

Lumped Construction Sequence for Column Shortening Analysis in High Rise Building with Outrigger System

Pratiksha K. Pawar^{1,*}, Sanjay S. Jamkar²

Abstract

The exact value of column shortening is not a straightforward task. Various parameters are affected on column shortening results like rate of construction sequence and reinforcement ratio. The building should stand with high stiffness and must be able to resist lateral deformation without having discomfort to the user. The excessive drift is controlled by using outrigger system. In high rise buildings, the construction sequence analysis and conventional sequence analysis are used for column shortening of columns. For analysis of high rise buildings, the construction sequence analysis shows very good results as compared to conventional sequence analysis. In this work, the lumped construction sequence method is used for column shortening, and its efficiency is investigated for different lumping ratios are 1/5, 1/10, 1/15, 1/25 of total number of storeys of the building. These different lumping ratios are considered on 75, 90, 120 storey buildings. The model analysis is carried out in ETABS software. The analysis results indicate that the saw-tooth shape of total shortening has occurred, which can be modified by the curve fitting technique. The results of column shortening are nearly matching for the 1F unit model and 1/15 ratio of a lumped model. The lumped models about 1/15 lumping ratio of the storeys of the building is recommended for construction sequence analysis with accuracy of results.

Keywords: Column shortening, construction sequence, lumped unit models, outrigger system, high rise building

INTRODUCTION

In recent year's population has increased in tremendous amounts, the buildings are becoming taller and slimmer to maximize rentable space. High rise building is defined in terms of their height. Constructability challenges and serviceability problems due to column shortening are addressed in high rise buildings. During construction of high rise building, the height increases load will be increased, and the load would be subjected to the column. Due to an increase in load, the vertical element causes column shortening. Due to creep and shrinkage, column shortening takes place, and additional forces are introduced in the beam and slab [1]. The exact value of axial shortening is a very

difficult task. Axial shortening depends on various parameters like type of concrete, reinforcement ratio and rate of construction sequence [2]. A lot of research is carried on long term column shortening analysis methods.

The analysis methods include the effective modulus method (EMM), rate and creep method (RCM) and step-by-step method (SSM) [3]. Among all the methods, the step-by-step method is the most exact method for column shortening of high rise buildings [3]. The constitution sequence method is also known as step-by-step method. This method is the most exact method for column shortening of high rise buildings.

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OBJECTIVE

The objective of this study is to influence the effect of lumped construction sequence on column shortening analysis, for which the following points are studied.

OUTRIGGER SYSTEM

The high rise building stands with high stiffness to resist lateral deformation without discomfort to the user. The outrigger system is used to control the excessive drift due to lateral load [4]. The outrigger is located to connect and couple the core and perimeter columns [5].

LUMPED CONSTRUCTION SEQUENCE ANALYSIS

The lumped construction sequence is defined as the number of storeys is combined into one single unit and that unit is assumed as constructed at a time [6]. For investigate the efficiency of column shortening, the lumped construction sequence is used. In lumped construction sequence, the construction stages are less as compared to construction sequence analysis. For example, the construction of 6 storey building with construction sequence analysis required 6 stages and if by lumping the 3 floors as 1 unit model, then in lumped construction sequence required only 2 stages.

CONSTRUCTION SEQUENCE ANALYSIS

The structure failure during construction is most unsafe, and that structure failure is not necessary due to construction error but it is due to inadequate details in building design. During construction of high rise building, with increase in height, the conventional approach of analysis for various structural responses like deflection, axial loads, shear force and bending moment may have varied in results from the actual behaviour of building [7]. It is unable to consider various parameters during the analysis of high rise buildings. But nowadays, a software tool is considered all parameters in non-linear stage construction analysis. The constitution sequence analysis is a non-linear analysis, and structure is analysed at various stages. The dead load is applied sequentially at every stage [8].

LITERATURE REVIEW

A substantial literature study is done on the axial shortening of high rise building to find out various parameters like the position of outrigger system, lateral deflection, natural first modal time period, vertical displacement, construction sequence or conventional analysis, etc. that must be considered in designing a 75, 90 and 120 storey high rise building. The detrimental effects are produced in building due to column shortening. The effect of column shortening is increased with increasing in height of building [9]. The natural time period depends on the height, number of storeys, stiffness and mass of building [10]. The natural time period should be less than or equal to 10% of the number of storeys of building [11]. It was also expressed that the construction stage analysis should be used for column shortening of high rise buildings; it shows the axial shortening increases at 2/3 of the height of the building after it decreases [12, 13]. The lateral deflection is minimized by using an outrigger system. The minimum position of the outrigger system should be multiple of $1/3^{\text{rd}}$ of a total number of storeys of building [14]. The number of outriggers increases, the maximum differential axial shortening building decreases, but the maximum differential axial shortening is not reduced when the number of outrigger systems is greater than two [15–20].

SYSTEM DEVELOPMENT

Model Information

In previous research, the lumped construction sequence analysis was carried out for 151 storey buildings. While in this study, the high rise building of 75, 90, and 120 stories is considered as symmetric type of building. The building consists of an internal core for lift, staircase and duct purposes. The outrigger and belt truss system is used for reducing the lateral deflection. The 3d view of the outrigger and belt truss system of 75, 90 and 120 storey building is shown in Figure 1.

The different lumped unit models are designed for 75, 90 and 120 storey buildings. Following Table 1 shows the different lumping ratio 1/5, 1/10, 1/15 and 1/25 of the total number of storey

buildings and corresponding lumped unit models for 75, 90 and 120 storey high rise buildings. The lumped construction sequence results are compared with construction sequence results. The column shortening, lateral deflection and natural time period for 75, 90 and 120 storeys of the building are modelled in ETABS software.

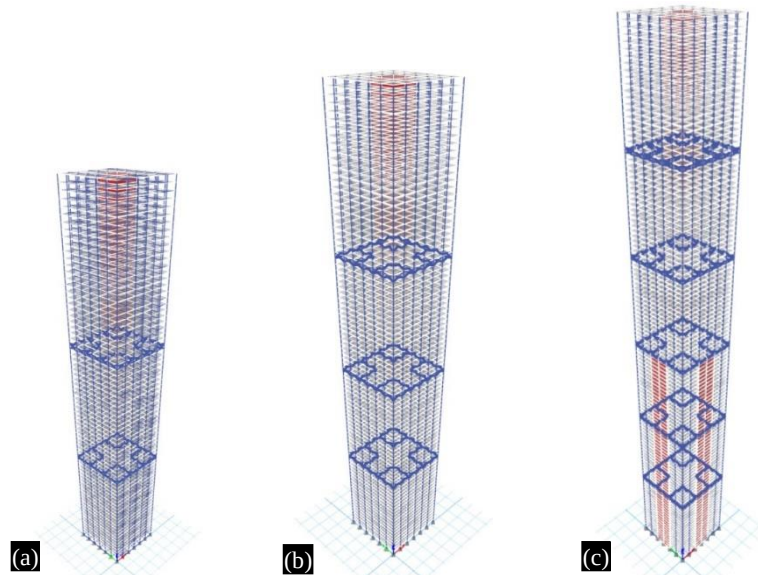


Figure 1. The 3D view of outrigger and belt truss system of (A) 75, (B) 90, (C) 120 storey building.

Table 1. The lumped ratio and corresponding lumped unit models.

Lumping Ratio and Lumped Models				
Different Storey Building	1/25	1/15	1/10	1/5
75	3F	5F	8F	15F
90	4F	6F	9F	18F
120	5F	8F	12F	24F

RESULT AND DISCUSSION

The output data for each lumped model are reviewed and compared in ETABS software. The results were presented in terms of the lateral deflection, natural time period and vertical displacement for each structural model.

Lateral Deflection

According to IS 16700:2017, the lateral deflection is equal to $(H/500) \times 1000$ where, H- total height of the building. Following Table 2 shows the values of lateral deflection according to IS 16700:2017 and from ETABS software. The lateral deflection values from software are lesser than the maximum permitted IS code values. Therefore a lateral deflection criterion is satisfied for 75, 90 and 120 storey buildings. As the outrigger system is used in the building, the lateral deflection values from ETABS software are lesser in amount.

Table 2. The lateral deflection values for different storey Building.

Different storey building	Height of building (mm)	Lateral deflection According to IS code (mm)	Lateral deflection From ETABS software (mm)
75	262.5	525	371.83
90	315	630	461.694
120	420	840	612.15

Natural Time Period

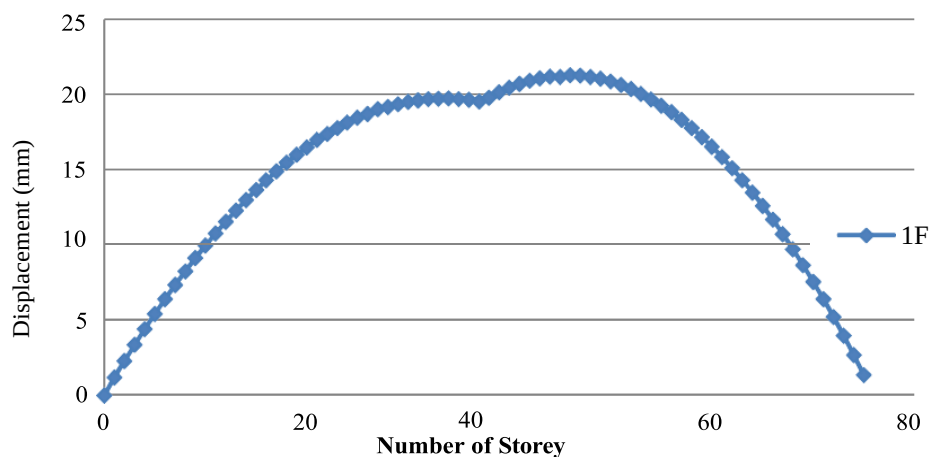
The natural time period depends on stiffness, mass, column orientation and the number of storeys of the building. Following Table 3 shows the values of the natural time period for 75, 90 and 120 storeys of high rise building. The 1st natural modal period should be less than or equal to the number of storeys/10 (i.e. 10% of the number of storeys of the building).

Table 3. The natural time period values for different storey building.

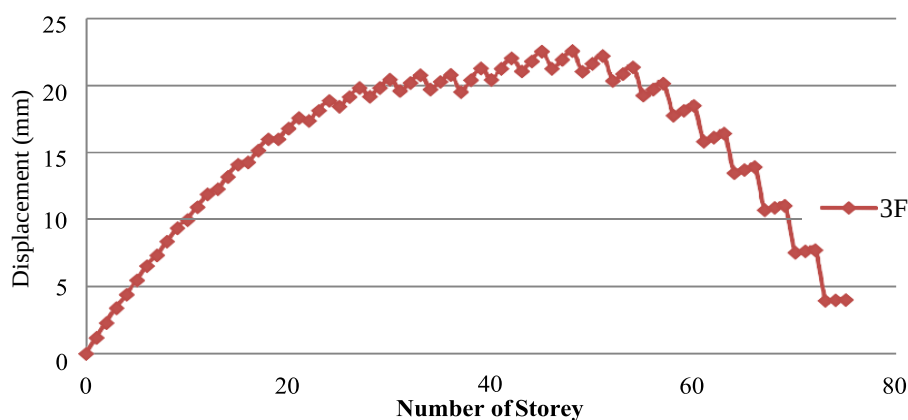
Different storey building	Total number of storey	Natural time period According to number of storey/10 (sec)	Natural time period From ETABs software (sec)
75	75	7.5	7.367
90	90	9	8.578
120	120	12	12

Column Shortening

In high-rise buildings, the column carries a huge load, effectively compressing the column along with the vertical axis. The column shortening of the particular column is observed after 10,000 days, different lumping ratios 1/25, 1/15, 1/10, 1/5 for 75 storey building. The data of column shortening values of 75 storey is presented in multiple of 15 storeys shown in the following Table 4 while plotting the whole 75 storey building data is considered. Figure 2 shows the column shortening values for different lumped models.



(a) For 1F Unit Model



(b) For 3F Unit Model

Figure 2. Column shortening for (a) 1F, (b) 3F Unit model of 75 storey building.

Table 4. Column Shortening Values for 75 Storey Building.

Storey Building	Number of Storey	1F	3F	5F	8F	15F
75	0	0	0	0	0	0
	15	13.635	14.08	14.459	14.772	15.338
	30	19.462	20.424	21.318	21.753	24.781
	45	21.217	22.495	23.682	23.679	29.324
	60	16.489	18.468	20.357	19.417	28.437
	75	1.364	4.025	6.598	14.889	18.104

Similarly, the column shortening values for 5F, 8F and 15F models of 75 storey of building are compared with 1F unit model; the comparison is shown in Figure 3.

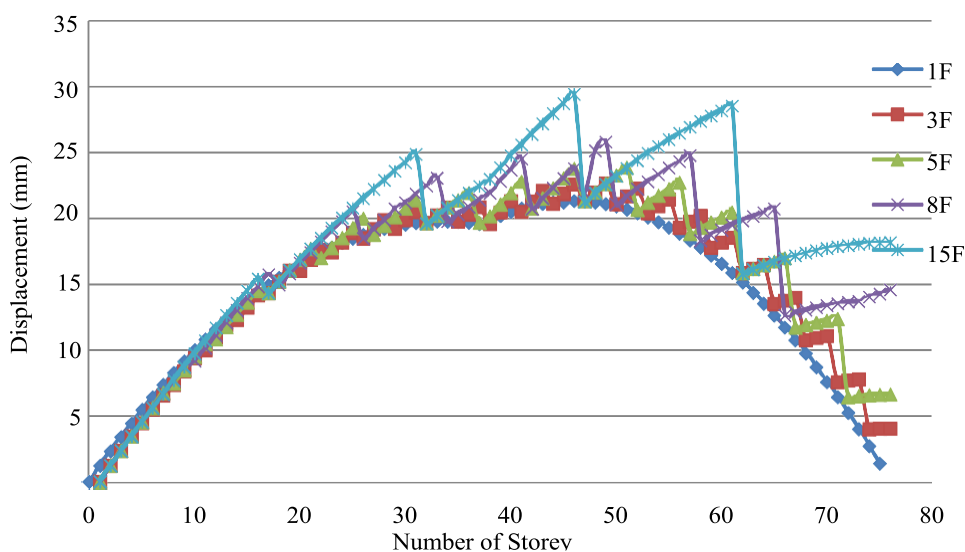


Figure 3. Column Shortening of 75 Storey Building.

It is observed from Figures 2 and 3 the column shortening of lumped unit models are formed saw-tooth shaped, and the saw-tooth shape of lumped models show discrepancy except for the 1-F unit model. This saw-tooth shape is formed because the column shortenings are compensated simultaneously by lumped models. The lumped models are lumped into a unit while the automatic compensations occur for every single storey in the 1F unit model. Therefore, the correction is needed in the column shortening of the lumped unit models. The column shortenings of the 1F unit and lumped unit models curve is corrected by using the curve fitting technique. The curve fitting technique is applied in an Excel sheet by using a 3rd-degree polynomial curve. The 3rd-degree polynomial curve gives the exact result for the 1F unit model, and corresponding R^2 values are noted down in respective Figure 4 for 75 storey building. Figures 5(a and b) shows the modified curve for the 1F and 3F unit model of the 75 storey building.

Similarly, the modified curve of column shortening values for 5F, 8F and 15F models of 75 storey of building are carried out and compared with the 1F unit model; the comparison is shown in Figure 4. Similar results are carried out for 90 and 120 storey building models, and the modified curves are shown in Figures 6 and 7 respectively.

From the above-modified curve, the lumped unit models have the R^2 value of more than 0.95 showing good approximation in results. Therefore the lumped 5F, 6F, and 8F unit model corresponding to lumping ratio 1/15 of 75, 90, and 120 numbers of storeys show sufficient approximation to the exact result of the 1F unit model.

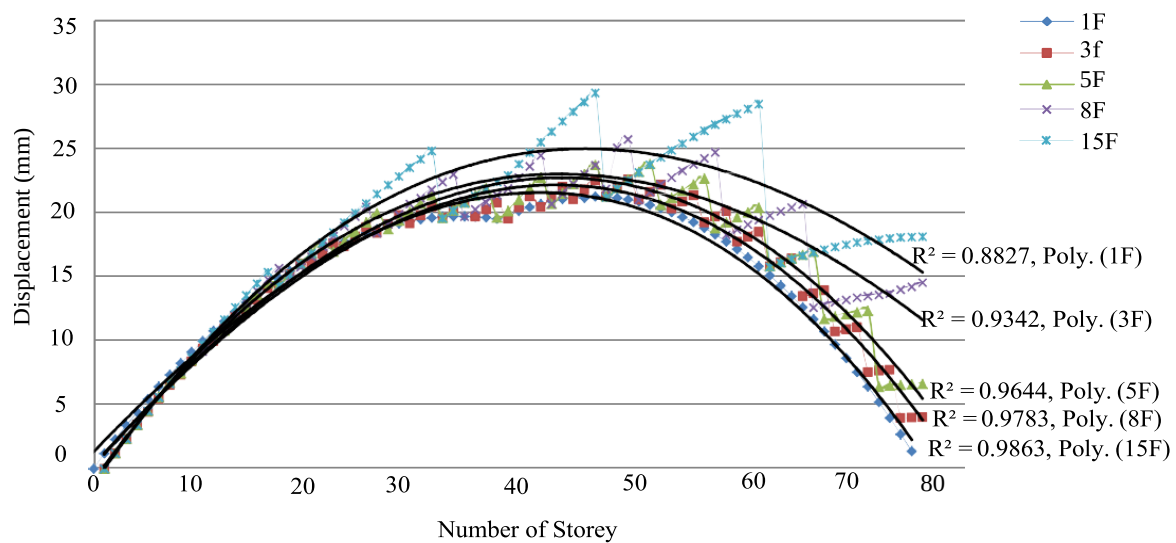
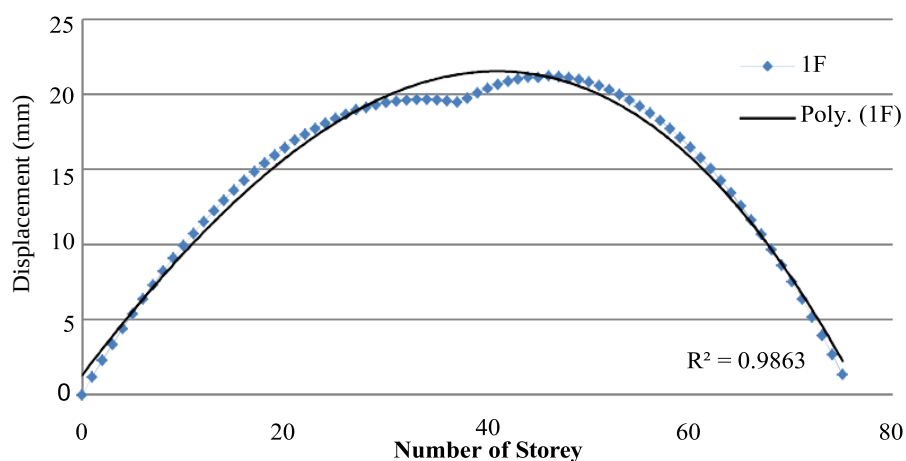
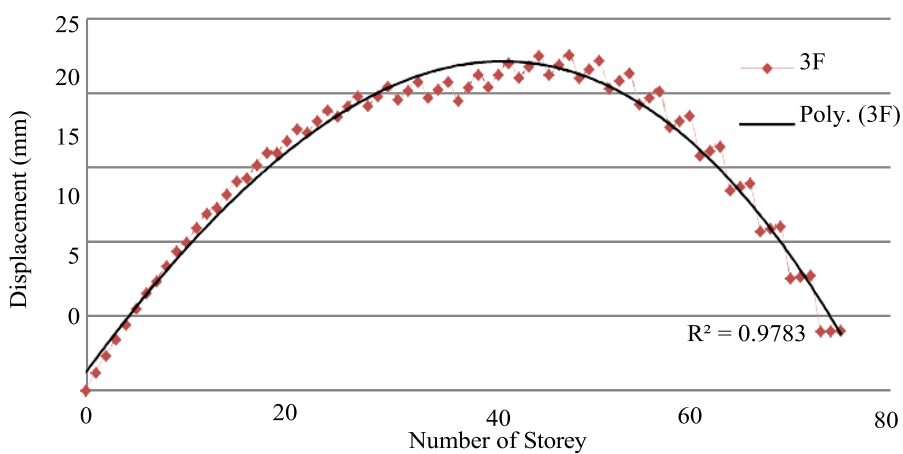


Figure 4. The modified curve of column shortening for 75 storey building.



(a) For 1F Unit Model



(b) For 3F Unit Model

Figure 5. The Modified Curve of Column Shortening for (A) 1F, (B) 3F Unit Model of 75 Storey Building.

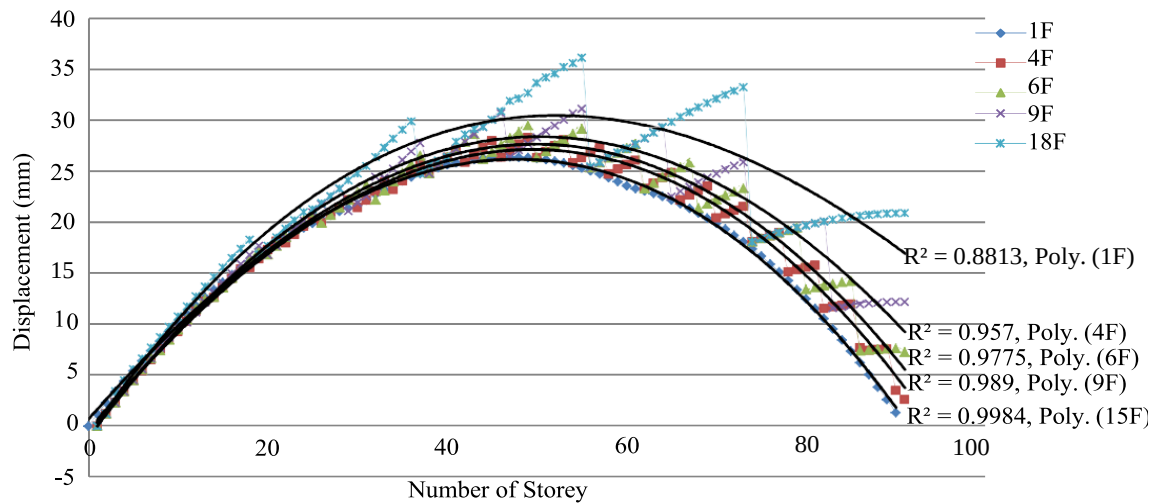


Figure 6. The modified curve of column shortening for 90 storey building.

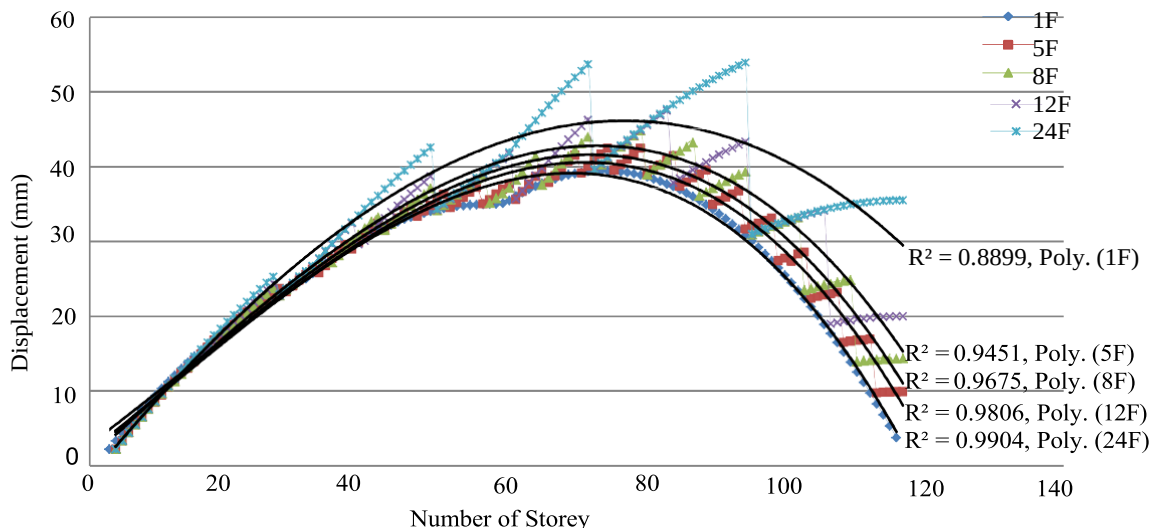


Figure 7. The modified curve of column shortening for 120 storey building.

CONCLUSION

After the modelled structures are designed safely, a simplified lumped construction sequence method is used for column shortening analysis. The behavior of 75, 90, and 120 story structure for different lumping ratios 1/25, 1/15, 1/10 and 1/5 is studied, and the following conclusions have been made;

- The 75, 90 and 120 storey building model shows acceptable results in the natural time period, which is 10% of the total number of storey buildings.
- The lateral deflection criteria according to is 16700:2017 is the total height of building/500 satisfied by the designed 75, 90 and 120 storey model.
- The outrigger and belt truss system is effective to reduce the lateral deflection of high rise buildings.
- The column shortening analysis is done for 75, 90 and 120 storey buildings for different lumping ratios 1/25, 1/15, 1/10 and 1/5, respectively.
- The column shortening of different lumping ratios shows the saw-tooth shaped type curve because column shortenings compensate simultaneously for lumped stories.
- The curve fitting technique is used for the saw-tooth shaped curve; the 3rd-degree polynomial curve gives the exact good result of the 1F unit model.

- In the modified curve, for R^2 value greater than 0.95 is considered as a good agreement result. From the modified curve, the lumped models about 1/15 lumping ratio of storeys of building is recommended for construction sequence analysis with accuracy of results.
- The proposed lumped construction sequence method is effective as compared to construction sequence analysis.

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