# ADOPTION OF REGULAR COLUMN INSTEAD OF SHEAR WALL AT LIFT-CORE OF MODERATELY TALL RC FRAME STRUCTURE

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## ABSTRACT

Shear wall are prominently used in lift-core of reinforced concrete (RC) frame structure for their optimum lateral stiffness and dynamic vibration resistivity. The ambient lateral load resistance, high stiffness and vibration resilience are the prime motivation to use such kind of solid element in the building structure. Providing shear wall, the deflection might be significantly reduced and therefore structural engineers are frequently choose this option. This study investigates the optimization of shear wall and evaluating the potentiality of regular column (instead of shear wall) in lift-core of a typical RC building frame. Two different modelling approaches of the lift-core (shear wall oriented and column oriented) have been employed to assess the seismic performances of a RC frame by nonlinear dynamic analysis. The RC building frame was considered as a intermediate moment resisting frame (IMRF) and a fixed restraint condition at foundation level of the building frame was considered. Five optimization schemes were adopted for both models by changing the relative position of shear wall and column arrangement. The seismic performance considered in this studies are storey deflections for both models, which further compared with the maximum permissible storey deflections following BNBC-2006, ACI Code 9.5.2 and Nilson et al. (2003). The numerical result shows that, the shear wall oriented lift-core posses less storey deflection than the column oriented lift-core whereas, for moderately tall structure (i.e., up to 9 storey), column oriented lift-core may use instead of shear wall as the permissible limit allows this initiation. But, for more than 9 storey, column oriented lift-core may not be adequate and then mandatorily shear wall have to adopted at lift-shaft because of the exceeding of permissible storey deflection at top storey.

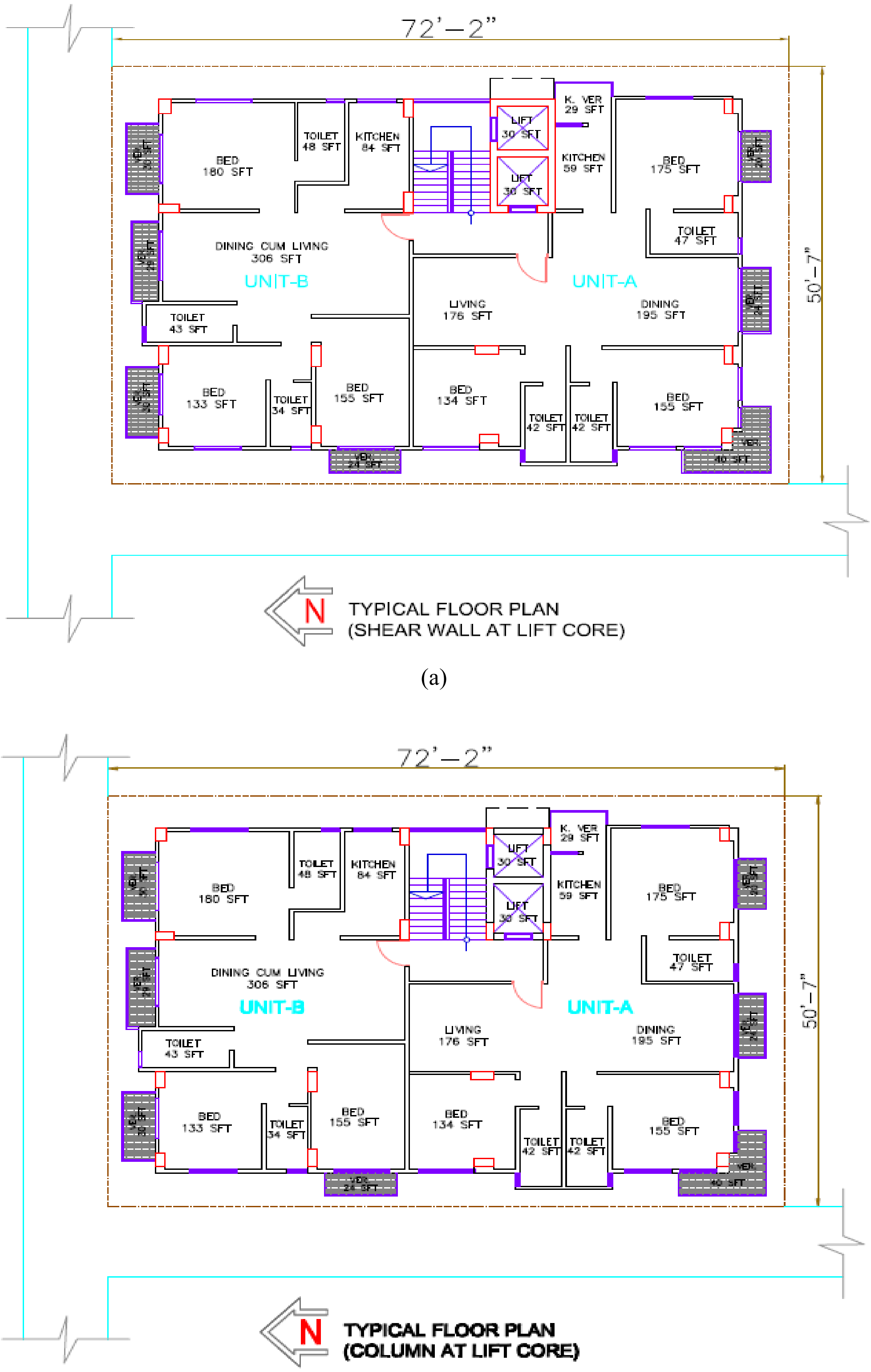
Keywords: Shear wall, rc frame structure, nonlinear dynamic analysis, maximum permissible deflection, seismic performance, building code

## INTRODUCTION

Shear wall is a common practice in lift-core for the multi-storied reinforced concrete (RC) building construction. At the RC building frame, lift-core is the most vibratory portion as the lift-cabin moves up and down continuously for transporting human being and goods at different floors of structure. The vibration produced by the lift in a RC frame may cause dilemmatic situation. In the very early stage of its invention, the weight of the lift's machine unit and cabin was quite heavy. But trend of modern science makes this issue a simple one. Recently, most of the lift is made from light fiber materials and they are comparatively lighter than earlier one. Earlier heavy lifting unit produced huge vibratory effect and they are dominantly manually operated (i.e., Pulley-Crane subsystem), so that structural engineers tried to emphasis on thicker lift-core (10 to 12 inch) with adequate reinforcement to reduce the vibration phenomena. Today's nominal-weighted lift is fully automated by the modern electromagnetic interaction and is appealing to rethink about the lift-core mechanism i.e., simple column instead of shear wall (Khan, 2015). Different authors focused on the shear wall and column analogy in the lift-core and the vibration effect of the continuous movement of lift-core. The optimization of shear wall has been assessed by Katkhoda and Knaa (2012) in the selection of structural systems for the design of RC high rise building for seismic resilience. The authors studied RC high rise building (10, 15, 20 storied), where the genetic algorithm was applied to access optimum solution, which ensures the economic dimensions that achieve the saving in concrete and steel amount thus gain lower cost also. The authors consider shear wall system, moment resisting frame and the optimum combination of frame and shear wall system. Effect of change in shear wall location on storey drift of multi-story building was critically observed by Agrawal and Charkha (2012) when structure subjected to lateral loads. The authors argued that, shear wall is very prominent for high plain stiffness and strength which can be used to resist large gravity loads. It is very important to determine effective, efficient and ideal location of shear wall. The analysis proceeds by changing various position of shear wall with different shapes for determining parameters like storey drift, displacement and axial load etc. incorporating ETABS software. Shear wall are oblong in cross section, i.e., one dimension of the cross section is much higher than the other. While rectangular cross section is common, box shaped, L-shaped, U-shaped and other required sections are also used. Husain (2013) argued that, the hollow RC shaft around the lift-core of RC building act as shear walls and could be utilize to significantly resist seismic forces. Properly designed and detailed shear walls have shown very good performance in past earthquake as lateral loads caused by wind. Shear wall buildings are a popular choice in many earthquake prone countries, like Chile, New Zealand, USA, India and even in Bangladesh. Optimum structural modelling for tall buildings was performed by Jameel et al. (2012) where more emphasis was adopted on shear wall at lift-core. The authors argued that, dual system modelling combining frame and shear wall is appropriate for multi-storied buildings at lift-core and stair case portion. The investigation promotes the effects of multi-storied framed and shear wall structure in terms of storey displacement, natural frequency and natural time periods. Lateral displacement and storey drift were measured and it was observed that shear wall is a fruitful solution with cost effectiveness. Effect of different configuration of shear walls on seismic behaviour of high rise building was evaluated by Kharade and Chore (2014) where shear wall mainly used at lift-core. In multi-storied building, presence of lift-core wall causes localized increase of lateral stiffness of the overall system. Effect of placement and opening in shear wall on the displacement at various levels in a building subjected to seismic thrust was evaluated by Gupta and Pande (2014). Considering column at lift-core might reduce significant amount of costing in compare to shear wall construction. Moreover, the structural self weight could be noticeably reduced at the lift-core portion which finally helps to reduce foundation volume. In the BNBC-2006, ACI Code 9.5.2 and Nilson et al. (2003), a guideline provided for maximum permissible computed deflections for the residential building structure. It could be earnestly possible to analyse the effectiveness of simple column in compare with shear wall made lift-core and check the deflection limits accordingly. Column based lift-core allows the deflection limit for certain height (i.e., up to 9 storey) might be a cost effective alternative. The objective of this work is to carry out the optimization of shear wall in lift-core of RC building structure and evaluating the effectiveness of regular column instead of shear wall at lift-core.

## MODELLING OF THE RC FRAME BUILDING

A RC building frame [Fig. 1 & Fig. 2] suitable for FE software analysis was selected after taking the necessary permission from the project owner. Geometric and material data of RC building frame have been assigned after critically analyse the collected information. Some initial hand approximation has been initiated to primarily consider the tentative section of beam, column, slab and shear wall members. A Professional finite element (FE) based software namely Extended Three Dimensional Analysis of Building System (i.e., ETABS Nonlinear Version 9.7.0) was incorporated for dynamic analysis of the RC building frame. A new model was initiated from the software opening interface and assign total number of stories (B+G+7). The grid spacing have to be defined according to the column to column distance following the spacing in X and Y direction. The grid ID in X direction are delimited to A - J with corresponding spacing with 50", 182", 118", 109", 74", 83", 84", 47" and 42", respectively. Again, the grid ID in Y direction are delimited to 1 - 10 with corresponding spacing were 34", 63", 74", 32", 96", 92", 32", 35", 41", 45" and 30", respectively. The storey ID has been assigned according to features including level, height and comparative elevations. In this study, the height of typical floor was 10 ft and the basement floor was at 5 ft top of foundation level. *"Define"* menu helps to confirm the materials properties and frame sections. Four structural elements of the RC frame were Beam ($f_c$'=3500 lb/in$^2$), Column ($f_c$'=4000 lb/in$^2$), Slab ($f_c$'=3500 lb/in$^2$) and Shear wall ($f_c$'=4000 lb/in$^2$). 72 Grade ($F_y$=72000 lb/in$^2$) steel was blended in each structural elements.



(a)

(b)

Fig. 1: Physical model (typical plan) of the RC building frame (a) shear wall at lift-core (Model A), (b) only column at lift-core (Model B)

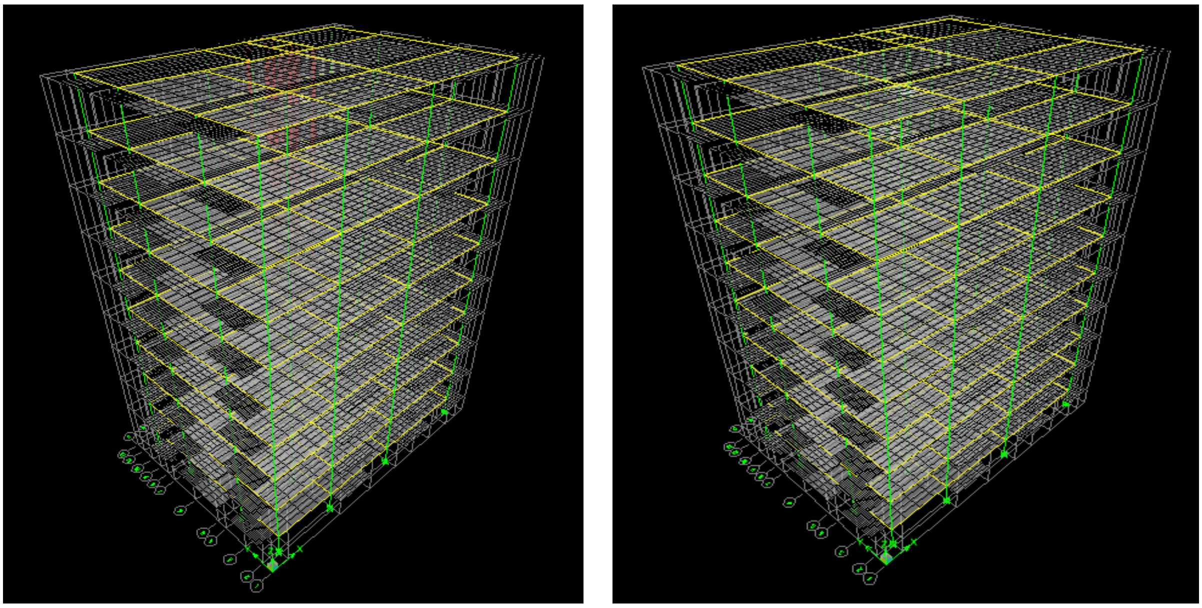

(a) (b)

Fig. 2: 3D Model at FE scheme (a) shear wall at lift-core (Model A), (b) only column at lift-core (Model B)

The modulus of elasticity was assigned following the formula [$E = 57000\sqrt{(f_c')}$], where $f_c'$ is in $lb/in^2$. Frame sections of the structural elements were ensured with the relevant cross section of Beam (10" x 24"), Column (10" x 25") and Column (10" x 30") at lift-core, Column (12" x 20") at corner, Column (12" x 25") at side span and Column (12" x 30") at mid span. All sections are rectangular in shape. Slab is 5.5" thick and shear wall is 10" thick with pier level P1. All the structural members have been digitally drawn based on the grid and following the sequence of columns → beams → shear walls → slab chronologically. The base support condition was assigned as fixed. The dead load and live load at each floor slab was assigned as uniformly distributed in nature. The entire slab member and shear wall elements was meshed to 4 by 4 for accurate analysis. The inner portion of lift-core was assigned as opening. The centre of diaphragm was checked which should be nearly at centre of RC building frame. The model was critically checked for the FE software ETABS analyse. After successful analysis, the design combination following the *"select design combo"* was initiated for both USD (Ultimate Strength Design) and WSD (Working Strength Design) loading pattern. Both the concrete frame and shear wall member was designed individually to find the deformed shape and storey deflection. The storey deflection was then compared with the code provided allowable deflection values for shear wall based lift-core and simple column based lift-core. Other optimization models was analysed and designed following aforementioned steps chronologically to find out the storey deflections at every grid of each model.

## LOADS AND LOAD COMBINATIONS

Following expert based opinion, assume that, the dead load is 100 $lb/ft^2$ and live load is 40 $lb/ft^2$. These loads were uniformly distributed on the top of each slab from basement floor to 7th floor. At the top roof, the entire distributed loads assigned as its half of the regular floor by the practical observation. Earthquake and wind load was assigned according to UBC (Uniform Building Code) 1994. For earthquake loads, seismic zone factor (Z) is 0.15, site coefficient (S) is 1.2 and structural importance factor (I) is 1.0 with time period 0.030 and numerical response modification factor ($R_w$) is 8.0. The active zone for seismicity is base to top roof. For wind load, basic wind speed is 150 mph (mile/hour), exposure type is B, and structural importance factor is 1.0 with windward coefficient is 0.8 and leeward coefficient is 0.5. The active zone for wind induced vibration is ground floor to top roof. Two load combinations are considered in this study, namely WSD and USD combination. For WSD combination, both the dead load and live load coefficient is 1. Whereas, for USD combination, dead load coefficient is 1.2 and live load coefficient is 1.6. Some other default combinations were automatically initiated by the professional finite element environment of ETABS 9.7.0.

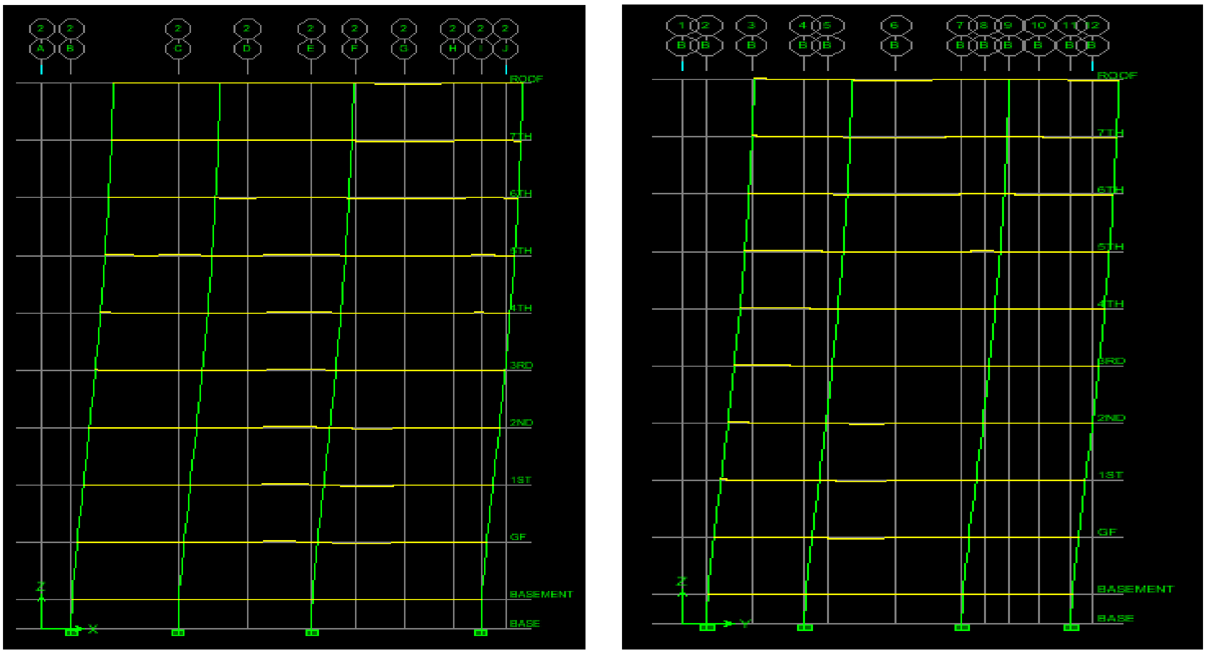
## ALLOWABLE DEFLECTION BY BNBC-2006 AND OTHER CODES

According to BNBC–2006 (Table 6.6.4), ACI Code 9.5.2 and Table 6.2 of Nilson et al. (2003), the maximum permissible computed deflection for RC frame structure is **[(L/480)++]** with complying some other conditions. Current study incorporates **(L/500)** to compute the maximum permissible deflection, where **L** means total height of building structure in "inch". The allowable deflection at top roof becomes 2.28". Following same approximation, the allowable deflections at basement floor to 7th floor were 0.12", 0.36", 0.60", 0.84", 1.08", 1.32", 1.56", 1.80" and 2.04", respectively. The allowable deflection at foundation level was considered as zero for fixed support condition.

## NUMERICAL OUTCOMES

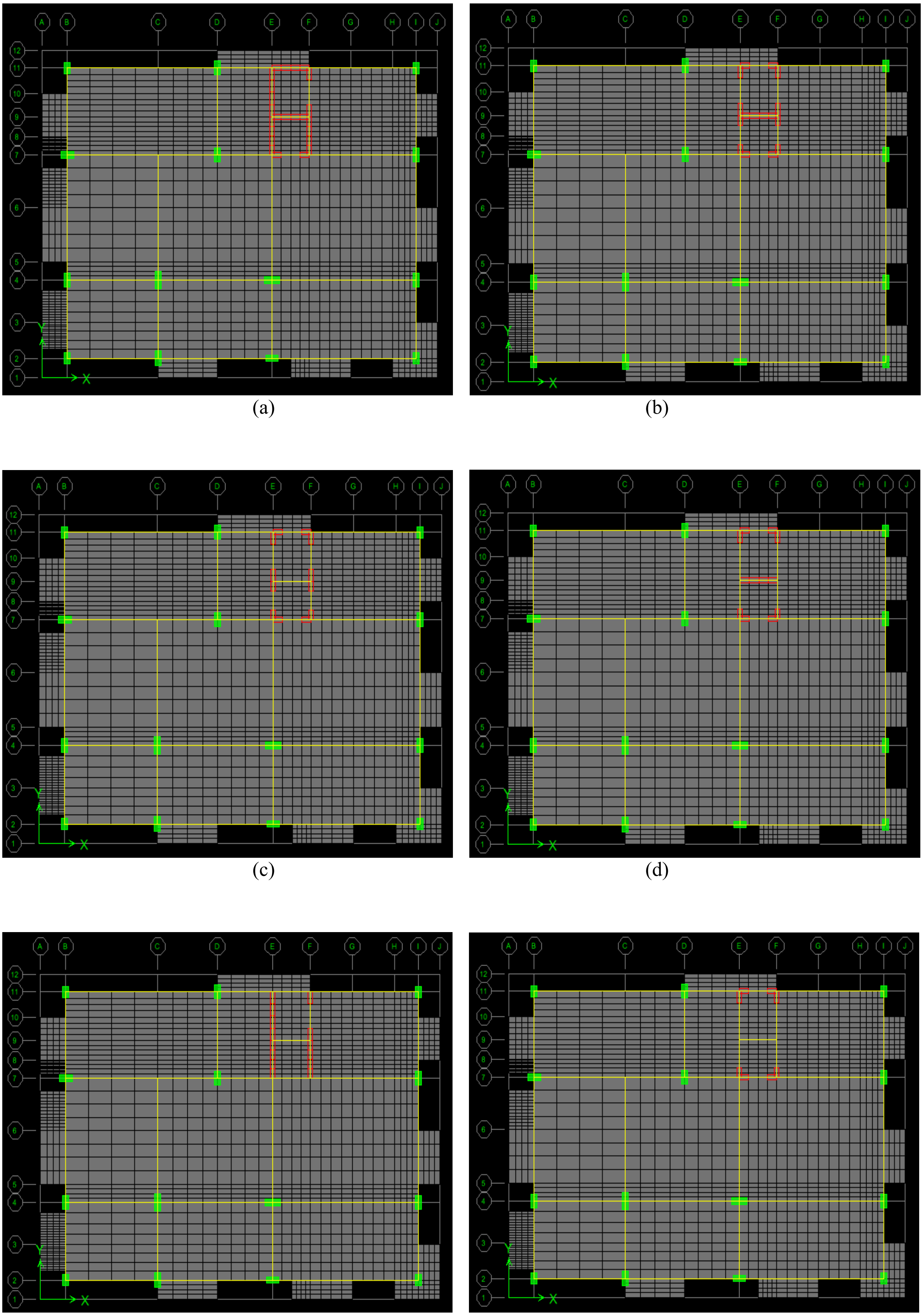
Table 1: Comparison of maximum and allowable storey deflection for different modelling approaches

| Model | Storey ID | Grid ID | Maximum Storey Deflection, $\delta_U$ (inch) | Allowable Storey Deflection by BNBC – 2006, $\delta_A$ (inch) | Comparison of Maximum and Allowable Storey Deflection | % Change in between $\delta_U$ & $\delta_A$ |
|---|---|---|---|---|---|---|
| Model A (Shear wall at Lift) | Top Roof | Grid 2 | 1.194 | 2.280 | $\delta_U < \delta_A$ (Safe) | 90.888 |
| 1st Optimization of Model A | Top Roof | Grid B | 1.464 | 2.280 | $\delta_U < \delta_A$ (Safe) | 55.749 |
| 2nd Optimization of Model A | Top Roof | Grid B | 1.470 | 2.280 | $\delta_U < \delta_A$ (Safe) | 55.052 |
| 3rd Optimization of Model A | Top Roof | Grid B | 1.646 | 2.280 | $\delta_U < \delta_A$ (Safe) | 38.534 |
| 4th Optimization of Model A | Top Roof | Grid 2 | 1.573 | 2.280 | $\delta_U < \delta_A$ (Safe) | 44.915 |
| 5th Optimization of Model A | Top Roof | Grid B | 1.689 | 2.280 | $\delta_U < \delta_A$ (Safe) | 35.013 |
| Model B (Column at Lift) | Top Roof | Grid B | 1.665 | 2.280 | $\delta_U < \delta_A$ (Safe) | 36.956 |
| 1st Optimization of Model B | Top Roof | Grid B | 1.862 | 2.280 | $\delta_U < \delta_A$ (Safe) | 22.436 |
| 2nd Optimization of Model B | Top Roof | Grid B | 1.931 | 2.280 | $\delta_U < \delta_A$ (Safe) | 18.056 |
| 3rd Optimization of Model B | Top Roof | Grid B | 1.826 | 2.280 | $\delta_U < \delta_A$ (Safe) | 24.856 |
| 4th Optimization of Model B | Top Roof | Grid B | 1.891 | 2.280 | $\delta_U < \delta_A$ (Safe) | 20.601 |
| 5th Optimization of Model B | Top Roof | Grid B | 1.786 | 2.280 | $\delta_U < \delta_A$ (Safe) | 27.680 |



(a) (b)

Fig. 3: Deformed shape with maximum deflection (a) Model A (at grid 2), (b) Model B (at grid B)

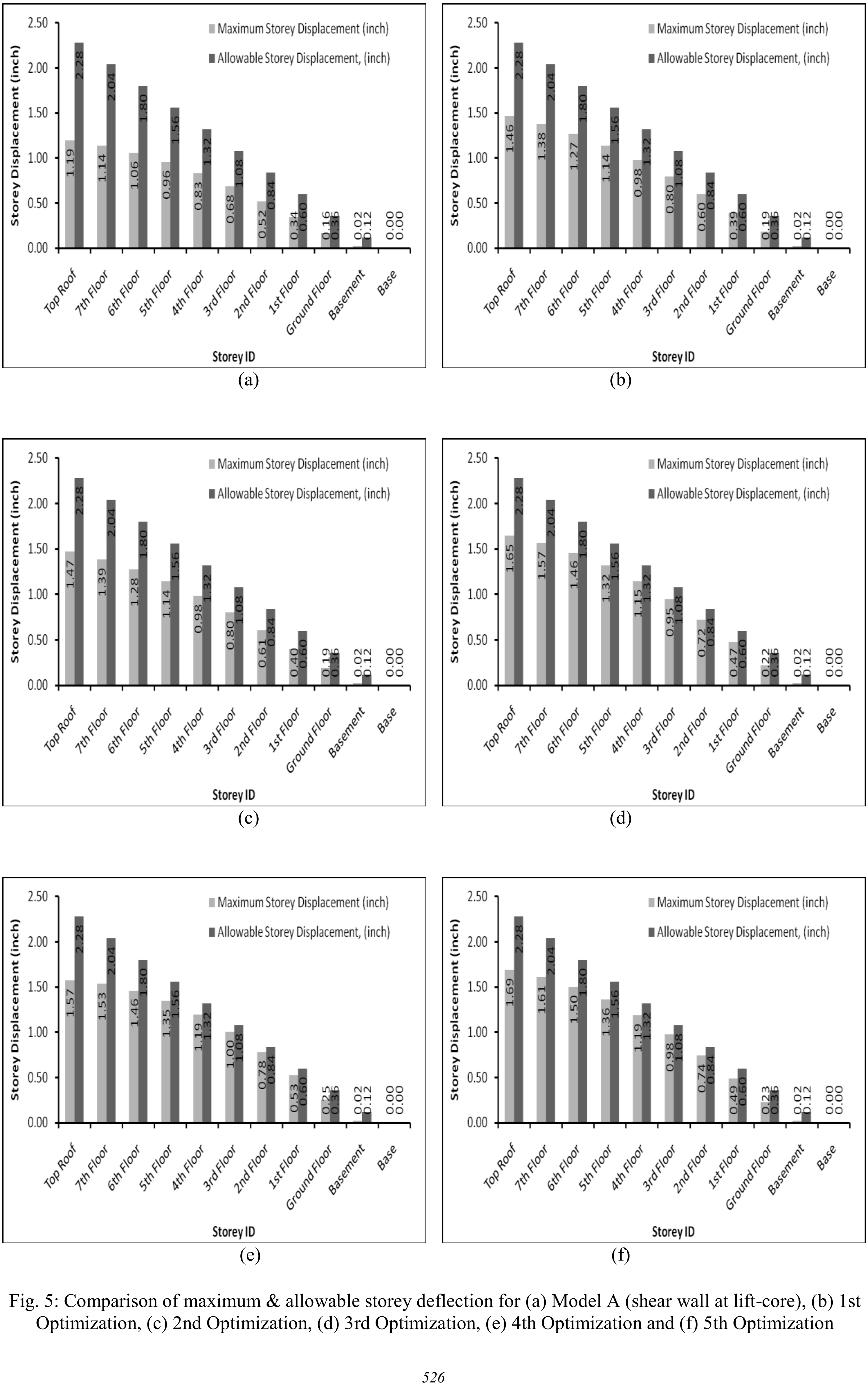


(a) (b)

(c) (d)

(e) (f)

Fig. 4: Plan of the RC frame (shear wall provided at lift-core) (a) Model A, (b) 1st Optimization, (c) 2nd Optimization, (d) 3rd Optimization, (e) 4th Optimization, and (f) 5th Optimization

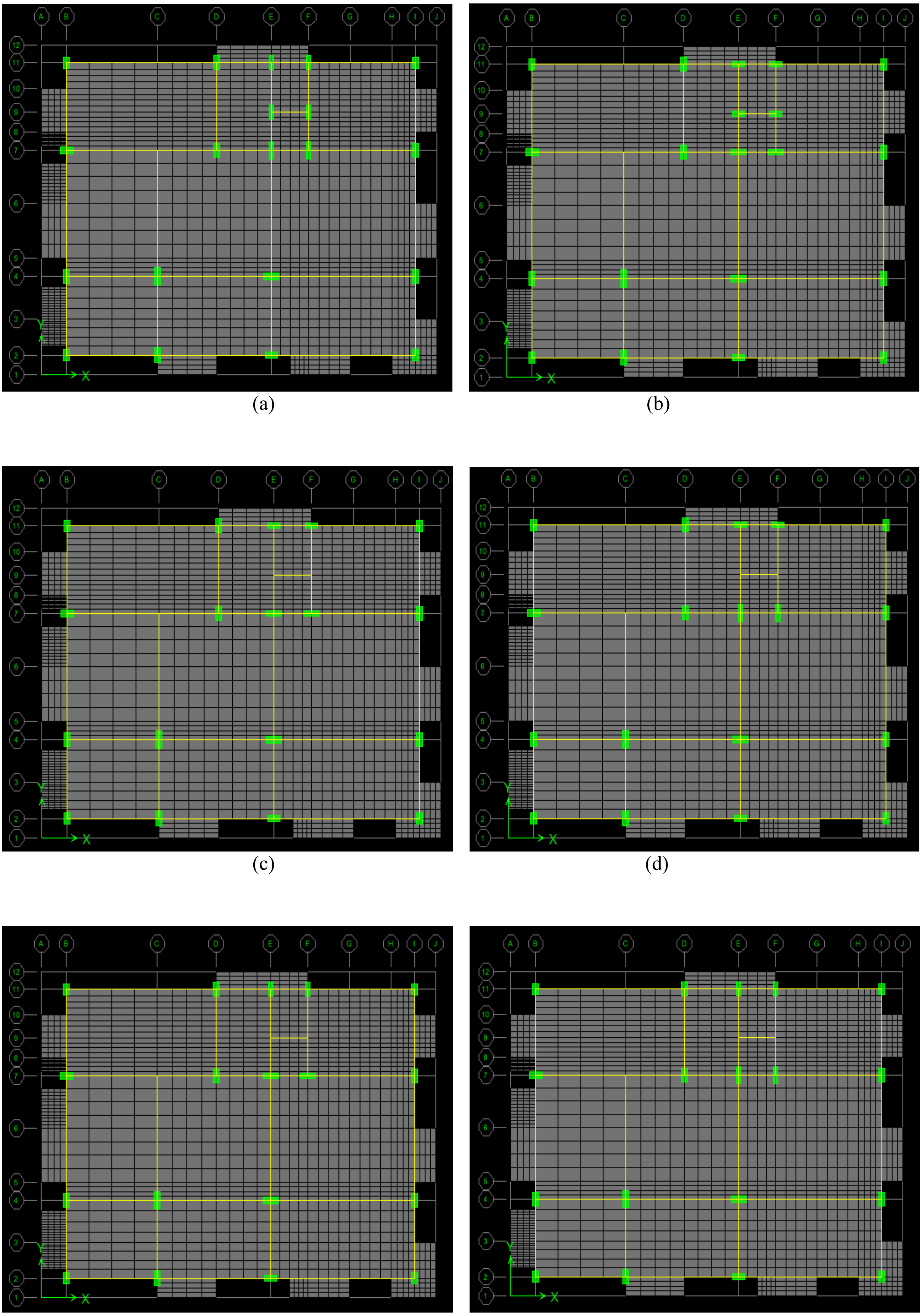


(a) (b)

(c) (d)

(e) (f)

Fig. 5: Comparison of maximum & allowable storey deflection for (a) Model A (shear wall at lift-core), (b) 1st Optimization, (c) 2nd Optimization, (d) 3rd Optimization, (e) 4th Optimization and (f) 5th Optimization

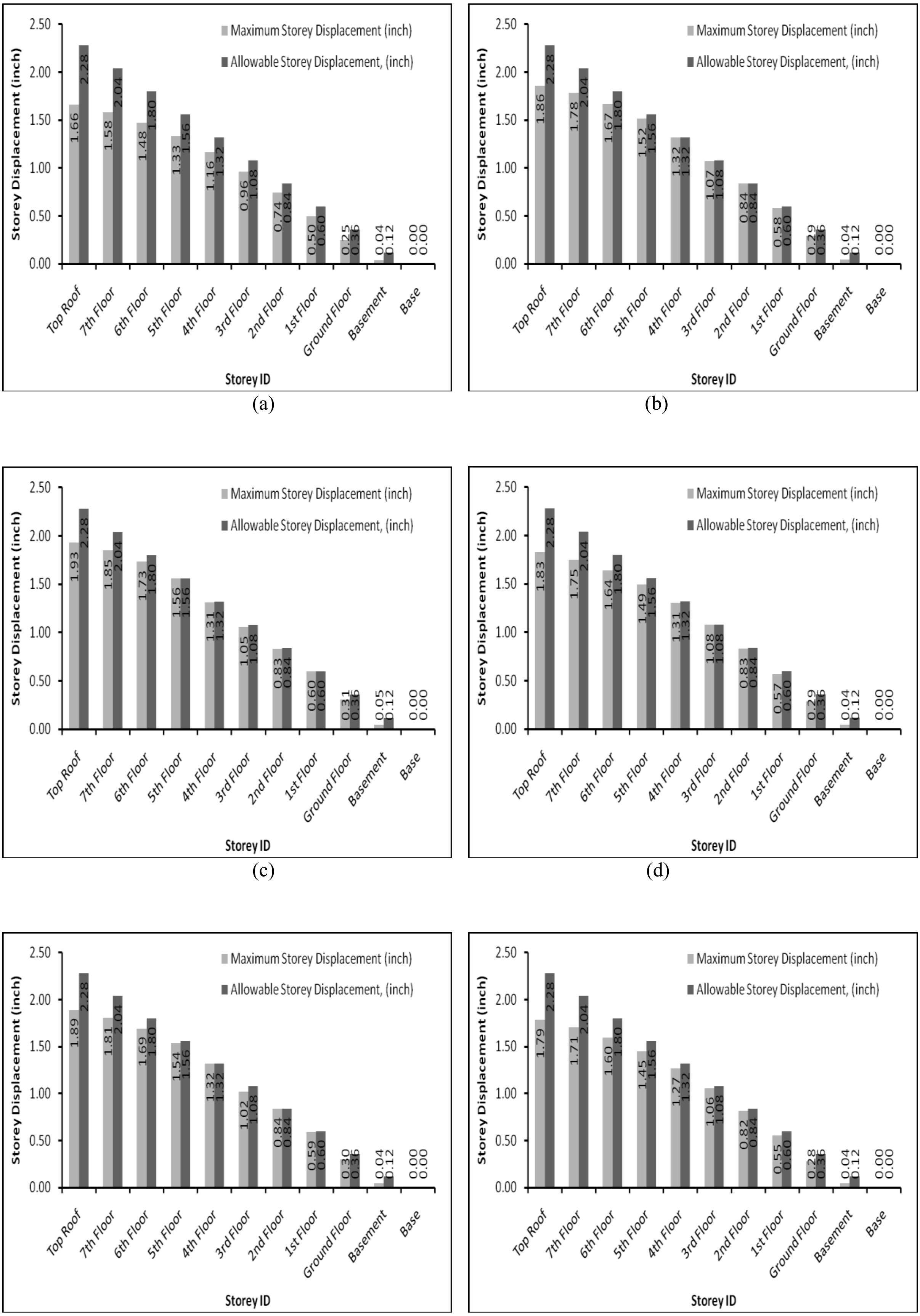


(a) (b)

(c) (d)

(e) (f)

Fig. 6: Plan of the RC frame (only column provided at lift-core) (a) Model B, (b) 1st Optimization, (c) 2nd Optimization, (d) 3rd Optimization, (e) 4th Optimization and (f) 5th Optimization



(a) (b) (c) (d) (e) (f)

Fig. 7: Comparison of maximum & allowable storey deflection for (a) Model B (only column at lift-core), (b) 1st Optimization, (c) 2nd Optimization, (d) 3rd Optimization, (e) 4th Optimization & (f) 5th Optimization

## CONCLUDING REMARKS

This study presents the optimization of shear wall and evaluating the effectiveness of traditional column instead of shear wall in lift-core of a typical residential RC building frame. Two individual situation of the lift-core have been considered to assess the seismic performances of the target RC frame by nonlinear dynamic analysis. These are lift-core made by shear wall (Model A) and lift-core made by regular column instead of shear wall (Model B). The RC building frame was considered as a intermediate moment resisting frame (IMRF) following the provision of building codes. A fixed restraint condition at foundation level of the building frame was considered which causes zero deflection after dynamic analysis. Five optimization schemes were adopted for both Model A and Model B by changing the relative position of shear wall and column arrangement. Storey deflection has been considered as the seismic performance for both Model A and Model B, which further compared with the maximum permissible storey deflection following BNBC-2006, ACI code 9.5.2 and Nilson et al. (2003). The numerical results revealed that, the shear wall based lift-core posses less storey deflections than the column based lift-core. For moderately tall (i.e., up to 9 storey) building frame, column based lift-core may practice instead of shear wall because, the permissible limit allows this operation. For high-rise/tall RC frame (i.e., more than 9 storey) column based lift-core may not be adequate and then obviously shear wall have to exercised at lift-core because of the exceeding of permissible storey deflection at top storey. For both the model A and B, 5th optimization possess the most cost effective and convenient alternatives. More rigorous analysis is required using further sophisticated finite element software to gain refined knowledge about this column-shear wall analogy at lift-core of RC building frame which might be dealt as a future work.

## REFERENCES

Agrawal, AS and Charkha, SD. 2012. Effect of Change in Shear Wall Location on Storey Drift of Multistorey Building Subjected to Lateral Loads, *International Journal of Engineering Research and Applications (IJERA),* 2(3): 1786-1793.

American Concrete Institute (ACI) Code Clause 9.5.2.

Bangladesh National Building Code (BNBC) - 2006.

Gupta, PR and Pande, AM. 2014. Effect of Placement and Openings in Shear Wall on the Displacement at Various Levels in a Building Subjected to Earthquake Loads, *International Journal of Research in Engineering and Applied Sciences (IJREAS),* 02(02): 5-9.

Husain, FAB. 2013. *Shear Walls in Reinforced Concrete Building,* Article published by Civil Engineering Division, Baghdad University, Iraq, Paper ID: 7913, pp. 1- 7.

Jameel, M; Islam, ABMS; Hussain, RR and Khaleel, M. 2012. Optimum structural modelling for tall buildings, *Struc. Design of Tall & Special Building,* wileyonlinelibrary.com/journal/tal, pp. 1-13.

Katkhoda, A and Knaa, R. 2012. Optimization in the Selection of Structural Systems for the Design of RC High-rise Buildings in Resisting Seismic Forces, *Energy Procedia,* 19: 269–275.

Khan, AKMTA. 2015. *Optimization of Shear Wall and Evaluate the Effectiveness of Regular Column instead of Shear Wall in Lift-Core of Reinforced Concrete Building Structure,* Term Paper Submitted to the Department of Civil Engineering, CUET, Chittagong, Bangladesh.

Kharade, VV and Chore, HS. 2014. Effect of Configuration of Shear Walls on Behavior of High-Rise Buildings, *Integrated Journal of Engg. Research and Technology*, 1(6): 336–342.

Nilson, AH; Darwin, D and Dolan, CW. 2003. *Design of Concrete Structures* (E-Book), 13th Edition, Published by McGraw Hill Publishers Inc., United States of America, ISBN No. 007-123260-5.