LINEAR ELASTIC ANALYSIS OF R.C. TALL BUILDING CONSIDERING CREEP AND SHRINKAGE -AN APPROXIMATE PROCEDURE-

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ABSTRACT

An approximate procedure which takes into account the effect of creep and shrinkage in frames is available, in which the shearing action of horizontal members is neglected, while evaluating axial forces in column based on which creep deflections are evaluated. Evaluation of loads on vertical members is based on tributary areas and also the sequential application of dead load is considered very approximately. The vertical deflections, due to elastic shortening, and also due to the effect of creep and shrinkage are estimated. The forces in members owing to these deflections are evaluated and superimposed on those obtained from linear analysis of frames in which vertical deflections have been neglected. Neglect of shearing action of horizontal members would result in increasing error as the shear stiffness of beams becomes large in comparison to axial stiffness of columns. The procedure hence forth would referred to as Approximate Procedure(AP).

This paper deals with AP. In this procedure shearing action of beams is neglected while evaluating axial forces in columns based on which creep deflections are computed(3,5,6).The procedure may, therefore, be used for frames in which shear stiffness of beams(=12EI/L³, E=modules of elasticity, I moment of inertia of beam and L= span of the beam) is low, e.g: in buildings employing flat plate construction, where a slab is modeled as an equivalent beam.

Parameters which affect creep and shrinkage behaviors are identified. An exhaustive study is carried out to study the effect of these parameters. Studies on the behavior of frames with low values of shearing stiffness are reported. Such studies are lacking in literature.

Key Words: *Creep and Shrinkage, differential Shortening, Age of Concrete at Loading, Specific Creep, Member Size, Variation of Creep and Shrinkage with Time, Support Shortening, Influence of reinforcement on Column stresses, Influence of vertical shortening on Structural Actions in Horizontal Members.*

INTRODUCTION

Until the 1950's, only a few concrete buildings stood more than twenty stories high. The structures of that time had heavy cladding and masonry partitions, which contributed substantially to the strength and stiffness of the buildings. Because of the low stress, levels used for concrete and steel, the buildings frame members had sizeable dimensions which resulted in substantial rigidity. The effects of frame distortions due to shrinkage and creep were secondary and could be neglected since the capacity of the usual structure for over-stress was quite high.

In the late 1950's and early 1960's the height of concrete buildings jumped from 20 to 60 stories. The increase in height was accompanied by a sharp increases in the strength of concrete and reinforcing steel, allowing reduced cross-sections and causing a reduction in the overall rigidity. The change over from working stress to ultimate strength design contributed further to this trend toward smaller sections.

With reduced overall stiffness and increase in height, the volume change effects become magnified and could no longer be treated as secondary consideration in design, while column length changes within a single story may be minor, they are cumulative and when multiplied by a large number of stories, they become substantial. Therefore, as buildings reached greater heights differential inelastic shortening (creep and shrinkage) needed to be considered in the structural analysis.

In the early 1960's although a large amount of research information was available on creep and shrinkage strains, it was not directly applicable to columns of high rise buildings.

In 1971 an analytical procedure for estimating structural effects of creep and shrinkage was established (by Khan and Fintel). The first part of this procedure handles prediction of the inelastic shortenings as a function of incremental loading sequence, volume to surface ratio, and effect of percentage of reinforcement. The second part handles the analysis of multi storied structures taking into account the structural effects of differential shortenings between adjacent columns and walls.

The objective of the paper are, therefore, defined as:-

- To study the adequacy of the approximate procedure available in literature for high beam shear stiffness and low beam shear stiffness, and

- To identify structural parameters that affect creep and shrinkage behavior of buildings and to carry out studies on the effect of those parameters on the behavior of frames system.

EVALUATION OF COLUMN SHORTENINGS DUE TO CREEP AND SHRINKAGE

In this section, creep and shrinkage phenomena and factors which affect them are described briefly and the procedure for evaluation of column shortenings are presented.

Creep and Shrinkage Phenomena

The time dependent deformation of concrete under sustained loading is known as creep. During the initial period of loading the rate of creep is significant. The rate diminishes as time progresses until it eventually approaches zero. Figure 1 shows typical creep strain versus time curve.

The creep basically consists of two components:-

a. Basic (or true) creep:- This occurs under conditions of hygral equilibrium, which means that no moisture movement occurs to or from the ambient medium.

b. Drying creep:- This results from the exchange of moisture between the stressed member and the environment. Its effect is only during initial 3 months and beyond that the rate of creep is basic creep only.

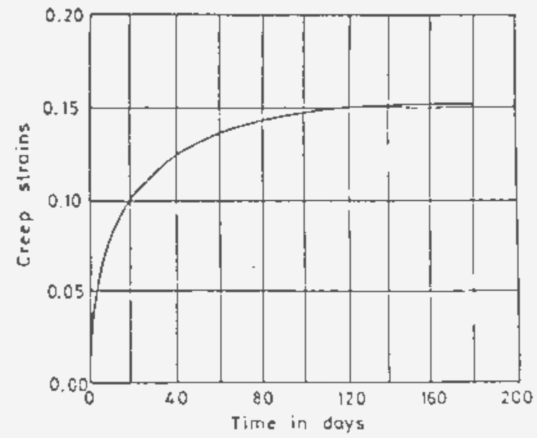

Figure 1 Typical creep strain versus time curve

During the process of drying and hardening, concrete undergoes volume contraction known as shrinkage. It is independent of the externally imposed stresses and temperature changes. Although both creep and shrinkage have similar effect in the sense that they cause length shortening, their combined effects on the structure can be considered only after the creep and shrinkage strains have been computed separately and modified for the condition of the designed stricture. The reasons are:-

a. Length of construction time has a pronounced effect on the amount of creep while shrinkage proceeds independently of construction time.

b. Creep deformation depends on loading history, but shrinkage is independent of the loading on the structure.

c. Creep and shrinkage are affected by different amounts with change in member size.

Specific Creep

For structural engineering practice it is convenient to define specific creep (ϵ_c) as the ultimate creep strain per unit sustained stress. Specific creep values corresponding to ages at which the incremental loading are applied in the intended multistory structure can be obtained by:

a. Extrapolation of a number of laboratory samples prepared in advance from the actual mix to be used in the structure. It is obvious that sufficient time is required for these tests prior to the start of construction but it is not clearly a practical approach although it yields an accurate value of specific creep.

b. Basic creep value can also be predicted from the value of modulus of elasticity at the time of load application (without testing). Figure 2 shows the variation of specific creep values with initial elastic modules for different load durations [2] and is based on long term creep studies at Bureau of Reclamation in Denver [2]. The graph gives sufficiently accurate results. For design purposes, the extrapolated 20 year creep may be regarded as the ultimate creep.

From the specified 28 days concrete strength, the basic specific creep for loading at 28 days may be determined, and the value obtained is then modified to take account of construction sequence, member dimensions and the percentage of reinforcement which are described later.

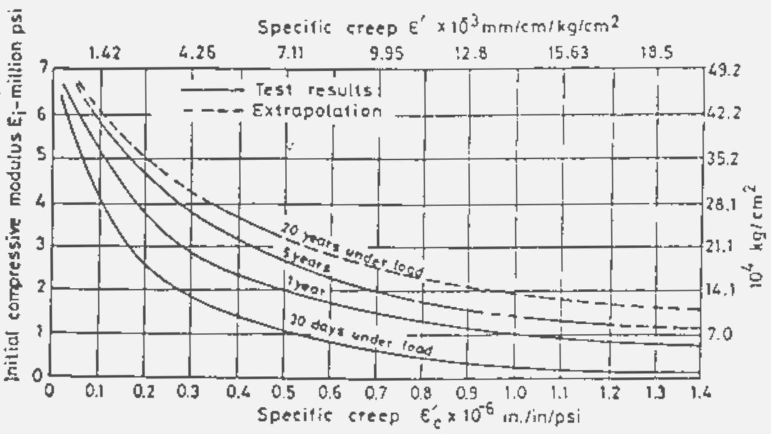

Figure 2 Variation of specific creep values with initial elastic modulus for different load durations

Factors Affecting Creep and Shrinkage Movements in Concrete

a. Age of concrete at loading

It has been found that a concrete specimen exhibits a much greater specific creep if it is first loaded at an early age rather than when it is older. This is of considerable practical importance, since creep decreases with the age of concrete, and so each increment in a loading sequence will add a smaller component of specific creep to the final average creep of a column. Provided stresses are not near the ultimate strength, the strains produced in a concrete member at any time by a load increment are virtually independent of the effects of any previous or subsequent applied loads. That is each applied load produces all creep strain that corresponds to the strength to stress ratio at the time of load application as if it were the only loading or the member.

Figure 3 shows the relationship between creep and age of the concrete at loading and has been established based on research data from numerous tests [8]. In this curve, creep has been expressed as a ratio λ_a of the unit datum creep value at age of 28 days. The curve allows the effects of increment of loading on a column to be summed up to give the total creep effect produced by the application of all loads.

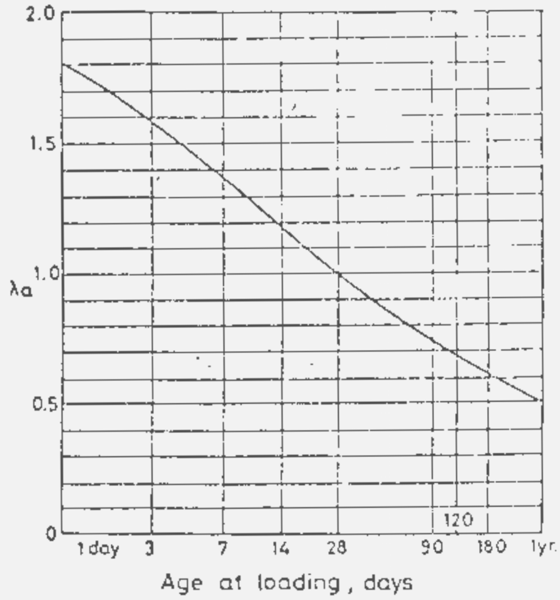

Figure 3 Relationship between creep and age of concrete at loading

b. Member size

Both creep and shrinkage depend on the member size but not to the same degree. Creep is less sensitive to member size than shrinkage which is caused by evaporation of moisture from the surface and hence the volume to surface ratio of a member has a pronounced effect on the amount of shrinkage. However, only drying creep component is affected by member size and shape. The variations of creep coefficient λ_r and shrinkage coefficient λ_s with volume-to-surface ratio are given in Fig. 4 and Fig. 5, respectively. Although it is expected that higher rates of creep and shrinkage would result under fluctuating humidity conditions and temperature but sufficient research data has not yet been gained to allow for a general conclusion to be reached.

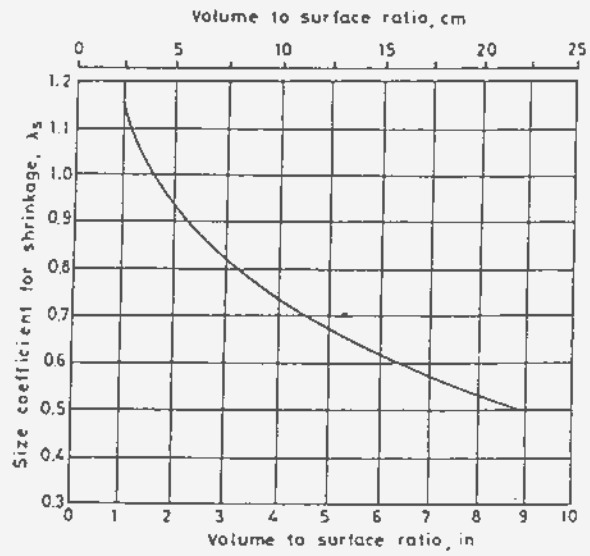

Figure 4 Variation of shrinkage coefficient λs with volume to surface

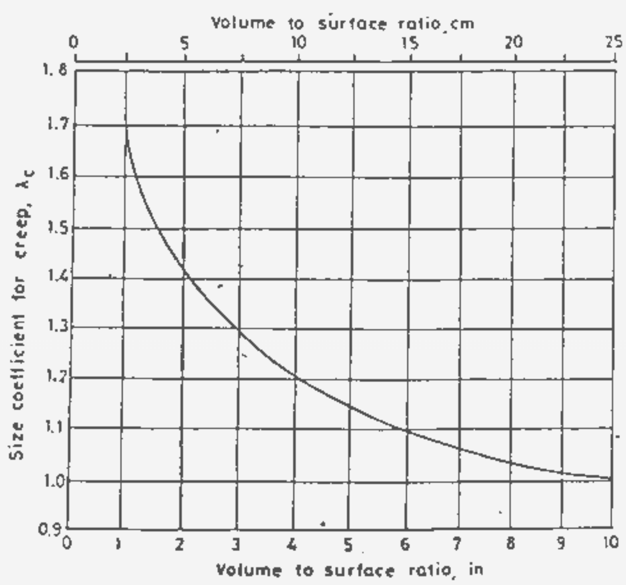

Figure 5 Variation of creep coefficient λs volume to surface ratio

c. *Variation of creep and shrinkage with time*

The rate of change of both creep and shrinkage with time follows an essentially similar curve of Fig. 6. The curve allows the ultimate creep or shrinkage to be estimated from a laboratory test of a finite time duration or, conversely, a value at a particular time to be estimated from a known ultimate value. If it is desired to evaluate the amount of creep or shrinkage that results after a particular time $t(I)$, for example, the final value would have to be multiplied by a factor $(1-\lambda_{t(I)})$ where $\lambda_{t(I)}$ is the value of λ_t at the particular time $t(I)$.

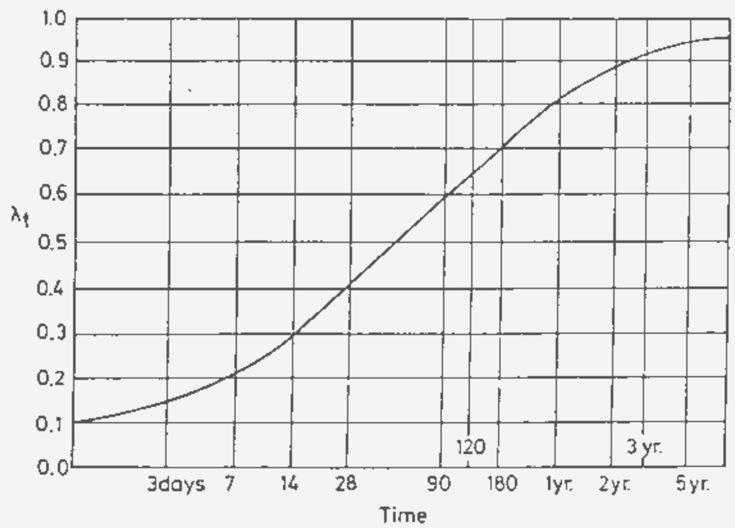

Figure 6 Change of creep or shrinkage with time

Determination of Support Shortening Due to Creep and Shrinkage for Frame Analysis

A rigorous frame analysis for inelastic strains in support is warranted in case of ultra high rise building or in case of rigid slab systems connecting vertical elements with high differential shortening. Where an exact knowledge of the effects of inelastic shortenings of supports on the structure is required, the following numerical procedure given by Fintel and Khan [2,3] may provide the needed information.

Figure 7 shows a schematic section of a multistory building with slabs up to level L already cast. The slabs above level L would be cast as construction proceeds. The slab at level L would be subjected to differential inelastic vertical movements of supports between levels ℓ and L as a result of summation of the following:-

a. Creep, Δ_{c1} due to loads that were applied before slab was cast.

b. Creep, Δ_{c2} due to loads applied during subsequent construction from level L to roof level R.

c. Shrinkage, Δ_s

Creep effects of the individual floor load are summed up to give total shortening.

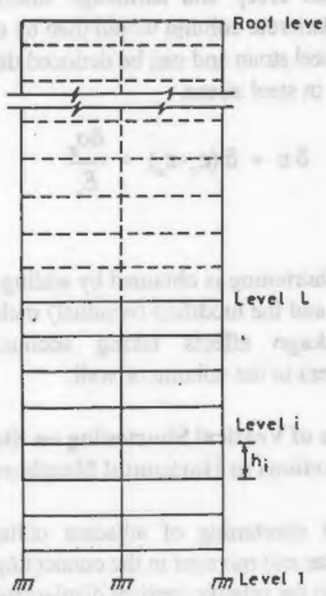

Figure 7 Schematic section of a multistoreyed building

It should be noted that each slab is affected by only differential shortening of snpport which would occur after the slab has become part of the frame for all subsequent time (i.e. to time $t=\infty$). All elastic and inelastic shortenings prior to casting is of no consequence as framework of the slab is usually laid horizontally and differentials are automatically compensated for.

Creep deflection Δ_{c1} is obtained by summing up the contribution of shortenings, $\delta_{c1,i}$ of individual storeys given by :

$$\delta_{c1,i} = h_i \sum_{j=i}^{L} \varepsilon'_{c(28)} \; \sigma_{cj} \, \lambda_c \, \lambda_a \, (1 - \lambda_t) \qquad (1)$$

where

$\delta_{c1,i}$ = creep of i^{th} storey by summing all the creep components that occur due to loads applied to all stories from levels I to L.

h_i = storey height

$\varepsilon'_{c(28)}$ = specific creep value

σ_{cj} = stress occurring in the transformed section due to load increments between level I and L.

λ_c = size coefficient for creep to take into account the effect of volume to surface ratio of Fig.5.

λ_a = creep ratio; to include the effect of age of column when each load increment is applied as in Fig.3.

$(1-\lambda_t)$ = creep that would occur over time t that elapses after the slab L is placed at time $t_L (t=t_L \text{ to } \infty)$.

Δ_{c1} is, thus expressed as

$$\Delta_{c1} = \sum_{1}^{L} \delta_{c1,i} \qquad (2)$$

The value of specific creep can be obtained from 28 day test on specimen of the design mix or estimated from generalized curves given in Fig.2.

Creep deflection Δ_{c2} is similarly obtained by summing up the contribution of shortenings $\delta_{c2,i}$ of individual storeys given by:

$$\delta_{c2,i} = h_i \sum_{j=L}^{R} \varepsilon'_{c(28)} \, \sigma_{cj} \, \lambda_c \, \lambda_a \qquad (3)$$

Δ_{c2} is now given by

$$\Delta_{c2} = \sum_{1}^{L} \delta_{c2,i} \qquad (4)$$

In a manner similar to creep, columns of storeys below level L would contribute their remaining shrinkage $\delta_{s,i}$ during a period subsequent to casting of slab L. The shrinkage deformation for each storey is given by the product of storey height, the ultimate shrinkage strain, the size coefficient and $(1-\lambda_t)$ to include only that part of the shrinkage that takes place after the slab a L was cast.

$$\Delta_s = \sum_{1}^{L} \delta_{s,i} = \sum_{1}^{L} h_i \, \varepsilon_s \, \lambda_s \, (1 - \lambda_t) \qquad (5)$$

ε_s = ultimate shrinkage strain

The ultimate shrinkage strain (ε_s) should ideally be obtained from a specimen of the concrete mix to be used in the structure and site conditions.

Therefore total inelastic shortening

$$\delta = \Delta_{c1} + \Delta_{c2} + \Delta_s \qquad (6)$$

Influence of Reinforcement on Column Stresses, Creep and Shrinkage

Tests have shown that when reinforced concrete columns are subjected to sustained loads there is a tendency for additional stress to be gradually transferred to the steel with a simultaneous decrease in the concrete stress. Long-term tests by Troxell *et. al.* [1] showed that in columns with low percentage of reinforcement the stress in the steel increased until yielding; while in highly reinforced columns after the entire load had been transferred to the steel, further shrinkage actually caused some tensile stresses in the concrete. It should, however, be noted that despite the redistribution of load between concrete and steel, the ultimate load capacity of the column remains unchanged.

The transfer of stresses from the concrete may reduce significantly the shortening due to ereep and shrinkage and hence reduce the differential effects on the slabs. According to Fintel and Khan [2,3] the influences of the reinforcing steel can be estimated by a separate calculation once the basic shortening has been determined.

By considering the conditions of equilibrium and compatibility between the steel and concrete, it was shown [2] that the changes in steel stresses, $\delta\sigma_s$ and concrete stress $\delta\sigma_c$ become

$$\delta\sigma_s = \frac{\sigma_c \varepsilon_c' + \varepsilon_s}{p\,\varepsilon_c'} F \qquad (7)$$

$$\delta\sigma_c = \left(\sigma_c + \frac{\varepsilon_s}{\varepsilon_c'}\right) F \qquad (8)$$

where the function F is given by

$$F = 1 - \exp\left[-\left[\frac{pn \times 100}{(1 + pn \times 100)}\right] \varepsilon_c' E_c\right] \qquad (9)$$

and

σ_c = initial elastic stress in concrete
E_c = modulus of elasticity of concrete
p = percentage reinforcement ratio of cross-section
n = modular ratio (E_s/E_c)

The residual creep and shrinkage strains $\delta\epsilon$ of a reinforced concrete column would then be equal to the additional steel strain and can be deduced directly from the change in steel stress.

$$\delta\varepsilon = \delta(\varepsilon_s + \varepsilon_c) = \frac{\delta\sigma_s}{E_s} \qquad (10)$$

The total shortening is obtained by adding the elastic shortening and the modified (residual) inelastic creep and shrinkage effects taking account of the reinforcement in the column or wall.

Influence of Vertical Shortening on Structural Actions in Horizontal Members

Differential shortening of adjacent column would produce shear and moment in the connecting beams or slabs, due to the relative vertical displacement caused by elastic and inelastic column shortening of the supports. The deflecting slabs or beams in turn develop resistant shears which act on columns decreasing the length changes. This rebound of columns present the actual resistance of the structure, and depends on slab or beam stiffness and on axial stiffness of columns.

Vertical shears in the deflected slab (see Fig. 8) resulting from differential shortening of adjacent colmmns cause transfer of loads to the element that shortens less. The accumulation of shears starts at the roof level, proceeding downward. The biggest accumulation of load occurring at lowest level of the structure. The amount of load transfer can be extremely high for very rigid connecting beams. Flexible slab systems follow the column length changes more easily and therefore transfer only insignificant amount of load from one column to the other. The method by Mark Fintel and Khan assumes that the shortening of vertical members can be calculated without reference to the horizontal connecting element. Neglecting the effect of horizontal connecting element would lead to error.

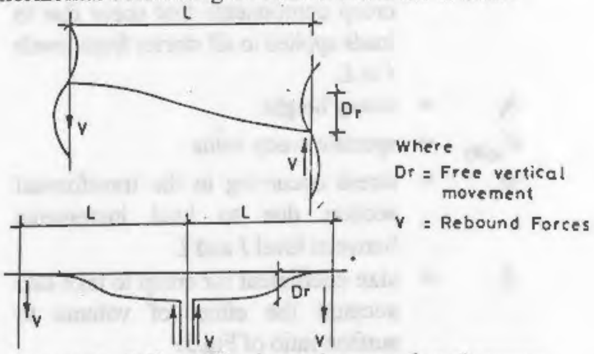

Figure 8 Effect of horizontal connecting elements

The effects of differential shortening between adjacent vertical elements may be estimated by replacing the floor slabs by beams of equivalent stiffness. The analysis starts with the known calculated differential vertical settlements Δ_i unrestrained by frame action. At floor level I, this differential movement Δ_i produces equal end moments 'M' of magnitude

$$M = \frac{6\,EI_i \Delta_i}{L_i^2} \tag{11}$$

where

EI_i = effective flexural rigidity of the beam,
L_i = span of the beam.

Associated end shear V are given by

$$V = \frac{2M}{L_i} \tag{12}$$

The analysis of the equivalent frame subjected to these initial forces may then be achieved using a plane frame program. This analysis yields the distribution of the additional slab moments and axial forces in the columns throughout the structure.

The support which settles less, receive additional load from the support which settles more. The transferred component of load is

$$V_i = \frac{M_{i1} + M_{i2}}{L_i} \tag{13}$$

where

M_{i1} and M_{i2} are the settlement moments (reduced due to creep relaxation) at the two ends of the horizontal elements. The effect of creep in beam may be taken into account by following the procedure given by Fintel and Khan [2,3].

METHODOLOGY AND SOFTWARE DEVELOPMENT

Methodology

a. Assumptions made in AP

Assumptions made in AP may now be listed as follows:-

1. The loads are estimated based on tributary areas.
2. For the calculation of elastic and inelastic deformation, the effect of the shearing action of horizontal members is not considered.
3. Principle of superposition is valid. The principle usually assumes
   a) The stresses are within the services stress range, i.e. less than about 0.4 of the concrete strength.
   b) unloading, i.e. strain of decreasing magnitude does not take place
   c) There is no significant change in moisture content distribution during creep.
4. Construction of every storey takes place instantaneously at the beginning or end of each storey construction time.
5. Calculation of elastic and inelastic deflection is considered under axial load only and analytical procedure is described in steps as follows:-

b. Analytical Procedure

In this sub-section the steps to develop software for AP solution procedure are described. This procedure takes into account the effect of creep and shrinkage in frames in which the shearing action of horizontal members is neglected while evaluating column axial forces based on which creep deflections are evaluated. Evaluation of loads on vertical members is therefore, based on tributary areas. The sequential application of load is considered. The vertical deflections, due to elastic shortening, and due to the effect of creep and shrinkage are estimated without considering the effect of the shearing action of horizontal members. The forces in members owing to these deflection are evaluated and superimposed on those obtained from linear analysis of frames in which deflection has been neglected.

The following steps have been carried ont for AP solution procedure.

Step 1: Evaluation of Elastic Shortening

The elastic shortening of supports occur mainly during the period of construction above the slab under consideration. The magnitude of elastic shortening to which each support of level I is subjected caused by loads above level L is (cf. Fig. 7) :

$$\Delta_e = \sum_{1}^{L} \delta_{ei} = P \sum_{1}^{L} \frac{h_i}{E_i A_i} \qquad (14)$$

where

Δ_e = total elastic deformation

δ_{ei} = individual elastic deformation in each story

E_i = elastic modules

A_i = transformed cross-sectional area of the member in storey I.

P = the sum of all loads above the particular level L.

The loads i.e. dead load and superimposed live load which is of permanent nature are taken based on tributary area. In the analysis of the elastic deformation the load is assumed to be applied sequentially.

Step 2: Evaluation of Inelastic Deformation due to Creep and Shrinkage

The inelastic deformation is evaluated using Eq.6.

Step 3: Steel Effect

The residual strain is evaluated using Eq. 10 and followed by residual deformation Δ_{CR}.

Step 4 : Total Shortening

Total shortening δ, is evaluated as

$$\delta = \Delta_c + \Delta_{CR} \qquad (15)$$

Step 5 : Frame Analysis

Step 5a : Load vector arising from total shortening δ is evaluated as explained earlier.

Step 5b : For the load vector evaluated in (Step 5a) corresponding to total shortening δ frame analysis is carried out.

Step 6: Frame analysis is also carried out for the imposed load.

Step 7: Member forces arising from total shortening (Step 5b) and from imposed load (Step 6) are added together to yield the final forces.

Software Development

A computer software, *AP* is developed for Approximate Procedure in Fortran 77. The flow chart is shown in Appendix 1.

LOAD TRANSFER BETWEEN ADJACENT COLUMNS DUE TO CREEP AND SHRINKAGE

For understanding the mechanism of load transfer between adjacent columns consider a one story, 3-bays frame having volume to surface ratio. $R = R_e$ for the exterior columns, $R=R_i$ for the interior columns; reinforcement percentage $p = p_e$ for exterior columns, $p = p_i$ for the interior columns; and having axial load $P=P_e$ for the exterior columns and $P=P_i$ for the interior columns. If R and p are kept constant and P_e is less than P_i then the load transfer would take place from the interior columns to exterior columns as shown in Fig. 9a. If P and p are kept constant, R_e is less than R_i as shown in Fig. 9b, the load transfer would take place from exterior columns to interior columns. Similarly for P and R kept constant and p_e less than p_i as shown in Fig. 9c the load transfer would take place from exterior columns to interior columns.

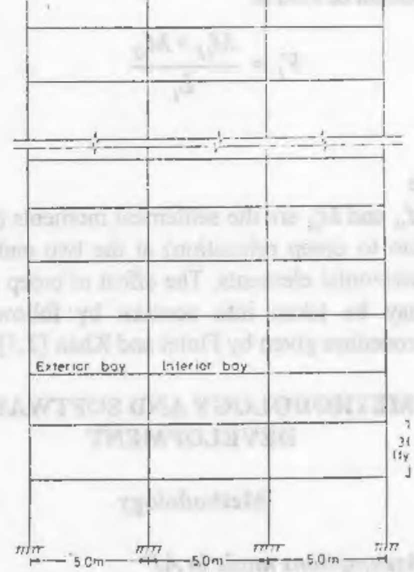

Figure 9 Nature of load transfer

In multistory frames also the above factors influence the load transfer.

PARAMETRIC STUDY

Parameters that influence creep and shrinkage behavior of a multistoreyed frame are:-

(1) Volume to surface, R (cm)
(2) Steel ratio, p (%)
(3) Number of storeys.

A 3-bay, 60 storeyed example building (Fig.10) with each bay of span 5m and loaded by a uniformly distributed loading, 20 KN/m dead load and 7 KN/m superimposed live load are considered. The ratio R is varied by changing the size of columns (exterior or interior) as 0.8 m × 0.8 m (R=20 cm) 1.0 m × 1.0 m (R = 25 cm) and 1.2 m x 1.2 m (R=30 cm). Moment of inertia of beam, I_b is taken as 1/10th of moment of inertia of interior column, I_c. It may be noted that as R is varied, shearing stiffness of beam also gets changed. Steel ratio $p=p_e$ in exterior column and that, $p=p$ in interior column are varied as 1%, 2%, 3% and 4%.

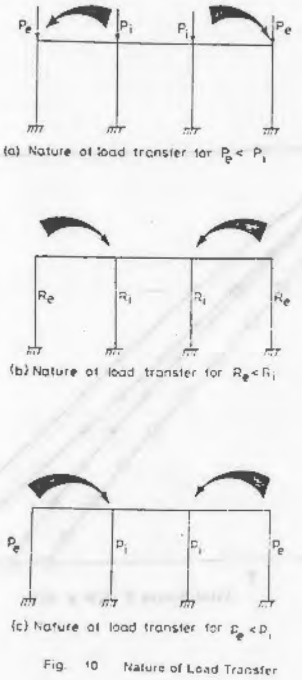

Figure 10 Schematic view of a 20/40/60 storeyed frame

The other data for material properties are:-

Concrete mix, C40, $E_c = 3.6 \times 10^7$ KN/m^2, $E_s = 2.1 \times 10^8$KN/m^2; $\epsilon_c = 27 \times 10^{-9}$ m/m/KN/m^2, $\epsilon_s = 0.620 \times 10^{-6}$ m/m for first 90 days.

Studies are carried out for Effect of R.

Effect of R

The effect of R is studied by changing $R=R_i$ for the interior columns and keeping $R=R_e$ for the exterior columns constant. First R_e is kept equal to 20 cm and R_i is changed from 20 cm to 30 cm in steps of 5 cm. The difference $R_d = R_i - R_e$ thus varied from 0 to 10 cm in steps of 5 cm.

Creep deflection δ of exterior and interior columns for R_d = 0, 5 cm and 10 cm are shown in Figs. 11 to 13, respectively. It is seen from the figures that the deflection at the top floor is smaller than at some of the floors below. This is owing to the fact that due to the sequential nature of application of the load, a part of the creep is made up. This effect is the maximum in the top portion of the frame. This trend has also been reported in literature (Fintel and Khan [3]).

The deflection δ in the interior column is more than that in the exterior column (Fig. 11) over considerable height. However the reverse is observed in the top portion. This may occur since the residual creep and shrinkage strain vary along the height and get modified (See Eq. 7-10) differently for the exterior and interior columns owing to different reinforcement percentages in the two columns. It may be noted that R is the same for exterior and interior columns.

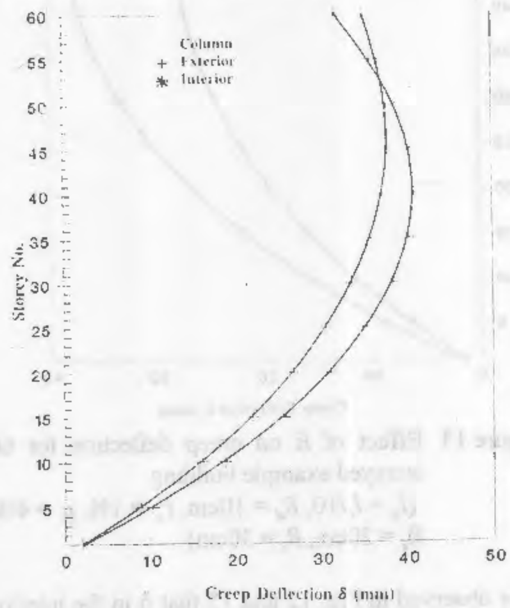

Figure 11 Effect of R on creep deflection for 60 storeyed example building ($I_b = I_c/10$, $R_d = 0$, P_e = 1%, p_i = 4%, R_e = 20cm, R_i = 20cm)

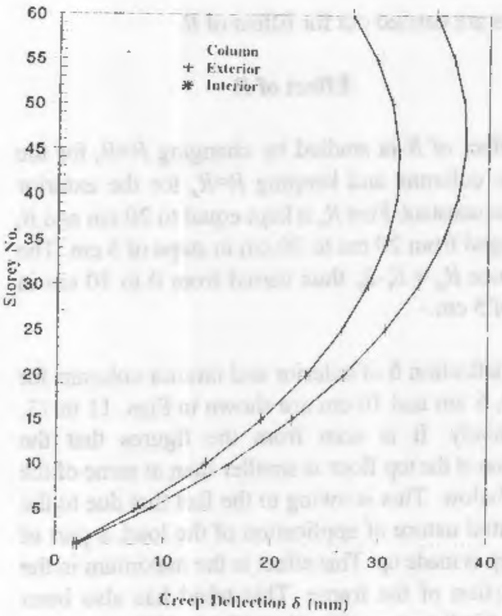

Figure 12 Effect of R on creep deflection for 60 storeyed example building ($I_b = I/10$, $R_d = 5$cm, $P_e = 1\%$, $p_i = 4\%$, $R_e = 20$cm, $R_i = 50$cm)

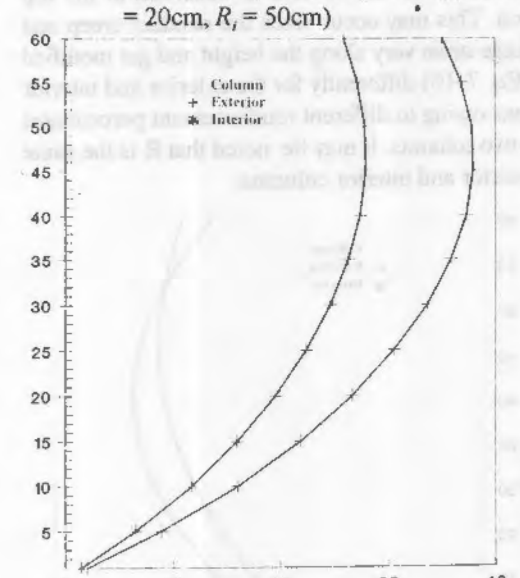

Figure 13 Effect of R on creep deflection for 60 storeyed example building ($I_b = I_c/10$, $R_d = 10$cm, $P_e = 1\%$, $p_i = 4\%$, $R_e = 20$cm, $R_i = 30$cm)

It is observed in Fig. 12 and 13 that δ in the interior column is smaller than that in exterior column. This is owing to increase in R for interior column resulting in much lesser creep deflection.

As R_e is kept constant equal to 20 cm and R_d changing from 0 cm to 10 cm the differential creep deflection, δ_d between interior and exterior columns generally increases. The value of maximum δ_d is 4.783 mm at floor 30 for $R_d = 0$, 7.744 mm at floor 60 for $R_d = 5$ cm and 9.9862 mm for $R_d = 10$ cm at floor 45. This occurs since creep deflection, δ for the exterior columns remains practically unchanged while that for the interior columns decreases as R_i changes from 20 cm to 30cm.

Axial force, P in exterior columns for R_d=0, 5 cm and 10 cm are shown in Figs. 14 to 16 respectively. It is observed that the load transfer due to creep and shrinkage is from exterior columns to interior columns in all the storeys. For R_d=0, P in the interior columns increases in the 1st storey, 30th storey and 60th storey by 8.38%, 18.17% and 45.23%, respectively. The corresponding percentage for R_d = 5 cm are 26.67%, 36.64% and 42.66%; and for R_d = 10 cm are 29.56%, 37.12% and 33.67% respectively. Thus the nature of load transfer is observed to vary along the height.

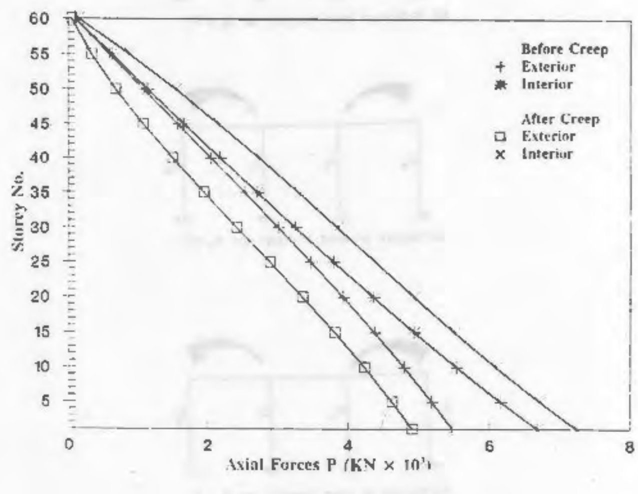

Figure 14 Effect of R on axial load distribution for 60 storeyed example building ($I_b = I_c/10$, $R_d = 0$, $P_e = 1\%$, $p_i = 4\%$, $R_e = 20$cm, $R_i = 20$cm)

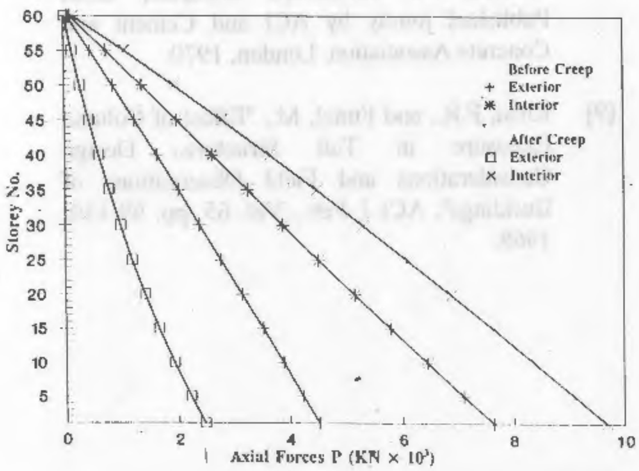

Figure 15 Effect of R on axial load distribution for 60 storeyed example building ($I_b = I_c/10$, R_d = 5cm, P_e = 1%, p_i = 4%, R_e = 20cm, R_i = 25cm)

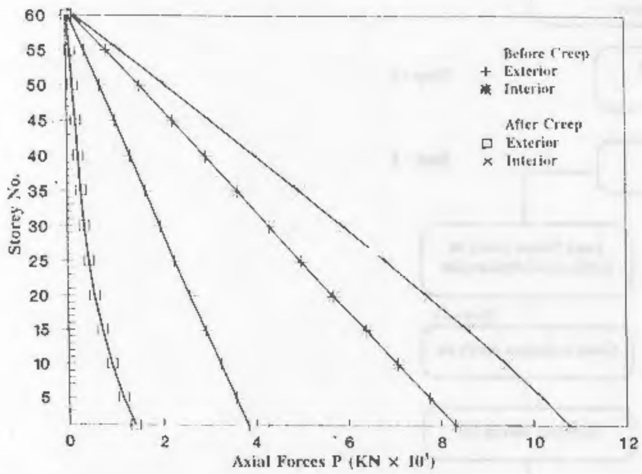

Figure 16 Effect of R on axial load distribution for 60 storeyed example buildiug ($I_b = I_c/10$, R_d = 10cm, P_e = 1%, p_i = 4%, R_e = 20cm, R_i = 30cm)

The nature of load transfer between exterior and interior columns may be understood by considering beam shear resulting from δ_d. The shear due to δ_d in a beam at a floor changes axial forces in the adjacent columns of all the storeys below the floor level. If $\delta_i > \delta_e$ the beam shear would result in increase in P_e and decrease in P_i. The reverse will occur when $\delta_e > \delta_i$. The total change in P_e or P_i in a column of a storey is the sum of the changes induced by all the beams in the storey above. The percentage increase or decrease in P_e or P_i therefore would not be uniform along the height. Further the nature of load transfer along the height may change, it may be from interior columns to exterior columns at a floor level and in the reverse manner at other floor levels depending on the cumulative effect of shears (due to δ_d) in all the beams above the level.

CONCLUSIONS

1. Based on AP. a software in Fortran 77 has been developed.

2. Using the software developed behavior of frames under creep and shrinkage is studied when shear stiffness of the beam is low ($I_b = I_c/10$). From the studies following conclusions are drawn.

   a. The nature of load transfer may change along the height. The load transfer may take place from exterior columns to the interior columns in a portion of the frame and from interior columns to exterior columns in the other portion.

   b. In 1st storey where high axial forces occur, the load transfer from exterior columns to interior columns can be as high as 40% for high p_d (3%).

   c. The percentage of load transfer increases with number of storeys.

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APPENDIX 1

SCHEMATIC BLOCK DIAGRAM FOR API - SOFTWARE