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The Effect of Core Eccentricity on the Structural Behavior of Concrete Tall Buildings

Tarek Anwar Taha Awida

Civil and Architecture Engineering Department, College of Engineering, International University of Kuwait (IUK), Ardiya Government Area, Kuwait

Abstract: The main purpose of this paper is to investigate the effect of core eccentricity on the structural behavior of concrete tall buildings. Concrete buildings of 55 floors with plan dimensions 48.0 × 48.0 m^2 were investigated. Three cases of main core locations are studied: centric (A), eccentric by one sixth (B) and one third (C) of building width. The three-dimensional finite element method has been used in conducting structural analysis through ETABS software. Gravity and lateral (wind and seismic) loadings are applied to all building cases. It has been concluded that the core location is the prime parameter governing the structural behavior of tall buildings. Although the first two cases (A, B) have acceptable and similar structural behaviors conforming to code limits, in the third case (C), the building behavior came beyond code limits. The author introduced remedial action by adding two secondary cores in the opposite direction of the main core (C-R) to restore the building behavior to the code limits. The results of this action were satisfactory.

Key words: Concrete tall buildings, core eccentricity, structural behavior, gravity, wind, seismic loadings.

1. Introduction

Construction of tall buildings in the Middle East especially in the Gulf region is currently increasing because of several reasons such as scarcity of land in urban areas, increasing demand of commercial and residential spaces, economic growth, technological advancement, innovations in structural systems, desire of aesthetics and prestige and human aspiration to build higher [1]. As the structure becomes taller and slenderer, it becomes more sensitive for lateral displacements and the foundation becomes more complicated and costly. Concrete is considered the most common building material in the Middle East due to its availability, cheap workmanship, and its advantages over structural steel since it is more economical, requires less lead time and has higher resistance to fire [2]. Therefore, studies for the different parameters affecting the structural analysis, design and construction of concrete tall buildings considering wind and seismic loadings conditions in the Gulf region are required to deepen structure and architect engineers' understanding for the behavior of such type of buildings. Awida [3] emphasized the influence of building slenderness ratio on the structural behavior. This paper emphasizes building core location parameters (size and location in the layout) as it plays a significant role in the structural behavior of tall buildings. Most studies in the literature considered centric core location while architects are sometimes forced to use eccentric core in the building layout due to site location restrictions, arrangement of spaces to serve certain functions, the building form, and the main façade view to consider natural lighting and/or wind direction. The author believes that the study of concrete tall buildings with eccentric core locations shall be very useful for researchers and practitioners.

Corresponding author: Tarek Anwar Taha Awida, Ph.D. degree in structural engineering / assistant professor, research fields: three-dimensional finite element analysis modelling, analysis and design of concrete tall buildings, analysis of wind loadings impact on tall buildings, structural assessment of existing concrete buildings including repair/upgrade.

2. Description of the Investigated Buildings

A square plan office concrete building with side length BL= 48.0 m is investigated in this study. The building comprises 55 floors (two basements, ground, 50 typical floors and two mechanical floors in the mid height and top floor). The floor height for basement and typical floors is considered 4.0 m while floor height for ground and mechanical floors is used as 6.0 m. The overall building height (H = 226.0 m) above foundation raft. H/BL (slenderness ratio) equals 4.70 which is considered an acceptable value.

Reinforced concrete is used as the construction material for the investigated building. Higher performance concrete is used for the vertical structural elements (columns, shear walls, piles) (f_c' = 60 MPa) rather than floor structural elements (beams, slabs, foundation) (f_c' = 45 MPa) to minimize the sizes of vertical elements since they have an impact on the architectural layout.

A flat slab system with constant slab thickness (250 mm) is selected to give adequate space for services and for free interior design environment. Columns are arranged with spacing 8.0 m in the two directions to match with the common engineering practice and to allow architects to properly furnish all the office building facilities. The main building core is designed as square with side length 16.0 m (BL/3) and includes spaces for elevators, mechanical/electrical rooms, and staircases as per local authorities' requirements. Three core locations (centric (model A), eccentric by 8.0 m (BL/6) (model B), and eccentric by 16.0 m (BL/3) (model C)) are introduced to investigate the effect of core location on the structural behavior of tall buildings. Fig. 1 shows the typical structural layout plans for all models used in this study and Fig. 2 shows the 3D view for the building using ETABS software. Table 1 provides the core wall thicknesses and columns sizes in all floors as designed and typically used in the analysis of these models.

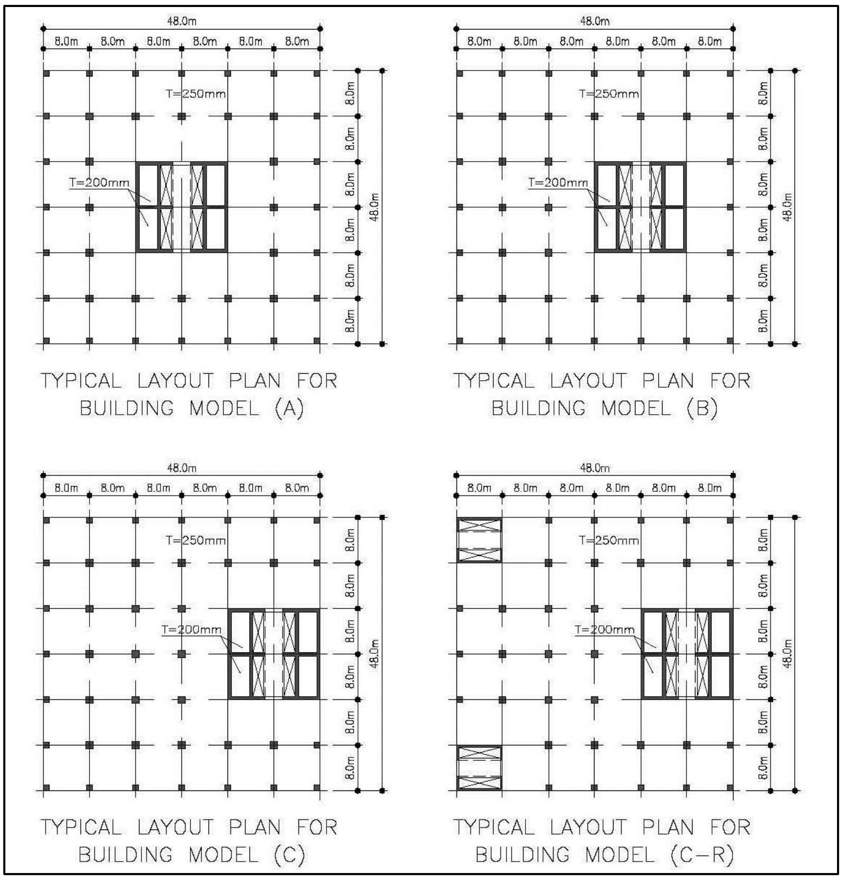

Fig. 1 Typical structural layout plans for all models.

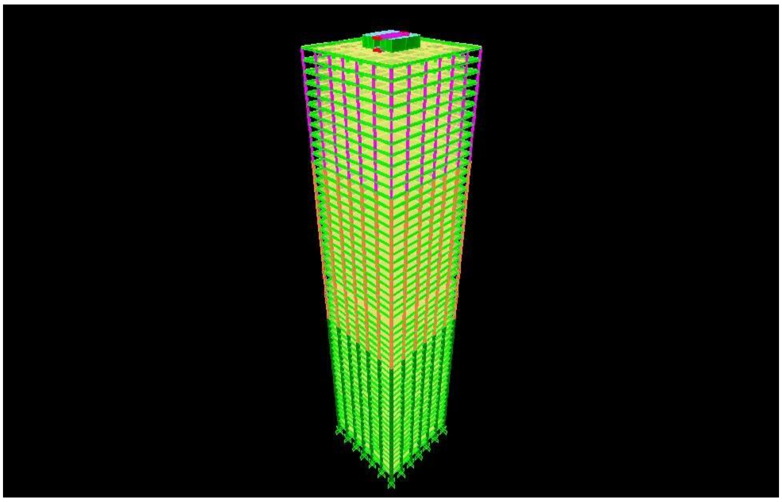

Fig. 2 3D view for ETABS structural model.

Table 1 The investigated building vertical element sizes.

Element	Basement up to 20th floor	20th floor up to 40th floor	Above 40th floor
Core wall thickness (mm)	800	600	400
Interior columns (mm)	1,400 × 1,400	1,200 × 1,200	800 × 800
Edge columns (mm)	1,200 × 1,200	1,000 × 1,000	600 × 600

3. Structural Loadings

3.1 Service Loadings Include Dead and Live Loads

Own weight of the structure elements is automatically calculated by the software (ETABS) [4]. Superimposed dead loads include floor finish and external/interior partitions' loads. It is common practice to use raised floor system (150 mm thick and 2.50 kN/m^2) as floor finish for offices space to facilitate running of services and network cables while public areas such as lift lobbies and corridors are finished with stone or marble flooring (2.80 kN/m^2). An additional load (1.0 kN/m^2) is used to cover equivalent interior dry partitions load which can be rearranged any time safely. Exterior curtain wall double tempered glass skins (6 mm each and cavity 16 mm in between) are considered along building edge. The cavity is introduced to provide thermal insulation and minimize the energy consumption of the building especially in the high temperature condition in Kuwait summer season. Live loads in the office areas are considered (2.50 kN/m^2) as specified in ASCE7-05 (American Society of Civil Engineers7-05).

3.2 Lateral Loadings Include Wind and Seismic Loads

Three-second gust wind speed based on 50 years' return period consistent to ASCE7-05 [5] is considered 38 m/s for Kuwait City. In the common engineering practice, buildings with height more than 100 m or with complex geometry in plan and/or elevation or with irregular surround buildings may affect the wind aerodynamic flow; wind tunnel test is recommended for precise definition of wind loads. In this paper, we applied wind loads as defined by code for study purpose only.

Kuwait City is categorized in seismic zone (1) according to UBC-97 Code where overall seismic lateral force shall not exceed 1% of the building mass. The SC (soil profile type) is selected to match with the soil conditions in most Kuwait areas.

4. Structural Analysis

Three-dimensional structural models for the investigated buildings were built using finite element method through ETABS software. The framing elements (columns and beams) were represented as line elements. Slabs and shear walls were represented as shell elements. The stiffness modifier factors for slabs, beams, columns, and shear walls were used as specified in ACI (American Concrete Institute) code [6] to maintain slabs acted as diaphragm for transferring lateral loads to the framing elements and to minimize its contribution in the lateral system stiffness. The P-delta option is selected for concrete structures.

4.1 Serviceability Study

This study is performed by applying service (unfactored) gravity and lateral loads and their load combinations as defined by ASCE7-05 Code. The main purpose of this study is to ensure that buildings have sufficient stability to limit lateral drift due to wind and limit peak acceleration at the highest occupied level within the acceptable range of occupancy comfort.

4.2 Ultimate Strength Study

This study is performed using the ultimate (factored) gravity and lateral loads and their combinations as defined by ASCE7-05 Code. This study is carried out to design the different structural elements to withstand loads safely as per ACI318-011 Code requirement.

5. Analysis Results and Discussions

5.1 Effect of Core Eccentricity on Building Wind Drift

Fig. 3 shows the building lateral wind drift in X and Y directions for all the investigated building models. It can be noticed from this figure that:

- X-wind drift for models A and B is almost the same and found within the acceptable range as defined in ASCE code limits. X-drift for model C is found 1.65 times than that of models A and B and beyond the code limits. This can be referred to core eccentricity. When eccentricity is below BL/6, it has minor effect on the wind drift and when eccentricity increases to BL/3, its effect on the wind drift becomes significant due to the distance between the centers of mass and rigidity increases and the building wind drift becomes unacceptable.
- The author introduced remedial action by adding two secondary cores in the opposite direction of the main core model (C-R) as shown in Fig. 1 to restore the building drift to the code limits. This action comes with satisfactory results and wind drift for model (C-R) approaches the same for models A and B and within the code limits. In this case, the distance between the centers of mass and rigidity is calculated and found (BL/5).
- Y-wind drift for models A and B is less than the same in X-direction because the core stiffness in Y-direction is bigger than that in X-direction.
- It is also noticed from the analysis results that the building X-drift due to gravity loads is very minor for models A, B and C-R while it is found to be increased by 25% of X-drift in the case of model C which provides additional lateral deformations for the building due to large core eccentricity.

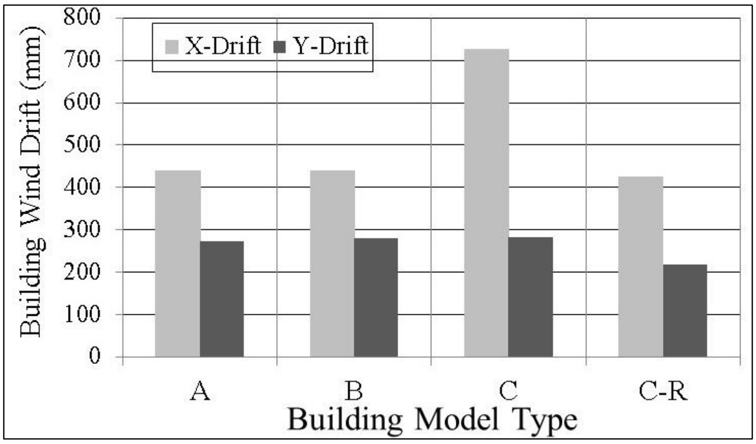

Fig. 3 Effect of core eccentricity on the wind drift.

5.2 Effect of Core Eccentricity on the Building Fundamental Periods

Fig. 4 shows the building core locations' (models A, B, C and C-R) impact on the first three fundamental periods in X, Y, and torsion directions (T1, T2 and T3) respectively. From these analysis results it can be noticed that:

- The first three fundamental periods for models A and B are almost the same while the first three periods (T1, T2 and T3) for model C are found about 27%, 22% and 2% respectively, higher than the same for model A. This is mainly can be attributed to core eccentricity impact.
- The first three fundamental periods (T1, T2 and T3) for model C-R are restored to slightly less values than the same for models A and B due to introduced two additional secondary cores which reduce the core eccentricity impact significantly.

5.3 Effect of Core Eccentricity on the Building Peak Acceleration

Fig. 5 presents the peak acceleration values for all the investigated building models calculated at the highest occupied level. The peak acceleration for models A, B and C-R are almost the same while it is slightly higher by about 11% for model C due to core eccentricity. All the models' peak accelerations are found within the acceptable range of occupancy comfort for such type of buildings.

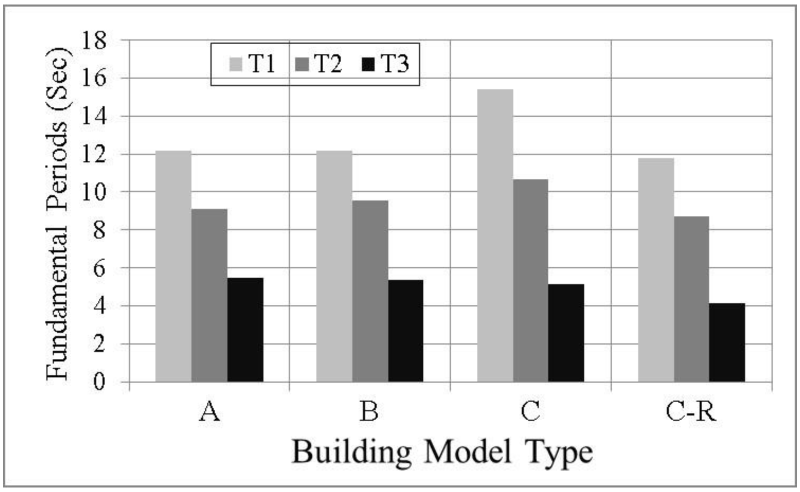

Fig. 4 Effect of core eccentricity on the building fundamental periods.

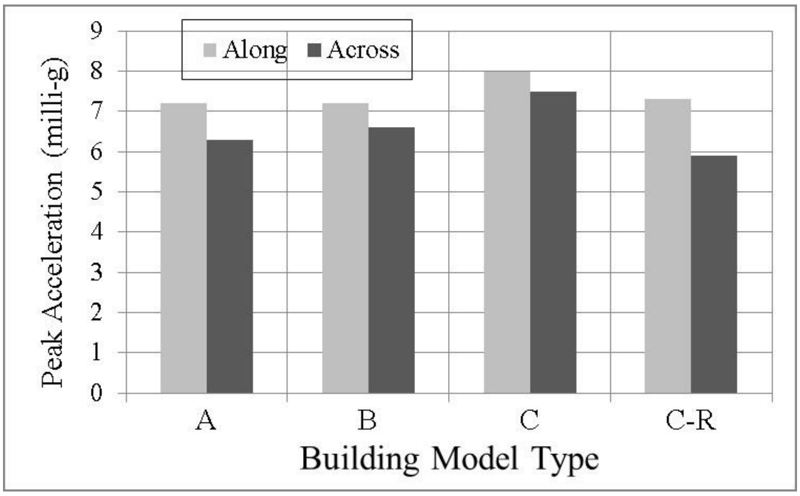

Fig. 5 Effect of core eccentricity on the building peak acceleration.

6. Conclusions

In this paper, buildings of 55 floors with three different core locations (centric, eccentric by one sixth and one third of building width) were investigated to study the influence of core eccentricity on the structural behavior. The finite element method was used for structural analysis of these buildings. It was concluded that:

- Core eccentricity within one sixth of the building width has minor impact on the building wind drift, the fundamental periods, and the peak acceleration at the highest occupied level. The building structural behavior in this case was found to be very similar to the case of centric core location.
- Core eccentricity of one third of the building width has a significant impact on the building wind drift as it increased by 65% more than centric core case. The first three fundamental periods of the building increased by 27%, 22% and 2% respectively more than the centric core case. The peak acceleration at the highest occupied level increased by 11% more than centric core case. The above increased parameters resulted in unsatisfactory building behavior because these values came beyond code allowable limits.
- Remedial action was proposed by the author by introducing two additional secondary cores in the opposite corners of the building to restore the building behavior to the acceptable code limits. As a result, the building drift decreased by 41.4% and the first three fundamental periods decreased by 23.4%, 18.6% and 22% respectively and the peak acceleration at the highest occupied level decreased by 10% compared to the one third core eccentricity core. This remedial action resulted in satisfactory building behavior.
- Architects are advised to avoid core eccentricity if possible. Otherwise, eccentric core can be used in coordination with the structural engineer to ensure acceptable structural building behavior within code limits.

References

[1] Ali, M., and Moon, K. 2007. “Structural Developments in Tall Buildings: Current Trends and Future Prospects.” *Architectural Science Review Journal* 50 (3): 205-23.

[2] Awida, T. A. 2010. “The Structural Behavior of Low/Medium/High Rise Concrete Office Buildings in Kuwait.” *Journal of Civil Engineering and Architecture* 4 (10): 59-65.

[3] Awida, T. A. 2011. “Slenderness Ratio Influence on the Structural Behavior of Residential Concrete Tall Buildings.” *Journal of Civil Engineering and Architecture* 5 (6): 527-534.

[4] Computer and Structures Incorporation (CSI). 2020. *Extended Three-Dimensional Analysis of Building Systems (ETABS) Software.* Berkeley, CA: University Avenue.

[5] American Society of Civil Engineers (ASCE). 2005. *Minimum Design Loads for Buildings and Other Structures—ASCE 7-05 Code.* New York: ASCE.

[6] American Concrete Institute (ACI). 2011. *Building Code Requirements for Structural Concrete and Commentary—ACI318-11 Code.* Farmington Hills: ACI.