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Importance of Construction Sequence Analysis in design of High Rise Building

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Abstract

While analyzing Tall structure in Conventional method the gravity loads are applied after modeling the whole structure. In actual practice the complete frames are constructed at various stages and the stability of frames varies accordingly. The applied load assumed in Conventional method will be unsuitable as per the actual construction practice. The frame should be analyzed at every construction stage considering the effect of variation of loads at each stage. This methodology is known as construction sequential analysis.

In this project the realistic structure in seismic zone III as per IS 1893:2002 (Part 1) considered to study the effect of construction sequence. Tall building of three different heights has been considered for comparative study and effect on columns and beams has been studied based on different structural parameters. Based on study the necessity of the construction sequence analysis for tall building has been understood.

Keywords: *Linear Static analysis, Linear Dynamic analysis, Construction Sequence analysis, Tall buildings, Etabs version 15.*

1. Introduction

A failure of the structure during construction is most vulnerable. During the construction process failure of the structures or partially completed structures often occurs. It is not necessary that the collapse of the structure is due to construction error. It may be due to lack of information during design. Generally, finite element analysis with linear static elastic method has been considered for calculation of summations of vertical column loads to determine the behavior of structures. As the construction of tall building goes on increasing with height in construction phase, the typical approach of analysis for various structural responses like Deflection, Axial loads; Shear Force and Bending Moments may have diverged from the actual behavior. During analysis it was unable to consider so many parameters that are complex in nature. But due to advance method of finite element modeling and simulation, nonlinear analysis became very easy to accelerate proper design of structures especially high-rise.

Linear Static Analysis (LSA):

In linear static analysis first mode of the structure is considered for analysis. The modeling of the entire frame of the structure has done and then all the loads are applied after the modeling of the complete structure.

Linear Dynamic Analysis (LDA):

Linear Dynamic Analysis is also known as response spectrum analysis. In this analysis, the structure is modeled and analyzed as a multi-degree of freedom system with linear elastic stiffness matrix. The response spectrum procedure is accurate as compared to the LSA because all the higher modes are considered for analysis in this procedure. Both linear static and linear dynamic procedure are based on Conventional Method.

2. Construction Sequence Analysis (CSA)

CSA is a nonlinear analysis approach in which the structure is analyzed at various stages corresponding to the construction sequence and the partial required loads are applied sequentially at every stage. In general, the structures are analyzed and designed using single step using gravity analysis or seismic analysis on the basic assumption that the structure will be fully loaded at once as shown in the fig.1. Practically, the structure is constructed story-wise hence dead load is applied story-wise and the finishing loads are also imposed as the structure is constructed in stage wise as shown in the fig.2. This analysis will provide more reliable results and hence the method should be adopted in usual practice.

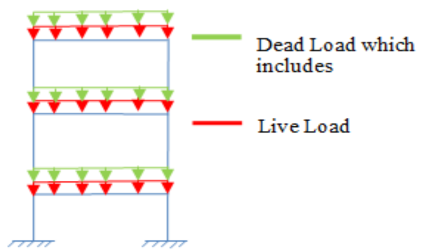

Fig. 1 Conventional Analysis

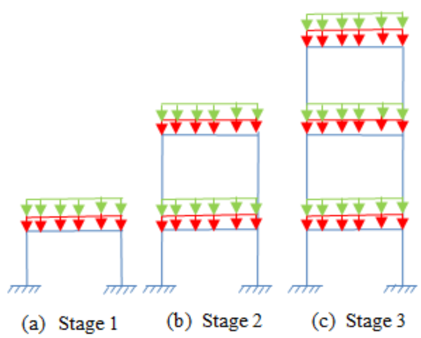

Fig. 2 Construction Sequence Analysis

2.1 Effect of Construction Sequence Analysis

In High Rise buildings the important facts that have very significant effect on accuracy of analysis but are rarely considered in practice during analysis, they are:
1) The effect on Structural members in terms of response due to sequential application of load during construction.
2) The effect of differential column shortening of the external and internal column supports due to the different tributary areas.
As the construction of building proceeds, the structural members are added in stage wise and the dead load is carried by that part of building completed at that particular stage of construction. Hence, the stresses and displacements distribution in the part of the completed structure at any stage due to partial dead load of members installed at that stage does not depend on the geometry, properties or the presence of members com-posing the rest of the overall structure and can be obtained correctly by summating the results of analysis at each stage. The results of the analysis of the overall structures can be obtained incorrectly by ignoring this effect. Therefore, it is very important to analyze the structure at every construction stage.

3. Objective and Scope

1) The main objective of this work is to reduce the potential for structural failure during the construction phase ultimately reducing the risk of injury and delays in construction projects.
2) To understand the high-rise structure behavior analytically during construction at different stages using construction sequence analysis.
3) Comparative study of Construction Sequence analysis with the conventional method.
4) To calculate the percentage, change in the values of various structural parameters like deflection, Bending moments, shear force and axial force of the structural elements with conventional method of analysis and Construction sequence analysis.

The Scope of work is limited to

- Detailed analytical study on Construction Sequence Analysis of high-rise buildings using Etabs version 15 for three different height of buildings as 20 stories, 45 stories and 68 stories of R.C.C. Buildings.
- To determine the effect on structure by providing shear wall system, Study of Transvsrse structure supporting floating column and
- Comparative study of Conventional method of analysis with Construction Sequence Analysis.

4. Methodology

Staged construction is a feature that permits you to define a sequence of stages where the portions of the structure can be either added or can be removed; similarly selective load can be applied to portions of the structure. Staged construction is considered a type of nonlinear static analysis due to the feasibility of the change in analysis of structure during the course of the analysis. Consideration of material and geometric nonlinearity is optional. Sequence of stages has to be defined for each nonlinear staged-construction analysis case. In a single analysis any number of stages can be defined as per the requirement.
For each stage specify
1) Duration, in days if time-dependent affects needs to be considered. If the user doesn't want to consider time-dependent effects in a given stage, the duration should be assigned as zero. In this project time dependent affects are not considered.
2) Any number of groups of objects to be added or removed to the structure, or none.

Each stage is analyzed separately in the order the stages are defined. These occur instantaneously in time, i.e., the analysis may be incremental, but no time elapses from the point-of-view of the material. The stage is analyzed as follows:
1) The groups to be added, if any, are processed. For each non-joint object added, all joints connected to that object also added, even if they are not explicitly included in the group.
2) All specified loads will be increased linearly during the course of the analysis. Loads specified on all objects in a group will only be applied to objects that are actually present in the structure or are being added in this stage.

5. Problem Statement

The present study conducted on ongoing project of DB Crown in Prabhadevi, Mumbai involves conducting sequential analysis. The aim of study is to find out the differences in forces & displacement of an irregular shaped high rise building using Etabs 15.0 software as compared to normal linear dynamic analysis.
In this present study sequential analysis of 20 story, 45 story and 68 story will be carried keeping the plan same as shown in Figure 3. The plan dimension in X direction is 64.8m and in Y direction is 38.1m. In the elevation typical floor height 3.0m.

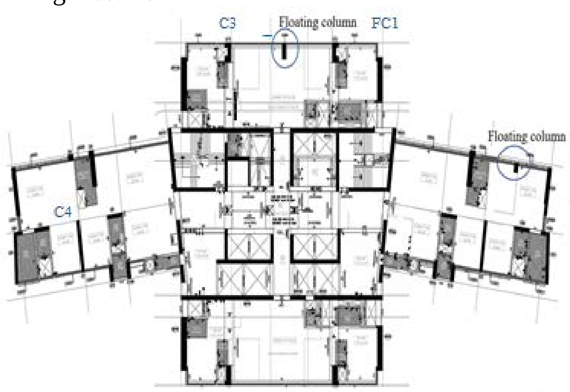

Fig. 3 Typical floor Plan

In this present study sequential analysis of 20 story, 45 story and 68 story will be carried keeping the plan same as shown in Fig.3. The plan dimension in X direction is 64.8m and in Y direction is 38.1m. In the elevation typical floor height 3.0m.

- Building 1: story's 20 and height is 67.55m.
- Building 2: story's 45 and height is 159.35m.
- Building 3: story's 68 and height is 249.15m.
- Transfer Girder Level: 2nd podium level and 1st typical level.
- Size of Transfer Girder GB1: 750mm X 2000mm.
- Floating Column: FC1
- Column from Base: C3
- Beams supporting on floating column: B1
- Minimum thickness of Wall: 230 mm.
- Maximum thickness of Wall: 900 mm.
- Grade of Concrete: M70, M60, M50, M40.
- Grade of reinforcement: Fe 500.
- Seismic Zone (Z): III
- Seismic Zone Factor: 0.16
- Response Reduction Factor (R): 4
- Importance Factor: 1
- Soil Type: Hard Soil

Table 1: Load Configuration

Description	Loadings
Self-weight	As per Etabs
LL	5 kN/m2
SDL	2.5 kN/m2
RLL	2 kN/m2
Chajja load	7.35 kN/m
Partition load	Varying with height in kN/m

Table 2: Load Combination

Comb 1	1.5(DL)	Comb 12	1.2(DL+LL-Wy)
Comb 2	1.5(DL+LL)	Comb 13	1.5(DL+Wx)
Comb 3	1.2 (DL+LL+Sx)	Comb 14	1.5(DL–Wx)
Comb 4	1.2(DL+LL+Sy)	Comb 15	1.5(DL+Wy)
Comb 5	1.5(DL+Sx)	Comb 16	1.5(DL-Wy)
Comb 6	1.5(DL+Sy)	Comb 17	0.9DL+1.5Wx
Comb 7	0.9DL+1.5Sx	Comb 18	0.9DL-1.5Wx
Comb 8	0.9DL+1.5Sy	Comb 19	0.9DL+1.5Wy
Comb 9	1.2(DL+LL+Wx)	Comb 20	0.9DL-1.5Wy
Comb 10	1.2(DL+LL–Wx)	Envelope	Envelope Of Comb 1 To 20
Comb 11	1.2(DL+LL+Wy)		

Note: DL= self-weight, SDL, Chajja, Partition load
LL= Live, RLL= Reducible Live, Sx, Sy = Dynamic Seismic Force; Wx, Wy= Dynamic Wind force.

5.1 Procedure used for Nonlinear Analysis in Etabs

1) Created 2 models for each of RC framed 20, 45 and 68 story in computer program Etabs v.15. Model 1 is for Conventional method and Model 2 is for Construction sequence analysis.
2) Define the static load to be used in the analysis.
3) Define dynamic function need to be used for dynamic earthquake force and wind force.

4) Define Auto Construction sequence load case with load case Dead and SDL having scale factor 1.0.
5) Replace Dead and SDL type load case in default load combination.
6) Run the model for basic linear dynamic analyses and Construction sequence analysis.
7) Review results of various structural parameters.

6. Results

The structure has been studied for parameters axial force, bending moment, shear force and deflection for conventional method and compared with CSA for Envelope combination as shown below.

6.1 Building 1 of 19 story

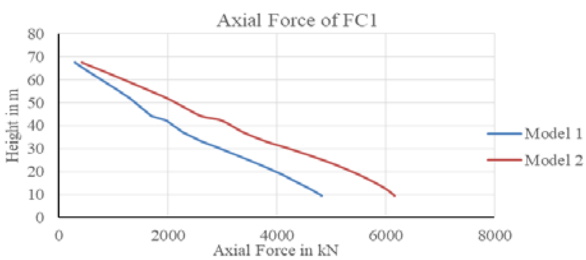

Fig. 4 Axial Force of FC1

From Fig. 4 for FC1 axial force in model 1 is 4827kN and in model 2 it is 6164kN having difference of 28% at P2 level and increasing upto maximum 54% at story 18.

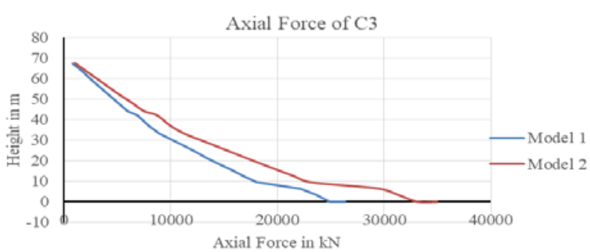

Fig. 5 Axial Force of C3

From Fig. 5 for C3 axial force in model 1 is 26373kN and in model 2 it is 34957kN having maximum difference of 33% at B2 level.

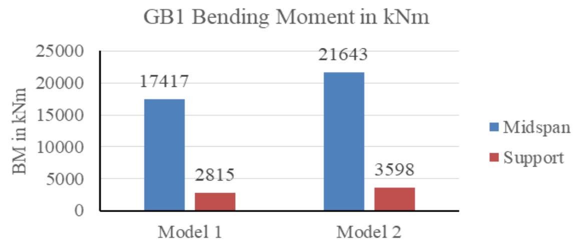

Fig. 6 Bending Moment of GB1

From Fig. 6 for GB1 the variation of Bending Moment is 24% at midspan and 28% support respectively.

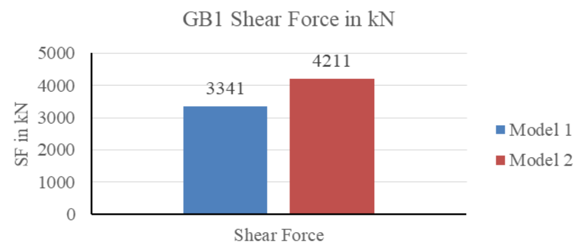

Fig. 7 Shear Force of GB1

From Fig. 7 for GB1 the variation of Shear Force is 26%.

Fig. 8 Deflection of GB1

From Fig. 8 for GB1 the variation of Deflection is 29%.

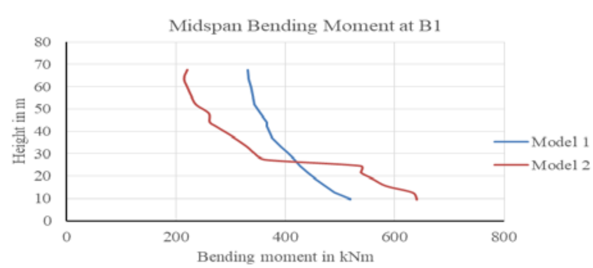

Fig. 9 Midspan Bending Moment of B1

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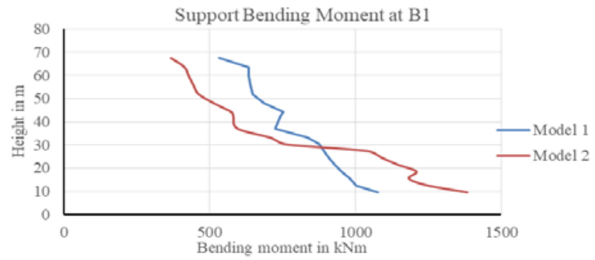


Fig. 10 Support Bending Moment of B1

From Fig. 9, 10 For B1 bending moment at midspan in model 1 is 519kNm & in model 2 it is 640kNm with difference of 23% at P2 level and reducing at P8 level & at Support in model 1 is 1076kNm & in model 2 it is 1383kNm with difference of 29% at P2 level and reducing at P9 level in CSA.

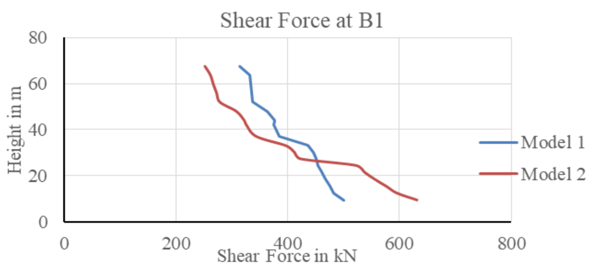
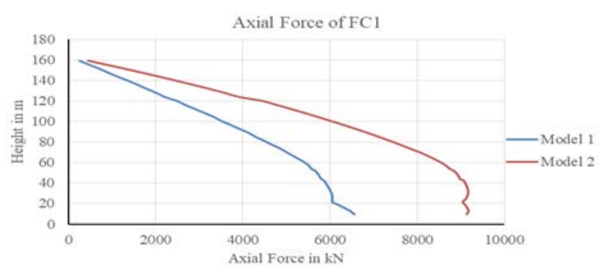


Fig. 11 Shear Force of B1

From Fig. 11 for B1 Shear force in model 1 is 501kN and in model 2 it is 631kN with difference of 26% at P2 level and reducing at P8 level in CSA.

6.2 Building 2 of 45 story



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g. 12 Axial Force of FC1

From Fig. 12 for FC1 it can be seen that axial force in model 1 is 6565kN & in model 2 it is 9129kN having difference of 40% at P2 level and increasing upto maximum 85% at story 44.

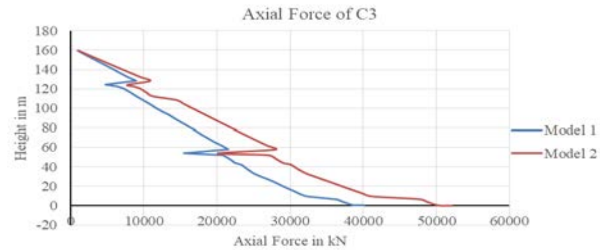

Fig. 13 Axial Force of C3

From Fig. 13 for C3 it can be seen that axial force in model 1 is 40051kN and in model 2 it is 52086kN having difference of 31% at B2 level and increasing upto maximum 65% at story 36.

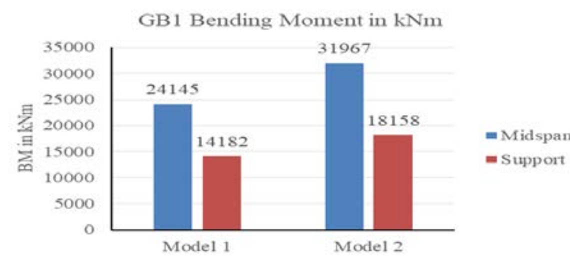

Fig. 14 Bending Moment of GB1

From Fig. 14 for GB1 the variation of Bending Moment is 32% at midspan and 28% support respectively.

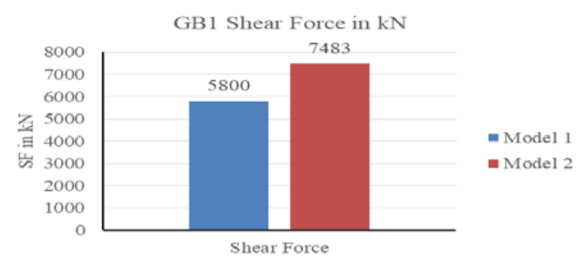

Fig. 15 Shear Force of GB1

From Fig. 15 for GB1 the variation of Shear Force is 29%.

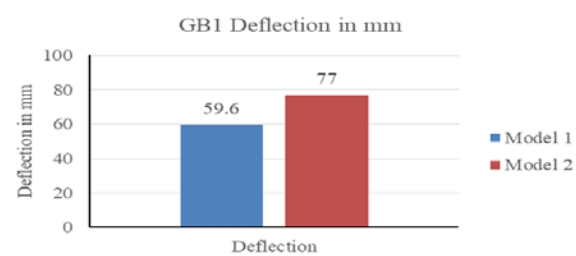

Fig. 16 Deflection of GB1

From Fig. 16 for GB1 the variation of Deflection is 29%.

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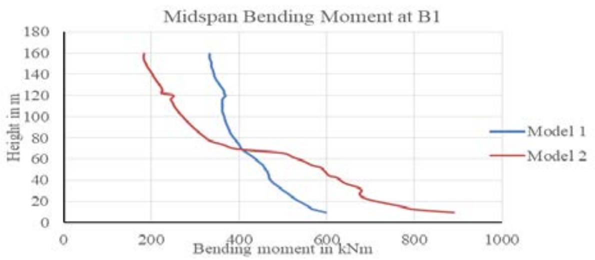

Fig. 17 Midspan Bending Moment of B1

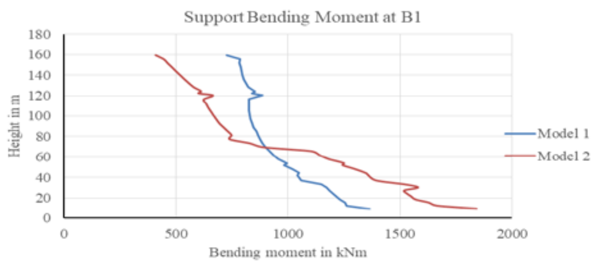

Fig. 18 Support Bending Moment of B1

From Fig. 17, 18 For B1 Bending moment at midspan in model 1 is 599kNm & in model 2 it is 890kNm with difference of 49% at P2 level and reducing above story 20 & in support in model 1 is 1364kNm and in model 2 it is 1842kNm having difference of 35% at P2 level and reducing above story 20 in CSA.

Fig. 18 Shear Force of B1

From Fig. 18 for B1 Shear force in model 1 is 567kN & in model 2 it is 731kN having diff. of 29% at P2 level & reducing above story 22 in CSA.

6.3 Building 3 of 68 story

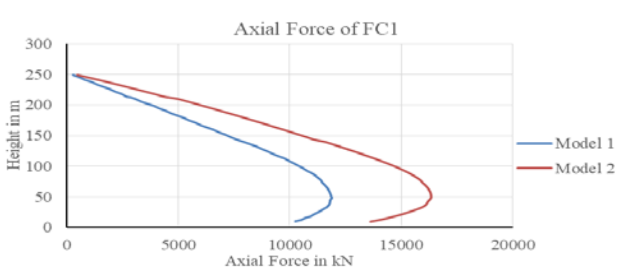

Fig. 19 Axial Force of FC1

From Fig. 19 for FC1 axial force in model 1 is 10239 kN and in model 2 it is 13617 kN having difference of 33% at P2 level with maximum difference of 67% at story 68.

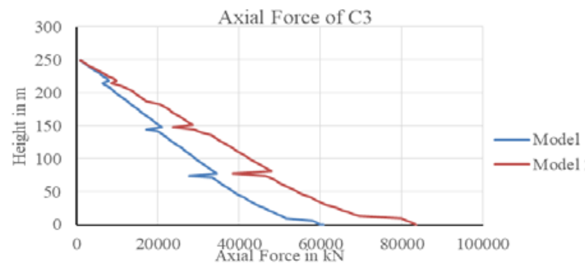

Fig. 20 Axial Force of C3

From Fig.20 for C3 axial force in model 1 is 60856kN and in model 2 it is 83528kN having difference of 38% at B2 level with maximum difference of 55% at story 38.

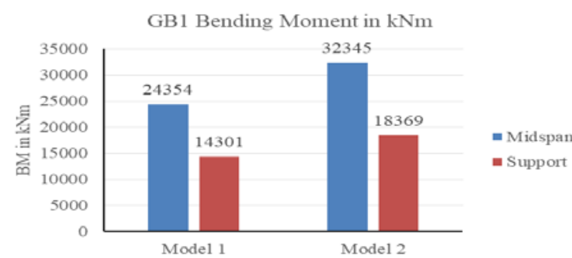

Fig. 21 Bending Moment of GB1

From Fig. 21 for GB1 the variation of Bending Moment is 33% at midspan and 28% support respectively.

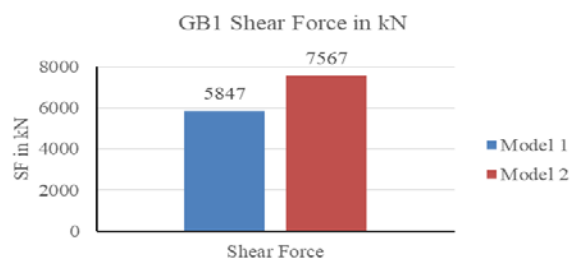

Fig. 22 Shear Force of GB1

From Fig. 22 for GB1 the variation of Shear Force is 29%.

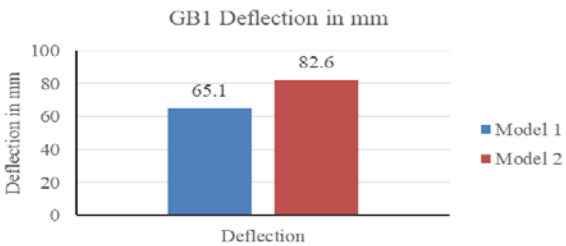

Fig. 23 Deflection of GB1

From Fig. 23 for GB1 the variation of Deflection is 27%.

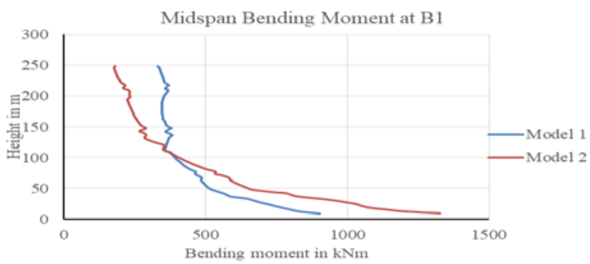

Fig. 24 Midspan Bending Moment of B1

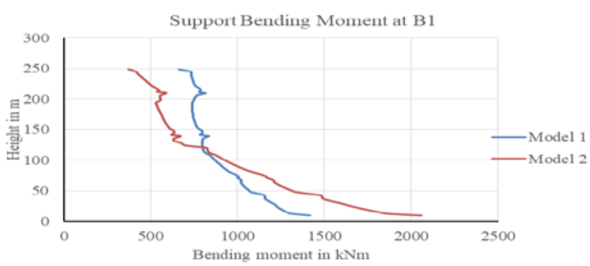

Fig. 25 Support Bending Moment of B1

From Fig. 24, 25 for B1 bending moment at midspan in model 1 is 903kNm & in model 2 it is 1327kNm having difference of 47% at P2 level and reducing above story 30 & in Support in model 1 is 1415kNm and in model 2 it is 2058kNm having difference of 45% at P2 level and reducing above story 34 in CSA.

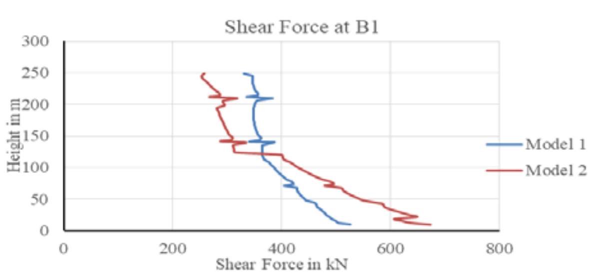

Fig. 18 Shear Force of B1

From Fig.18 for B1 Shear force in model 1 is 526kN and in model 2 it is 673kN having difference of 28% at P2 level and reducing above story 34 & in B2 Shear force in model 1 in CSA.

Table 3 - Results of GB1 for 19 storey

Parameters	location	Model 1	Model 2	% difference
Bending moment (kNm)	Midspan	17417	21643	24
	Support	2815	3598	28
Shear Force (kN)	Support	3341	4211	26
Def^n (mm)	Midspan	68.8	88.66	29

Table 4 - Results of GB1 for 45 storey

Parameters	location	Model 1	Model 2	% difference
Bending moment (kNm)	Midspan	24145	31967	32
	Support	14182	18158	28
Shear Force (kN)	Support	5800	7483	29
Deflection (mm)	Midspan	59.6	77	29

Table 5 - Results of GB1 for 68 storey

Parameters	location	Model 1	Model 2	% difference
Bending moment (kNm)	Mid-span	24354	32345	33
	Support	14301	18369	28
Shear Force (kN)	Support	5847	7567	29
Deflection (mm)	Mid-span	65.1	82.6	27

7. Conclusion

The structure has been studied for parameters axial force, shear force, bending moment and deflection for Envelope combination by conventional method and compared with CSA for columns and beams as shown below.

1) The Envelope Forces of Dead load and Live load including Earthquake and Wind forces combination in CSA are higher than Conventional method.

2) The Axial Force in Floating Column supported by Girder Beams and the Columns starring form base increases by approximately 30% to 80% in CSA as compared to Conventional method concludes that ignoring CSA can probably underestimate the Column Axial Force which can effect in design of Columns.

3) The Transfer Girder Bending Moment, Shear Force and Deflection increases by approximately 25% in CSA as compared to Conventional method concludes that the CSA method should be adopted to avoid the probability of failure of Girder Beam.

4) For the Beams supported on Floating Column, Bending Moment at midspan and support, increases at bottom story

and linearly reduces for above story which concludes that the Beam Forces can be probably overestimated at top story and underestimated at bottom story using conventional approach.

5) Shear Forces probably increases at bottom levels and goes on reducing at top levels in CSA which get ignored in Conventional method.

Hence it is necessary to consider the Construction Sequence Analysis method for tall buildings.

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