Research Article

A Comparative Studyof Construction Sequence with ConventionalAnalysis

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ABSTRACT:Rising incidents of failure of buildings during the construction phase is an increasing concern in India. The failure of structural elements like slabs, beams, columns, and shear walls is critical. Construction sequence analysis (CSA) helps in analysing the building in a staged fashion. Despite its importance, our knowledge of CSA is poor, and the implementation is imperfect. The purpose of this study is to investigate the change in values of numerous structural parameters namely axial force, shear force, and bending moment during and after construction. Using CSA, this study analysed the values of structural parameters of a 15 storied building located in Pune and measured these results against the dynamic analysis of the building. The values of deflection and shear forces found in CSA are up to 45% more than dynamic analysis. This study definitively answers the question regarding the failure of buildings during the construction phase and how it can be avoided by using CSA. Experimental studies are needed to establish real-world values of structural parameters.

Keywords: Dynamic, analysis, Construction, sequence, CSA, high-rise, building, stage.

1. INTRODUCTION

Conventionally buildings are analysed by assuming that the building has already been constructed and the loads are applied only after the completion of the building, which is not the case in reality. In reality, the building is constructed in stages. Therefore, the results generated by the conventional analysis method are markedly different from the actual results. Which may lead to the failure of the building during the construction phase. To overcome this assumption a method called 'Construction sequence analysis (CSA)' is developed. CSA helps in analysing the building in a staged fashion.

In this study, a 15 storied building was analysed by conventional method and by construction sequence using ETABS software. At first, the building was analysed using the conventional method, in which single-step analysis is used. In this method, loads are applied after the building is completed. Then the result of the conventional analysis is tabulated in an excel sheet. After that CSA is done on the same building. In CSA the building is analysed after each story is completed. CSA replicates the real-life construction progress in the software. The software is programmed in such a way that the analysis is run after a story is completed. The result of CSA is tabulated in an excel sheet.

The results of axial force, shear force, and a bending moment of each structural element were compared between the conventional method and CSA. It is found that the values of structural parameters are markedly different in the case of CSA when compared to conventional analysis. This happens primarily due to the incomplete action of the truss in the building frame. Due to this, there is irregular load transfer in the building frame. And some members are subjected to higher loads in CSA than in conventional analysis.

1.1 Construction Sequence Analysis

CSA is a method in which a structure is analysed in sequential form. It is a nonlinear analysis method. The loads are partially applied on the structure at each stage. This story wise loading ensures that the values generated are more realistic and can be trusted over conventional methods.

1.2 Dynamic analysis

Dynamic analysis is the type of analysis in which the effect of lateral forces is taken into account. The lateral forces are earthquake forces. In this analysis the structure is subjected to dynamic loading (actions have high acceleration).

2. Problem Statement

To analyze a building by conventional method and construction sequence and compare the analysis.

3. Objectives

To reduce the risk of failure of the building during construction.

Comparative study of CSA with the conventional method.

To calculate the change in the values of structural parameters like bending moment, axial force, and shear force of the structure.

4. Literature Review

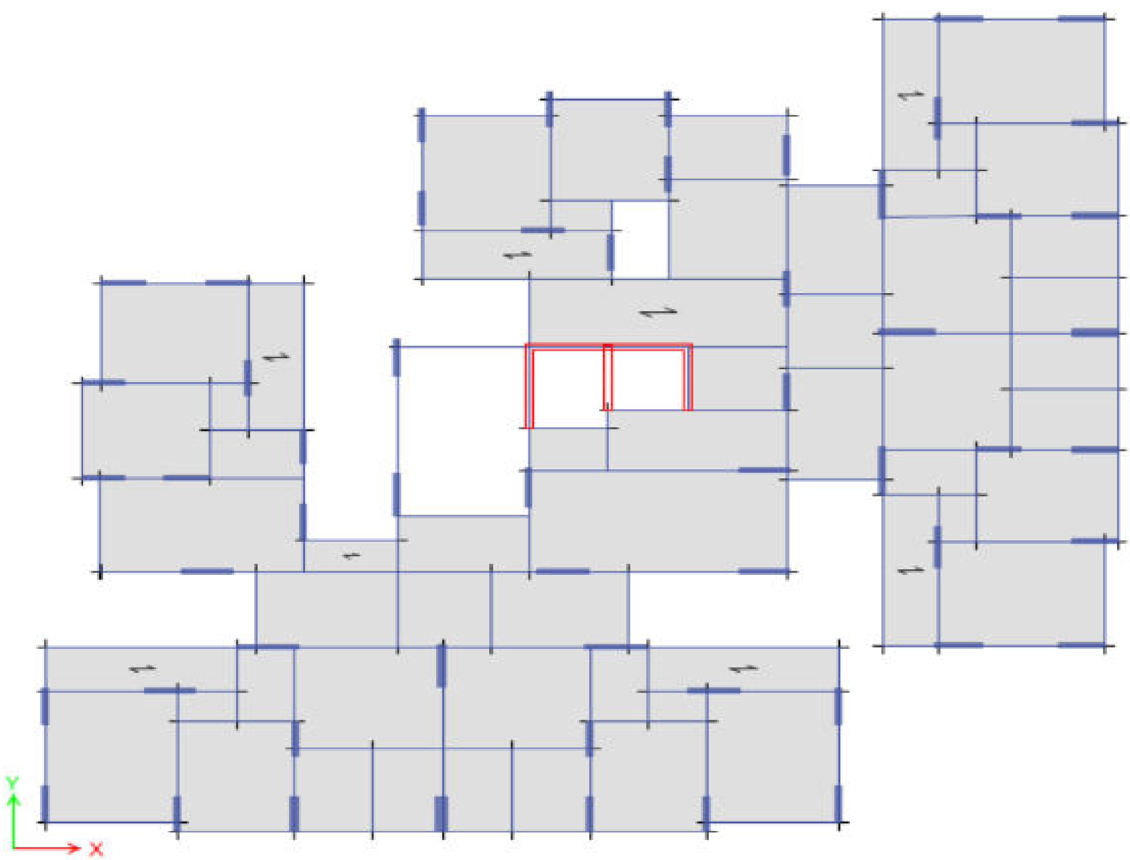
The previous studies state general information about construction sequence. It also talks about finite element modeling of CSA and the use of different analysis software. The studies also elaborate on the importance of CSA in composite structures and analysis of shear walls using CSA.

1. Taehun Ha, et al. have studied the application of construction sequence analysis in a high-rise building. Also, it talks about finite element modeling of construction sequence analysis.
2. Ankur Dubey, et al. have studied multi-storied frame of RCC with shear wall with and without CSA. And the application of SAP structural software in CSA and analysis of shear wall with CSA.
3. Vignesh Kini K, et al. have studied the difference between response spectrum and construction sequence analysisin G+20 multi-storied composite structure with floating column. The importance of CSA in composite structure and the difference between response spectrum analysis and CSA.
4. Kiran Y. Naxane, et al. have studied the effect of CSA on rigid RC frame. And results were compared with single step analysis.And the difference in the values of axial force, shear force bending moment and axial deformation is calculated between two methods.
5. Sagupta R Amin, et al. have studied the effect of construction sequence analysis on multi-storied building on different stories considering earthquake forces and wind forces. The parameters such as bending moment, axial load, displacement, shear, etc. have been inquired under seismic forces and wind forces, with and without CSA.
6. S. C. Chakrabarti, et al. have studied a model of the sequence of construction on two multistoried frames of different configurations. The CSA program was based on Kani's method. Also, the effect of a sequence of construction due to the self-weight of members and its effect on the overall design forces.
7. Chang-Koon Choi, et al. have studied the bending moments and shear forces induced in the members of the frame by the differential column shortening. Correction factor method is used to solve the problem of single step analysis. They studied sub structuring techniques in which the entire frame is analyzed by the "one substructure at a time" approach in the reverse order of construction.
8. Yousuf Dinar, et al. have studied the advancement of finite element modeling accelerating the accuracy of finite element simulation by taking the consideration of construction sequential effects. The effect of a sequence of construction due to the self-weight of members has been studied.
9. M. T. R. Jayasinghe, et al. have studied the effects of rate of construction, construction sequence, and grade of concrete on axial shortening of columns due to long-term creep and shrinkage.
10. Meghana. B.S, et al. have studied the analysis of the model with the help of ETABS software. It involves two types of analysis such as linear static analysis and CSA, which is carried out on RC building structure of G+ 5 stored with a floating column in an exterior position where the RC transfer girder is replaced by composite transfer girder and the parameter such as beam moments and deflection are compared.

All the previous work done was on hypothetical buildings. Therefore, to validate CSA it is needed work on the live building. In this study, a building situated in Pune is analysed by using conventional and construction sequence analysis.

5. Methodology

In this study, a residential building located in Pune with 15 stories and plan dimensions 28.52 x 27 m is analysed. The modeling of the building is done in ETABS (Extended Three-Dimensional Analysis of Building System) software. The software is capable of analysing multi-storied frame structures both with and without stimulation of construction sequence.
The building is analysed using two methods viz. conventional and construction sequence analysis. In conventional analysis, the building is analysed using the single-step method. In this method, it is assumed that the structure is completed and the loads are applied only after the construction is completed. Then the building is analysed by using a construction sequence. In this method, the building is analysed at each story and the loads are applied to each story as the construction progresses. Simulating the actual behavior of the structure. The results were validated using manual calculations. To finish, the results of axial forces, shear forces, and bending moments of both methods were compared.



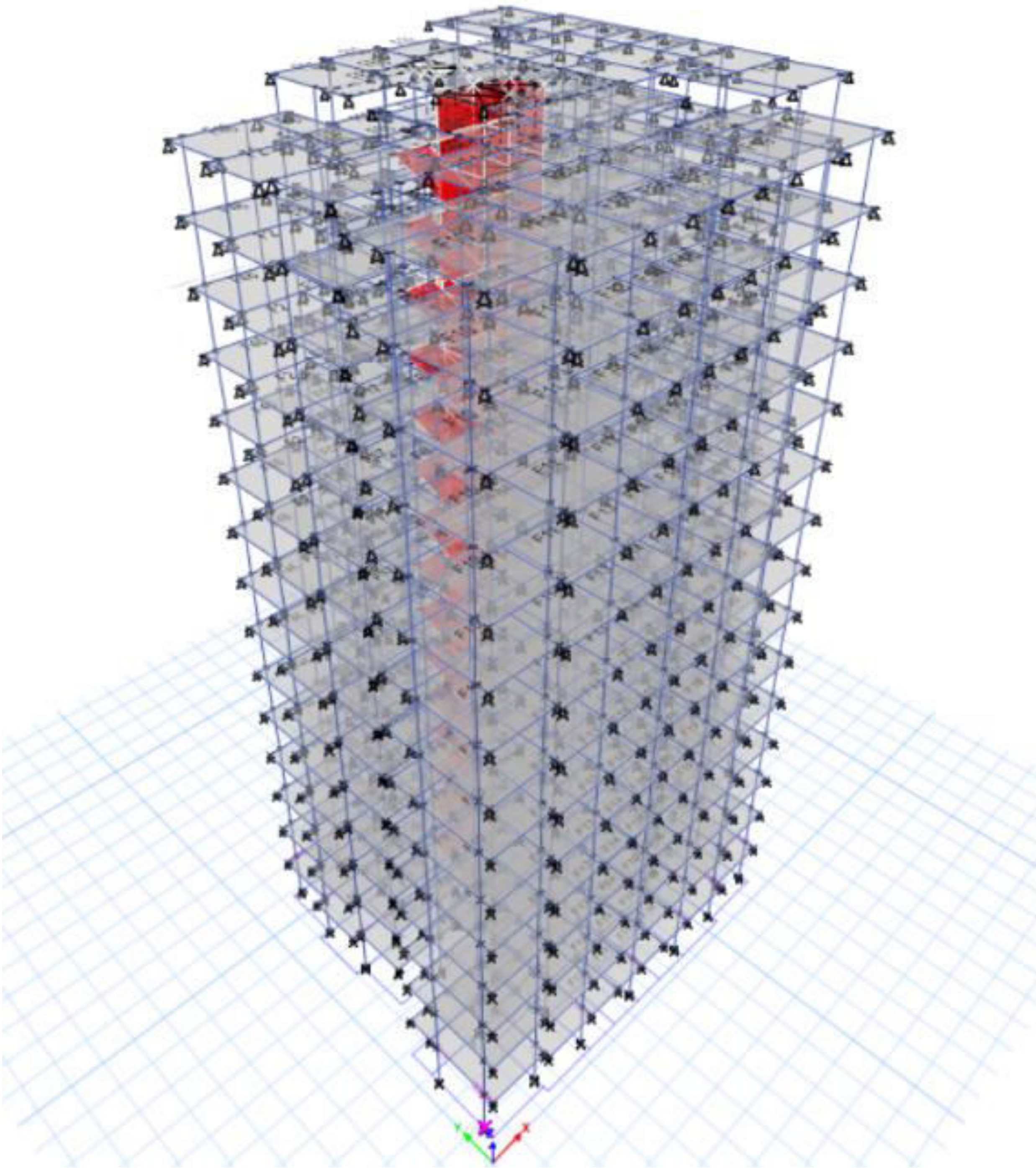


figure 1.1 Plan view

Figure1.2 3-D view

4.1 Structural Details

Table 4.1 Structural details

Type of structure	RCC residential building
Location	Pune, India
Number of stories	15
Ground storey height	3 meters
Storey height	2.85 meters
Grade of concrete	M20 for beams and slab, and M25 for columns
Grade of steel	Fe415 and Fe500
Modulus of elasticity of steel	200000 MPa
Modulus of elasticity of concrete	25000 MPa
Load on the structure	Dead, Live, Wind, and Earthquake
Soil type	Medium type
Earthquake zone	Zone III
Wind speed	39 m/s
Wall thickness	250 mm
Importance factor	1
Response reduction	5

4.2 Validation

In this study, manual calculations are done for slabs, beams, and column to check whether the software values are correct. Values of shear force, bending moment, and axial force are taken maximum of conventional method and CSA. Sample calculations are shown below.

4.2.1 Check for slab

Dimension: 6.8*3.5meters

Live load: 3 kN/m^2

Type of slab:$\frac{lx}{ly} = 1.94 < 2$

Therefore, two-way slab

From IS 456 : 2000 Cl. 23.2.1

$$d = \frac{span}{BV * MF}$$

$$\therefore d = \frac{3500}{26*1.5}$$

$\therefore$ d = 89.74mm ≈ 100mm

Assuming effective cover as 25

$\therefore$ D = d + e = 100 + 25 = 125mm

From cl. 22.1a Leff is least of

Leff = lx + D = 3500 + 125 = 3625mm

Leff= lx + c/c between support = 3500+200=3700mm

$\therefore$Leff = 3625mm

Load calculation

DL = density of concrete * D

DL = 25 * 0.125 = 3.125 kN/m^2

LL = 3 kN/m^2

Total load = 6.125 kN/m^2

Factored load (Wu) = 1.5 * 6.125 = 9.1875 kN/m^2

Calculation of moment from IS 456 : 2000 table 26

$\alpha_{x1} = 0.075$, $\alpha_{x2} = 0.053$, $\alpha_{y1} = 0.047$, $\alpha_{y2} = 0.035$

Design moment (Md) Maximum of

$M_{x1} = \alpha_{x1}$ Wu le^2 , $M_{x2} = \alpha_{x2}$ Wu le^2

$M_{y1} = \alpha_{y1}$ Wu le^2 , $M_{y2} = \alpha_{y2}$ Wu le^2

$\therefore$ Md = 8.44 kN.m.

Check for depth

$$Md = 0.36 * fck * xumax * b(d - 0.42 * xumax)$$

$$Md = 0.36 * 20 * 0.42d * 1000 * (d - 0.48 * 0.42d)$$

$\therefore$ d = 59.12 < $d_{provided}$

4.2.3 Check for beams

Table 4.2.2Check for beam

BEAMS		B27	B92	B86	B88	B45	B105
Type of Beam		Primary	Primary	Primary	Secondary	Primary	Primary
Type of Span		Mid-span	Support	Complete Span	Mid-span	Complete Span	Support
Type of Setion		Rectangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular
GIVEN DATA	Fck	20	20	20	20	20	20
	Fy	500	500	500	500	500	500
	le	9400	5600	4700	600	8500	4300
	D	900	900	900	700	900	900
	EC	30	30	30	30	30	30
	d	870	870	870	670	870	870
	Wu	21.75	21.75	21.75	14.5	21.75	21.75
	Reaction from secondary beam						
	lo	0	2990	0	1722	1722	0
	Vu	21.39	40.90	8.75	42.69	32.93	32.19
	Mu	21.6321	20.7879	18.3244	35.6025	10.6143	10.61
	bw	200	200	200	200	200	200
	df	0	0	0	0	0	0
	bf	NA	NA	NA	NA	NA	NA
Design of Flexure	Muf/Mu,lim	503.34	503.34	503.34	298.52	503.34	503.34
	Type Of Rein	Singly Reinforced	Singly Reinforced	Singly Reinforced	Singly Reinforced	Singly Reinforced	Singly Reinforced
	Ast 1	57.666	55.397	48.786	125.139	28.175	28.163
	Ast 2	0	0	0	0	0	0
	Ast total	57.67	55.40	48.79	125.14	28.17	28.16
	Asc reqd	NA	NA	NA	NA	NA	NA
	Ast min	270	306	306	238	270	270
	Ast req	270.000	306.000	306.000	238.000	270.000	270.000
	dc/d	0.034	0.034	0.034	0.045	0.034	0.034
	Fsc	355.931	355.931	355.931	355.313	355.931	355.931
	xu max	NA	NA	NA	NA	NA	NA
	xu act	NA	NA	NA	NA	NA	NA
	xu act < xu max	NA	NA	NA	NA	NA	NA
	Dia of bars	12	12	12	12	12	12
	ast	113.04	113.04	113.04	113.04	113.04	113.04
	no of bars	3	3	3	3	3	3
	Ast pro	339.12	339.12	339.12	339.12	339.12	339.12
	pt pro	0.250	0.250	0.250	0.375	0.250	0.250
	Tv	0.123	0.235	0.050	0.319	0.189	0.185
	Tc max	3.5	3.5	3.5	3.5	3.5	3.5
	Tv < Tc,max	SAFE	SAFE	SAFE	SAFE	SAFE	SAFE
compression reinforcement	diam of A bar	10	10	10	10	10	10
	Ao	NA	NA	NA	NA	NA	NA
	Asc reqd	NA	NA	NA	NA	NA	NA
	no of bars	NA	NA	NA	NA	NA	NA
	Asc provd	NA	NA	NA	NA	NA	NA
Design for Shear	diam of stirr-ups	8	8	8	8	8	8
	fy	250	250	250	250	250	250
	Ao	50.24	50.24	50.24	50.24	50.24	50.24
	Area of stirr ups (2legged)	100.48	100.48	100.48	100.48	100.48	100.48
	tc	0.23	0.23	0.23	0.27	0.23	0.23
	sv1	270	270	270	270	270	270
	sv2	650	650	650	500	650	650
	sv3	300	300	300	300	300	300
	sv pro	270	270	270	270	270	270
Check for Deflection	pt pro	0.250	0.250	0.250	0.375	0.250	0.250
	fs	50	50	50	110	30	30
	KT	1.30	1.30	1.30	1.30	1.30	1.30
	(l/d)Basic Value	20	26	26	26	20	20
	(l/d)max	26.00	33.80	33.80	33.80	26.00	26.00
	(l/d)act	10.80	6.44	5.40	0.90	9.77	4.94
	(l/d)max>(l/d)act	SAFE	SAFE	SAFE	SAFE	SAFE	SAFE

4.2.3 Check for column

For column C59, Dimension of column 0.24 * 1.5 m

Load = 2798.84 kN ≈ 2800 kN

Factored load = 1.5 * 2800 = 4200 kN

Materials used Fe500 steel and M25 grade concrete

According to IS 456 : 2000

Area of steel and area of concrete in terms of Ag,

Asc = 1% Ag ; Ac = 99% Ag

Where,Ag = gross area

Asc = area of steel

Ac = area of concrete

Calculate dimensions of column

From Cl. 39.3

Pu = 0.45*fck*Ac + 0.67*Ay*Asc

Provide p% = 1.5%

$$Ac = \frac{100 - 1.5}{100} * Ag$$

$$Asc = \frac{1.5}{100} * Ag$$

$$\therefore 4200 * 10^3 = 0.45 * 25 * \frac{98.5}{100} * Ag + 0.67 * 500 * \frac{1.5}{100} * Ag$$

∴ Ag = 260788.57 mm^2

Consider one side of column as 1500 mm,

D = 1500 mm

Ag = D * b

260788.57 = 1500 * b

∴ b = 173 mm ≈ 240 mm

Therefore, column provided in the software is correct.

6. Result

The most vulnerable structural elements to sequential loading are mentioned in the table below.

Table 6.1 Axial forces comparison

Most vulnerable beams	Axial force of conventional analysis (kN)	Axial force of CSA (kN)
B92	0	13.2879
B45	0	5.5251
B38	0	0.0921

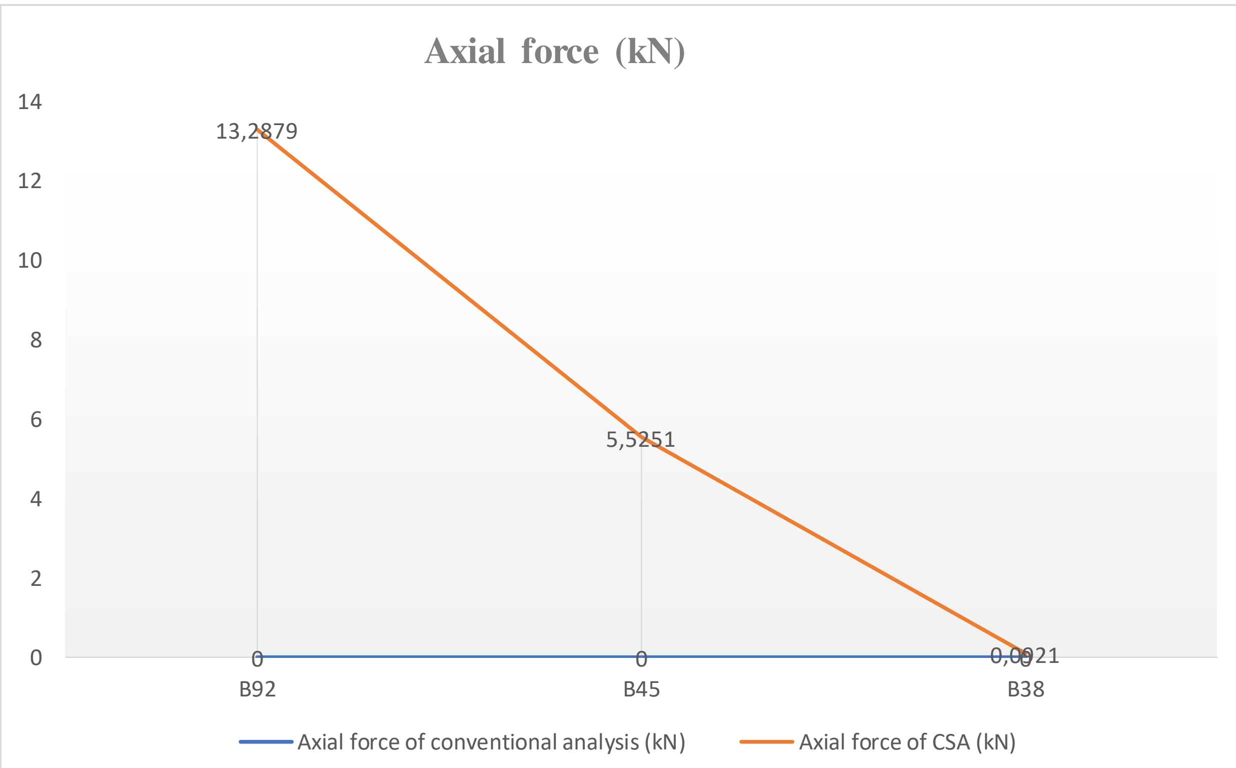
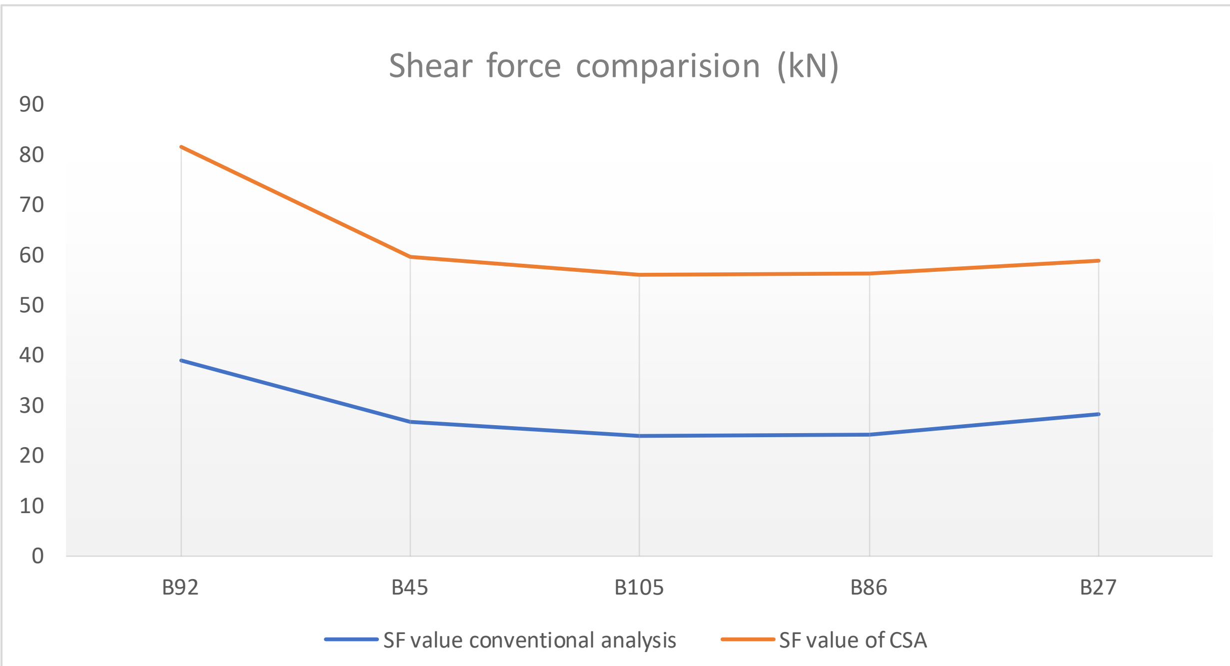


Fig.6.1 Chart of axial forces(kN)

Fig. 6.1 compares the result between the axial force of conventional analysis and CSA. In Conventional analysis, the axial force in beams is near zero and in CSA axial force can be observed in some beams. This is because in CSA the frame is not completed which leads to uneven load distribution in the structure due to this axial force is generated in the beams.

Table 6.2 Sher force comparison

Most vulnerable beam	SF value conventional analysis	SF value of CSA	percentage change
B92	38.8772	42.6932	9.815521694
B45	26.6799	32.9348	23.4442408
B105	23.9251	32.1976	34.57665799
B86	24.2301	32.0943	32.45632498
B27	28.1915	30.5353	8.313853466



Fig, 6.2 Chart of Shear forces(kN)

Fig. 6.2 compares the result between the shear force of conventional analysis and CSA. The shear force values are up to 35% more in CSA than in conventional analysis

Most vulnerable beams	BM of conventional analysis	BM of CSA	Percentage change
B88	31.8756	35.6025	11.69201521
B27	15.9908	21.6321	35.27841009

B92	17.4684	20.7897	19.01318953
B86	12.7034	18.3244	44.2479966
B88	30.1919	32.9182	9.029905372

Table 6.3 Bending moment comparison

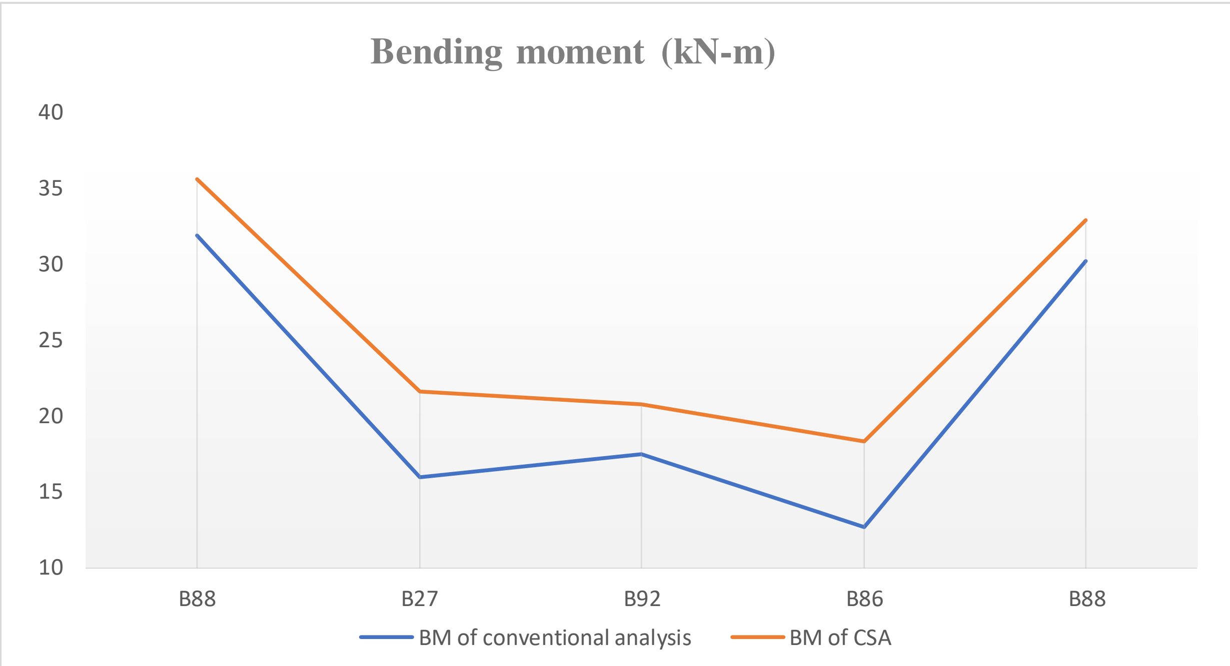


Fig.6.3 Chart of bending moment(kN-m)

Fig. 6.3 Compares the result between bending moment of conventional analysis and CSA. The bending moment values are up to 45% more in CSA than in Conventional analysis.

Table 6.4 Axial force comparison of columns

Most vulnerable beams	Axial force conventional analysis	Axial force of CSA	Percentage change
C59	-2596.9879	-2798.8406	7.772569907
C2	-2444.3332	-2409.6529	-1.418804114
C64	-2269.4824	-2372.4166	4.535580448
C43	-2309.5494	-2287.4117	-0.958528967
C13	-2066.9392	-2129.5169	3.027553979

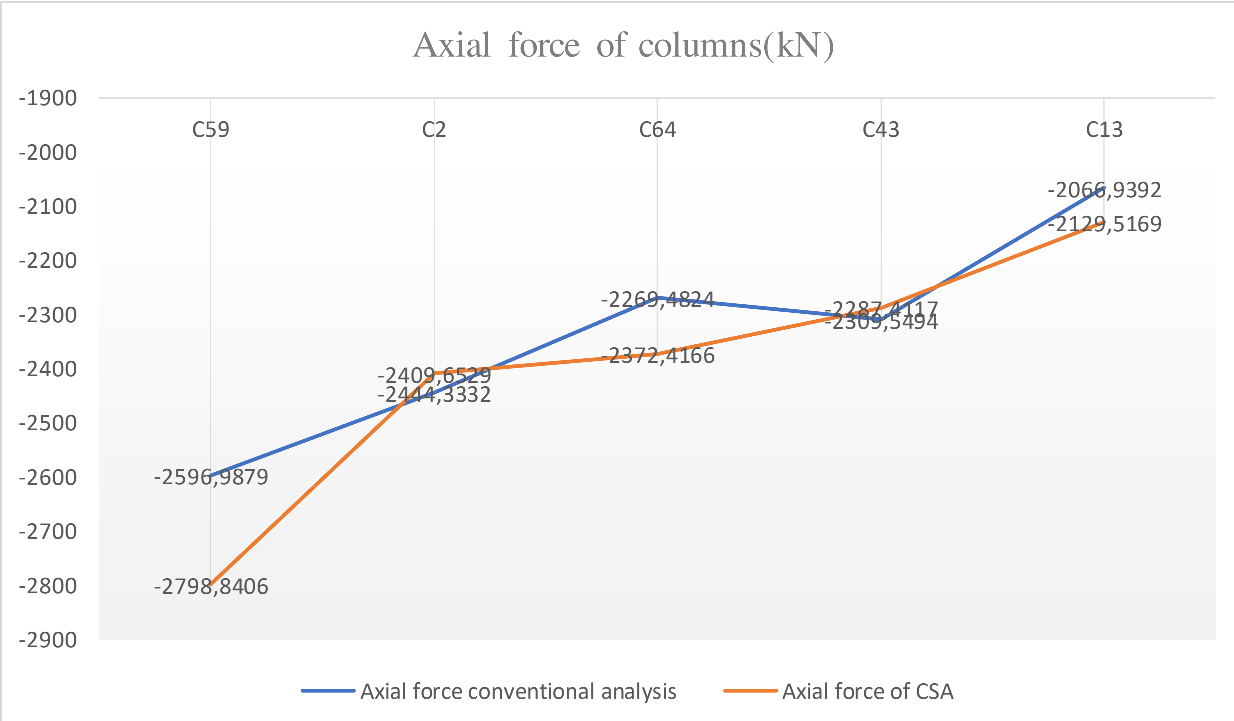


Fig. 6.4 Axial force comparison of columns

Fig. 6.4 compares the result between axial force of conventional analysis and CSA of columns. The difference between two values is up to 7%.

7. Conclusion

The values of shear force and bending moment are markedly different in conventional and construction sequence analysis. The results clearly state that in high-rise buildings CSA is necessary due to considerable difference in the values of Shear force, bending moment, and axial forces.

It is found that the change in values of structural parameters is caused due to the incomplete truss, which causes uneven load transfer.

In conventional analysis, the staging of construction is neglected due to which the values are different from real-world values.

Beams are more vulnerable to sequential loading as compared to columns.

The structural members must be designed for the higher values of axial force, shear force, and bending moment between the two methods.

7.1 Future Scope

Further analysis can be done on the building having floating columns and shear walls. And experimental work is needed to find real-world values. Such sequential analysis can be done by using different types ferrocement elements, with different combinations of meshes and mortars.

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