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Effect of creep and shrinkage in a class of composite frame - shear wall systems

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Abstract. The behaviour of composite frame - shear wall systems with regard to creep and shrinkage with high beam stiffness has been largely unattended until recently since no procedure has been available. Recently an accurate procedure, termed the Consistent Procedure (CP), has been developed which is applicable for low as well as for high beam stiffness. In this paper, CP is adapted for a class of composite frame - shear wall systems comprising of steel columns and R.C. shear walls. Studies are reported for the composite systems with high as well as low beam stiffness. It is shown that considerable load redistribution occurs between the R.C. shear wall and the steel columns and additional moments occur in beams. The magnitude of the load redistribution and the additional moment in the beams depend on the stiffness of the beams. It is also shown that the effect of creep and shrinkage are greater for the composite frame - shear wall system than for the equivalent R.C. frame - shear wall system.

Key words: tall building; creep; shrinkage; composite frame - shear wall system; R.C. frame - shear wall system; beam stiffness.

1. Introduction

In a tall building, adjacent vertical members; columns (or shear walls) may have different characteristics which affect creep and shrinkage behaviour, such as percentage of reinforcement, volume to surface ratio and stress level etc., and this results in differential time dependent deformations. With the increasing height of buildings, these differential deformations become more critical owing to the

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cumulative nature of such deformations along the height. These cumulative deformations may lead to distress in non-structural members of the buildings and also result in redistribution of member forces.

In a form of composite construction the interior service core is a R.C. shear wall whereas steel frames are on the periphery of the building. The service core and frame form a frame - shear wall system to resist the lateral loading. When the core R.C. shear wall and steel frames are not adequate to resist lateral loading, R.C. shear walls may be introduced on the periphery to provide additional lateral resistance. In the case of monolithic connections between the steel columns and the R.C. shear wall and high stiffness of the steel beams, considerable load redistribution takes place between peripheral R.C. shear walls and adjacent steel columns. No studies on this load redistribution for different beam stiffnesses have been reported since an appropriate procedure has not been available.

The most widely used procedure available in the literature (Fintel and Khan 1969 and 1971, Fintel *et al*. 1987) for determining creep and shrinkage deformations in R.C. and composite buildings, henceforth designated as the Approximate Procedure (AP), has been recommended for buildings having low beam stiffness. In this procedure, analysis is carried out in two parts. In part 1, vertical member forces are obtained on the basis of tributary areas neglecting shearing action of beams. Based on these forces elastic and inelastic deformations are evaluated. No distinction is made between the sequential nature of application of dead load and simultaneous nature of application of live load. In part 2, end forces (moments and shears) in horizontal members, which result from vertical member deformations of part 1 are evaluated and frame analysis carried out for these end forces. The major inconsistency in the procedure is that, the deformations in part 1 are evaluated without taking into account the shearing action of beams while in part 2 this action is considered.

Recently an accurate procedure termed the Consistent Procedure (CP), has been developed (Maru 2000, Maru *et al*. 2001) for R.C. buildings. This procedure is applicable for low as well as high beam stiffness. In this procedure the shearing action of beams is considered in determining elastic axial forces resulting from elastic vertical deformations as well as inelastic axial forces resulting from inelastic (creep and shrinkage) deformations. Further, in the evaluation of creep deformation, the actual time of occurrence of these elastic and inelastic forces and the sequential nature of application of the dead load and the simultaneous nature of the application of the live load are also considered. This procedure overcomes serious inconsistencies in the AP.

Studies have been reported on load transfer among vertical members due to creep and shrinkage in R.C. frames (Maru *et al*. 2003a) and frame - shear wall systems (Maru *et al*. 2003b) with high beam stiffness. As indicated above no such studies are available for composite frame - shear wall systems even though a high magnitude of load redistribution would be expected. In this paper, the CP, which has been used for R.C. frame shear walls system, is adapted to evaluate creep and shrinkage effects in composite frame shear wall systems. Studies are reported for the composite frame shear wall systems with high beam stiffness as well as low beam stiffness.

2. Consistent Procedure (CP)

In composite frame - shear wall systems, steel members have only elastic deformations whereas R.C. shear walls have both elastic and inelastic deformations.

In a segment of a R.C. shear wall, the 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):

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

where h = height of a storey, $\varepsilon_c^{cr}(t_2, t_a)$ 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 (Gilbert 1988) and are given by:

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

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

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):

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

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

$$\delta = \delta^{cr} + \delta^{sh} \tag{5}$$

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

$$R_f = \delta A E / h \tag{6}$$

where, A = 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 frame - shear wall system is different. The live load comes into operation only after the construction of the main load bearing structure is complete, and it is resisted by the whole structure, whereas the dead load builds up sequentially and it is resisted at any stage of construction by the part of structure completed at that stage. 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.

2.1. Stage 1: dead load analysis

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

The construction time Ct_k of the kth storey is taken as the time required for the casting of the kth floor and subsequent time duration after which the load is transferred to vertical members (Fig. 2). It is further assumed that there is no time lag between the casting of the (k - 1)th floor and vertical members of the kth storey, although in practice some time lag would exist. Therefore, the age of the concrete of the shear wall of the kth storey, when these begin to receive the load from the kth floor, is also taken to be equal to Ct_k.

For the R.C. shear wall variation of the modulus of elasticity of the concrete with time (Fintel *et al*. 1987, Maru *et al*. 2001) and the effect of the age of the concrete on the creep and the nature of the progress of the creep and shrinkage with time (Fintel and Khan 1969, 1971) are taken into account. The analysis is

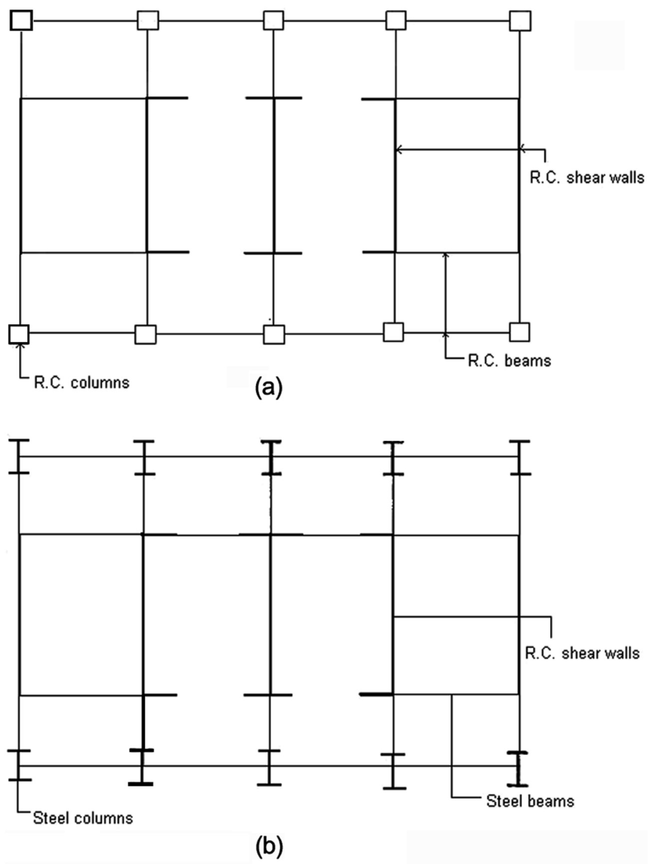

Fig. 1 Frame - shear wall systems (a) R.C. (b) composite

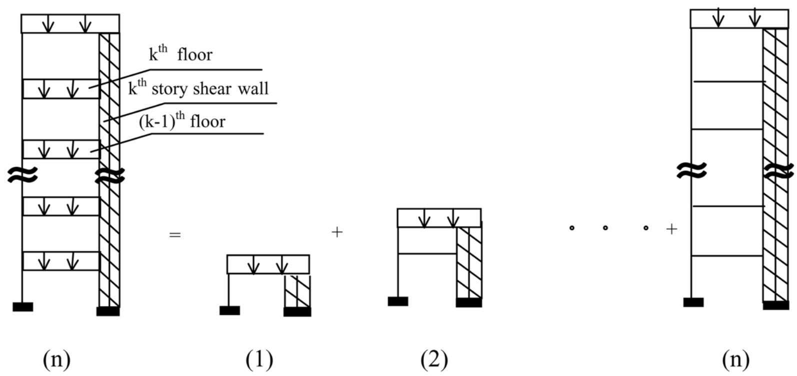

Fig. 2 Substructures of *n* story frame - shear wall system

carried out progressively, starting from the first substructure and ending at the *n*th substructure.

For the first substructure, first, elastic analysis is carried out for the loading at the first floor when the age of the concrete, t_a is Ct_1 to yield elastic member forces (moments and shears in beams and vertical members and axial forces in vertical members) and elastic vertical deflections. Let $\Delta M^e_{1,1}$, $\Delta d^e_{1,1}$ represent elastic member forces and elastic vertical deflections, in which the first and second subscripts indicate storey/floor and substructure, respectively, and the super-script indicates elastic analysis for the applied loading.

Among these member forces, let $\Delta P_{1,1}^{e}$ represent elastic vertical member axial forces. Total unrestrained inelastic deformations δ in the shear walls are evaluated on the basis of $\Delta P_{1,1}^{e}$ for the next time interval Ct_2, after which the members of this substructure become members of the next substructure. Restraining vertical member end forces, R_f due to δ are obtained and the 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. Let $\Delta M_{1,1}^{i}$, $\Delta d_{1,1}^{i}$ represent these inelastic member forces and inelastic vertical deflections in which the changed superscript i refers to inelastic analysis. Among these member forces let $\Delta P_{1,1}^{i}$ represent inelastic vertical member axial forces. In evaluation of δ in subsequent intervals, $\Delta P_{1,1}^{i}$ are assumed to have been generated at the end of the time interval Ct_2.

Elastic member forces in the first storey $M_1^e(t_c)$ and vertical deflections at the first floor $d_1^e(t_c)$, up to the current time, t_c $(=Ct_1+Ct_2)$ are obtained by adding $\Delta M_{1,1}^{e}$ and $\Delta d_{1,1}^{e}$ to the respective quantities at previous time, t_p $(=Ct_1)$. For the first substructure, $M_1^e(t_p)$, $M_1^i(t_p)$, $M_1^t(t_p)$, $d_1^e(t_p)$, $d_1^i(t_p)$ and $d_1^t(t_p)$ are equal to zero. Among these member forces let $P_1^e(t_c)$ represent elastic vertical member axial forces in the first storey. Similarly, inelastic member forces $M_1^i(t_c)$ and inelastic vertical deflections $d_1^i(t_c)$ are obtained. Total member forces $M_1^t(t_c)$ and vertical deflections $d_1^t(t_c)$ are obtained by including both elastic and inelastic contributions.

As stated above, at the end of the time interval Ct_2, storey 1 becomes a part of 2nd substructure.

In a similar way, the 2nd and all the remaining substructures are analyzed (Maru 2000).

For the last substructure, n the time interval Ct_{n+1} should be interpreted as the waiting period after which live load on the complete frame is applied and is designated as Wt $(=Ct_{n+1})$.

In the stage 1 of this procedure it can be seen that creep deformations are evaluated for a number of elastic and inelastic forces which get generated progressively with time in the evolving structure. Fig. 3 shows schematically the elastic and inelastic forces generated in stage 1. On a column/shear wall line, the number of elastic and inelastic forces generated in the jth storey are $(n-j+1)$ and $(n-j)$ respectively. As explained above the actual time of occurence of these elastic and inelastic forces is considered in the evaluation of creep deformations.

2.2. Stage 2: combined dead and live load analysis

Let the total time for which creep and shrinkage effects are being studied be T (=20 years typically). The part of the live load that is of permanent nature is applied to the complete frame - shear wall system (n storeys) after the time interval Wt $(=Ct_{n+1})$, after the construction of the complete frame - shear wall system $(t_b=\sum_{i=1}^{n+1} Ct_i)$. The remaining period $t_r = T - t_b$ is divided into a number of intervals q of duration $r_1, r_2, \ldots, r_q$. The duration of the intervals is progressively increased, because creep and shrinkage decrease with time.

Let $\Delta M_{k,n,s}^{e}$ and $\Delta d_{k,n,s}^{e}$ represent increments in elastic member forces and elastic vertical deflections, in which the first and second subscripts and the superscript have the same meaning as in $\Delta M_{k,n}^{e}$ and $\Delta d_{k,n}^{e}$ and third subscript refers to the sth interval after the application of live load. Further, let $\Delta M_{k,n,s}^{i}$ and $\Delta d_{k,n,s}^{i}$ represent corresponding inelastic quantities in the interval. These quantities in an interval are obtained in a manner described earlier in stage 1. Forces that contribute to δ in the first interval are $\Delta P_{k,l}^{e}$, $\Delta P_{k,l}^{i}$ $(k = 1,\ldots, n$ and $l = k, k+1,\ldots, n)$ generated in stage 1 and $\Delta P_{k,n,1}^{e}$, $(k = 1,\ldots, n)$ in stage 2

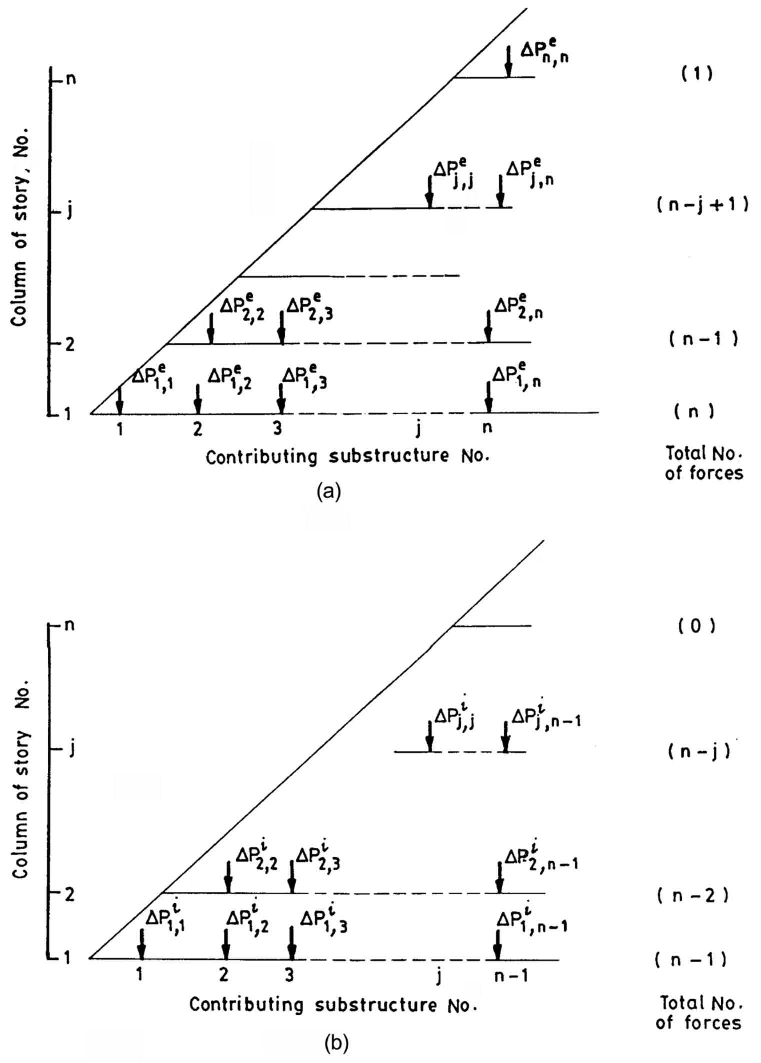

Fig. 3 Forces generated in stage 1: (a) Elastic, due to dead load; (b) Inelastic, due to inelastic deflections

(Fig. 4), whereas in subsequent intervals, contributing forces are (Fig. 5) $\Delta P^e_{k,l}$, $\Delta P^i_{k,l}$, $\Delta P^e_{k,n,1}$ and $\Delta P^i_{k,n,m}$ (k = 1,…, n; $l = k$, k + 1,…, n; and m = 1,…, s–1).

Elastic Member forces in the kth storey, $M^e_k(t_c)$ and vertical deflections at the kth floor $d^e_k(t_c)$ up to the current time t_c (= $t_b + r_1$), at the end of the 1st interval are obtained by adding $\Delta M^e_{k,n,1}$ and $\Delta d^e_{k,n,1}$ to the respective quantities at the previous time, t_p (= t_b) which is the end of stage 1.

Similarly inelastic member forces, $M^i_k(t_c)$ and inelastic vertical deflections, $d^i_k(t_c)$ are obtained. Total member forces, $M^t_k(t_c)$ and total vertical deflections $d^t_k(t_c)$ are obtained by including both elastic and inelastic contributions.

In subsequent intervals, $\Delta M^e_{k,n,s}$ and $\Delta d^e_{k,n,s}$ ($s \neq 1$) are equal to zero. Elastic member forces and vertical deflections remain constant in the subsequent intervals and therefore $M^e_k(t_c)$ and $d^e_k(t_c)$ at t_c (= $t_b + r_1$) become the final elastic forces and the final vertical deflections respectively.

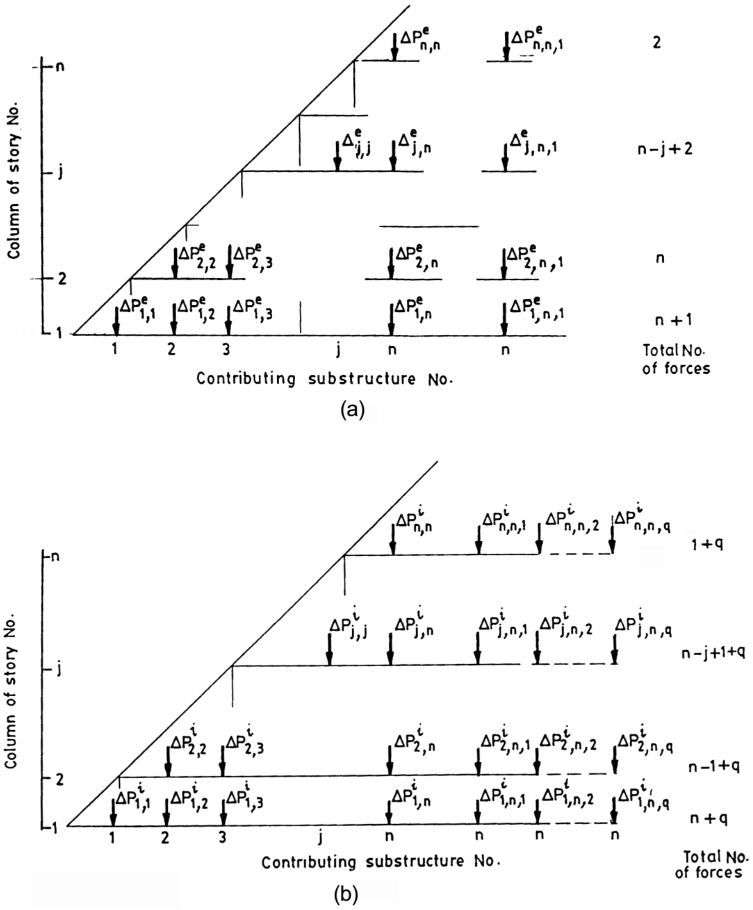

Fig. 4 Forces generated in stage 2: (a) Elastic, due to dead and live load; (b) Inelastic, due to inelastic deflections

Similarly, inelastic and total member forces, $M_k^i(t_c)$ and $M_k^t(t_c)$ and vertical deflections, $d_k^i(t_c)$ and $d_k^t(t_c)$ at the end of any interval, sth up to current time t_c (= $t_p + r_s$) are obtained by adding $\Delta M^i_{k,n,s}$, $\Delta M^t_{k,n,s}$, $\Delta d^i_{k,n,s}$, and $\Delta d^t_{k,n,s}$ to the respective quantities at the previous time, t_p (= $t_b + \sum_{m=1}^{s-1} r_m$). At the end of the qth interval, these values become the final inelastic member forces, $M_k^i(t_c)$ and the final total member forces $M_k^t(t_c)$, and the final inelastic vertical deflections, $d_k^i(t_c)$ and the final total vertical deflections $d_k^t(t_c)$.

In a manner similar to that adopted in stage 1, the elastic and inelastic forces generated in stage 2 are schematically shown in Fig. 4. The number of elastic and inelastic forces generated in any storey, say jth are $(n-j+2)$ and $(n-j+1+q)$ respectively.

3. Numerical study

A 60 storey (storey height = 3.0 m) composite frame - shear wall system comprising of 3 bays, with each bay of span 5.0 m is considered Fig. 5. Columns are of steel (moment of inertia, I_c = 0.002684 m^4,

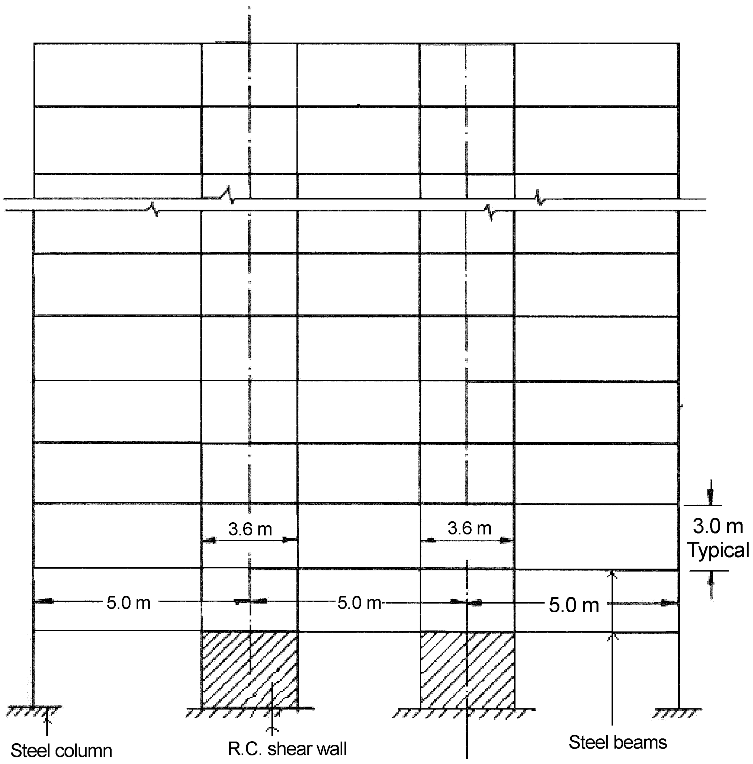

Fig. 5 Example composite frame - shear wall system

area, A_c = 0.05858 m^2) and R.C. shear walls are of size 3.6×0.3 m (moment of inertia = 1.1664 m^4, area = 1.08 m^2 and volume to surface ratio = 13.8 cm). Percentage of reinforcement in shear walls is taken as 0.3%.

This frame - shear wall system is subjected to uniform dead loading of 27 kN/m and uniform live loading of permanent nature 10 kN/m. Construction time Ct_k for each storey and the total time, T are taken as 4 days and 7244 days (≈ 20 years) respectively. The time duration of stage 2, t_r 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) = 3.6×10^7 kN/m^2, E_s (modulus of elasticity of steel) = 2.1×10^8 kN/m^2, $\varepsilon_{c(28)}$ = 81×10^{-9} (m/m)/(kN/m^2), ε_s = 480×10^{-6} m/m for first 90 days.

First, a composite frame - shear wall system with high beam stiffness ($I_b = I_c$) is considered.

Final vertical deflections, elastic $d_k^e(t_c)$ and total $d_k^t(t_c)$ in columns and shear walls are shown in Fig. 6. In columns, high $d_k^t(t_c)$ is observed, although these are of steel and therefore, undergo no creep and shrinkage deformations. Creep and shrinkage deformations in shear walls induce high $d_k^t(t_c)$ in columns as beams are monolithically connected to columns and shear walls.

Final differential vertical deflections, elastic $\delta(d_k^e(t_c))$, inelastic $\delta(d_k^i(t_c))$ and total $\delta(d_k^t(t_c))$ between columns and shear walls are shown in Fig. 7. It may be noted that $\delta(d_k^e(t_c))$ is small while $\delta(d_k^i(t_c))$ is higher owing to the absence of inelastic deformations in columns.

Fig. 8 shows variations in final axial forces, elastic, $P_k^e(t_c)$ and total, $P_k^t(t_c)$. It may be seen that $P_k^t(t_c)$ in columns increases whereas $P_k^t(t_c)$ in shear walls decreases owing to load transfer from shear walls to

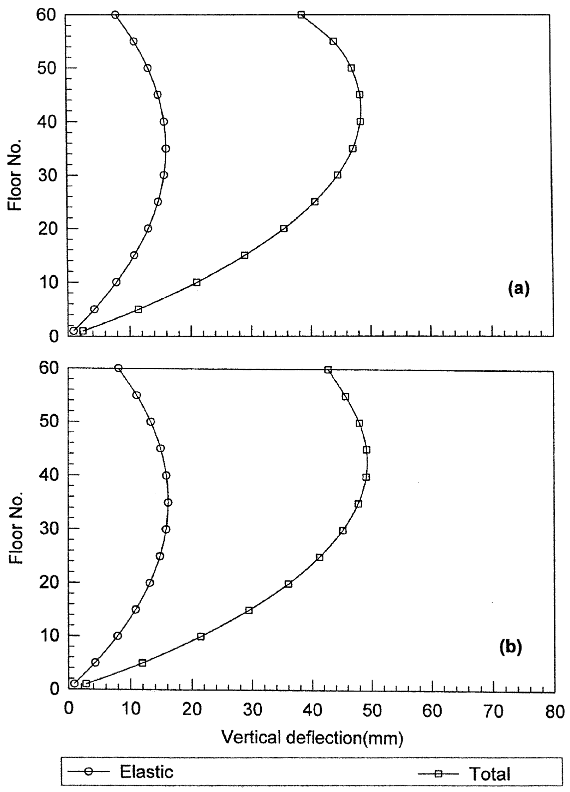

Fig. 6 Final vertical deflections in composite frame - shear wall system with high beam stiffness: (a) Columns; (b) Shear walls

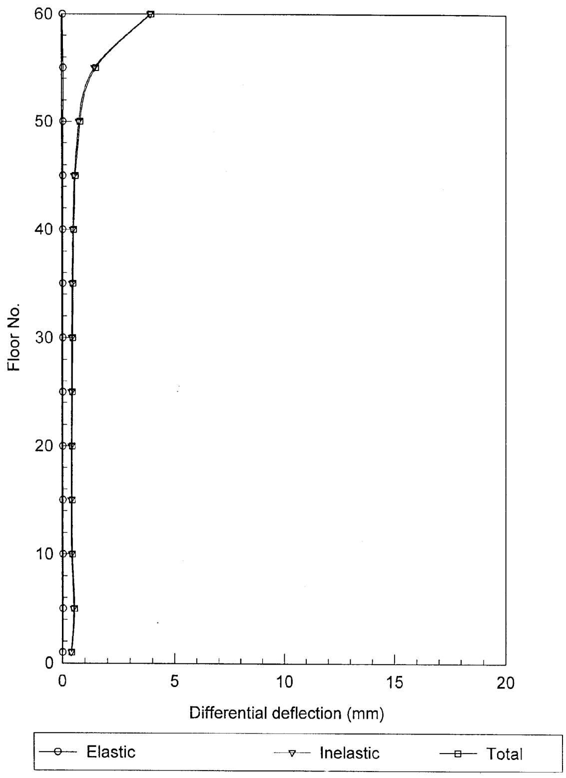

Fig. 7 Final differential vertical deflections between columns and shear walls of composite frame - shear wall system with high beam stiffness

columns. This load transfer results from $\delta(d_k^i(t_c))$ (Fig. 7). The magnitude of load transfer (net change) in $P_k^e(t_c)$, in columns and shear walls in 1st storey is shown in Table 1. It may be seen that the net change in $P_k^e(t_c)$ is very high.

Final beam end moments, elastic, $M_k^e(t_c)$ and total, $M_k^t(t_c)$ in exterior and interior bays for left end are shown in Fig. 9. Similar behaviour is also observed for right end final beam end moments (not shown). The net change in $M_k^e(t_c)$ is quite high in exterior bays owing to high value of $\delta(d_k^i(t_c))$ between columns and shear walls (Fig. 7) and high beam stiffness. Very high changes in the top portion are owing to cumulative nature of $\delta(d_k^i(t_c))$ along the height. Net changes in $M_k^e(t_c)$ in the interior bays is very small owing to the symmetry; only rotations at the two ends contribute to the net changes.

It is of interest to compare the behaviour of this composite frame shear wall system with that of an equivalent R.C. frame shear wall system. In this R.C. frame shear wall system, all the columns and beams are also of R.C. construction. The sizes of columns are evaluated by equalizing axial and flexural stiffness of these members (with E_c at 28 days = 3.6×10^7 kN/m^2) in composite and R.C. systems. Accordingly, all columns are of size 0.74×0.461 m ($I_c = 0.0156$ m^4, $A_c = 0.3412$ m^2). Percentage of reinforcement in these columns is taken as 2%. All beams have moment of inertia, $I_b = I_c$.

Final vertical deflections, $d_k^e(t_c)$ and $d_k^t(t_c)$ in columns and shear walls are shown in Fig. 10 and final differential vertical deflections between these members are shown in Fig. 11.

Table 1 Final axial forces and load transfer (net change) among columns and shear walls in the 1st story of the composite frame - shear wall system with high beam stiffness

Vertical member	Axial force (kN) Elastic $P_k^e(t_c)$	Axial force (kN) Total $P_k^t(t_c)$	Load transfer (net change) from immediate exterior member (kN)	Load transfer (net change) from immediate interior member (kN)
1	2	3	4	5
Columns	3703.51	9822.17	-	+6118.66 (Shear wall to col.)
Shear walls	12976.50	6827.84	-6118.66 (Shear wall to col.)	-

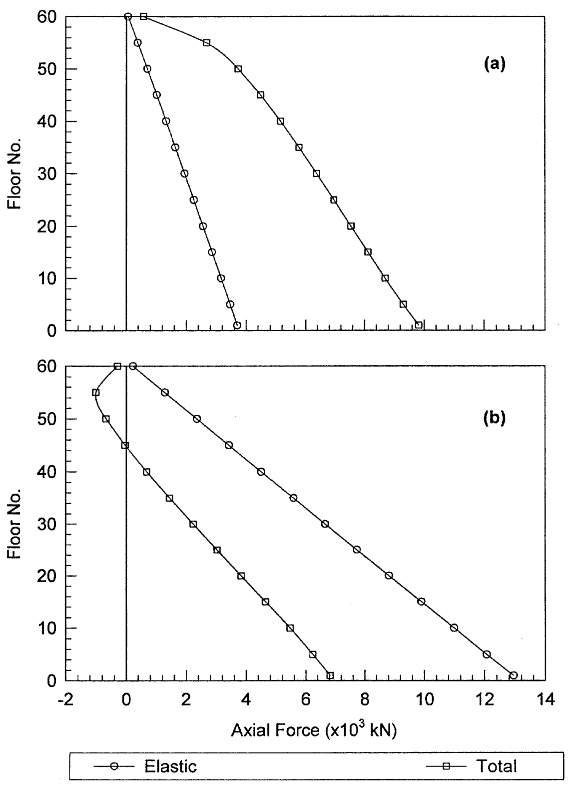

Fig. 8 Final axial forces in composite frame - shear wall system with high beam stiffness: (a) Columns; (b) Shear walls

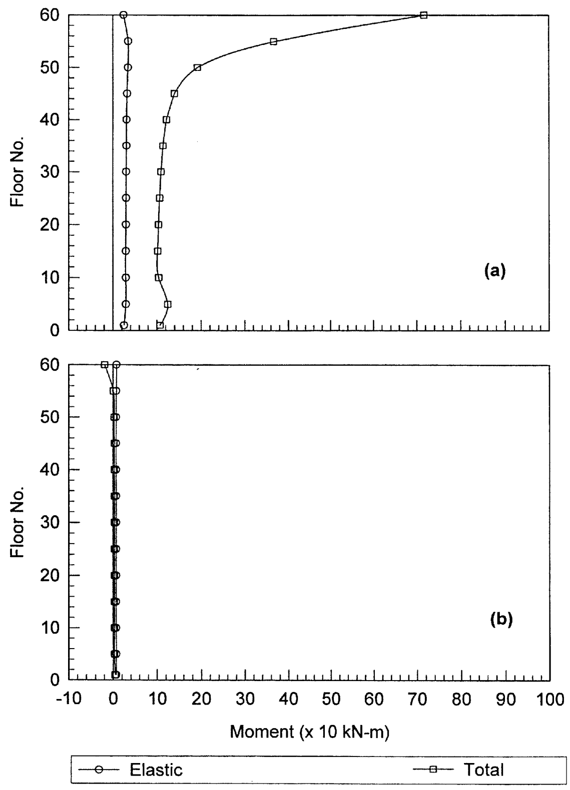

Fig. 9 Final beam end moments (left end) in composite frame - shear wall system with high beam stiffness: (a) Exterior bays; (b) Interior bays

It is seen that the differential inelastic deflections $\delta(d_k^i(t_c))$ between columns and shear walls are much higher for the composite system (Fig. 7) than those for the R.C. system (Fig. 11). This is owing to occurrence of inelastic deformations in both columns and shear walls of the R.C. system whereas in the composite system, only inelastic deformations take place in shear walls.

Fig. 12 shows variations in final axial forces, $P_k^e(t_c)$, and $P_k^t(t_c)$ in columns and shear walls of the R.C system. The magnitude of load transfer (net change) in $P_k^e(t_c)$, in these members in 1st storey is given in Table 2. Net changes in $P_k^e(t_c)$, in columns and shear walls of the composite system with high beam stiffness are much higher (Table 1) than the net changes in $P_k^e(t_c)$ for the R.C. system (Table 2).

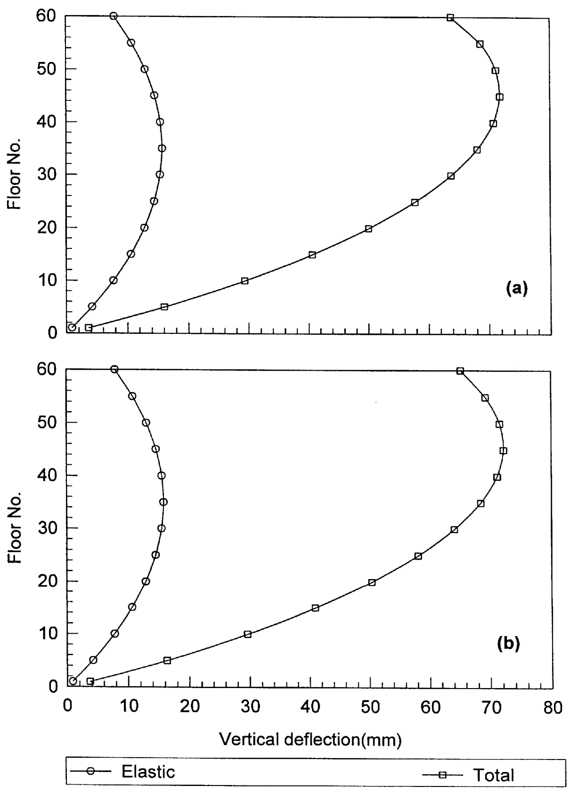

Fig. 10 Final vertical deflections in R.C. frame - shear wall system with high beam stiffness: (a) Columns; (b) Shear walls

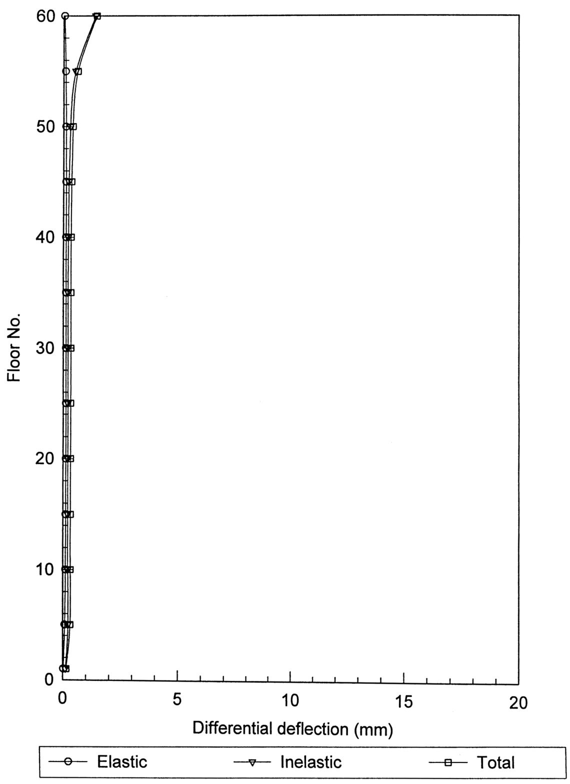

Fig. 11 Final differential vertical deflections between columns and shear walls of R.C. frame - shear wall system with high beam stiffness

Table 2 Final axial forces and load transfer (net change) among columns and shear walls in the 1st story of the R.C. frame - shear wall system with high beam stiffness

Vertical member	Axial force (kN)		Load transfer (net change) from immediate exterior member (kN)	Load transfer (net change) from immediate interior member (kN)
	Elastic $P_k^e(t_c)$	Total $P_k^t(t_c)$		
1	2	3	4	5
Columns	3917.78	4939.92	-	+1022.14 (Shear wall to col.)
Shear walls	12732.28	11710.14	-1022.14 (Shear wall to col.)	-

This is owing to higher value of $\delta(d_k^i(t_c))$ in the composite system (Figs. 7 and 11).

Variations in final beam end moments, $M_k^e(t_c)$ and $M_k^t(t_c)$ in exterior and interior bays for left end of the R.C. system are shown in Fig. 13. Net changes in $M_k^e(t_c)$, in exterior bays are much higher for the composite system than those for the R.C. system, again owing to higher value of $\delta(d_k^i(t_c))$ for the composite system.

As noted above, very large redistribution of forces have been observed for the composite system with high beam stiffness. Lower redistribution of forces would occur for a composite system with low beam stiffness. Therefore, next a composite system with low beam stiffness ($I_b = I_c / 20$) is considered.

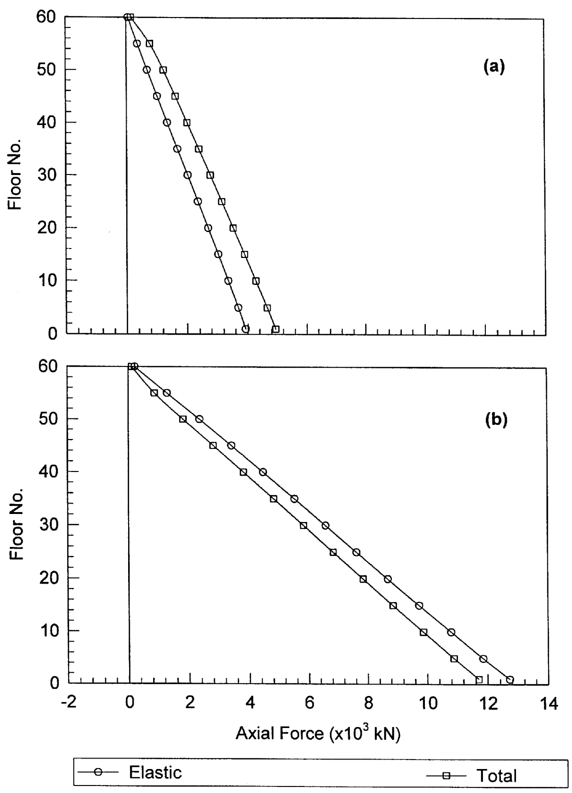

Fig. 12 Final axial forces in R.C. frame - shear wall system with high beam stiffness: (a) Columns; (b) Shear walls

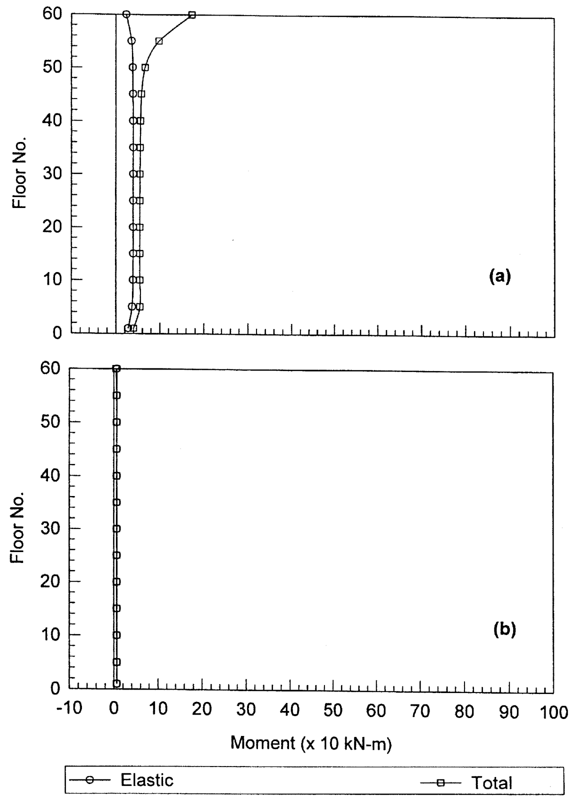

Fig. 13 Final beam end moments (left end) in R.C. frame - shear wall system with high beam stiffness: (a) Exterior bays; (b) Interior bays

Final vertical deflections, $d_k^e(t_c)$ and $d_k^t(t_c)$ in columns and shear walls of the composite system with low beam stiffness are shown in Fig. 14 whereas final differential vertical deflections, $\delta(d_k^e(t_c))$, $\delta(d_k^i(t_c))$ and $\delta(d_k^t(t_c))$ are shown in Fig. 15. As expected $\delta(d_k^i(t_c))$ of the system with low beam stiffness is higher than those of the composite system with high beam stiffness.

Fig. 16 shows variations in final axial forces, $P_k^e(t_c)$ and $P_k^t(t_c)$ in columns and shear walls of the composite system with low beam stiffness. The magnitude of the load transfer (net change) in $P_k^e(t_c)$, in these members in 1st storey is given in Table 3.

The net changes in $P_k^e(t_c)$, in the columns and shear walls of composite system with low beam stiffness (Table 3) are smaller than those in the composite system with high beam stiffness (Table 1). Although $\delta(d_k^i(t_c))$ between the columns and shear walls of the composite system with low beam stiffness are more than those for the composite system with high beam stiffness (Figs. 15 and 7) but owing to lower beam stiffness, the net changes in the composite system with low beam stiffness are lower.

Final beam end moments, $M_k^e(t_c)$ and $M_k^t(t_c)$ in exterior and interior bays for left end of the composite system with low beam stiffness is shown in Fig. 17. The magnitude of these moments is much smaller than those for the composite system with high beam stiffness.

Comparison along the height of variations of percentage net changes in $P_k^e(t_c)$ in columns and shear walls of the composite system with high beam stiffness, composite system with low beam stiffness and in the R.C. system with high beam stiffness is made in Table 4. As expected throughout the height the

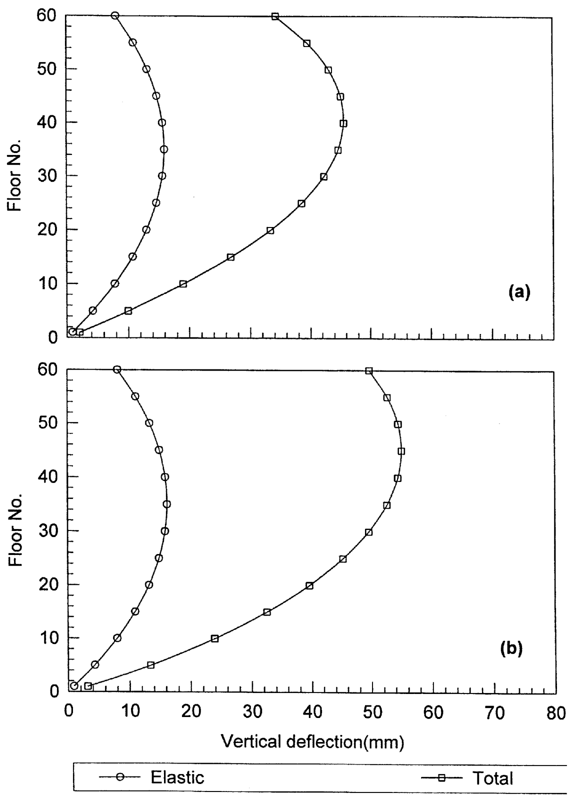

Fig. 14 Final vertical deflections in composite frame - shear wall system with low beam stiffness: (a) Columns; (b) Shear walls

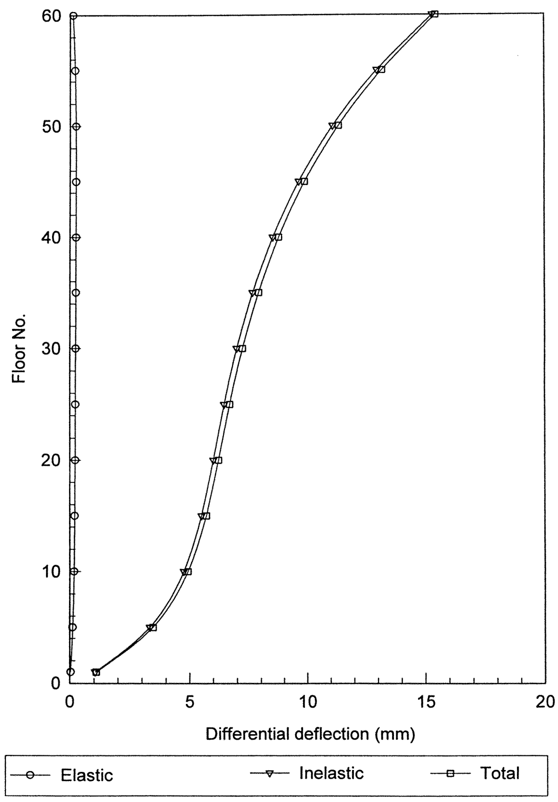

Fig. 15 Final differential vertical deflections between columns and shear walls in composite frame - shear wall system with low beam stiffness

percentage net changes for the composite system with high beam stiffness are higher than those for the other two systems. It may be noted that very high percentage changes in the top portion are in the values of $P_k^e(t_c)$ the magnitudes of which are small.

From the above it is seen that owing to creep and shrinkage, the beams connecting R.C. shear walls to steel columns (link beams) are subjected to substantial additional moments. The magnitude of these moments can be reduced by providing link beams of low stiffness. These moments can be eliminated if link beams are pin-connected to the adjacent vertical members. However provision of link beams of low stiffness or provision of pin connection to the adjacent members would adversely affect the lateral resistance. The choice of a value of stiffness of link beams or the mode of connection (monolithic or pinned) would, therefore, depend on the effect of creep and shrinkage and the magnitude of lateral resistance that would need to be mobilized on the peripheral framing.

4. Conclusions

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

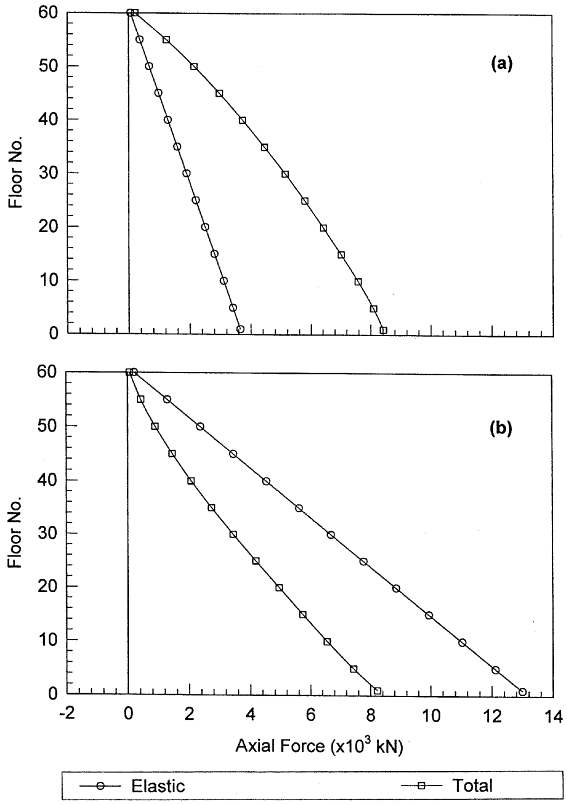

Fig. 16 Final axial forces in composite frame - shear wall system with low beam stiffness: (a) Columns; (b) Shear walls

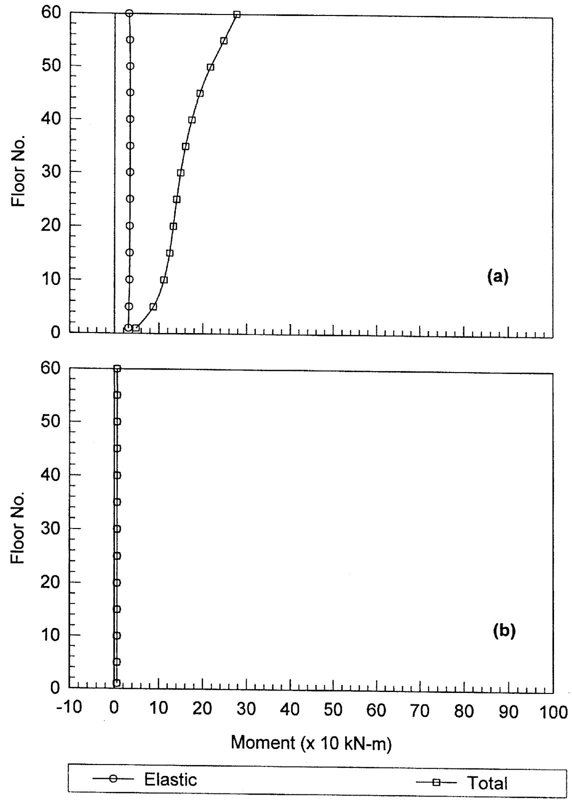

Fig. 17 Final beam end moments (left end) in composite frame - shear wall system with low beam stiffness: (a) Exterior bays; (b) Interior bays

Table 3 Final axial forces and load transfer (net change) among columns and shear walls in the 1st story of the composite frame - shear wall system with low beam stiffness

Vertical member	Axial force (kN)		Load transfer (net change) from immediate exterior member (kN)	Load transfer (net change) from immediate interior member (kN)
	Elastic $P_k^e(t_c)$	Total $P_k^t(t_c)$		
1	2	3	4	5
Columns	3653.67	8417.69	-	+4764.02 (Shear wall to col.)
Shear walls	12996.30	8232.28	-4764.02 (Shear wall to col.)	-

(a) For the composite frame - shear wall system with high beam stiffness, the redistribution of member forces (column axial forces and beam end moments) between columns and shear walls is very high.

(b) For the composite frame-shear wall system with high beam stiffness, final differential vertical inelastic deflections $\delta(d_k^i(t_c))$ and net change in elastic $P_k^e(t_c)$ and elastic $M_k^e(t_c)$ are much higher than those in the equivalent R.C. frame shear wall system.

(c) For the composite frame-shear wall system with high beam stiffness, the net changes in elastic $P_k^e(t_c)$ and elastic $M_k^e(t_c)$ are significantly higher than those in the system with low beam

Table 4 Comparison of variations of percentage net changes in elastic $P_k^e(t)$ in the composite frame - shear wall systems (with high and low beam stiffness) and the R.C. frame - shear wall systems

Story	Percentage net changes in elastic $P_k^e(t)$					
	Composite systems				R.C System	
	High beam stiffness		Low beam stiffness		High beam stiffness	
	Columns	Shear walls	Columns	Shear walls	Columns	Shear walls
1	2	3	4	5	6	7
1st	165.21	-47.15	130.39	-36.66	25.69	-7.94
10th	174.89	-50.32	143.68	-40.53	26.38	-8.20
20th	195.22	-56.54	156.31	-44.15	27.49	-8.55
30th	227.68	-66.47	171.72	-48.52	29.06	-9.03
40th	287.41	-84.80	192.51	-54.32	31.06	-9.63
50th	432.88	-128.77	221.50	-62.18	33.58	-10.38
60th	884.12	-236.78	259.02	-71.22	36.91	-11.37

stiffness although $\delta(d_k^i(t_c))$ is smaller for the former system.

(d) The choice of the value of the stiffness of link beams or there mode of connection to the adjacent vertical members depends on the effect of creep and shrinkage and the magnitude of lateral resistance that is to be mobilized.

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Notation

The following symbols are used in this paper:

A	: cross sectional area of shear wall segment
A_C	: Cross-sectional area of column
Ct_k	: construction time
$d_k^e(t),\ d_k^i(t),\ d_k^t(t)$	: vertical deflections at time t
E	: modulus of elasticity of concrete
E_s	: modulus of elasticity of steel
$I_b,\ I_c$	: moment of inertia of beam and column respectively
$M_k^e(t),\ M_k^i(t),\ M_k^t(t)$	: beam end moments (positive; anticlockwise)member forces at time t
$P_k^e(t),\ P_k^i(t),\ P_k^t(t)$	: axial forces at time t
q	: number of time intervals in stage 2
R_f	: restrained column end forces
r_m	: duration of mth interval in stage 2
T	: total time for which creep and shrinkage effects are being studied
t_a	: age of concrete
t_b	: time duration from beginning of construction after which live load acts
$t_c,\ t_p$	: current and previous time
t_r	: remaining time after construction of the frame
$\Delta d_{k,j}^e,\ \Delta d_{k,j}^i,\ \Delta d_{k,j}^t$	: vertical deflections
$\Delta d_{k,n,s}^e,\ \Delta d_{k,n,s}^i,\ \Delta d_{k,n,s}^t$	: vertical deflections
$\Delta M_{k,j}^e,\ \Delta M_{k,j}^i,\ \Delta M_{k,j}^t$	: member forces
$\Delta M_{k,n,s}^e,\ \Delta M_{k,n,s}^i,\ \Delta M_{k,n,s}^t$	: member forces
$\Delta P_{k,j}^e,\ \Delta P_{k,j}^i,\ \Delta P_{k,j}^t$	: axial forces
$\Delta P_{k,n,s}^e,\ \Delta P_{k,n,s}^i,\ \Delta P_{k,n,s}^t$	: axial forces
δ	: total unrestrained inelastic deformation
$\delta^{cr},\ \delta^{sh}$	: creep and shrinkage deformations
$\delta(d_k^e(t)),\ \delta(d_k^i(t)),\ \delta(d_k^t(t))$	: differential vertical elastic, inelastic and total deflections at time t
$\varepsilon_{c(28)}$	: specific creep value for loading at 28 days
ε_s	: ultimate shrinkage strain
$\varepsilon_c^e(t, t_a)$	: elastic strain in concrete at time t for loading at t_a
$\varepsilon_c^{cr}(t, t_a)$	: creep strain in concrete at time t for loading at t_a
$\varepsilon_c^{sh}(t)$	: shrinkage strain in concrete at time t
$\varepsilon_c(t, t_a)$	: total strain in concrete at time t for loading at t_a

Superscript

e	: elastic
i	: inelastic
t	: total
cr	: creep
sh	: shrinkage

Subscript

c	: concrete
j	: sub - structure
k	: story/floor
n	: total no. of stories in frame-shear wall system
s	: interval no. after the application of live load / steel

CC