Proc. 1st International Conference on Structural Engineering Research (iCSER 2017)
20-22 Nov 2017, Sydney, Australia
ISBN: 978-0-6480147-6-8

Influence of Analysis Approach on the Design of High-Rise Buildings with Transfer Plate

A. Osman[1] and M. Abdel Azim[2]

[1]Professor, Structural Eng. Dept., Cairo University, Egypt
[2]Structural Engineer, DAR Al-Handasah, Egypt
Corresponding author's E-mail: Mohamed.AbdelAzim@dargroup.com

Abstract

This study examines the consequences of the different analysis approaches traditionally followed by designers in consulting offices during the design process of high-rise buildings utilizing thick transfer slabs between their tower and podium floors. Emphasis is placed on the importance of accounting for the interaction between the transfer plate slabs and the building structural elements during the analysis process. The effect of the transfer slab span to thickness ratio on the structural behaviour of such buildings is investigated. It was concluded that interaction between the transfer slabs and building vertical structural elements can significantly affect the straining actions calculated within these elements and consequently this effect should be accounted for during analysing these structures. Also, it was shown that the transfer slab should be accurately modelled during developing the building structural numerical model to simulate the real structural behaviour for such type of building.

***Keywords**: High-rise buildings, transfer plate, finite elements, two-stage analysis.*

1. INTRODUCTION

Currently, high-rise buildings are commonly constructed for various uses and occupancy demands. Lower floors (podiums) are conventionally used as parking zones, shopping malls, assembly halls or open spaces for different functional requirements, while higher floors (towers) accommodate apartments, offices or hotel rooms. Such diversity in architectural functional demands forces the vertical structural elements, such as columns, walls and cores, within podium floors not to be vertically aligned with those belonging to the tower floors. In turn this leads to the need for utilizing structural transfer system to transmit the heavy loads from tower vertical structural elements to podium vertical structural elements. One of these transfer systems that are recently becoming common and sometimes even inevitable in modern building developments is the transfer plate slab system. This system involves the use of 2 to 3m thick reinforced concrete solid slab located about 20 to 30m above ground level at the interface level between tower and podium. Although, the system gained popularity due to its ability to satisfy easily the architectural layouts and provide column- free open space areas at podium floors, from structural prospective, it poses a great challenge to structural designers. This is attributed to the fact that transfer slab thickness is not only dictated by the magnitude of applied loads over it (strength design), but also by its contribution to building overall behavior (stiffness effects).

Current design practice followed by most consulting offices for analyzing this type of structure is usually limited to one of two codified approaches. In the first, the so called two-stage analysis technique is adopted (ASCE, 2010). In this approach, the tower is analyzed separately assuming it is fixed at the transfer slab level which is presumed to be infinitely rigid. Then, the obtained reactions are reversed in directions and applied to the below podium structure. In the second approach, the structure is globally simulated numerically using finite element technique and the transfer slab is modelled using either thick shell elements, as in most cases, or solid elements, as in lesser cases (Zhang, 2004).

This raised an important questions regarding understanding the consequences of following each approach on the design of vertical structural elements within the building and its global behavior.

Therefore, in this study real buildings utilizing transfer slabs were developed and analyzed using the previously described different design approaches. The consequence as a result of following these analysis approaches on the design the structural elements were evaluated. The evaluation included; (1) Examining the variation in the straining actions developed within the vertical structural elements; (2) The resulting story drift and lateral displacement for the buildings; and (3) The structural stiffness and natural periods. In addition, the study examined the effect of transfer slab depth-thickness ratio and stiffness on the design behavior of such structures types.

2. STUDIED BUILDINGS

For this study, three real structures designated as A, B and C were developed and analyzed under the action of both gravity and lateral loads. Both two stage and global modelling techniques were utilized for analyzing these structures to assess the effect of different analysis approaches on the design outcomes for these structures. With the global modelling approach, the transfer slabs were modelled once using thick shell elements and in another case was modeled using solid element. Various design aspects for the transfer slab such as depth-thickness ratio and stiffness were varied in order to examine their effects on the behavior and design of these structures.

The buildings were accurately modelled to simulate to great extant its real structural behavior. For analysis purpose SAP2000 program (integrated software for structural analysis and design) was used to model the structures with transfer slab simulated as solid element, while ETABS (integrated analysis design and drafting of building system) program was used to model structures with transfer slabs simulated using thick shell elements.

In all these models, the tower and podium beams and columns were simulated using beam-column elements, while walls and floor slabs were simulated using shell elements. The transfer slab was modelled using thick shell elements or solid elements. The applied gravity loads to all the examined buildings consisted of both dead and live loads. The dead loads included the structure self-weight, flooring, partitions, and electro-mechanical installation loads. The live loads were in accordance to UBC code (1997). No reduction to live loads was considered in these analyses. Also, for all buildings, seismic loads are calculated using UBC (1997).

3. ANALYSIS RESULTS

Figure 1 shows the global finite element model for building A. As shown it consisted of 24 stories forming the tower top supported over 10 stories representing the podium with total height of 130.50m.The concrete transfer slab were located at the interface between podium and tower floors at elevation 46m from the ground level and its thickness was 2m thick. The building resists the lateral loads by several shear walls and cores. All floor slabs were flat slabs having thickness 0.30m.

For all tower typical floors which were designated as residential floors, the gravity loads were assumed to be equal to the self-weight of the structural elements determined from calculating their weights based on density of construction material and element dimensions, 0.55 t/m^2 as superimposed dead loads and 0.20 t/m^2 as live loads. For the transfer floor level, superimposed dead load and live loads were taken to be 0.65 t/m^2 and 0.50 t/m^2, respectively. For all podium floors which were designated as commercial floors, in addition to structural elements self-weight, 0.65 t/m^2 superimposed dead loads and 0.5t/m^2 as live loads were considered. For lateral loads acting on the building, the equivalent seismic forces were calculated based on UBC(1997) and the seismic parameters utilized were based on assuming that the soil type is SB (Rock), the seismic zone factor (Z) was 0.075 and seismic coefficient (C_a) was 0.08. The reduction coefficient (R) which is representing the inherent over-strength and ductility capacity of the lateral force-resisting systems was taken as 5.50, the seismic coefficient (C_v) was taken 0.08 and the numerical coefficient (C_t) was taken as 0.02. For mass source, dead load factor was assumed to be 1.0.

For analyzing the structure, three different approaches were adopted. In the first approach, two stage analysis technique was used, since the building satisfied the approach requirements, were the lateral stiffness of the podium were equal to 21.3 times and 29.2 times the stiffness of the tower in both x- and y-directions, respectively, and the period of the entire structure was equal 0.91 times the period of the tower. In this approach the tower floors were modelled separately using the widely used commercial code SAP2000 (integrated software for structural analysis and design) assuming fixed bases and the outcome reactions of this first stage analysis were reversed and applied to podium floors which were modelled separately in the second stage. In the second and third approaches the structure was globally modelled once using the commercial code ETABS (integrated analysis design and drafting of building system) with the transfer slab simulated using thick shell and another using the commercial code SAP2000 (integrated software for structural analysis and design) with the transfer slab modelled using solid element. The columns and beams in both cases were modelled using the available beam-column elements, while the cores and shear walls were modelled using shell elements.

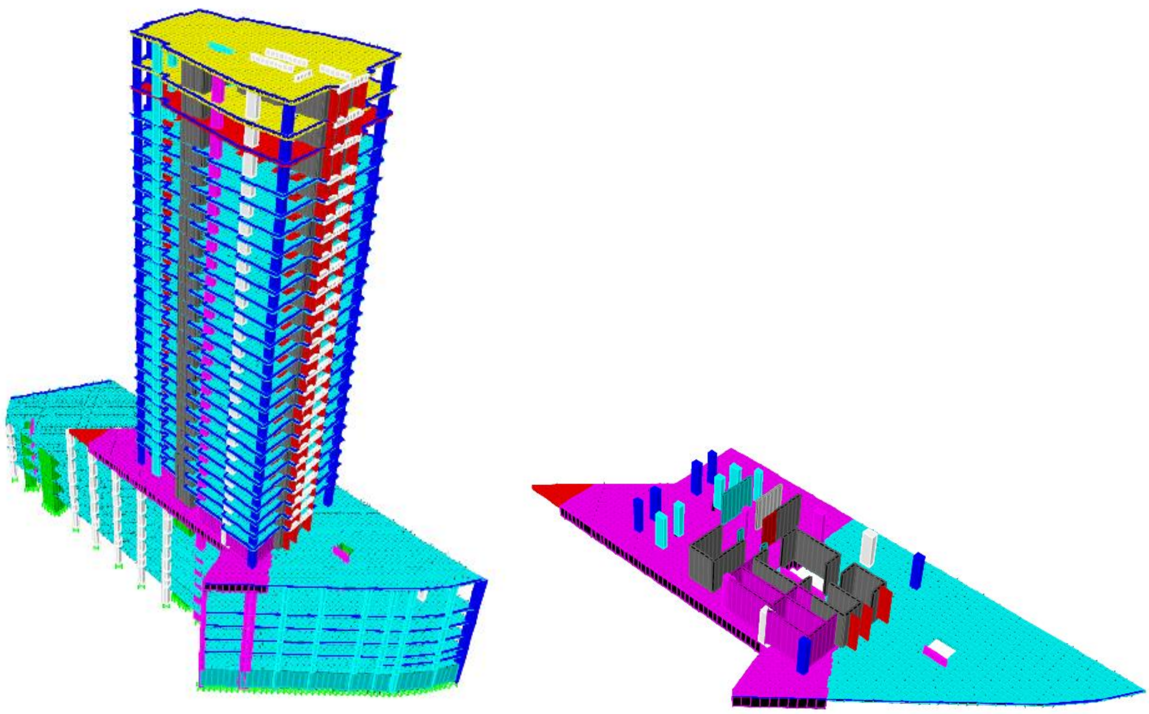

Figure 1: 3D view for the finite element model for building A with close up to transfer slab

The straining actions (axial forces, bending moments in both directions) were determined and compared for the three cases. Figures 2, 3, 4 and 5 show the axial forces, bending moments around the two principal axes and shear forces, respectively for some of the tower columns located directly above the transfer slab. As can be noted, the columns axial forces were slightly affected regardless of the followed analysis approach. On the contrary different trends for the moments and shear forces were observed. Separated model (two-stage-analysis) gave the lowest moment and shear force results while the global model utilizing shell elements for the transfer slab gave the highest moment and shear force values. This can be understood by examining the deformation of the transfer slab in the three approaches along the same section. As can be noted from Figure 6, the deformation and rotation of the transfer slab at same node in global model using shell element for transfer slab was the highest compared to those of other models. Such high slab rotations induced high rotations for tower column at connection with the transfer slab producing these observed high moments. On the other hand for separated model the deformation and rotation were nil, since the tower column bases were assumed fixed. This drastically reduced the resulting bending moments on these columns, since the transfer slab deformations and rotations were not accounted for. Analysis showed that this effect is dying with height. In other words after about six floors, the moments within the columns became the same regardless the followed analysis approach, which indicate that it is a local effect confined to few floors above the transfer slabs. For the columns below the transfer slab similar behavior was noted. Regarding the building overall lateral displacement, Figure 7 shows the building lateral displacement values in X-direction plotted along the building height. The figure indicated that the analysis approach followed affected the obtained displacement values. For instance, when solid element utilized for modelling transfer slab the drift was less than when the transfer slab was modelled using shell elements. In addition, eigenvalue analyses showed that natural periods for building analyzed with transfer slab modelled using shell element were longer than this analyzed with transfer slab modelled using solid element.

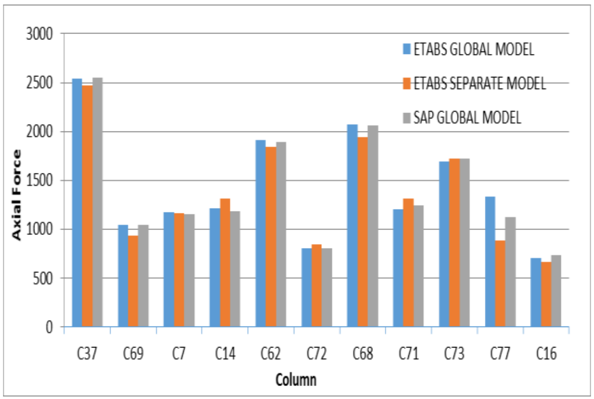

Figure 2. Axial force for tower columns above transfer levels

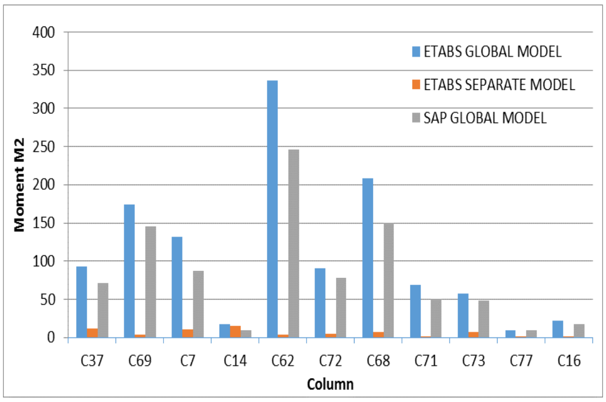

Figure 3. Moments in x-direction for columns above transfer levels

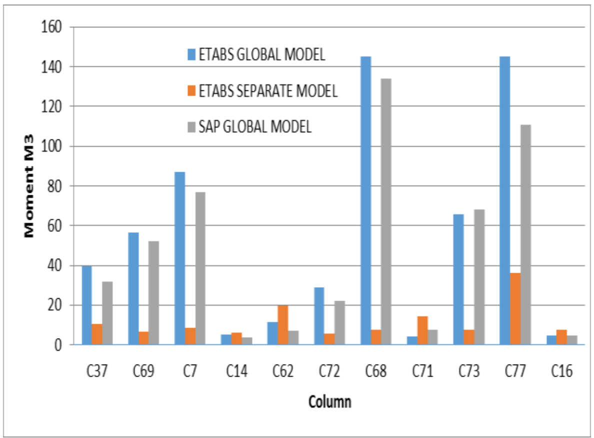

Figure 4: Moments in Y-direction for columns above transfer levels

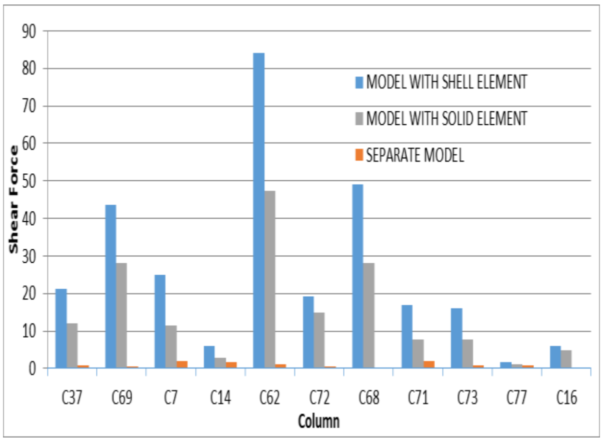

Figure 5: Shear forces for columns above transfer levels

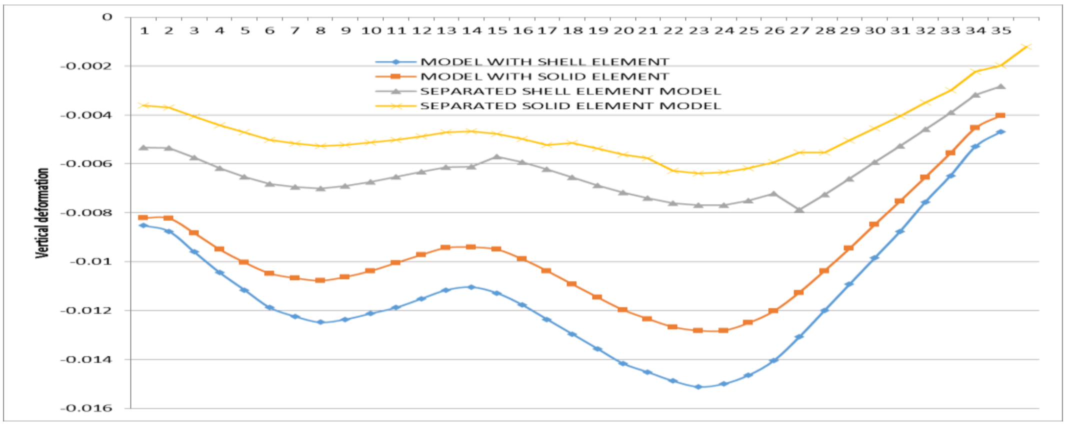

Figure 6. Vertical deformation of points in a horizontal section at the transfer level

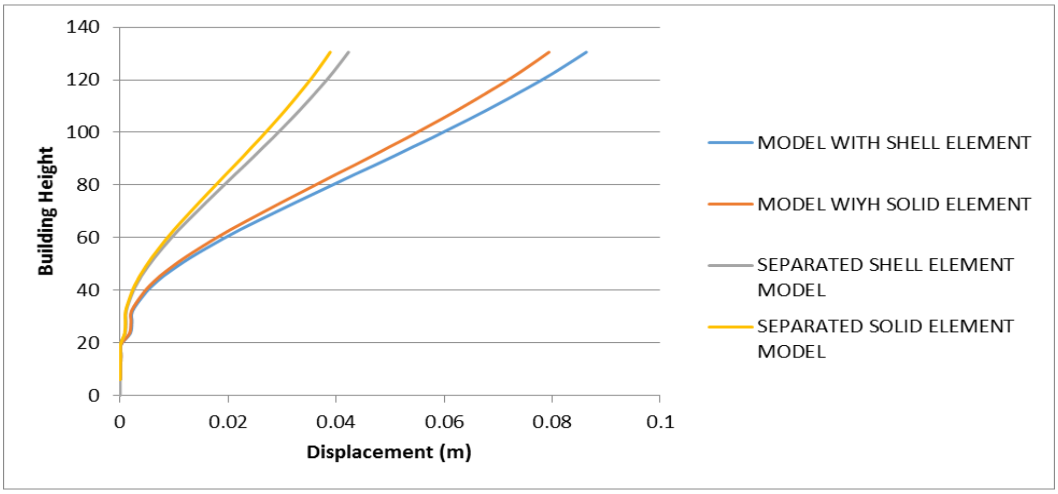

Figure 7. Story displacement in X-direction due to lateral load

To examine the effect of transfer slab span to it thickness ratio on the behavior, a modified building was produced from model A by removing many of the tower floors to allow for adopting less transfer slab thickness. This situation can exist in reality if the tower is not high-rise one, and still the design requesting podium utilized for different architectural purposes other than that of tower. For such purpose the tower was assumed to be only 6 floors high and the transfer slab was taken as 60 cm thick. Consequently the aspect ratio for the transfer slab span to depth ratio was about 16.66. In this case the structure was modelled globally once utilizing transfer slab modelled using thick shell elements and in other case the transfer slab was modelled using solid elements. Figures 8 and 9 show the moments and shears in columns above transfer slab for both analyses. As can be noted the obtained results are approximately the same. This proves that in case the aspect ratio of the transfer slab (span to depth ratio) is ranging between 14 and 18, which will be the case for low and intermediate high-rise towers, using solid elements or thick shell will yield the same results. However, for less aspect ratio the transfer slab should be modelled using solid elements to capture the real deformation and rotation behavior of the transfer slab, since shell element developed based on plate bending theory cannot simulate behaviour of thick slabs.

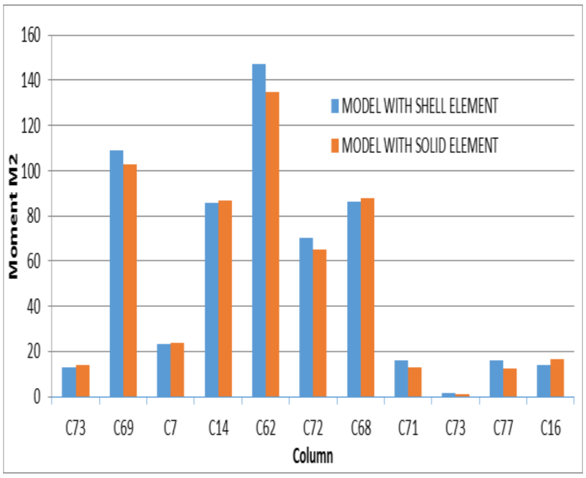

Figure 8. Moment of columns above transfer level

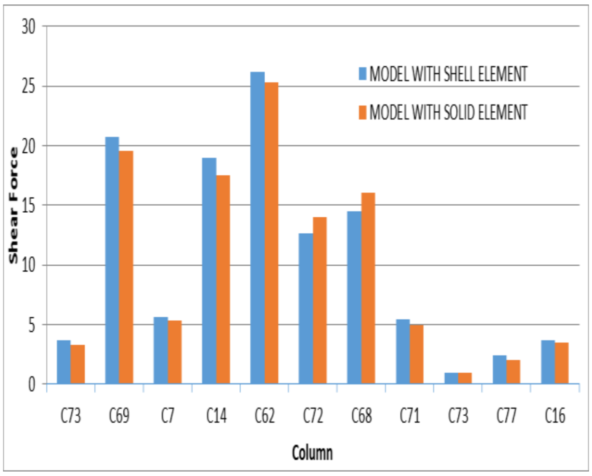

Figure 9. Shear forces of columns above transfer levels

Similarly, the above indicated analyses were performed for buildings B and C shown on Figures 10 and 11, respectively. Building B is 291 m high (21 podium storey and 44 typical storey) and having a transfer slab 4.5 m thick located at elevation 112.8 m from ground level, while building C is 230.15 m high (18 podium storey and 34 typical storey) and having a transfer slab 3 m thick located at elevation 84.5 m from ground level. Results from these analyses supported the previously achieved conclusions (Abdel Azim 2016). It is worth to mention here that the lateral loading system for building B consisted mainly from shear walls and cores, while that of Building C, similar to building A, consisted of cores and columns.

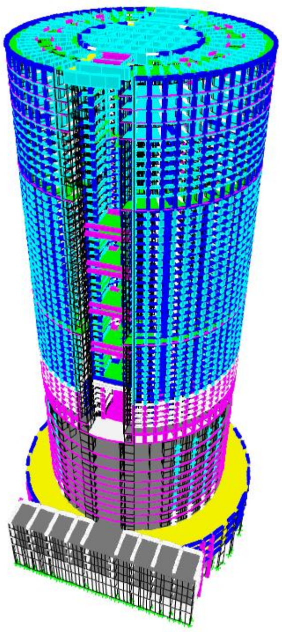

Figure 10. 3D view for building B

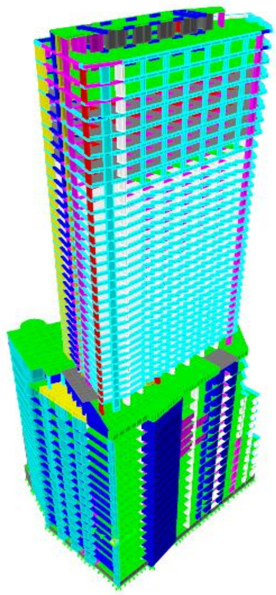

Figure 11. 3D view for building C

4. CONCLUSION

In conclusion, the two stage analysis technique should not be used in analyzing high-rise buildings with transfer slab in spite of it is allowed by codes, since it neglects the interaction between the transfer floor and the vertical structural elements of the building resulting in estimating the straining actions acting on these elements and building lateral deformation incorrectly. In addition, it was showed that in global modelling to such buildings type, the transfer slab should be modelled accurately with elements capable of capturing its real structural behavior in order to achieve accurate results. In this regard for transfer slabs having span to thickness ratio less than 1:15 ,the use of solid elements, although considered tedious and time consuming task, may be the solution for this problem. Shell elements developed based on plate bending theory, in spite of their simplicity, should not be utilized for modelling the transfer slab except if the span to depth ratio of the transfer slab exceeded 1:14.

5. REFERENCES

Abdel Azim M (2016). Structure behaviour of buildings with transfer plate system. M.Sc, Structural Engineering Department, Cairo University, Egypt.

ASCE (2010). Minimum design loads for buildings and other structures -7-2010. American Society of Civil Engineers, U.S.A.

UBC (1997).Uniform Building Code. International Conference of Building Officials, California, U.S.A.

Zhang H (2004). Finite element modelling of transfer plates in tall buildings. Ph.D. thesis, Civil and Structural Engineering, Hong Kong University.