Wall edge opening and internal pressure

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ABSTRACT

The internal pressure in a building is similar to the external pressure at a small dominant opening on the edge of a wall. Increasing envelope porosity reduces the internal pressure. AS/NZS 1170.2 (2021) satisfactorily estimates the peak negative pressures but may underestimate the peak positive pressures in a building that does not have a porous envelope.

INTRODUCTION

The external pressure at “a dominant” opening on the envelope has a significant influence on the pressure inside a building. For an opening with an area larger than six times other openings on the envelope, the wind loading standard, AS/NZS 1170.2 (2021) specifies the internal pressure aerodynamic shape factor, $C_{shp,i} = C_{pi} \times K_v$, where, the internal pressure coefficient $C_{pi} = (K_a \times K_l \times C_{pe})$. Here, C_{pe} is external pressure coefficient at the opening, K_a is Area reduction Factor, K_l is Local pressure Factor and K_v is Open Area-Volume Factor. The porosity ε, (defined as the ratio of effective leakage area to the surface area of the building envelope) typically ranges from 10^{-4} to 10^{-3}.

An open door or window or an opening caused by debris impact may generate large internal pressures in strong winds, and in combination with large external pressures acting in the same direction will result in large net pressures across the envelope. This scenario, a common cause of roof and wall failures in windstorms, is often the governing design criterion. The magnitude of the internal pressure will depend on the size and location of the opening, the volume of the building and the background porosity.

Internal pressures measured in model-scale and full-scale buildings with a range of openings in the envelope by Liu (1978), Holmes (1979), Ginger et al (1997), and Humphreys and Ginger (2022) compare favourably with theoretical analysis. The internal pressure specified in AS/NZS 1170.2 (2021) are based on theory and are derived from the external pressures at the openings and their sizes. The validity of the internal pressures given for a small, dominant opening on a wall is often questioned by designers. This paper presents the internal pressures in a building with a small-dominant opening at the edge of a wall and compares the values with the external pressures at the opening, and with data in AS/NZS 1170.2 (2021).

CHARACTERISTICS OF INTERNAL PRESSURE

Equation 1 is the basis for the internal pressure coefficients in AS/NZS 1170.2 (2021) for a given A_W/A_L ratio in a building. Here, windward opening area (A_W), leeward opening area (A_L), mean internal pressure coefficient ($C_{\bar{p}_I}$), mean external windward pressure coefficient ($C_{\bar{p}_W}$) and mean external leeward pressure coefficient ($C_{\bar{p}_L}$). Previous studies have shown that the mean internal pressures can be satisfactorily estimated using Equation 1. Equation 1 shows that the mean internal pressure is equal to the mean external pressure at the opening for a building with a single opening.

$$C_{\bar{p}_I} = \frac{C_{\bar{p}_W}}{1+\left(A_L/A_W\right)^2} + \frac{C_{\bar{p}_L}}{1+\left(A_W/A_L\right)^2} \tag{1}$$

For a case where the size of a wall opening is greater than six times all other openings (including background porosity), Table 5.1(B) in AS/NZS1170.2 (2021) stipulates that the internal pressure is equal to the external pressure at the opening. In addition, the response of internal pressure to external pressure fluctuations also depends on the volume of the building. Holmes and Ginger (2012) analysed many studies and introduced the open area-volume factor, K_v given in Clause 5.3.4 of AS/NZS1170.2 by Equation 2, to relate the peak internal pressure to the peak external pressure at the single opening,

$K_v = 1.05 + 0.15[\log_{10}(100(A^{3/2}/Vol)]$ for $0.09 \leq 100(A^{3/2}/Vol) \leq 3$

$K_v = 0.85$ for $100(A^{3/2}/Vol) < 0.09$;

$K_v = 1.085$ for $100(A^{3/2}/Vol) > 3$ (2)

MODEL SCALE STUDIES

External and internal pressures were measured on a 1/50 model of the 10 × 20 × 10 m building shown in Figure 1 with a range of wall openings, in the wind tunnel at James Cook University, by Nosworthy (2023) and Simkins (2023). The tests were carried out in an approach flow simulated to terrain category 2.5. This paper presents the external pressures averaged over the four Taps shown in Figure 1 representative of the external pressures on the 2.35m × 1.7m opening at the edge of the 20 m long wall, and the internal pressures for winds approaching from, $\theta = 0^\circ$ to 360° at 5° intervals. Two additional tests were carried out with background wall porosity of 0.13% and 0.27%. The external and internal pressures varying with time $p(t)$ were analysed, and the mean, maximum and minimum, pressure coefficients in an observation period of 10 min in full-scale: $C_{\bar{p}} = \frac{\bar{p}}{\frac{1}{2}\rho \bar{U}_h{}^2}$, $C_{\hat{p}} = \frac{\hat{p}}{\frac{1}{2}\rho \bar{U}_h{}^2}$ and $C_{\check{p}} = \frac{\check{p}}{\frac{1}{2}\rho \bar{U}_h{}^2}$, where ρ is the density of air and $\bar{U}_h$ is the mean wind speed at roof height, h =10m.

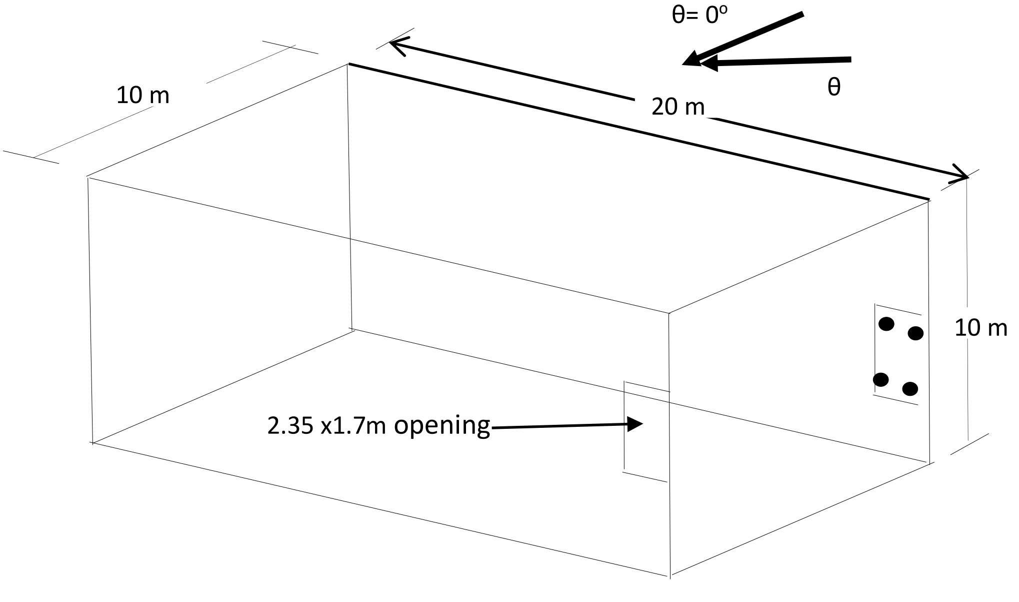

Figure 1. 10m × 20m × 10m building with a 2.35m × 1.7m opening at the edge of a wall

RESULTS AND DISCUSSION

The mean external *Cp*s averaged over the four Taps and the mean internal *Cp*s for the non-porous (0% porosity) case for $\theta = 0^o$ to 360^o, are presented in Figure 2. Figure 2 shows that the mean internal pressures (for θ) are "equal" to the mean external pressures at the averaged over the four Taps equivalent to the opening (for $180^o - \theta$), in agreement with Equation 1 and other previous studies. The variation of the mean internal *Cp* with background porosity, ε, of 0.13% and 0.27% are shown in Figure 3. The mean internal pressure decreases in magnitude with increasing porosity, especially when the opening is on the windward wall and experiencing positive pressures, in agreement with Equation 1.

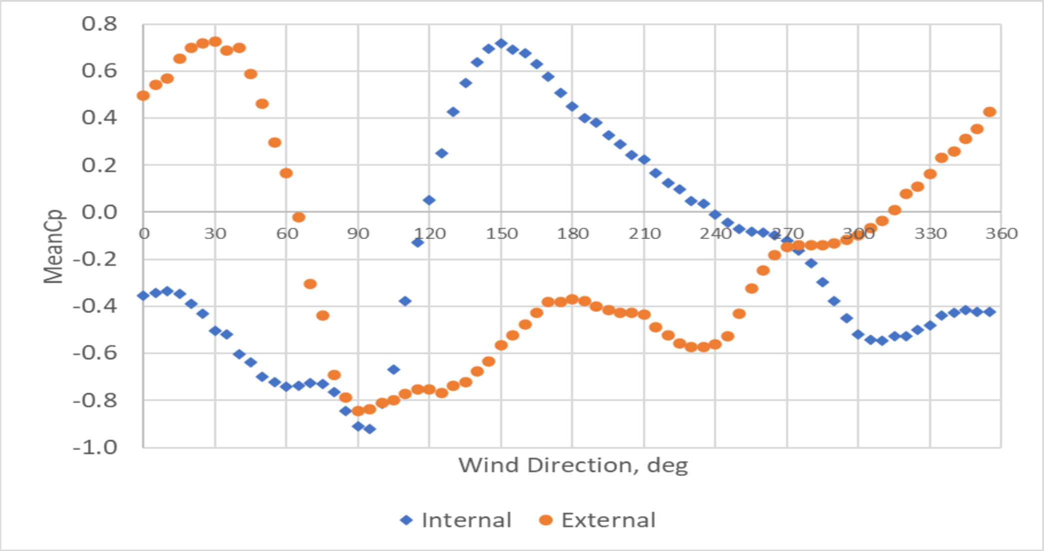

Figure 2. Mean external and internal C_p vs wind direction – Non porous

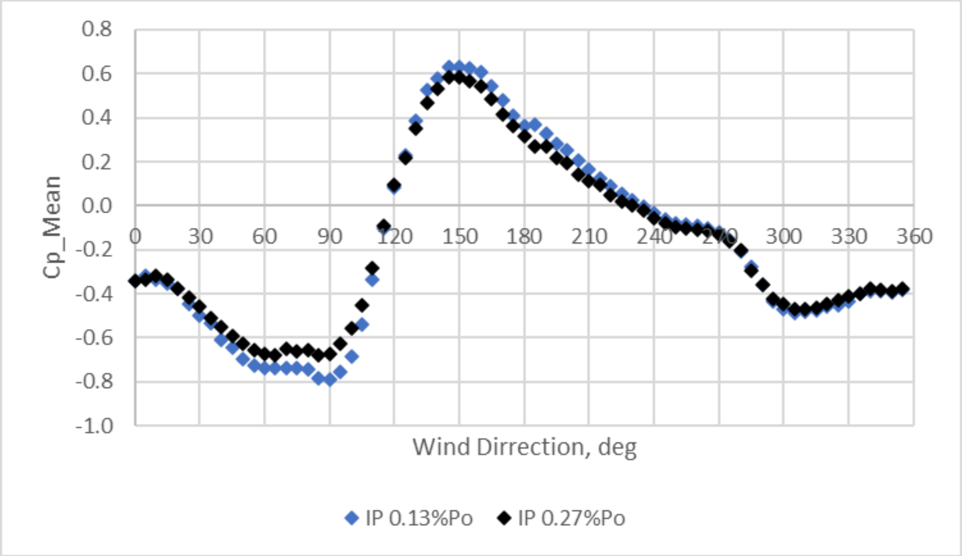

Figure 3. Mean internal C_p vs wind direction: ε = 0.13% and 0.27%

The maximum and minimum external C_ps averaged over the four Taps and the maximum and minimum internal C_p for the 0% porosity case for $\theta = 0^\circ$ to 360°, are presented in Figure 4. The peak internal pressure coefficients ($C_{shp,i} \times G_U^2$) derived from AS/NZS1170.2 (2021) are also shown in these Figures. Here, the velocity gust factor, $G_U = 1.7$. The opening area, A is 4 m^2, and the dimension "a" from Clause 5.4.4 of AS/NZS1170.2 is 2 m. The Local Pressure Factor, $K_l = 1.5$, when $\theta = 90^\circ \pm 45^\circ$ and 1.0 for all other wind directions. From Clause 5.4.2, the Area reduction Factor, $K_a = 1.0$. Applying Volume (Vol) of 2000 m^3, gives 100 ($A^{(3/2)/}Vol$) = $100 \times 4^{(3/2)/}2000 = 0.4$ and $Kv = 0.95$ from Equation 2.

The corresponding peak internal pressure coefficients derived from AS/NZS 1170.2 (2021) are: -1.37 for $\theta = 0^\circ \pm 45^\circ$, -2.68 for $\theta = 90^\circ \pm 45^\circ$, +1.92 for $\theta = 180^\circ \pm 45^\circ$, and -1.37 for $\theta = 270^\circ \pm 45^\circ$, as shown in Figure 4.

Figure 4 shows that minimum internal pressures (for θ) are "equal" to the minimum external pressures at the opening (for $180^\circ - \theta$), but the maximum internal pressure is significantly higher than the external pressure and also underestimated by AS/NZS1170.2.

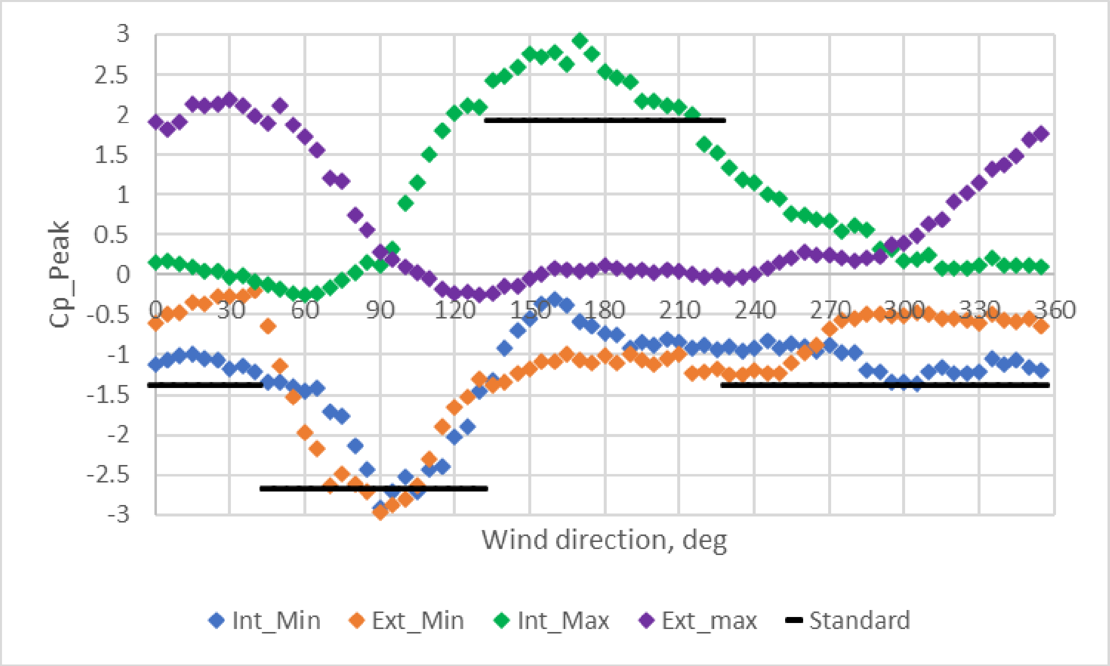

Figure 4. Peak external and internal C_p vs wind direction: Non porous

The variation of the peak positive and negative internal pressure with porosity of 0.13% and 0.27% are shown in Figure 5. The corresponding peak pressures ($C_{shp,i} \times G_U^2$) from AS/NZS1170.2 (2021) are also shown in these figures. These figures show that the peak internal pressure decreases in magnitude especially when the opening experiences large positive pressures for $\theta = 120^\circ$ to 180° or large negative pressures for $\theta = 85^\circ$ to 115°, compared to values in Table 5.1B of AS/NZS 1170.2 (2021).

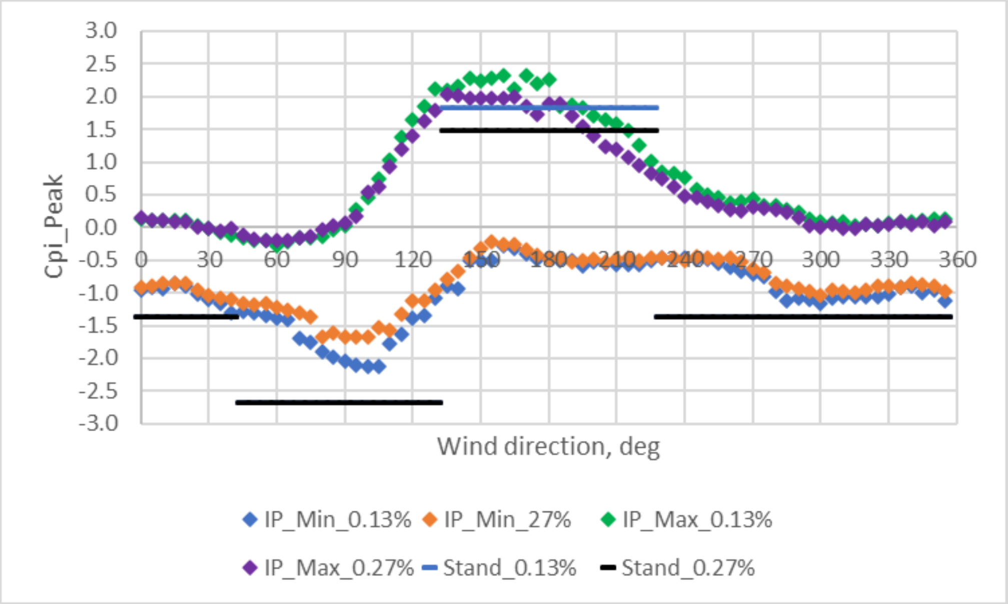

Figure 5. Peak Internal C_p vs wind direction: ε = 0.13% and 0.27%

CONCLUSIONS

The relationship between the external pressure at an opening near the edge of a wall in a building and the internal pressure is presented and assessed against data in AS/NZS 1170.2 (2021).

This study showed that:

The mean and minimum internal pressures closely followed the mean and minimum external pressures at the dominant wall opening on a building and are satisfactorily represented by the revisions in AS/NZS1170.2 (2021). The peak positive internal pressures are underestimated.

The mean and peak internal pressures are reduced in magnitude with increasing envelope porosity.

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