WIND LOADING ON INTER-TENANCY WALLS OF TALL BUILDINGS

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ABSTRACT

The pressure within a building, produced by wind action, is dependent on the magnitude of external surface pressure, the size and position of all openings connecting exterior to interior of the building and the effective enclosed volume. Internal pressure fluctuations within a sealed building are generally small in magnitude and intensity in comparison with its external pressures. But when there are dominant openings (operable façades) or sudden failures across the exterior façade, the building interiors can experience wind pressures of similar magnitude to that of the exterior. Therefore, in such cases, it becomes essential to determine the realistic values of wind pressures to be used for the design of inter-tenancy walls. This paper outlines a methodology using wind tunnel pressure measurements to calculate the wind loads on the inter-tenancy walls of tall buildings (i.e. walls separating individual apartments and do not include the walls within the same apartment).

Keywords: Internal pressure, Inter-tenancy wall, Net pressure coefficients, Wind loading.

Introduction

With the advancements in sustainable building designs, more and more contemporary architectural components as automated building vents or operable windows are being used in modern buildings. These innovative systems present further challenges for engineers as they replace conventional cladding elements [Cochran and Peterka (2001); Irwin and Sifton (1998)]. Internal pressures form a large portion of cladding design pressures on a building where envelope breach occurs as a result of flying debris damage, windows/doors left open during a storm or motorized openings are subjected to a power failure [Cochran and Peterka (2001)]. The high internal pressure in combination with the external pressure acting in the same direction could result in large net pressures across the envelope and can cause façade failures during windstorms. As a result, the internal walls may experience wind pressures similar to those on the exterior façade which is a predominant reason for the internal wall failure during windstorms.

Inter-tenancy walls refer to those separating individual apartments and do not include the walls within the same apartment. The design of internal partitions within the same apartment or unit is not considered critical as these walls rarely create an effective air-lock between either sides, as they are mostly left open. On the other hand, inter-tenancy walls are usually sealed for acoustic and fire safety reasons and could be subjected to high net wind pressures depending on the situation on either sides of the inter-tenancy walls. Further, the integrity of the inter-tenancy walls is important to restrict progressive failure of façades and water damage inside the apartments during storms. Even though internal pressure acting on external façades have always been a subject of interest to many, the wind pressure acting on the inter-tenancy walls is often neglected. A study by Aurelius and Rofail (2006) is the only one available. Under these circumstances, an investigation on the wind loading on inter-tenancy walls seems warranted, which is the subject of this paper.
Methodology

Wind Tunnel Testing and Data acquisition

Fig. 1 Image showing a scaled model in RWDI’s Wind Tunnel facility

Since many decades, wind tunnel testing has been widely used to obtain external pressure coefficients. Reasonable methods have also been proposed for obtaining net pressure measurements from wind tunnel tests for the estimation of internal pressures in the event of a dominant opening occurring using instantaneous point pressure measurements at potential opening locations [Dale et al. (2012) and Cochran and Peterka (2001)].

A scaled model in RWDI Wind tunnel facility is shown in Figure 1. RWDI's boundary layer wind tunnel facility simulates the mean speed profile and turbulence of the natural wind approaching the modeled area by having a long working section with a roughened floor and specially designed turbulence generators, or spires, at the upwind end. Floor roughness and spires have been selected to simulate the appropriate terrain conditions for the case study.

Pressure taps, which measure wind pressure on the surface of the model, were installed on the outside surfaces of the scaled building model. The distribution of pressure taps on the model will take into consideration possible regions that represent the location of operable portions of the façade. Commonly, the inter-tenancy wall is designed to work as linked system and as such the net pressure on the inter-tenancy wall is the critical combination of the pressure on either side of inter-tenancy wall. These differential pressures will be measured by simultaneously measuring the instantaneous pressures on the adjacent pressure taps on each level across elevations. The pressure taps were strategically placed taking into consideration the respective floor plans for locating the inter-tenancy walls, separating
adjacent apartments, so as to obtain worst differential combinations along the entire building height. The test model including immediate surroundings are mounted on a turntable, allowing any wind direction to be simulated by rotating the model to the appropriate angle in the wind tunnel for 36 wind directions at 10° intervals. During tests, the instantaneous wind pressures at each pressure tap will be measured as time series for each of these 36 wind azimuths, and this wind tunnel data is used for further analysis of various parameters. A sample sketch of load paths investigated to obtain inter-tenancy wall pressures is shown in Figure 2.

Fig. 2 Plan showing schematic representation of load combinations

Pressure tap combinations on adjacent apartments considered for the calculation of inter-tenancy wall pressures in a typical model is shown Figure 3.

Fig. 3 Pressure tap combinations on adjacent apartment considered
Analysis

The mean, root-mean-square (RMS) and the statistical maximum and minimum pressure coefficients, based on the reference wind pressure were derived from the wind tunnel data. For prediction of full-scale wind pressures acting on the building as a function of return period, the wind tunnel data were combined with a statistical model of the local wind climate using Upcrossing Method. Scaling factors derived using the ESDU methodology, for predicting the effect of changes in the earth’s surface roughness on the planetary boundary layer, are also accounted at the analysis stage to account for remaining minor differences between the expected wind speed and turbulence properties, and the basic upwind flow conditions simulated in the wind tunnel. This data were analyzed for different scenarios as discussed in Scenarios 1 and 2.

During the analysis stage, one another important parameter the correlation between external and internal pressure has been given careful consideration. Since the measurements are taken only at the external façade, the assumption of internal pressure to be equal to the external pressure at the dominant opening location seems an overestimation. Considering the volume of the units and the area of the dominant opening, there will be a time lag between the peak occurrences of the external and internal pressures, and further the magnitude of internal pressure will subside as well. Eurocode 1 (EN 1991-1-4:2005) suggests an internal pressure coefficient as 0.9 times the external pressure coefficient, when the area of the openings at the dominant face is at least 3 times the area of the openings in the remaining faces.

The lack of correlation between external pressure and internal pressure during façade breach is also investigated by Irwin and Sifton (1998). According to their expression, the reduction factor is found to be about 0.9 (90%) for a typical apartment area of 1000 ft, floor height of 12 ft and the breach opening of 1 ft² (12” x 12”). Based on these evidences, we have calculated the internal pressure as 90% of the external pressure.

Scenario-1: When a single dominant opening / breaching occurs on any external wall in an apartment

A sketch showing this case is depicted as Scenario-1 in Figure 4 where we assumed a 100% probability of opening occurring on any wall in an apartment. Considering the volume and open area within the apartment, it is assumed that 90% of the external pressure, read by the pressure tap on the dominant opening location, acts on one side of the inter-tenancy wall whereas uniform leakage internal pressure acts on its opposite side. Thus the net pressure acting on the inter-tenancy wall will be the sum total of 90% of external pressure and the worst-case uniform leakage pressure. Here, the building’s positive external pressure is augmented with negative internal pressure and vice versa for arriving at the worst-case wind pressure loadings.

Scenario-2: When dominant opening / breaching occurs simultaneously on façades of adjacent apartments

A sketch showing this case is depicted as Scenario-2 in Figure 4. When breaching or dominant opening occurs simultaneously on adjacent apartments, a considerable percentage of external façade pressure is being inflicted on either side of the inter-tenancy walls. In order to obtain the resultant differential pressure, net pressure coefficients were determined by simultaneously measuring the instantaneous pressures on adjacent pressure taps on each level across elevations during wind tunnel tests. Here also, considering the volume and open area
within the apartment, 90% of the net pressures determined were considered when the probability of opening is 100%.

![Inter-tenancy Wall](image)

**Scenario-1: Single dominant opening on one unit**

**Scenario-2: Simultaneous openings on adjacent units**

Fig. 4 Pictorial representation of the scenarios considered

*Inter-Tenancy Wall Pressures Corresponding to Different Risk Levels of Breach*

In order to evaluate the risk of a particular net pressure acting on inter-tenancy wall, one has to consider two cases: wind-induced internal pressure due to dominant openings on the façade; and due to uniform leakage through the façade cracks/gaps in the absence of dominant openings (i.e., enclosed façade). For raising the uniform leakage pressure (in the absence of dominant openings) equivalent to the dominant opening case, wind speed has to be very high. It appears that the wind speed corresponding to 10,000 year return period is required for producing the same internal pressure under the uniform leakage condition. Combined return period for the same pressure with particular risk is

\[
\frac{1}{T} = \frac{r}{T_o} + \frac{(1-r)}{T_{no}}
\]

(1)

Where,  
\(T\) - Return period associated with particular probability of opening.  
\(r\) - Probability of dominant opening  
\((1-r)\) - Probability of no dominant opening.  
\(T_o\) - Return period associated with dominant opening, which is 50 year.  
\(T_{no}\) - Return period associated with uniform leakage (no dominant opening), which is 10,000 year.

From equation (1), the combined return period, integrating cases of dominant opening; and uniform leakage through cracks in the absence of dominant opening, have been worked out. The probability of opening occurring due to window being left open or possible façade breach was considered for three risk levels, 100%, 50% and 25% breach. Inter-tenancy wind loads pertaining to these risk levels were then computed, for the 50 year return period.

**Results**

The methodology explained above has been used to determine the pressures on the inter-tenancy walls for a few projects tested at RWDI.
Case Study 1

A 125 m tall tower of regular cross-sectional area located in Manila, Philippines tested in RWDI’s Wind Tunnel facility was selected next. Basic wind speed as per National Structural Code of Philippines used for the detailed analysis of this case study was 200 kph 3-second gust speed at 10 m in open terrain with an importance factor of 1.0 on wind pressures. The typhoon simulation for the location was provided by Applied Research Associates, Raleigh, NC using the Monte Carlo Technique with over 100,000 years of tropical storms data to account for the variability of typhoon wind speed with direction.

The resulting differential pressure combinations thus obtained plotted over the building height for Scenarios 1 and 2 have been presented in Figure 5. From Figure 5, it can be seen that majority of the pressure values do not seem to fluctuate much with respect its mean with increasing building height, with the exception of a few outliers.

Fig. 5 Wind pressures on Inter-tenancy walls – Case Study 1

For Case Study 1, a mean value of 2.5 kPa was selected out of the pressures obtained from Scenarios 1 and 2 for a 50 year return period, setting apart a few outliers whose magnitudes were comparable to the maximum external positive pressure obtained for this
study building. Calculations for determining the combined return period have been tabulated in Table 1.

Table 1: Calculation of combined return period - Case Study 1

<table>
<thead>
<tr>
<th>r</th>
<th>1</th>
<th>0.5</th>
<th>0.25</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1-r)</td>
<td>0</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td>T_{no} years</td>
<td>10,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T_{o} years</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>50</td>
<td>99.50</td>
<td>197.04</td>
</tr>
</tbody>
</table>

This mean value of 2.5 kPa has been used in the computation of inter-tenancy wall pressures for different breach levels and the results corresponding to each breach level is being summarized in Table 2.

Table 2: Inter-tenancy wall pressures - Case Study 1

<table>
<thead>
<tr>
<th>Risk levels of breach</th>
<th>100%</th>
<th>50%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (kPa)</td>
<td>2.5</td>
<td>2.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Case Study 2

A 158 m tall residential tower of regular cross-sectional area located in Seattle, Washington, tested in RWDI’s Wind Tunnel facility, was selected next. Basic wind speed as per IBC 2012 / ASCE 7-10 (Risk Category III) used for the detailed analysis of this case study was 185.1 kph 3-second gust speed at 10 m in open terrain with an importance factor of 1.0 on wind pressures.

The resulting differential pressure combinations for Scenarios 1 and 2 have been worked out and the combined return period calculated similar to Case Study 1.

For Case Study 2, a mean value of 2.0 kPa was selected out of the pressures obtained from Scenarios 1 and 2 for a 50 year return period, setting apart a few outliers whose magnitudes were comparable to the maximum external positive pressure obtained for this study building. This mean value has been used in the computation of inter-tenancy wall pressures for different breach levels and the results summarized in Table 3.

Table 3: Inter-tenancy wall pressures - Case Study 2

<table>
<thead>
<tr>
<th>Risk levels of breach</th>
<th>100%</th>
<th>50%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (kPa)</td>
<td>2.0</td>
<td>1.75</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Case Study 3

A 175 m tall residential tower of regular cross-sectional area located in Jersey City, New Jersey, tested in RWDI’s Wind Tunnel facility was considered next. Basic wind speed as per ASCE 7-05 used for the detailed analysis of this case study was 160.9 kph 3-second gust speed at 10 m in open terrain with an importance factor of 1.0 on wind pressures. The hurricane simulation for the location was provided by Applied Research Associates, Raleigh, NC using the Monte Carlo Technique with over 100,000 years of tropical storms data to account for the variability of hurricane wind speed with direction.
The resulting differential pressure combinations for Scenarios 1 and 2 have been worked out and the combined return period was calculated as explained for the above cases.

For Case Study 3, a mean value of 2.75 kPa was selected out of the pressures obtained from Scenarios 1 and 2 for a 50 year return period, setting apart a few outliers whose magnitudes were comparable to the maximum external positive pressure obtained for this study building. This mean value has been used in the computation of inter-tenancy wall pressures for different breach levels and the results summarized in Table 4.

Table 4: Inter-tenancy wall pressures - Case Study 3

<table>
<thead>
<tr>
<th>Risk levels of breach</th>
<th>100%</th>
<th>50%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (kPa)</td>
<td>2.75</td>
<td>2.5</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Discussion

The case study results are compared with ASCE 7-05 in Table 5. On comparing, it was inferred that the inter-tenancy loads obtained for the three case studies were greater than the wind-induced internal pressure for the building but less than the highest external pressure obtained from the wind-tunnel tests. The inter-tenancy loads even at 25% chance of dominant opening appear higher than the dominant opening internal pressures from ASCE 7-05, where the value of product of gust effect factor and internal pressure coefficient, i.e., GC_{pi} = ± 0.55. It can be inferred that the Zone 4 façade loads from ASCE 7-05 can be a reasonable approximation for the design of inter-tenancy walls in case of expected dominant openings, which equates to total GC_{pi} of 1.08.

Table 5: Case study results comparison to ASCE 7-05

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Wind Tunnel Results</th>
<th>ASCE 7-05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Highest external pressures (kPa) (including internal pressure) (kPa)</td>
<td>Internal pressures (kPa)</td>
</tr>
<tr>
<td>Case 1</td>
<td>+3.5, -4.5</td>
<td>±0.50</td>
</tr>
<tr>
<td>Case 2</td>
<td>+2.5, -3.5</td>
<td>±0.3, -0.6</td>
</tr>
<tr>
<td>Case 3</td>
<td>+2.5, -4.0</td>
<td>±0.35, -0.7</td>
</tr>
</tbody>
</table>

Conclusions

The present study stipulates a methodology to determine the net wind pressure acting on the inter-tenancy walls using wind tunnel local pressure measurements. In summary, it was inferred that inter-tenancy wall loads are largely dependent on the dominant opening area on the façade and the chance of having one. Further, the loads are also dependent on building geometry, floor plan, geographic location and its immediate surroundings. For the case studies considered here, the wind loads obtained for inter-tenancy walls, neither exceeded the highest external façade pressure value nor did it go below the minimum internal pressure leakage. Hence, it is not advisable to pick the value of internal pressure alone for the design of inter-tenancy walls, especially when there may be chances of dominant opening occurring. However, determination of loads on inter-tenancy walls is case specific and can be
determined accurately by wind tunnel measurements along with the traditional cladding studies.

References


