External wind pressures for a Hong Kong apartment building – wind tunnel test results

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1. Introduction

In Hong Kong, only the very privileged few reside in stand-alone, low-rise houses with large internal volumes. The overwhelming majority of people live in compartmentalised apartments in medium-rise and, more often than not, high-rise buildings. These more typical dwellings can range from three storey town houses, commonly configured with one apartment per floor, to multi-storey towers with heights of 150 m to 250 m that are commonly divided into a number of apartments, each further partitioned into smaller rooms with floor plans as small as 10 to 20 m^2. Neither height nor shape would seem to preclude a Hong Kong apartment building from occupying a vertiginous perch and examples of most types of housing are abundant on both mountainside and reclaimed plateau. Coupled with an active and interesting wind environment that serves up thunderstorms, winter monsoons, typhoons and even tornadoes on an annual basis, the building envelope, in particular glass windows and doors, may be vulnerable to damage caused by strong winds exacerbated by the local topography.

Designing for typhoons in Hong Kong requires the determination of nett wind pressures acting across a cladding element, i.e. the difference between the external wind pressure and the internal pressure. This can be particularly important for well-compartmentalised buildings[1], for which the response time of the internal pressure to external pressure fluctuations at a window opening would be virtually instantaneous. Design pressures would be very large if peak positive and peak negative pressures due to sudden window openings were applied simultaneously and they would almost certainly be well in excess of that specified in wind codes.

This paper reports preliminary wind tunnel model test results for a residential apartment block located within the campus of The Hong Kong University of Science and Technology (HKUST) and investigates external wind pressures at key locations for future application to the study of internal pressures for a typical Hong Kong apartment and comparisons with full-scale measurements.

2. The HKUST Test Building

The test building, shown in Figure 1 along with the location of the test apartment that is the focus of this study, is situated within the HKUST campus at Clear Water Bay and is located on a hillside facing northeast, which is the dominant wind direction for strong winter monsoon winds in Hong Kong[2]. The site has a relatively open exposure to winds from the northeast quadrant, as shown in Figure 2. The building has an

Figure 1: Northeast aspect of test building

overall height of approximately 35 m, with the upper 8 floors used for staff quarters and the lower levels comprising public facilities, and the adjacent ground level is approximately 108 m above mean sea level. The terrain to the northeast of the building slopes steeply downhill and is likely to accelerate wind flows approaching the site from the northeast quadrant.

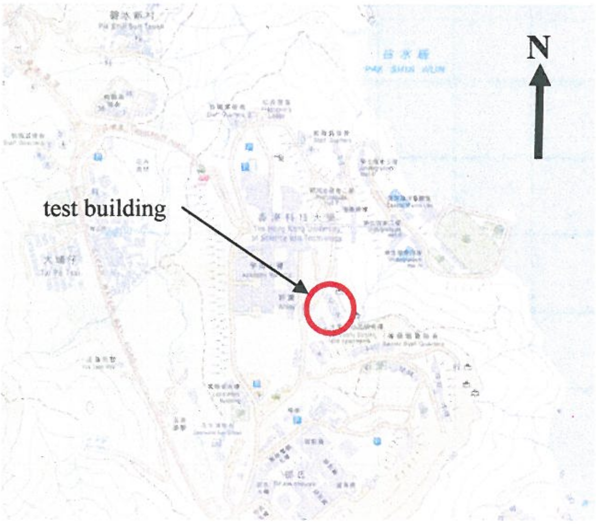

Figure 2: Location and orientation of the test building

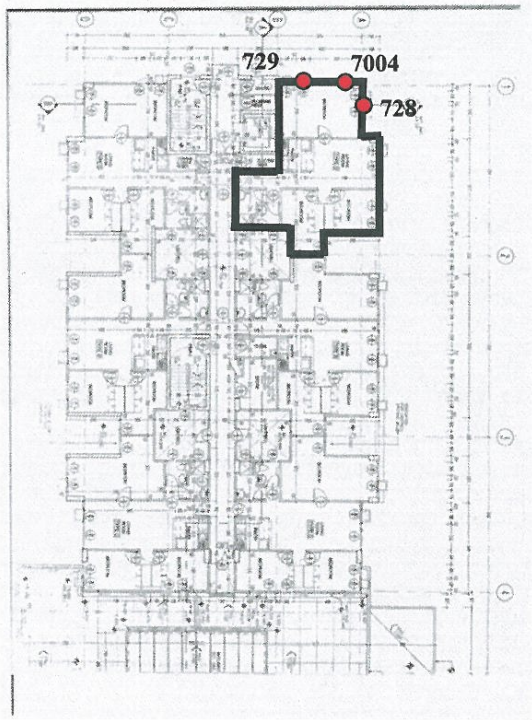

Figure 3: Internal building layout

The internal layout of the building, shown in Figure 3, is similar to most residential buildings found in Hong Kong, separated into six apartments per floor, with three apartments facing northeast and three facing southwest. Each apartment has a similar layout and size (lounge/dining room, open-plan kitchen, three bedrooms, a bathroom and a toilet) and all are accessed through a common corridor. Each room has a standard sized door along with window(s) of different sizes, each of which can be opened to the external environment.

3. Wind Tunnel Study

A 1:400 scale model of the test building was fitted with 102 pressure taps distributed around floors 5, 7 and 8 of the test building. Key pressure taps, designated as taps 728 and 729 in Figure 3, were mounted in locations equivalent to the windows in the corner bedroom of the apartment located in the north-eastern corner of the building on the 7th floor. These locations are consistent with pressure taps that are being used in full-scale studies of the building. An additional tap (7004 in Figure 3) was also mounted close to the corner in a position that was expected to experience large negative pressures for the prevailing wind directions. The wind tunnel model also included the surrounding buildings and topography within a distance of up to approximately 500 m from the building site. The approaching wind simulated the modifying effects of far-field topography on mean wind speed and turbulence intensity profiles relevant to typhoons[3], determined from a 1:2000 scale topography study that included a model extent of up to 10 km.

The model was tested at 11 wind directions encompassing the north-east quadrant, ranging from north (0°) to 100° at 10° increments and also at 45°. For each wind direction tested, measurements were taken at a sample frequency of 800 Hz and low pass filtered during post-processing at 200 Hz. The frequency response of the pressure measurement system was essentially flat up to a full-scale frequency of approximately 2.2 Hz, which is sufficient for typical glazing studies[4]. A minimum of five data samples were taken for each test direction, with each data sample 36 s in length and equivalent to approximately 1 h in full-scale. Approximately 2850 data samples, each equivalent to 1 h in full-scale and requiring approximately 28.5 h of wind tunnel test time, were taken at a wind direction of 45° for more detailed analyses of the external pressure coefficients.

4. Results and Discussion

All pressure measurements are expressed as pressure coefficients referenced to the mean dynamic pressure at a height equivalent to the roof height of the test building. The reference pressure was measured by a Pitot static tube located in undisturbed wind flow upstream of the model.

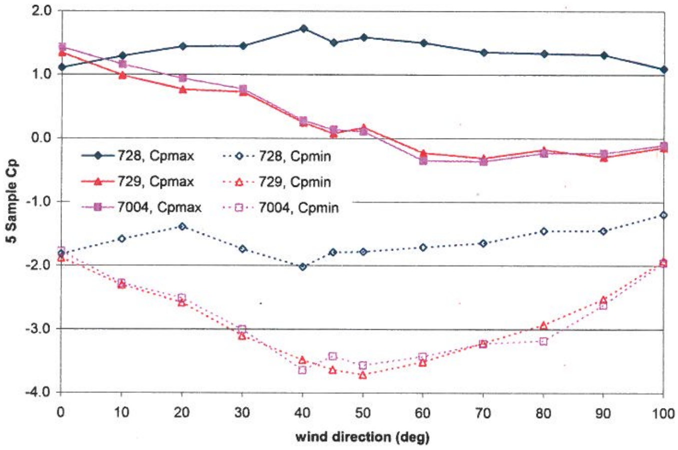

Figure 4: Five sample average maximum and minimum C_p's

Five sample average maximum and minimum pressure coefficients were determined for the three key pressure taps for all measured wind directions. The results shown in Figure 4 indicated that the largest magnitude minimum pressures for taps 729 and 7004 occurred approximately at 45°. Representative peak factors (g_f), presented in Table 1 below, were back-calculated for taps 728, 729 and 7004 from the five sample average maximum and minimum pressure coefficients and the measured mean and standard deviation. Peak factors determined from upcrossing analyses[5] of records corresponding to approximately 1 h in full-scale for the same three taps, for a probability of exceedance of once in 3600 cycles, are also included in Table 1. There is close agreement between the two sets of peak factors, particularly for the large minimum pressures determined at taps 729 and 7004.

Table 1: Representative peak factors, wind direction = 45°

Tap	5 sample max g_f	5 sample min g_f	Upcrossing max g_f	Upcrossing min g_f
728	4.91	4.05	4.00	4.50
729	5.05	4.82	4.91	4.85
7004	5.19	5.28	5.18	4.69

Approximately 750 of the 2850 data samples measured at tap 7004 for a wind direction of 45° were analysed using a Type I Gumbel analysis[6], as shown in Figure 5. Although it is recognised that a Type I

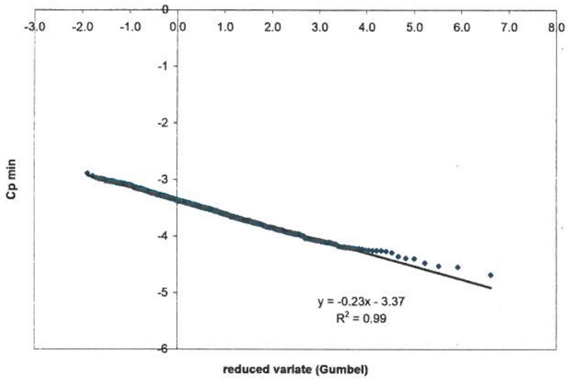

Figure 5: Type I extreme value distribution fitted to minimum pressure coefficients – Tap 7004

distribution may not fit data at higher reduced variates[7], the authors intend to revisit this data at a later stage to further investigate appropriate probability distributions. It is worthwhile noting that the value of the mode determined from the Gumbel analysis (the y-intercept in Figure 5) is very similar in magnitude (-3.37) to the 5 sample average minimum pressure coefficient (-3.43).

5. Concluding Remarks

The results of the 1:400 scale wind tunnel model tests conducted on the HKUST test building will be analysed further and compared with full-scale measurements that are to be conducted over the next 12 months. It is the intention of the authors to utilise results from wind tunnel model tests, full-scale measurements and computational fluid dynamics to assess the adequacy of wind tunnel model test results to be used for predicting likely internal pressures in well-compartmentalised residential buildings.

6. Acknowledgements

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