# Numerical Analysis of Wind loads on Tapered Shape Tall Buildings

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## Abstract

The development of high strength concrete, higher grade steel, new construction techniques and advanced computational technique has resulted in the emergence of a new generation of tall structures that are flexible, low in damping, slender and light in weight. These types of flexible structures are very sensitive to dynamic wind loads and adversely affect the serviceability and occupant comfort. Thus, aerodynamic modification has become an important aspect of tall building design process. Various aerodynamic modifications on building could be made in order to improve the aerodynamic performance. To ensure the functional performance of tall flexible structures and to control the wind induced motion of the tall buildings various types of aerodynamic modifications to the shape/geometry of the buildings are possible. The purpose of the present work is to investigate the effect of height to width ratio of tapered shape tall building on wind pressure coefficient distribution around different surface of building models. For the present study height to width ratio 3, 3.5, 4, 4.5 and 5 are taken to study the wind pressure coefficient variation along height. The results show that height to width ratio has significant effect on wind pressure coefficient distribution around building.

**Keywords: Tapered, Pressure Coefficient, H/B Ratio, Computational Fluid Dynamics, k-ε Method**

## I. INTRODUCTION

The current tallest building in the world is the 828 m-high Burj Khalifa, which is over 300 m higher than Taipei 101, and the tallest buildings in the next decade will be Kingdom Tower (over 1000 m), which will be completed in 2018, making Burj Khalifa the third tallest building (http://www.skyscrapercenter.com/List/future-tallest-100-buildings, 2012). Current trend of tall building construction, i.e., manhattanization with various building shapes, requires attention. Their freewheeling building shapes are expressed by taper, set-back, helical, openings, or combinations of these, reflecting architects' and engineers' challenging spirits for new forms. These irregular and unconventional building shapes are a resurrection of an old characteristic, motivated by new trends in architecture, but they have the advantage of mitigating across-wind responses, which is a major factor in safety and habitability of tall buildings.

The effectiveness of aerodynamic modifications in reducing wind loads has been widely examined, and they can be tentatively classified as corner modification and height modification (Kim and Kanda, 2010a). Corner modification includes corner cut, recess, chamfer and addition of fins (Kawai, 1998; Kwok et al., 1988), and height modification includes taper, set-back, opening, helical (twisting) and inclined (tilted) shape, and so on (Dutton and Isyumov, 1990; Kim and Kanda, 2010a). In particular, Tanaka et al. (2012) conducted a series of wind tunnel tests to investigate aerodynamic characteristics and to evaluate the most effective building shape in wind-resistant design for 31 tall buildings with various aerodynamic modifications. Unlike structural modification, this controls mass, spring and damping directly in a governing equation of motion, aerodynamic modification controls forces applied to tall buildings by altering the separated shear layer or disturbing the alignment of the vortex over the whole height.

However, most previous researches have focused on the results of mitigation effect in terms of wind forces (or local wind forces) and responses. And although many studies have been conducted to investigate the characteristics of pressure fluctuations, only the conventional building shapes with square/rectangular or circular cross-sections have been focused on the existing studies .There have been few detailed investigations of pressure fluctuations, especially for the height-modified tall buildings. In the present work, the pressure fluctuations on height modified tapered shape tall buildings including peak pressures, mean pressure coefficient variation on windward, leeward and side surface have been studied.

## II. METHODOLOGY

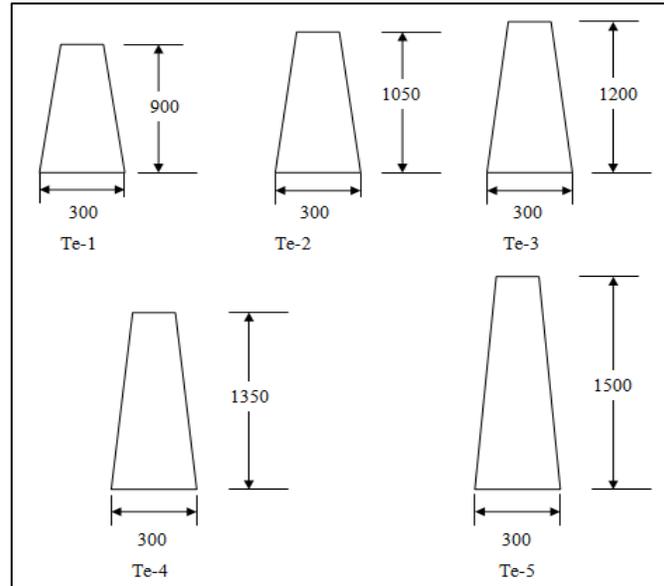### A. Dimensions and Designation of Model:



Fig. 1: Details of Building Models

Table - 1

| Model shape and designation | Length(mm) | Breadth(mm) | Height(mm) | Side Ratio |
|---|---|---|---|---|
| Tapered-1 (Te-1) | 335.5 | 268.5 | 100 | 1.25 |
| Tapered-2 (Te-2) | 367.5 | 245 | 100 | 1.5 |
| Tapered-3 (Te-3) | 397.5 | 226.5 | 100 | 1.75 |
| Tapered-4 (Te-4) | 424.5 | 212.2 | 100 | 2.0 |
| Tapered-5 (Te-5) | 450 | 200 | 100 | 2.25 |

### B. Solution Strategy:

Numerical simulations were carried out using Computational Fluid Dynamics (CFD) package ANSYS CFX 14.0. Standard k-$\varepsilon$ method was used to numerically formulate the viscosity and turbulence. The governing equations are as follows.

The standard k-$\varepsilon$ model is a typical example of a two-equation turbulence model. In this case an equation for the turbulent kinetic energy and its dissipation are used to determine the eddy viscosity.

$$k = \frac{1}{2}\overline{u_i' u_i'} = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right) \tag{1}$$

It can be observed that the eddy viscosity is dependent on the turbulent kinetic energy, k, and an unknown constant and an unknown length scale.

$$\mu_t = C \cdot \rho k^{\frac{1}{2}} l \tag{2}$$

The governing equations for determining k & $\varepsilon$ are

$$\rho \frac{dk}{dt} + \rho u_j \frac{dk}{dx_j} = \tau_{ij} \frac{du_i}{dx_j} - \rho\varepsilon + \frac{d}{dx_j}\left[\left(\mu + \frac{\mu_T}{\sigma_k}\right)\frac{dk}{dx_j}\right] \tag{3}$$

$$\varepsilon = \vartheta \frac{\overline{du_i'}}{dx_k}\frac{du_i'}{dx_k} \tag{4}$$

$$\rho \frac{\partial\varepsilon}{\partial t} + \rho u_j \frac{\partial\varepsilon}{\partial x_j} = C_{\varepsilon 1}\frac{\varepsilon}{k}\tau_{ij}\frac{du_i}{dx_j} - C_{\varepsilon 2}\rho \frac{\varepsilon^2}{k} + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right] \tag{5}$$

The closure coefficients $C_{\varepsilon 1}$ , $C_{\varepsilon 2}$, $C_\mu$ , $\sigma_k$ and $\sigma_\varepsilon$ replace the unknown correlations with algebraic expressions involving known turbulence and mean flow properties. For this, general arguments have been used. For the standard k-E model the following closure coefficients are often used: $C_{\varepsilon 1}$ = 1.44 $C_{\varepsilon 2}$ = 1.92 $C_\mu$ = 0.09 $\sigma_k$ = 1.0 and $\sigma_\varepsilon$ = 1.3.

## C. *Details of Domain:*

The analysis was carried out on Tapered shape model having different height to width ratio but same cross sectional area. A domain having 5H upwind fetch, 15H downwind fetch, 5H top clearance and 5H side clearance, where H is the height of the model, is considered as per Franke's recommendation [3] (Fig. 3). Such a large size provides enough space for generation of vortex on the leeward side and avoids backflow of wind. Moreover no blockage correction is required.
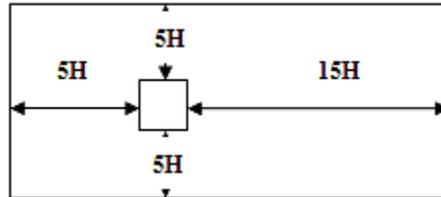


Fig. 2: Detail of Computational Domain (Plan)
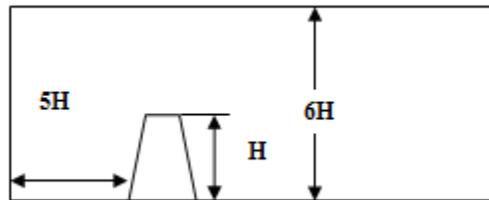


Fig. 3: Detail of Computational Domain (Elevation)

## D. *Boundary Condition:*

The flow at inlet was simulated similar to that of terrain category 2 as per Indian standard for wind load IS: 875 (part 3) – 1987. Inlet velocity was considered as 10m/s. The power law is used for generating the boundary layer flow at inlet. The outlet was considered as pressure outlet .The no slip boundary conditions are applied to the surfaces of Building Model. The velocity profile near the windward side as obtained from numerical method is shown in Fig. 3.
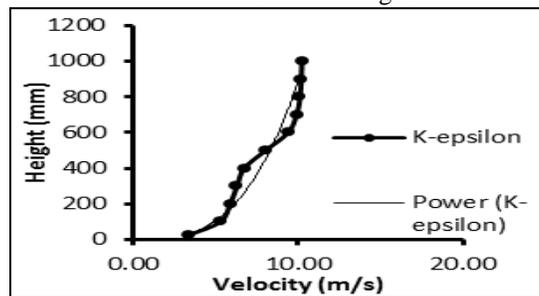


Fig. 4: Velocity Profile at Inlet

## III. RESULT AND DISCUSSION
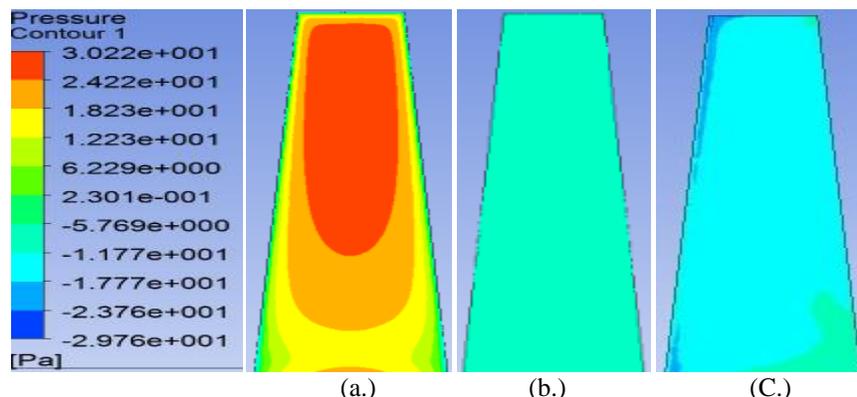
## A. *Rectangular (Re-1):*



Fig. 5: (A) Pressure Contour of Windward Face (B) Pressure Contour of Leeward Face (C) Pressure Contour of Sidewall
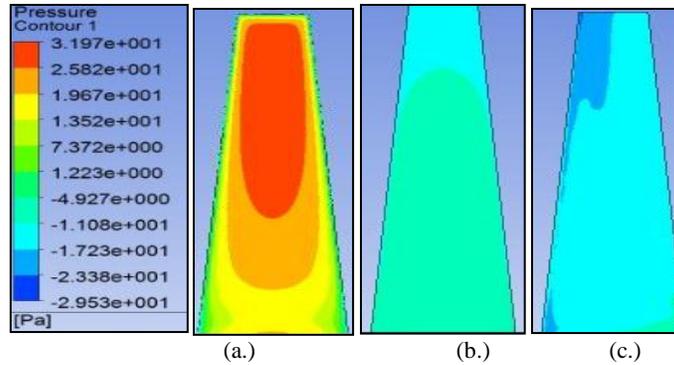
*B.* *Rectangular (Re-2):*



Fig. 6: (A) Pressure Contour of Windward Face (B) Pressure Contour of Leeward Face (C) Pressure Contour of Sidewall
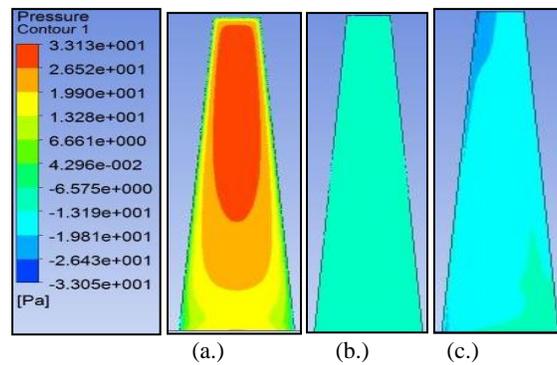
*C.* *Rectangular (Re-3):*



Fig. 7: (A) Pressure Contour of Windward Face (B) Pressure Contour of Leeward Face (C) Pressure Contour of Sidewall
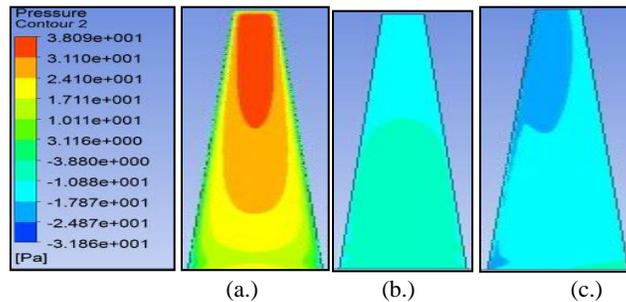
*D.* *Rectangular (Re-4):*



Fig. 8: (A) Pressure Contour of Windward Face (B) Pressure Contour of Leeward Face (C) Pressure Contour of Sidewall
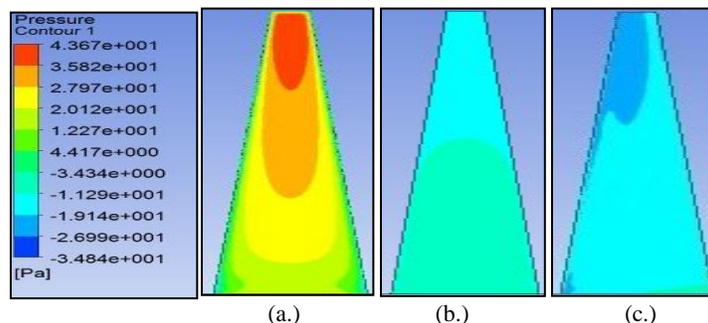
*E.* *Rectangular (Re-5):*



Fig.9 (A) Pressure Contour of Windward Face (B) Pressure Contour of Leeward Face (C) Pressure Contour of Sidewall
− Variation of pressure coefficient along height for tapered shape building
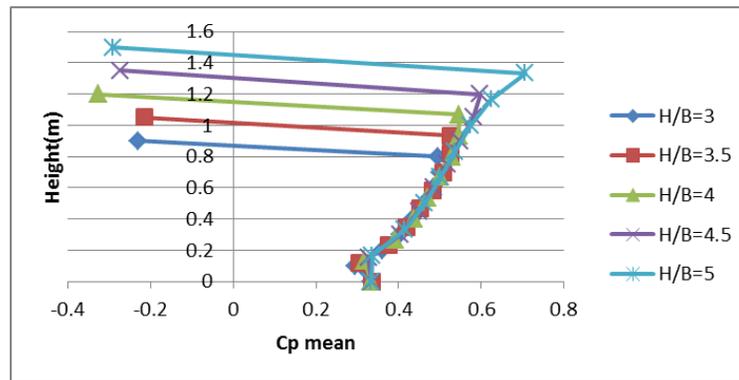
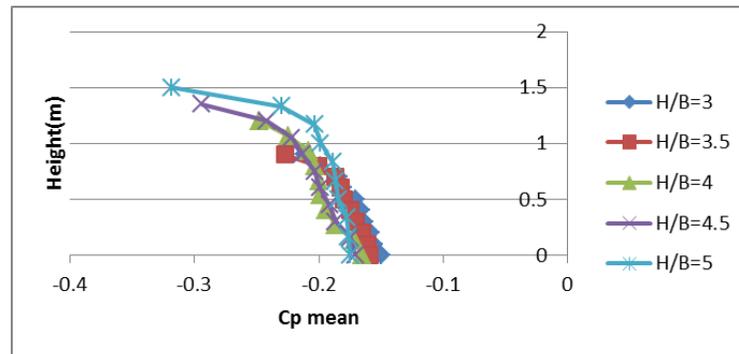Fig. 10: Variation of Pressure Coefficient on Wind Ward Face



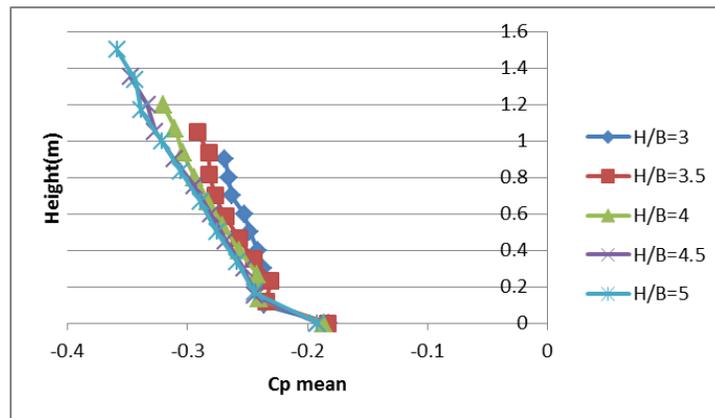Fig. 11: Variation of Pressure Coefficient on Lee Ward Face



Fig. 12: Variation of Pressure Coefficient on Sidewall

## IV. PRESSURE DISTRIBUTIONS ON MODELS

The evaluated mean pressure at a particular grid point locations non-dimensionalized to evaluate the mean pressure coefficients along the considered wind direction by $1/2\rho v^2$, where $\rho$ is the density of air (1.226 kg/m3), v is the free stream velocity at the roof level of the building model(10 m/s).

$$Cp = \frac{\text{Static Pressure}}{\text{Dynamic Pressure}}$$

Dynamic Pressure = $1/2\rho v^2$

The comparison of mean pressure coefficient on windward, leeward and side face is shown in fig.9, fig.10 and fig.11. On windward face of building variation of mean pressure coefficients almost constant with increasing H/B ratio. Absolute values of peak pressure coefficient for H/B ratio 3, 3.5, 4, 4.5 and 5 are respectively 0.49, 0.52, 0.55, 0.60 and 0.70. For Leeward side mean pressure coefficient distribution decreases with increasing H/B ratio near bottom but increases near top. The smallest negative mean pressure coefficients of H/B ratio 3, 3.5, 4, 4.5 and 5 are -0.15, -0.159, -0.165, -0.171 and -0.175 respectively. And largest negative mean pressure coefficient of H/B ratio 3, 3.5, 4, 4.5 and 5 are -0.21, -0.23, -0.25, -0.29 and -0.32 respectively. On side surface of building smallest negative mean pressure coefficient are nearly same for all H/B ratio while largest mean pressure coefficient increases with increasing H/B ratio.

# V. CONCLUSION

In the present study effect of change in H/B ratio of tapered building is studied by computational fluid dynamics technique. Outcome of above study is summarised below

1) The absolute values of peak pressure coefficient on windward face of tapered shape building increases with increasing H/B ratio.
2) Smallest and largest negative mean pressure coefficient on leeward face of building increases with increasing H/B ratio while on side surface of building smallest negative mean pressure coefficient are nearly same for all H/B ratio while largest mean pressure coefficient increases with increasing H/B ratio.

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