COMPARATIVE STUDY OF MODIFIED CONSTRUCTION STAGE ANALYSIS AND CONSTRUCTION STAGE ANALYSIS FOR RC BUILDINGS

NEHAL DESAI and SANDIP VASANWALA

1Dept of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India

A significant difference is found in axial shortening of vertical members in tall concrete buildings when analyzed by Construction Stage Analysis considering the effect of creep and shrinkage as compared to the conventional One Step Analysis method. In Construction Stage Analysis the self-weight of structural members, and a load of brick walls along with floor finishing load, gets added sequentially as construction is carried out. In addition to the above loads, construction loads such as the weight of formwork, the weight of wet concrete, staking of materials, and other construction loads of men and machines get imposed on the structure during construction. Also, stagewise reduction of load due to removal of formwork, material staking, and other construction loads of men and machines should also be considered during the analysis with the Construction stage method. The axial shortening of vertical members of RC buildings was analyzed by the Conventional one-step method, Construction Stage method, considering self-weight along with brick wall and floor finishing load as sequential loads. Modified Construction Stage method-in which in addition to self-weight, brick wall, and floor finishing load, above mentioned all loads that appear during construction, were added, and removed sequentially in the analysis, by taking 20, 30, and 40 floor RC building models. Modified CSA gives 2.068% to 20.56% lesser axial shortening in comparison to the CSA method. The study also concludes that the difference of axial shortening between Modified CSA & CSA increases from first to a certain floor, after that it reduces till top floor.

Keywords: Axial shortening, Time-dependent properties, Creep, Shrinkage, Sequential loads.

1 INTRODUCTION

Researchers have done studies on the Construction stage method of analysis for RC building in which unlike the one-step method, loads like self-weight of structural members as well as loads induced due to brick walls and floor finishes were applied as per the progress of construction. Researchers recommended the Construction Stage Method of Analysis (CSA) method considering time-dependent properties of concrete like creep and shrinkage.

Dinar et al. (2014) and Correia and Lobo (2017) studied the effect of self-weight on construction sequence by the computerized method. Ha et al. (2017) developed an algorithm of the construction stage and checked the results by laser survey and suggested to consider, the movement caused by the time-dependent effect of the concrete that occurs during the construction stage of a tall building in design. Samarakkody et al. (2017) developed a technique to evaluate the differential axial shortening for high-rise buildings with composite CFT columns. Afshari et al.
(2017) proposed an improved correction factor method. Zucca et al. (2018) and Secer and Arslan (2019) observed considerable change in vertical displacements of columns in comparison to conventional analysis. Elansary et al. (2021) had indicated that one-step analysis (OSA) gives an unsafe solution in certain element zones and an uneconomic solution in other zones.

Temporary loads due to formwork, wet concrete, stacking of materials, small equipment, workers, etc. are added and removed on the skeleton of the building frame during construction. So, if the CSA method is adopted, these temporary loads should also be accommodated stagewise as per its construction schedule for more actual prototype models for analysis. This CSA method, which includes all stagewise loads including temporary loads as per their construction schedule and timing in the analysis is referred to here as the Modified Construction Stage method of analysis (MCSA). Analysis of axial shortening in vertical members using CSA, MCSA, and One-Step linear Static method was done in this study. The time-dependent properties of concrete were considered for CSA and MCSA methods. The building models were analyzed using Midas Gen 17. To consider the long-term effects of concrete-like creep and shrinkage in CSA and MCSA; the code of practice of Indian Roads Congress -IRC: 112-2011 was used (IRC 2011).

2 METHODS AND APPROACH

2.1 Modelling of Building

Three RC framed building models of the same 40 m X 40 m plan with a column grid spacing of 5.72 m x 5.72 m and a constant floor height of 3.2 m with 20, 30 and 40 floors were selected for the study as shown in Figure 1. The grade of concrete and steel taken for building models were M35 & HYSD 500 respectively. Models were first analyzed and designed by the Conventional One-Step Linear Static Method of Analysis (LSA) method, with a 3 (three) KN/m$^2$ live load, 1 (one) KN/m$^2$ floor finishing load, and 5 (five) KN/m brick wall load.

![Figure 1. Beam-column grid of models.](image)

2.2 Sequential Loads

With the same design cross-sections, stage-wise construction loads were applied on all three RC building models and analyzed by CSA as well as MCSA methods...During the first seven days of construction activity, formwork for the first slab was carried out and on the eighth day concreting of the first slab was done. Formwork for the second floor (on the first-floor slab) was started on the 22$^{nd}$ day. Curing for the first floor continued up to 28 days and formwork below the first floor was removed at this stage. After 36 days structural members transferred self-weight on columns.
when the age of the first slab was 28 days. From this point, the First Stage of CSA and MCSA methods was considered.

Using the CSA method, the self-weight of structural members, a load of a brick wall, and a load of floor finishing were applied stagewise as per construction schedule, load cycle, and as per timeline as tabulated in Table 1. In addition to the above loads, the following temporary loads were added and removed sequentially in the MCSA method and the same is referred into Table 1.

(i) Load of formwork was taken 500 N/m²; as per Cl.no.7.3.1.2 of IS:14687-1999 (BIS 2005).

(ii) Weight of wet concrete on the slab.

(iii) Construction load for the working surface of medium-duty was taken equal to 2.4 KN/m², as per chapter 4, Clause no 4.1.1 of ASCE/SEI 37-14 (ASCE/SEI 2002).

(iv) Construction load was removed in two stages, in the first part 1.4 KN/m² load was removed sequentially as ‘part of construction load’, and the remaining 1.0 KN/m² construction load was removed at the final stage; from all floors, when construction work was completed.

### Table 1. Stagewise sequential loading with its timeline cycle and load transfer schedule.

<table>
<thead>
<tr>
<th>SR No</th>
<th>Type of construction loads - Starting floor</th>
<th>Applied methods</th>
<th>Load cycle starts from /On</th>
<th>Cycle Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Add Self-weight of RC members -of first floor</td>
<td>CSA+</td>
<td>On first day of stage One (At the age of 28 days of first floor slab)</td>
<td>14 days</td>
</tr>
<tr>
<td>2</td>
<td>Weight of form work - on first floor</td>
<td>MCSA</td>
<td>From 1st day of Stage 1</td>
<td>One time</td>
</tr>
<tr>
<td>3</td>
<td>Add wet weight of concrete slab - of second floor</td>
<td>MCSA</td>
<td>On 1st day of Stage 1</td>
<td>14 days</td>
</tr>
<tr>
<td>4</td>
<td>Add Weight of form work - on Second floor</td>
<td>MCSA</td>
<td>On 7th day of stage 1</td>
<td>14 Days</td>
</tr>
<tr>
<td>5</td>
<td>Remove Weight of form work - from first floor</td>
<td>MCSA</td>
<td>On 11th day of Second stage 2, i.e., on 25th day</td>
<td>One time</td>
</tr>
<tr>
<td>6</td>
<td>Add construction load - on first floor</td>
<td>MCSA</td>
<td>On 11th day of stage 2, i.e., on 25th day</td>
<td>14 days</td>
</tr>
<tr>
<td>7</td>
<td>Add Load of Brick wall -on first floor</td>
<td>CSA+</td>
<td>On first day of stage 3, i.e., on 29th day</td>
<td>14 days</td>
</tr>
<tr>
<td>8</td>
<td>Remove Weight of formwork - from second floor</td>
<td>MCSA</td>
<td>On 11th day of stage 3, i.e., on 39th day</td>
<td>14 days</td>
</tr>
<tr>
<td>9</td>
<td>Remove wet weight of second floor concrete slab</td>
<td>MCSA</td>
<td>On 11th day of stage 3, i.e., on 39th day</td>
<td>14 days</td>
</tr>
<tr>
<td>10</td>
<td>Load of Floor finishing material -on first floor</td>
<td>CSA+</td>
<td>On first day of 4th stage, i.e., on 43rd day</td>
<td>14 days</td>
</tr>
<tr>
<td>11</td>
<td>Remove part of construction load - from first floor</td>
<td>MCSA</td>
<td>On 1st day of stage 5, i.e., on 57th day</td>
<td>14 days</td>
</tr>
<tr>
<td>12</td>
<td>Removal of remaining construction load -from all floors</td>
<td>MCSA</td>
<td>At last stage after completion of construction</td>
<td>One time</td>
</tr>
</tbody>
</table>

The live load was applied at the last stage, after the completion of construction and finishing work. All loads were applied and activated in both methods CSA and MCSA. All models were analyzed considering long-term properties of concrete like creep and shrinkage for analysis.

# 3 ANALYSIS AND OBSERVATIONS

Building models were analyzed by LSA, CSA, and MCSA for axial shortening of vertical members.
3.1 Axial Shortening Axial Shortening Induced in Vertical Members (Dz) - Graph and Observations

- In the LSA method continuous increase was observed in Dz of vertical members from the first floor to top floor, which became maximum at the top floor, e.g., Dz increased continuously from 0.58 mm to 18.73 mm in CA of 40F, from 0.93 mm to 27.82 mm in CH of 40F and from 0.98 mm to 29.945 mm in CO of 40F from first to top floor and maximum was observed at the top floor.
- The Dz in a graph of MCSA & CSA methods increased from 1.2 mm at first floor, becomes maximum equal to 17.92 mm at 28th floor in CA of 40F, after that, it again was observed to decrease up to 12.66 mm at the top floor in MCSA method. While in the CSA method, it (Dz) varied from 1.33 mm at the first floor become maximum equal to 20.78 mm at 28th floor and was observed to decrease to 14.15 mm at the top floor.
- Similar pattern of axial shortening graph was observed in all columns, with a varying magnitude as per its location, when analyzed by LSA, CSA, and MCSA in 20F,30F, and 40F building models. Axial shortening induced in the MCSA method was lesser as compared to CSA at all floor levels in all columns and shear walls of all building models (Figure 2).

![Figure 2. Axial shortening of columns CA, CH, and CO of 40F Model.](image)

3.2 Percentage Difference of Axial Shortening Between MCSA and CSA Methods \( \Delta_{Dz}, \% \)

The percentage difference of axial shortening between MCSA & CSA methods (\( \Delta_{Dz} \)) was calculated for all vertical members, plotted as shown in Figure 3, and the observations were listed.

![Figure 3. Graph of \( \Delta_{Dz} \), %, for columns and shear wall of 40F,30F and 20F.](image)
In CA of 40F, Percentage difference of axial shortening, by MCSA with respect to that by CSA ($\Delta_\text{Dz}$) increased from first floor (-9.83%), became maximum at 31st floor (-13.78%), then again decreased to 40th floor (-10.52%). A similar behavior pattern was observed in $\Delta_\text{DZ}$ for all columns and shears walls of 40F and 30F, where maximum $\Delta_\text{Dz}$ was observed at 77.5 % and at 70 % of total floors in 40F and 30F RC building models respectively.

In the case of the 20F model, maximum $\Delta_\text{Dz}$ was induced at 30 % of total floors, after that percentage difference decreased up to the top floor.

Maximum Axial shortening ($\Delta_\text{Dz}$) was observed in column CO, which is nearer to lift core in all models. As moving away from the lift core towards the periphery, the reduction was observed in $\Delta_\text{Dz}$ for columns, with minimal in corner column CA.

The average of $\Delta_\text{Dz}$, %, of all columns was calculated for columns of 40F, 30F, and 20F models and plotted in a graph of Figure 4. It showed that (Percentage difference of axial shortening, by CSA with respect to that by LSA ($\beta_\text{Dz}$)),

- Range of Av.$\Delta_\text{Dz}$ for columns varied from -16.157 % to -20.561 % in 40F, from -16.56 % to -19.85 % for 30F & -10.482 % to -2.517 % in 20F model.
- Range of Av.$\Delta_\text{Dz}$ for shears walls varied from -15.873 % to -19.164 % in 40F, from -15.334 % to -19.396 % for 30F & -13.156 % to -2.068% in 20 floor model. Maximum $\Delta_\text{Dz}$ occurred on the 27th floor in 40F, on the 21st floor in 30F, and on the 6th floor in 20F models. As total floors of building increased, the range of Av. $\Delta_\text{Dz}$ decreased.

### 3.3 Percentage Difference of Dz in MCSA & CSA With Respect to LSA ($\alpha_\text{Dz}$% & $\beta_\text{Dz}$%)

MCSA gave an average 76.882% higher to 40.597% lower percentage difference of shortening in comparison to LSA (AV Percentage difference of axial shortening, by MCSA with respect to that by LSA ($\alpha_\text{Dz}$) 40F) in 40F columns as moving from the first floor to 40th floor. While CSA gave an average 110.458% higher to 27.424% lower percentage difference in comparison to LSA (AV.$\beta_\text{Dz}$ 40F) as moving from the first floor to the 40th floor. Similarly, the range of AV.$\alpha_\text{Dz}$ for 30F varied from 77.51 % to -30.38% & that for 20F varied from 89.88% to 0.447%, meaning that as total stories in building increased, the range of percentage difference between CSA & LSA also increased. Similar behavior was seen for MCSA & LSA (Figure 5).

### 4 CONCLUSIONS

From the study of RC building models with respect to total floor numbers, it is concluded that,
In the LSA method, axial shortening of vertical members increases continuously from the first floor to the top floor and becomes maximum at the top floor. Whereas in the MCSA & CSA method axial shortening increases from the first floor, becomes maximum between 70% to 77% of total floors in 40F and 30F models while in 20F it becomes maximum at 30% of total floors. After that, it again reduces up to the top floor.

Though the behavior of axial shortening in MCSA, and CSA method is similar, MCSA gives 2.52% to 20.56% lesser axial shortening in comparison to the CSA method in columns, whereas it gives 2.068% to 19.396% lesser axial shortening in the wall. The percentage difference of axial shortening between MCSA and CSA i.e., \( \Delta D_z \) increases from the first floor, becomes maximum at a certain floor, then again decreases up to the top floor.

\( \Delta Axial \) shortening in peripheral columns are lesser than that near to lift core column.

As total floor numbers of building increases, the range of Av. \( \Delta Axial \) shortening reduces in columns and walls.

The percentage difference of axial shortening in MCSA with respect to LSA(\( \alpha D_z \% \)); increases as moving from top floor to first floor compared to percentage difference of CSA with respect to LSA (\( \beta D_z \% \)).

References


Indian Roads Congress (IRC), IRC:112-2011, Code of Practice for Concrete Road Bridges, New Delhi, 2011.

