

Optimum Positioning of Outriggers to Reduce Differential Column Shortening Due to Long Term Effects in Tall Buildings

Kiran Kamath, Shashikumar Rao* and Shruthi

Department of Civil Engineering, Manipal Institute of Technology, Manipal, Karnataka, India.

*Corresponding Author's Email: shashi0990@gmail.com

ARTICLE INFO

Article history:

Received 30 Mar. 2015
Accepted 07 Apr. 2015
Available online 15 Apr. 2015

Keywords:

Creep,
Differential Shortening,
H/h1 and H/h2 ratio
MidasGen,
Outrigger,
Shrinkage.

ABSTRACT

In the present study, a 60-storey 3-D RC frame with core wall at the centre is considered for finding out the shortening of column. The parameter considered to reduce the effect of differential column shortening is the effects of outriggers at different levels under the action of elastic, creep and shrinkage shortening. It was found that the differential column shortening is reduced by 34% when one outrigger is introduced at the optimum level of $H/h_1=1.715$. Along with this optimum position of the outrigger, another outrigger is introduced at different levels to further reduce the differential column shortening and the optimum position of second outrigger is found out that will give the minimum differential column shortening. It was found that second outrigger at $H/h_2=1.33$ level reduces the differential shortening by 14% in addition to that reduced by first outrigger. The present analysis is carried out using a finite element software MIDASGen and by plotting storey height versus differential column shortening between the outer peripheral column and the core wall for different positions of the outriggers.

© 2015 International Journal of Advanced Research in Science and Technology (IJARST).

All rights reserved.

Introduction

The effects of column shortening both elastic and inelastic takes on added significance and need special consideration in design and construction with increased height of structures. Differential shortening of vertical members result from differing stress levels. Differential shortening of columns due to elastic shortening, creep and shrinkage in reinforced concrete tall buildings is inevitable. Creep in concrete is the function of loading history. It is found from researches that creep decreases with the delay in loading. Creep depends on the cross-section of the member and the percentage of the reinforcement used in the cross-section. Shrinkage is due to the moisture evaporation from the concrete. It depends on the volume to surface-area ratio. Shrinkage shortening increases with the decrease in volume to surface area ratio. Elastic shortening takes place because of the dead load and live loads of the structure.

The formulation of précised values of differential shortening is not an easy task since few parameters like type of concrete, reinforcement ratio, temperature and rate of construction are responsible. All these information may not be available to the design engineer at the preliminary stage of design. Also the long term shortening of columns could affect the horizontal members such as beams and floors and hence could

affect the finishes, partitions, pipelines, etc. since these non-structural elements are not intended to carry vertical loads and are therefore not subjected to shortening. The method of quantification of axial shortening of reinforced concrete columns was originally introduced by Fintel and Khan (1969). Liu et al., (2011) studied the performance and control for super tall building construction. They proposed a performance based structural design methodology for the performance assessment and control of different structural states in different construction stages. A 60 story RC frame was taken as an example and it was shown that the proposed structural performance assessment method during construction stage is feasible and effective [1]. Moragasipitiya et al., (2010) studied the differential distortion comprising axial shortening and consequent rotation in concrete buildings is caused by time dependent effects of creep, shrinkage and elastic deformation [2]. Hassanien Serror and Essam El-Din (2012) conducted a parametric study and investigated the influence of variation of controlling parameters such as floor levels and type of statically system using construction sequence analysis method. They obtained the results by preparing a 3D finite element model using a program software MidasGen [3]. Khan and Fintel (1968), showed that exposed columns

when subjected to seasonal temperature variations change their length relative to the interior columns which remain unchanged in a controlled environment. If the exterior columns have difference in size and are subjected to different average temperature due to the location of glass lines, there will be relative displacement between these adjacent columns when exposed to seasonal changes [4]. Kim and Shin proposed an analysis method with lumped construction sequences for the column shortening of tall buildings. They observed that lumped model shows results that are close to the exact model in post-installation shortening as well as total shortening. They studied the effect of the size of the lumping and about 1/15 of the total stories of the building is recommended considering the accuracy of the results [5]. Jayasinghe and Jayasena (2005) studied the effect of relative humidity on absolute and differential shortening of vertical elements in reinforced concrete buildings. They showed that the variation of absolute shortening is very small when the relative humidity changes from 40 to 80%. The guidelines were developed with a 7 day duration for the floor construction cycle. If the rate of construction is reduced, the magnitude and the effects of axial shortening could be reduced accordingly [6]. Jayasinghe and Jayasena (2004) also studied the effects of construction sequence, rate of construction, and grade of concrete on axial shortening are determined based on a number of case studies covering 10–40 story range. These are presented as 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 [7].

Differential Column Shortening:

The usage of concrete in tall buildings increasing day by day. Application of ultimate strength design and replacement of traditional, load bearing heavy masonry partition with lightweight partitions results in a significantly larger load increment on relatively smaller columns of recent high rise structures. The cumulative differential shortening of columns causes the slabs to tilt with resulting rotation of partitions. Improper functioning of elevators, deformation, or damage to pipelines, cracking of partitions, and finishes, and many other service problems can appear in the building due to differential shortening of columns. Thus an approximate and reasonable prediction of the differential shortening will be of lot importance to a design engineer and construction engineer too. The knowledge of the total shortening is needed to make allowance in the architectural details to avoid future distress of partitions, windows, cladding and other non-structural elements. In this paper the effects of construction sequence, creep and shrinkage of concrete on differential shortening need to be determined using few case studies consisting of high rise buildings along with the effects of outriggers. An analysis software MidasGen is used for modelling tall RC structures and its behavior under the effects of construction stage

sequence and long-term deformation need to be studied. The effects of differential shortening of columns are:- slabs may not be truly horizontal after some time, beams could be subjected to higher bending moments, load transfer, cracks in partition walls, cracks in staircases, deformation of cladding, mechanical equipment, architectural finishes, built in furnishings.

In the present study, the analysis software MidasGen uses the formulae recommended by the ACI 209R-92 [8] to predict the shortening of columns because of creep and shrinkage. In the model the Modulus of Elasticity is given by

$$E_c(t) = 5000\sqrt{f_{ct}} \text{ in N/mm}^2 \dots\dots\dots(i)$$

where f_{ct} is the compressive strength in N/mm^2 at any time t , given by

$$f_{ct} = \left[\frac{t}{\alpha + \beta(t)} \right] f_{c,28} \text{ in N/mm}^2 \dots\dots\dots(ii)$$

where α & β are constants depending on type of cement and type of curing.

The creep coefficients are predicted as

$$V_t = \left[\frac{t^{0.6}}{10+t(0.6)} \right] V_u \dots\dots\dots(iii)$$

where t = time in days after loading,
 V_u = ultimate creep coefficient = $2.35 Y_c$ and
 Y_c = product of applicable correction factors.

Shrinkage can be predicted by

$$(\epsilon_{sh})_t = \left[\frac{t}{35+t} \right] (\epsilon_{sh})_u, \text{ in mm} \dots\dots\dots(iv)$$

after 7 days for moisture cured concrete and

$$(\epsilon_{sh})_t = \left[\frac{t}{55+t} \right] (\epsilon_{sh})_u, \text{ in mm} \dots\dots\dots(v)$$

after 1-3 days for steam cured concrete.

Where t = time in days after the end of Initial Curing,
 $(\epsilon_{sh})_u$ = Ultimate Shrinkage Coefficient = $780e-6x Y_{sh}$ m/m

Y_{sh} = Product of applicable correction factors.

H/h_1 and H/h_2 = relative height ratio, where H is the total height of the structure and h_1 is the height from the top of the building at the level where first outriggers is installed and h_2 is the height from the top of the building at the level where second outriggers is installed

Outrigger Systems:

The outrigger system consist of a main core element connected to the external columns by outrigger beams at one or several floors and resists against rotation, axial shortening and storey drift. When using outrigger beams in building design, their location in the optimum position for an economic design is necessary. Earlier outriggers were used in sailing ships for many years to resist wind. Introduction of outrigger increases the axial stiffness of the peripheral columns which increases the resistance against overturning and axial deformations. Outriggers resist the rotation of the core causing the lateral deflections and moment in the core to be smaller than if the free standing core alone resisted the loading. It also increases the structure’s flexural stiffness and the shear resistance is carried by the core.

Description of the RC frame:

A 60 story RC frames is considered with beam size 450mmX300mm, column of size 750mmX750mm and it is kept constant throughout the height of the building. The core wall considered at the centre is of thickness 300mm and the slab thickness taken is 150mm. The grade of concrete used in beams, slabs and core-wall is M25 and that in column is M40. The floor height is taken as 4m. Along with the dead load of the structure, live load of 3kN/m² and a floor finish of 1kN/m² is also taken into account. The rate of construction sequence is assumed to be 7 days for each story construction. The structure is analysed using construction stage analysis option in MidasGen, which analyses the structure step by step at every floor. In the 60 story frame, outriggers are introduced at different levels with different H/h1 ratio and the change in differential column shortening is recorded. A typical plan of the frame is shown in Fig. 1.

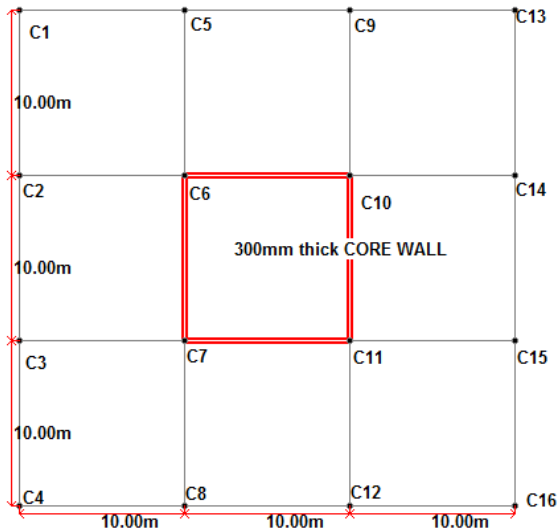


Fig. 1: Typical Plan of the RC Frame

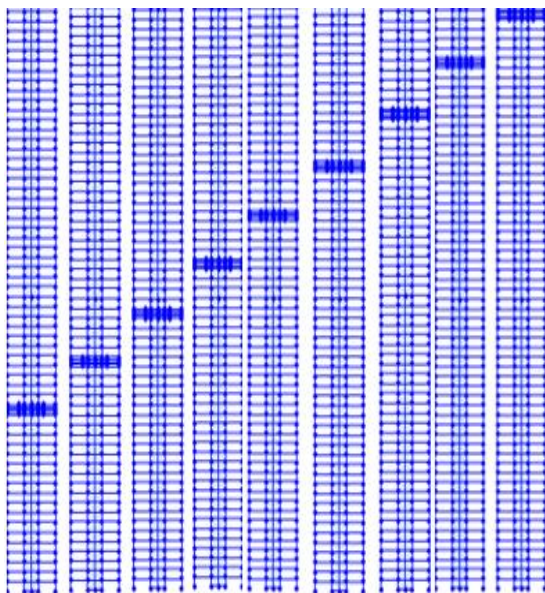


Fig. 2: Elevation of the RC Frame with one out rigger at different H/h1 ratio.

For a 60 story RC frame outriggers are introduced at different H/h1 ratios at different story levels ranging from 20th story to 60th story and the differential shortening between the RC core-wall and outer peripheral column is obtained. The outriggers are connected to the RC corewall and the thickness of outriggers are kept same as that of the corewall. Figure 2 shows the elevation of the 60 story frame with outrigger system at different levels.

Results and Discussions:

Figure 3 and Figure 4 shows the variation of total differential shortening as the outriggers are introduced at different levels.

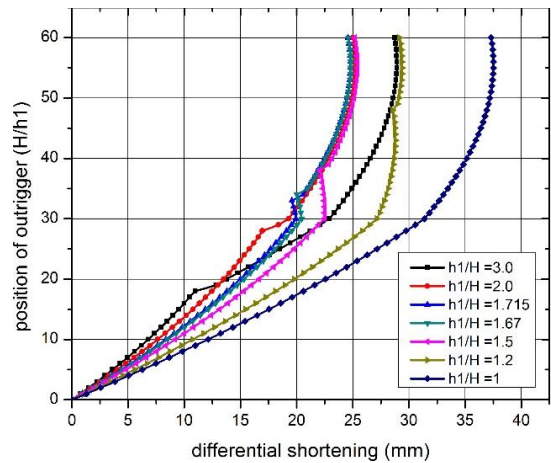


Fig. 3: Differential Shortening of Columns for different story heights.

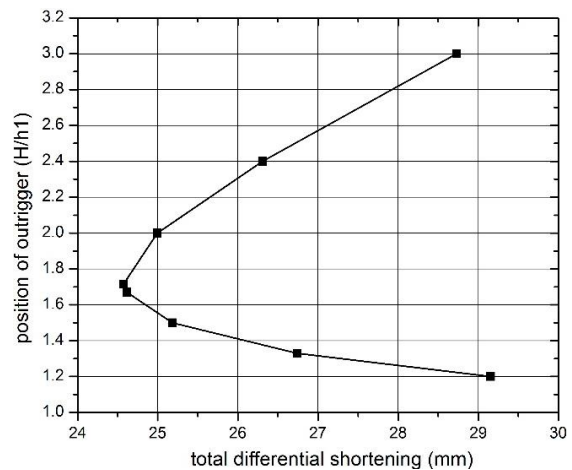


Fig. 4: Total Differential Shortening for different story height.

Table 1 and Figure 4 shows that as the position of outrigger is varied from H/h1 =0 to H/h1 =1.2 that is from 20th story till 55th story, the differential column shortening decreases till H/h1=1.715 by 34% and then again increases till H/h1=1.2. Thus we can say that when outrigger is introduced at H/h1=1.715, the minimum differential column shortening is found and hence this is the optimum position of the one outrigger.

Table 1: Total Differential Shortening for outriggers at different positions

H/h1 (position of the outrigger)	Total differential shortening (mm)	% decrease in differential shortening
0	37.31	0
3.0	28.73	23.0
2.4	26.31	29.50
2.0	25.0	33.0
1.715	24.60	34.14
1.67	24.61	34.03
1.5	25.18	32.50
1.33	26.74	28.33
1.2	29.15	21.86

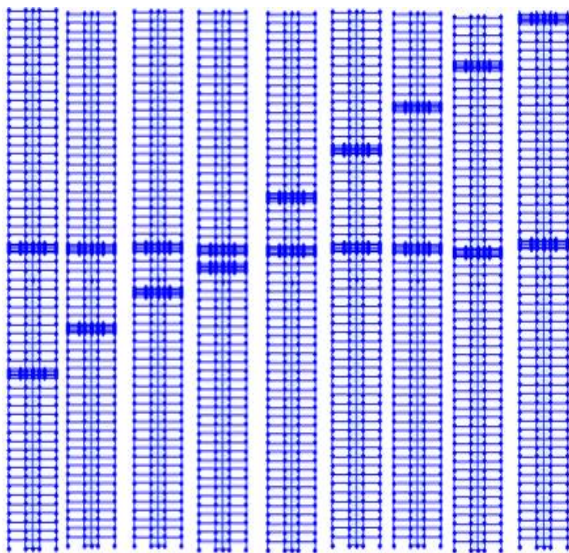


Fig. 5: Elevation of the 60 story RC frame with one outrigger fixed at H/h1=1.715 and another outrigger with varying H/h2 ratio.

A 60 story frame with one outrigger at H/h1=1.715 and another outrigger position is varied from H/h2=3.0 to H/h2=1.0 and the model is analysed and the differential shortening between the outer peripheral column C1 and the corewall is found out. It is found that the total differential shortening is reduced for second outrigger position of H/h2=3.0 to H/h2=1.33 and then again increases. Hence the optimum position of second outrigger can be considered for the position with H/h2=1.33 which will give the least differential column shortening. At this level, the differential column shortening is reduced by 14% more along with that reduced by providing first outrigger at its optimum position.

As the second outrigger is introduced at H/h2=3.0 and as its goes higher till H/h2=1.76, differential shortening increases and still further, till H/h2=1.33 it decreases to least value which shows that H/h2=1.33 is the optimum position of the second outrigger. The results more precisely are shown in the Table 2.

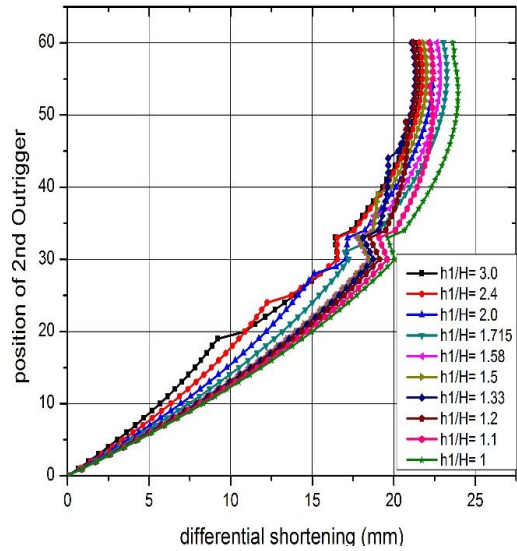


Fig. 6: Total Differential Shortening of 60 Story Frame one Outrigger H/h1=1.715 and another outrigger with varying H/h2 ratio.

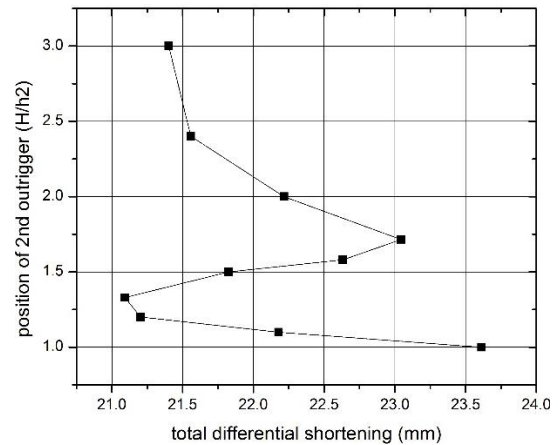


Fig. 7: Total Differential Shortening of 60 Story Frame with one outrigger at H/h1=1.715 and another outrigger with varying H/h2 ratio.

Table 2: Variation of Differential Shortening with one outrigger at H/h1= 1.715 and another Outrigger for varying H/h2 ratio.

H/h2 (Position of the second Outrigger)	Total Differential Shortening (mm)	Percentage decrease when two outriggers are introduced (%)
3.0	21.4	13.00
2.40	21.55	12.36
2.0	22.22	9.68
1.76	23.04	6.32
1.587	22.63	8.00
1.5	21.82	11.28
1.33	21.09	14.25
1.2	21.20	13.80
1.10	22.15	9.85
1	23.61	4.02

Conclusion:

The findings from the present study are as follows:

1. The differential shortening of columns is reduced to a high extent on introduction of outriggers.
2. The differential shortening is decreased by 34% when one outrigger system is introduced at $H/h_1 = 1.715$ and further there will be an increase in the differential shortening as the H/h_1 ratio is increased.
3. The same model is analysed by keeping one outrigger fixed at its optimum position with $H/h_1=1.715$ and second outrigger optimum position is found to be at $H/h_2=1.33$ which will further reduce the differential shortening by a total of 58%.

Acknowledgement:

The authors would like to express their sincere thanks to the Director and the H.O.D, Civil Engineering, Manipal Institute of Technology, Manipal and MIDAS Information Technology Co. Ltd., Mumbai for providing us the necessary facilities required for the present study.

References:

1. Liu, Zhao, Sun, Zheng, and Ding, 2011, "Structural performance assessment and control of super tall buildings during construction", *Procedia Engineering*, Volume No. 14, PP. 2503-2510.
2. Moragaspiya P, Thambiratnam D, Perera N and Chan T, 2010, "A numerical method to quantify differential axial shortening in concrete buildings", *Procedia Engineering*, Volume No. 46, PP. 49-61.
3. Serror M H and Essam El-Din, 2012, "Assessment of Internal Forces Induced due to Differential Shortening of Vertical Elements in Typical Medium- to High-Rise Buildings", *Journal of American Science*.
4. Khan F R and Fintel M, 1968, "Effects of column temperature, creep and shrinkage in tall structures", *IABSE congress report*.
5. Kim H S and Shin S H, 2011, "Column Shortening Analysis with Lumped Construction Sequences", *Procedia Engineering*, Volume No. 14, PP. 1791-1798.
6. Jayasinghe and Jayasena, 2005, "Effect of Relative Humidity on Absolute and Differential Shortening of Columns and Walls in Multi-storey Reinforced Concrete Buildings", *Practice Periodical on Structural Design and Construction*, Volume 10, Issue 2, PP. 88-97.
7. Jayasinghe and Jayasena, 2004, "Effects of Axial Shortening of Columns on Design and Construction of Tall Reinforced Concrete Buildings", *Practice periodical on structural design and construction*, Volume No. 9, Issue No. 2.
8. *Guide for Modelling and Calculating Shrinkage and Creep in Hardened Concrete*, 2008, ACI Committee 209.2R-08.