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Effect of Height Variation of Closely Located Interfering Buildings on Wind Loads on Tall Buildings

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Abstract: *This research paper investigates the modification of wind loads on a tall building (principal building) having rectangular cross-sectional shape due to the variation in height of two closely located interfering buildings having a similar plan shape. The models of the three buildings (principal and interfering buildings) are placed in a U shape plan for the study. The heights of interfering building models are varied in two different manners: (1). Height of both the interfering building models is reduced simultaneously (2). Height of only one of the interfering building model is reduced. Wind tunnel experiments are undertaken using five component force balance load cell and the results are reported in the form of X-Y plots. The interference effect causes increase in the torsional moment as height difference of the two interfering buildings increase, also shielding effect causes reduction in the along wind force as height of the interfering buildings increases. Value of torsion on the principal building is observed to be as high as 33 times of that in the isolated case. However, a reduction is high as 69 percent is observed in the force in along wind direction due to shielding.*

Keywords: *Wind tunnel, Tall building, Rectangular plan, Interference effects, Height variation, U-Shape, Force measurement.*

1. Introduction

With the growing demand of tall buildings in metropolitan cities due to population concentration, the wind tunnel studies to understand effects of wind on these tall buildings have started to become inevitable. Information available in various codes of practice on wind loads [AS/NZS: 1170.2 (2002), ASCE: 7-02-2002, EN: 1991-1-4-2005, IS: 875 (Part-3) 2015] provide guidance limited to isolated cases only. Many researchers have carried out the studies in the area of the effect of wind on tall buildings due to the presence of other interfering buildings. It has been shown that the wind loads on tall buildings are greatly affected in the presence of closely located interfering buildings [Khanduri *et al.* (1998)].

The significance of interference studies on wind loads on tall buildings has been shown by several research studies in the past. Khanduri *et al.* (1998) analyzed the experimental data available on interference studies and concluded that the wind loads on the principal building are greatly affected if the interfering building is closely located. Xie and Gu in 2004 studied the effect of interference on square plan shaped principal building due to the presence of one and two interfering buildings also having square plan shape by varying the location, height and plan size of the interfering buildings. In 2008 Amin carried out wind tunnel experiments to study the effect of interference on rectangular plan shape buildings having aspect ratio of 1:2.5 and 1:1.5 due to the mutual presence of the buildings arranged in L - and T -shape patterns, concluding that the wind loads on the buildings are greatly affected by the arrangement, wind direction and relative dimensions of the buildings. Zhao and Lam (2008) studied the effect of mutual presence on 5 square plan shaped buildings arranged in L- and T-shape patterns with a variation in spacing amongst the buildings and the wind direction. Kim *et al.* (2011) carried out wind tunnel studies to understand the interference effects on local peak pressures on a square plan shape tall building due to the presence of an interfering building having a similar shape with a variation in wind direction, location and height of the interfering building. Kushal (2013) had conducted wind tunnel experiments to study the effect of interference on rectangular plan shape tall building due to the presence of a square plan shape tall building by varying the spacing amongst the buildings arranged in L- and T- shape patterns. Pandey (2013) studied the effect of presence of two square plan shape tall buildings on a similar plan shape principal building with a variation in wind direction and spacing of the buildings. Mara et al. (2014) undertook wind tunnel experiments to study the aerodynamic and peak response interference factors on square plan shape buildings due to the presence of another identical building at different upstream positions. Yan and Li (2016) carried out Wind tunnel experiments to understand the interference effects between identical tall buildings with aerodynamic modifications by varying the location of the interfering building. Going through the literature it can be observed that the wind loads are greatly affected by the relative dimensions and location of the buildings. However, it can be observed that no research is available for interference studies on commonly used rectangular plan shape tall buildings due to the presence of closely located two

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other interfering tall buildings having a similar plan shape.

Therefore, an attempt has been made here to study the effect of interference on rectangular plan shape tall buildings due to the presence of two closely located interfering buildings having a similar plan shape with a relative variation in height. Models of three rectangular plan buildings are arranged in U-shape plan to study the effect of height variation of the interfering buildings. The heights of the interfering building models are varied in two different manners: (1). Height of both the interfering building models is reduced simultaneously (2). Height of only one of the interfering building model is reduced, as shown in Figure 1. Results of the force measurements are presented in the form of X-Y plots showing the variation of forces and moments with respect to height of the interfering building.

2. Materials and Methods:

2.1. Model Description:

Rigid models are made using plywood at a geometric scale of 1:200 to the corresponding prototype, having width to length ratio of 1:3 and width to height ratio of 1:5. The assumed prototype for the principal building considered in this study is of rectangular shape in plan having plan dimensions of 60m x 20m (i.e. 1200 m^2 area in plan) and having height of 100m. Similarly, the prototype considered for the interfering tall buildings in the study are also of rectangular shape in plan having plan dimensions of 60m x 20m (i.e. 1200 m^2 area in plan) but having variation in heights as 100m, 80m, 60m, 40m and 20m. Figure 1 shows the dimensions and arrangement of the models used for principal (hatched) and interfering buildings for wind tunnel tests.

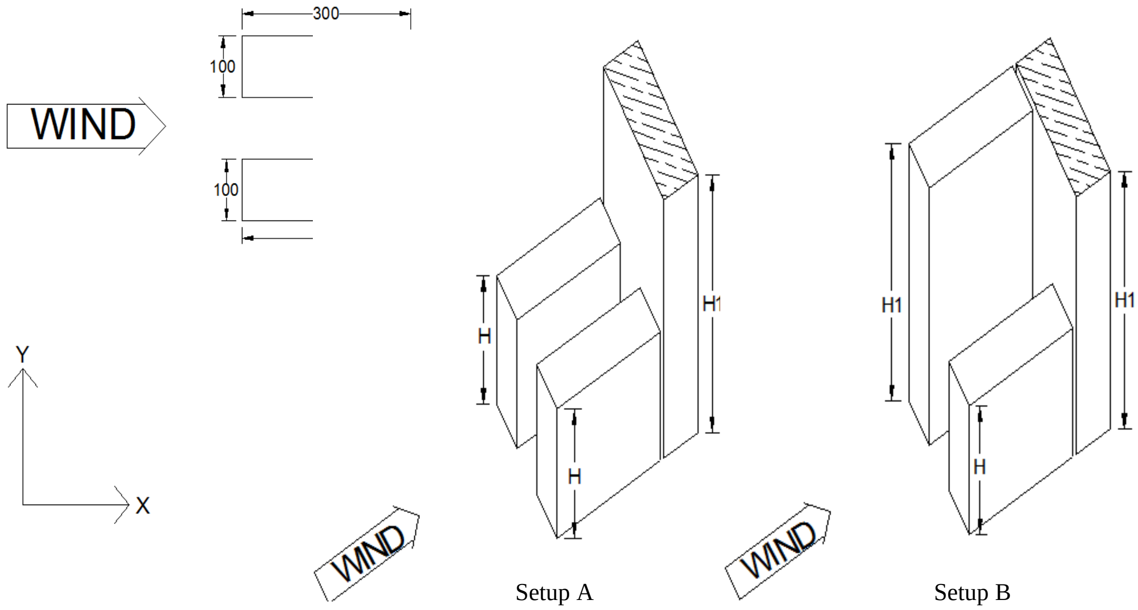


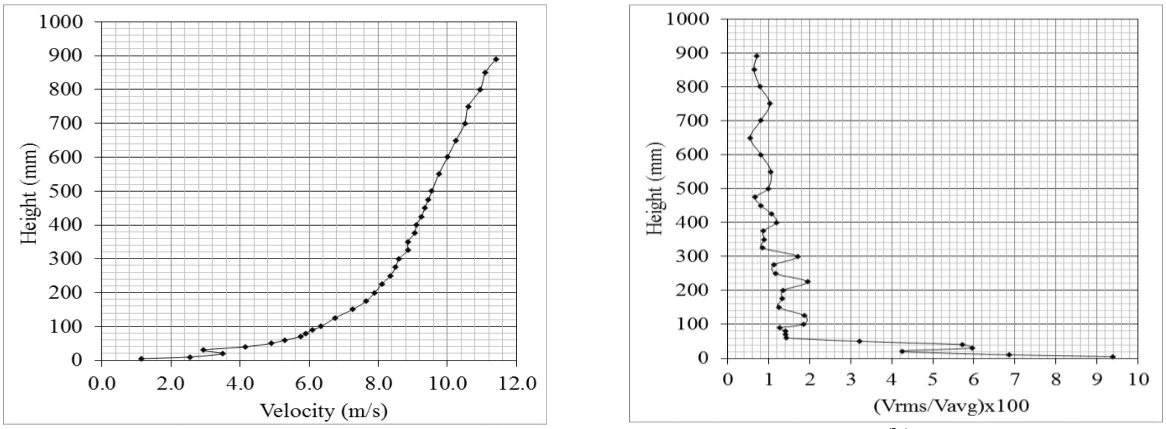
Figure 1: *Plan and isometric view of different arrangements for experimentation. (All dimensions are in mm) [H/H1 =1.0, 0.8, 0.6, 0.4, 0.2, 0; H1 =500 mm]*

2.2. Wind Flow Characteristics:

An open circuit boundary layer wind tunnel having a cross-section of 2m x 2m and length of the test section as 15m is used for the testing of the models. Vortex generators for generating turbulence in horizontal plane, barrier wall for generating turbulence in vertical plane, and floor roughening cubical blocks of size 70mm, 50mm and 38mm are used on the upstream end of the test section to achieve the mean wind velocity profile of the approaching flow corresponding to power law exponent of 0.3. The wind velocity profile and the turbulence intensity profile used during the experimentation are shown in Figure 2.

2.3. Measurement Technique:

Force measurements are conducted by placing the principal building plywood model of rectangular cross-section on top of the 5 component load cell and are tested under free stream mean wind velocity of 11.4 m/sec measured at 0.89 m height above the floor of the tunnel. Recording of observations are undertaken at an interval of 1 second for 60 seconds. The principal building model is tested for isolated condition and for 6 different variations in the height of interfering building models for two different setups (Figure 1) making a total of 13 different arrangements. Photographs for some arrangements are added in Figure 3.



(a) *(b)*

Figure 2: *Wind characteristics used for experiments: (a) Mean wind speed profile; (b) Turbulence intensity profile*

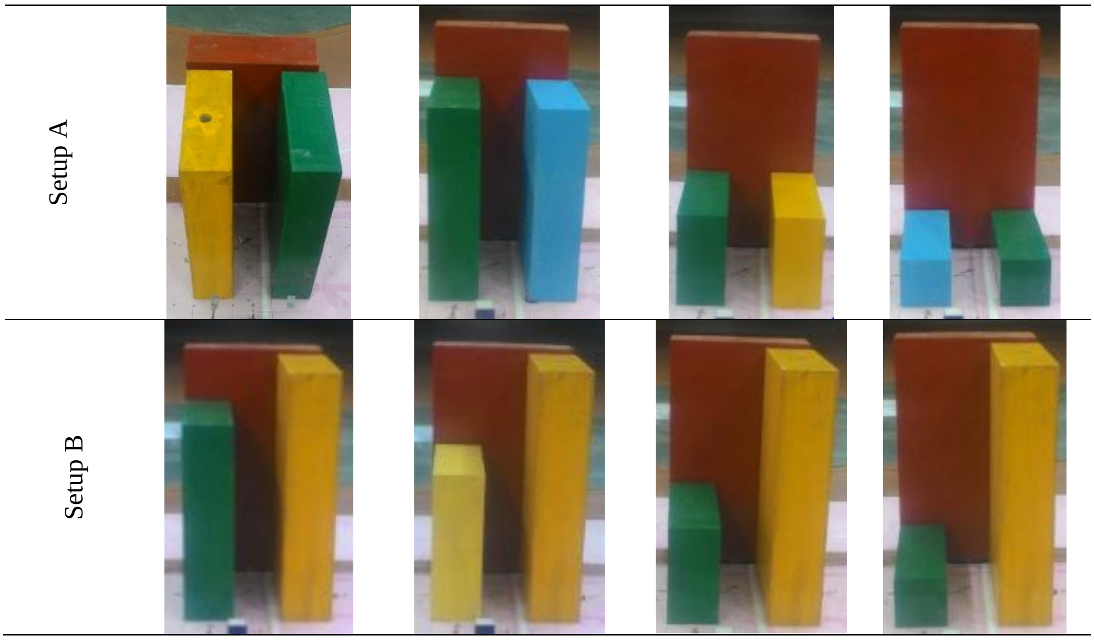


Figure 3: *Photographs for some arrangements*

3. Experimental Results

Experimental results are reported in the form of X-Y plots with height ratio (H/H1, Figure 1) on X axis and the corresponding value of interference factor on Y axis, where the interference factor being defined as:

Interference Factor (K_{FX} or K_{FY} or K_{MX} or K_{MY} or K_{MZ}) =

$$\frac{\text{Measurment Parameter (Fx or Fy or Mx or My or Mz) under interference condition}}{\text{Corresponding Parameter (Fx or Fy or Mx or My or Mz) under isolated condition}}$$

Where,

Fx =Base shear force on the principal building along the wind flow;

Fy =Base shear force on the principal building across the wind flow;

Mx =Base overturning moment on the principal building about the X-axis;

My = Base overturning moment on the principal building about the Y-axis;

Mz = Twisting moment on the principal building about the Z-axis;

Interference factors for various measurement parameters are calculated using average values (for 60 readings) for the corresponding parameter and are reported in the form of line graphs in Figure 4. Numerical values for isolated case are also reported in Figure 4 in form of bar charts. The numerical values observed during the experiments for setup A and setup B are also reported in Table 1. Going through Table 1 and Figure 4, it can be concluded that the variation in the height of the interfering building greatly affects the wind loads on the principal building. A high increase in the torsional moment of the building is observed, which is of the order of 33.3 times of that in the isolated case for H/H1=0.0 in setup B, i.e. when only one interfering building is present and is of same height as that of the principal building. The torsional moment is seen to increase with the increase in the height difference of the interfering buildings. Since the various codes of practice on wind loads give information limited to isolated cases only, structural designers need to be very careful, and must study research publications to ascertain the magnitude for such a high increase in wind loads. Another observation is the reduction in wind load of about 69 percent is observed in along wind force for H/H1 =1.0, i.e. when the two interfering buildings present in front of the principal building are of the same height as that of the principal building. This is due to the high shielding effect of the interfering buildings; designers can take advantage of this reduced force while designing the buildings, hence reducing the overall cost of the project. However, this shielding effect can be seen to reduce as the height of the interfering building reduces.

Table1: *numerical values observed for different parameters for setup a and setup B*

	Fx (gms.)		Fy (gms.)		Mx (gm-mm)		My (gm-mm)		Mz (gm-mm)	
H/H1	A	B	A	B	A	B	A	B	A	B
1.0	316.5	316.5	2.2	2.2	323.4	323.4	88100.4	88100.4	397.9	397.9
0.8	457.6	371.6	1.9	2.7	-1021.8	1389.9	131296.6	108327.0	510.2	-2144.7
0.6	701.8	496.2	-8.2	-8.8	-3362.2	-1546.6	198414.1	142644.8	726.2	-10679.0
0.4	822.9	557.4	-12.0	-12.1	-3881.7	-3839.3	228279.0	153385.3	18.6	-15047.9
0.2	940.4	573.9	-8.8	-5.9	-1409.8	-2342.6	252039.8	156995.7	349.2	-17842.9
0.0	1022.7	584.8	14.5	13.6	4790.9	4155.3	270269.4	159660.7	730.7	-24321.2

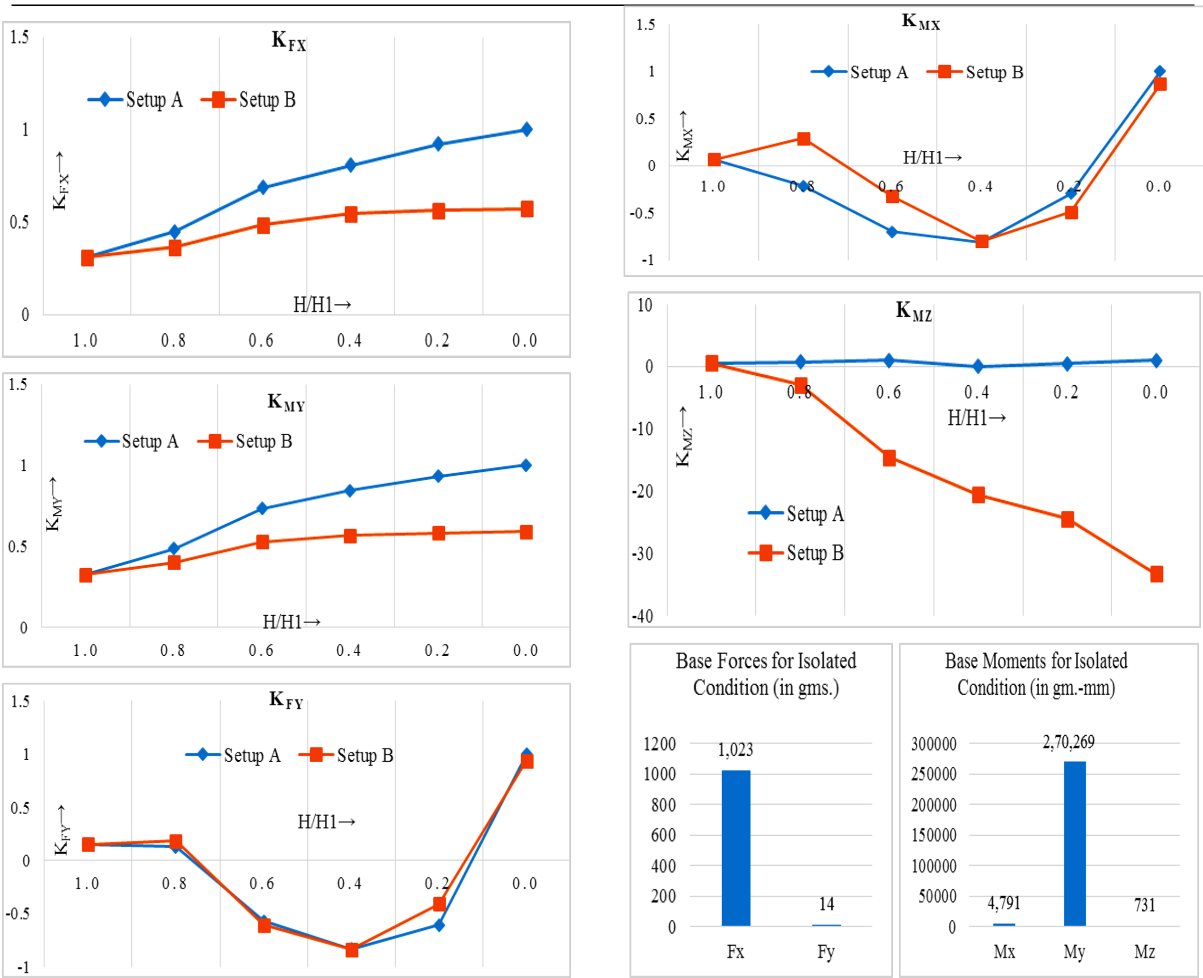


Figure 4: *Line graphs - Interference factors for the experimental setups; Bar charts - Numerical values for isolated condition*

4. Conclusions:

- It can be seen that with the increase in height of the interfering buildings the wind loads reduce due to shielding of the principal building.
- The variation in height of the interfering building with respect to the principal building causes a reduction in the force in along wind direction (K_{FX}) due to shielding. The lowest value observed for the along wind force is found to be reduced by 69 percent when two interfering building are placed in

front of the principal building, both having height ratio (H/H1) equal to 1.0.

- K_{MY} follows the trend similar to K_{FX}. Also, it can be observed that the values of interference factors for these two parameters are always greater for setup A as compared to setup B as the shielded area in setup B will always be higher.
- K_{MX} follows almost a similar trend to K_{FY}. However, it can be seen that these two parameters are not affected by the height variation of the interfering buildings, as all the values for these two parameters are within the range of -1.0 to +1.0.
- K_{MZ} is seen to be close to 1.0 for all height ratios for setup A as expected due to symmetric arrangement and equal heights of the interfering buildings. However for setup B the value of K_{MZ} increases with increase in the height difference of the two interfering buildings.
- The maximum value observed for K_{MZ} is seen to be as high as 33.3 for H/H1=0.0 in setup B, i.e. due to the unequal heights of the interfering building the principal building is partially shielded and partially subjected to pressure causing high value of torsion.

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