

# Economic and Functional Feasibility of Concrete Encased Composite Columns in Buildings

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## ABSTRACT

Modern day construction is widely influenced using concrete-steel composite columns. A lot of research on concrete-steel composite columns is being carried out around the world. The rapid growth in concrete-steel composite construction has widely decreased the use of conventional reinforced cement concrete construction (R.C.C), and the steel construction practices. The concrete-steel composite construction has obtained an extensive receiving around the globe. As Pakistan is a developing country, so, it is relatively a new concept for its construction industry when compared with the developed countries around the globe. Although, the R.C.C construction is suitable and economical for construction of framing systems of low-rise buildings, however, the increased dead load, span restrictions, less stiffness and risky formwork makes it uneconomical and unviable when it comes across the construction of intermediate to high-rise buildings. This research is an effort to learn the cost effectiveness, increased or decreased stiffness, and change on the functionality of the composite construction for intermediate to high-rise buildings constructed in Pakistan. A Base + Ground + 11 storey commercial building is selected for this study. A comparison is made between conventional R.C.C columns structure and concrete-encased composite columns structure. The equivalent static nonlinear analysis is performed using ETABS 2017 software. Although, for Base + Ground + 11 storey building, the construction cost of concrete-encased composite structure is 7.7% more than the conventional R.C.C columns structure, but the concrete-encased composite structure will have 13.013% more constructed floor area. This increased floor area helps to settle the cost difference between the two structures.

**Keywords:** Composite structures, Concrete-encased composite column, Economic comparison between R.C.C columns and concrete-encased composite columns, Modeling of composite columns.

## INTRODUCTION

Concrete-steel composite structures are widely used around the world. Its use in Pakistan's construction field is considerably low, when compared with many developing countries.

Concrete-steel composite structures play a vital role in the economic aspects when constructing high-rise buildings. Reduction in the erection time makes the concrete-steel composite structures economically viable. Under seismic conditions, due to inherent ductility characteristics, the concrete-steel composite frames perform better than the conventional R.C.C frames. Effect of seismic forces on the composite structures is less due to low dead weight as compared with the R.C.C structures.

Lately, with the primer of modern-day composite mount construction in tall buildings, engineers started to develop strategies to get the stiffening and consolidation effects, advantages of concrete and steel reinforcement. These factors directly affect bearing capacity and axial compressibility of concrete-steel composite columns. Using concrete-steel composite structural members leads to large openings, lowering the peak stages and delivers a higher stiffness. Under earthquake loadings having high magnitudes, the concrete sections tend to crack, resulting in the reduction of flexural strength of the composite columns and beams. The steel core acts as a back-up system in giving the shear strength and the needed plasticity to forestall the brittle failure modes.

In the past, the investigations [1-7] on concrete-encased composite columns describe the experimental results. The ultimate flexural stiffness, ductility, and strength absorption capacity may be enhanced by introducing the cross ties and reducing the spacing of the hoops. It is often attributed to the expanded confinement furnished through the transverse reinforcement. The test results indicate that by resisting concrete flexural and concrete shear cracking occurring due to increased axial compression of concrete-steel encased composite columns, the joint behavior improves, thus, resulting in increased joint stiffness and strength [2]. This result was based on the obtained results of large number of tests. When load is applied on the concrete-steel encased composite column, the crushing strength increases by a margin of 30% as compared to the conventional R.C.C columns [3], which is also complemented by other results [4]. The story number for each building type was chosen different to find the effect on the cost of these two different types of constructions for medium, high-rise & low-level buildings. According to the obtained results, the composite concrete construction was found well suited for high-rise buildings while R.C.C construction works efficiently in the low-rise buildings [5]. The price comparison shows that concrete-steel composite structures are steeply-priced, direct cost reduction of the concrete-steel composite structure as a result of rapid construction that makes concrete-steel composite buildings economically feasible [6].

The construction history plays an important role in the development of proposed method, as several ideas from other authors were considered to make it as easy as possible. Concrete and steel composite structures are widely used around the world. Its use in the construction industry of Pakistan, considerably low when compared with many other developing countries around the world. There is a huge potential for increasing the volume of composite construction, considering the current development requirements. Three basic types of concrete composite columns are: the sections which are completely encased, sections which are partially encased, and concrete filled hollow columns. Under seismic conditions, due to inherent ductility characteristics, steel-concrete composite structures perform better than the conventional reinforced cement concrete

structures. The seismic forces effect it less due to low dead weight as compared with the R.C.C structures.

The premature evolution of the composite column was due to its fire-resistant property for the structural steel in buildings. By early 1960, research shows that the concrete encasement or wrapping can increase the load resistance of the steel columns. Economy in construction can be achieved by using better quality of concrete and introducing the composite sections in the design of columns. Both steel and concrete sections oppose the exterior loadings by collaborating collectively through friction and the chemical bond. And using mechanical shear connectors in some circumstances. Although steel concrete composite columns were infrequently used at the time of world war II till the early 1970s, research had commenced a long time before, at the start of the 20<sup>th</sup> century. To protect the steel columns from fire they were customarily encased in concrete, while steel was merged in concrete as reinforcement.

### Previous Studies

Volume of steel in construction can greatly be increased, especially when we consider current needs of development. Initially, the concept of composite beam was introduced in a period 1850-1900 by Emerges. The composite construction includes a large variety of structural systems, such as framed structures using all composite members and mechanisms (composite beam-columns and joints) and sub-groupings of steel and reinforced concrete elements. To increase the resistance and deformation capacity such elements are used (Uchida & Tohki, 1997). Steel and concrete composite columns are comparatively new components which are being used in the framed structures. Henceforth, framed systems & composite columns are discussed from a design, economy, functionality, and technical point of view in detail.

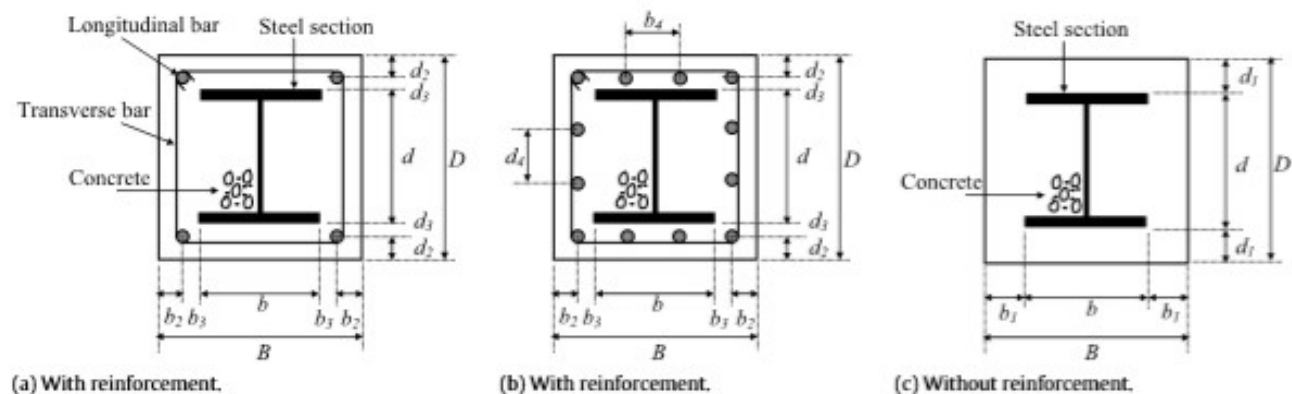


Figure 1: Concrete steel composite columns (encased)

### Design of Composite Structures in Previous Studies

(Ellobody & Young, 2011) studied the effects of eccentrically loaded concrete and steel columns (encased). In their study, a nonlinear 3D finite element model was used to represent these eccentrically loaded columns. Pin-ended columns were subjected to normal load posing along principal trajectory, with an eccentricity ranging from 0.1250 to 0.3750 of total depth of sections for under study columns. Considering model's limitations, the model was responsible for an

inelastic behavior in the transverse and longitudinally embedded reinforcement bars along with concrete confinement of steel encased concrete composite columns. The functionality between reinforced concrete sections, the transversely and longitudinally embedded reinforcement bars and concrete were taken under consideration to allow the bonding behavior. Geometrical imperfections had already been carefully integrated into the model. Nonlinear 3D finite element model was validated against test results. The variation in concrete strength was 30-110 MPa (normal-to-high). The stress variation was 275-690MPa (normal-to-high). In addition, a parametric study examined the influencing variables for the composite columns' strength; column dimensions, eccentricities, sizes for the structural steel, yield stresses for structural steels and concrete strengths. Because of the increase in yield stress of structural steel, for oddly loaded columns with low eccentricity of 0.125D, the effect was significant on the composite column's strength. While, due to the increment in structural steel's yield stress with a higher eccentricity of 0.375D and concrete strength less than 70 MPa, the effect on the composite column's strength is remarkable. The strength which was obtained using finite element model analysis was compared with the strengths of composite columns calculated using Euro-code 4 (CEN, 1994).

(Johnson, 2018) proposed a relative analysis of R.C.C structure and steel-concrete and composite structure of multistoried building. The research carried explains that reinforced cement concrete structures are not economically viable due to the increased load and unsafe framework. Pushover analysis as well as different parameters like story displacement and story drift were analyzed by using ETABS 15. It is compiled from different reviews that composite structure constructions are suitable for high-rise buildings as compared to R.C.C. structures. Introduction of concrete composite members in high-rise buildings is the main objective of this study. Composite columns are the compression members, which are built using different combinations of structural steel and concrete to use the beneficial properties of each material. Advantages for concrete composite columns explained in the cited research are for a given cross-sectional dimensions that increases the strength, buckling resistance and the stiffness, resistance to fire and protection against corrosion in case of an embedded section. Plastic design method is used for analysis of a thirteen-story reinforced cement concrete and composite structures. In ETABS 15 non-linear analysis was adopted for frame analysis. The results and observations show that overall composite structure is better than R.C.C structures as composite structures produces less displacement and resist more structure forces.

(Wagh & Waghe, 2014), did a relative study of steel concrete composite and R.C.C structures. In their study, they did a comparison of steel concrete composite structures and R.C.C structures with (G+12, G+16, G+20, G+24) story buildings situated in zone 2. Dimensions used for plan were 63.20m x 29.50m. Equivalent static method was used for the analysis. Both the structures were modeled using STAAD pro software and comparison was made between the results. This study includes shear force, axial force, deflection, construction cost, and the bending moment in the column. Design method for this study mainly follows EC4. It can be seen from the results and analysis that reinforced cement concrete structure is less economical than the steel concrete composite structure when considering high-rise buildings. Cost difference in this study shows that with increase in number of stories the cost reduces, when compared to R.C.C buildings. Also, the construction time consumed by the composite structure is less. Studies reveal that composite

structure behaves better than R.C.C structure during earthquakes. The results also concluded that smaller size of foundation can be used in case of composite structures.

(Panchal & Marathe, 2011) did a relative study of composite and R.C.C multistoried buildings. The building considered for their study was a residential structure with G+14 stories situated in zone 4. The dimensions used for plan of the building are 20m x 10m, with each story height of 2.3m. The advantages of composite construction are that; it permits easy structural repairs, lighter construction, Good fatigue resistance, and corresponding steel have lower stiffness as compared with the composite sections. The building was examined using equivalent static method and response spectrum method. Parameters analyzed were deflection, base shear, time-period, and the story drift. The results showed that the composite structure is lighter in weight than R.C.C structure. The time-period of composite structure was found more than the R.C.C. structures. However, the displacement for R.C.C structure was less than the composite structure. Whereas, composite construction is more economical than the R.C.C structures and consume less time.

(Kumawat & Kalurkar, 2014) performed analysis and design of multi-storied building of the composite structures. For their study, a G+9 story building was considered in seismic zone 3. The provisions used by them was Indian standard: 1893 (Part1)-2002. The response spectrum analysis and equivalent static method were used for analysis and modeling of their study, and SAP2000 was also used. From their study, it was concluded that for composite structures, the dead weight was 15-20% less than the R.C.C building, that also results in the reduction of 15-20% in the seismic forces. The authors also concluded from their study that for composite structures, the stiffness rises from almost 6-10% in longitudinal direction and it increases from almost 12-15% in transverse direction when compared to R.C.C structure. In linear static analysis, the twisting moment for composite column is 49-65% less in longitudinal direction and it is 48-63% less for transverse direction than R.C.C columns. In the linear static analysis, axial force for composite columns is found to be 20-30% less than in case of R.C.C structures. While, for linear dynamic analysis axial force in composite columns is found to be 18-30% less than R.C.C structures. The researchers concluded that structurally the composite structure performs better than the R.C.C structure.

In (Committee & Standardization, 2008) the American Code International (ACI 318-14, section 10.3.1.6), is given that the steel thickness encasement is to be taken per (a) or (b) for concrete core encased by the structural steel for the composite columns.

a)  $b \sqrt{\frac{fy}{3Es}}$  for each face of width  $b$

b)  $h \sqrt{\frac{fy}{8Es}}$  for circular sections of diameter  $h$

Steel-encased concrete sections should have a steel wall thickness large enough to attain the longitudinal yield stress before buckling outwardly.

However, the literature disagrees with the precise value of maximum unlimited compressive stress, particularly when higher-strength concrete is used. Conditions like AISC-LRFD (AISC 2001) and ACI-318 (Committee, 2002) recommend  $0.85 f_c'$ .

(Young & Ellobody, 2011) in their research gave a strength reduction factor of 0.92 for high strength concrete in the range of 75-90 MPa (11-13 Ksi). (Martinez et al., 1984) proves a ratio of 0.85 for unconfined column strength to the cylindrical strength for concrete strength ranging from 25-70 MPa (3.5-10 ksi). The value given by the researcher is irrespective of the concrete strength. (Cusson & Paultre, 1994) performed many tests on concrete strength ranging from 59-117 MPa (8.5-17 Ksi) and found an average value of 0.88 for  $f_c'$ . While, (Collins, Mitchell, & MacGregor, 1993) through an extensive research gave a value of  $f_c'$  ranging from  $0.77 f_c'$  to  $1.0 f_c'$  for maximum compressive stress value. From above given values of  $f_c'$  a conclusion can be drawn that there is an agreement on lower part of stress strain curve.

(Ahmad & Shah, 1982) concluded in their study that high strength concrete of 69 MPa (10 Ksi) can be ductile same as low to intermediate concrete strength. However, these trends cannot be found for concrete strength ranging from 76-90 MPa (11-13 Ksi) in the tests performed by (Young & Ellobody, 2011). (Martinez et al., 1984) gives conclusion for concrete strength from 48-68 MPa (7-10 Ksi) that stress-strain curve goes down instantly after it achieves the highest value. After this, it goes flat showing high axial compressive stress. (Mirza & Skrabek, 1992) in their study showed that from yielding of transverse reinforcement such as hoops, column flanges and in case of steel encased columns, steel tube can be used to find the confined compressive strength. We can take that the confining pressure that is generated after loading can be assumed as active pressure and will remain always there (Hajjar & Gourley, 1996). The results which are extracted from the tests performed are quite promising for steel encased concrete filled columns and for concrete encased steel section composite columns.

(El-Tawil & Deierlein, 1999) describe the requirements of ACI 318 and conclude that the provisions for composite construction are similar as for the reinforced concrete concretion for calculation of strength interaction between axial and flexural effects. The whole provisions are based on a simple assumption of linear strain distribution over the steel concrete composite column cross-section giving maximum value at outermost point in the given figure. For finding the nominal strength of concrete block, the tensile strength is not considered and a stress block with value for stress ordinate of 0.85 is taken and then it is related to nominal strength. For calculation of induced stresses in both reinforcing and structural steel, the values of elastic modulus and strain is taken to the limiting point of nominal yield strength. In this case stress hardening is not taken into consideration. The compressive strength for encased column is limited to a value of  $0.8P_0$ .

where,

$$P_0 = (0.85f_c' A_c + F_{yr} A_r + F_{ys} A_s)$$

In the above equation  $A_c$ ,  $A_r$  and  $A_s$  stand for the concrete area, structural steel area and reinforcing steel area respectively. Due deflection in columns, the slenderness effect will take place through the moment modification.

The ACI 318 and AISC LFRD gives conclusions: i) the ACI 318 is better than AISC LFRD in modelling the overall behavior of composite structure. The accuracy of modelling depends upon the slenderness ratios along with steel and concrete strength ratios, ii) when compared with both



short and long columns, the ACI 318 gives some un-conservative results ( $A_s$  up to 8-10 %), and iii) the conservative value for short columns in both the codes (ACI 318 and AISC LFRD) is 40%. The value for long columns is with steel ratios of ( $L/r = 40$  and  $A_s/A_g = 16\%$ ). The outer fiber strength and AISC LFRD does have much of difference. The strength reduction is very less that is 6% resulting from the sequence of construction for the columns having value less than  $L/r < 40$ .

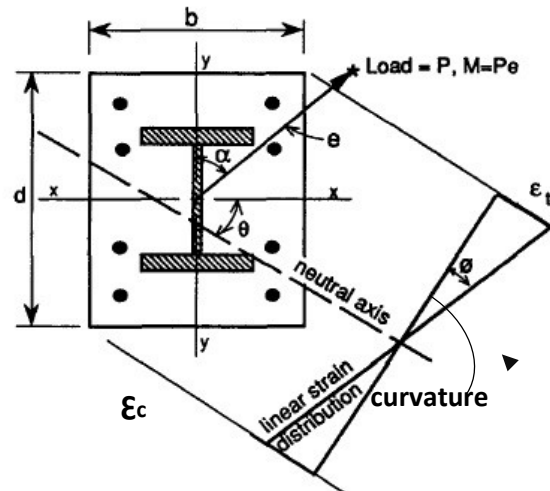


Figure 2: Definition of analysis for composite sections.

The method for analysis and specification is developed using a limited amount of data. But this limited number of data can produce some feasible results to check for the differences in existing design. As a result of this research, amore methods for computer analysis can be used such as fiber integration technique. Models and computer programs can be developed using this method to design the reinforced and composite structures using nonlinear analysis method. Some of such programs can greatly improve the practical importance of this method in the context of response of structural system.

### Economic Comparison of R.C.C and Steel-Concrete Composite Column Structures

(Boke & Suryawanshi, 2017) made a study of composite structure (G+10) and reinforced concrete residential building. Objective of the analysis was to review the behavior of R.C.C and composite structures underneath the impact of seismic loading. Response spectrum analysis was used for G+10 storied structures. Base shear, displacement and inter-story drift were core considerations for their study. For composite structure, base shear was determined to be 34% and for steel concrete structure was determined to be 26% as compared with R.C.C structure. Dislocation of composite concrete structure was 49% enhanced and 46% was enhanced for steel concrete structure when compared with R.C.C structure. Forces in the column for steel structure were reduced to 44% and that in composite steel structure, were reduced to 54% when compared with R.C.C building. Due to the reduction of column forces the footing sizes also decreased in comparison to the footing size of reinforced concrete building. The researchers concluded that the structure of composite steel concrete is cheaper than the reinforced concrete structures. As much formwork is not required in the composite structures, this reduces the construction time when compared with reinforced concrete buildings.

(Liang, 2014) performed a comparative study of cost of reinforced concrete and steel concrete composite structures. They compared reinforced concrete structure with composite structure having different stories like G+9, G+12, G+15, and G+18 having a height of 3m of every floor, located at Pune seismic zone 3. As far as analysis is concerned, equivalent static method was used. Stiffness, drift, displacement, axial and shear forces in the column, bending and twisting moments in the columns of stories of composite structures has been compared with R.C.C structures. Complete dimensions of building were 15m x 9m. STAAD-PRO 2007 was used by the researchers for analysis and design calculations. The study of load combinations has been done as per the Indian standard code of practice. The economic results found from their research were:

Table 1: Economic comparison

| Story | Cost of R.C.C Structure | Cost of composite Structure | Difference % |
|-------|-------------------------|-----------------------------|--------------|
| G+9   | 6007325                 | 3418120                     | 43.1%        |
| G+12  | 7730830                 | 4042635                     | 47.3%        |
| G+15  | 9695255                 | 4970475                     | 48.7%        |
| G+18  | 10876325                | 4591360                     | 57.8%        |

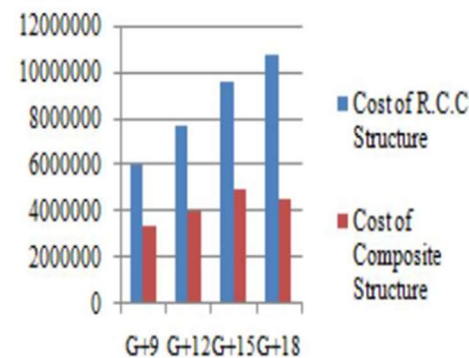


Figure 3: Economic comparison

The cost evaluation reveals that composite structure is economical, decreases the direct cost of composite structure. The performance of the composite structure will be better than the reinforced concrete structure under seismic conditions due to its inherent ductility characteristics. In reinforced concrete structures, the bending moments, deflections, and axial forces remain slightly additional to that in the steel concrete composite structures. Forces produced due to earthquakes do not cause destruction to the composite steel concrete structure when compared with reinforced concrete structures. Due to less dead weight of the steel, the composite building weighs less when compared to the reinforced concrete buildings which gives relief in falling down the cost of the foundation.

(Ambe & Maru) performed a relative study on the steel concrete composite structure and reinforced concrete structure. They compared a G+15 story office building for both steel concrete composite building, and reinforced concrete building located in the earthquake zone 4 with wind speed of 39m/s. The equivalent static method was used for the analysis. STAAD-PRO was used for the steel composite and reinforced concrete structures. The modeling was done, and the obtained results were compared. The results showed that the steel concrete composite structures are economical than R.C.C structures. The cost comparison in their study showed that the composite steel structures are economical than the reinforced concrete structures. Moreover, they concluded that the composite construction is fast as compared with RCC construction. A structure, if constructed using R.C.C construction approach can take up to 24



months of time to finish. While, if same structure is constructed using composite construction approach it can save almost 9 months of time.

(Shashikala & Itti, 2013) performed a comparative study of R.C.C and composite multi-storied buildings. In their study, the residential building (B+G+15) locates in earthquake zone per requirements of Indian standard: 1893 (Part1 2002). STAAD Pro V8i software was used by them for modeling of composite and reinforced concrete buildings. The equivalent static method was used for composite and R.C.C structures. Their work determined that the composite column cost is less by 20.45% compared with R.C.C columns.

Table 2: Cost of construction of columns for composite structure

| <b>Material</b>    | <b>Quantity of R.C.C column for composite structure</b> | <b>Rate (Rs)</b> | <b>Amount (Rs)</b> |
|--------------------|---|------------------|--------------------|
| Steel              | 107.87 (tons)   | 51500M/T         | 5606805            |
| Concrete           | 475.75 (m <sup>3</sup> )                                | 6000             | 2254500            |
| <b>Total cost:</b> |   |                  | <b>7861305</b>     |

Table 3: Cost of construction of columns for R.C.C structure

| <b>Material</b>    | <b>Quantity of R.C.C column for R.C.C structure</b> | <b>Rate (Rs)</b> | <b>Amount (Rs)</b> |
|--------------------|---|------------------|--------------------|
| Steel              | 145.94 (tons)                                       | 51500M/T         | 7515910            |
| Concrete           | 394.53 (m <sup>3</sup> )                            | 6000             | 2367180            |
| <b>Total cost:</b> |   |                  | <b>9883090</b>     |

(Tedia & Maru, 2014) performed a relative study of the cost, analysis, and design of composite concrete and R.C.C structures. The building taken by the researchers for their study was G+5 story with height of each story as 3.658m and with the overall dimensions of 56.3m x 31.94m. The building was in zone 3. The modeling of R.C.C and steel concrete composite structures was performed using STAAD-PRO. The equivalent static load technique was used for the analysis of these buildings. The result of their study revealed that the composite structure for G+5 building is costlier than that of R.C.C structure.

## Modeling of Steel-concrete composite Column Structure

(Bridge, 2011) presented design for steel concrete composite structures. In this study, the material design approaches defined by AS3600, AS4100 and Eurocode 4 (CEN, 1994) are compared. A comparison is made to discuss the differences and to point out the likenesses. Simple plastic method or strain compatibility method is used for the determination of cross-section. Using moment magnification of the first order or direct analysis, all this needs to determine the second order effects. Difference between these approaches is the method in which geometric and material imperfections along with stability is considered. In Eurocode 4 (CEN, 1994), the approach for composite column is similar to that of R.C.C columns. The effects of second order imperfections are to be taken explicitly for the members. By using Eurocode 4, for the expression of  $C_m$ , the value for the column is 1.1 through identical end moment's determination in an equal arc. This shows that the end moments cause 10% imperfections. In the analysis of second order, the effective stiffness used, is the elastic stiffness which is modified by the calibration and the correction factors.

In Eurocode 4, for the design of composite column with a symmetrical cross-section, a general method is specified. For calculation of flexural strength, the sections are assumed as plane. The ACI 318 code uses the same design philosophy, that is why for the prediction of strengths of specimens, the ACI code provisions are used. In ACI code and AISC LRFD specification, the requirements used for composite-column design is principally based on the provisions to design for structural steel column and reinforced concrete column, respectively. The method adopted by AISC LRFD specification is a bilinear communication curvature among the flexural strength and axial compression as.

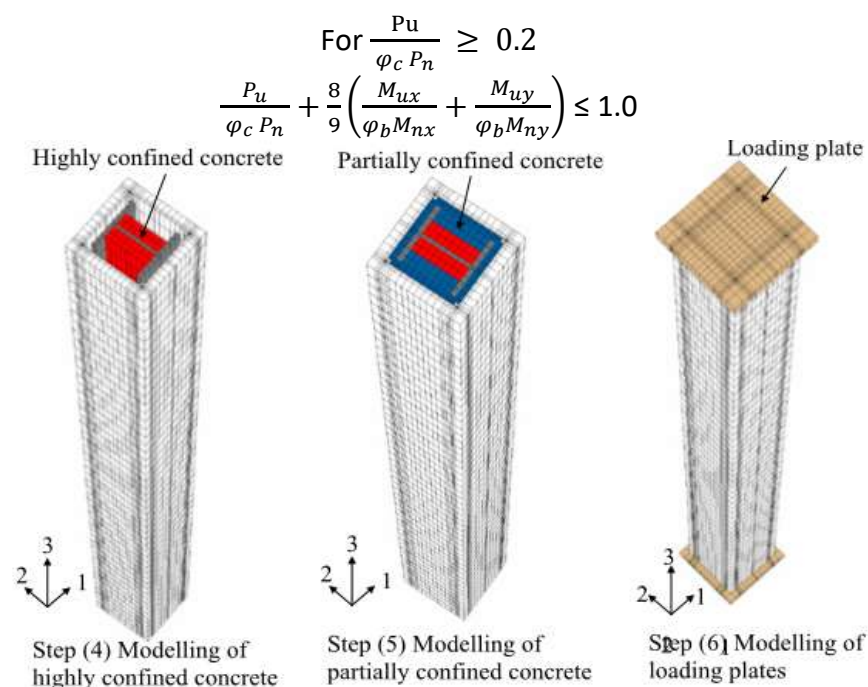


Figure 4: Modelling Steps-I

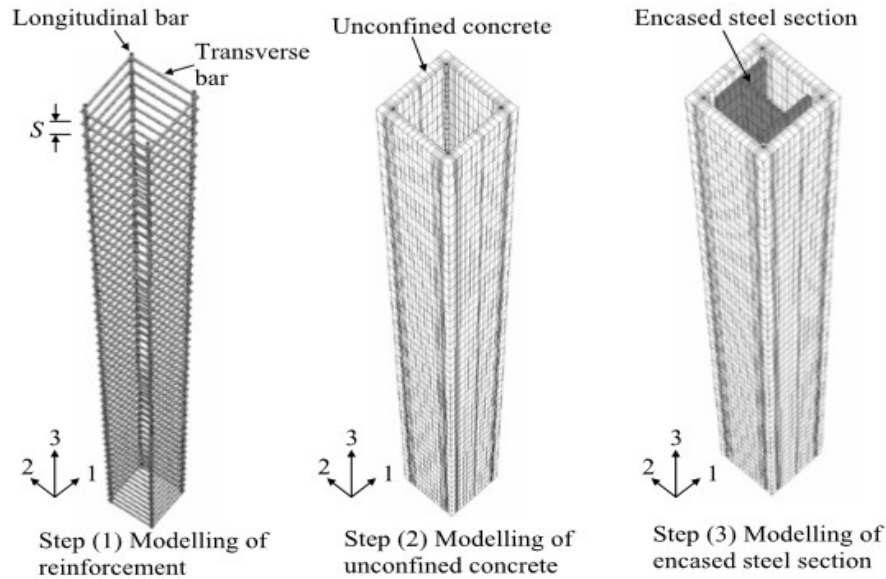


Figure 5: Modelling Steps-II

### Beam-column Joints

The beam-column connection region is one of the most important areas in the earthquake resisting structure design principles. Recently, by increasing the construction of high-rise buildings, the bridges with longer spans, heavily load industrial buildings, indoor stadiums and the deep piers, the usages of the concrete encased composite and concrete filled steel tubular columns have been extensively being used. Due to sufficient structural behaviors such as high strength, good stiffness, greater ductility, and large strain energy absorption capacity concrete encased composite columns are preferred in the modern structures, especially in high seismic zone areas (Liang, 2015).

The failure criteria of any element can be projected according to the location of the plastic hinge. In this study, plastic hinge had two expected locations; first one is before the transfer part in the reinforced concrete beam and second one is located at the joint where the beam section is a composite one as depicted in Figure 6.

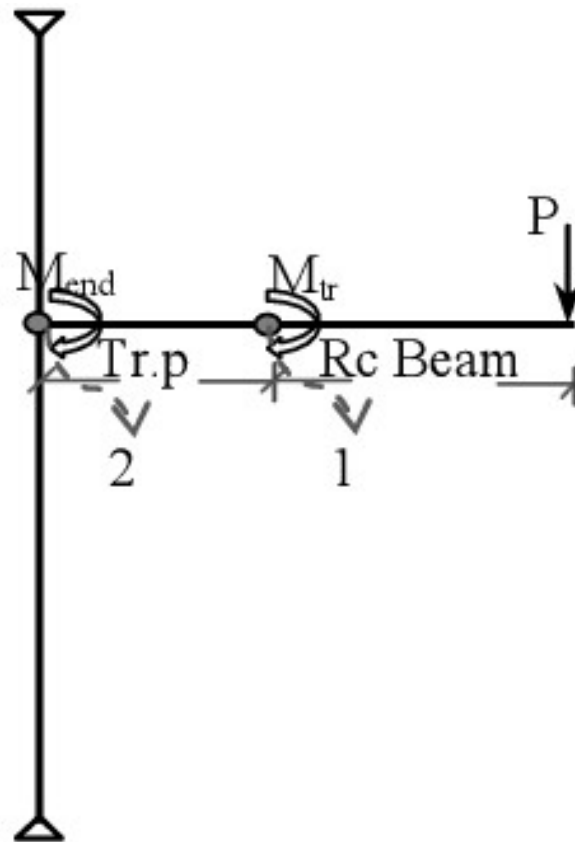


Figure 6: Model static system.

## METHODOLOGY

### 1.1 Selection of Building

For this study, a R.C.C commercial building located in Islamabad, is selected. The city exists in the seismic zone 2B, per building code of Pakistan, 2007. The overall dimensions of the building under discussion are 160 *ft.* x 78 *ft.* The building comprises of a basement which is 10 *ft* deep *and* is used as car parking. The ground, first, and second floors are used for the commercial activities such as mall and shops having height of 14 *ft.* each. The third to tenth floors have story height of 12 *ft.* each. The third, fourth and fifth floors are used as Offices. The sixth to tenth floors have been reserved for residential purposes. The total height of building including basement and a room constructed at top of the building to cover the stairs is 170 *ft.*



Figure 7: Architectural view of the building.

1.2 Architectural Drawings and Modeling

The drawings for building are produced using AutoCAD 2009. The plans are drawn along with side and front elevations. The building has been modeled in ETABS 2017 as bare frame structure situated in the seismic zone 2B, using  $S_D$  soil profile. In general, the building has been designed per Uniform Building Code (UBC, 1997), Building Code of Pakistan (Seismic Provisions, 2007), ACI 318-14, Eurocode 4 and AISC LFRD

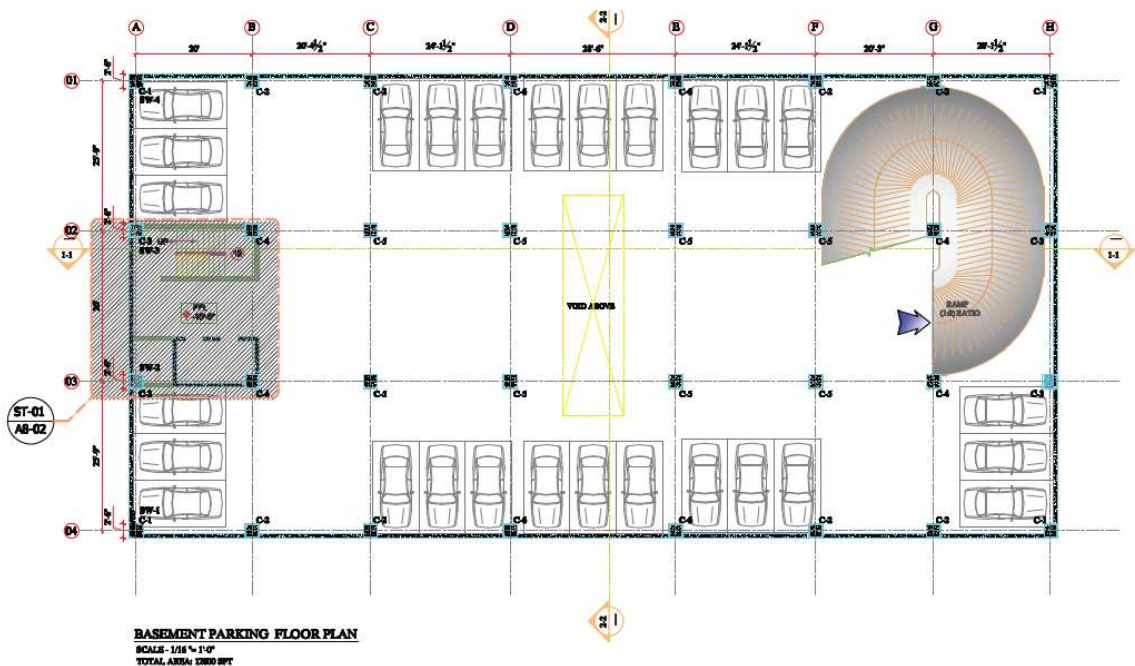


Figure 8: Plan view of basement of the building

1.3 Analysis of Building

The parameters used for demonstration of procedure for the computer-aided seismic analysis and design of basement, ground and eleven-story building located in the seismic zone 2B and

having soil type  $S_D$  are given below. The building is a reinforced concrete frame structure. For modeling of building in ETABS 2017, the foot-pound system (FPS System) is used. The Economic comparison is done by preparing the bill of quantities (BOQ) using current cost of the building materials and presented in the tabular form.

### 1.3.1 Concrete Compressive Strengths

The concrete compressive strength taken for design is:

|                           |          |
|---------------------------|----------|
| For R.C.C columns         | 4000 psi |
| For R.C.C beams and slabs | 3000 psi |
| For lean concrete         | 800 psi  |

### 1.3.2 Dead Loads

The dead loads of building are calculated from respective sizes of structural members and densities of the materials used. The material properties used are:

|  |               |
|--|---------------|
| For reinforced cement concrete (R.C.C) | 150 $lb/ft^2$ |
| For plain cement concrete (P.C.C)      | 144 $lb/ft^2$ |
| For brick masonry                      | 120 $lb/ft^2$ |
| For soil                               | 110 $lb/ft^2$ |
| For structural steel                   | 490 $lb/ft^2$ |

### 1.3.3 Superimposed Dead Loads

The superimposed dead loads of the building are calculated from respective sizes of the structural members and densities of materials used. It includes the dead weights from floor finishes and partition walls, and exterior walls of brick masonry. The material properties used are:

|                    |              |
|--------------------|--------------|
| For floor finishes | 35 $lb/ft^2$ |
| For exterior walls | 25 $lb/ft^2$ |

### 1.3.4 Live Loads

The live loads are obtained per "*Design of Concrete Structures*, Arthur H. Nilson; 14th edition".

|                    |               |
|--------------------|---------------|
| For roof live load | 20 $lb/ft^2$  |
| For assembly area  | 100 $lb/ft^2$ |
| For stairs         | 80 $lb/ft^2$  |

### 1.3.5 Earthquake Loads

The earthquake loads are calculated per Building Code of Pakistan (Seismic Provisions 2007) and Uniform Building Code (UBC, 97). The following parameters are used for the design of building.



|                                       |                                      |
|---------------------------------------|--------------------------------------|
| For seismic zone                      | 2B (BCOP, 2007)                      |
| Soil profile                          | S <sub>D</sub> (Geotechnical report) |
| Response modification coefficient (R) | 8.5                                  |
| Importance factor (I)                 | 1.0                                  |

### 1.3.6 Load Combinations

The orthogonal effects have been applied in the calculation of load combinations by considering 100% EQ in one direction and 30% EQ in the perpendicular direction per UBC, 97, clause 1633.1-General.

### 1.4 Equivalent Static Analysis

The equivalent static load method is a simplified lateral force procedure to inculcate the seismic (dynamic) loading in the design process. It uses the static force procedure for distributing the effect of lateral load  $V$  in the two main axes, that is in the directions of  $x$ -axis and  $y$ -axis, that may include the following steps:

- i) The first step is calculation of lateral force  $V$  acting on the structure. The calculation of lateral force depends upon the soil type, importance factor of the structure, fundamental and natural time-period of the structure, design ground acceleration that depends upon seismic zone, and the system resisting the lateral force, as well as on the overall weight of the structure including dead and some or full live load application.
- ii) The vertical seismic force distribution is determined along height of the structure. The height and magnitude of the force are proportional to each other.
- iii) Considering that the diaphragm is rigid, the overall distribution of the forces on each level horizontal and resisting vertical elements is calculated.
- iv) Calculation of the additional forces from the inherent and accidental torsion is to be added to the forces resulting from the horizontal distribution of the level forces.
- v) Determination of the drift, overturning moment, and P-Delta effect that are the direct results of the action of the lateral seismic forces are determined.

### 1.5 Modeling of Composite Column

The overall purpose of the structural design is to develop the best possible structural system that satisfies the design objectives in terms of functionality, safety, and economy. The structural design is a complex, iterative, trial-and-error, and decision-making process. In the design process, a conceptual design has been created based on intuition, creativity, and experience. Structural analysis has been undertaken in ETABS 2017 to evaluate the performance of the design. If the design does not satisfy the design aims, a modern design is then developed. This process is repeated until the design satisfies the multiple performance goals. The composite columns have been modeled using Eurocode 4 and AISC LRFD provisions. The composite columns are modelled in ETABS 2017.

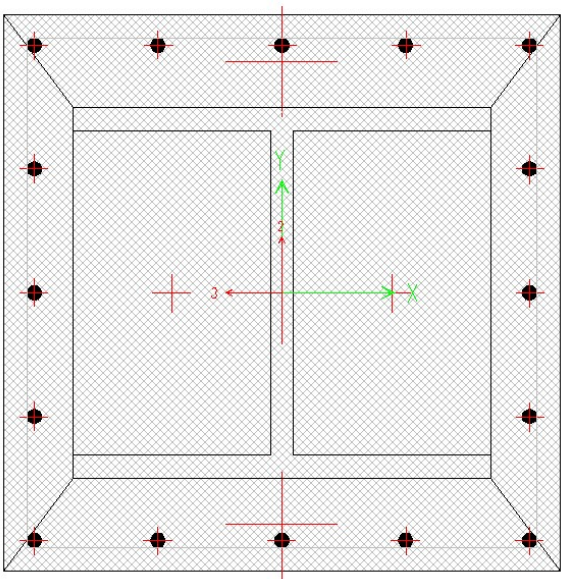


Figure 9: Cross-section of composite column

1.6 Design of Building

The structural design of the building has been done using ACI 318-14 and UBC 97, building codes. The material properties are taken per ASTM standards. The Finite Element Modelling (FEM) has been done using ETABS 2017 software. The column sizes of the building are:

Table 4: Sizes of columns.

| Column | Size of R.C.C column | Expected size of composite column |
|--------|----------------------|-----------------------------------|
| C1     | 30"x30"              | 18"x18"                           |
| C2     | 36"x36"              | 21"x21"                           |
| C3     | 36"x36"              | 18"x18"                           |
| C4     | 24"x24"              | 15"x15"                           |
| C5     | 42"x42"              | 21"x21"                           |

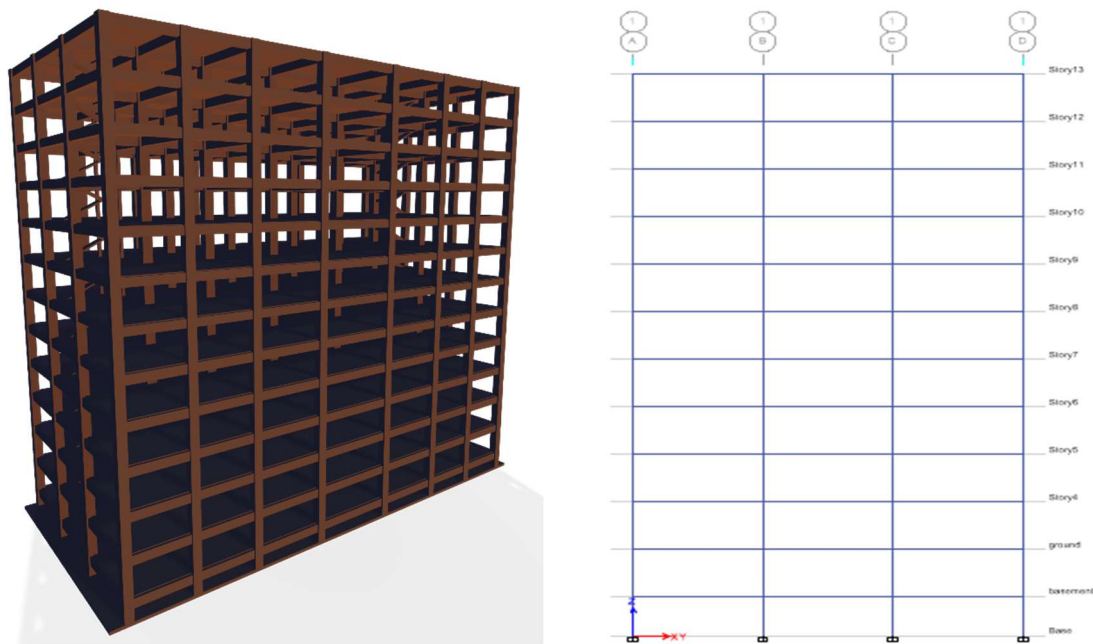


Figure 10: ETABS model representing the building.

## 1.7 Results Comparison

The behavior of composite columns and R.C.C columns in a reinforced concrete frame structure has been compared. The result comparison is made as under:

### 1.7.1 Structure Displacement

The structural displacement has been checked by using results obtained from ETABS 2017 model for both R.C.C column and steel-concrete composite column.

### 1.7.2 Story Drift

The change in the story drift of a normal R.C.C column and steel-concrete composite column has been compared from the results using ETABS 2017 model.

### 1.7.3 Base Shear

The base shear has been compared in the tabular form for both R.C.C column structure and steel-concrete composite column structure. Furthermore, the yield strength, economic comparison, and the effect on the functionality of the two structures types have also been checked.

### 1.7.4 Beam-column Connection

The proposed connection technique for concrete beam-column joints modelled in ETABS 2017 is shown in Figure 11.

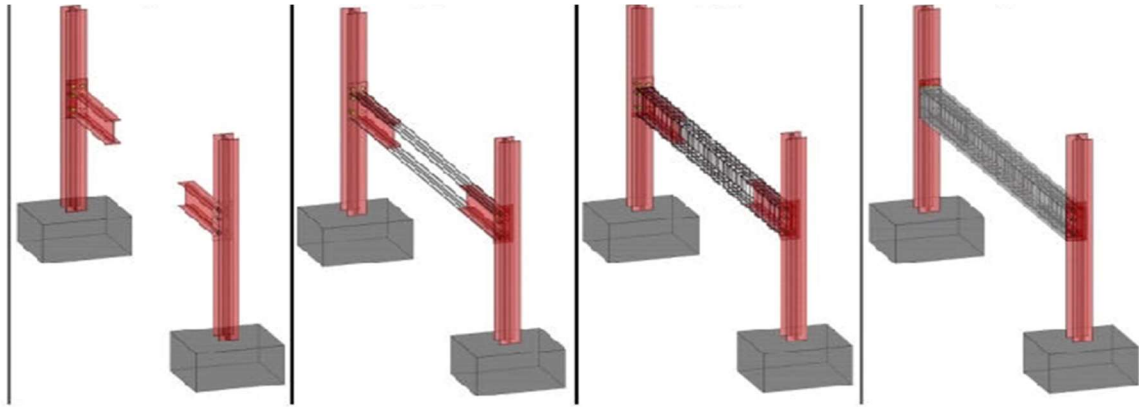


Figure 11: Proposed connection technique for composite columns

All the beams are connected to the column in the same way; the steel beam is welded to an end plate which is then connected to the column by using steel bolts. The beam is considered as a transfer part; the remaining part is reinforced concrete one with top and bottom reinforcement. It is important to state that the reinforcement covers the whole span of the beam including the transfer part. All the beams and columns have the similar connection details which are shown in Figure 12.

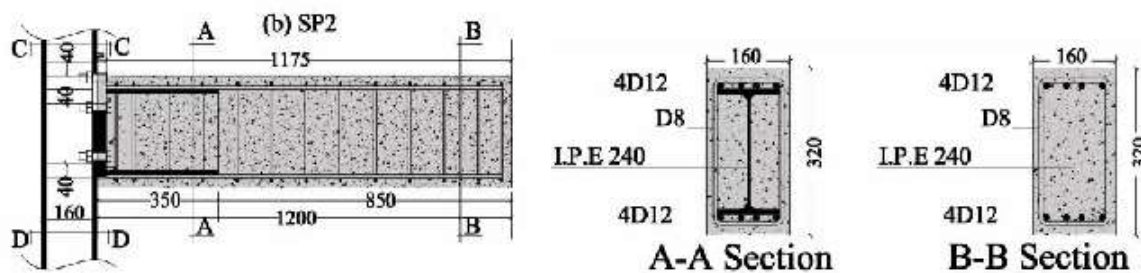


Figure 12: Elevation and cross-sectional views

### 1.7.5 Foundation Connection of Composite Column

The proposed way to connect the column to the foundation is shown in Figure 13. This method is used around the world to connect steel-column to the foundation. The size of baseplate and foundation is dependent of load acting at the foundation.

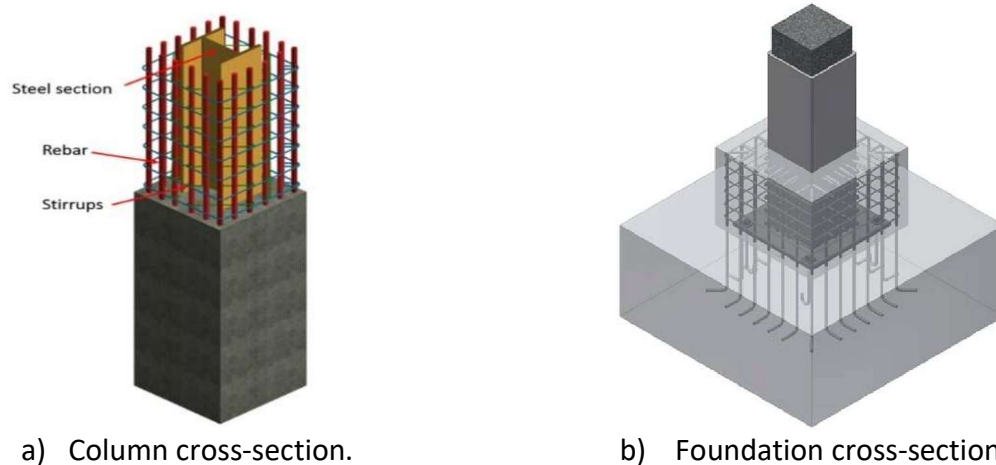


Figure 13: Column and foundation details.

## 1.8 RESULTS AND DISCUSSION

The equivalent static analysis has been performed on the R.C.C columns structure and steel-concrete composite column structures using ETABS 2017. For the study, a R.C.C commercial building, located in Islamabad was selected. The city of Islamabad exists in seismic zone 2B as defined by Building code of Pakistan, 2007. The overall dimensions of said commercial building are 157.5 ft. x 78 ft. The building comprises of one basement of 12 ft in depth that will be used for the car parking. The ground, first and second floors are to be used for the commercial activities such as mall and shops having height of 12 ft. each. The third to tenth floors each having story height of 12 ft. The third, fourth and fifth floors will be used as Offices. The sixth to tenth floors are reserved for residential purposes. The total height of the building including basement and a room constructed at top of the building to cover the stairs is 170 ft. The results in the form of base shear, displacement, ground over-turning moment, storey drift, storey shear, ductility, mode shape, model period, quantities, and the floor area ratio are compared for R.C.C columns structure and steel-concrete composite columns structure.

According to the building code of Pakistan, 2007, the peak ground acceleration is 0.2g against which this building has been designed. The results in X and Y-directions for comparison between a R.C.C structure and concrete encased composite column structure include base shear, displacement, ground over-turning moment; storey drift, storey shear, ductility, mode shape, model period, quantities, cost effectiveness, the floor area ratio, and the column sizes.

1.8.1 Lateral Force Comparison

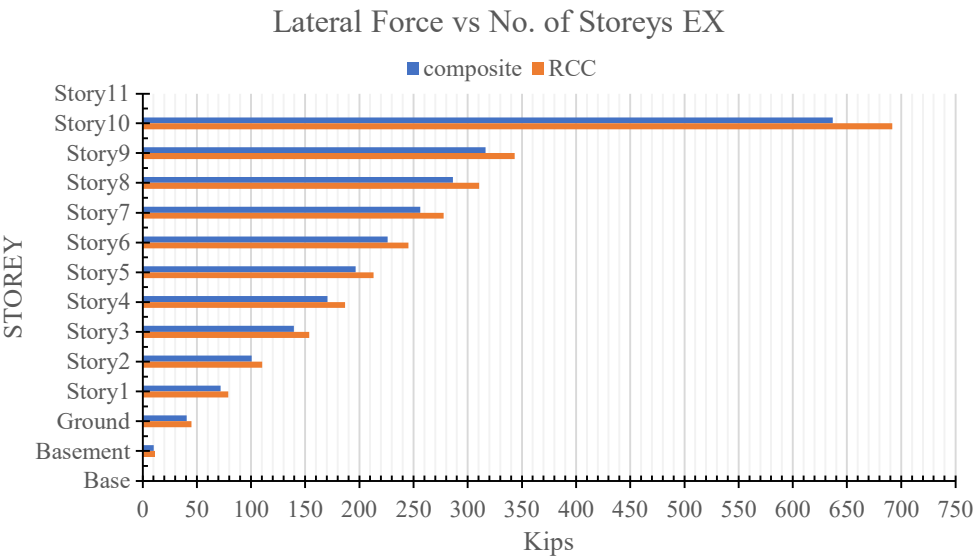


Figure 14: Lateral Force Comparison (X-Direction)

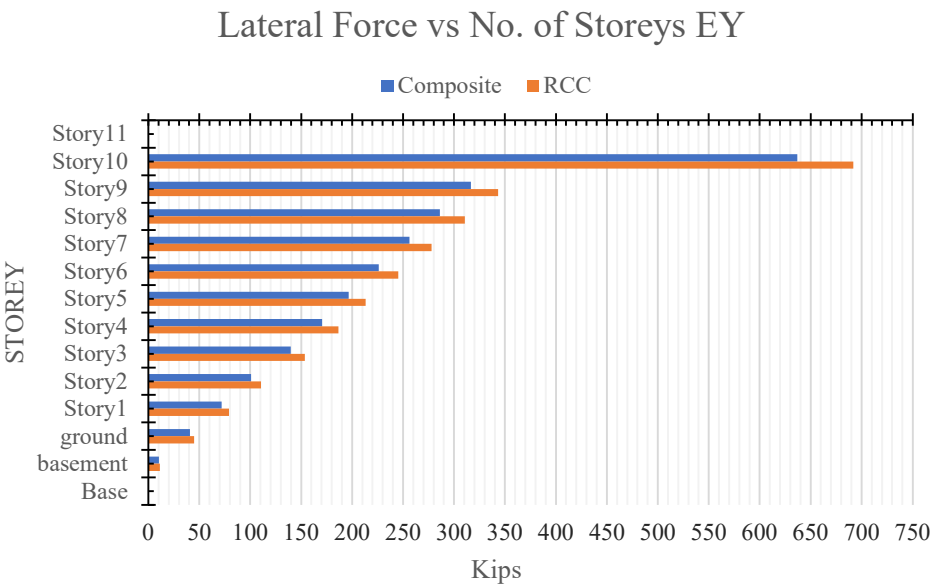


Figure 15: Lateral Force Comparison (Y-Direction)

Figures 14 and 15 are plotted for lateral force versus storey levels, both for R.C.C column structure and concrete encased composite column for X and Y directions. It is observed that the values of lateral forces gradually increase as the storey level increases. The comparison of results shows that the lateral force for R.C.C columns structure is greater than the concrete encased composite columns structure. The difference between frames with concrete encased composite column and R.C.C is 7.943%. The storey lateral forces decreases in the concrete encased composite column structure.



1.8.2 Storey Shear Comparison

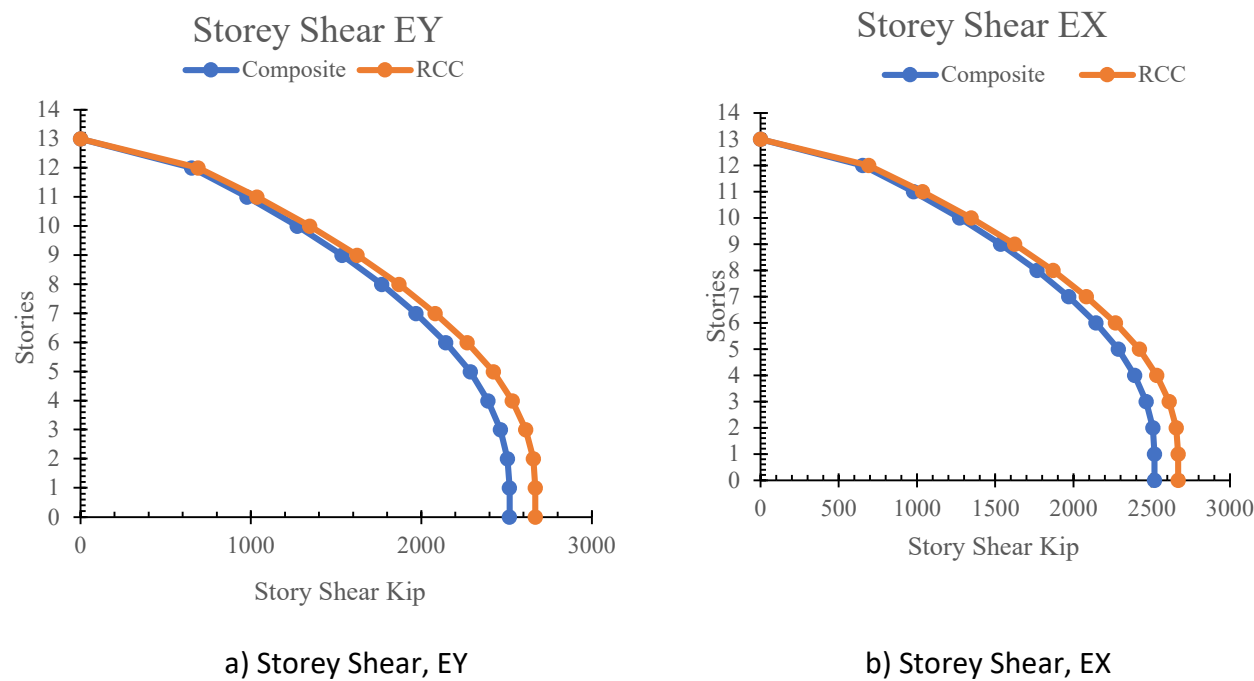


Figure 16: Storey Shear Lateral Force Comparison

Figure 16 is plotted for storey shear and storey levels both for R.C.C columns structure and concrete encased composite columns structure in the X and Y-directions. It is evident that the values of storey shear gradually decrease with the increase in storey levels. The comparison of results shows that shear force for R.C.C columns structure is greater than the concrete encased composite columns structure. The difference between frames with concrete encased composite columns structure to the R.C.C columns structure is 5.67%. There is less shear acting on the concrete encased composite columns structure than the R.C.C columns structure and the reason is due to overall less dead weight acting on the structure.

1.8.3 Storey Drift Comparison

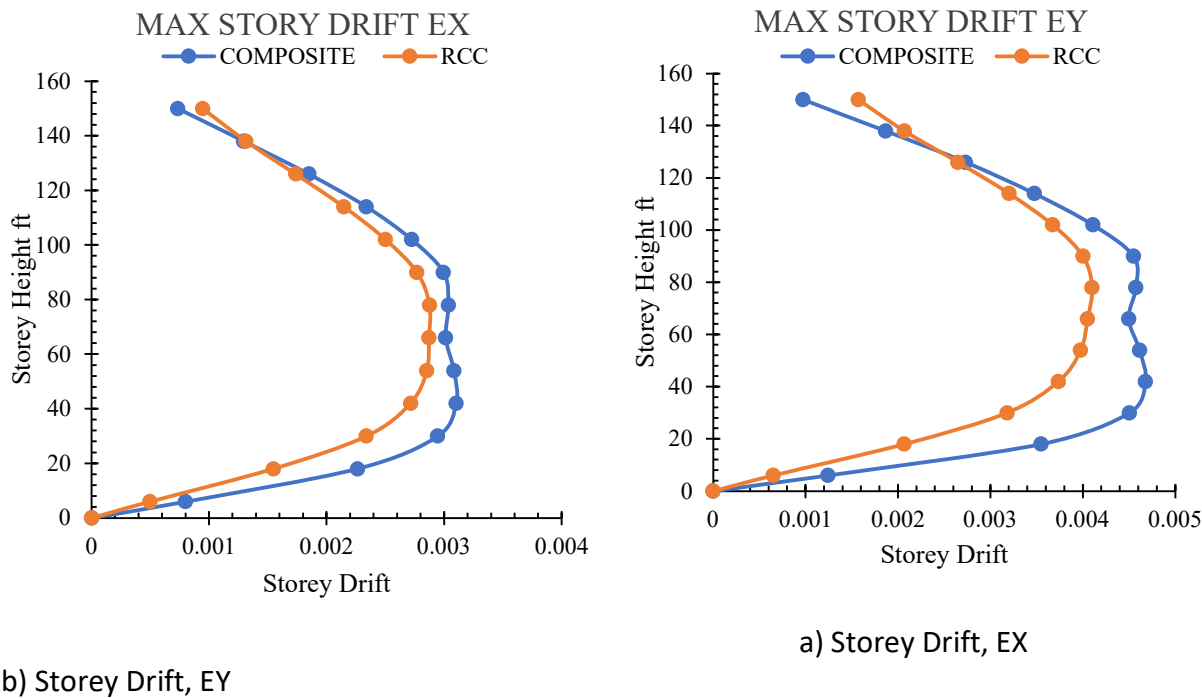
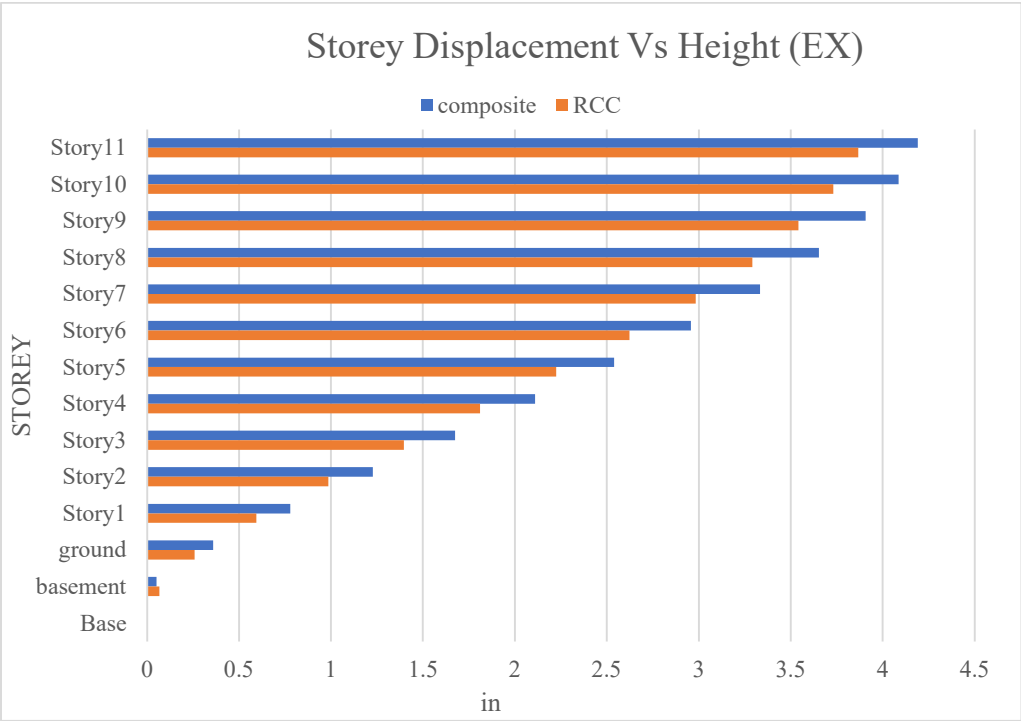


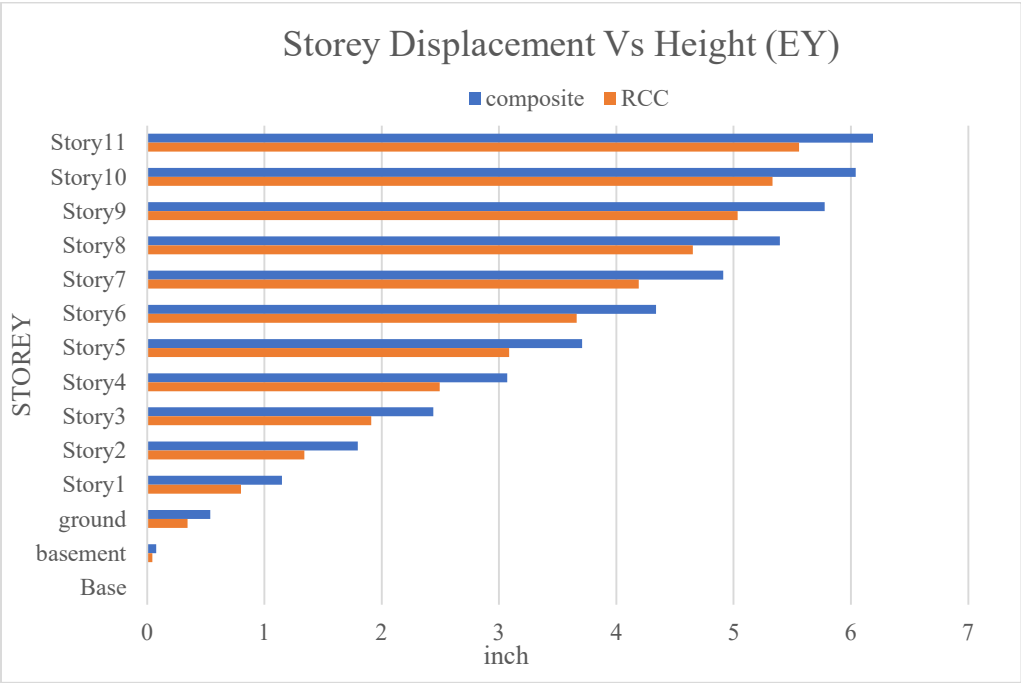
Figure 17: Storey Drift vs Storey Height for EX and EY

Figure 17 is plotted for storey drift and storey levels both for R.C.C columns structure and concrete encased composite columns structure in the X and Y-directions. It is observed that the storey drift gradually increases at first from base to the ground storey. As the number of stories increases, somewhere around the fifth story, the storey drift for both frames reaches to the maximum value for concrete encased composite columns structure having larger storey drift value than R.C.C columns structure. The storey drift for both the structures gradually decreases as it moves along the top storey. The trend of graphs in Figure 17 (a) and (b), respectively shows that the storey drift for concrete encased composite columns structure is more as compared with R.C.C columns structure. This is due to small sizes of columns in the concrete encased composite columns structure when compared with R.C.C columns structure. This difference is also depicted in Table 4. The storey drift in EY direction is more as shown in Figure 17(a). It is because of building orientation that is in the EY direction building spans only 78 ft. as compared with EX direction that spans for 157.5 ft.

1.8.4 Storey Displacement Comparison



a) Story Displacement in EX-Direction



b) Story Displacement in EY-Direction

Figure 18: Story Displacement versus building height

Figure 18 shows the displacement versus storey level. Figure 18(a) shows that the concrete encased composite column exhibits more displacement than the R.C.C columns structure and the difference is 7.73% with less base shear. Figure 18(b) shows that, the concrete encased composite column composite has more displacement than the R.C.C columns structure and the difference is 10.17%. Thus, the concrete encased composite columns structure displays more displacement and less base shear in both the directions. The displacement of greater amount in case of concrete encased composite columns structure is due to their smaller sizes as compared to R.C.C columns structure. It is also because the concrete encased composite columns structure results in less dead weight which results in less base shear.

1.8.5 Overturning Moment Comparison

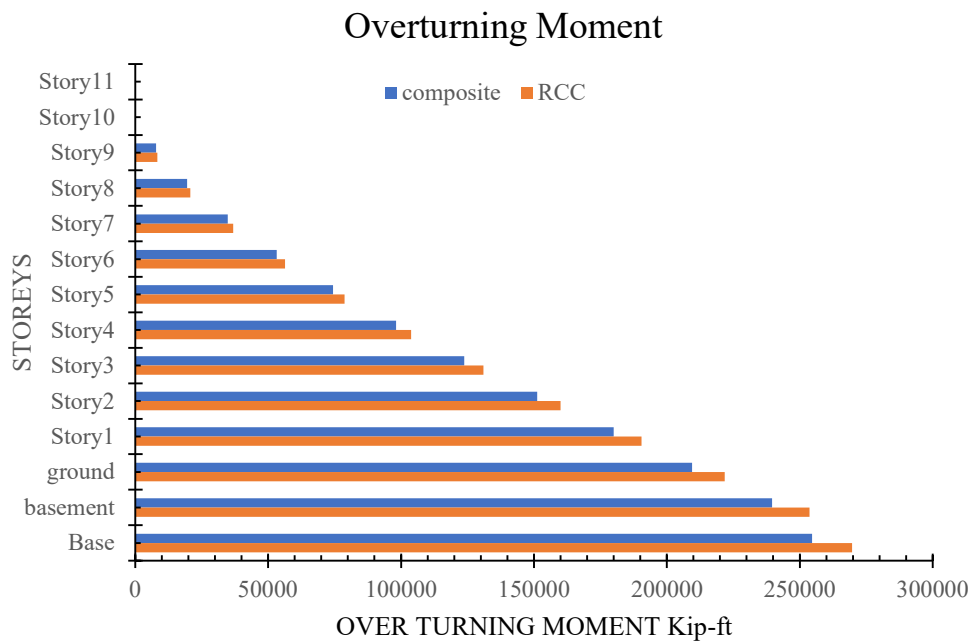


Figure: Overturning Moment

Above figure shows the graphs of over-turning moment against storey level. The trend in graph gradually decreases from maximum at base as the storey level increases. As figure illustrate that the encased composite column structure has less overturning moment as compared to R.C.C structure and percentage difference is 5.5%.

Mode Period and Frequency Comparison

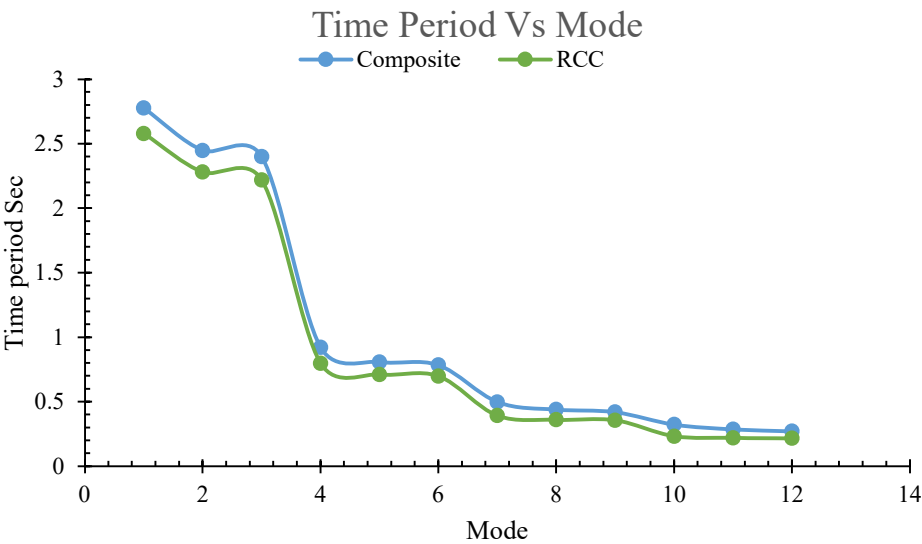


Figure: Time Period Comparison

Above figure shows the graph of mode and time period of both R.C.C and composite column structure. The maximum value of time period for R.C.C structure is 2.579 sec and for encased composite column structure it is 2.776 sec. The time period of R.C.C structure is less as compared to encased composite column structure which means the time period R.C.C will be greater than composite column structure. The percentage difference is 7.096%

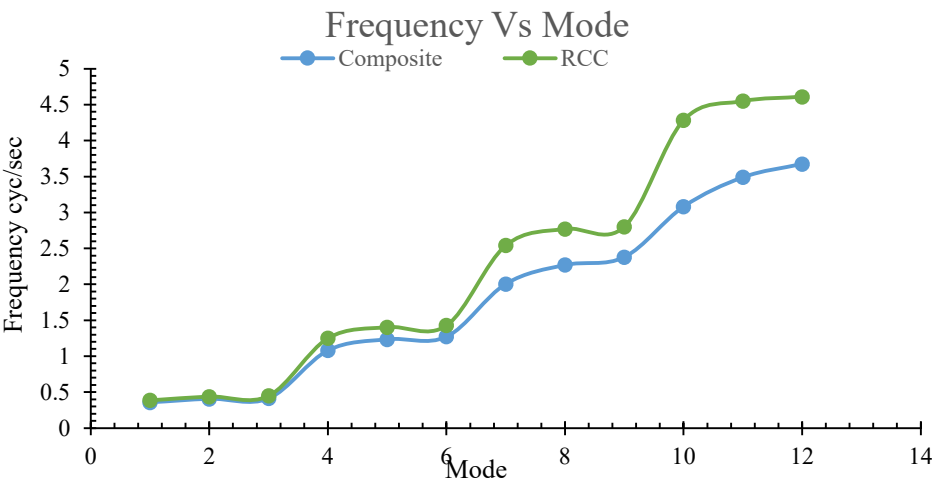


Figure: Frequency Comparison

The above figure shows the frequency of composite column structure is less than R.C.C structure and the difference is 20.255 %.

Moment Curvature/ Ductility

Column Comparison

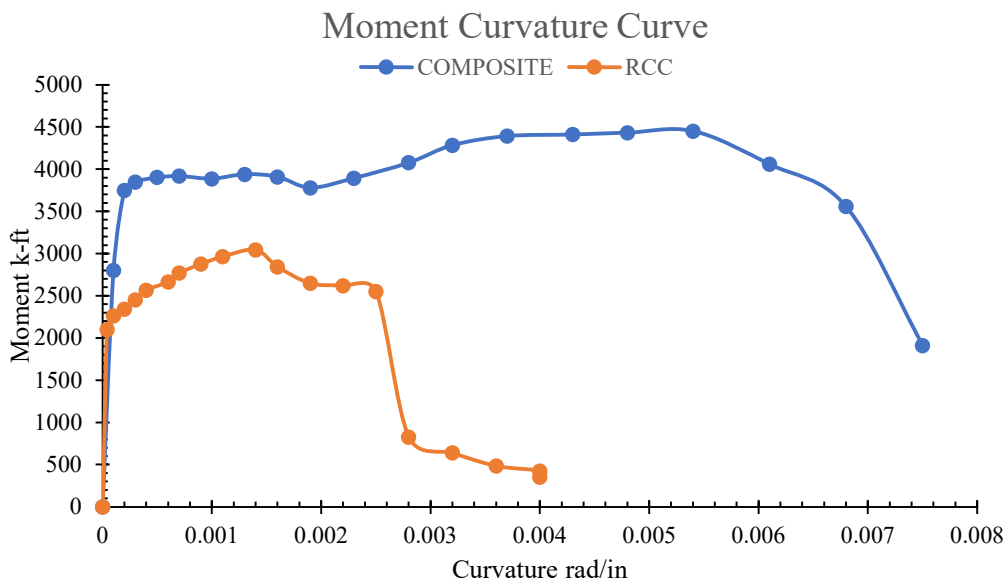


Figure: Moment Curvature Comparison

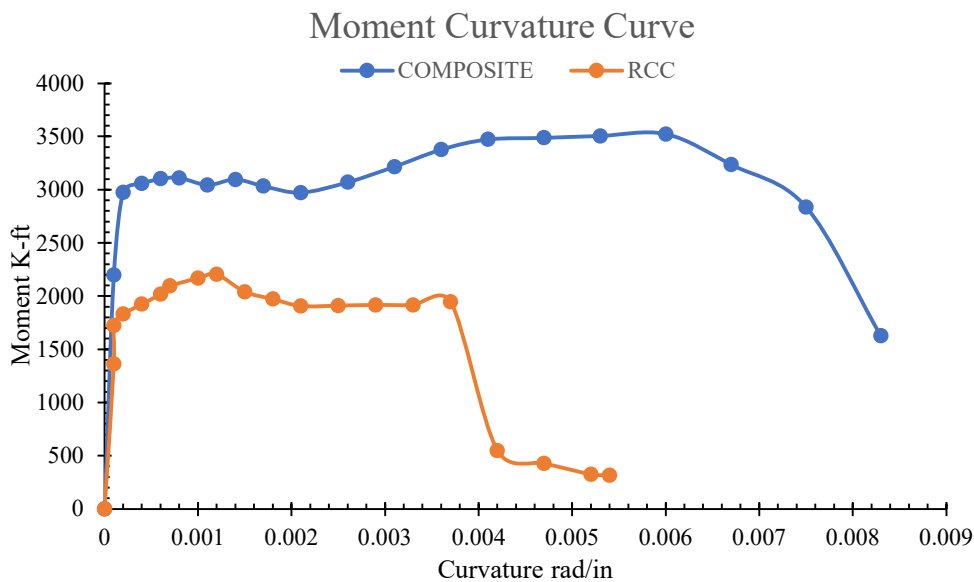


Figure: Moment Curvature Comparison

R.C.C and composite columns are compared and the R.C.C column has a size of 54x54 inches whereas encased composite column has a size of 42x42 inches. In figure 4-12 the moment capacity of Encased composite column is 39% more than R.C.C column of greater cross-section. This shows that encased composite column can resist more moment than R.C.C and thus will perform better in case of earthquake. Similarly figure 4-13 column are compared. The size of



composite column is 33x33 inches while the R.C.C column size is 44x44 inches. The moment capacity of encased composite column is 20.9% more than R.C.C column.

### Column Sizes Comparison

Table: Column Size Comparison

| Column | Size of column of R.C.C | Composite Column Size |
|--------|-------------------------|-----------------------|
| IC     | 54"x54"                 | 36"x36"               |
| OC     | 45"x45"                 | 33"x33"               |
| OC     | 42"x42"                 | 30"x30"               |

\*IC inner column \*OC outer column

It can be seen that the column sizes in encased composite section are reduced by 1.5 ft. This means that the composite column structure the span beam is increased by 3 ft saving valuable space to be utilized for commercial purposes.

### Quantities and Cost Comparison

#### R.C.C Structure

The total steel requires for the construction of super structure i.e. from base to mumty is 558.979 tons. The total concrete require for construction of super structure is 209437 cft.

#### Encased Composite Column Structure

The total steel required for the construction of super structure i.e. from base to mumty is 740.979 tons. The total concrete require for construction of super structure is 198701 cft.

#### Floor Area Ratios

Floor area for R.C.C structure is 147182.22 ft<sup>2</sup> and for encased composite Column structure it is 159452.5 ft<sup>2</sup>. The floor area for composite column structure is 12270.25 ft<sup>2</sup> more than R.C.C structure that is 7.7%.

### Cost Comparison

Table: Cost Comparison

| Structure | Steel tons | Steel Cost Rs | Concrete cft | Concrete Cost Rs | Total Cost Millions |
|-----------|------------|---------------|--------------|------------------|---------------------|
| R.C.C     | 558.9495   | 58689695.1    | 209437.7     | 41510000         | 100.20              |
| Composite | 748.6616   | 78609464.2    | 198701.5     | 36582000         | 115.19              |

## CONCLUSION & RECOMMENDATIONS

A B+G+11 storey commercial building was selected for the study. The comparison is done between conventional R.C.C structure and Encased Composite column structure. Equivalent Static non-linear analysis was performed using ETABS 2017 software. The results were extracted in X and Y direction. In X-direction and Y-direction, base shear, displacement, ground over-turning moment, storey drift, storey shear, lateral forces, floor area, column sizes and cost is compared between conventional R.C.C structure and Encased Composite column structure. The important conclusions of this study are elaborated as under:

- The storey shear for conventional R.C.C structure is more than encased composite column structure. This is due to the more dead weight of R.C.C building.
- Storey drift for the R.C.C is less than encased composite column structure in both X and Y direction.
- Storey displacement for R.C.C structure is less as compared to encased composite column structure. This is due to the small sizes of columns in encased composite column structure.
- The overturning moment of R.C.C structure is 5.5 % more than encased composite column structure.
- The modal time period of Encased composite column structure is more than R.C.C structure and this due less stiffness of encased composite column structure.
- Moment capacity of encased composite column of 36x36 inches is 39% more than a 54x54 inches R.C.C column. This shows that encased composite column can sustain more load for smaller cross-sections.
- Inner columns are reduced by 18 inches for encased section. This means that a lot of valuable space can be saved in structure.
- The floor area for encased composite column structure is increased by 7.7 %, i.e. 12170.55 ft<sup>2</sup>
- The cost of R.C.C structure is less than encased composite column by 13.01%. This cost can be overcome by floor area increased in encased composite column structure.

As stated in the above-mentioned results, there are differences in seismic response of frames for R.C.C and encased composite column. Building analysis and design shows that encased composite column structure has less weight and is less stiff than R.C.C structure thus it has more modal time period and less frequency. The axial compression and moment carrying capacity of encased composite structure is also more than conventional R.C.C structure. From the results we can easily conclude that in performance encased composite column is superior than a conventional R.C.C structure. Although for B+G+11 storey building the construction cost is more than R.C.C structure but encased composite column building has more floor area. This increased floor area will help to settle the cost difference between two structures. For better performance and cost control it is recommended that encased composite column should be used in construction of medium to high rise buildings where cost will be less than R.C.C structure.

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This study was not funded by any agency.

## Conflict of Interest

The authors declare that there is no conflict of interest among them.

## Notation

|                  |  |
|------------------|--|
| $A_c, A_r$       | area of concrete and longitudinal reinforcement, respectively.               |
| $A_s, A_w$       | area of steel shape and web of steel shape, respectively.                    |
| $B_1$            | moment magnifier suggested in AISC LRFD specification.                       |
| $E_c$            | elastic modulus of concrete.   |
| $E_m$            | modified modulus of elasticity.  |
| $F_{cr}$         | critical stress of column.   |
| $F_{my}$         | modified yield stress.   |
| $F_y$            | specified yield strength of steel shape.                                     |
| $F_{yr}$         | specified yield strength of longitudinal reinforcement.                      |
| $f_c'$           | specified compressive strength of concrete.                                  |
| $h_1$            | width of composite cross-section perpendicular to the plane of bending.      |
| $h_2$            | width of composite cross-section parallel to the plane of bending.           |
| $I_g$            | gross-section moment of inertia.   |
| $KL$             | effective length.  |
| $M_n$            | nominal moment capacity without axial load.                                  |
| $M_u$            | factored moment.   |
| $M_{u1}, M_{u2}$ | smaller and larger required moments applied at ends of column, respectively. |
| $P_0$            | composite column capacity under uniaxial compression.                        |
| $P_c$            | critical load of column.   |
| $P_n$            | nominal axial compressive capacity.  |
| $P_u$            | factored axial load.   |
| $r$              | radius of gyration.  |
| $r_m$            | modified radius of gyration.   |
| $Z$              | plastic section modulus of steel shape.                                      |
| $\delta$         | moment magnifier.  |
| $\varphi_b$      | resistance factor for bending, taken as 0.9                                  |
| $\varphi_c$      | resistance factor for compression, taken as 0.85                             |
| $\lambda_c$      | slenderness parameter.   |

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