

# Predicting Axial Shortening of Vertical Elements in High Rise Buildings by Using PCA Method

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**ABSTRACT:** Tall concrete buildings experience time-dependent axial shortening which may be interpreted as either absolute or differential, the former being with respect to a single column or core element, the latter being with respect to adjacent elements. The effects of column shortening, both elastic and inelastic, take on added significance and need special consideration in design and construction with increased height of structures. Calculation of exact values of axial shortening is not a straight forward task since it depends on a number of parameters such as the type of concrete, reinforcement ratio, and the rate and sequence of construction. All these parameters may or may not be available to the design engineer at the preliminary design stage of construction. Furthermore, long term shortening of columns could affect the horizontal structural members such as beams and floors and hence could affect the finishes and partitions. Therefore, a reasonable idea about the probable axial shortening could be important for construction engineers and project managers as well. This paper does a study of column shortening by using PCA (Portland Cement Association) method. In order to analytically solve the problem, the construction stage analysis function of MIDAS Gen considering shrinkage and creep effect is applied on a G+40-storey RC frame structure with internal core wall.

**KEYWORDS:** Column shortening, Construction stage analysis, Creep, Deformation, High rise buildings, Shrinkage.

## I. INTRODUCTION

In tall buildings, vertical structural members such as columns and core walls are continuously subjected to a certain amount of vertical movement or axial shortening. For steel structures, axial shortening is rather fundamental as steel columns only undergo elastic shortening at the instance of load application. However, in the case of reinforced concrete columns and core walls, the focus of this paper, the phenomenon becomes more complicated as the columns also undergo long-term shortening due to creep and shrinkage. According to Fintel and Ghosh (1984), axial shortening in concrete buildings is defined as the combined shortening due to elastic, shrinkage and creep effects of a column and can be as high as 1 inch for every 80 feet of building height.

Combination of axial creep, shrinkage and elastic shortenings causes axial shortening. In high rise buildings, perimeter columns tend to be more heavily stressed compared to shear walls of internal core. These perimeter columns thereby tend to deform axially at higher rates compared to the shear walls. This leads to differential axial shortening (DAS) between the columns and shear walls. DAS increases with building height and non-vertical load path as a result of geometric complexity of structural framing systems and causes serviceability related problems; impacting on floor flatness, load redistribution and cracking.

Therefore to mitigate above effects column shortening needs to be investigated.

PCA (Portland Cement Association) method is concerned with the prediction of strains in columns from the moment the columns become part of a structure. It also attempts to predict differential column movements in reinforced concrete or composite structures of significant height. To carry out an analysis for elastic, shrinkage, and creep strains in reinforced concrete columns, information is required on the modulus of elasticity and the shrinkage and creep characteristics of the concrete mixes to be used in the structure being considered.

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

In this paper column deformation is predicted by defining time dependent material properties i.e creep and shrinkage using PCA method. This research can be applied in designing of high rise buildings where considering column shortening at design stage and suggesting compensation for this column shortening will increase the safety and serviceability limit state of building structure. Ultimately future cost for repairing and retrofitting of damaged structural components can be reduced. Also analysing structure by construction stage analysis more accurate results about load distribution can be obtained

## II. LITERATURE REVIEW

Fintel, M., and Khan, F. R. (1969) [1] outlined a procedure for prediction of the amount of creep and shrinkage strains. Consideration is given to the loading history of columns in multi-storey buildings, which receive their load in as many increments as there are stories in the building, thus considerably reducing the creep as compared to a single load application. Also, volume-to-surface ratio of sections and the effect of reinforcement on the creep and shrinkage is considered.

S.C.Chakrabarti, et al. (1978) [2] observed that simulation of sequence of construction in the analysis leads to considerable variations in the design moments obtained by conventional one step analysis. It is, therefore, necessary that for multi-storied building frame, the effect be taken into consideration. Although exact simulation of the construction sequence may be difficult, idealization of the sequence of construction on the basis of a simplified model is always possible and some approximate ratios of sequential analysis and one step analysis depending upon relative beam and column stiffness are desirable as a design load.

Mark Fintel, et al. (1987) [3] explained how to predict and compensate axial shortening of column. An analytical procedure had been developed to predict the anticipated elastic and inelastic shortenings that will occur in columns and the walls both before the slab is installed and after slab installation. This is also called as PCA method (Portland Cement Association). Limitations of slab distortions caused by column shortening due to gravity loads and shrinkage effects are recommended. For several different structural systems, different construction methods to compensate for differential shortening are suggested.

M. M. Elnimeiri and M. R. Joglekar (1989) [4] developed a procedure to predict the long-term deformations of reinforced concrete columns, walls, and composite columns. The procedure incorporates the effects of concrete properties, construction sequence, and loading history. For composite columns, the effects of load transfer from the steel erection column to the reinforced concrete column are also included. Methods to minimize differential shortening of columns and walls are discussed. The methods involve corrections during both design and construction phases. Differential shortening effects for three tall buildings, in Chicago, which were designed using the procedure, were discussed.

Brian Uy, (1998) [5] studied the effects of composite action on creep and shrinkage strains and concluded that these strains are low than those of reinforced concrete members because of the confinement effects. This study also presented the factors limited to three concrete strengths and these factors can be used to predict the creep strain of the composite members comprising the limited concrete strengths.

K. Sakata, et al. (2005) [6] developed and maintained the data base and making technical reports on prediction equation for creep and shrinkage of concrete. Most data in the database were collected from technical papers published in Japan and classified into data of standard specimens and structures.

M. T. R. Jayasinghe and W. M. V. P. K. Jayasena (2005) [7] discussed the effect of relative humidity on absolute and differential shortening of vertical elements in reinforced concrete buildings. They found that the absolute shortening of a column reduces with an increase in relative humidity of the surrounding environment. This is due to the lower moisture evaporation from concrete surfaces in highly humid environments. The variation of absolute shortening is very small when the relative humidity changes from 40 to 80%.

Tsu-Te Huang, et al. (2007) [8] developed a robust possibility-based differential shortening prediction framework, and associated risk distribution profiles, which overcomes the deficiencies in the current models for predicting axial column shortening in reinforced concrete high rise buildings.

A.Vafaia, et al. (2009) [9] made an attempt 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

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(FEM) is used to calculate the creep and shrinkage strains. 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 analysis that ignore this phenomenon.

HN Praveen Moragaspiya (2010) [10] developed a numerical method incorporating time dependent parameter to predict during design the axial shortening of column and core shear wall components of concrete building that will occur during construction and service life. Develop a post construction monitoring procedures that incorporate time dependent behaviour to quantify axial shortening using ambient measurement of vibration characteristics.

### III. METHODOLOGY

**3.1 Analytical Model-** A G+40 story RC frame (figure 1) is considered with beam size 500mmX750mm, column of size 1300mmX1300mm at top 10 floors reducing 100mm at each 10 floors. The core wall considered at the center is of thickness 600mm at top 10 floors and reducing 100mm at each 10 floors and the slab thickness taken is 150mm. The grade of concrete used in beams and slabs is M35, for core wall M50 and that in column is M50. The floor height is taken as 3m. Along with the dead load of the structure, live load of 2kN/m<sup>2</sup> and a floor finish of 1kN/m<sup>2</sup> is also taken into account. The rate of construction sequence is assumed to be 3 days for each story construction. The structure is analysed using construction stage analysis option in Midas Gen, which analyses the structure step by step at every floor.

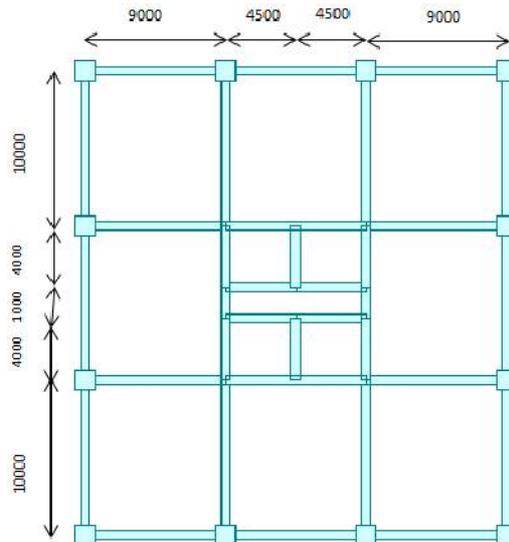


Figure 1 Typical Plan View

**3.2 Material Properties-**In order to define the properties of concrete shrinkage and creep, the PCA standard is used, and the concrete material properties are shown in table 1.

In V/S column in table 1, 9m wall is along X-direction and 4m wall is along Y-direction

Elastic strains of concrete with time are determined from compressive strength  $f'_c(t)$  and elastic modulus  $E_c(t)$ , in Equations (1) & (2)

$$f'_c(t) = \frac{f_{28}t}{4.0+0.85t} \quad (1)$$

$$E_c(t) = 0.43w^{1.5}\sqrt{f'_c(t)} \quad (\text{MPa}) \quad (2)$$

Where  $t$  is age of concrete in days,

$f_{28}$  is compressive strength of concrete at 28 days (MPa),

$w$  is unit weight of concrete

PCA method suggests shrinkage strains with time in the form of Equation (3)

$$\epsilon_{sh,t} = (\epsilon_{sh})_u * SH_{v,s} * SH_t * SH_H * SH_R \quad (3)$$

Where  $(\epsilon_{sh})_u$  = Ultimate shrinkage strain

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$SH_{v:s}$  = Coefficients of volume to surface of member  
 $SH_t$  = Shrinkage with time  
 $SH_H$  = Shrinkage with relative humidity  
 $SH_t$  = Residual shrinkage of reinforced concrete  

$$SH_t = \frac{t-t_s}{26.0e^{0.36(v:s)} + t-t_s} \quad (4)$$

Where,  $t$  is time in days after concrete pouring,  
 $t_s$  time in days of initial wet curing  
 $v:s$  volume to surface area ratio

PCA method suggests creep strains with time in the form of Equation (5)

$$\epsilon_{cr,t} = \sigma * (\epsilon_{sh})_u * CR_{t'} * CR_{v:s} * CR_t * CR_H * CR_R \quad (5)$$

Where,  $\sigma$  = Acting stress  
 $(\epsilon_{sh})_u$  = Specific creep  
 $CR_{t'}$  = Age of concrete at loading  
 $CR_{v:s}$  = Member size  
 $CR_t$  = Creep with time  
 $CR_H$  = Creep with relative humidity  
 $CR_R$  = Residual creep of reinforced concrete  

$$CR_t = \frac{(t-t')^{0.6}}{10.0 + (t-t')^{0.6}} \quad (6)$$

$t'$  time in days to first loading after concrete pouring

**Table 1 Material properties for PCA method**

Column	Compressive Strength (N/mm <sup>2</sup> )	Humidity (%)	Ultimate Creep Strain	Ultimate Shrinkage Strain	V/S Ratio(mm)	% Reinf.	E <sub>steel</sub> (GPa)
Column (1-10th)	50	70	4	780	325	0.8	200
Column (11-20th)	45	70	4	780	300	0.98	200
Column (21-30th)	40	70	4	780	275	1.18	200
Column (31-40th)	35	70	4	780	250	1.45	200
Shear Wall (1-10th)	50	70	4	780	282(9m wall) & 261(4m wall)	0.4	200
Shear Wall (11-20th)	45	70	4	780	237(9m wall) & 222(4m wall)	0.4	200
Shear Wall (21-30th)	40	70	4	780	192(9m wall) & 182(4m wall)	0.4	200
Shear Wall (31-40th)	35	70	4	780	145(9m wall) & 140(4m wall)	0.4	200

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## IV. RESULTS AND DISCUSSION

The observation points for the shortening of vertical members are selected at a column and a wall, highlighted in figure 2. From the analysis results, deformations due to the creep and shrinkage effects and elastic deformations, are shown in table 2. It shows that axial shortening increases with floor no. and maximum deformation is at top floor. Deformation of column and wall is calculated after 3 years(1095 days) of building completion.

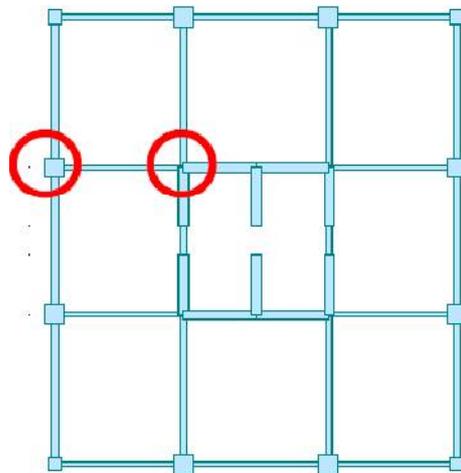


Figure 2 Observation points for shortening in vertical members

Table 2 The deformation of column by PCA method (1095 days)

Floors	Column			Shear Wall		
	Elastic Deformation	Deformation Due to Creep & Shrinkage	Total Deformation (mm)	Elastic Deformation	Deformation Due to Creep & Shrinkage	Total Deformation (mm)
1	0.806529	0.994138	1.800667	0.435185	0.863059	1.298244
2	1.984953	2.458969	4.443921	1.070869	2.141488	3.212357
3	3.131204	3.895706	7.026911	1.689441	3.40265	5.092091
4	4.245531	5.304607	9.550138	2.291411	4.647644	6.939055
5	5.328166	6.6859	12.014067	2.876856	5.876713	8.753568
6	6.379328	8.039775	14.419103	3.445759	7.089784	10.535544
7	7.39922	9.366376	16.765596	3.998086	8.286662	12.284748
8	8.388031	10.66581	19.053841	4.533797	9.467057	14.000854
9	9.34593	11.938138	21.284069	5.052869	10.630513	15.683382
10	10.273066	13.183366	23.456432	5.555324	11.776136	17.331459
11	11.169553	14.401421	25.570975	6.041327	12.901763	18.94309
12	12.241259	15.962304	28.203562	6.634573	14.401702	21.036275
13	13.276453	17.489533	30.765986	7.20718	15.875436	23.082616
14	14.275318	18.983132	33.25845	7.759447	17.326113	25.085559
15	15.238013	20.44305	35.681062	8.291417	18.754637	27.046054
16	16.164676	21.869181	38.033857	8.803075	20.161144	28.964218

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17	17.055428	23.261375	40.316803	9.294395	21.54549	30.839885
18	17.910366	24.619428	42.529793	9.765358	22.907405	32.672763
19	18.729565	25.943073	44.672638	10.215968	24.246503	34.462471
20	19.513073	27.231983	46.745055	10.646312	25.562161	36.208473
21	20.260898	28.485696	48.746594	11.056735	26.853081	37.909816
22	21.160328	30.099162	51.259491	11.573366	28.550687	40.124053
23	22.015998	31.666408	53.682406	12.063441	30.212015	42.275456
24	22.827949	33.186979	56.014927	12.52756	31.840564	44.368123
25	23.596188	34.660247	58.256435	12.965863	33.437268	46.403131
26	24.320696	36.085539	60.406235	13.37838	35.002227	48.380607
27	25.6383	38.788709	64.427009	14.126088	38.035711	52.161799
29	25.001426	37.462019	62.463445	13.765117	36.535179	50.300296
28	26.231209	40.06456	66.295769	14.461342	39.503382	53.964723
30	26.780003	41.288399	68.068401	14.771062	40.937751	55.708812
31	27.284481	42.458713	69.743194	15.055843	42.338358	57.394202
Floors	Column			Shear Wall		
	Elastic Deformation	Deformation Due to Creep & Shrinkage	Total Deformation (mm)	Elastic Deformation	Deformation Due to Creep & Shrinkage	Total Deformation (mm)
32	27.880028	43.943098	71.823125	15.424427	44.159537	59.583964
33	28.419113	45.351524	73.770637	15.756835	45.923268	61.680103
34	28.901439	46.68136	75.582798	16.054159	47.633566	63.687725
35	29.32664	47.929796	77.256436	16.316665	49.29107	65.607735
36	29.694281	49.093521	78.787802	16.544405	50.895099	67.439504
37	30.003837	50.168701	80.172539	16.73736	52.444392	69.181752
38	30.254662	51.150483	81.405145	16.89545	53.937073	70.832523
39	30.445915	52.032941	82.478856	17.018516	55.370829	72.389345
40	30.576382	52.807948	83.38433	17.106203	56.742187	73.84839
41	30.643848	53.4626	84.106448	17.157696	58.046359	75.204054

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Table 3 shows the comparison between axial shortening amounts at the 41th story by PCA method.

**Table 3 Comparison between Axial Shortening Amounts at the 41th Story by PCA Method**

	Construction Stage Analysis		
	Elastic	Creep and Shrinkage	Total
Shortening at Column	30.64mm	53.46mm	84.10mm
Ratio (%)	36.43	63.57	100
Shortening at Shear Wall	17.16mm	58.04mm	75.20mm
Ratio (%)	22.82	77.18	100
Comparison	Column > Shear Wall	Column > Shear Wall	Column > Shear Wall

The column exhibits the maximum vertical displacement of 84.10mm at the highest story, and the wall exhibits the maximum vertical displacement of 75.20mm at the highest story. These values gradually increase with the increase in no. of stories. Column shows maximum elastic as well as inelastic shortening as compared to shear wall.

For a column, elastic shortening contributes 36.43% of total shortening and shortening due to creep and shrinkage is 63.57%.

Figure 3 and figure 4 shows the distribution graphs of the vertical deformations by stories for the column and wall, respectively. In both fig. deformation due to creep and shrinkage is more than elastic deformation. Thus it shows effect of inelastic deformation on RC structure.

Also, in both fig. total axial shortening in column is more than shortening in wall.

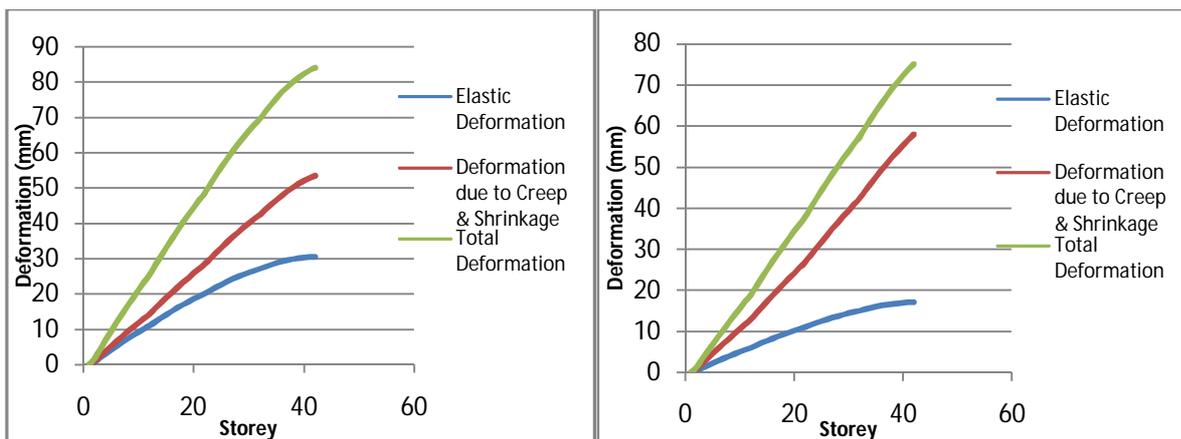


Figure 3 Vertical deformation of column by PCA method      Figure 4 Vertical Deformation of shear wall by PCA method

## V. CONCLUSION

The construction stage analysis reflecting deformations due to creep and shrinkage of the 40-story reinforced concrete structure consisting of core walls and exterior frame shows the following effects:

- Inelastic shortening (due to creep and shrinkage) is 1.75 times the elastic shortening for a column and 3.38 times for a wall element.

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- The proportion of the deformations due to creep and shrinkage that contribute to the total amount of deformations is 63.57% for the column, and 77.18% for the shear wall. Therefore for concrete buildings, deformations due to the creep and shrinkage must be considered.
- Since there are considerable amounts of deformations due to creep and shrinkage, their effects must be considered in analysis. This fact becomes more significant for high-rise construction or for structures with longer construction periods.

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