Appendix F: Application of the effective static load method to a simple structure

F1 Introduction

In this appendix, the formula of Kasperski (1992) is applied to a simple structure – a pitched free roof – to illustrate the method of determining the effective static wind pressures. Data was obtained from wind tunnel tests carried out by Ginger and Letchford (1991).

F2 Wind pressure data

A model of a pitched free roof (i.e. no walls), with a roof pitch of 22.5 degrees, at a geometric scaling ratio of 1/100, was tested in a boundary-layer wind tunnel by (Ginger and Letchford, 1991). Net area-averaged pressures across the windward and leeward roof slopes were measured. Three panels per roof half were used, but the data used here applies to the central panels, that is the central third of the roof.

Figure F1(b) shows the mean and standard deviation pressure coefficients for a wind direction normal to the ridge as shown; the latter values are in brackets. Maximum and minimum panel pressure coefficients were also recorded and are shown in Figure F1(c). The directions for positive net panel pressures are shown on the Figure.

F3 Effective static loads for total lift and drag

At first, one might assume that the maximum total lift force should be obtained from the two recorded minimum pressures on the two roof panels. Similarly, the maximum drag could be obtained from the maximum on panel 1 and the minimum on panel 2. However, this would be incorrect, and conservative, as these values do not occur simultaneously. The *expected* pressure coefficients coinciding with the maximum and minimum lift and drag are derived in the following.

F3.1 Mean lift and drag

The mean lift force (positive upwards) is obtained as follows:

$$\bar{L} = (-1)\,(0.46)q_h(d/2) + (-1)\,(-0.60)q_h(d/2) = 0.14q_h(d/2)$$

where q_h is the reference mean dynamic pressure at roof height $\left(= \frac{1}{2}\rho_a \bar{U}_h^{\,2}\right)$; and d is the along-wind length of the roof. In this case, the *influence coefficients* for the *lift force* are both equal to $-(d/2)$.

The mean drag force is given by:

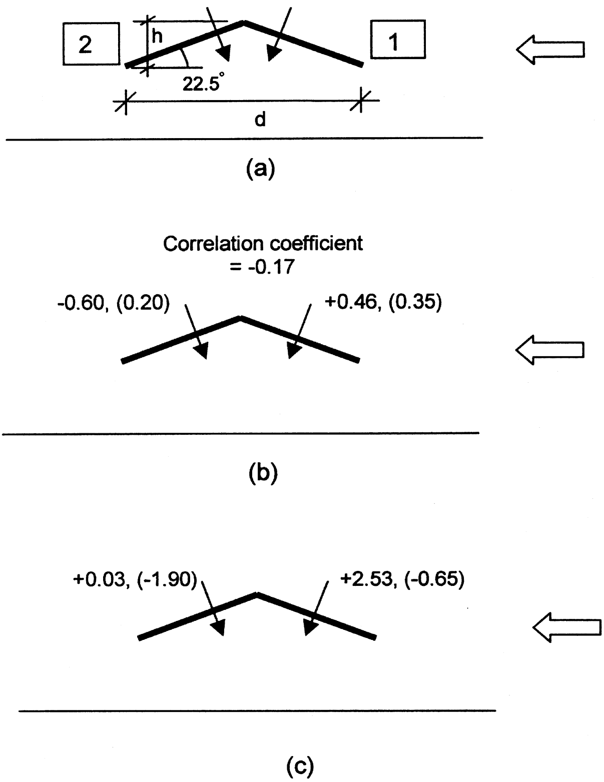

Figure F1 Pressure coefficients for a pitched free roof. a) Roof geometry; b) Mean, (standard deviation) pressure coefficients and correlation coefficient; c) Maximum and (minimum) pressure coefficients.

$$\bar{D} = (+1)(0.46)q_h(h) + (-1)(-0.60)q_h(h) = 1.06q_h(h) = 0.44q_h(d/2)$$

since, $h/(d/2) = \tan 22.5° = 0.414$.

The *influence coefficients* for the *drag force* are equal to $+h = (d/2) \tan 22.5°$ for panel 1, and $-h = -(d/2) \tan 22.5°$, for panel 2.

F3.2 Standard deviations of lift and drag

The r.m.s. fluctuating, or standard deviation, lift and drag forces can be obtained by *covariance integration* (Holmes and Best, 1981; Ginger and Letchford, 1991, 1994).

The standard deviation of the lift force , σ_L, is obtained as follows:

$$\sigma_L = q_h(d/2)[(0.35)^2 + (0.20)^2 + 2(-0.17).(0.35)(0.20)]^{1/2} = 0.372q_h(d/2)$$

The standard deviation of the drag force, σ_D, is:

$$\sigma_D = q_h(d/2) \tan 22.5^o[(0.35)^2 + (0.20)^2 - 2(-0.17) .(0.35) (0.20)]^{1/2}$$
$$= 0.432\ q_h(d/2) \tan 22.5^o = 0.179\ q_h(d/2)$$

F3.3 Effective pressures for peak lift force

The expected pressure on panel 1 when the *lift* is a maximum is given by (Kasperski, 1992):

$$(p_1)_{\hat{L}} = q_h\,[\bar{C}_{p1} + g\,\rho_{p1,L}\,\sigma_{Cp1}]$$

where g is a peak factor for the lift (it will be taken as 4), and $\rho_{p1,L}$ is the correlation coefficient between the pressure $p_1(t)$ and the lift $L(t)$.

The *covariance* between the pressure $p_1(t)$ and the lift $L(t)$ is given by:

$$-(d/2)[\overline{p_1'^2} + \overline{p_1'p_2'}] = -q_h{}^2(d/2)[(0.35)^2 + (-0.17)(0.35)(0.20)]$$

$$= -(0.111)\,q_h{}^2(d/2)$$

Then,

$$\rho_{p1,L} = \frac{-0.111}{(0.35)(0.372)} = -0.853$$

Hence,

$$(p_1)_{\hat{L}} = q_h\,[\bar{C}_{p1} + g\,\rho_{p1,L}\,\sigma_{Cp1}] = q_h[(0.46) + 4(-0.853)(0.35)] = -0.73\,q_h$$

Similarly, the *covariance* between the pressure $p_2(t)$ and the lift $L(t)$ is given by:

$$-(d/2)[\overline{p_1'^2} + \overline{p_1'p_2'}] = -q_h{}^2(d/2)[(0.20)^2 + (-0.17)(0.35)(0.20)]$$

$$= -\,(0.028)\,q_h{}^2(d/2)$$

Then,

$$\rho_{p2,L} = \frac{-0.028}{(0.20)(0.372)} = -0.376$$

Hence,

$$(p_2)_{\hat{L}} = q_h[\bar{C}_{p2} + g\,\rho_{p2,L}\,\sigma_{Cp2}] = q_h[(-0.60) + 4(-0.376)(0.20)] = -0.90\,q_h$$

Thus the expected pressure coefficients corresponding to the maximum lift (acting upwards) are

$$(C_{p1})_{\hat{L}} = \mathbf{-0.73}\ (C_{p2})_{\hat{L}} = \mathbf{-0.90}$$

The pressures corresponding to the *minimum* lift force (downwards) are also of interest. In this case,

$$(p_1)_{\check{L}} = q_h[\bar{C}_{p1} - g\,\rho_{p1,L}\,\sigma_{Cp1}] = q_h[(0.46) - 4(-0.853)(0.35)] = +1.65\,q_h$$

and,

$$(p_2)_{\check{L}} = q_h[\bar{C}_{p2} - g\ \rho_{p2,L}\ \sigma_{Cp2}] = q_h[(-0.60) - 4(-0.376)(0.20)] = -0.30\ q_h$$

Hence,

$$(C_{p1})_{\check{L}} = +\mathbf{1.65}\ (C_{p2})_{\check{L}} = \mathbf{-0.30}$$

These pressure coefficients are shown in Figure F2(a) and (b).

F3.4 Effective pressures for maximum drag force

The expected pressures for the maximum *drag* force can be determined in a similar way as the lift force, as follows.

The *covariance* between the pressure $p_1(t)$ and the drag $D(t)$ is given by:

$$(d/2)\tan 22.5^o[\overline{p_1'^2} - \overline{p_1' p_2'}] = q_h^2(d/2)\tan 22.5^o\ [(0.35)^2 - (-0.17)(0.35)(0.20)]$$

$$= (0.134)\ q_h^2(d/2)\ \tan 22.5^o$$

Then,

$$\rho_{p1,D} = \frac{0.134}{(0.35)(0.432)} = 0.886$$

Hence,

$$(p_1)_{\hat{D}} = q_h[\bar{C}_{p1} + g\ \rho_{p1,D}\ \sigma_{Cp1}] = q_h[(0.46) + 4(0.886)\ (0.35)] = 1.70\ q_h$$

(again taking a peak factor of 4)

Similarly, the *covariance* between the pressure $p_2(t)$ and the drag $D(t)$ is given by:

$$-(d/2)\tan 22.5^o\ [\overline{p_1'^2} - \overline{p_1' p_2'}] = -q_h^2(d/2)\tan 22.5^o\ [(0.20)^2 - (-0.17)(0.35)(0.20)]$$
$$= -(0.052)\ q_h^2(d/2)\tan 22.5^o$$

Then,

$$\rho_{p2,D} = \frac{-0.052}{(0.20)(0.432)} = -0.602$$

Hence,

$$(p_2)_{\hat{D}} = q_h\ [\bar{C}_{p2} + g\ \rho_{p2,D}\ \sigma_{Cp2}] = q_h[(-0.60) + 4(-0.602)\ (0.20)] = -1.08\ q_h$$

Thus the expected pressure coefficients corresponding to the maximum drag are

$$(C_{p1})_{\hat{D}} = +\mathbf{1.70} \quad (C_{p2})_{\hat{D}} = \mathbf{-1.08}$$

These pressure coefficients are shown in Figure F2(c)

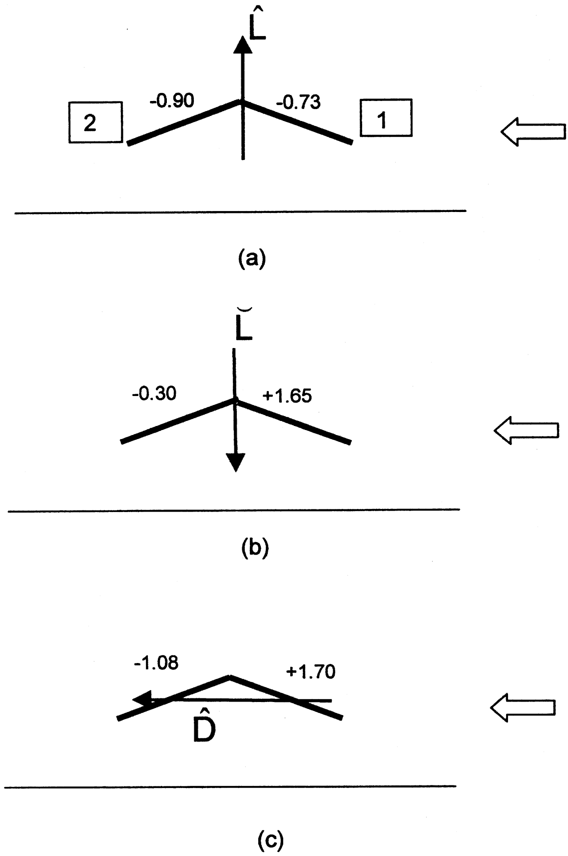

Figure F2 Pressure coefficients for a pitched free roof. a) Effective pressures for maximum lift force; b) Effective pressures for minimum lift force; c) Effective pressures for maximum drag force.

F4 Discussion

The effective pressure coefficients for maximum and minimum lift, and maximum drag, as summarised in Figure F2, are clearly quite different to each other, and indicate the difficulty in specifying a single set of pressure coefficients in a code or standard, for a structure such as this.

It can be checked that the values obtained in the previous section will in fact give the correct values of the peak load effects. For example, the maximum lift can be obtained in two ways as follows.

From the effective static pressure coefficients:

$$\hat{L} = (-1).(-0.73)q_h\,(d/2) + (-1).(-0.90)q_h(d/2) = 1.63q_h(d/2)$$

Directly from the mean and standard deviation:

$$\hat{L} = \bar{L} + 4\,\sigma_L = 0.14\,q_h(d/2) + 4 \times 0.372\,q_h(d/2) = 1.63\,q_h(d/2)$$

The effective static pressure coefficients for each panel should lie between the limits set by the maximum and minimum pressure coefficients for each panel. This is the case here (see Figures F1 and F2), except the value on panel 1 for $\hat{L}$, –0.73, is slightly more negative that the measured minimum value of –0.65. This could result from a sampling error in the measured peak, or the choice of a slightly conservative peak factor of 4 for the lift force.

F5 Conclusions

This example has explained, using a simple 2-panel case, the methodology for determining the expected pressure distributions corresponding to peak load effects, based on correlations. More complex cases, such as large roofs, require a large number of panels, and a matrix of correlation coefficients, but the principles of the calculation are the same.

References

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Kasperski, M. (1992) 'Extreme wind load distributions for linear and nonlinear design', *Engineering Structures* 14: 27–34.