COMPARATIVE STUDY ON DIFFERENTIAL AXIAL SHORTENING IN TALL STRUCTURES USING ACI CODE AND EUROCODE-2

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Abstract - *With increasing height of structures, the effect of column shortening, both elastic and non-elastic, take on added significance and need distinct consideration in design and construction. Axial shortening in tall buildings would be of little concern if all vertical elements shorten equally. However, vertical members such as walls and columns may shorten in different amounts due to different service axial stress. Axial shortening depends on number of parameters such as type of concrete, environmental conditions, and the rate and sequence of construction. Thus, it's a difficult task to determine the exact value of axial shortening. This study is concerned with predicting of differential axial shortening by comparing two standards: ACI 209R-92 and Eurocode-2 (British Standards) for tall structures with different number of stories (40,60 and 80). Also, the effect of parameters such as construction sequence, rate of loading and type of concrete are considered. The analysis of the structures is carried using ETABS and results obtained from this study gives idea about different effects of changing parameters for different standards.*

Key Words: **Differential Axial Shortening (DAS), Construction Sequence, Creep and Shrinkage of Concrete, ETABS**

1. INTRODUCTION

In tall buildings, columns carry massive loads which effectively compress the column along its axis. This can be commonly referred to as 'axial shortening'. Differential axial shortening (DAS) for gravity load bearing components in tall buildings is a phenomenon which was first noticed in the 1960's with the use of concrete in combination with reinforcing steel in tall buildings. As buildings increased by height, elastic shortening became apparent during construction, and methods for correcting of instantaneous shortening such as construction of each floor to a corrected level or datum, became more common practice.

The components of column shortening are the elastic shortening and the inelastic shortening due to creep and shrinkage. Analysis of column shortening may be viewed as an application of long-term analysis of concrete structures. The method of quantification of axial shortening of reinforced concrete columns was originally introduced by Fintel and Khan (1969) and this method was further refined by Ghosh (1996). A widely used method for predicting column shortening in a tall building is the method proposed by Fintel et al. (1987) and published by Portland Cement Association (PCA).

Reliable shrinkage and creep material models for concrete has been an area of research interest for many years and there are several well-established empirical relationships between these long-term strains and the various properties of concrete. Among them are several popular models with an increasing number of factors to be considered such as the B3 (Bazant and Baweja 2000) model and simple but popular models like the ACI 209, EC2 (BSI 2004) and GL2000 (Gardner and Lockman 2001) method. The time dependent strain components of concrete considered in these material models are as given in Table 1.

Table 1. Components for Different Models

Features	ACI 209R	EC-2
Basic Creep	✓	✓
Drying Creep	✓	×
Autogenous Shrinkage	×	✓
Drying Shrinkage	✓	✓

The main objective of research are

1. To predict the effects of differential shortening in tall buildings and addressing them through design and construction.
2. To provide guidelines by comparing different standards available to calculate time dependent properties.

2. MODELING IN SOFTWARE

The following was applied to reach the above objectives:

1. The present study was carried out for 40-story building with moment resisting frame + shear wall core, 60-story building with outrigger system and tube system, each and 80-story building with outrigger system and tube system, each.
2. These structural systems were analyzed using ETABS (v17) software. Both elastic and inelastic shortening were calculated using sequential analysis.

2.1. Geometric Parameters

The common geometric parameter for all structural system is building plan with dimensions 36 m x 36 m and a typical story height of 3 m. The mean compressive strength of concrete is 60 MPa and 40 MPa for column and shear wall, respectively. The relative humidity of 50% is considered. The rate of construction is taken as 7 days/floor. The typical floor plan of different structural system is shown in Appendix A.

The size of structural elements for different structural systems is shown in Table 2.

2.2. Loading Conditions

A super-imposed load of 2 kN/m^2 is applied at all floors. The wind loads are applied as shell loads with basic wind speed of 39 m/s as per IS 875 (Part 3) : 2015. The factor for basic wind speed is 1 and the terrain category considered is 4. Similarly, the topography factor and importance factor are also 1.

3. ANALYSIS AND RESULTS

3.1. Analysis cases:

The following cases of analysis were considered to calculate axial shortening using ETABS.

- Sequential Analysis without considering time-dependent properties.
- Sequential Analysis considering time-dependent properties complied to ACI 209R and EC2.

The results for elastic shortening are denoted as SEQ. While, total axial shortening results including inelastic shortening are denoted as ACI & EC according to time-dependent parameters considered. Differential axial shortening (DAS) between a particular column element (denoted by C1, C2,….) and shear wall (denoted by S1, S2,….) are shown in terms of SEQ, ACI & EC. The differential axial shortening (DAS) at the end of construction and at 4500 days are also compared.

Table-2: Geometric parameters for different structural system under case-study

	Structural System	**Floor**	**Column Size (m)**	**Shear Wall thickness (m)**	**Outrigger thickness (m)**
40-story	MRF+SW Core	1-20 21-40	0.75*0.75 0.65*0.65	0.8 0.6	- -
60-story	Outrigger system	1-21 21-40 41-60	0.9*0.9 0.75*0.75 0.65*0.65	1 0.8 0.6	0.75 (20-21)* 0.6 (40-41)
	Tube System	1-21 21-40 41-60	0.75*0.75 0.65*0.65 0.55*0.55	0.75 0.65 0.55	- - -
80-story	Outrigger system	1-21 21-40 41-60 61-80	1*1 0.9*0.9 0.75*0.75 0.65*0.65	1.2 1 0.8 0.6	0.9 (20-21) 0.75 (40-41) 0.6 (60-61)
	Tube System	1-21 21-40 41-60 61-80	0.85*0.85 0.75*0.75 0.65*0.65 0.55*0.55	0.85 0.75 0.65 0.55	- - - -

* (20-21) indicates position of outrigger belt.

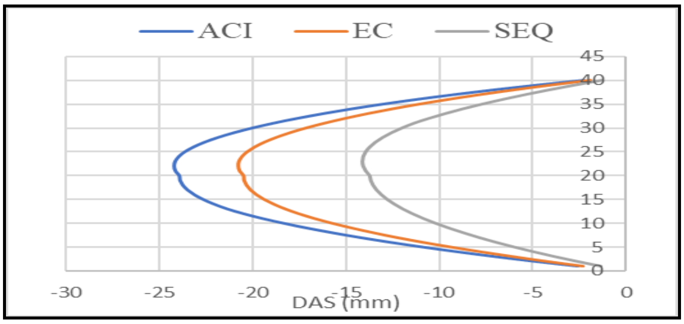

Chart 1 DAS at the end of construction between C11-S7 of 40-story structure

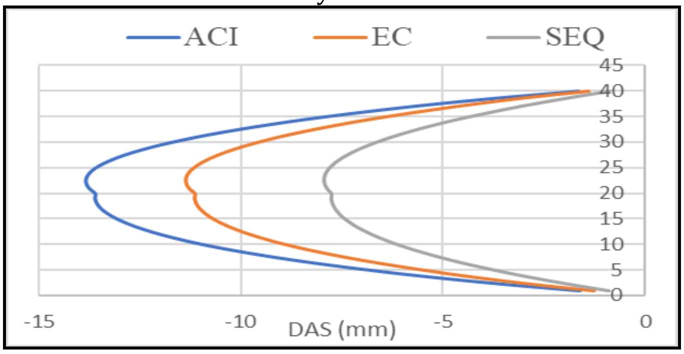

Chart 3 DAS at the end of construction between C12-S4 of 40-story structure

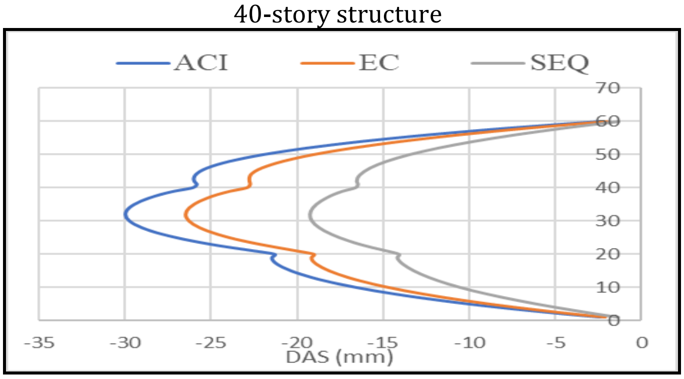

Chart 5 DAS at the end of construction between C11-S7 of 60-story outrigger system

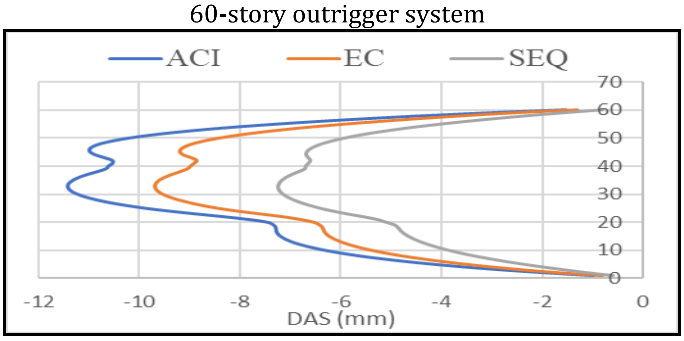

Chart 7 DAS at the end of construction between C12-S4 of 60-story outrigger system

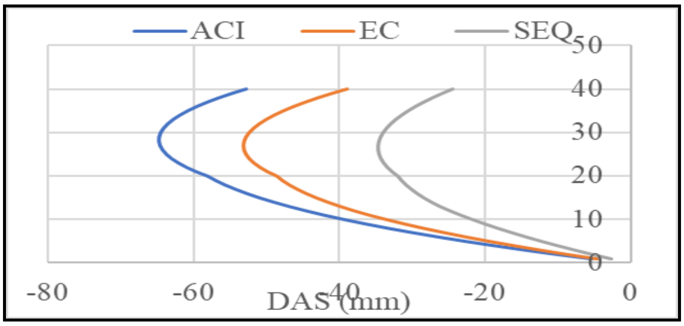

Chart 2 DAS at 4500 days between C11-S7 of 40-story structure

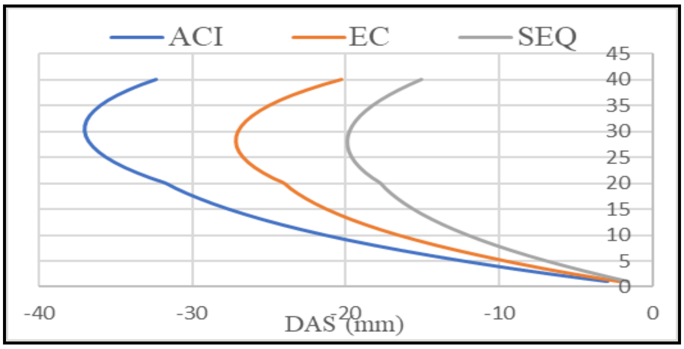

Chart 4 DAS at 4500 days between C12-S4 of 40-story structure

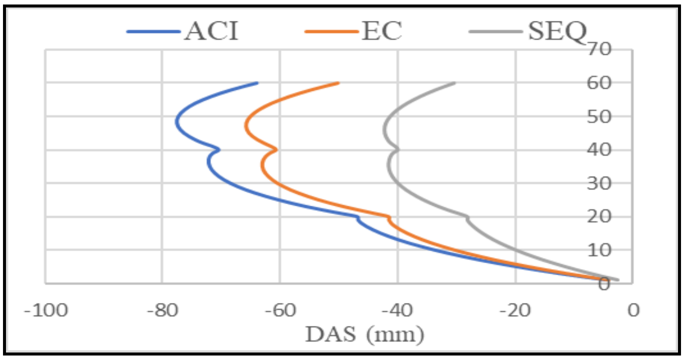

Chart 6 DAS at 4500 days between C11-S7 of 60-story outrigger system

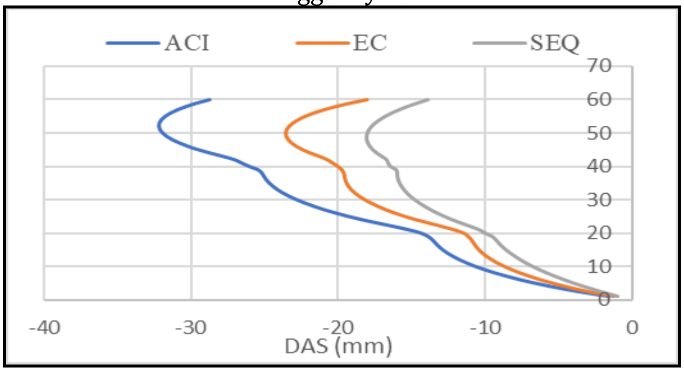

Chart 8 DAS at 4500 days between C12-S4 of 60-story outrigger structure

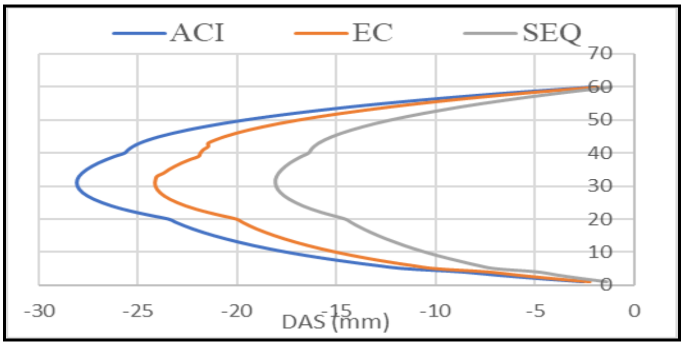

Chart 9 DAS at the end of construction between C11-S7 of 60-story tube system

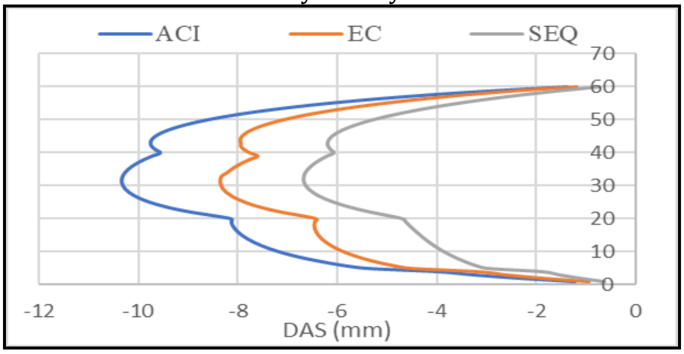

Chart 11 DAS at the end of construction between C12-S4 of 60-story tube system

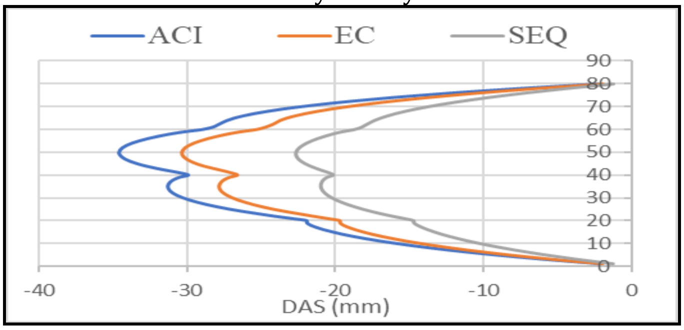

Chart 13 DAS at the end of construction between C11-S7 of 80-story outrigger system

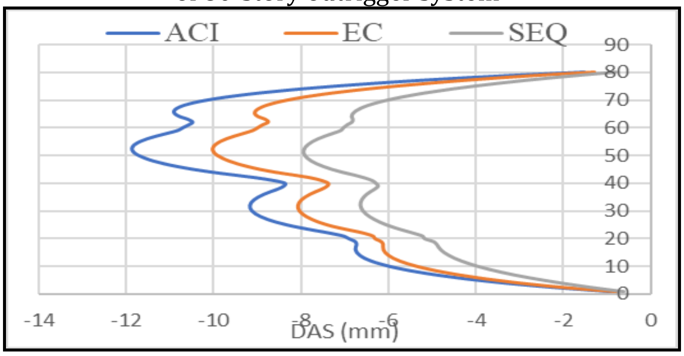

Chart 15 DAS at the end of construction between C12-S4 of 80-story outrigger system

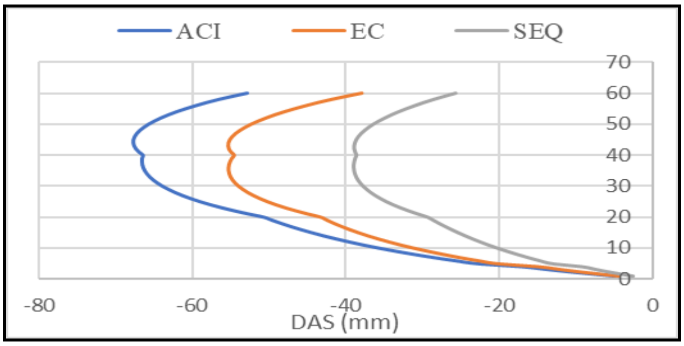

Chart 10 DAS at 4500 days between C11-S7 of 60-story tube system

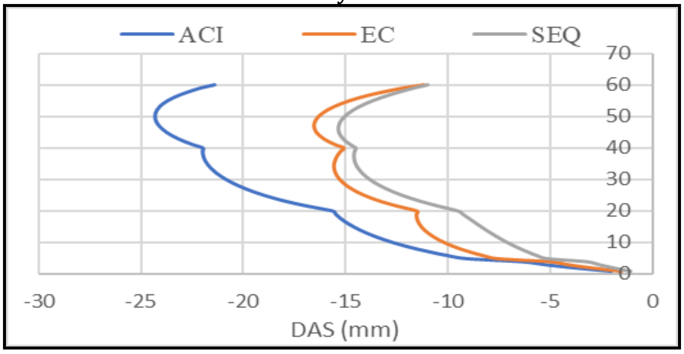

Chart 12 DAS at 4500 days between C12-S4 for 60-story tube system

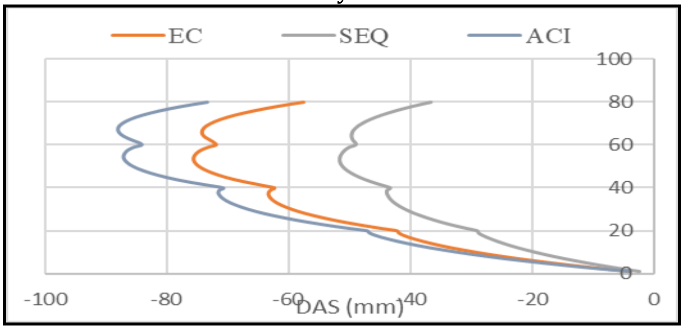

Chart 14 DAS at 4500 days between C11-S7 of 80-story outrigger system

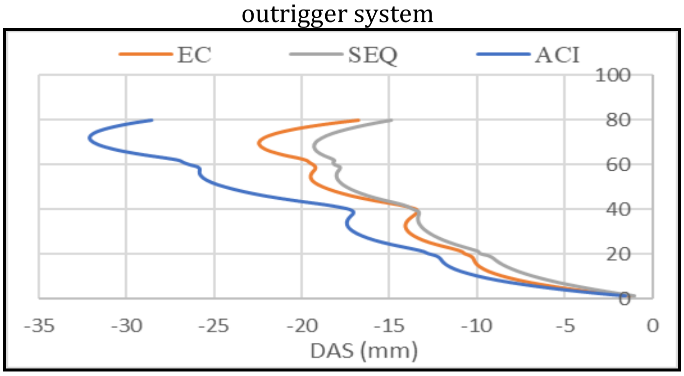

Chart 16 DAS at 4500 days between C12-S4 of 80-story outrigger system

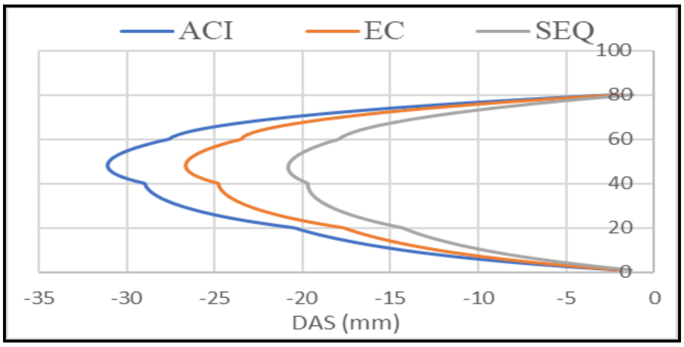

Chart 17 DAS at the end of construction between C11-S7 of 80-story tube system

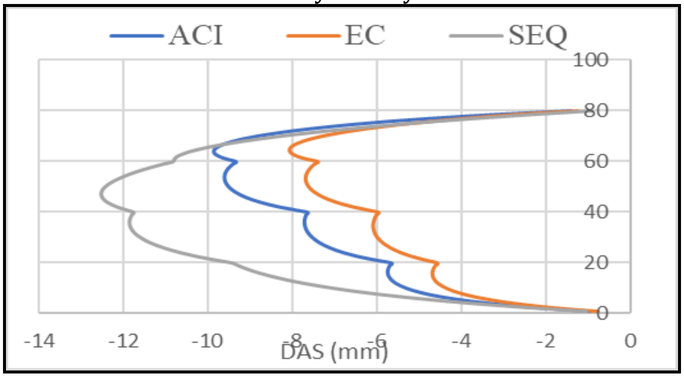

Chart 19 DAS at the end of construction between C12-S4 of 80-story tube system

4. CONCLUSIONS

The following conclusion can be drawn from the above results:

1. For 40-story structure, the maximum amount of differential shortening at the end of construction is about 25 mm. While, it is 65 mm after 4500 days.
2. For 60-story outrigger system, the maximum amount of differential axial shortening at the end of construction is 30 mm. While, it is about 80 mm at 4500 days.
3. For 60-story tube system, the maximum amount of differential shortening at the end of construction is 30 mm. While, it is 65 mm at 4500 days.
4. Similarly, for 80-story outrigger system, the maximum amount of differential axial shortening at the end of construction is about 35 mm and it is 85 mm at 4500 days.
5. For 80-story tube system, the maximum amount differential axial shortening at the end of construction is about 30 mm and 75 mm at 4500 days.
6. Thus, one can expect total differential axial shortening of 60-65 mm in 40 story structure, 65-80 mm in 60-story structure and 75-90 mm in 80-story structure.

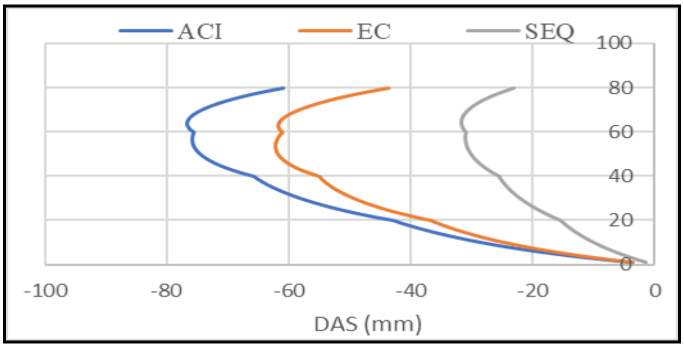

Chart 18 DAS at 4500 days between C11-S7 of 80-story tube system

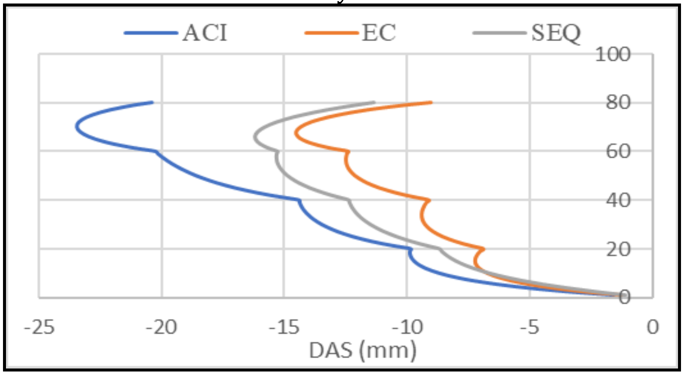

Chart 20 DAS at 4500 days between C12-S4 of 80-story tube system

7. Overall provision of 25 mm, 30 mm and 35 mm should be provided to accommodate differential shortening at the end of construction for 40, 60 and 80 story structures, respectively. And further provision of 40 mm, 50 mm and 55 mm should be provided to accommodate long-term effect of shortening for 40, 60 and 80 story structures, respectively
8. For 60-story and 80-story structures, it is observed that closely spaced peripheral columns; i.e tube system slightly reduces differential axial shortening by 15-20 mm compared to outrigger system.
9. Non-linear axial shortening, i.e. considering time-dependent properties for computing axial shortening by ACI code and Eurocode-2 shows variations in range of 1%-7% for columns, which is not significant. But in the case of shear wall the range is about 5%-20%. So, it is suggested to take average of both results to avoid large variations in calculations.
10. The amount of inelastic shortening is about 70%-190% higher than elastic shortening. Thus, for tall buildings inelastic shortening should be considered during analysis.

5. APPENDIX A

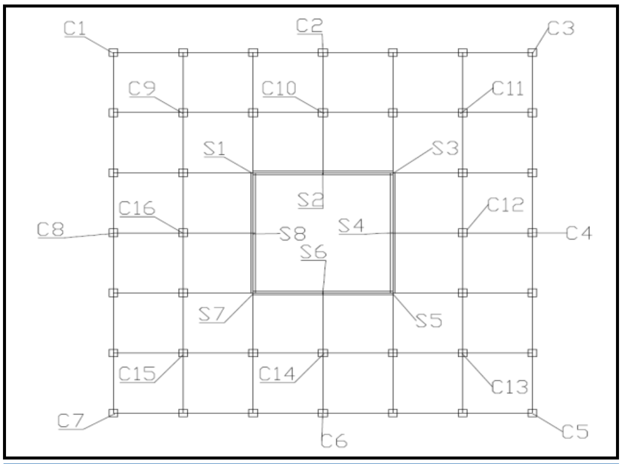

FIG-1: Typical Plan Layout for 40-story and 60 & 80 story outrigger system.

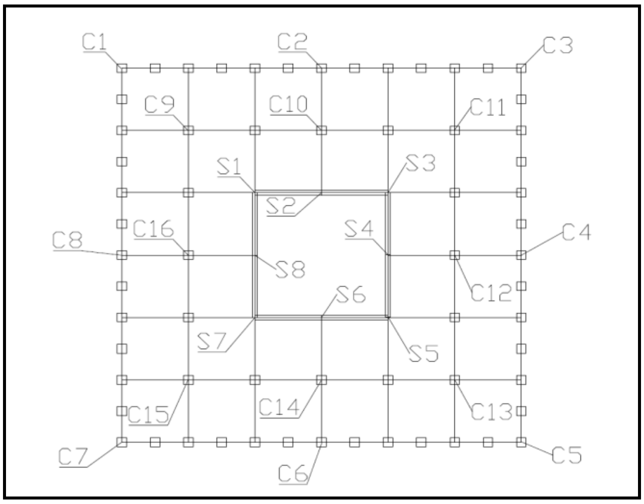

FIG-2: Typical Plan Layout for 60 & 80 story tube system.

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