ABSTRACT

Adjacent vertical members (columns and shear walls) in a tall building undergo differential time dependent deformations due to creep and shrinkage in concrete. These differential deformations in adjacent vertical members produce shear and moments in the connecting beams or slabs which further result in a redistribution of forces among vertical members. Shear walls in composite frame-shear wall systems are of concrete and properties of these will affect creep and shrinkage behaviour of these composite frame-shear wall systems. In this paper, behavioural studies are reported for these systems with varying shear wall properties. In these studies, the creep and shrinkage effects on deflections, differential deflections and axial forces in various members are evaluated. It is shown that significant change occurs in net change in elastic forces when volume to surface ratio is varied.

Keywords: creep, shrinkage, vertical deflections, composite buildings, shear walls, differential deflections.

INTRODUCTION

Creep and shrinkage behaviour of a tall building is affected by different characteristics such as percentage of reinforcement, volume to surface ratio, stress level etc. in adjacent vertical members (columns or shear walls). These characteristics result in differential time dependent deformations between adjacent members and these differential deformations become more critical with increasing height of building because of the cumulative nature of such deformations along the height. Distress in non-structural members of the buildings as well as in redistribution of member forces may be caused by these cumulative deformations.

Fintel and Khan (1969, 1971) and Fintel et al. (1987), developed a method for determining creep and shrinkage deflections. This procedure has been recommended for the buildings having low beam stiffness. Maru et al. (2001), developed an accurate procedure termed as Consistent Procedure, CP for both low and high stiffness of beams of R.C. buildings. In this procedure the shortcomings of earlier method developed by Fintel et al. (1987), have been overcome.

Recently, Sharma et al. (2003) modified the CP for composite buildings in which some members are of structural steel and other are of RC construction. Using this procedure few studies for composite tall buildings have been reported in the literature (Sharma et al. 2003; Sharma and Chowdhary 2007). No systematic studies are available for the effect of shear wall properties on deflection and load transfer among various vertical members.

Detailed numerical studies are reported in this paper to evaluate the effect of shear wall properties on deflection and load transfer among various vertical members in a composite frame shear wall system using recently developed procedure CP.

CONSISTENT PROCEDURE

In composite frame-shear wall systems (Figure-1) steel members have only elastic deformations whereas R. C. shear walls have both elastic and inelastic deformations. Accordingly these deformations are evaluated in this procedure.

In a segment of a R.C. shear wall, total unrestrained inelastic deformation \( \delta \) consists of creep deformation \( \delta' \) and shrinkage deformation \( \delta'' \). Creep deformation. \( \delta' \) is given by (Sharma 2002):

\[
\delta' = h\left[\varepsilon_c^{cr}(t_2, t_a) - \varepsilon_c^{cr}(t_1, t_a)\right] \tag{1}
\]

Where \( h \) = height of a story, \( \varepsilon_c^{cr}(t_2, t_a) \) and \( \varepsilon_c^{cr}(t_1, t_a) \) = creep strains at time \( t_2 \) and \( t_1 \) respectively owing to loading at age \( t_a \) and are evaluated using stress transfer method, Age-Adjusted Effective Modulus Method, AEEM (Uy and Das 1997) and are given by:

\[
\varepsilon_c^{cr}(t_2, t_a) = \varepsilon_c(t_2, t_a) - \varepsilon_c(t_1, t_a) \tag{2}
\]

\[
\varepsilon_c^{cr}(t_1, t_a) = \varepsilon_c(t_1, t_a) - \varepsilon_c(t_1, t_1) \tag{3}
\]

Where \( \varepsilon_c(t_1, t_a) \) = instantaneous elastic strain and \( \varepsilon_c(t_2, t_a) \) and \( \varepsilon_c(t_1, t_a) \) = total strains.

Shrinkage deformation \( \delta'' \) is evaluated from (Sharma 2002):

\[
\delta'' = h\left[\varepsilon_c^{sh}(t_a) - \varepsilon_c^{sh}(t_1)\right] \tag{4}
\]

Where \( \varepsilon_c^{sh}(t_a) \) and \( \varepsilon_c^{sh}(t_1) \) = shrinkage strains at time \( t_a \) and \( t_1 \) respectively.

The total unrestrained inelastic deformation, \( \delta \) is evaluated as

\[
\delta = \delta' + \delta'' \tag{5}
\]
When \( \delta \) is restrained, the restraining end forces, \( R_f \), in a segment of a shear wall arises and is given by:

\[
R_f = \delta A_{sw} E / h
\]

Where, \( A_{sw} \) = cross sectional area of the shear wall; and \( E \) = modulus of elasticity of concrete.

In a composite frame shear wall system, the restraining action is provided by the beams. The restraining end forces, \( R_f \), are evaluated for applied dead and live load for shear wall segments. The nature of the application of dead and live load in a composite frame shear wall system is different. Thus, the analysis that incorporates creep and shrinkage effect for two loads should be carried out in two stages: (1) for dead load; and (2) for combined dead load and live load.

Stage-1: Dead load analysis

Dead load (Sequential) analysis of an n-story frame - shear wall system, shown schematically in Figure 2, comprises of linear analysis of n-substructures having number of stories varying from 1 to \( n \).

For the first substructure, first, elastic analysis is carried out for the loading at the first floor to yield elastic member forces (moments and shears in beams and vertical members and axial forces in vertical members) and elastic vertical deflections.

Total unrestrained inelastic deformations \( \delta \) in the shear walls are evaluated for the above calculated forces. Restraining vertical member end forces, \( R_f \), due to \( \delta \) are obtained using Eqn. 6. Frame analysis, designated as inelastic frame analysis, to indicate that loading arises from inelastic deformations, is carried out for these forces. This analysis yields inelastic member forces and inelastic vertical deflections. Total member forces and vertical deflections are then obtained by including the both elastic and inelastic contributions.

In a similar way, for 2nd substructure, elastic frame analysis is first carried out to yield elastic member forces and elastic deflection. Unrestrained inelastic deformations are then evaluated for these forces. Restrained forces and inelastic deflections and forces are then evaluated in similar way as for the first substructure. Total member forces and vertical deflections are then obtained by including both elastic and inelastic contributions.

Similarly deflections and forces are evaluated for the subsequent substructures (Figure-2).

Stage-2: Combined dead and live load analysis

In this stage, the part of live load that is of permanent nature is applied to the complete frame - shear wall system (\( n \) stories). Elastic (simultaneous) analysis is then carried out to yield elastic member forces and elastic vertical deflections in members of all the storeys at the end of 1\textsuperscript{st} time interval after the application of live load.

Unrestrained inelastic deformations are then evaluated corresponding to the calculated column axial forces for 1\textsuperscript{st} time interval. Restraining column end forces due to these unrestrained inelastic deformations are then evaluated. Inelastic frame analysis is carried out to yield inelastic member forces and inelastic vertical deflections for this time interval. Total member forces and total deflections at the end of 1\textsuperscript{st} time interval are then evaluated considering both elastic and inelastic contributions.

Similarly, final member forces and elastic and inelastic vertical deflections are obtained for all the time intervals in stage 2.

In both stages of analysis, the effect of creep in horizontal members is not considered as beams are of structural steel.

NUMERICAL STUDY

A 60 storied (story height = 3.0m) composite frame-shear wall system comprising of 3 bays, (each bay of span 5.0m) is considered (Figure-1). Columns are of steel (moment of inertia, \( I_s \) = 0.002684 m\(^4\), area, \( A_s \) = 0.05858m\(^2\)) and R.C. shear walls are of size 3.6 x 0.3m (moment of inertia, \( I_{sw} \) = 1.1664m\(^4\), area, \( A_{sw} \) = 1.08m\(^2\) and volume to surface ratio = 13.8cm).

![Figure-1. Composite frame shear wall system.](image)

![Figure-2. Substructures.](image)
intervals of 1500 days duration. Material properties are:
concrete mix M40, \( E_{(28)} = 3.6 \times 10^7 \text{kN/m}^2 \), \( E_s \) (modulus of elasticity of steel) = \( 2.1 \times 10^8 \text{kN/m}^2 \), specific creep, \( \varepsilon_c (28) = 81 \times 10^{-9} \text{(m/m)} / \text{(kN/m}^2) \), shrinkage strain, \( \varepsilon_s = 480 \times 10^{-6} \text{m/m} \) for first 90 days.

**VARIED SHEAR WALL PROPERTIES**

Behaviour of Composite frame-shear wall systems incorporating creep and shrinkage effects has been studied by changing the reinforcement ratio in the shear walls. Subsequently, studies are also carried out by changing the volume to surface ratio of shear walls.

**Effect of reinforcement ratio**

To carry out this study, composite frame-shear wall system (Figure-1) is chosen. In this composite frame-shear wall system, reinforcement percentage in shear walls, \( p_{sw} \) is varied from 0.15% to 0.45% in steps of 0.15%. In these cases, volume to surface ratio, \( R_{sw} (= 13.8\text{cm}) \) and beam stiffness \((IB= I_c/20)\) are kept constant.

**Deflections**

Final vertical total deflections, \( d(y_t) \) in both, columns and shear walls are compared in Figures-3 and 4 respectively for varying \( p_{sw} \). As \( p_{sw} \) increases from 0.15% to 0.45%, \( d(y_t) \) in both, column and shear walls, decreases. The decrease in \( d(y_t) \), in shear walls is owing to increased reinforcement in shear walls which provides higher restraint to deflections. As beams rigidly connect shear walls and columns, decrease in \( d(y_t) \), in shear walls induces decrease in columns also. However, the decrease in \( d(y_t) \), in shear walls and columns is only marginal.

**Differential deflections**

Variations in final differential total deflections, \( \delta(d(y_t)) \) between adjacent vertical members are compared in Figure-5 for varied \( p_{sw} \) in shear walls. It may be seen that when \( p_{sw} \) increases from 0.15% to 0.45%, \( \delta(d(y_t)) \) between adjacent column and shear walls, decreases. As \( p_{sw} \) increases from 0.15% to 0.45%, \( d(y_t) \) in column and shear walls, decreases and this decrease in both members’ results decrease in \( \delta(d(y_t)) \). As expected, the change in \( \delta(d(y_t)) \) for \( p_{sw} = 0.15\% \) to 0.45% is also marginal.

**Figure-3.** Comparison of final vertical deflections in columns: (a) \( p_{sw} = 0.15\% \); (b) \( p_{sw} = 0.30\% \); (c) \( p_{sw} = \text{axial forces.} \)

**Figure-4.** Comparison of final vertical deflections in shear walls (a) \( p_{sw} = 0.15\% \); (b) \( p_{sw} = 0.30\% \); (c) \( p_{sw} = 0.45\% \).
Figure-5. Comparison of final vertical differential deflections between columns and shear walls: (a) $p_{sw} = 0.15\%$; (b) $p_{sw} = 0.30\%$; (c) $p_{sw} = 0.45\%$.

Final total axial forces, $P'_t(t_c)$ in both columns and shear walls are shown through out the height for varying $p_{sw}$ in Figure-6 and Figure-7 respectively. It may be seen that change in elastic $P'_t(t_c)$ decreases in columns and shear walls when $p_{sw}$ increases from 0.15% to 0.45%.

Figure-6. Final axial forces in columns for: (a) $p_{sw} = 0.15\%$; (b) $p_{sw} = 0.30\%$; (c) $p_{sw} = 0.45\%$

Figure-7. Final axial forces in shear walls for: (a) $P_{sw} = 0.15\%$; (b) $P_{sw} = 0.30\%$; (c) $P_{sw} = 0.45\%$.

This decrease in axial forces owes to decrease in $\delta(d'_t(t_c))$ (Figure-4). It may be seen that although, the
percentage net change in elastic $P_i'(t_c)$, in columns and shear walls (Table-1) and the change in this percentage net change owing to the increase in $p_{sw}$ is significant.

**Table-1.** Variation of percentage net change in elastic final axial forces for columns and shear wall for varied $p_{sw}$.

<table>
<thead>
<tr>
<th>$p_{sw}$</th>
<th>Level</th>
<th>Percentage Net Change</th>
<th>Columns</th>
<th>Shear Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>1</td>
<td>133.44</td>
<td>-37.51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>176.03</td>
<td>-49.74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>267.73</td>
<td>-73.61</td>
<td></td>
</tr>
<tr>
<td>0.30</td>
<td>1</td>
<td>130.39</td>
<td>-36.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>172.72</td>
<td>-48.52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>259.03</td>
<td>-71.22</td>
<td></td>
</tr>
<tr>
<td>0.45</td>
<td>1</td>
<td>127.46</td>
<td>-35.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>167.58</td>
<td>-47.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>250.83</td>
<td>-68.97</td>
<td></td>
</tr>
</tbody>
</table>

**Figure-8.** Comparison of final vertical deflections in columns: (a) $R_{sw} = 8.8$ cm; (b) $R_{sw} = 13.8$ cm; (c) $R_{sw} = 18.8$ cm.

**Figure-9.** Comparison of final vertical deflections in shear walls: (a) $R_{sw} = 8.8$ cm; (b) $R_{sw} = 13.8$ cm; (c) $R_{sw} = 18.8$ cm.

**Effect of Volume to Surface Ratio**

To carry out this study, volume to surface ratio of shear walls, $R_{sw}$ in composite frame–shear wall system (Figure-1), is varied from 8.8cm to 18.8cm in steps of 5.0 cm. In all these cases, in order to isolate the effect of $R_{sw}$, cross-sectional area, $A_{sw}$ and moment inertia of shear walls, $I_{sw}$ in the evaluation of column axial forces and inelastic deflections are the same for varied $R_{sw}$. Reinforcement percentage in shear walls ( $p_{sw} = 0.30\%$ ) and beam stiffness ( $I_b = I_c/20$ ) are kept constant in these cases.

**Deflections**

Final vertical total deflections, $d_i'(t_c)$ in both columns and shear walls are shown in Figure-8 and Figure-9 respectively for varying $R_{sw}$. As $R_{sw}$ increases from 8.8cm to 18.8cm, $d_i'(t_c)$ in both, column and shear walls decrease.
Creep and shrinkage deflection decreases as volume surface ratio, $R$ of any member increases. This decrease in $d_i(t)$, in shear walls induces decrease in columns also as beams rigidly connect shear walls and columns.

**Differential deflections**

Final differential total deflections, $\delta(d_i(t))$ between adjacent column and shear walls are compared in Figure-10. For varied $R_{sw}$ in shear walls. It may be observed that when $R_{sw}$ increases from 8.8cm to 18.8cm, $\delta(d_i(t))$ decreases. As $R_{sw}$ increases from 8.8cm to 18.8cm, $d_i(t)$ in column and shear walls, decreases and this decrease in both members' results decrease in $\delta(d_i(t))$. It may be also observed that change in $\delta(d_i(t))$ is more than that of in the effect of reinforcement ratio.

Table-2 for varied $R_{sw}$. It may be seen that the percentage net changes in elastic $P'(t_c)$ are different for $R_{sw} = 8.8$ and 18.8cm. In the lower and middle portion of the building, the maximum percentage net change in elastic $P'(t_c)$ for 8.8cm is 190.36% whereas the corresponding percentage net change in elastic $P'(t_c)$ for 18.8cm is 159.09%.

![Figure-10](image)

**Figure-10.** Comparison of final vertical differential deflections between columns and shear walls: (a) $R_{sw} = 8.8$cm; (b) $R_{sw} = 13.8$cm; (c) $R_{sw} = 18.8$cm.

Final total axial forces, $P'(t_c)$ in both columns and shear walls are shown through out the height for varying $R_{sw}$ in Figure-11 and Figure-12 respectively. It may be seen that change in elastic $P'(t_c)$ decreases in columns and shear walls when $R_{sw}$ increases from 8.8cm to 18.8cm.

The percentage net changes in elastic $P'(t_c)$ for columns and shear walls are compared along the height in

![Figure-11](image)

**Figure-11.** Final axial forces in columns for: (a) $R_{sw} = 8.8$cm; (b) $R_{sw} = 13.8$cm; (c) $R_{sw} = 18.8$cm.
Within practical range of reinforcement percentage in shear walls, $p_{sw}$ (from 0.15% to 0.45%), change in net changes in elastic $P^e(t_e)$ is maximum for $p_{sw} = 0.45$

Within practical range of size coefficient for creep, $\lambda_c$ ($= 0.91$ for $R_{sw} = 8.8$cm and $= 0.79$ for $R_{sw} = 18.8$ cm) and size coefficient for shrinkage, $\lambda_s$ ($= 0.80$ for $R_{sw} = 8.8$cm and $= 0.60$ for $R_{sw} = 18.8$cm), net changes in elastic $P^e(t_e)$ are significantly different for $R_{sw} = 8.8$ and 18.8cm.

If the percentage of reinforcement and volume to surface ratio are such that the nature of change in net elastic forces due to these is similar, the effect on final elastic forces can be significant.

REFERENCES


NOTATIONS

\( \delta^c, \delta^s, \delta \) = un-restrained deformation, creep, shrinkage and total respectively,

\( E, E_s \) = modulus of elasticity, concrete and steel respectively,

\( A_c, A_{sw} \) = sectional area, column and shear wall respectively,

\( h \) = height of a story,

\( R_f \) = restraining end force,

\( I_c, I_{sw}, I_b \) = moment of inertia, column, shear wall and beam respectively,

\( A_c, A_{sw} \) = sectional area, column and shear wall respectively,

\( P_{sw}, R_{sw} \) = reinforcement percentage and volume to surface ratio of shear wall respectively,

\( \lambda_s, \lambda_c \) = Size coefficient for shrinkage and creep respectively,

\( \varepsilon_{C(28)}, \varepsilon_s \) = specific creep and shrinkage strain respectively,

\( d_k(t), \delta(d_k(t) \hat{d}_k(t)) \) = Vertical deflections at time \( t \), total and total differential respectively,

\( P_k^e(t), P_k^a(t) \) = Axial forces, elastic and total respectively,

\( \varepsilon_c(t_a, t), \varepsilon_c^{a\epsilon}(t, t_a), \varepsilon_c^{a\epsilon}(t, t_a), \varepsilon_c^{a\epsilon}(t, t_a) \) = Strains, instantaneous elastic, creep, shrinkage and total respectively,