CREEP-SHRINKAGE BEHAVIOUR OF COMPOSITE SYSTEMS DUE TO VARYING SHEAR WALL PROPERTIES

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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.
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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 δ consists of creep deformation δ^{cr} and shrinkage deformation δ^{sh}. Creep deformation. δ^{cr} is given by (Sharma 2002):

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

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, AEMM (Uy and Das 1997) and are given by:

$$\varepsilon_c^{cr}(t_2,t_a) = \varepsilon_c(t_2,t_a) - \varepsilon_c^{e}(t_a,t_a) \quad (2)$$

$$\varepsilon_c^{cr}(t_1,t_a) = \varepsilon_c(t_1,t_a) - \varepsilon_c^{e}(t_a,t_a) \quad (3)$$

Where $\varepsilon_c^{e}(t_a, t_a)$ = instantaneous elastic strain and $\varepsilon_c(t_1, t_a)$ And $\varepsilon_c(t_2, t_a)$ = total strains.

Shrinkage deformation δ^{sh} is evaluated from (Sharma 2002):

$$\delta^{sh} = h\left[\varepsilon_c^{sh}(t_2) - \varepsilon_c^{sh}(t_1)\right] \quad (4)$$

Where $\varepsilon_c^{sh}(t_2)$ and $\varepsilon_c^{sh}(t_1)$ = shrinkage strains at time t_2 and t_1 respectively.

The total unrestrained inelastic deformation, δ is evaluated as

$$\delta = \delta^{cr} + \delta^{sh} \quad (5)$$

When δ is restrained, the restraining end forces, R_f, in a segment of a shear wall arises and is given by:

$$R_F = \delta A_{sw} E / h \tag{6}$$

Where, Asw = 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 δ in the shear walls are evaluated for the above calculated forces. Restraining vertical member end forces, R_f due to δ 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 1st time interval after the application of live load.

Unrestrained inelastic deformations are then evaluated corresponding to the calculated column axial forces for 1st 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 1st 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_c = 0.002684 m^4, area, A_c = 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).

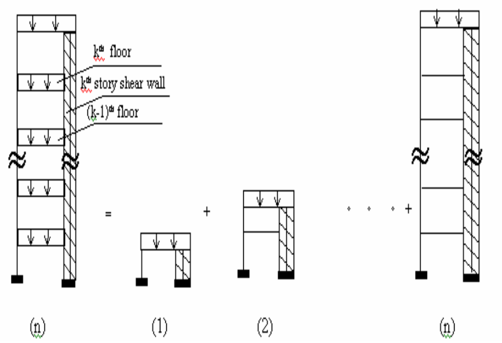

Figure-1. Composite frame shear wall system.

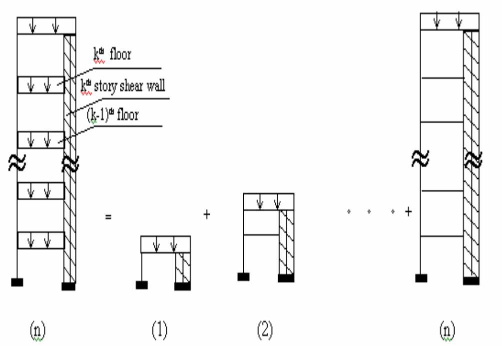

Figure-2. Substructures.

This frame-shear wall system is subjected to uniform dead loading of 27 kN/m and uniform live loading of permanent nature 10kN/m. Construction time for each story and the total time for the effect of creep and shrinkage effects are taken as 4 days and 7244 days (≈ 20 years) respectively. The time duration of stage 2, is divided into 20 intervals, 10 intervals of 50 days, 5 intervals of 100 days, 3 intervals of 1000 days and 2 intervals of 1500 days duration. Material properties are: concrete mix M40, E (28 days) = 3.6 x 10^7 kN/m^2, E_s (modulus of elasticity of steel) = 2.1 x 10^8 kN/m^2, specific creep, $\varepsilon_{c\,(28)}$ = 81 x 10^{-9} (m/m)/ (kN/m^2), shrinkage strain, ε_s = 480 x 10^{-6} 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} (= 13.8cm) and beam stiffness (IB= I_c/20) are kept constant.

Deflections

Final vertical total deflections, $d_k^t(t_c)$ 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%, $d_k^t(t_c)$ in both, column and shear walls, decreases. The decrease in $d_k^t(t_c)$, 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 $d_k^t(t_c)$, in shear walls induces decrease in columns also. However, the decrease in $d_k^t(t_c)$, in shear walls and columns is only marginal.

Differential deflections

Variations in final differential total deflections, $\delta\left(d_k^t(t_c)\right)$ 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%, $\delta\left(d_k^t(t_c)\right)$ between adjacent column and shear walls, decreases. As p_{sw} increases from 0.15% to 0.45%, $d_k^t(t_c)$ in column and shear walls, decreases and this decrease in both members' results decrease in $\delta\left(d_k^t(t_c)\right)$. As expected, the change in $\delta\left(d_k^t(t_c)\right)$ for p_{sw} = 0.15% to 0.45% is also marginal.

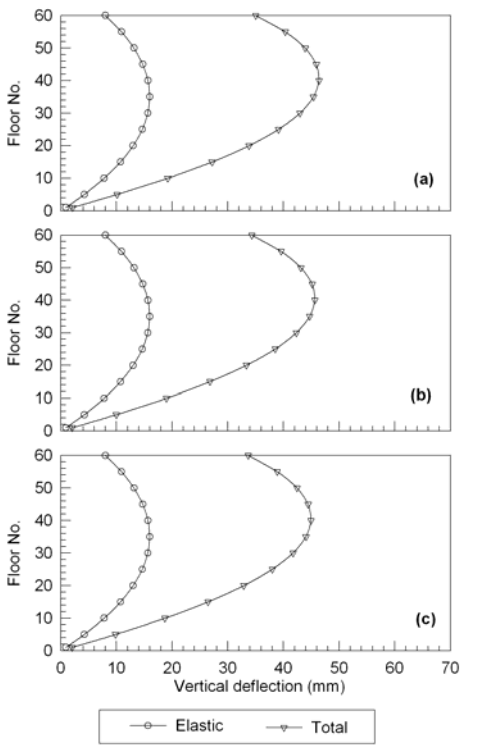

Figure-3. Comparison of final vertical deflections in columns: (a) p_{sw}= 0.15%; (b) p_{sw}= 0.30%; (c) p_{sw}=axial forces.

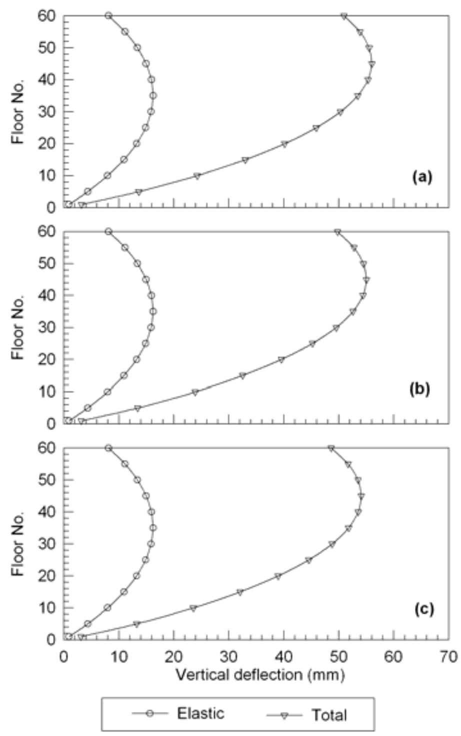

Figure-4. Comparison of final vertical deflections in shear walls (a) p_{sw} = 0.15%; (b) p_{sw} = 0.30%; (c) p_{sw} = 0.45%.

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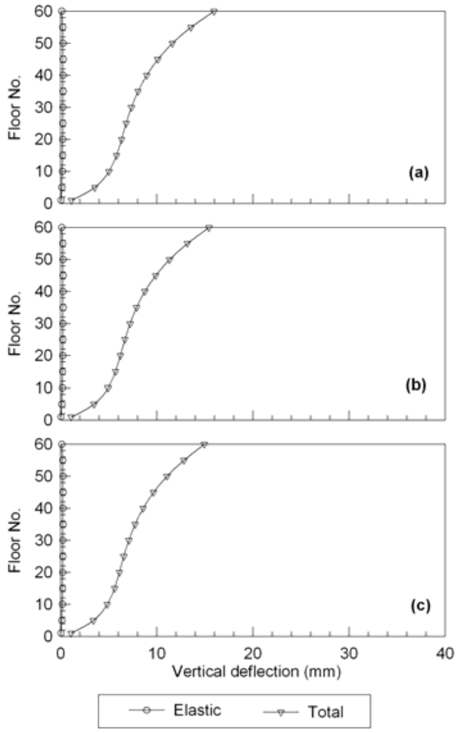

Figure-5. Comparison of final vertical differential deflections between columns and shear walls: (a) p_{sw} = 0.15%; (b) p_{sw} = 0.30%; (c) p_{sw} = 0.45%.

Final total axial forces, $P_k^t(t_c)$ 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 $P_k^e(t_c)$ decreases in columns and shear walls when p_{sw} in increases from 0.15% to 0.45%.

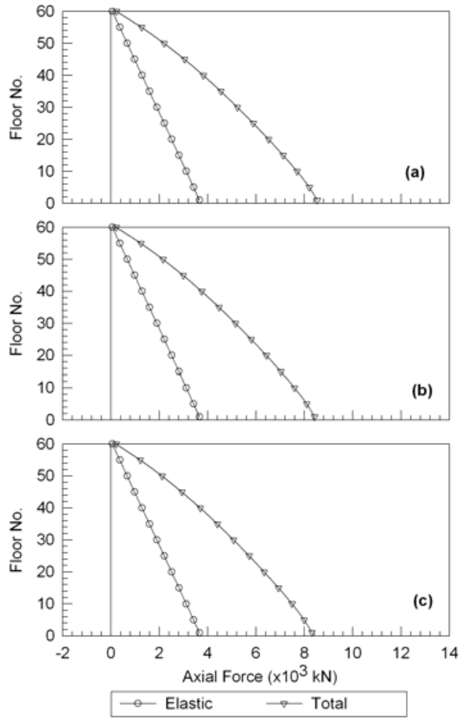

Figure-6. Final axial forces in columns for: (a) p_{sw} = 0.15%; (b) p_{sw} = 0.30%; (c) p_{sw} = 0.45%

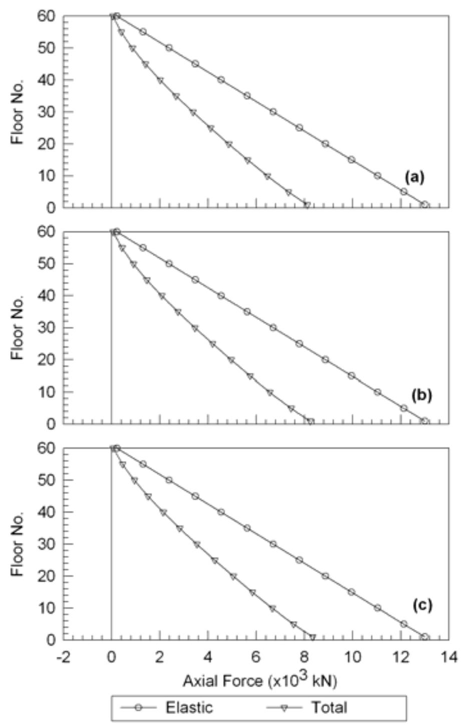

Figure-7. Final axial forces in shear walls for: (a) Psw = 0.15%; (b) p_{sw} = 0.30%; (c) p_{sw} = 0.45%.

This decrease in axial forces owes to decrease in $\delta\left(d_k^t(t_c)\right)$ (Figure-4). It may be seen that although, the

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percentage net change in elastic $P_k^e(t_c)$, 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}.

p_{sw}	Level	Percentage Net Change	
		Columns	Shear Wall
1	2	3	4
0.15	1	133.44	-37.51
	30	176.03	-49.74
	60	267.73	-73.61
0.30	1	130.39	-36.66
	30	172.72	-48.52
	60	259.03	-71.22
0.45	1	127.46	-35.83
	30	167.58	-47.35
	60	250.83	-68.97

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, $d_k^t(t_c)$ 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, $d_k^t(t_c)$ in both, column and shear walls decrease.

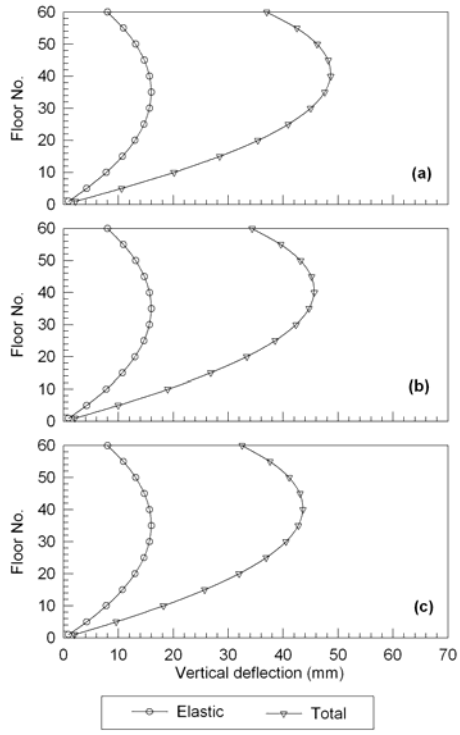

Figure-8. Comparison of final vertical deflections in columns: (a) R_{sw} = 8.8 cm; (b) R_{sw} = 13.8 cm; (c) R_{sw} = 18.8 cm.

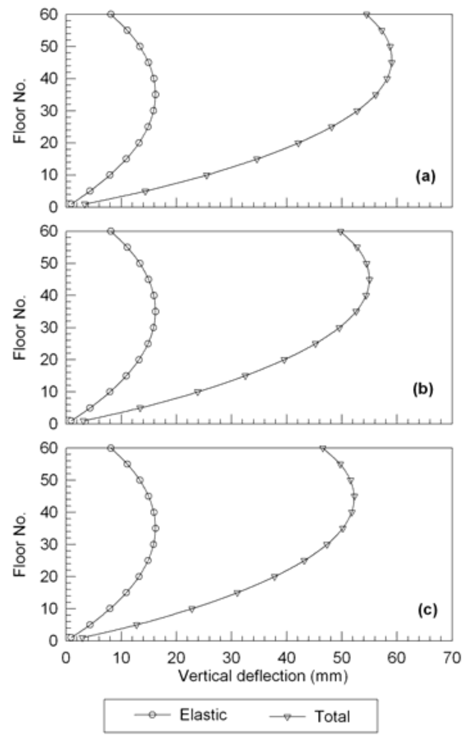

Figure-9. Comparison of final vertical deflections in shear walls: (a) R_{sw} = 8.8 cm; (b) R_{sw} = 13.8 cm; (c) R_{sw} = 18.8cm.

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Creep and shrinkage deflection decreases as volume surface ratio, R of any member increases. This decrease in $d_k^t(t_c)$, in shear walls induces decrease in columns also as beams rigidly connect shear walls and columns.

Differential deflections

Final differential total deflections, $\delta\left(d_k^t(t_c)\right)$ 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, $\delta\left(d_k^t(t_c)\right)$ between adjacent column and shear walls, decreases. As R_{sw} increases from 8.8cm to 18.8cm, $d_k^t(t_c)$ in column and shear walls, decreases and this decrease in both members' results decrease in $\delta\left(d_k^t(t_c)\right)$. It may be also observed that change in $\delta\left(d_k^t(t_c)\right)$ is more than that of in the effect of reinforcement ratio.

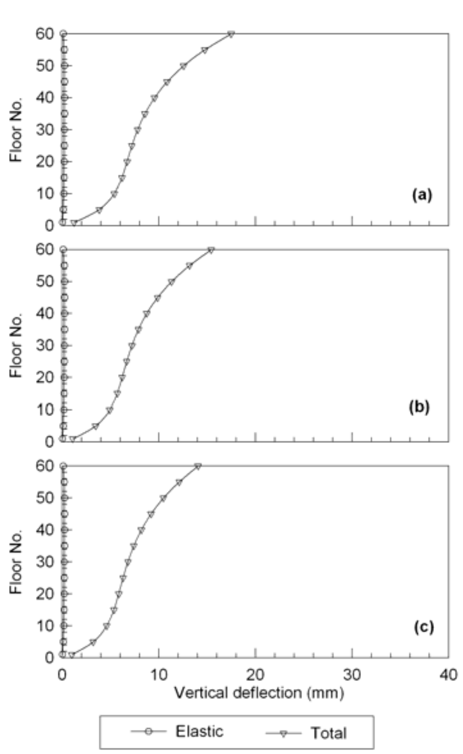

Figure-10. Comparison of final vertical differential deflections between columnsand shear walls: (a) R_{sw} = 8.8cm; (b) R_{sw} = 13.8cm; (c) R_{sw} = 18.8

Final total axial forces, $P_k^t(t_c)$ 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 $P_k^e(t_c)$ decreases in columns and shear walls when R_{sw} in increases from 8.8cm to 18.8cm

The percentage net changes in elastic $P_k^e(t_c)$ for columns and shear walls are compared along the height in Table-2 for varied R_{sw}. It may be seen that the percentage net changes in elastic $P_k^e(t_c)$ 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 $P_k^e(t_c)$ for 8.8cm is 190.36% whereas the corresponding percentage net change in elastic $P_k^e(t_c)$ for 18.8cm is 159.09%.

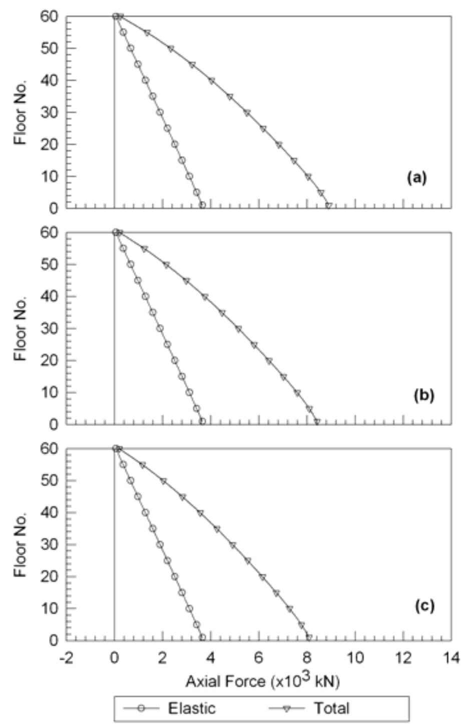

Figure-11. Final axial forces in columns for: (a) R_{sw} = 8.8cm; (b) R_{sw} = 13.8cm; (c) R_{sw} = 18.8cm.

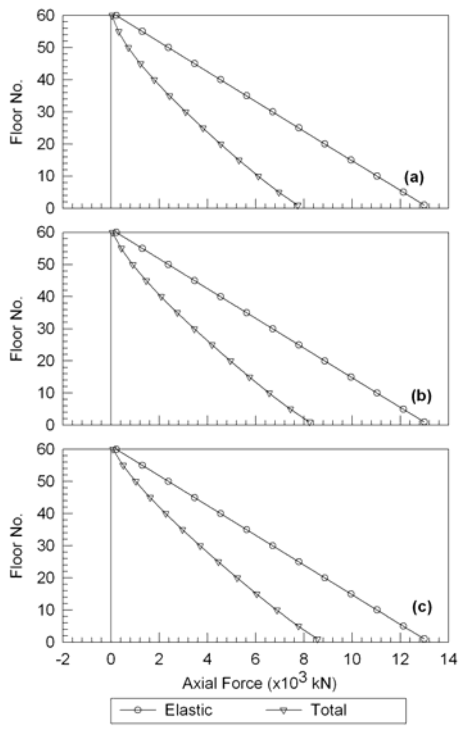

Figure-12. Final axial forces in shear walls for:
(a) R_{sw} = 8.8cm; (b) R_{sw} = 13.8cm; (c) R_{sw} = 18.8cm.

Table-2. Variation of percentage net change in elastic final axial forces for columns and shear wall for varied VS_{sw}.

VS_{sw} (cm)	Level	Percentage net change	
		Columns	Shear wall
1	2	3	4
8.8	1	143.78	-40.42
	30	190.36	-53.79
	60	294.10	-80.87
13.8	1	130.39	-36.66
	30	172.72	-48.52
	60	259.03	-71.22
18.8	1	121.22	-34.08
	30	159.09	-44.95
	60	236.03	-64.90

CONCLUSIONS

Using CP (Composite) behaviour of composite frame - shear wall systems due to creep and shrinkage has been studied. From these studies following conclusions are drawn:

(a) Within practical range of reinforcement percentage in shear walls, p_{sw} (from 0.15% to 0.45%), change in net changes in elastic $P_k^e(t_c)$ is maximum for p_{sw} = 0.45%

(b) Within practical range of size coefficient for creep, λ_c (= 0.91 for Rsw = 8.8cm and = 0.79 for Rsw = 18.8 cm) and size coefficient for shrinkage, λ_s (= 0.80 for Rsw = 8.8cm and = 0.60 for Rsw = 18.8cm), net changes in elastic $P_k^e(t_c)$ are significantly different for Rsw = 8.8 and 18.8cm.

(c) 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.

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NOTATIONS

δ^{Cr}, δ^{sh}, δ	=	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,
λ_s, λ_c	=	Size coefficient for shrinkage and creep respectively,
$\varepsilon_{C\,(28)}$, ε_s	=	specific creep and shrinkage strain respectively,

$d_k^t(t)$, $\delta\left(d_k^t(t_c)\right)$ = Vertical deflections at time t, total and total differential respectively,

$P_k^e(t_c)$, $P_k^t(t_c)$ = Axial forces, elastic and total respectively,

$\varepsilon_c^e(t_a, t_a)$, $\varepsilon_c^{cr}(t, t_a)$, $\varepsilon_c^{sh}(t)$, $\varepsilon_c(t, t_a)$ = Strains, instantaneous elastic, creep, shrinkage and total respectively,