minimising end effects is given in Section 6.1.
- (8) This Data Item does not apply to natural windbreaks (also known as a shelterbelts) such as trees and hedges because of irregular depth, geometry, porosity and response effects due to wind action.
- (9) This Data Item does not apply to fences on bridges because there is then no ground plane immediately upwind, as a result of which there is a different flow pattern around the fence from that around a ground-based fence.

2.4 Applications

2.4.1 Agricultural and horticultural

Solid and porous fences are used in agricultural and horticultural applications³ to shelter gust-sensitive static structures, such as *e.g.* glass-houses and livestock protection areas, and to provide protection for crops. They may also be used to provide temporary shelter for trees or hedges during the early stage of growing, *i.e.* artificial windbreaks help the development of long term natural windbreaks (or shelterbelts).

Example of beneficial effects in agricultural and horticultural applications are as follows.

- (1) Reduction in physical damage for crops susceptible to wind damage.
- (2) Reduction of the risk of structural damage and of heat losses from glasshouses and other buildings.
- (3) Plants use water at a slower rate when sheltered and so are less likely to wilt in very hot conditions.
- (4) Reduction of evaporation of water from the soil. The resulting increase in humidity may mean the difference between having a frost and no frost.
- (5) Raising of the daytime temperature of the soil by as much as 3°C where shelter is provided by a fence. This can mean several days earlier maturity of fruit and vegetable crops.
- (6) Improved pollination improved by providing shelter from the wind for pollinating insects.
- (7) Reduction of soil erosion, especially important for fine or organic soils.
- (8) Reduction of the risk of wind-borne disease spread.
- (9) Spraying can be done when it may be impossible on more exposed sites. It is also more efficient where the site is protected by fences.

- (10) Protection of crops near sea coasts from the worst effects of wind-blown salt spray.

2.4.2 Civil engineering

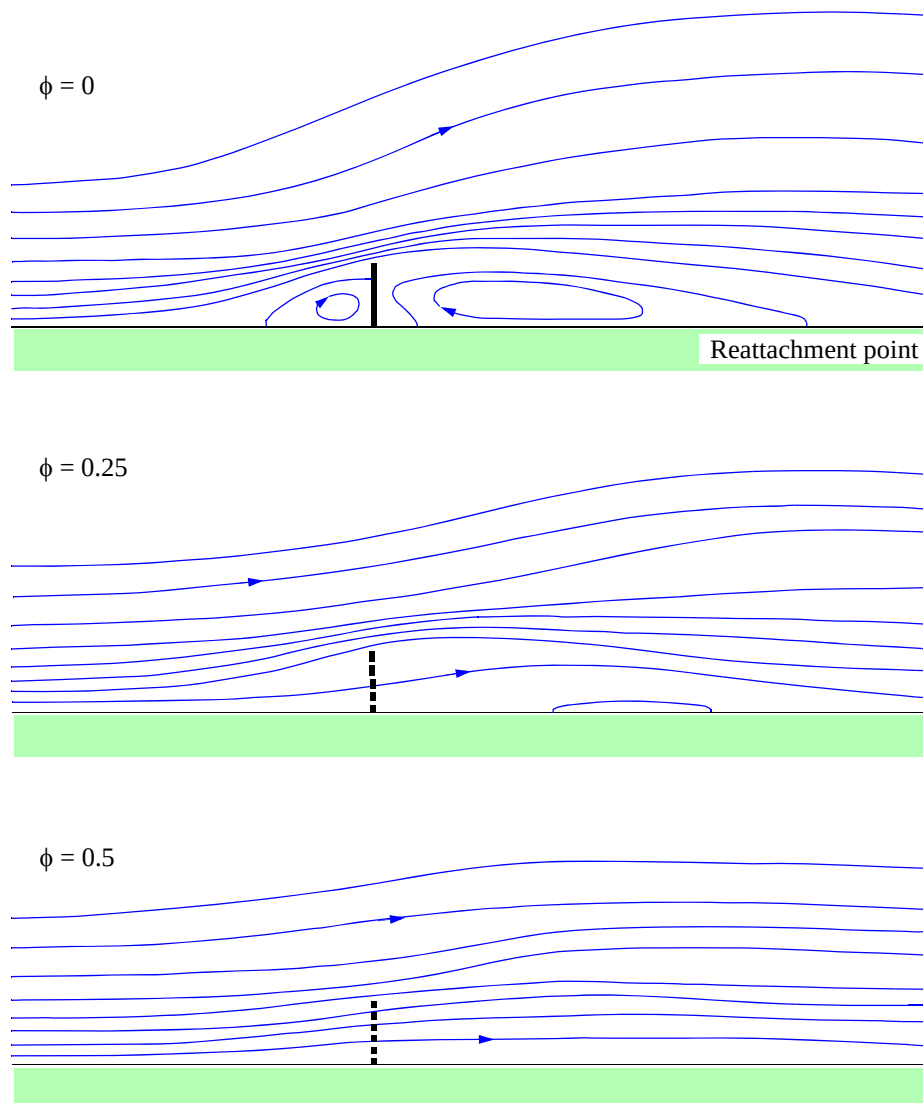
Solid and porous fences are used in a variety of situations in civil engineering to provide shelter for people and for objects that are sensitive to wind effects.

Some examples of the situations in which they may be used are as follows.

- | | |
|-------------------------|---|
| (1) Town centres: | fences can be used to control wind speed in the neighbourhood of the ground for the comfort of pedestrians. A typical threshold of pedestrian discomfort is a mean wind speed of 5 m/s and a turbulence intensity of 20% at ground level ($z = 1.5$ m is classed as head height). However, the threshold will depend on the situation. |
| (2) Motorways: | fences provide protection to vehicles travelling on roads through terrain with high cross winds. They also help to reduce noise pollution. |
| (3) Railways: | fences can be used to protect trains whilst travelling along exposed lengths of track. For example, on the Calais side of the Channel tunnel, fences protect the high-sided trains from the effects of gusts. |
| (4) Industrial sites: | fences can be used to shelter large industrial sites (<i>e.g.</i> chemical and oil plants) that are located in exposed areas. |
| (5) Port protection: | fences are used for protecting ships whilst in exposed ports. An example is at Port Autonome in Marseilles, France, where a porous fence of metallic construction provides shelter at the quay side. |
| (6) Cargo containers: | fences are used to protect stacked containers (covering many acres) from the high winds in exposed areas. An example is in the coastal area of Fos harbour, France, where porous fences are used to protect shipping containers. |
| (7) Storage piles: | fences are used to protect areas containing easily-blown material such as coal and ash piles around power stations. |
| (8) Recreational areas: | fences are used to shelter sports fields (<i>e.g.</i> football pitches and tennis courts) located on the edges of towns and cities. |

3. AERODYNAMICS OF SOLID AND POROUS FENCES

The aerodynamic action of a fence is simple in principle. The fence exerts a drag force on the wind field, causing a net loss of momentum in the airflow, thus creating a sheltering effect. As the porosity of a fence is reduced (*i.e.* towards a solid fence), 'the bleed flow' decreases and the drag force increases². This is accompanied by a greater upward deflection of the approach flow and, below a certain porosity, a large region of separated flow in the lee of the fence is created. For a solid fence this separation region, or 'quiet zone' can be approximated to a triangular zone extending from the top of the fence ($z = H$) to the ground at around $x = 7.5H$, depending on the turbulence intensity. The more solid the fence, the stronger is the turbulence in the separation bubble and the steeper the return of the displacement flow to the ground at its downstream reattachment point. As porosity increases (and hence bleed flow increases), the separation bubble diminishes in size and moves downstream (see Sketch.3.1). The separation bubble disappears at a porosity of about 0.35.



Sketch 3.1

The type of porosity (*e.g.* vertical or horizontal slats, or circular holes) has an effect only in the very near wake ($x < 2.5H$). The influence of porosity type in the far wake is negligible even for low porosity fences⁶.