Axial Shortening Effect on Vertical Element using Elastic and Inelastic Approach by ACI Code

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ABSTRACT
Axial shortening of columns due to long term creep and shrinkage is inevitable in tall reinforced concrete buildings. However, 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 presents a set of guidelines so that the effect could be taken into account approximately, especially at the preliminary design stage and also during the construction phase. In this study it is assumed, construction stage analysis considers the creep and shrinkage effects of a 40-story building consist of an exterior concrete frame and interior shear walls. The displacements of vertical members are evaluated and compared with the results from conventional analysis (Without construction stage).

Keywords
Axial Shortening, Concrete Buildings, Creep, Shrinkage, Construction Sequence and Deflection

1. INTRODUCTION
In high-rise buildings, the axial deformations of columns cannot be ignored, and special considerations are required for design and construction. A vertical member undergoes both elastic deformation and deformation due to creep and shrinkage. The elastic deformation takes place instantaneously due to dead loads and live loads applied to the structure, while deformation due to creep and shrinkage occurs over many years. Most of the vertical deformations in a high-rise building, however, take place during its construction.

Due to the difference in axial stiffness and load distribution areas on vertical members, differential shortening inevitably develops. If this differential shortening in vertical members, which takes place during and after the construction, is not considered in analyses of high-rise buildings, structuralsafety will be compromised due to additional stresses in the horizontal members and, subsequently, in the vertical members. The structural safety problem is also magnified when incorporating serviceability issues such as the curtain wall function, floor unevenness, excess stress in piping, etc. As such, total displacements of vertical members must be calculated at the design stage. Comparatively reasonable and accurate results can be predicted when construction stage analysis is carried out reflecting the creep and shrinkage behavior of concrete.

Conventional structural analysis has the assumption that all structural loads are instantaneously applied to the entire completed structure. However, since most buildings are constructed by one story or several floor units at a time, or even if it is the same story, the construction sequence and loading sequence may be different depending on the construction plan. Therefore, the actual structural behavior can be significantly different from the conventional analytical behavior based on the above assumption. Vertical members (columns and walls) in high-rise reinforced concrete buildings not only exhibit elastic shortening, but also have shrinkage and creep effects that develop from long-term compressive loading. In lower stories of a building, additional stresses in girders become very large due to differential shortening and undergo significant redistribution of the member forces. In order to analytically solve the problem described above, the construction stage analysis function of midas Gen considers shrinkage and creep during construction stages to simulate the construction process of a high-rise building. Also, with input variables, such as the strength of concrete, construction duration of building components, casting condition, ambient condition, etc., the elastic shortening, shrinkage and creep of vertical members can be estimated and are reflected in the analysis. Change in strength gain based on the maturity of concrete members is also reflected in the calculation of modulus of elasticity at various construction stages.

2. BRIEF REVIEW OF THE LITERATURE
Fintel, M., and Khan, F. R. (1969) [1] In this research they give the how to predict And Compensate Axial shortening of column. This is also called as PCA method (Portland Cement association). Henry G. Russell (1990) [2] In recent years, questions have been raised about the validity of methods for calculating deformations in high-strength concrete members and the in-place properties of high-strength concrete members. These properties include compressive strength, modulus of elasticity, shrinkage, and creep. This paper reviews existing state-of-the-art technology concerning instantaneous shortening, shrinkage, and creep of high-strength concrete members. K. Sakata, T. Ayano, K. ImamotoAnd Y. Sato (2005) [3] They develop and maintain 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. H.N.Praveen, Moragaspitiya, David.P.Thambiratnam, Nimalparera, Tommy H.T.Chen (2007) [4] The procedure and illustrates it through a numerical example of an unsymmetrical high rise building

with two outrigger and belt system. Result indicate that the method has the capability to capture influence of different tributary areas, shear wall of outrigger and belt system as well as the geometric complicity of the building.Tsu-Te Huang, Rodney A. Stewart, Jeung-Hwan Doh,Dennis Song (2007) [5] This research aims to develop 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. O. Esmaili,S. Epackachi, M. Samadzad and S.R. Mirghaderi (2008) [6] In this paper they research the Structural aspect of the one of the tallest RC building, located in the high seismic zone, with 56 stories. Some especial aspects of the tower and the assessment of its seismic load bearing system with considering some important factors will be discussed in this paper. Bazant and Z.P (1978) [7] Have shown that CEB-FIP updated 1999 model is better than ACI 209R model. Also, Ghodousi et al. (2009) presented an experimental study to compare various prediction models and recommended that CEB-FIP updated 1999 model (FIB 1999) is simple and easy to apply. F.Mola,L.M.pellegrini (2010) [8] The problem of long time column shortening will be discussed, then approximate solution will be derived and applied with reference to the case study of palazzo lambardia, at present the tallest building in Italy. Shieh, cang&jong (2010) [9] Column of Taipei 101 Tower, Which is the second highest building in the world, was designed and construction in steel box section filled with high strength concrete. The composite action between concrete and steel plates of the steel section impacts on elastic, creep and shrinkage strain and hence this impact was incorporated into the design procedure. HN Praveen Moragaspitiya (2011) [10] Develop 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 behavior to quantify axial shortening using ambient measurement of vibration characteristics.

3. MODEL SUMMERY

3.1 Structural System

The structural system, as shown in figure 1, is a 40-story building constructed with core walls and perimeter RC columns & RC girders. In order to evaluate the influence that gravity has on the displacements of a vertical member, and the member forces of horizontal members, the member sections are selected according to the dead load and the live load. The typical plan view of a story as shown in figure 1.

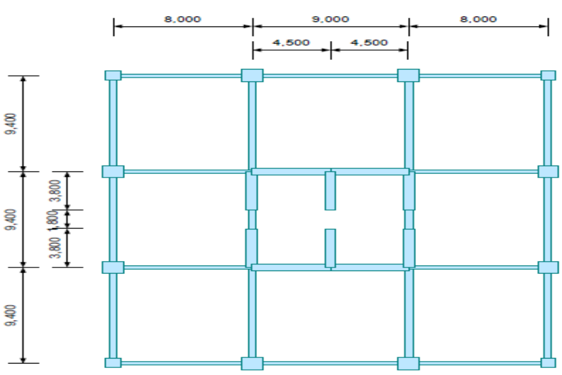


Figure 1: Typical Story Plan View

3.2 Design load

Table 1: Design Loads

Types of Load	Symbol	Loads
Frame self-Weight	SW	-
Slab self-weight	DS	3.75 kN/m2
Finishing and wall load	WL	1.5 kN/m2
Live Load	LL	2.5 kN/m2

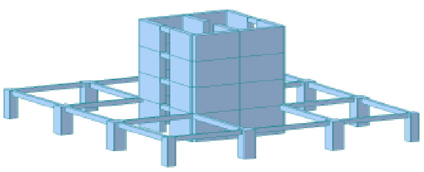
3.3 Construction Sequence

During the construction stages (please refer to table 2 and figure 3), after the core walls are constructed on the 4th story (after construction of three preceding stories is completed through a 5 day cycle), the girder, column, and slab construction is initiated at the same time. During the construction of the 21st story, the interior finishing for the floor is initiated, starting from the 1st story, in a 5 day cycle. It is assumed that the live loads applied to the structure reach 100% loading 90 days after the completion of construction.

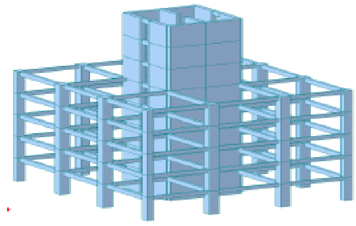
Table 2: Construction Sequence

Stage	Element Group		Stage Load	Duration (days)	Total Construction Period (days)	Description
#CS1	1ST FL. Core		SW/DS	5	5	
#CS2	2nd FL. Core		SW/DS	5	10	
#CS3	3rd FL. Core		SW/DS	5	15	
#CS4	4th FL. Core	1ST FL. Core	SW/DS	5	20	
#CS5	5th FL. Core	2nd FL. Core	SW/DS	5	25	
#CS6	6th FL. Core	3rd FL. Core	SW/DS	5	30	
#CS7	7th FL. Core	4th FL. Core	SW/DS	5	35	
……	……	……	………	……	………	
#CS21	21st FL.	18th FL.	SW/DS/WL	5	105	1st FL.

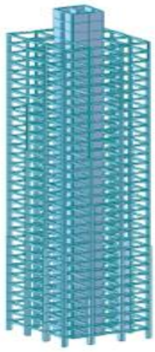
	Core	Core				Int. Finishing
#CS22	22nd FL. Core	19th FL. Core	SW/DS/WL	5	110	1st FL. Int. Finishing
……	……	……	………	……	………	
#CS40	40th FL. Core	37th FL. Core	SW/DS/WL	5	200	20th FL. Int. Finishing
#CS41		38th FL. Core	SW/DS/WL	5	205	21st FL. Int. Finishing
#CS42		39th FL. Core	SW/DS/WL	5	210	22nd FL. Int. Finishing
#CS43		40th FL. Core	SW/DS/WL	5	215	23rd FL. Int. Finishing
#CS44			WL	85	300	24-40 FL. Int. Finishing
#CS45				90	390	
#CS46			LL	260	650	Live Load



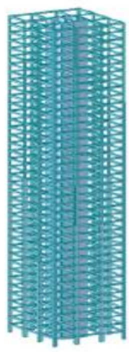
Stage 4



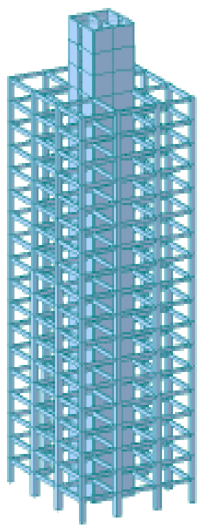
Stage 8



Stage 35



Final Stage



Stage 21 (Input Finishing Loads)

Figure 2: Sequence of Construction Stages

3.4 Material Properties

In order to define the properties of concrete shrinkage and creep, the ACI standard is used, and the concrete material properties are shown in table 3.

Compressive strength fc' (t) as per ACI 209R-92

$$f'c(t) = \frac{t}{\alpha + \beta t} f'c(28)$$

As, t = age of concrete (days),

α, β = constant used for compressive strength,

f'c= compressive strength of concrete.

Creep coefficient ϕ (t,τ) as per ACI 209R-92

$$\phi\,(t,\tau) = \frac{(t-\tau)^{0.6}}{10 + (t-\tau)^{0.6}} \phi^*(\tau)$$

As, t = age of concrete (days) at loading

ϕ*(t) = final creep coefficient

Shrinkage Strain εsh as per ACI 209R-92

$$\varepsilon_{sh} = \frac{t}{35 + t} \varepsilon^*_{sh}$$

As, ε*sh = final shrinkage strain at time infinity

Table 3: Concrete material properties

Column	Comp. Strength (N/mm2)	Humidity (%)	Slump (cm)	Slump (cm)	Aggregate (%)	Air (%)	Cement (kg/m3)	V/S Ratio (mm)	Code
C1 (1~5th)	50	55	12	60	60	4.5	45	300	ACI
C1 (6~10th)	50	55	12	60	60	4.5	45	275	ACI
C1 (11~15th)	40	55	12	60	60	4.5	38	250	ACI
C1 (16~20th)	40	55	12	60	60	4.5	38	225	ACI
C1 (21~25th)	35	55	12	60	60	4.5	35	200	ACI
C1 (26~30th)	35	55	12	60	60	4.5	35	175	ACI
C1 (31~35th)	30	55	12	60	60	4.5	32	150	ACI
C1 (36~40th)	30	55	12	60	60	4.5	32	125	ACI

C2 (1~10th)	50	55	12	60	60	4.5	45	225	ACI
C2 (11~20th)	40	55	12	60	60	4.5	38	200	ACI
C2 (21~30th)	35	55	12	60	60	4.5	35	175	ACI
C2 (31~40th)	40	55	12	60	60	4.5	32	150	ACI
Wall (1~10th)	50	55	12	60	60	4.5	45	266	ACI
Wall (11~20th)	40	55	12	60	60	4.5	38	266	ACI
Wall (21~30th)	35	55	12	60	60	4.5	35	226	ACI
Wall (31~40th)	30	55	12	60	60	4.5	32	226	ACI

4. RESULT AND DISCUSSION

The elastic deformation and deformations due to creep and shrinkage of an actual structure cannot be physically isolated; but, for the purpose of analysis, they are separately calculated. The observation points for the shortening of vertical members re selected at a column and a wall, highlighted in figure 3.

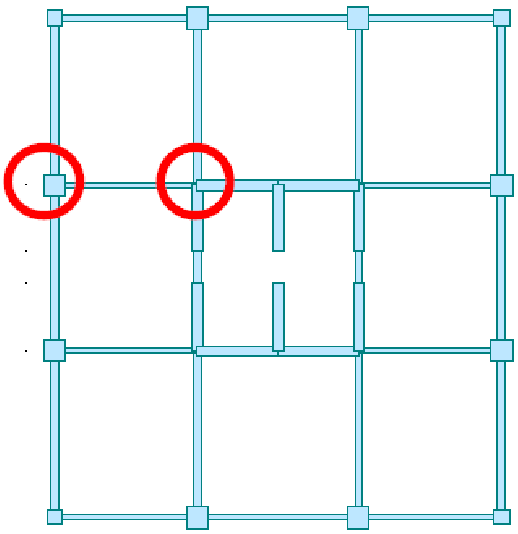


Figure 3: Observation Points for Shortening in Vertical Members

Deformation after 650 days, which is 260 days after applying the live loads, is calculated. Disparity may occur depending on the magnitudes of the live loads assumed for shortening calculation. In this case, 100% of the design live loads is applied. From the analysis results, deformations due to the creep and shrinkage effects, as shown in table 4 and table 5, contribute to 61.7~73.6% of the total deformations of the column and 70.1~83.1% of the total deformations of the wall.

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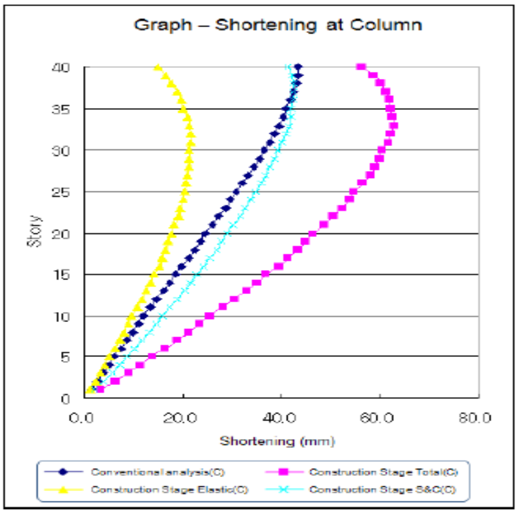

Figure 4: Distribution of the Vertical Displacements of Column by Stories

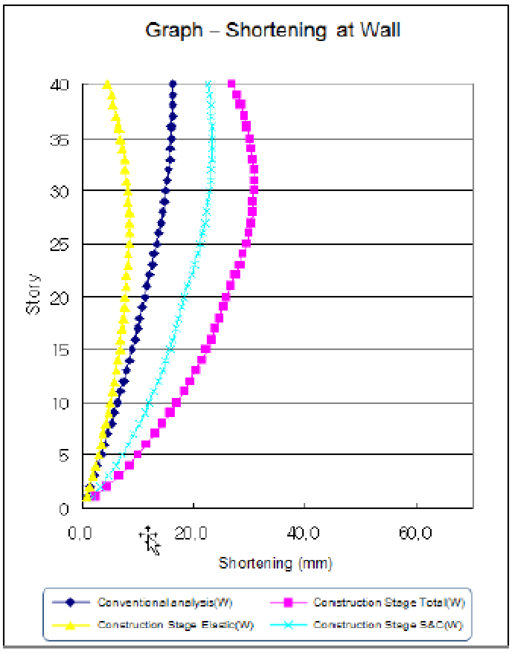

Figure 5: Distribution of the Vertical Displacements of Wall by Stories

Figure 4 and figure 5 show the distribution graphs of the vertical displacements by stories for the column and wall, respectively. As the number of stories increases in conventional analysis in which construction stages are not considered, the maximum vertical displacements occur at the highest story (column: 43.5mm, wall: 16.4mm). When construction stages are considered, the column exhibits the maximum vertical displacement of 62.8mm at the 33 story, and the wall exhibits the maximum vertical displacement of 32.4mm at the 36 story. These values gradually decrease with the increase in stories.

For reference, when midas Gen calculates the differential shortening for 10,000 days (approximately 27 years), the results show the differential shortening at the 28th story of 32.8mm, a 15% increase from the results for 650 days.

As mentioned previously, the displacements due to creep and shrinkage contribute to the displacements of all columns and walls by 1.5~4 times more than the displacements with no creep and shrinkage effects. Observing the differential shortening, displacements due to creep and shrinkage are less influential at the stories 1 to 16, and more pronounced at the stories above the 16th story, also shown in figure 9. The higher the story, therefore, the more likely that differential shortening will be dominated by displacements due to creep and shrinkage.

Table 5: Comparison between Differential Shortening Amounts at the 28th Story

	Conventional Analysis	Construction stage Analysis		
		Elastic	S&C	Total
Differential Shortening Amount	20.1 mm	13.1 mm	15.5 mm	28.6 mm
Ratio(%)	70.4	45.7	54.3	100
Comparison	Column >Wall	Column >Wall	Column >Wall	Column >Wall

5. 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:

- The proportion of the deformations due to creep and shrinkage that contribute to the total amount of deformations is 61.7~73.6% for the column, and 70.1~83.1% for the shear wall. Therefor for concrete buildings, deformations due to the creep and shrinkage must be considered.
- The amount of differential shortening due to deformations caused by creep and shrinkage is 54.3% of the total differential shortening. Since there are considerable amounts of deformations due to creep and shrinkage, their effects must be considered in analysis. This fact becomes more significant forhigh-rise construction or for structures with longer construction periods.

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