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CALCULATION OF CREEP AND SHRINKAGE IN TALL CONCRETE BUILDINGS USING NONLINEAR STAGED CONSTRUCTION ANALYSIS

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ABSTRACT

This paper attempts to calculate column shortening and differential shortening between columns and walls in concrete frames using a nonlinear staged construction analysis based on the Dirichlet series and direct integration methods. Prototype frame structures are idealized as two-dimensional and the finite element method (FEM) is used to calculate the creep and shrinkage strains. It is verified with respect to published experimental and analytical results. B3 model and methods such as AAEM, EMM, IDM, and RCM are used for verification purposes.

For each frame, effects of creep and shrinkage parameters such as relative humidity percent, rate of construction, shrinkage parameter, and concrete strength have been taken into consideration separately. The manner in which creep and shrinkage can influence the behavior of concrete structures also has been discussed.

Keywords: Tall concrete buildings; creep; shrinkage; nonlinear staged construction analysis; B3 model; dirichlet series; finite element method

1. INTRODUCTION

The determination of strains in frame structures caused by creep and shrinkage is a complex problem. Even though much research has been carried out to determine of these effects, the phenomenon of creep and shrinkage still constitutes an interesting research topic and remains to be understood fully. Fundamental research studying the effects of creep and shrinkage in concrete has been published by the several scientists up to now [1-5]. In this regard, different methods for the prediction of creep and shrinkage in concrete buildings are proposed in this paper. Moreover, creep and shrinkage in concrete structures have not been researched fully by using nonlinear staged construction analysis. Hence staged analysis and consideration of nonlinear behavior is a main feature of this paper.

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In this study, attempt is made to use a combination of creep analysis using Dirichlet series and direct integration methods, coupled with structural analysis including nonlinear staged construction. For the prediction of different parameters due to creep and shrinkage, CEB-FIP 1990 criterion is used and the FEM is uses for analysis of structures with inclusion of plastic hinges for each element. For model verification, two different approaches have been utilized. In the first approach, program results are compared with AAEM, RCM, IDM and EMM methods. In the second approach, the B3 model is used to verify the behavior of a 45-story building. Several parameters, such as rate of construction, relative humidity, shrinkage parameter, concrete strength are taken into consideration.

2. CASE STUDY

Six buildings, ranging in size from 15 to 45 stories, were selected for the case studies. All frames include shear walls with different spans and column dimensions in a suitable range were selected. They were analyzed using nonlinear staged construction analysis and designed according to ACI-318 (American Concrete Institute) criteria. The dimensions of the columns and beams in each building model are shown in Table 1. A schematic of the buildings studied is shown in Figure 1.

For all columns $\rho = 2.5\%$, and the thicknesses of walls are in the range of 15 to 35 cm. In all buildings, the height of the first story is 3.5m and the height of other stories is 3m, and all buildings the length of spans is 6 m.

Creep and shrinkage parameters were determined in accordance with CEB-FIP. Parameters such as relative humidity percent (h), national size (n), shrinkage coefficient (Bsc) and shrinkage start time were assigned to concrete. The finite element method calculated the creep and then the shrinkage coefficient and creep and shrinkage analysis was started using full integration or Dirichlet series methods.

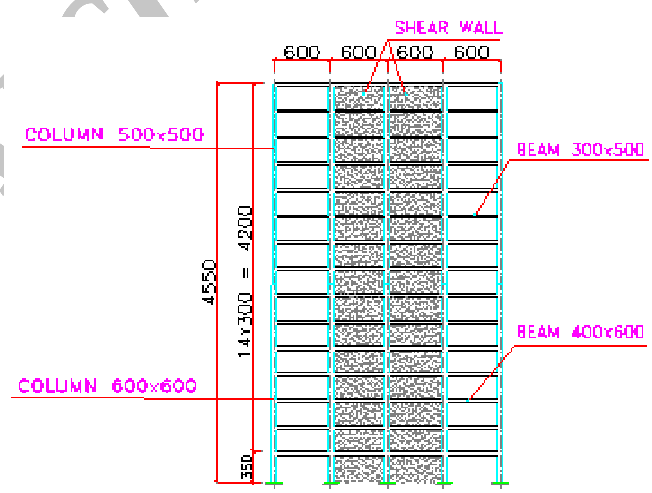

Figure 1. Schematic form of studied buildings

Table 1.Dimensions of columns and beams in each building

No. of stories	Beam dimensions	Column dimensions
15	$600\times400(9th);500\times300(15th)$	$600\times600(8th);500\times500(15th)$
20	$800\times800(13th);600\times400(20th)$	$800\times800(13th);600\times600(20th)$
25	$800\times800(15th);800\times500(25th)$	$1000\times1000(15th);800\times800(25th)$
30	$800\times950(14th);800\times800(23rd);$ $600\times600(30th)$	$1100\times1100(14th);800\times800(23rd);$ $600\times600(30th)$
40	$1100\times1100(15th);1000\times1000(25th);$ $800\times800(33rd);700\times700(40th)$	$1500\times1500(15th);1250\times1250(25th);$ $1000\times1000(32nd);700\times700(40th)$
45	$1100\times1100(15th);1000\times1000(25th);$ $800\times800(33rd);700\times700(45th)$	$1500\times1500(15th);1250\times1250(25th);$ $1000\times1000(32nd);750\times750(45th)$

3. MODEL VERIFICATION

For verification of the numerically procedure, two separate methods are used. In the first part, a concrete column subjected to a concentrated load was studied [1].

For the creep analysis, manual methods such as the Effective Modulus Method (EMM) [2], Age-Adjusted Effective Modulus Method (AEMM) [3], Rate of Creep Method (RCM) [4], and Improved Dischinger Method (IDM) [5], are used. The results for the deflections of the column over time are shown in Figure 2. It is clear that the calculated results from manual methods are very close to the deflections calculated by the finite element method. The small difference between results is caused by different assumptions creep coefficient, and ultimate shrinkage for manual methods over several times. The coefficients and ultimate shrinkage for manual methods are shown below:

$(t-t_0)=0$ Days $\phi_{(t)}=0.0$ $\varepsilon_{sh}(t-t_0)*10^{-6}=0.0$

$(t-t_0)=25$ Days $\phi_{(t)}=1.0$ $\varepsilon_{sh}(t-t_0)*10^{-6}=200.0$

$(t-t_0)=100$ Days $\phi_{(t)}=2.0$ $\varepsilon_{sh}(t-t_0)*10^{-6}=400.0$

$(t-t_0)=10000$ Days $\phi_{(t)}=3.0$ $\varepsilon_{sh}(t-t_0)*10^{-6}=600.0$

$t_0=10$ Days

For which column, section properties and size of load are equal to: $A_S=1800\ mm^2$,

$A_C = 90000 \quad mm^2$, $E_S = 200 \quad GPa$, $E_C(t_0) = 25\, GPa$, $\rho = 0.02$, $P = 1000 \; KN$, $L_{column} = 6 \;\; m$

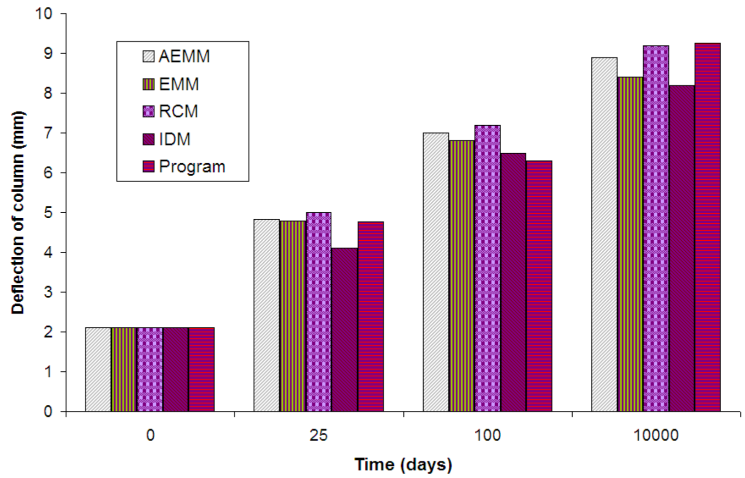

Figure 2. Deflections of column for EMM, AEMM, IDM, RCM and FEM

In the second part, a 45-story building, already analyzed by Bast, is modeled by FEM [6]. Bast used a B3 Model for the creep analysis of a 45 story building [7]. In this part, the results by methods (Model B3 and CEM-FIP, Nonlinear staged construction and FEM) are compared and shown in Figures 3, 4 and 5, which show that FEM results are very close to the experimental results.

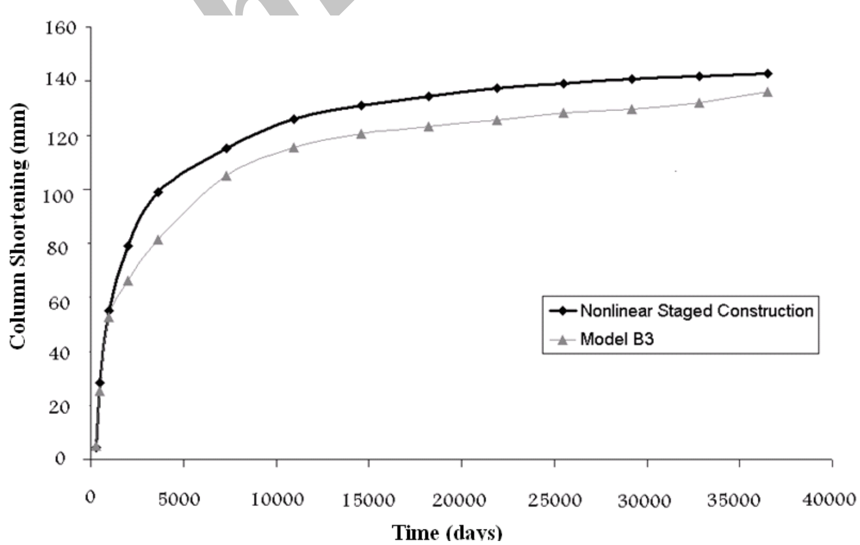

Figure 3. Column shortening for the 45th story of a 45-story building

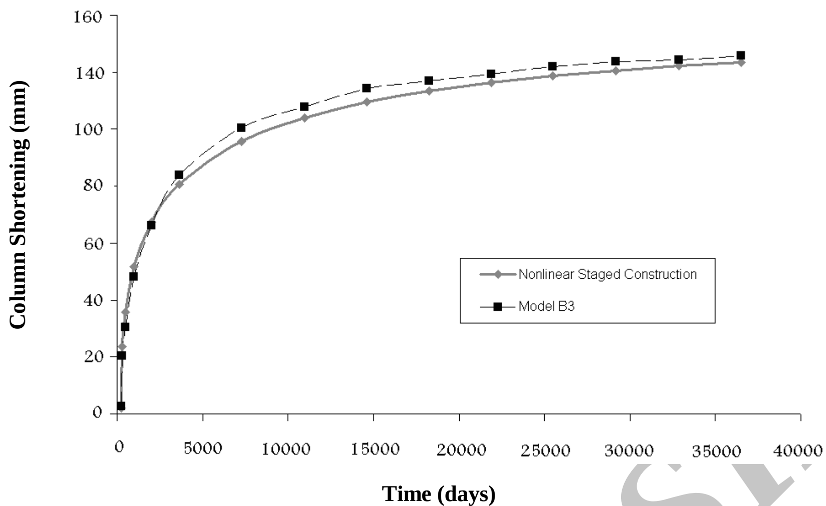

Figure 4. Column shortening for the 40th story of a 45-story building

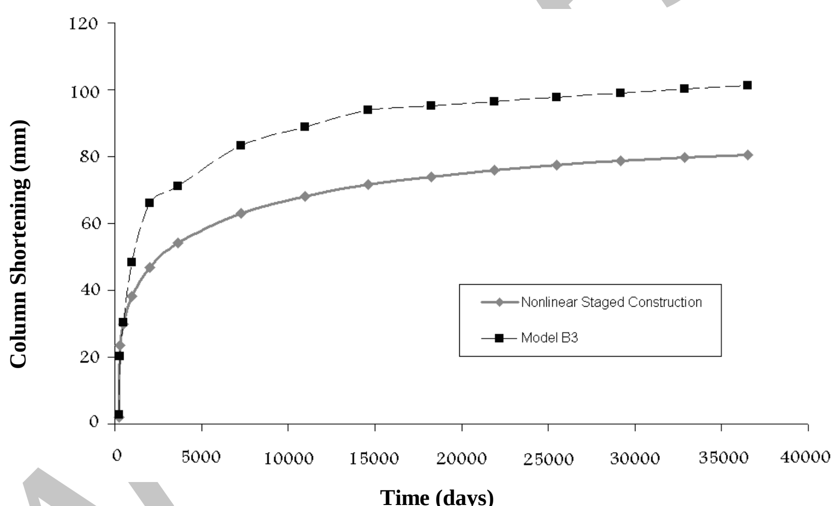

Figure 5. Column shortening for the 19th story of a 45-story building

4. RESULTS

4.1 Rate of construction effect

The construction rate is one of the important parameters in creep and shrinkage studies; it may determine both engineering and climatic conditions. The deflected shapes of 40 and 15 story buildings are shown in Figure 6 and 7.

In this study, column shortening and differential shortening between the shear wall and column were calculated for the rate of construction of 7, 14, 21, 28, and 35 days per story. All the results in this section are for 70% relative humidity. The results for the column shortening for these buildings are shown below (Figures 8-10).

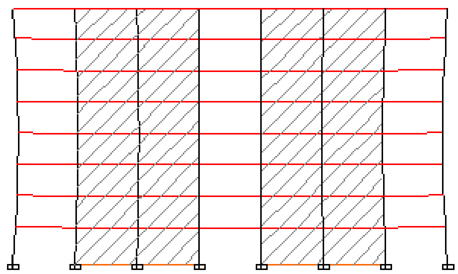

Figure 6. Deformed shape of a 40-story building at the 8th step

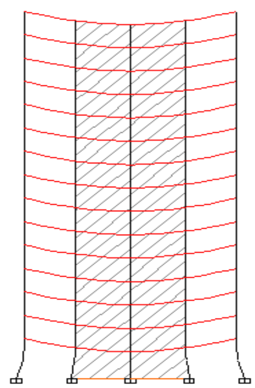

Figure 7. Deformed shape of a 15-story building at the final step

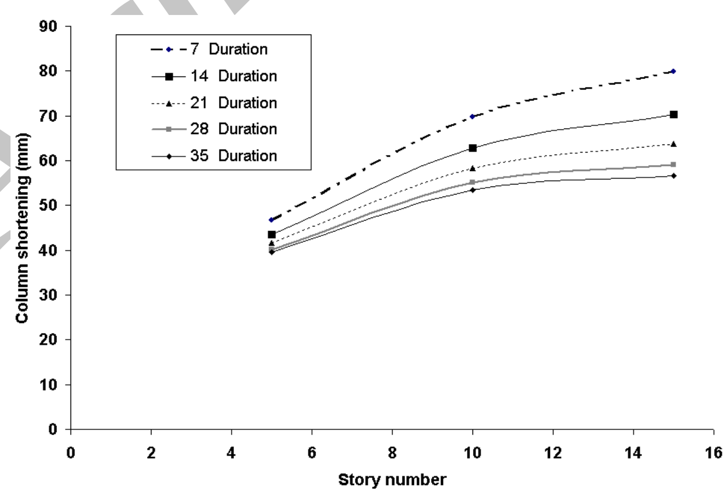

Figure 8. Column shortening of a 15-story building for different rates of construction

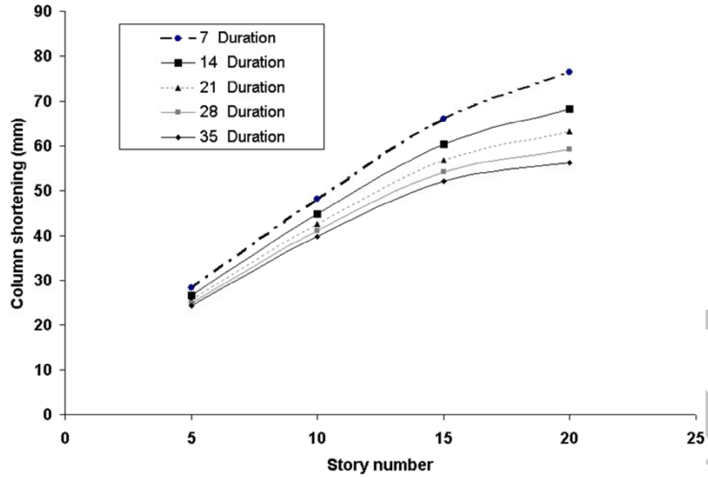

Figure 9. Column shortening of a 20-story building for different rates of construction

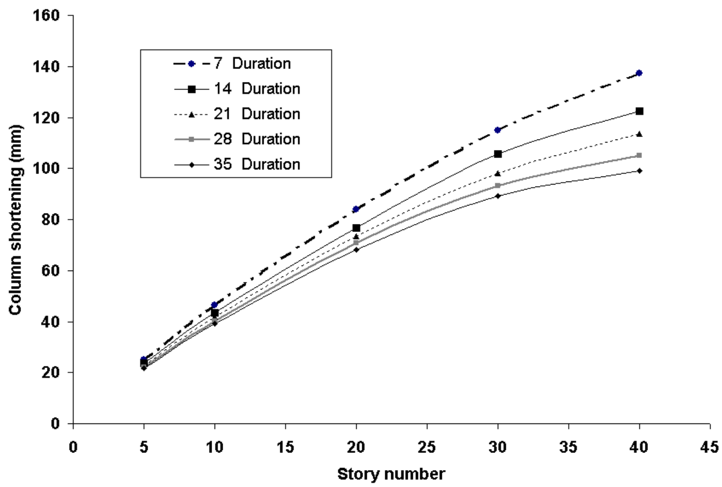

Figure 10. Column shortening of a 40-story building for different rates of construction

As seen above, column shortening values increase when the rate of construction increases. Also, column shortening increases continuously with the height of the structure. Shortening for different stories Based on the percentage change of column the values are shown in Table 2.

Table 2. Percentage of changes of column shortening for a 40 story building

Rate of Cons. (days/story)	Number of stories				
	5	10	20	30	40
! !7	0	! !0	0	0	! !0
14	4.87	6.38	8.72	8.2	10.85
21	8.82	9.73	12.53	14.7	17.13
28	11.11	13.08	15.88	18.98	23.5
35	13.37	15.34	18.69	22.38	27.74

The values of differential shortening for the rates of construction 7, 14, 21, 28, and 35 days per story for some of the buildings are shown in Figures 11-13.

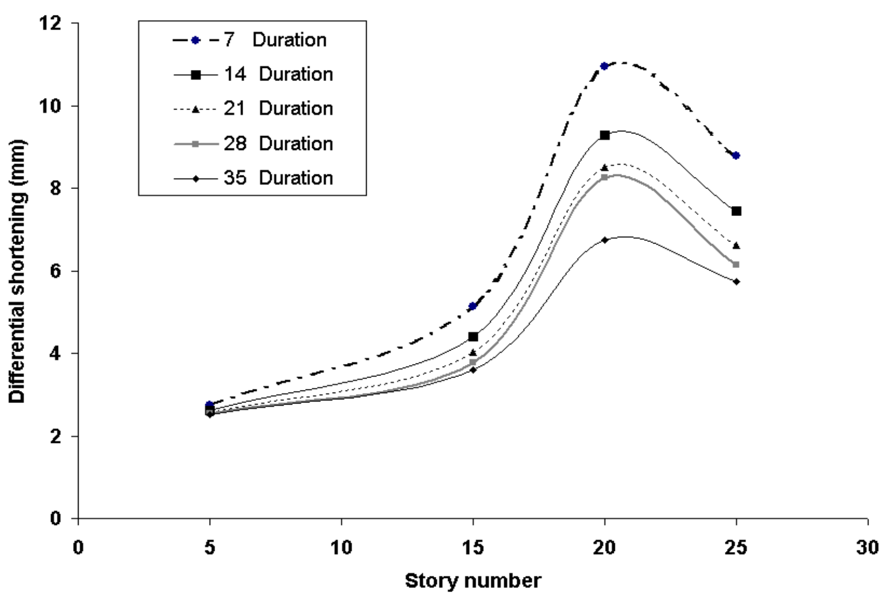

Figure 11. Differential shortening of a 25-story building for different rates of construction

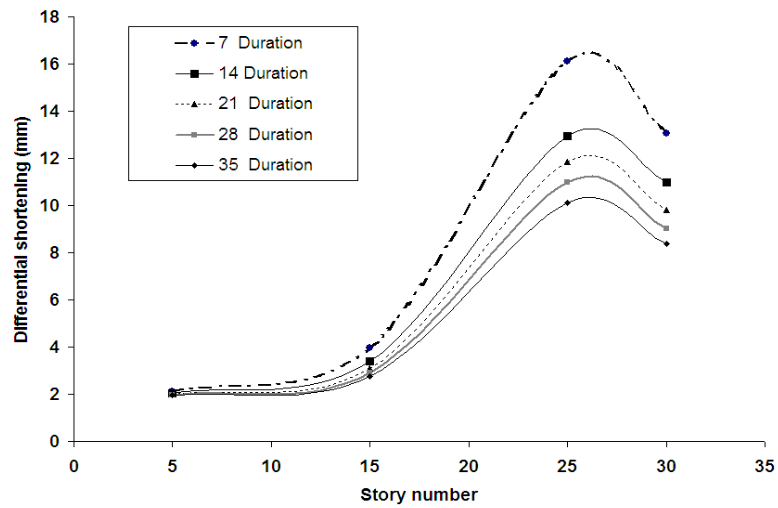

Figure 12. Differential shortening of a 30-story building for different rates of construction

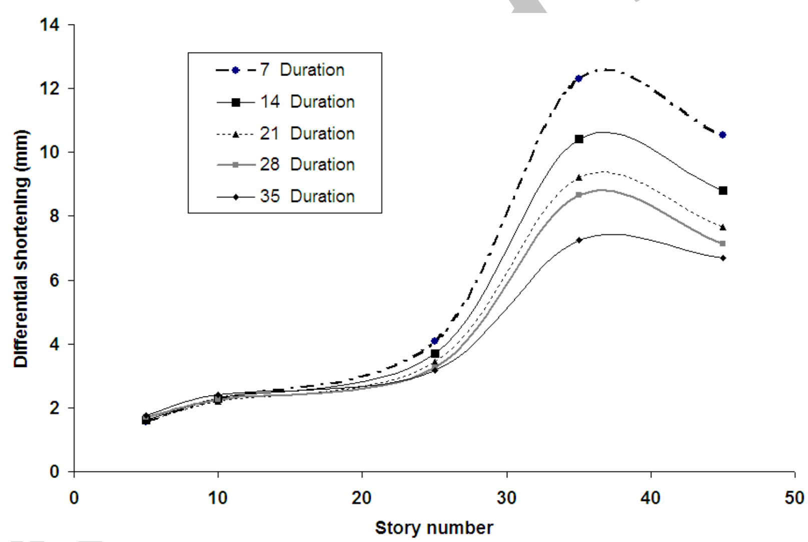

Figure 13. Differential shortening of a 45-story building for different rates of construction

It is clear that if the rate of construction decreases, the differential shortening decreases. However, the important point is that maximum differential shortening occurred in the vicinity of the top of the buildings. It is important that the values of differential shortening do not follow on from the number of stories in the buildings. Therefore, these parameters are related to other parameters such as relative humidity or the properties of cross sections [8-9].

Creep and shrinkage analysis shows that at the end of a building usefulness, the shear walls shortage is more than the columns and, so structures (buildings) deflect in a concave form. It is a phenomenon already confirmed by White and Salmon [10].

4.2 Relative humidity effect

Relative humidity affects both creep and shrinkage and, therefore, studies for the relative humidity are important. Due to the effect of relative humidity on the rate of cement hydration, creep and shrinkage are highly dependent on it. In this study, 40, 50, 60, 70, 80, and 90% relative humidity were considered.

For all of the buildings, creep and shrinkage strains were calculated separately and the rate of construction was seven days/story. Column shortening and differential shortening are calculated and compared for all of the buildings. The calculated values for column shortening are shown in Figures 14-16.

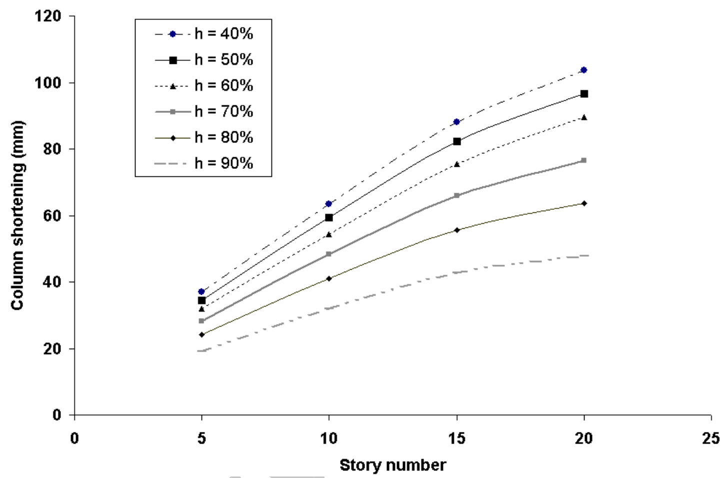

Figure 14. Column shortening of a 20-story building for different relative humidity

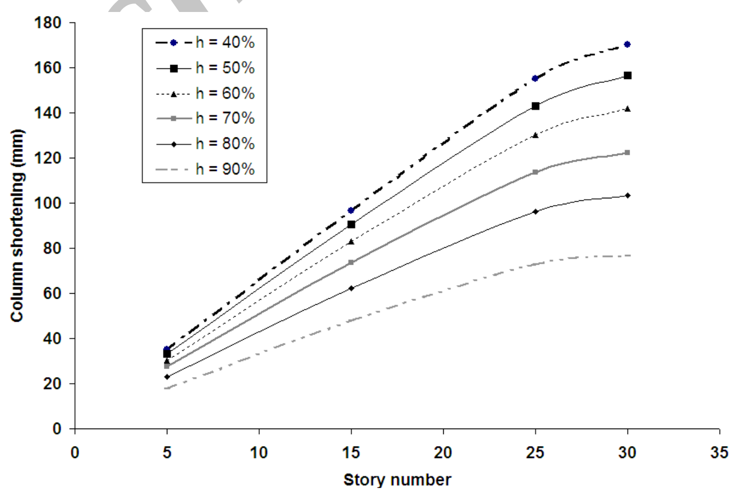

Figure 15. Column shortening of a 30-story building for different relative humidity

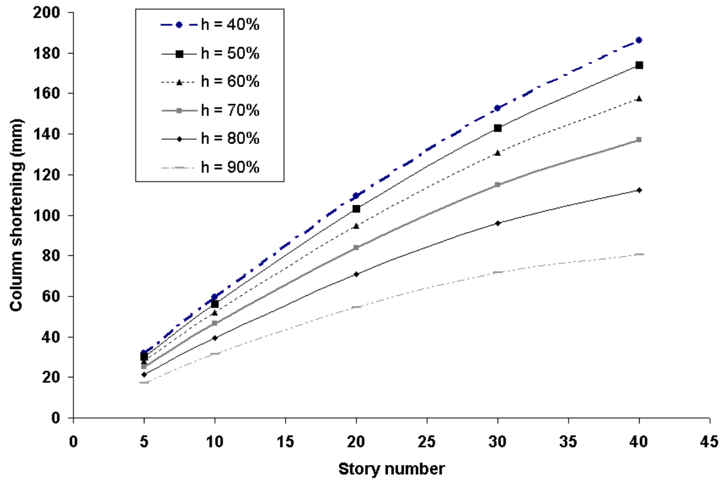

Figure 16. Column shortening of a 40-story building for different relative humidity

As can be seen in Figures 14-16, the effect of relative humidity on creep and shrinkage strains is very noticeable. Actually, structural engineers should pay attention to climate conditions in each region. If the results in Figures 14-16 are noted carefully, it is clear that, whenever relative humidity increases, then creep and shrinkage decreases. The percentage values of changes in column shortening for different stories in a 25-story building are shown in Table 3. From Table 3, it can be seen that the number of stories has no effect on creep and shrinkage strains. Also, it is possible to show that relative humidity has a considerable effect on creep and shrinkage strains and that the percentage of change of column shortening in a story exceeds 50 percent. The differential shortening between a column and a shear wall is shown in Figures 17-19.

Table 3. Percentage of change of column shortening for a 40 story building

Story No.	Relative humidity percent					
	40	**50**	**60**	**70**	**80**	**90**
5	0	6.51	15.72	25.93	38.08	52.47
15	0	6.81	15.38	25.98	38.41	53.06
! !20	0	! !6.86	15.51	26.31	38.89	53.75

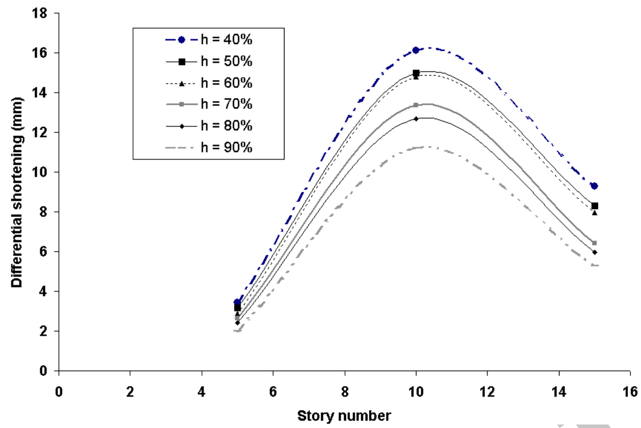

Figure 17. Differential shortening of a 15-story building for different relative humidity

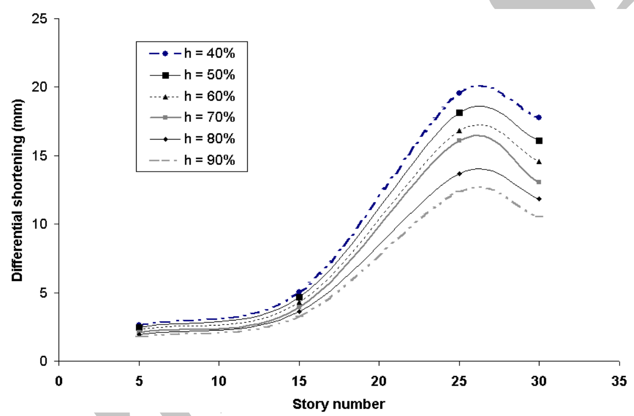

Figure 18. Differential shortening of a 30-story building for different relative humidity

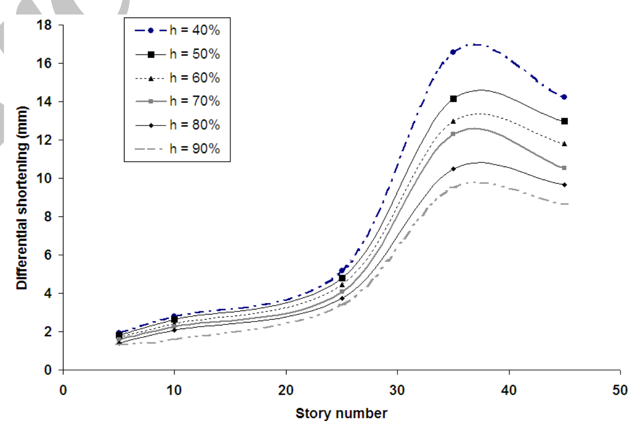

Figure 19. Differential shortening of a 45-story building for different relative humidity

Maximum differential shortening occurs close to the top of buildings. The relative humidity parameter does not have a great effect on the differential shortening in the lower stories of buildings.

4.3 Effect of different methods on the creep strain

The Dirichlet series method and the full integration method can be used for creep analysis [11]. In former method, the creep function of concrete can be approximated with the desired accuracy using the Dirichlet series.

Expansion in the Dirichlet series is accomplished easily with a computer. The Dirichlet series method was recommended for large structures and the full integration method was recommended for small structures because it avails itself of numerical integration. In this study, both methods are used for 20-45 frames to determine the effective number of sentences of the Dirichlet series. In other sections of this paper, the Dirichlet series method is used. The values of column shortening, via the mentioned methods, are shown in Figures 20-22.

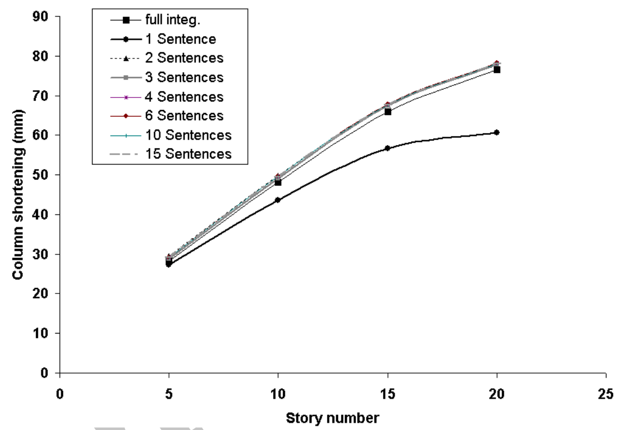

Figure 20. Column shortening of a 20-story building for different methods

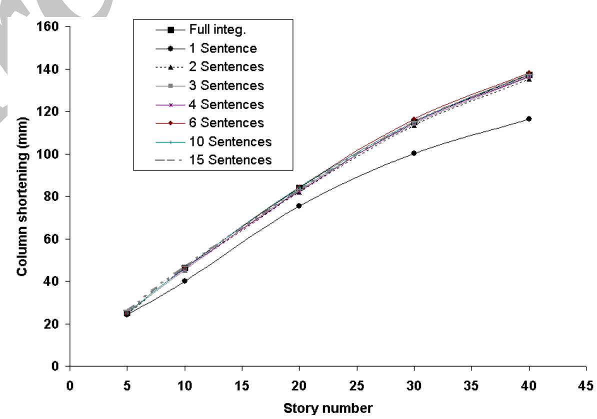

Figure 21. Column shortening of a 40-story building for different methods

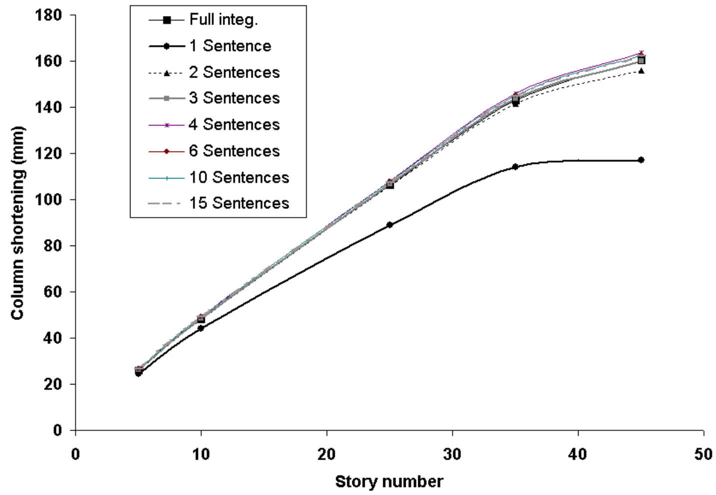

Figure 22. Column shortening of a 45-story building for different methods

As can be seen from these figures, column shortening for both methods is very close to the second sentence of the Dirichlet series. Therefore, for practical cases, it is possible to recommend that three sentences from the series can be sufficient for calculation of creep strain in the actual buildings. Actually, the objective of this section is to determine the sufficient number of sentences due to the Dirichlet series, for practical purposes.

4.4 Effect of shrinkage parameter (B_{sc})

The total shrinkage of concrete can be determined from the following equations:

$$\varepsilon_{sh}(t,t_0) = \varepsilon_{sh0}\beta_s(t-t_0) \tag{1}$$

In this equation, for ε_{sh0} and $\beta_s(t-t_0)$, one has:

$$\varepsilon_{sh0} = \varepsilon_s(f_c)\times\beta_{RH} \tag{2}$$

$$\beta_s(t-t_0) = [\frac{(t-t_0)/t_1}{350\times(n/n_0)^2+(t-t_s)/t_i}]^{0.5} \quad t_1 = 1\ ;\ n_0 = 100mm \tag{3}$$

$$\beta_{RH} = -1.55\times[1-(h/100)^3] \tag{4}$$

$$\varepsilon_s(f_c) = [160+10\times B_{sc}(9-\frac{f_c}{f_{c0}})]\times 10^{-6} \tag{5}$$

In this equation, B_{sc} is the shrinkage parameter that is dependent on the type of cement used in the concrete [12]. For more details about shrinkage strain, the CEB-FIP criterion and ACI 209 code are recommended[13-14]. The values of shrinkage parameters for different types of cement are equal to:

$B_{sc} = 4$ For low-speed hardening cement

$B_{sc} = 5$ For normal hardening or high speed hardening cement

$B_{sc} = 8$ For high strength and high speed hardening cement

The values of column shortening are determined according to different shrinkage parameters (B_{sc}) and are shown in Figures 23-25.

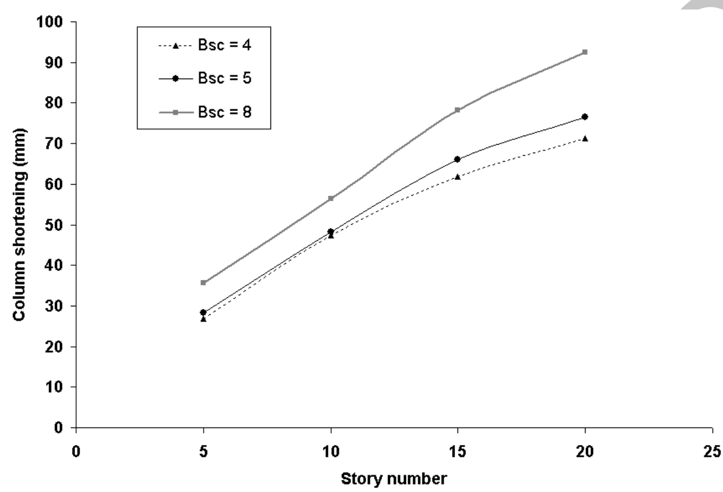

Figure 23. Column shortening of a 20-story building for different B_{sc}

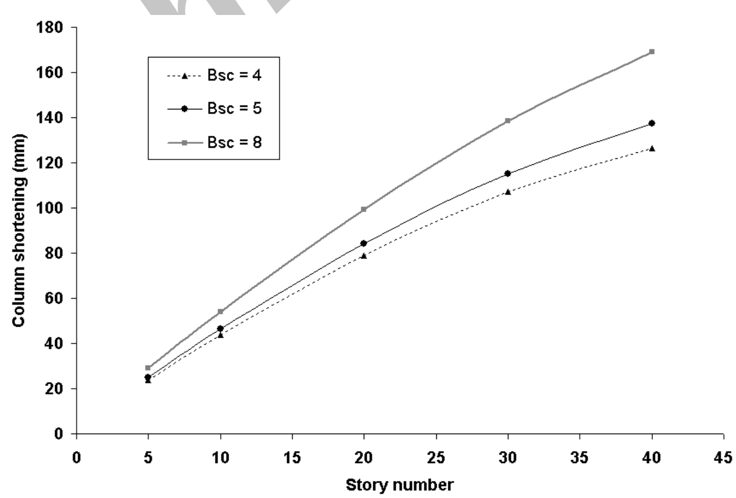

Figure 24. Column shortening of a 40-story building for different B_{sc}

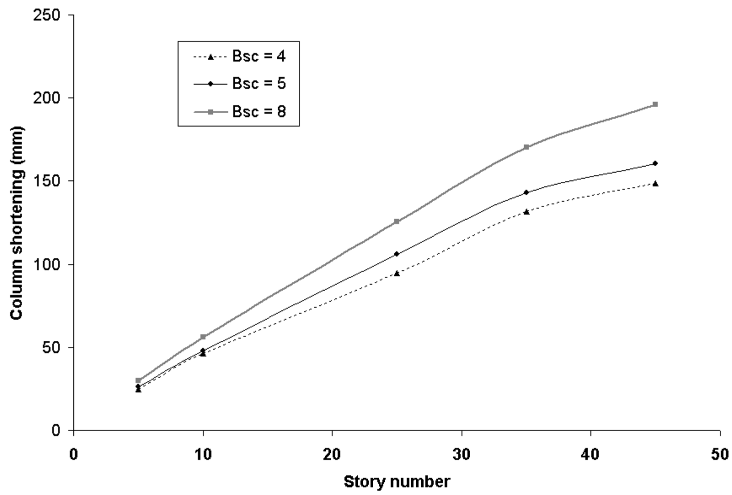

Figure 25. Column shortening of a 45-story building for different B_{sc}

It is clear that if low speed cement is used, shrinkage strain will be reduced. Of course, it was important that, in this study, strains due to creep and shrinkage were not separated. Thus, since the shrinkage parameter has no effect on creep strain, it is possible to determine the effects of B_{sc} on the shrinkage strain. Results from software analysis show that shrinkage parameters have no effect on differential shortening.

4.5 Compressive strength effect

For this section, compressive strength, in the range of 15 to 75 Mpa, was studied. The values of column shortening are shown in Figures 26 and 27.

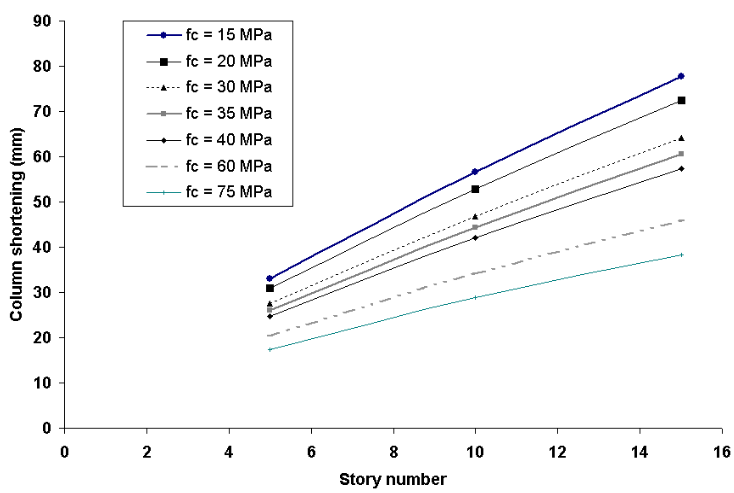

Figure 26. Column shortening of a 15-story building for different compressive strength

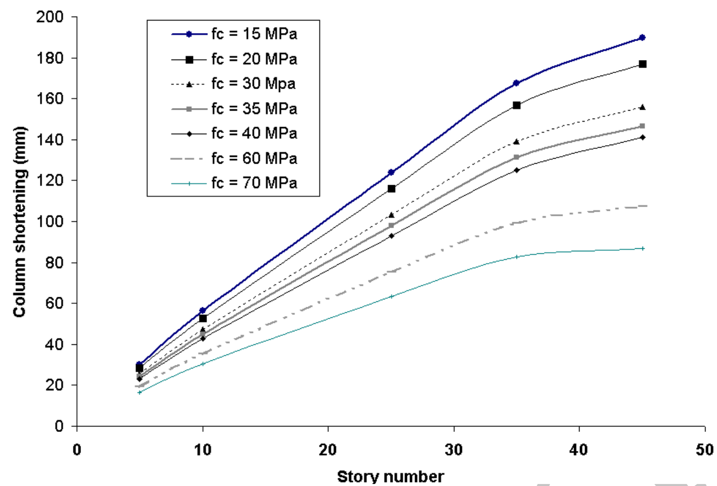

Figure 27. Column shortening of a 45-story building for different compressive strength

5. CONCLUSION

Results show that, for tall concrete buildings, a nonlinear static staged construction analysis can result in more realistic and significantly different results as compared to traditional analyses that ignore this phenomenon. For regions with relatively low humidity, using a material nonlinearity concept, the assessment of structures for creep and shrinkage effects, also can be very important. It is recommended that a nonlinear stage construction analysis can be undertaken for regions with 60% relative humidity or less. In the design stage, it is better to avoid sudden changes in the cross section geometry or rebar percentages in adjacent members. If nonlinear staged construction analysis is to be used, critical values of relative humidity, rate of construction etc should be applied. When using the Dirichlet series for the creep analysis of structures, three sentences of the series yield good accuracy.

The results and the discussion herein can be summarized as follows:

1) For different rates of construction, maximum column shortening and differential shortening are around 30mm and 7mm for the frames studied in this research respectively.
2) Differential shortening and column shortening at the required floor level can be obtained from relevant figures, depending on relative humidity of surrounding environment, rate of construction of building and strength of concrete that used in building. For other buildings that are not covered in this study, interpolating of graphs can be useful.
3) Maximum differential shortening occurs close to the top of buildings.
4) The relative humidity parameter does not have a great effect on the differential shortening in the lower stories of buildings.
5) Creep and shrinkage analysis shows that, at the end of a building usefulness, the shear

walls shortage is more than the columns and, so, structures (buildings) deflect in a concave form

6) Different method for creep analysis and shrinkage parameter (B_{sc}), have no significant effect on the differential shortening between wall and column.
7) For nonlinear staged construction analysis, FEM based software such as SAP2000, OPENSEES, LUSAS, etc., can be used. Correct estimation of creep and shrinkage parameters is very important.

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