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Long Term Static Performance of High Rise Buildings by considering Static Non-Linearity with Staged Construction Analysis

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Abstract

Non-linear static analysis in terms of material non-linearity and geometrical non-linearity has been analysed with staged construction analysis in three high rise buildings with different structural systems. In the concrete structures, behaviour of material properties is not changes linearly with the time, ex. creep, shrinkage, modulus of elasticity etc. Geometrical non-linearity affects the serviceability criteria and differential axial shortening of columns affects in both serviceability and strength criteria effectively with staged construction analysis. Mostly these effects have been ignored while designing of high rise structures which should be considered in analysis and design phases. Now a day with the use of finite element software it becomes easy to incorporate these effects into design consideration. This paper does the analysis of material non-linearity as per CEB-FIP model code 1990 and P-Delta analysis with staged construction analysis on three high rise G+25 buildings with different structural system. Differential axial shortening triggering due to these non-linearity effects is also studied.

I. Introduction

High rise building present extreme challenges in terms of both design and construction. Structure must be hold their strength as well as serviceability throughout their designed life without any failure. Axial and differential axial deformations in high-rise buildings are extremely significant during construction. Force redistribution caused by differential shortening in columns of the high-rise building leads to potential safety hazards. Geometric non-linearities involve non-linearity in kinematic quantities such as the strain displacement relations in solids and non-linearity in material occur when the stress-strain or force displacement law is not linear, or when properties of material changes with the applied loads time. Therefore, these nonlinear effects should be considered in the analysis and design at each construction stages of the structure. In this paper, analysis of P-Delta (Geometric Non-Linearity) and time dependent properties of the material (Material Non-linearity) with staged construction analysis are carried out on two G+25 prototype models with different framing systems. Maximum shear forces, bending moments and axial shortenings of columns are compared with Linear Static analysis. Differential axial shortenings in vertical structural components are also analysed within these models.

II. Methodology

Analysis of P-Delta and time dependent properties of the material with staged construction analysis are carried out on two different G+25 prototype models. These models include Moment resisting Frame with columns only and Core supported structure (Shear walls at centre). Initially strength design of these models has been done by considering zone II, soil type 2 as per Indian standards and after that nonlinear analysis with construction staged analysis is carried out for the same prototype models. CEB-FIP 1990 model code is used for the calculation of time dependent parameters. Strength and serviceability design of prototypes has been done with linear static and equivalent static analysis by considering zone II and medium soil as per Indian standards to finalised section sizes of each model. Analytical calculations of time dependent nonlinear parameters are carried out as per CEB-FIP Model code 1990. Afterwards material nonlinearity and geometric nonlinearity analysis has been done on prototype model and comparison of maximum shear forces, bending moments, axial shortening and differential axial shortening is monitored on these structures with the help of finite element software Etabs.

III. Calculation of Material Nonlinear Parameters

As per CEB-FIP-1990 prediction model estimation of time dependent parameters are carried out: -

1. Mean concrete compressive strength of concrete at age t days,

$$f_{cm}(t) = \beta_{cc}(t)\, f_{cm}$$

$$\text{With} \quad \beta_{cc(t)} = \exp\left\{s\left[1-\left({}^{28}/_{(t/t_1)}\right)^{1/2}\right]\right\}$$

2. Combined effect of sustained stresses and of continued hydration is given by,

The mean compressive strength of concrete at time t when subjected to a high sustained compressive stress at an age at loading $t_0<t$:

$$f_{cm,sus}(t,t_0) = f_{cm}\,\beta_{cc}(t)\,\beta_{c,sus}(t,t_0)$$

With

$$\beta_{c,sus}(t,t_0) = 0.96 - 0.12\,\{ \ln [72\,(t-t_0/t_1)\,]\,\}^{1/4}$$

3. Modulus of elasticity at an age of t days

$$E_{Ci}(t) = \beta_E(t)\,E_{ci}$$

$$\text{with}\quad \beta_E(t) = [\beta_{cc}(t)]^{0.5}$$

4. Stress dependent strain

$$\varepsilon_{c\sigma}(t,t_0) = \sigma_c(t_0)\,J(t,t_0) + \int_{t_0}^{t} J(t,\tau)\,\frac{\partial\sigma_c(\tau)}{\partial\tau}d\tau + \varepsilon_{cn}(t)$$

Creep compliance,

$$J(t,t_0) = \left[\frac{1}{E_C(t_0)} + \frac{\phi(t,t_0)}{E_{Ci}}\right]$$

Creep coefficient,

$$\phi\,(t,t0) = \phi_0\ \beta c(t - t_0)$$

Notional creep coefficient,

$$\phi_0 = \phi_{RH}\beta(f_{cm})\beta(t_0)$$

With

$$\phi_{RH} = 1 + \frac{1 - RH/RH_0}{0.46(h/h_0)^{1/3}}$$

$$\beta(f_{cm}) = \frac{5.3}{(f_{cm}/f_{cm0})^{0.5}}$$

$$\beta(t_0) = \frac{1}{0.1 + (t_0/t_1)^{0.2}}$$

And

$$\beta c(t - t_0) = \left[\frac{(t-t_0)/t_1}{\beta_H + (t-t_0)/t_1}\right]^{0.3}$$

With

$$\beta_H = 150\left\{1 + \left(1.2\frac{RH}{RH_0}\right)^{18}\right\}\text{h/h}_0 + 250 \le 1500$$

5. Total shrinkage strain

$$\varepsilon_{cs}(t,t_s) = \varepsilon_{cso}\beta_s(t-t_s)$$

Notional shrinkage coefficient

$$\varepsilon_{cso} = \varepsilon_s(f_{cm})\beta_{RH}$$

With

$$\beta_{RH} = -1.55 * \left[1 - \left(\frac{RH}{RH_0}\right)^3\right] \text{for } 40\% \le RH < 99\%$$

$$= +0.25 \qquad\qquad \text{for } RH \ge 99\%$$

And

$$\varepsilon_s(f_{cm}) = [160 + 10\beta_{sc}(9 - f_{cm}/f_{cmo})X10\text{^} - 6$$

Where,

f_{cm} = mean compressive strength after 28 days

f_{cmo} = 10 Mpa

s = coefficient depends on the type of cement as per code

t_0 = Age of the concrete at loading

$(t-t_0)$ = Time under high sustained loads (days)

t_1 = 1 day

RH = Relative Humidity of the ambient environment (%)

RH_0 = 100%

Notional size of member,

$h = (2A_c/u)\ mm$

Ac = Cross section area

u = Perimeter of the member in contact with the atmosphere

h_0 = 100 mm

β_{sc} = Coefficient which depends on the type of cement

IV. Mathematical Modelling of Prototypes

Three mathematical prototype models are constructed for the nonlinear static analysis in Etabs. Initially strength design of these models with linear static and equivalent static method has been done to finalised section sizes and reinforcement of the structural members for zone II and medium soil type.

Following are the material properties, loadings and section sizes which has been used for the modelling:

• Material Properties 1. Concrete - M30 2. Steel - fe500 • Load Definition 1. Floor Finish – 1.5 kN/m² 2. Live Load - 2 kN/m² 3. Wall Load – 11.5 kN/m² 4. Water & LMR – 20 kN/m² 5. Stair Case – 3. Dead Load – 3 kN/m² 4. Live Load – 4 kN/m² • Section Sizes Used – 1. Beam- 3. 400mm*1000mm 4. 400mm*1300mm 2. Transfer Girder 3. 3000mm*1800mm 3. Column 1. 1200mm*3000mm 2. 1200mm*2750mm 3. 1200mm*2500mm	3. 1200mm*2250mm 4. 1200mm*1750mm 5. 1200mm*1500mm 6. 1200mm*1200mm 7. 1200mm*2000mm 8. 800 mm* 800mm 9. 600mm *600mm 10. 500mm*500mm 1. Slab ▪ 150 mm Thick – Floor Slab ▪ 250 mm Thick – Stair Slab ▪ 350 mm Thick – Flat Slab ▪ 700 mm Thick – Drop Panel 2. Height • Total – 79 m • G to P-2 – 3 m • P-4 – 4 m • Floor 5 to 25 – 3 m • Plan Dimension – 32m x 32m

After passing the strength and serviceability criteria by assuming linear static analysis, the material

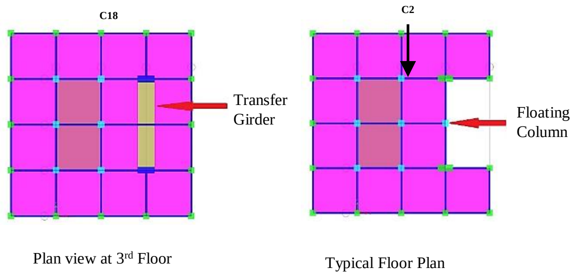

Fig. 1 Model 1 Moment Resisting Frame with Columns only (G+25)

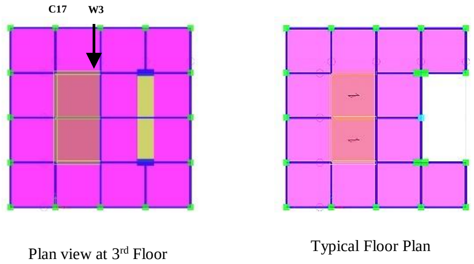

Fig. 2 Model 2 Moment Resisting Frame with columns and shear walls (G+25)

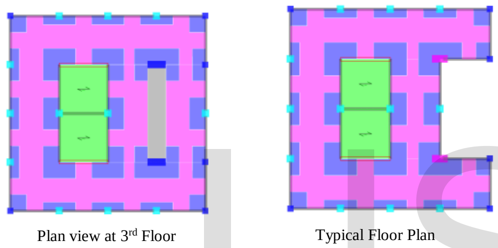

Fig. 3 Model 3 Flat Slab with Columns and Shear Walls (G+25)

and geometric non-linearity with construction staged analysis is performed on the models. Four load cases are created to compare the results are

- Linear static analysis,
- Construction Sequence with Geometric Nonlinearity,
- Construction Sequence with Material Nonlinearity.
- Construction Sequence with Geometric and Material Nonlinearity.

For construction sequence analysis or construction staged analysis propped period of 18 days is considered for individual floor.

V. Material Nonlinearity Case

Time dependent properties considered for M30 concrete is as follows

- Time dependent type considered for creep, shrinkage, compressive strength and stiffness creep analysis is full integration
- Current Time Dependent type is CEB-FIP 1990
- CEB-FIP parameters are
    - Cement type coefficient -0.25
    - Relative humidity – 50%
    - Shrinkage coefficient – 5
    - Shrinkage Start Days – 0 days

VI. Analysis Results

Abbreviations used in results are:

LSA = Linear Static Analysis
CS+GN = Construction sequence analysis with Geometric Non-Linearity
CS+MN = Construction sequence analysis with Material Non-Linearity
CS+GN+MN = Construction sequence analysis with Geometric & Material Non-Linearity
AS = Axial Shortening
DAS = Differential Axial Shortening

1. Displacement Results Comparison in Transfer Girder

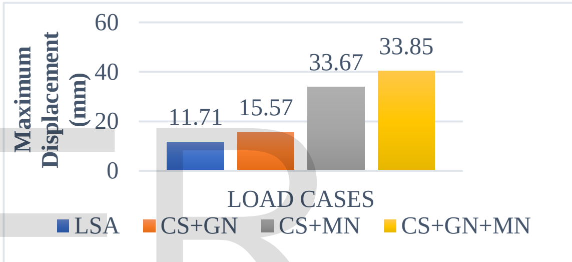

Fig. 4 Maximum Absolute Deflection of Transfer Girder for Model 1

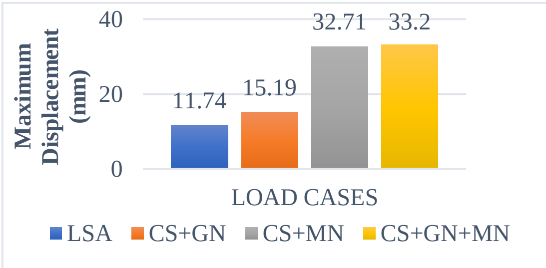

Fig. 5 Maximum Absolute Deflection of Transfer Girder for Model 2

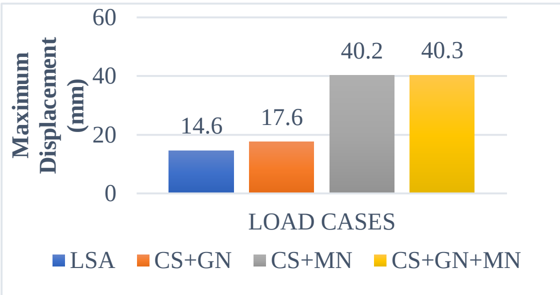

Fig. 6 Maximum Absolute Deflection of Transfer Girder for Model 3

2. Shear Force Comparison in Transfer Girder

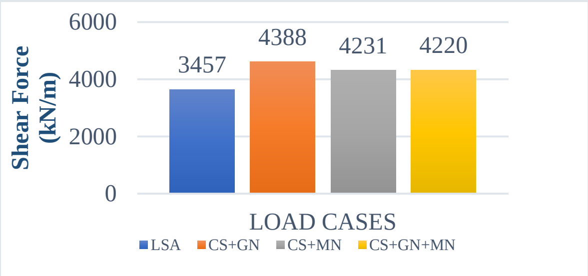

Fig. 7 Shear Force taken by Transfer Girder at final stage of Model 1

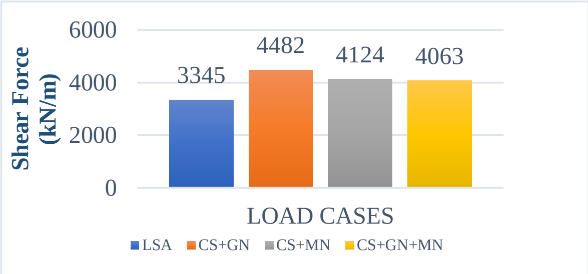

Fig. 8 Shear Force taken by Transfer Girder at final stage of Model 2

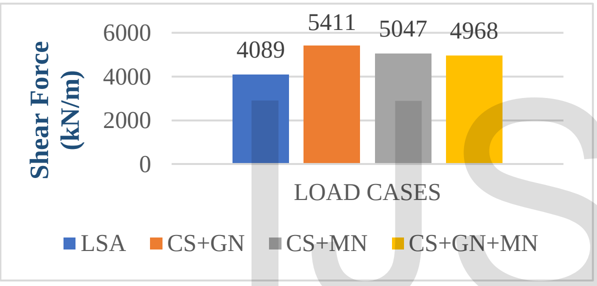

Fig. 9 Shear Force taken by Transfer Girder at final stage of Model 3

3. Bending Moment Comparison in Transfer Girder

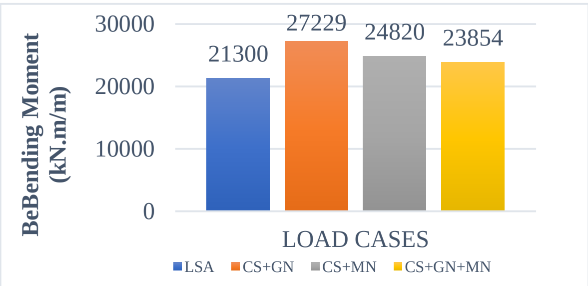

Fig. 10 Bending Moment taken by Transfer Girder at final stage of Model 1

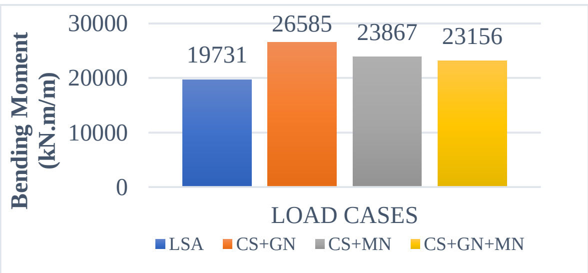

Fig. 11 Bending Moment taken by Transfer Girder at final stage of Model 2

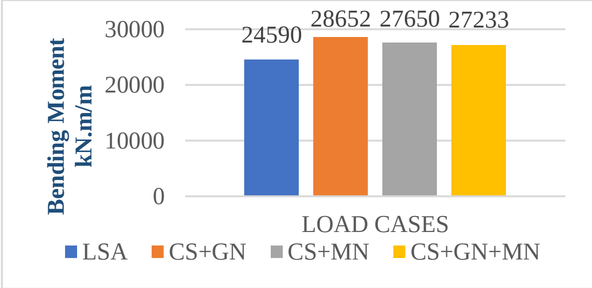

Fig. 12 Bending Moment taken by Transfer Girder at final stage of Model 3

4. Differential Axial Shortening

Table No. 1 Differential Axial Shortening Analysis of Model 1 between columns C2 & C18

Seq Analysis + (Mat+Geo) Non-Linearity			
Story	Joint Label	AS	DAS
25	8	-57.349	-9.167
25	42	-48.182	
24	8	-61.131	-9.631
24	42	-51.5	
23	8	-63.967	-10.002
23	42	-53.965	
22	8	-65.883	-10.276
22	42	-55.607	
21	8	-66.896	-10.454
21	42	-56.442	
20	8	-67.019	-10.534
20	42	-56.485	
19	8	-66.261	-10.516
19	42	-55.745	
18	8	-64.628	-10.397
18	42	-54.231	
17	8	-62.127	-10.175
17	42	-51.952	
16	8	-58.767	-9.857
16	42	-48.91	

Table No. 2 Differential Axial Shortening Analysis of Model 2 between columns C17 & W3

Seq Analysis + (Mat+Geo) Non-Linearity			
Story	Joint Label	AS	DAS
25	8	-57.349	-8.667
25	42	-48.182	
24	8	-61.131	-9.131
24	42	-51.5	
23	8	-63.967	-9.502
23	42	-53.965	
22	8	-65.883	-9.776
22	42	-55.607	
21	8	-66.896	-9.954
21	42	-56.442	
20	8	-67.019	-10.034
20	42	-56.485	
19	8	-66.261	-10.016
19	42	-55.745	
18	8	-64.628	-9.897
18	42	-54.231	
17	8	-62.127	-9.675
17	42	-51.952	
16	8	-58.767	-9.357
16	42	-48.91	
15	8	-54.561	-8.843

Table No. 3 Differential Axial Shortening Analysis of Model 3 between columns C17 & W3

Seq Analysis + (Mat+Geo) Non-Linearity			
Story	Joint Label	AS	DAS
25	17	-41.205	
24	4	-45.118	-2.565
24	17	-42.553	
23	4	-46.319	-2.675
23	17	-43.644	
22	4	-47.259	-2.773
22	17	-44.486	
21	4	-47.945	-2.859
21	17	-45.086	
20	4	-48.378	-2.93
20	17	-45.448	
19	4	-48.562	-2.987
19	17	-45.575	
18	4	-48.498	-3.027
18	17	-45.471	
17	4	-48.188	-3.051
17	17	-45.137	
16	4	-47.633	-3.056
16	17	-44.577	
15	4	-46.835	-3.044

VII. Conclusions

1. Construction staged analysis with geometric and material nonlinearity as per CEB-FIP Model code 1990 reflecting deformations due to creep and shrinkage of the G+25 story reinforced concrete structures shows the following effects:
   a. Maximum deflection in transfer girder due to construction sequence with geometric and material nonlinearity effect is approximately varying 2.5 to 3 times the deflection due to static linear analysis
   b. Model 3 which is flat slab with shear wall and columns consisted structure shows more deflections in transfer girder compare to other models with normal slab and beam column/wall framing.
2. Shear force and bending moment taken by transfer girder due to construction sequence analysis with geometric and material nonlinearity is less than the sequence analysis with geometric nonlinearity only. So while designing construction sequence analysis with geometric nonlinearity should be taken in the combinations.
3. In the structure with transfer girder and floating column, normal slab with beams and columns or/with shear walls framing is more efficient than flat slab with columns and shear walls.
4. Differential axial shortening due to construction sequence with geometric and material non-linearity is less in structure with flat slab and shear walls compare to other models.
5. Differential axial shortening is occurring more at the intermediate floors so special consideration should be taken while designing these floors.

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