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# Boundary walls, fences and hoardings: mean and peak wind loads and overturning moments

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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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# BOUNDARY WALLS, FENCES AND HOARDINGS: MEAN AND PEAK WIND LOADS AND OVERTURNING MOMENTS

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## 1. NOTATION AND UNITS

| | | Units | |
|---|---|---|---|
| | | *SI* | *British* |
| $A$ | frontal area of panel within wall (see Table 3.1); $A = lh$ | $m^2$ | $ft^2$ |
| $a_1, a_2, b$ | constants in Equation (A4.4) | | |
| $\bar{C}_F$ | area-averaged mean force coefficient for panel within wall; $\bar{C}_F = \bar{F}/(½\rho\bar{V}_h^2 A)$, | | |
| $\hat{C}_F$ | peak force coefficient; $\hat{C}_F = \hat{F}/(½\rho\bar{V}_h^2 A)$ | | |
| $\tilde{C}_F$ | area-averaged quasi-steady peak force coefficient of panel within wall; $\tilde{C}_F = \hat{F}/(½\rho\hat{V}_h^2 A)$, | | |
| $C_{Fqs}$ | coefficient defined as $g_F\sigma_{CF}/(G_u^2 - 1)$ | | |
| $\bar{C}_{Fref}$ | value of $\bar{C}_F$ for 5 m high panel based on $\bar{V}_h$ for open country terrain ($z_0 = 0.03$ m) | | |
| $\bar{F}, \hat{F}$ | mean and extreme (design) value respectively of local force acting normally to wall panel | N | lbf |
| $G_u$ | gust factor; $G_u = 1 + g_u I_u = \hat{V}/\bar{V}$ | | |
| $g_u$ | gust peak factor | | |
| $g_F$ | force peak factor (Equation (3.5)) | | |
| $h$ | panel height | m | ft |
| $h_0$ | height of panel base above ground | m | ft |
| $h'$ | height of panel top above ground; $h + h_0$ | | |
| $I_u$ | intensity of turbulence; $\sigma_u/\bar{V}$ | | |
| $k_R$ | factor accounting for effect of terrain roughness on $\bar{C}_F$ and $\sigma_{CF}$ | | |
| $l$ | width of panel within wall (see Table 3.1) | m | ft |
| $l_0$ | distance of panel edge from end of wall (see Table 3.1) | m | ft |
| $l'$ | $l_0 + l$ | m | ft |
| $L$ | diagonal length of panel; $(l^2 + h^2)^{½}$ | m | ft |

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| | | | |
|---|---|---|---|
| $\bar{M}$, $\hat{M}$ | mean and extreme (design) value respectively of local overturning moment acting on panel | N m | lbf ft |
| $u$ | fluctuating component of wind speed in mean wind direction | m/s | ft/s |
| $\bar{V}_h$, $\bar{V}_z$ | hourly-mean wind speed over site at top of panel and height $z$ respectively | m/s | ft/s |
| $\hat{V}_z$ | $\tau$-second gust speed at height $z$; $\hat{V}_z = G_u \bar{V}_z$ | m/s | ft/s |
| $w$ | width of wall or hoarding | m | ft |
| $z$ | height above ground | m | ft |
| $z_{cp}$ | vertical distance from base of panel to centre of pressure location for net force acting on wall or element thereof | m | ft |
| $z_0$ | terrain roughness parameter (see ESDU 82026[2]) | m | ft |
| $\rho$ | air density | kg/m$^3$ | slug/ft$^3$ |
| $\sigma_{CF}$ | standard deviation of fluctuating force coefficient | | |
| $\sigma_u$ | standard deviation of fluctuating component of wind speed in mean wind direction | m/s | ft/s |
| $\tau$ | averaging time for peak force coefficient and peak gust | s | s |
| $\Phi$ | angle between normal to panel face and mean wind direction | degree | degree |
| *Subscripts* | | | |
| $r$ | relates to value at height where local mean pressure on front face of panel is a maximum | | |
| $ref$ | relates to value for 5 m high panel in open country terrain ($z_0 = 0.03$ m) | | |



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## 2. INTRODUCTION

This Data Item gives mean and extreme (peak) loading coefficient data for boundary walls, panels, fences and other vertical plate-like structures such as ground-based or elevated hoardings and signboards in the atmospheric wind. Additionally, the centre of pressure position of these loads is given so that overturning moments may also be estimated. It replaces ESDU 70015[1] (in the Wind Engineering Series) which primarily deals with isolated plates in uniform flow.

For such structures the principal design load results from the action of the wind on the wall or panel face. This force is resisted either by vertical supports or piers at intervals along the wall or panel or by direct cantilever action of the wall or panel itself. The force coefficients given in this Item can be used with a predetermined wind speed to estimate mean or design forces and overturning moments in the structural supports resisting the wind action, or in isolated sections of an unsupported wall.

The force coefficients used in this Item are derived from the pressure difference measurements between the windward and leeward faces averaged over a panel face. Similarly, centre of pressure positions are derived from measurements obtained using a pneumatic averaging technique[10] so that local pressure differences are weighted according to their moment arm from the base. The derivation of the data is explained in Appendix A and a calculation procedure for practical applications is given in Section 3.2 .

### 2.1 Background to the Data Presented

The following force coefficients and overturning moment data are provided.

(i) Area-averaged values of mean force coefficient $(\bar{C}_F)$ corresponding to individual panels located in the wall.

(ii) Corresponding values of the peak fluctuating component of force coefficient which when added to the mean value give the peak force coefficient $(\hat{C}_F)$ and hence peak force, $\hat{F}$ .

(iii) Values of the centre of pressure position for $\bar{F}$ and $\hat{F}$ giving the overturning moments $\bar{M}$ and $\hat{M}$.

The data have been obtained from tests in boundary-layer wind tunnels where the typical variation of wind speed and turbulence properties with height in the atmospheric boundary layer have been appropriately scaled according to accepted criteria in relation to the integral length scales of turbulence obtained in the wind tunnel compared to the atmosphere.

To obtain peak coefficients from the wind-tunnel data, a statistical analysis is required in which a fully probabilistic method is applied to the results from a number of runs to obtain the extreme-value distribution of both the fluctuating wind speed and fluctuating loading. From these distributions an extreme loading $\hat{F}$ and a corresponding extreme gust speed $\hat{V}$ can be obtained for a specified gust duration time. This method, detailed by Cook and Mayne[A3–A6] and summarised briefly in Appendix A, accounts for the risk of wind speed and loading coefficient jointly instead of independently.

If quasi-steady theory applied exactly then the quasi-steady loading coefficient obtained from

$$\tilde{C}_F = \hat{F}/(\tfrac{1}{2}\rho\hat{V}^2 A) \tag{2.1}$$

would be identical to the mean loading coefficient obtained from the mean loading $\bar{F}$ and mean wind speed $\bar{V}$ ,

$$\bar{C}_F = \bar{F}/(\tfrac{1}{2}\rho\bar{V}^2)A . \tag{2.2}$$



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In general, for boundary walls, values of $\tilde{C}_F/\bar{C}_F$ for particular configurations lie between about 0.7 and 1.2 but in some cases much larger discrepancies are observed particularly where $\bar{C}_F$ is very small.

A convenient way of expressing the results obtained from the fully probabilistic approach is by the peak factor format in which the peak force coefficient (based on $\bar{V}_h$)is expressed as

$$\hat{C}_F = \hat{F}/(\tfrac{1}{2}\rho\bar{V}^2 A) = \bar{C}_F + g_F\sigma_{CF} \tag{2.3}$$

where $g_F$ is a loading peak-factor and $\sigma_{CF}$ is the rms value of the fluctuating force coefficient. This relation when used to estimate $C_F$ requires, in addition to an estimation of $\bar{C}_F$, a method for estimating the term $g_F\sigma_{CF}$ which depends on the particular configuration, structure element size, and the turbulence properties of the approaching wind. In practice it is found that $g_F\sigma_{CF}$ can be expressed as a function of the gust factor, $G_u$, and $\bar{C}_F$ as derived in Section A4 of Appendix A.

## 3. SCOPE AND APPLICABILITY OF DATA PRESENTED AND CALCULATION PROCEDURE

### 3.1 Scope and Applicability

Table 3.1 summarises the data presented. In general the force coefficient is a function of the position of a panel within the wall, panel size $(l/h)$ and wind angle of incidence. The data are presented graphically and Table 3.1 indicates, for each configuration, the design conditions giving rise to the highest loadings.

Data for both the front and rear wall of a pair of parallel walls is also provided in Figure 8.

Information for porous fences is to be given in a later Data Item.

The data are obtained from wind-tunnel tests simulating the atmospheric boundary layer. The loading coefficients given may be corrected to apply to any particular site terrain using the factor $k_R$, the derivation of which is explained in Section A3 of Appendix A. A comparison with the available experimental data indicates that approximately 90% of estimated values lie within $\pm 10\%$ of the corresponding measured values. An overall uncertainty of $\pm 15\%$ should be allowed for.

The peak loading coefficients presented are extreme values in a period of 1 hour relating to a design wind with a mean recurrence interval (return period) of 50 years. As an approximation, the same peak force coefficients may be used with wind speeds appropriate to other mean recurrence intervals.

### 3.2 Calculation Procedure

The mean and peak (design) loading and overturning moments on a panel are given by the following equations.

**Mean Values**

$$\bar{F} = \tfrac{1}{2}\rho\bar{V}_h^{\,2}\bar{C}_{Fref}\,k_R A, \tag{3.1}$$

$$\bar{M} = \bar{F}\,z_{cp} \tag{3.2}$$

where $k_R$ is given by Figure 1a.



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**Peak Values**

$$\hat{F} = \tfrac{1}{2}\rho \bar{V}_h^{\,2} \hat{C}_F A, \tag{3.3}$$

$$\hat{M} = \hat{F}\ z_{cp} \tag{3.4}$$

where $\hat{C}_F$ is given by

$$\hat{C}_F = \bar{C}_F + g_F \sigma_{CF}, \tag{3.5}$$

$$g_F \sigma_{CF} = (G_u^2 - 1)(C_{Fqs})_{ref}\, k_R, \tag{3.6}$$

$$Gu = 1 + g_u I_u \tag{3.7}$$

and $(C_{Fqs})_{ref}$ is given by Figure 2.

The calculation of the wind speed factors and coefficients in Equations (3.1) to (3.7) is as follows.

(i) Obtain the site terrain parameter, $z_0$, and the hourly-mean design wind speed, $\bar{V}_h$, for a mean recurrence interval of 50 years (or other values as appropriate) for the site at a height corresponding to the top of the wall or panel using appropriate sources such as Volume 1 of the Wind Engineering Series.

(ii) Evaluate the panel diagonal length, $L = (l^2 + h^2)^{1/2}$ and the panel area, $A$.

(iii) Evaluate the gust peak factor, $g_u$ from Figure 1b appropriate to the value of $L/\bar{V}_h$. Obtain a value of the turbulence intensity, $I_u$, from the tables in ESDU 84030[4] for the site terrain and height corresponding to the top of the panel. Evaluate the gust factor, $G_u = 1 + g_u I_u$.

(iv) Use Table 3.1 to locate the required value of $\bar{C}_{Fref}$ for the configuration under consideration together with the value of $z_r/h$.

(v) Providing the terrain upwind of the site is uniform for a distance of at least 100 $h'$, the terrain correction factor, $k_R$, can be taken from Figure 1a for the appropriate value of $h'/z_0$.

(vi) Evaluate $\bar{C}_F$ (based on $\bar{V}_h$ at the site) = $\bar{C}_{Fref}\, k_R$.

(vii) For the value of $\bar{C}_{Fref}$ from step (iv) obtain $(C_{Fqs})_{ref}$ from Figure 2.

(viii) Evaluate $\hat{C}_F$ from Equations (3.5) to (3.7).

(ix) For the required configuration obtain a value of the centre of pressure position $(z_{cp}/h)$ from Table 3.1.

(x) Evaluate $\hat{F}$ and $\hat{M}$ as required from Equations (3.3) and (3.4).



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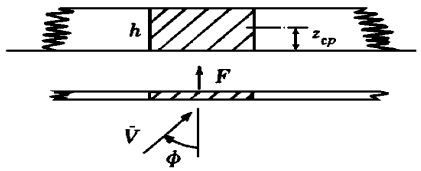
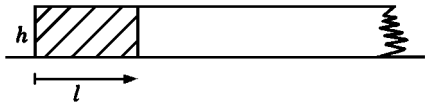
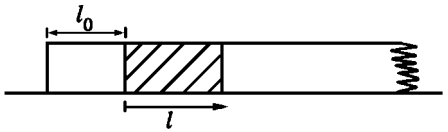
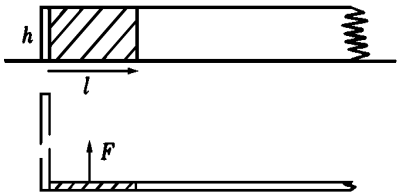
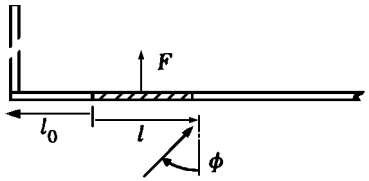
## TABLE 3.1 SUMMARY OF DATA PRESENTED

| *Configuration* | $\bar{C}_F = \bar{C}_{Fref}\, k_R$ (Fig 1a)<br>$\hat{C}_F = [\bar{C}_{Fref} + (C_{Fqs})_{ref}(G_u^2 - 1)]k_R$ | *Design case* $\Phi$ | $l/h$ | $\bar{C}_{Fref}$ | $z_r/h$ | $(C_{Fqs})_{ref}$ (Fig. 2) | $z_{cp}/h$ | *Other cases.* $\hat{C}_F$ (see Fig. 2) $\Phi$ | $\bar{C}_{Fref}$ | $z_r/h$ | $z_{cp}/h$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Infinite wall |  | 0° | all | 1.15 | 0.7 | 0.98 | 0.49 | 0 –90° | Fig. 3 | 0.7 | 0.49 |
| Semi-infinite wall: edge panel |  | 30°– 45° | 0.5 | 2.75 | 0.4 | 2.40 | 0.48 | | Fig. 4 | 0.7 | 0.53 |
| | | | 1 | 2.68 | | 2.34 | 0.50 | | | 0.4 | |
| | | | 2 | 2.23 | | 1.97 | 0.53 | | | | |
| | | | 3 | 1.90 | 0.4 | 1.72 | 0.54 | | | | |
| | | 90° | > 30 | 1.15 | 0.7 | 0.98 | 0.49 | | | | |
| panel $l_0$ from edge |  | 45° | See Fig. 4 | | 0.4 | Curve 1 | 0.52 | 0° | Fig. 4 | 0.7 | 0.53 |
| Corner: corner panel |  | 45° | 0.5 | 1.92 | 0.4 | 1.23 | 0.48 | 0° | Fig. 5 | 0.7 | 0.50 |
| | | | 1 | 1.92 | | 1.23 | 0.50 | 15 –75° | | 0.4 | 0.50 |
| | | | 2 | 1.87 | | 1.20 | 0.50 | 90 –180° | | 0.7 | 0.46 |
| | | | 3 | 1.68 | 0.4 | 1.06 | 0.50 | 180° | Fig. 6b | 0.7 | 0.46 |
| | | 90° | > 30 | 1.15 | 0.7 | 0.98 | 0.49 | 180 –270° | | 0.7 | 0.50 |
| | | | | | | | | 270 –360° | | 0.7 | 0.50 |
| panel $l_0$ from corner |  | 45° | See Fig. 6a | | 0.4 | Curve 2 | 0.50 | 180° | Fig. 6b | 0.7 | 0.46 |



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