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Importance of considering accidental eccentricity in wind design of tall buildings

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ABSTRACT

Torsional-wind load due to unbalance distribution over surfaces of building is one of the crucial parameters for design of tall buildings. Since natural frequency of tall buildings in torsional-mode is usually close to the high-energy frequencies of the load, resonant component is large due to induced dynamic vibration. In the presence of mass-stiffness eccentricity, resonant component of along- and across-wind load may intensify the torsional-wind load. Commonly, a small mass-stiffness eccentricity, so-called accidental eccentricity, is considered in seismic design because of uncertainty in mass distribution. For tall buildings, the resonant component of along- and across-wind loads is considerably large. Consequently, added components of torsional-wind load due to accidental eccentricity can also be large and neglect of this consideration may result in an undependable design. In this study, 5% accidental eccentricity is assumed based on seismic provisions in ASCE (2017), and torsional-wind load is calculated by the procedure in ISO (2009). Results indicate that accidental eccentricities can be critical in wind design of tall buildings.

1. INTRODUCTION

Torsional-wind load is a result of asymmetric pressure distribution on building walls and torsional vibration under these loads. If the center of mass and stiffness are not the same, extra terms are added to torsional-wind load due to the eccentric resonant component of along- and across-wind load. In practice, if the building has large intentional eccentricity, it is directly included in the analysis to calculate the wind load. However, even for symmetric building, considering zero eccentricity is too ideal because of uncertainty in mass distribution. That is why small eccentricity, known as accidental, is usually considered in seismic design. Since there is no inherent torsional excitation, so the entire torsional response under seimic load is due to this eccentricity,

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and neglecting the term is so critical in all cases.

While in wind design, the level of importance is different for short, mid-rise, and tall buildings. In the case of short and mid-rise buildings, most of wind load is due to aerodynamic force and resonant force is small, and considering accidental eccentricity is not crucial. While, it is very important in the design of tall buildings where the resonant components are so large. In this study, the effect is investigated for a series of case study buildings.

2. ASSUMPTION FOR CALCULATION OF WIND LOAD

Resonant components of wind load highly depend on the natural frequency and damping ratio of the structure. Therefore, four tall buildings with 20, 30, 40, and 50 stories with a floor height of 4 meters and a square plan with 42 m width (*B*) was designed to have a more realistic estimation for natural frequencies (especially for torsional vibration). The structural system was assumed to be a dual system consisting of reinforced concrete (RC) moment resisting frames (MRF) and shear walls with 2% damping ratio under ultimate load. The structural system was chosen as one of the most common structural systems for tall buildings (Fig. 1).

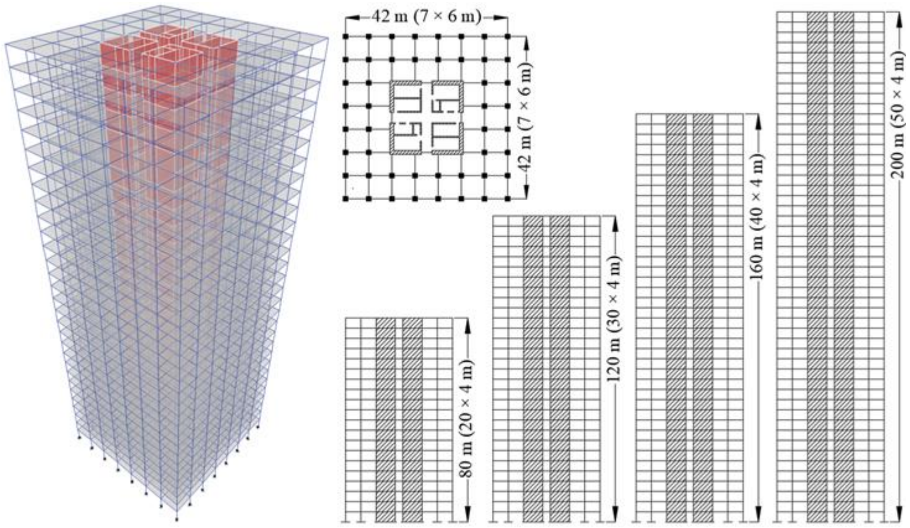

Fig. 1 Typical plan, elevations, and FEM model

For different values of reference wind speed (V_{ref}), torsional-wind load (T_W) for the case without eccentricity, and resonant components of along- and across-wind load (P_{DR} and P_{LR}, respectively) are calculated based on ISO (2009). Based on the procedure, three load cases should be considered to combine a maximum load with a fraction of other loads. Load case 1 is for the maximum along-wind load (P_D), and load cases 2 and 3 are for maximum across-wind load (P_L) and T_W, respectively. The load case factors for a combination of the P_D, P_L, and T_W are shown in Table 1. These load case factors are based on the temporal correlation between P_D, P_L, and T_W. Here, it is assumed that small eccentricity does not change the correlation factor and the same value can be used for combining T_W with extra terms. As a result, total torsional-wind load (T_{WM}) is defined by Eq. (1).

$$T_{WM} = T_W + \frac{a}{c} eBP_{DR} + \frac{b}{c} eDP_{LR} \tag{1}$$

Where, e is accidental eccentricity; B and D are the widths of building normal and parallel to wind direction, respectively; and a, b, and c are load component factors for T_{WM} and are shown in Table 1. The component factors are defined based on load case factors. However, the load case factors for along-wind load in load cases 2 and 3 should be modified by excluding the portion of the factor that is applied to mean load.

Table 1 Load case factors and components factors for T_{WM}

Load case	Load case factors			Load components factor for T_{WM}		
	(for P_D)	(for P_L)	(for T_W)	a	b	c
1	1	0.4	0.4	1	0.4	0.4
2	0	1	κ	0.4	1	κ
3	$0.4+0.6/C_{Dyn,m}$	κ	1	0.4	κ	1

$C_{Dyn,m}$: mean dynamic response factor for along-wind load (gust-effect factor)
κ: correlation factor between P_L and T_W

3. EFFECTS OF ACCIDENTAL ECCENTRICTY

Values of resonant components of along- and across-wind load at building height ($P_{DR}(H)$ and $P_{LR}(H)$, respectively) for the case study buildings under different reference wind speeds are shown in Fig. 2. It can be seen that by increasing building height and wind speed, the resonant loads are increased considerably.

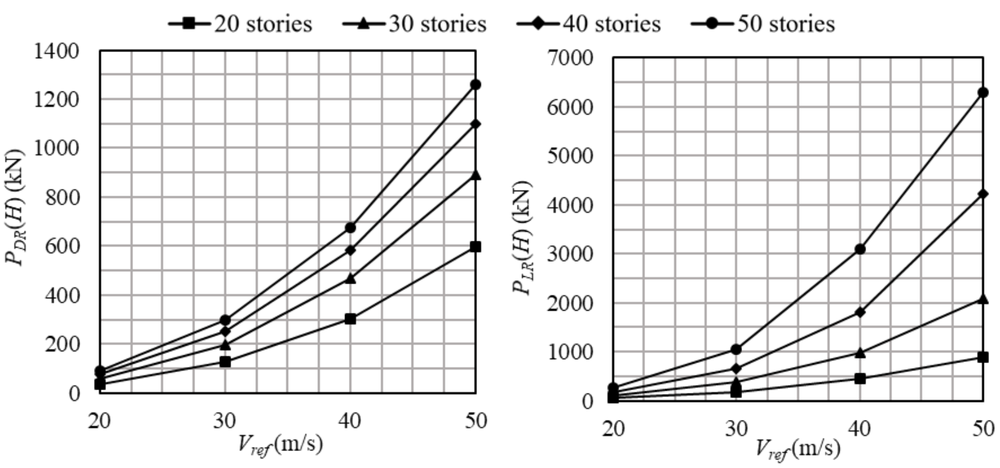

Fig. 2 Resonant components of along- and across-wind load

Torsional-wind load at building height ($T_W(H)$) based on the code procedure (i.e. zero eccentricity) is calculated. Accidental eccentricity is assumed to be 5% based on seismic provisions of ASCE (2017) and total torsional-wind load at building height ($T_{WM}(H)$) is calculated by Eq. (1). Note that for the case study buildings, B and D are the same (42 m). The ratio of $T_{WM}(H)/T_W(H)$ for each load case is shown in Fig. 3.

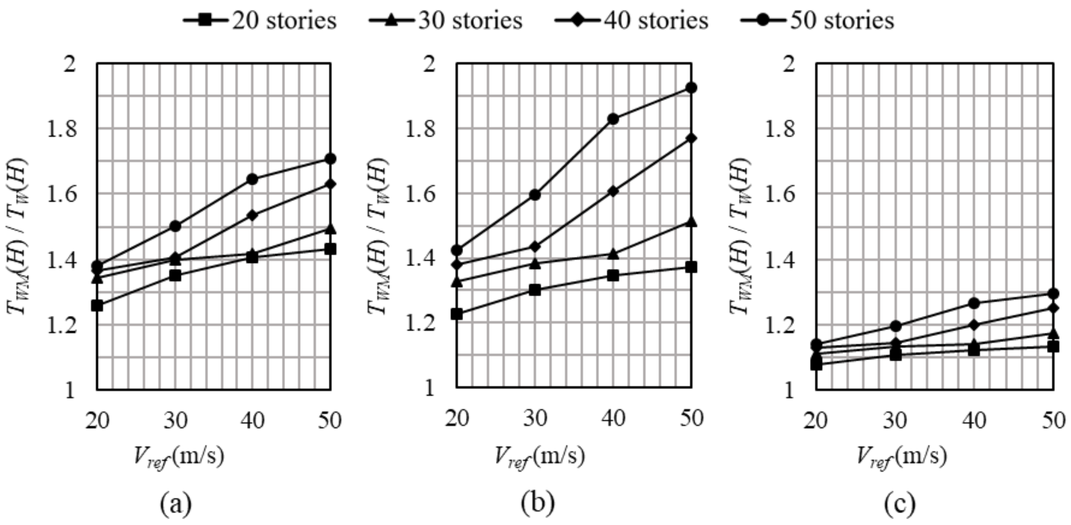

Fig. 3 Ratio of $T_{WM}(H)/T_W(H)$ for e = 5% for:
a) Load case 1; b) Load case 2; and c) Load case 3

3. CONCLUSIONS

Results indicated that in the presence of accidental eccentricity, resonant component of along- and across-wind load can intensify torsional-wind load considerably. Especially, under larger wind speed and for taller buildings, the influence is significantly larger and neglecting this effect can result in underestimation of wind load. Therefore, the study recommends considering accidental eccentricity in the calculation of torsional-wind load for tall buildings. In the study, extra terms due to resonant components were added based on current load case factors. Further studies are required to examine the approach for a more accurate evaluation of the load.

REFERENCES

ASCE (2017), *Minimum design loads and associated criteria for buildings and other structures (ASCE 7-16)*, American Society of Civil Engineers, Reston, VA.

ISO (2009), *Wind actions on structures (ISO 4354)*, International Organization for Standardization, Geneva, Switzerland.