Inter-Tenancy Wall Design for Tall Buildings with Operable Facades

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1. Introduction

In recent years a trend toward high-rise living has emerged. As a result, we see today many tall residential buildings throughout the various urban centres of Australasia, and as is the case for most residential buildings, the facades of these buildings feature operable elements (typically windows and balcony doors).

In response to this, Rofail *et al* (2003, 2004) have published a methodology for accurately accounting for the net façade pressures and inter-tenancy wall pressures for these types of structures.

To date the wind loads on the inter-tenancy walls have largely been ignored. This oversight can lead to:

- Damage amplification in the case of a failure in the facade or in the event of an extreme wind striking an open facade. Anecdotal evidence has suggested that significant inter-tenancy wall deformation has occurred within some tall buildings in Australia.

- Increased net façade design pressures.

The aim of this paper is to firstly present two alternative methods to determine the net pressure coefficients on the inter-tenancy walls within a tall building with an operable facade, namely:

- The use of data from the AS/NZS 1170.2:2002

- The use of wind tunnel modelling

A comparison of the resulting design pressures coefficients from these two methods is also presented. Based on this comparison it is sought to provide recommendations that could be detailed within the AS/NZS 1170.2:2002 such that the issue of design loads on Inter-Tenancy walls is specifically addressed.

2. Background

A recent study conducted by Windtech of the design pressures on the inter-tenancy walls within a tall building provided the impetus for this paper.

Tests were conducted to determine what would be the effects of ignoring the inter-tenancy walls on the net façade pressures of a tall building. The following were investigated:

- effect of the operable elements of the façade on the internal pressures and consequently the net façade pressures
- the effect of the assumed probability of the most critical combination of operable elements of a facade being open during an extreme wind event and their effect on the net facade pressures

These results of the latter are indicated in Figure 1.

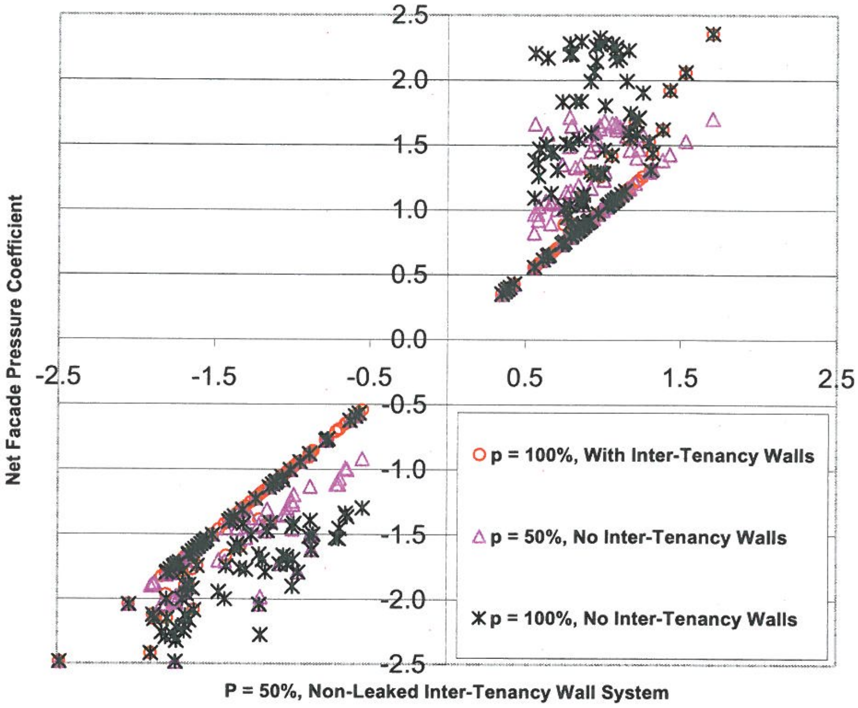

Figure 1: Net Facade Pressure Coefficient based on different methodologies of Inter-Tenancy Wall design

Figure 1 indicates, as expected, that should the probability, p, of the most critical load combination between two adjacent apartments occurring during an extreme wind event increase (from 50% to 100%) then the net facade pressure will also be increased.

Though more importantly, it also indicates that if the inter-tenancy walls are ignored then the net facade pressures can increase dramatically. A feasibility study confirmed the economic benefits of designing for the inter-tenancy walls in terms of overall cost.

Based on these results, a detailed investigation was undertaken to determine a suitable methodology for the determination of the design pressures on inter-tenancy walls, and to determine how this relates to the current provisions in the wind loading standard (AS/NZS1170.2:2002).

3. Methodology

3.1 Using AS/NZS 1170.2:2002

The Australian/New Zealand Standard AS/NZS1170.2:2002 does not formally stipulate a methodology for determining the net pressure coefficient on an inter-tenancy wall.

However, it is proposed that the net pressure coefficient on the inter-tenancy wall can be calculated as the difference between the internal pressure coefficients on either side of the inter-tenancy wall in question.

The wind loading standard stipulates that the internal pressure coefficient for large dominant openings (Table 5.1(B)) can be equated to the external pressure coefficient, $C_{p,e}$, that corresponds to the dominant opening in question. It should be noted that the combination factor K_c, which should be applied when determining the aerodynamic shape factor C_{fig} for internal pressures ($C_{fig} = C_{p,i} \times K_c$) is not included within these calculations as we are not examining forces on major structural elements. However, it should be noted that the correlation between the pressures at the two dominant openings located on two adjacent faces of a building would tend to be high and a K_c factor of 1.0 would be appropriate.

Commonly, the inter-tenancy wall is designed to work as a linked system and as such the net pressure on the inter-tenancy wall is the most critical combination of the internal pressures on either side of the inter-tenancy wall.

If the inter-tenancy wall is designed to work as an isolated system then the net pressure on the inter-tenancy wall is the combination of the internal pressure on the side of the inter-tenancy wall that faces the dominant opening combined with the pressure in the cavity, which is typically assumed as effectively sealed. An isolated wall system is less critical than a linked system and hence will not be examined in detail within this paper.

3.2 Wind tunnel modelling using risk analysis approach

A methodology similar to the one described in this paper for providing net façade pressures for an operable façade using wind tunnel modelling was presented in 2003 (Rofail and Aurelius). This technique is more versatile than that proposed by Irwin and Sifton (1998) in that information regarding the rate of change of wind direction over time is not required.

With regards to the internal and net pressure effects within a tall building with an operable façade there are 2 types of unit configurations, as shown in Figure 2. Figure 2 also illustrates the 2 possible categories of inter-tenancy walls. With regards to the design of inter-tenancy walls, the key difference between the 2 wall types illustrated is whether the operable elements for one of the units are located on different aspect(s) to the operable façade elements of the unit on the other side of the inter-tenancy wall.

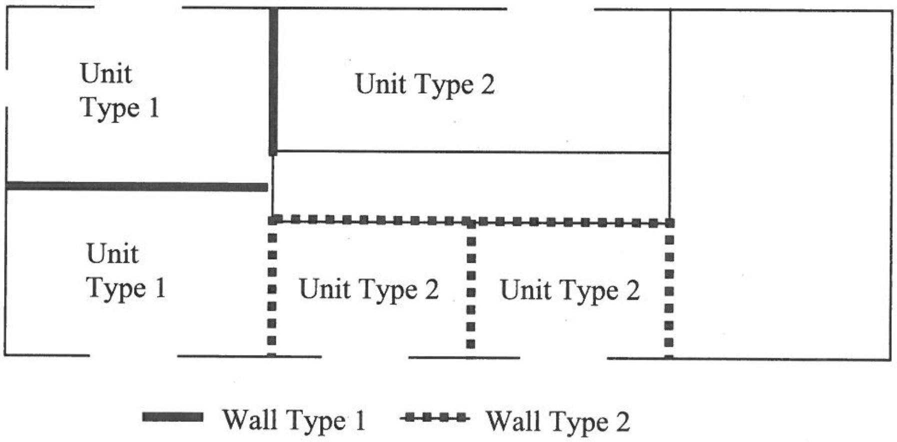

Figure 2: Different Unit and Inter-Tenancy Wall Configurations

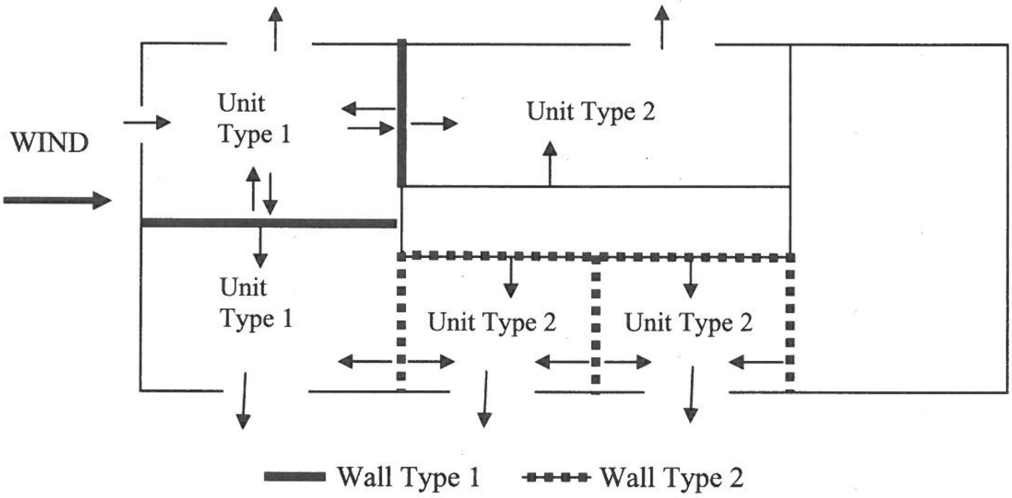

Figure 3: A Sample Load Combination for the different Inter-Tenancy Wall Configurations

Sensors are placed at specific locations within each unit that represent the location of operable portions of the façade, i.e. windows or balcony doors. The pressure differential used to compute the internal pressure is taken from different combinations of facade openings from the two adjoining units. This is shown in Figure 4 for the same hypothetical floor. The curved lines represent the load combinations for the subject walls (Type 1) due to the combination of openings in the building facade.

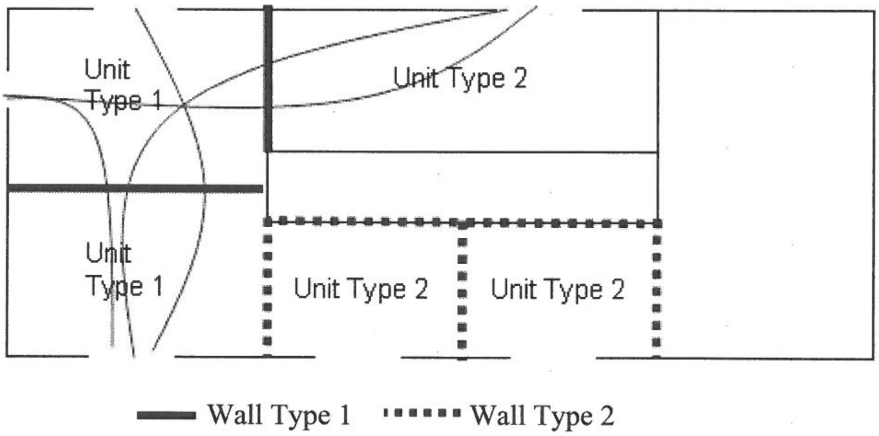

Figure 4: Load Combinations for Inter-Tenancy walls

The design of the internal partitions within a unit is not considered critical as these walls rarely create an effective air-lock between either side and hence can lead to pressure equalisation. On the other hand, inter-tenancy walls are usually sealed for acoustic and fire safety reasons.

The first step in the risk analysis approach is to assign a level of probability, p, to the case where the most critical combination of openings is in place at the same time as the extreme wind event. The effective internal pressure for the design of an inter-tenancy wall becomes:

$$C_{pi} = C_{pi,s} .(1\text{-}p) + C_{pi,o} .p \qquad (1)$$

where

$C_{pi,s}$ represents the internal pressure coefficient for an effectively sealed building

$C_{pi,o}$ in the case of a corner unit (Wall Type 1), this represents the most critical differential pressure across the inter-tenancy wall resulting from the most critical combination of openings on either side of the inter-tenancy wall;

or

in the case of a Wall Type 2, this represents the internal pressure coefficient resulting from the most critical dominant opening from one side of the wall with the corresponding most critical pressure for an effectively sealed unit on the other side of the wall.

p is the probability of the most critical opening being open in the event of the extreme non-cyclonic wind event.

The level of probability needs to be agreed with the client and the structural engineer. This level of probability is typically in the range of 0.5 to 1. It has been our experience to suggest a probability of 0.5, which is in line with the permissible stress design philosophy.

A probability of 1 is usually selected when analysing the effect of the extreme non-cyclonic wind event in a cyclonic region. The rationale behind this is that in tropical regions the climate is such that occupants tend to leave their windows open for natural ventilation. In cyclonic regions (Regions B, C and D) it needs to be established at the beginning whether the façade is to be designed as impact resistant. Our experience is that with the risk analysis approach, it is far more efficient to base the design on an impact resistant facade design, with the condition that a system is in place to ensure that the building management is able to ensure all operable parts of the façade are shut at the onset of a cyclone. In that case, the risk analysis approach is based on the most critical of the following two cases:

- Effectively sealed in the event of a cyclonic extreme wind event
- Open in the event of a non-cyclonic extreme wind event

The rationale behind this is that for cyclonic wind events there is usually several hours warning before the onset of the cyclone, while a non-cyclonic extreme wind event (thunderstorm) can occur at very short notice. In the open (non-cyclonic) scenario, a risk analysis approach can be adopted as per the non-cyclonic regions. This approach is described in the following subsections.

In the case of Wall Type 1, if an isolated wall system is used then the wall is treated in the same way as a Wall Type 2, isolated wall system. If a linked wall system is used, then all dominant openings for both units on either side of the wall need to be represented by pressure taps. An exhaustive set of combinations of pressure differentials (measured in real-time) are obtained from the wind tunnel modeling process - an example of such a set of combinations is illustrated in Figure 5. An example of a wind tunnel set-up is shown in Figure 6.

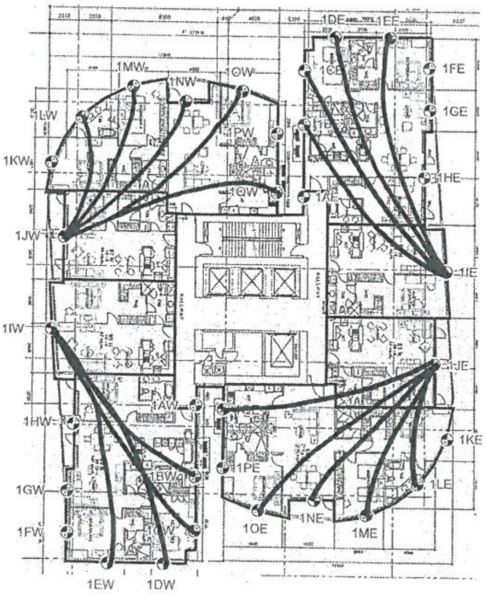

Figure 5: A sample set of load paths investigated to obtain inter-tenancy wall pressures for one of the levels of a 200m tall building

Figure 6: Example of a model set-up at Windtech's wind tunnel facility to determine the design wind pressures for a tall apartment building

In the case of Wall Type 2, all dominant openings for both units on either side of the wall need to be represented by pressure taps. If a linked wall system is used then the opening that corresponds to the highest external pressure is used to represent the internal pressure on one side of the wall. The most critical differential pressure is the combination of that pressure with the most critical pressure for an effectively sealed unit on the other side of the wall. If an isolated wall construction system then the highest value of external pressure from that side of the wall is used.

Having determined a level of combined probability to the case where the most critical combination of openings are in place at the same time as the extreme wind event, the inter-tenancy wall pressure is determined by equation (1).

4. Results

To compare the two methodologies outlined within this paper the experimental results of tests performed on several wind tunnel models were examined. These are summarized in Figure 7.

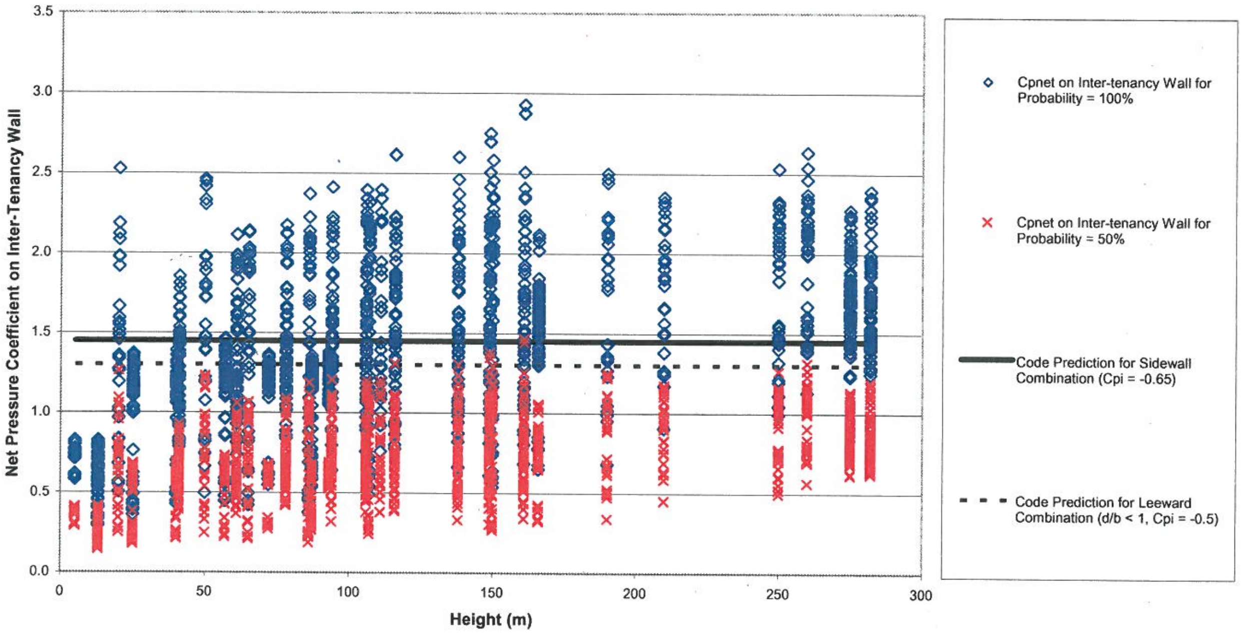

Figure 7: Net pressure coefficient for inter-tenancy wall vs. height

The two sets of symbols on Figure 7 indicate the experimental results obtained through wind tunnel testing based on two probability levels (red: p=0.5 and blue: p=1). It should be noted that net pressure coefficients are based on load paths that are formed between windward and sidewall aspects or between windward and leeward aspects (Type 1 units only). However, for simplicity these two types of load paths have not been differentiated. The horizontal lines represent the net pressure coefficients predicted by the proposed wind loading standard methodology.

In the case where the probability of the critical load combination occurring during the extreme wind event is 0.5 then the experimental results will fall within the results predicted by the proposed wind loading standard methodology, in either a windward/sidewall or windward/leeward load combination case. It is also evident that if the probability of the critical load combination occurring during the extreme wind event is selected as p=1 then the experimental values are generally greater than those predicted using the proposed wind loading standard methodology.

However, please note that the estimates from AS/NZS 1170.2:2002 should be considered only as a guide for buildings in the height range of 200m to 275m as the Wind Loading Standard only applies to only buildings less than 200m in height.

5. Conclusions and Recommendations

Methodologies to determine the net pressure coefficients across an inter-tenancy wall within a tall building involving both the wind loading standard and wind tunnel modelling have been presented.

The proposed methodology using the wind loading standard agrees well with the wind tunnel modelling approach in the case of the critical load combination probability of 0.5.

Should a greater level of critical load combination probability be assumed, as expected, the predictions made using the experimental techniques are generally greater than those predicted by the proposed wind loading standard methodology.

To provide guidance regarding the design of inter-tenancy walls to those wishing to use the wind loading standard it is recommended that the following clause be added:

> ***5.3.4 Inter-tenancy walls:***
> *Wind actions on an inter-tenancy wall within a tall building with an operable façade are obtained by considering the most critical combination of the internal pressures on either side of the wall as determined from Section 5.3.3. In this case the combination factor K_c shall be 1.*

6. References

Irwin PA, and Sifton VL, (1998) "Risk Considerations for Internal Pressures." *Journal of Wind Engineering and Industrial Aerodynamics*, v.77&78, pp.715-23

Melbourne W and Eaddy M, (2004), "Apartment Tower Design Pressures for a Vented Façade", Int. Conf. on Building Envelope Systems and Technologies, Sydney, 29th March to 2nd April.

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Standards Australia, SAA Structural Design Actions, Part 2, Wind Actions. AS/NZS 1170.2:2002.