Scaling parameters for wall pressure zones on low-rise and high-rise buildings

Korah Parackal[1], Murray Morrison[1], Jin Wang[2], Gregory Kopp[2]

[1]Insurance Institute for Business & Home Safety, Richburg, South Carolina

[2]Boundary Layer Wind Tunnel Laboratory, Faculty of Engineering, Univ. of Western Ontario, London, Ontario

ABSTRACT

Design wall pressures coefficients used in several codes and standards are based on wind tunnel data collected in the 1970s and 80s, with limited numbers of pressure taps and aspect ratios. Based on these studies, wall pressure zones had been defined using simplified relationships. For example, 10% of the least horizontal dimension of the building, with other limitations depending on the aspect ratio of the building. This paper will present the current work in progress in determining the updated wall design pressures, with a focus on the selection of scaling parameters that are used to define pressure zones. Additionally, how these parameters vary as building aspect ratios transition from those of a low-rise building to a high-rise building will be explored.

INTRODUCTION

Design pressure coefficients for building surfaces are required for the structural design of building facades and wall cladding elements. Wind pressures on wall surfaces of buildings have been studied by several researchers, however, to a lesser extent of those of roof pressures. These studies, conducted during the 1970’s and 80’s were limited by the technology of the time, with limited numbers of pressure taps and sampling rates that could be measured. The commentary of ASCE 7 (1993) provides an overview of these contributing studies: Wall pressures coefficients in the ASCE -7 Standards have originated from wind tunnel studies performed at Colorado State University (Peterka and Cermak 1975; Cermak 1977; Kareem 1978; Akins and Cermak 1976), and the University of Western Ontario (Davenport, AG and Surry, D 1977; Davenport, Surry, D, and Stathopoulos, T 1978; Stathopoulos 1979). The Australian Wind Loading Standard at the Time (Standards Australia 1973) was also used as a reference for the selection of pressure coefficients within the ASCE-7 Standard, which in turn was based on wind tunnel studies performed at James Cook University (Best and Holmes 1978)

More recently, one of the few studies that have specifically revisited wall pressures has been that of Gavanski and Uematsu (2014) that examined the zoning and magnitude of wall pressure coefficients. The study found that wall pressures in ASCE 7 (2010) were underestimated for both positive and negative pressure coefficients and found that pressure zones specified in the Standards scale with building height rather than plan dimensions.

This paper will present the current work in progress in determining updated wall design pressures, with a focus on the selection of scaling parameters that are used to define pressure zones. Additionally, how these parameters vary as building aspect ratios transition from those of a low-rise building to a high-rise building will be explored.

METHODS

Wall pressure coefficients and pressure patterns were determined from wind tunnel data collected by Wang and Kopp (2021). A subset of building shapes from this study were selected, with overall dimensions and aspect ratios shown in Table 1. A long wall of the buildings was selected for further study for all building buildings. The selected wall and its orientation with the range of wind directions tested is shown in Figure 1. Additionally, pressure data were converted to non-dimensionalized pressure coefficients (Cp) referenced to the roof height of the buildings for further analysis.

Table 1 selected building models and aspect ratios from the Wang and Kopp (2021) Study.

Building I.D.	B (m)	L (m)	H (m)	L/B	H/B
1	12	18	12	1.5	1
2	12	24	12	2	1
3	12	30	12	2.5	1
4	12	36	12	3	1
5	12	48	12	4	1
6	12	18	24	1.5	2
7	12	24	24	2	2
8	12	30	24	2.5	2
9	12	36	24	3	2
10	12	48	24	4	2
11	12	18	48	1.5	4
12	12	24	48	2	4
13	12	30	48	2.5	4
14	12	36	48	3	4
15	12	48	48	4	4
16	12	18	96	1.5	8
17	12	24	96	2	8
18	12	30	96	2.5	8
19	12	36	96	3	8
20	12	48	96	4	8

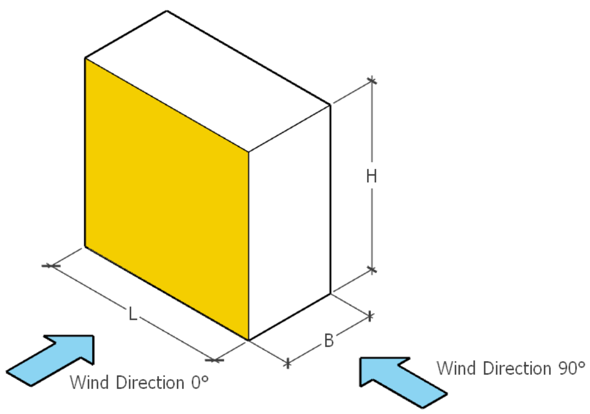

Figure 1. Building dimension naming convention, wind direction orientation and wall selected for further study (shown in yellow).

RESULTS

Codes and Standards divide wall and roof surfaces into zones that approximate the envelope of negative pressures or positive pressures experiences on the roof and wall surfaces. To determine the design pressure patterns and rationale for zoning, pressure data of the wall surface shown in Figure 1 were plotted as contour maps to show pressure patterns across the surfaces for individual wind directions as well as envelopes of worst-case pressures for a range of wind directions.

As shown in Figure 2, Similar patterns for mean pressure coefficients are observed on the walls for most buildings for wind direction 90° where the wall being studied is a side wall. Large negative pressures occur at the wall edge within the flow separation region of the building corner. Even larger negative pressures are present near the top corner of the buildings, especially for the taller building shapes.

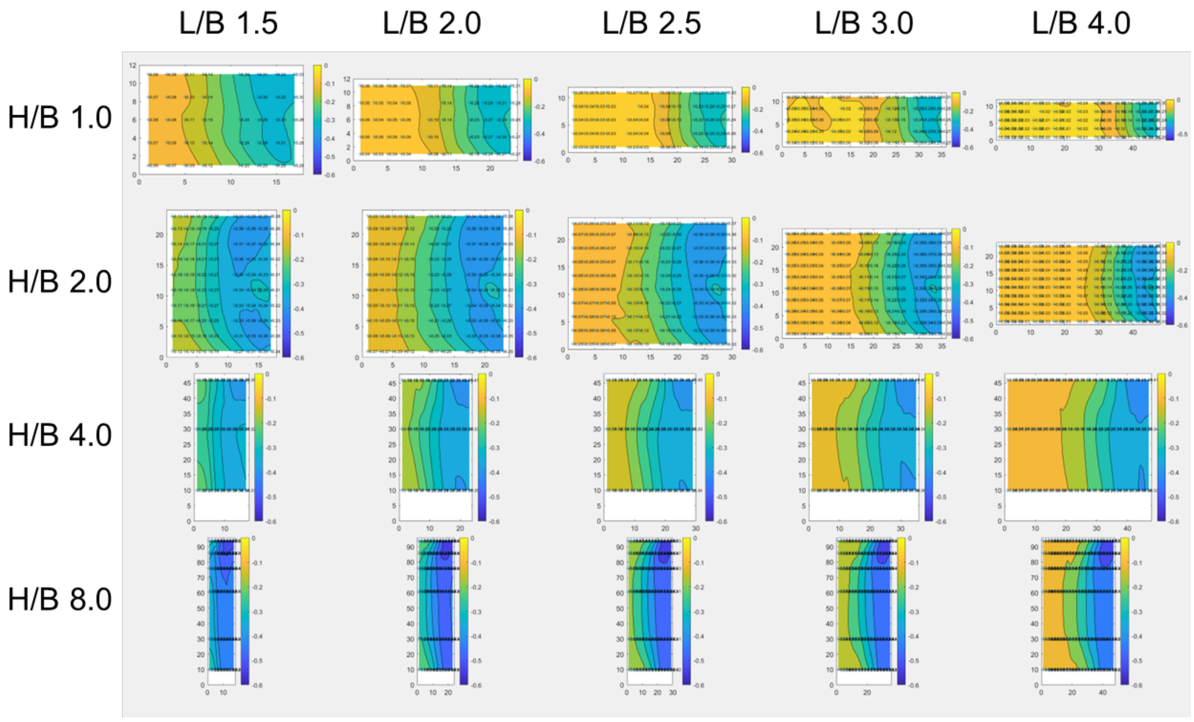

Figure 2. Mean Cp values on the side wall for wind direction 90°

To further examine how the pressure patterns scale with building size, the contour plots are redrawn with identical x and y dimensions regardless of building size. The minimums of the mean pressure coefficients for wind directions 0° to 90° were selected to create representative pressure pattern shapes of an envelope for design.

Additionally, the magnitudes of the enveloped pressure coefficients are divided by the minimum values of the envelope across the wall surface such that the pressure patterns can be more readily compared between the building sizes. These normalized pressure patterns for worst case negative pressures are shown in Figure 3.

Note that in this preliminary analysis, it is only the mean pressure coefficients that are examined to give an indication on shape of the design pressure patterns. Further extreme value analysis is required to determine design level peak pressure coefficients for design purposes.

High suction pressures are generated when the walls that are being examined are the sidewalls in relation to the wind direction. All buildings used in the preliminary analysis have the same width as the windward wall, therefore, clear scaling relationships with height and length can be seen for negative pressure on the sidewalls for a fixed building width.

Of interest for the purpose of codification is how the size high suction zone at the building edge varies with building size. As shown in Figure 3, A red line is drawn to approximately encompass the 50th percentile value of the normalized suction pressures, indicating that size of the high suction zone scales with increasing building height (H) for each plan aspect ratio. The largest increase in the size of the high suction zone for all plan aspect ratios occurs between H/B ratios 1.0 and 2.0, indicating the transition between 'low-rise' and 'high-rise' aerodynamic behaviour pertaining to wall pressures occurs between H/B ratios 1.0 and 2.0.

Furthermore, the size of the high suction zone as a proportion of the long wall (L) decreases with increasing building length. However, the scaling of the size of the high suction zone with increasing building width (B) cannot be determined from the current dataset, as all building shapes being studied are of the same width.

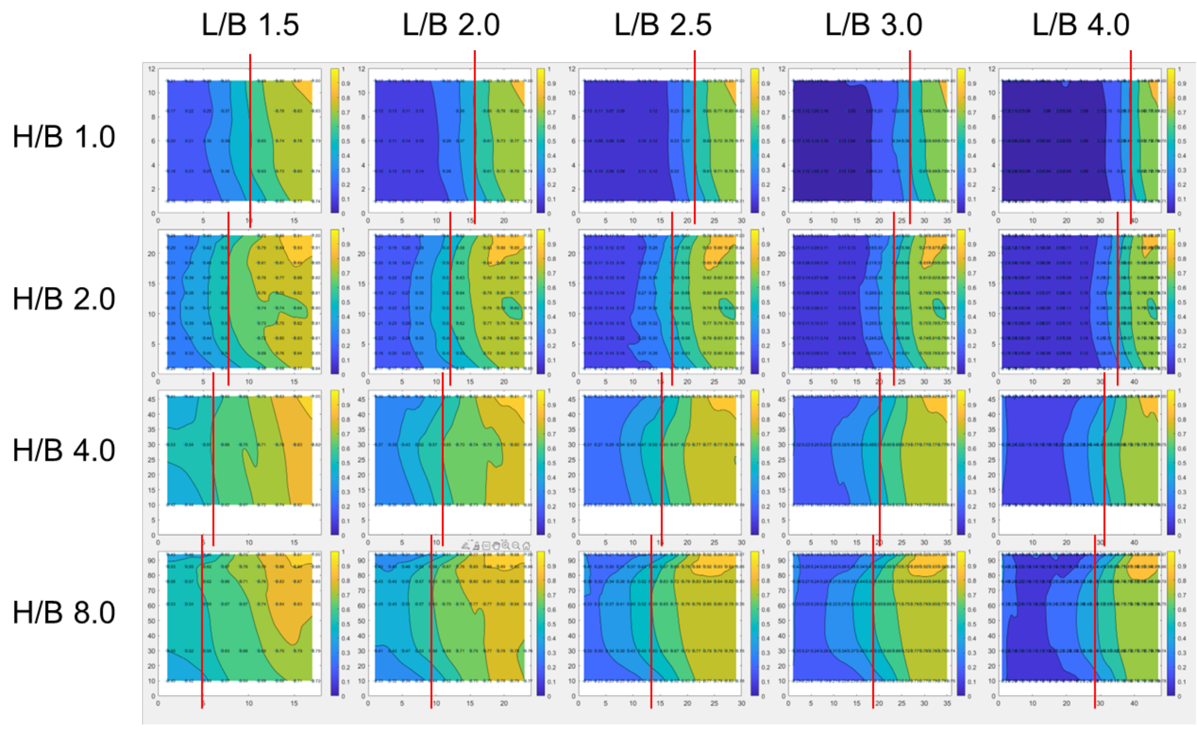

Figure 3. Envelope of normalized pressure coefficients for wind direction 0° to 90° with extent of high suction zone (50th percentile value) indicated by vertical red line.

FURTHER WORK

The results show that there is a scaling of the size of the high suction zone with height. However, further data is needed to verify the scaling with building width. Results also indicate that higher suction pressures occur in the top sidewall corner near the windward edge. This high suction zone may warrant a newly created zone in this corner.

Next steps will require additional wind tunnel data for buildings with a range of heights with a range of building widths for these heights. Additionally, the depth of the building models must be large enough to capture the size of the flow separation zone on the side walls to verify the scaling relationships with building width. Once zoning for design purposes is determined, a study of area averaging effects within each zone is required to be performed to allow for the reduction of design pressure coefficients to be taken with increasing tributary areas for component and cladding design.

REFERENCES

Akins, Robert Everett, and JE Cermak. 1976. "Wind Pressures on Buildings." Colorado State University.

Best, RJ, and JD Holmes. 1978. "Model Study of Wind Pressures on an Isolated Single-Storey House." Rep. 3/78. James Cook University.

Cermak, JE. 1977. "Wind-Tunnel Testing of Structures." *Journal of the Engineering Mechanics Division* 103 (6): 1125–40.

Davenport, AG and Surry, D. 1977. "Wind Loads on Low-Rise Buildings: Final Report of Phases I and II." *Engineering Science Report BLWT-SS8*.

Davenport, AG, Surry, D, and Stathopoulos, T. 1978. "Wind Loads on Low-Rise Buildings: Final Report of Phase III." *Engineering Science Report BLWT-SS8*.

Gavanski, E, and Y Uematsu. 2014. "Local Wind Pressures Acting on Walls of Low-Rise Buildings and Comparisons to the Japanese and US Wind Loading Provisions." *Journal of Wind Engineering and Industrial Aerodynamics* 132:77–91.

Kareem, A. 1978. "Wind Excited Motion of Buildings [Ph. D. Thesis]." Colorado State University.

Peterka, JA, and JE Cermak. 1975. "Wind Pressures on Buildings-Probability Densities." *Journal of the Structural Division* 101 (6): 1255–67.

Standards Australia. 1973. "SAA Loading Code, Part 2-Wind Forces."

Stathopoulos, T. 1979. "Turbulent Wind Action on Low Rise Buildings [Ph.D. Thesis]." London, Canada: University of Western Ontario.

Wang, J, and GA Kopp. 2021. "Comparisons of Aerodynamic Data with the Main Wind Force–Resisting System Provisions of ASCE 7-16. I: Low-Rise Buildings." *Journal of Structural Engineering* 147 (3): 04020347.