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Wind loads on attachments to buildings

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ABSTRACT

The paper suggests an alternative, possibly more logical, approach to the loading of attachments to buildings, based on Bernoulli's equation, which should be satisfied – at least approximately – outside the local boundary layers and shear layers in the wind flow around the building. This approach leads to estimates of the ratio of the local wind velocity to the freestream wind speed, and to wind loads on the attachments that are proportional to (1 - $C_{p,e}$), rather than $C_{p,e}$.

1. Introduction

A common approach when assessing wind loads on attachments to building walls and roofs, such as sunshades, solar panels or balconies, is to relate the *net* pressure coefficient for the attachment directly to the *external* pressure coefficient on the building surface at the point of attachment. For example, this method is apparently common in the rooftop solar panel industry, in which the external shape factor on the roof K_ℓ $C_{p,e}$ is equated to $C_{p,n}$ and applied to the panel. A similar approach has been adopted for *Table 4.3* in the AWES Handbook AWES-HB-001-2022, the only difference being that an 'appurtenance' factor, K_{ap}, is applied; the value of this varies depending on the type of attachment and the building surface involved, but K_{ap} averages around 1.0.

2. Applicability of Bernoulli's Equation to flow around buildings

It is well known that Bernoulli's Equation applies to steady, incompressible, inviscid (zero viscosity) and irrotational (zero vorticity) flow. Of course, those conditions do not apply in the boundary layers adjacent to any bluff body, in the separated shear layers or within the adjacent separation 'bubble' regions. However, Bernoulli's Equation can be applied to the outer regions of the flow around a bluff body such as a building.

Bernoulli's Equation relates the static pressure, p and the velocity U in the flow:

$$p + \frac{1}{2}\rho_a U^2 = \text{constant} \tag{1}$$

Denoting the pressure and velocity in the region outside the influence of the body by p_0 and U_0, we have:

$$p + \frac{1}{2}\rho_a U^2 = p_0 + \frac{1}{2}\rho_a U_0^2$$

Hence,

$$p - p_0 = \frac{1}{2}\rho_a (U_0^2 - U^2) \tag{2}$$

The surface pressure on the body is expressed in the form of a non-dimensional pressure coefficient:

$$C_p = \frac{p - p_0}{\frac{1}{2}\rho_a U_0^2} \tag{3}$$

In the regions in which Bernoulli's Equation holds:

$$C_p = \frac{\frac{1}{2}\rho_a(U_0^2 - U^2)}{\frac{1}{2}\rho_a U_0^2} = 1 - \left(\frac{U}{U_0}\right)^2 \quad (4)$$

In the regions where the flow velocity, U, is less than U_0, the pressure coefficients are negative, and vice-versa. As previously noted, Bernoulli's Equation is not valid in the separated flow and wake regions, but reasonably good predictions of surface pressure coefficients can be obtained from Equation (4), by taking the velocity, U, as that just outside the shear layers and wake region.

In the atmospheric boundary near the ground the flow is, of course, very turbulent. Since turbulence comprises random or near-random fluctuating vorticity, even the freestream flow is strictly not irrotational. However, Bernoulli's Equation can reasonably be applied to the *mean* flow, and if a quasi-steady pressure–velocity assumption is made, to peak pressures on a building surface.

Equation (4) can be rewritten to relate the local velocity near a building (strictly outside the boundary layers, shear layers and wake regions) to the free stream velocity:

$$U^2 = {U_0}^2(1 - C_p) \quad (5)$$

Based on Equation (5), it may be more logical to apply a modification factor not to $C_{p,e}$ but to (1 -$C_{p,e}$), or (1 - K_ℓ $C_{p,e}$), when relating wind loads on an attachment to the pressure coefficient on the adjacent building surface.

3. Examples

3.1 Roof-mounted solar panels

Taking as an example a large industrial warehouse with a low-pitch roof, as shown in Figure 1.

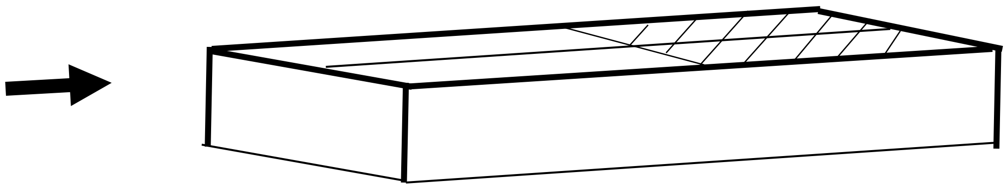


Figure 1. Warehouse with rooftop solar panels in the hatched area

The hatched region on the roof (downwind for the prevailing wind direction) is to be installed with inclined solar panels.

For that part of the roof, the flow is re-attached, with external pressure coefficients $C_{p,e}$ of +/- 0.2 (*Table 5.3(A)* in AS/NZS1170.2) . The local pressure factor in that region is 1.0.

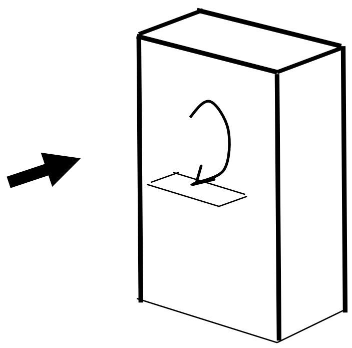
$(1 - C_{p,e})$ is then 0.8 or 1.2, with the latter value being critical. Thus, the square of the local velocity can be taken as 1.2 times the square of the reference gust velocity at the average building height (V_{des}). The estimated value of local velocity squared can then be used with net pressure coefficients, $C_{p,n}$, for arrays of solar panels from *Clause B.6.2* of AS/NZS1170.2 (*Tables B.13* and *B.14*) to generate design loads.

The relationship between the ‘appurtenance’ factor, K_{ap}, currently used in the AWES Handbook, AWESA-HB-001, and $C_{p,n}$ (i.e. the net pressure coefficients for the panels ground-mounted rather than roof mounted) is then given by Equation (6).

$$K_{ap} \cong C_{p,n} \frac{(1-C_{p,e})}{C_{p,e}} \tag{6}$$

3.2 Wall-mounted sunshades

As another example consider a horizontal sunshade mounted on the windward and side walls of a large building.



Bernoulli’s equation, through Eq. 5, gives an indication of the magnitude of the local velocity near a building wall, but no information on the local wind direction. However, it is likely that the largest wind load on the sunshade will occur when it is mounted below the stagnation point on the windward wall, with a vertical local velocity normal to the plane of the sunshade.

Consider the sunshade located at a point, roughly in the middle of the *windward* wall, where the external pressure coefficient, $C_{p,e}$ is about +0.5. The net pressure coefficient on the sunshade with respect to the *local vertical velocity* $C_{p,n}$ is about 1.2.

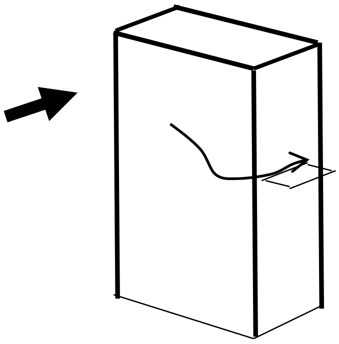
Then using Eq. (5), the net shape factor with respect to the *free-stream velocity*, U_0, is then:

$$C_{shp} \ = \ C_{p,n} \times \left(1 - C_{p,e}\right) = 1.2 \times (1 - 0.5) = \ 0.6$$

It is interesting to compare this value with that obtained from AWES-HB-001-2022. *Table 4.3(a)* in the Handbook gives K_{ap} = 1.1, for a sunshade mounted in the middle of a windward wall of a building, with d/b = 0.5, and hence,

$$C_{shp} = \ K_{ap} \times C_{p,e} = 1.1 \times 0.5 = \ 0.55$$

i.e. the two values are within 10% of each other, although obtained by different methods.



For a similar sunshade on a *side* wall, $C_{p,e}$ = -0.65. In this case the local velocity will be close to horizontal, i.e. parallel to the plane of the sunshade, and the peak wind loads can act upwards and downwards. For that case, take, $C_{p,n} = \pm 0.4$ (e.g. from *Table B.2(D)* in AS/NZS1170.2, by interpolation).

Then, $$C_{shp} = C_{p,n} \times \left(1 - C_{p,e}\right) = 0.4 \times (1 + 0.65) = 0.66$$

Table 4.3(a) in AWES-HB-001 gives K_{ap} = 1.0, for a sunshade mounted in the middle of a side wall of a building, with d/b = 0.5, then

$$\left|C_{shp}\right| = K_{ap} \times C_{p,e} = 1.0 \times 0.65 = 0.65$$

Again the estimates by the two methods are very close.

4. Discussion and Conclusions

This short paper has described a simple approach based on Bernoulli's Equation for estimating wind load shape factors for attachments to the walls or roofs of buildings. Unlike the present method, as used in AWES-HB-001, in which the local external pressure coefficient, $C_{p.e}$, is multiplied by an empirical 'appurtenance factor' derived from wind tunnel testing, the new approach multiplies (1 - $C_{p.e}$) by a factor which is directly related to a (net) pressure coefficient equal to that for the same attachment mounted on the ground, instead of the building.

By Bernoulli's Equation, (1 - $C_{p.e}$) is approximately equal to the ratio of the local velocity near the building surface to the upwind reference velocity, squared. However, no direct information on the local wind direction is available.

The main advantage of this approach is that estimates can be made of wind loads on attachments without the need of special wind-tunnel tests, provided a reasonable guess can be made of the local wind direction on the building surface.

Even when wind-tunnel tests are available with direct measurement of the load on an attachment, expressing the data in terms of a factor on (1 - $C_{p.e}$), instead of $C_{p.e}$, may be preferable. Alternatively, if the present approach in AWES-HB-001 is retained, Equation (6) can be used to suggest appropriate values for the 'appurtenance' factors, K_{ap}.

References

Australasian Wind Engineering Society, (2022), "Wind loading handbook for Australia and New Zealand – Background to AS/NZS 1170.2 Wind actions", AWES-HB-001-2022.

Standards Australia, (2021), "Structural design actions. Part 2 Wind actions", Australian/New Zealand Standard, AS/NZS 1170.2:2021.