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EFFECT OF CONCRETE CREEP ON THE SHORTENING OF VERTICAL ELEMENTS IN HIGH-RISE BUILDINGS

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Vertical structural elements are commonly subjected to the time-dependent behavior effects caused by creep which causes shortening in these elements in the direction of the load being applied. Significant amount of creep takes place instantaneously with loading and carries on for the long-term dimensions. In high-rise buildings, the axial shortening in columns is inevitable, so it cannot be ignored. The shortening is differential between vertical structural members due to the difference in axial stiffness and load distribution areas on these elements. Conventional structural analysis assumes that all structural loads are instantaneously applied to the entire completed structure. 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. The objective of this study is to highlight the effect of concrete creep behavior on the shortening of vertical elements specifically in high-rise buildings. In this study, we will be considering the ACI 209R-92 model. Based on experimental data, a procedure is developed to compute the elastic shortening due to creep. A 250 meters high-rise is studied taking into consideration the stress and modulus of elasticity depending its construction time and height.

Keywords: Creep shortening, Elastic shortening, Axial shortening, ACI 209R-92 model.

1 INTRODUCTION

The behavior of concrete is affected by its short-term and long-term properties. The short-term properties include strength in compression, tension, bond and modulus of elasticity that occur upon loading. The long-term properties become significant if the applied load is continuously held by the concrete. In buildings, vertical structural elements are subjected to volumetric changes due to axial shortening. Axial shortening is due to elastic shortening, creep and shrinkage of concrete. Most engineers believe that creep and shrinkage are not factors affecting the concrete behavior, so they do not take them into consideration.

Elastic shortening occurs upon hardening of concrete and applying loads. It depends on the applied stress, length and area of element and the time-dependent factor modulus of elasticity. Creep is the deformation of concrete on the long term when subjected to sustained loads. Thus, creep depends on the age of loading of the structure. It originates from calcium silicate hydrates in hardened cement paste (C-S-H) (Gambali and Shanagam 2014). Significant amount of creep takes place with loading and carries out to the long term dimensions causing deformation in the structural elements. The creep strains that occur in high-rise buildings can sometimes be larger than the elastic strains that occur at the age of loading. This makes determining creep properties an essential part before the construction phase. Shrinkage in its simplest definition is the decrease in volume due to the dissipation of water (loss of moisture) in concrete. Both creep and shrinkage are dependent of several factors including: relative humidity, volume-surface ratio (V/S), slump, size of fine aggregates, cement content, and air content and independent of the stress in concrete.

In high-rise buildings, deformations due to creep and shrinkage cannot be ignored (Waghmare *et al.* 2015). There are several prediction models developed to determine the creep and shrinkage. The ACI 209-R92 (2008) model is one of these models which is commonly used due to its practicality. This study highlights the importance of concrete creep and its effect on the axial shortening of vertical elements in high-rise buildings based on the self-weight of the structural elements. In order to achieve this, a 250 meters high-rise building is studied based on the ACI 209-R92 (2008) model.

2 BRIEF REVIEW OF THE LITERATURE

Axial shortening of gravity load bearing structural elements in tall buildings is a phenomenon that was first noticed in 1960's. Ever since, axial shortening has become an interest to many researchers. Axial shortening is cumulative over the height of the structure. Thus, axial deformation that is a combination of elastic, creep and shrinkage shortening effects due to differential shortening becomes critical with the increase in the height of the building. In 1969, Fintel and Khan (1971) developed a method to calculate the total strain in columns. This method is limited because it doesn't take into consideration the relative humidity, water/cement ratio, the percentage of fine aggregates and the percentage of air content. Today, there are four different methods available for predicting the creep and shrinkage behavior of concrete the ACI 209R-92 (2008) model, CEB-FIP model, B3 model and GL2000 model. The commonly used model is ACI 209 (2008). Mola and Pellegrini (2010) discussed the problem of long-term column shortening caused by creep of concrete and derived approximate solutions in reference to the case study of Palazzo Lombardia, the tallest building in Italy by the time the study was conducted. The research done ensures the importance of the topic currently being studied.

3 WORK METHODOLOGY FOR SHORTENING COMPUTATION

3.1 Building Description

A sample 215 meters high-rise (Figure 1) is considered as a case study. The area of slabs and vertical elements were gathered to be used for the calculation of the shortening. The vertical structural elements are distributed symmetrically with respect to the center of gravity of the floor slab. Thus, the axial deformation is assumed to be uniform at the same story level to avoid considering differential shortening which causes additional internal stresses.

3.2 Excel Spreadsheets

An excel workbook is prepared for computing the total axial shortening of vertical elements in the high-rise building. The workbook is divided into several sheets which include the different parameters needed for the calculation as follows: Floor Data, Loads and Stresses, Time Dependent Age of Concrete, Concrete Compressive Strength and Modulus of Elasticity, Creep Coefficient, Creep Strain, Creep Shortening, Elastic Shortening, Shrinkage Strain and Shrinkage Shortening. The objective is to provide a calculation method for the cumulative axial shortening in the studied building taking into consideration the time. The age at loading of concrete is 14 days which is equal to the construction time required for completion of one story.

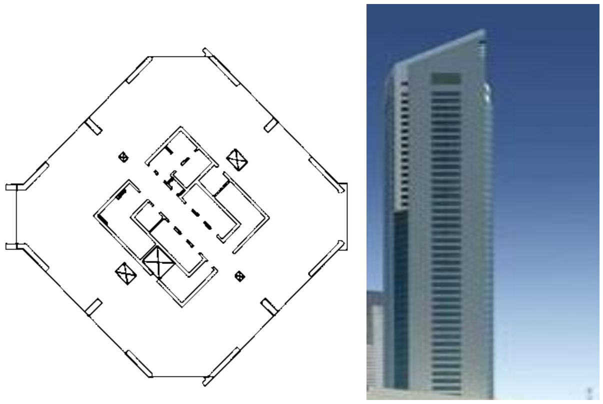

Figure 1. A typical floor plan showing structural symmetry and a side view of the studied tower.

3.2.1 *Elastic shortening*

The elastic shortening is calculated based on the following formula, Eq. (1):

$$\Delta = \frac{PL}{EA} \tag{1}$$

The load induced on each floor due to the self-weight of the structural elements on each floor was computed using the following defined Eq. (2):

$$\mathrm{P} = (\gamma_c \times \text{Area of Vertical Elements} \times \text{Floor Height}) + (\gamma_c \times \text{Area of Slab} \times t_s) \tag{2}$$

where γ_c is the unit weight of concrete (KN/m^3) and E is the modulus of Elasticity (MPa).

The modulus of elasticity is calculated based on the ACI equation, Eq. (3) and (4):

$$E_{cmt} = 0.043{\gamma_c}^{1.5}\sqrt{f_{cmt}}\ \text{(MPa)} \tag{3}$$

$$f_{cmt} = \left[\frac{t}{a+bt}\right] f_{cm28} \tag{4}$$

where f_{cmt} is the compressive strength of concrete at time t (MPa), and γ_c is the unit weight of concrete (kg/m^3). The areas of vertical elements and slabs are in m^2, and the floor heights and slab thicknesses are in (m).

3.2.2 *Creep shortening*

The creep shortening per floor is expressed as per the following Eq. (5),

$$\Delta_{creep}\,(\text{m}) = \text{creep strain} \times \text{floor height} \tag{5}$$

The creep strain was calculated based on the following formula, Eq. (6):

$$\text{Creep Strain}(m/m) = \frac{\sigma}{E} \times \varphi_{(t,t_0)} \tag{6}$$

where σ is the stress on floor, E is the modulus of elasticity at time t and $\varphi_{(t,t_0)}$ is the creep coefficient.

To determine the creep coefficient, the ACI 209R-92 (2008) recommends the following formula:

$$\varphi_{(t,t_0)} = \frac{(t-t_0)^{\psi}}{d+(t-t_0)^{\psi}}\phi_u \tag{7}$$

where, t = age of concrete

t_0 = age at loading of concrete

$\mathrm{d} = 26.0e^{\{1.42\times 10^{-2}(V/S)\}}$ when the shape and size are considered

ψ = psi value = 0.4527; this value was calibrated to fit the high-strength concrete mix

ϕ_u is the ultimate creep coefficient $= 2.35\gamma_c$

$$\gamma_c = \gamma_{c,to}\gamma_{c,RH}\gamma_{c,vs}\gamma_{c,s}\gamma_{c,\psi}\gamma_{c,\alpha} \tag{8}$$

$\gamma_{c,to}$, $\gamma_{c,RH}$, $\gamma_{c,vs}$, $\gamma_{c,s}$, $\gamma_{c,\psi}$, and $\gamma_{c,\alpha}$ are factors calculated based on equations proposed by ACI 209R-92 (2008) model and are shown in Eq. (8).

The load induced generates stress on the vertical elements of the floors. This stress is computed based of the following Eq. (9),

$$\sigma\left(KN/m^2\right) = \frac{P\ (in\,KN)}{Area\,of\,Vertical\,Elements\ (m^2)} \tag{9}$$

Table 1. Sample of creep shortening (m) per floor with construction time.

Floor	7									7
	6								6	0.00E+00
	5							5	0.00E+00	3.72E-06
	4						4	0.00E+00	3.72E-06	4.83E-06
	3					3	0.00E+00	5.58E-06	7.25E-06	8.43E-06
	2				2	0.00E+00	7.41E-06	7.72E-06	8.98E-06	9.98E-06
	1			1st	0.00E+00	4.33E-06	5.15E-06	4.80E-06	5.34E-06	5.79E-06
	GF		GF	0.00E+00	3.15E-06	5.31E-06	5.64E-06	5.03E-06	5.46E-06	5.83E-06
	Basement 1	B1	0.00E+00	3.57E-06	4.78E-06	7.20E-06	7.32E-06	6.37E-06	6.80E-06	7.19E-06
	Basement 2	0.00E+00	3.32E-06	3.98E-06	4.76E-06	6.86E-06	6.80E-06	5.83E-06	6.17E-06	6.47E-06
		Creep Shortening								

After calculating the creep shortening with time, the total creep shortening of each floor was computed which is the summation of the horizontal rows. The total cumulative creep shortening was calculated with the cumulative height as shown in Table 1.

The same procedure was followed to determine the shortening due to shrinkage based on the ACI model.

For shrinkage strain the ACI 209R-92 (2008) model recommends the following Eq. (10):

$$\varepsilon_{sh(t,t_c)} = \frac{(t-t_c)^{\alpha}}{f+(t-t_c)^{\alpha}}\varepsilon_{shu} \tag{10}$$

where $\alpha = 1.0$, $f = 26.0e^{\{1.42\times 10^{-2}(V/S)\}}$ and the ultimate shrinkage strain, $\varepsilon_{shu} = 780\gamma_{sh}\times 10^{-6}$

$$\gamma_{sh} = \gamma_{sh,tc}\gamma_{sh,RH}\gamma_{sh,vs}\gamma_{sh,s}\gamma_{sh,\psi}\gamma_{sh,\alpha} \tag{11}$$

where, $\gamma_{sh,tc}, \gamma_{sh,RH}, \gamma_{sh,vs}, \gamma_{sh,s}, \gamma_{sh,\psi}$ and $\gamma_{sh,\alpha}$ are factors depending on curing time, relative humidity, volume to surfae ratio, slump, fine aggregates percentage and air content respectively and determined based on the ACI 209R-92 (2008) equations, and shown in Eq. (11).

3.2.3 *Total shortening*

The total shortening of vertical elements is the summation of the elastic, creep and shrinkage shortenings, Eq. (12), (Figure 2.)

$$\Delta_{total} = \Delta_{creep} + \Delta_{shrinkage} + \Delta_{elastic} \tag{12}$$

The total obtained shortening in the 215 meters high-rise building studied is 3.8 centimeters.

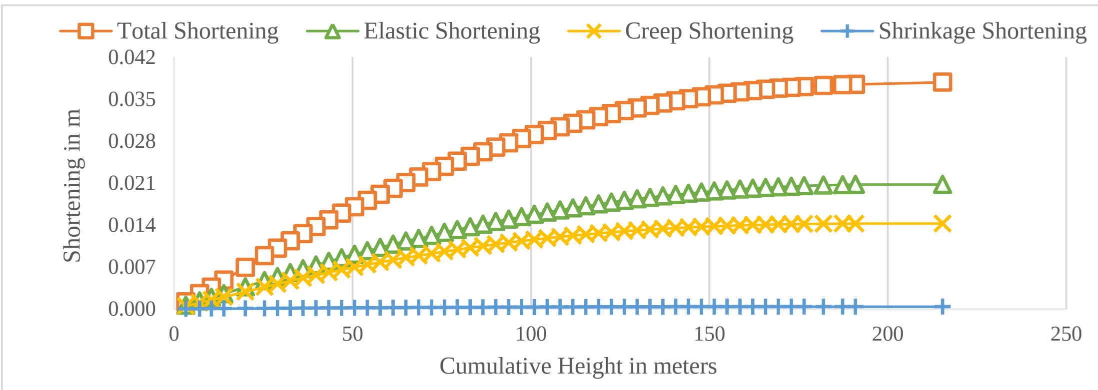

Figure 2. Total, elastic, creep, and shrinkage shortening in tower.

4 RESULTS

The effect of age at loading t_0 on the creep coefficients was studied by considering three different ages at loading 7, 14, and 28 and examining the variation in the creep coefficients. At 7, 14, and 28 days, the age at loading factors ($\gamma_{c,to}$) were 0.994, 0.916, and 0.844 respectively. Thus, the increase in age at loading decreases the value of age at loading factor. At 7, 14, and 28 days the

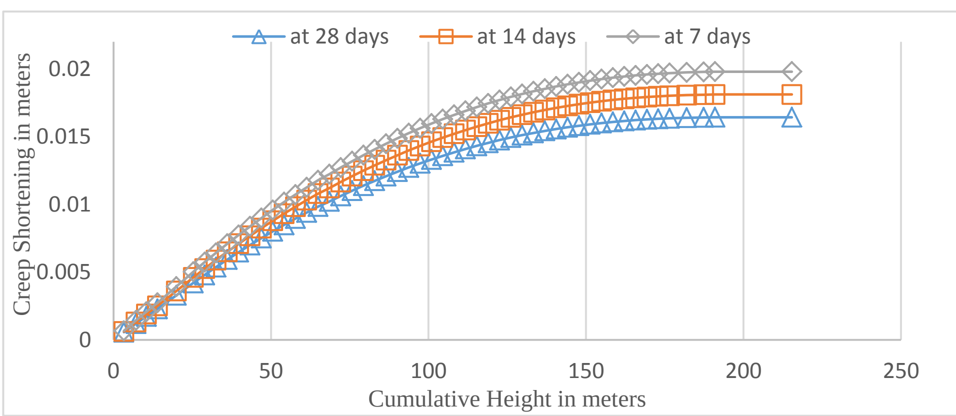

Figure 3. Creep shortening at different ages of loading.

ultimate creep values calculated were 3.45, 3.18 and 2.93 respectively. The obtained values showed that the decrease in age at loading factor decreases the ultimate creep for the same mixture resulting in an increase in the creep coefficients. The earlier the loading the higher the creep. A lower creep coefficient results in lower creep strain hence lower shortening due to creep occurs as shown in Figure 3.

5 CONCLUSIONS

It is of highly importance to study the creep effect in high-rise buildings. The proposed methodology with excel spreadsheets provides a useful tool for calculating axial shortening based on creep, shrinkage and elastic strain. The elastic and creep shortenings obtained are much larger than the shortening due to shrinkage (Figure 2). Though the total shortening in the studied high-rise building is 3.8 cm which is not quite large relative to the total height, the results ensure the importance of taking creep effect into consideration when designing concrete structures. With the increase of height, the importance of time-dependent shortening of vertical elements becomes more critical owing to the cumulative nature of shortening. In this study, the deformation was assumed to be uniform. However, in case the structural system lacked symmetry in stress distribution and design differential shortening occurs which affects the stability of the structure. In addition, the age at loading affects the shortening due to creep (Figure 3). This is due to the fact that the concrete did not reach it is ultimate strength before the load is induced from the new constructed floor.

References

ACI 209.2R-08, Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete, *ACI Manual of Concrete Practice*, 2008.

Gambali, A. K. and Shanagam, N. K., Creep of Concrete, *International Journal of Engineering Development and Research (IJEDR)*, 2(4), 3800-3802, 2014.

Fintel, M. and Khan, R., Effect of Column Creep and Shrinkage in Tall Structures-Prediction of Inelastic Column Shortening, *ACI Journal Proceedings*, *66*, 1969.

Mola, F. and Pellegrini L. M., Effects of Column Shortening In Tall Structures, *35th Conference on OUR WORLD IN CONCRETE AND STRUCTURES.* Singapore: CI-Premier PTE LTD, 2010.

Waghmare, A. P., Dode P. A., and Chore, H. S., Axial Shortening Effect on Vertical Element Using Elastic and Inelastic Approach by ACI Code, *International Journal for Computer Applications*, 5-11, 2015.