Economic and Functional Feasibility of Concrete and Steel Composite Column Building Structure

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Abstract: Modern day construction is widely influenced using Steel-Concrete composite columns. The rapid growth in Steel-Concrete composite construction has significantly reduced the use of conventional Reinforced Cement Concrete (R.C.C) as well as other steel construction practices. Steel-Concrete composite construction gained an extensive receiving around the globe. Considering the fact that R.C.C construction is most suitable and economic for low-rise construction so it is used in framing system in most structures. However; increased dead load, span restriction, less stiffness and risky formwork makes R.C.C construction uneconomical and not suitable when it comes to intermediate to high-rise buildings. One Basement and 11 storeys existing building has been analyzed and comparison has been made between R.CC structure and concrete steel composite columns. Equivalent Static non -linear analysis was performed in X and Y direction by using Etabs 2017 software which results that encased composite columns construction cost is more than R.C.C columns but on the other hand encased composite columns has more floor area, the storey shear is more, story drift is less, storey displacement is less, in conventional R.C.C structures, storey shear is less in R.C.C conventional structure. Therefore; this research aims to analyze and to learn This research is an effort to learn cost effectiveness, increased or decreased stiffness and change on functionality of composite construction for intermediate to high-rise buildings in Pakistan. A Base + Ground +11 storey commercial building was selected for this study. 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. Although for Base + Ground + 11 storey building the construction cost is 7.7% more than R.C.C structure but encased composite column building has 13.013% more floor area. This increased floor area will help to settle the cost difference between two structures.

Keywords: Composite Structures, Concrete Steel Composite Column, Composite Structure Behavior, Modeling of Composite Columns

1. Introduction

Concrete and Steel Composite Structures are being widely used around the world. Its use in Pakistan's construction field is considerably low, when compared with many developing countries from around the globe. Concrete and Steel Composite Structures play a vital role in economic aspects when constructing high-rise buildings. Reduction in speedy erection makes steel-concrete composite structures economically viable. Under seismic conditions, due to inherent ductility characteristics, steel and concrete composite frames perform better than conventional reinforced cement concrete structures. Effect of seismic forces on composite structures is less due to low dead weight compared to R.C.C structures.

Lately, with the primer of modern-day composite mount construction in tall structures, engineers started to develop strategies to get the stiffening and consolidation effect, advantages of concrete and steel reinforcement. These factors directly affect bearing capacity and axial compressibility of steel and concrete composite column. Using the steel-concrete composite structural members leads to large openings, lowering the peak stages and delivers a higher side stiffness.

Under earthquake loadings with high magnitudes, concrete section tends to crack, which results in reduction of the flexural strength of composite column and beam. The steel core acts as a back-up system in giving the shear strength and also the needed plasticity to forestall brittle failure modes.

Campian, Nagy, & Pop, describes experimental components for steel encased composite steel-concrete columns. The ultimate flexural stiffness, ductility, and strength absorption capacity can may be enhanced by offering the cross ties and reduced spacing of the hoops. This is attributed often to the expanded confinement furnished through the way of transverse reinforcement [1]. Chen, Li, & Weng, have proved by tests that by resisting concrete flexural and concrete shear cracking that occurs due to increased axial compression of steel and concrete composite column, joint behavior improves. Thus, increasing the joint stiffness and strength. This result is based on the obtained results of many tests. When load is applied on steel encased concrete composite column, crushing strength increases by the margin of 30% as compared to conventional R.C.C column [2]. Nishiyama, Kuramoto & Noguchi, have complemented that the story number for each building type was chosen different to find the effect on the cost of these two different types of construction for medium, high-rise & low buildings [3]. Begum, serajus, Tauhid, & Ahmed, described in their studies that according to results composite construction is well suited for high-rise buildings while R.C.C construction works efficiently in low-rise buildings [4]. Kumawat & Kalurkar concluded that the price comparison shows that steel-Concrete composite structure is steeply-priced, direct cost reduction of the steel concrete composite structure as a result of rapid construction makes steel-concrete composite building economically feasible [5].

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 construction industry of Pakistan's considerably low when compared to many other developing countries. There is a huge potential for increasing the volume of composite construction, considering current development requirements. Three basic types of concrete composite columns are; 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 conventional reinforced cement concrete structures. Seismic forces effect it less due to low dead weight compared to R.C.C structures.

The premature evolution of composite column was due to its fire-resistant property for structural steel in buildings. By early 1960, research showed that concrete encasement or wrapping can increase the load resistance of steel columns. Economy in construction can be achieved by using better quality of concrete and introducing the composite section in design of columns. Both steel section and concrete oppose the exterior loading by collaborating collectively through friction and chemical bond. And also, by the use of 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 20th century. To protect the steel columns from fire they were customarily encased in concrete, while steel was merged in concrete as reinforcement.

2. Literature Review

Volume of steel in construction can greatly be increased, especially when we consider current needs of development. Initially the concept of the composite beam was introduced in a period 1850-1900 by Emerges. 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. According to Uchida & Tohki, to increase the resistance and deformation capacity these elements are used [6]. Steel and concrete composite columns are comparatively new components which are being used in framed structures as shown in figure 1. Henceforth, framed systems & composite columns are discussed from a design, economy, functionality and technical point of view in detail.
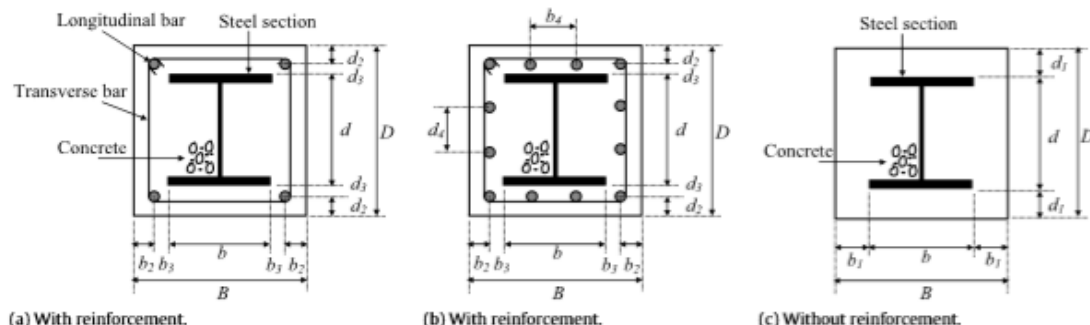

Figure 1. Concrete steel composite columns (encased).

2.1. Design of Composite Structures in Previous Studies

Ellobody & Young, studied the effects of eccentrically loaded concrete and steel columns (encased). In their study, a nonlinear 3D finite element model is 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 understudy columns. considering model's limitations, model was responsible for the inelastic behavior in transverse and longitudinally embedded reinforcement bars along with concrete confinement of steel encased concrete composite columns. The functionality between reinforced concrete sections, transversely and longitudinally embedded reinforcement bars and concrete were taken under consideration in order to allow bonding behavior. Geometrical imperfections had already been carefully integrated into the model. Nonlinear 3D finite element model was validated against test results. Variation in concrete strength was from 30–110 MPa (normal to high). Stress variation was 275–690 MPa (normal to high). In addition, a parametric study examined the influencing variables for composite columns' strength; column dimensions, eccentricities, sizes for 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 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 composite column's strength is remarkable. The strength which was obtained using finite element model's analysis was compared with strengths of composite columns calculated using Euro-code 4 [7].

Johnson proposed a relative analysis of R.C.C structure and steel-concrete and composite structure of multistoried building. Paper 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 was our main objective. Composite columns are 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 that are explained in this paper are as follows, for a given cross-sectional dimension it increases strength, buckling resistance and 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 [8].

Wagh & Waghe, did a relative study of steel concrete composite and R.C.C structures. During this 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 analysis. Both of these structures were modeled using STAAD pro software and comparison between results were made. This study includes; shear force, axial force, deflection produced, construction cost and bending moment in column. Design method for this report mainly follows EC4. It can be seen from results and analysis that reinforced cement concrete structure is less economical than 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 earthquake. Results also concluded that smaller size of foundation can be used in case of composite structures [9].

Panchal & Marathe did a relative study of composite and R.C.C multistoried buildings. The building considered for study is 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 than the composite sections. Building is examined using equivalent static method and response spectrum method. Parameters analyzed for this building are; deflection, base shear, time period and story drift. Results show that the composite structure is lighter in weight than R.C.C structure. Time period of composite is more than R.C.C. However, displacement for R.C.C is less than composite structure. Whereas, composite construction is more economical than the R.C.C structures and consume less time [10].

Kumawat & Kalurkar, did analysis and design of multi storied building of composite structures. For this study, a G+9 story building was considered in seismic zone 3. The provisions used for this is Indian standard: 1893 (Part1)-2002. Response spectrum analysis and Equivalent Static method were being used for analysis and modeling of this study, and software used was SAP2000. From this paper it is settled that for composite structure the dead weight is 15% to 20% less than R.C.C building, which results in 15%-20% decrease in seismic forces. It is also concluded from the results of study that for composite structures the stiffness rises from almost 6% to 10% in longitudinal direction and it increases from almost 12% to 15% in transverse direction when compared to R.C.C structure. In linear static analysis, twisting moment for composite column is 49% to 65% less in longitudinal direction and it is 48% to 63% less for transverse direction than R.C.C columns. In linear static analysis axial force for composite columns is found to be 20% to 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% to 30% less than R.C.C structures. So, it can be said that structurally, composite structure performs better than R.C.C structure [5].

In (Committee & Standardization, 2008) ACI 318-14 (10.3.1.6) it is given that steel thickness encasement is to be

taken (a) or (b) for concrete core encased by structural steel for composite columns [11].

$b\sqrt{\dfrac{fy}{3Es}}$ for each face of width b ACI318-14 10.3.1.6

$h\sqrt{\dfrac{fy}{8Es}}$ 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 outward.

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 $0.85 fc'$. [12]

Young & Ellobody, introduced a strength reduction factor of 0.92 for high strength concrete in a range of [75-90 MPa (11 - 13 Ksi) [7]. Martinez et al. proved in their research that a ratio of 0.85 for unconfined column strength to cylindrical strength for concrete strength ranging from [25–70 MPa (3.5–10 ksi)]. His given value is irrespective of concrete strength. Cusson & Paultre, performed many tests on concrete strength ranging from 59–117 MPa (8.5–17 Ksi) and found the average value of 0.88 for fc' [13]. While, Collins, Mitchell, & MacGregor, after extensive research and test performances gave a value of fc' ranging from $0.77 fc'$ to $1.0 fc'$ for maximum compression stress value. From above given values of fc' a conclusion can be made that there is an agreement on lower part of stress strain curve [14].

Ahmad & Shah, concluded in their study that high strength concrete of 69 MPa (10 Ksi) can be ductile same as low to intermediate strength concrete. However, these trends cannot be found for concrete strength ranging from 76-90 MPa (11-13 Ksi) in tests performed by Young & Ellobody in 2011 [15]. Martinez et al. gives conclusion for concrete strength from 48-68 MPa (7-10 Ksi) that the stress- strain curve goes down instantly after it achieves highest value. After this it goes flat showing high axial compressive stress. Mirza & Skrabek, 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 there always as said by Hajjar & Gourley. 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 [16, 17].

El-Tawil & Deierlein, describes the requirements of ACI 318 and concluded that these provisions are same as for reinforced concrete 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 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 [18]. 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

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

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 moment modification.

The ACI-318 and AISC-LFRD gives conclusions; (1) it concludes that ACI-318 is better than AISC-LFRD in modelling the overall behavior of composite structure. The accuracy of modelling depends upon slenderness ratios along with steel and concrete strength ratios. (2) When compared with both short and long column ACI-318 gives some un-conservative results (A_s up to 8-10%). (3) The conservative value for short columns in both codes ACI- 318 and AISC-LFRD is 40%. The value for long column 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 i.e. 6% resulting from the sequence of construction for columns having value less than $L/r<<40$.
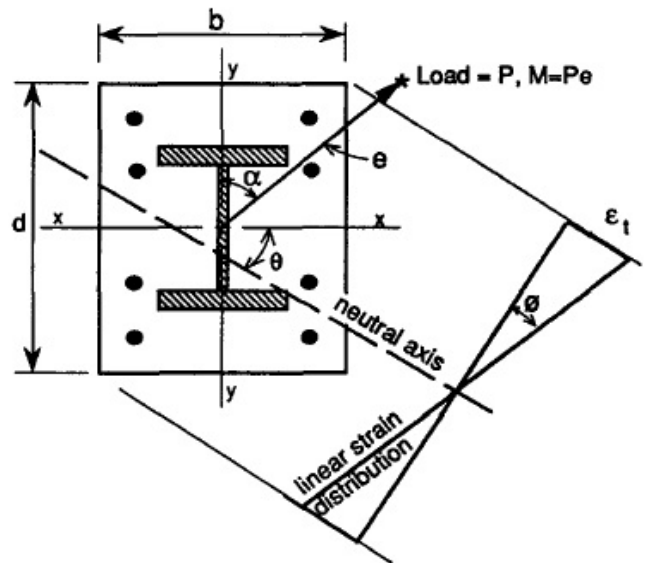

Figure 2. *Composite section analysis.*

The method for analysis and specification is developed using a limited number 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.

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

Boke & Suryawanshi, made a qualified 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 this study. For composite structure, base shear was determined to be 34% and for steel concrete structure it was determined to be 26% as compared to 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 column for steel structure were reduced 44% and that in composite steel structure, were reduced 54% when compared with R.C.C building. Due to the reduction of column forces the footing sizes also decrease in comparison to the footing size of reinforced concrete

building. This concludes that structure of composite steel concrete is cheaper than the reinforced concrete structures. As there is no form work required in composite structures, this reduces construction time when compared with Reinforced concrete buildings [19].

Liang, did a comparative study of cost of reinforced concrete and steel concrete composite structure. 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. STAAD-PRO software was used for the comparison of results. Stiffness, drift, displacement, axial and shear forces in column, bending and twisting moments in column of stories of composite structures will be compared with R.C.C structures. 15m x 9m is the complete building dimension. STAAD-PRO 2007 is used for the analysis and load calculation for study and design. Study of load combination has been done as per Indian standard code of practice. Economic results which were found from this research are shown in Table 1 [20].

***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%

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 structure bending moment, deflections and axial forces remain slightly additional to that in the steel concrete composite structures. Forces produced due to earthquake does not cause destruction to the composite steel concrete structure when compared with reinforced concrete structures. Due to less dead weight of steel, composite building weighs less when compared to reinforced concrete building reliefs in falling the cost of foundation.

Ambe & Maru, did a relative study on the steel concrete composite structures and reinforced concrete structure. They compared a G+15 story office building for both steel concrete composite building and reinforced concrete building located in earthquake zone 4 with wind speed 39 m/s. Analysis Method used was equivalent static method. STAAD-PRO was used for the steel composite structure and reinforced concrete structure. modeling and their results were

compared. Results show that steel concrete composite structures are economical than R.C.C. structures. The cost comparison in this paper showed that composite steel structures are economical than reinforced concrete structures. More it concludes that composite construction is fast. A structure, if constructed using R.C.C construction approach can take up to 24 months of time to finish. While, if same structure was constructed using composite construction approach it can save almost 9 months of time [21].

Shashikala & Itti, did a comparative study of R.C.C and composite multi-storied buildings. In their study the building that is chosen is located in earthquake zone, residential building (B+G+15). earthquake loading, requirements of Indian standard: 1893 (Part 1 2002) is used. Software used was STAAD Pro V8i for the modeling of the composite structure and reinforced concrete building. Composite structure and R.C.C structure are analyzed by STAAD pro using equivalent static method. The work determined that the composite column cost less than R.C.C columns by 20.45% shown in table 2 and table 3. [22].

***Table 2.** Cost of R.C.C Columns for Composite Structure.*

Material	Quantity of R.C.C column for Composite Structure	Rate	Amount in Rs
Steel	107.87 ton	51500M/T	5606805
Concrete	475.75 m^3	6000	2254500
	Total Cost of R.C.C Column for Composite Structure		7861305

Table 3. *Cost of R.C.C Columns for R.C.C Structure.*

Material	Quantity of R.C.C column for R.C.C Structure	Rate	Amount in Rs
Steel	145.94 (ton)	51500M/T	7515910
Concrete	394.53 m³	6000	2367180
	Total Cost of R.C.C Column for R.C.C Structure		9883090

Tedia & Maru, did a relative study of cost, analysis and design of composite concrete structures and R.C.C structures. The building thought-about for the study is G+5 story building with height of each story is 3.658m and arrange dimensions of 56.3m x 31.94m. Building is located in zone three. Modeling of R.C.C and steel concrete composite structure is finished on STAAD-PRO code and therefore the technique used is Equivalent static technique. This study reveals that composite structure for G+5 is costlier than that of R.C.C structures [23].

2.3. Modeling of Steel-Concrete Column Structure

Bridge, presented the design for steel concrete composite structures. material design approaches of AS3600, AS4100 and Euro code 4 (EC4) are compared in this paper. Comparison is done to discuss the differences and to point out the likenesses. Simple plastic method or strain compatibility method is used for the determination of the cross-section. Using moment magnification of first order or direct analysis, all of 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 euro code 4, the approach for composite column is similar to R.C.C columns. Effects of second order imperfections are to be taken explicitly for members. By using euro code 4, for the expression of Cm, the value for a column is 1.1 through identical end moment's determination in equal arc. This shows end moments causing 10% imperfections. In the analysis of second order the effective stiffness used, is elastic stiffness which is modified by calibration factor and correction [24].

In Eurocode 4 (CEN, 1994) for the design of column (composite) with symmetrical cross section a general method is specified. Plane sections are assumed for the calculation of the flexural strength. In United States the ACI codes for building uses the same design philosophy. That's why for the prediction of the strengths of the specimens ACI provisions are used. In ACI and AISC-LRFD the requirements used for composite-column design is principally based on provisions to design for structural steel column and reinforced concrete column respectively. Method adopted by AISC-LRFD is a bilinear communication curvature among flexural strength and axial compression through following equation and modeling steps are shown in figure 3 and figure 4 [25].
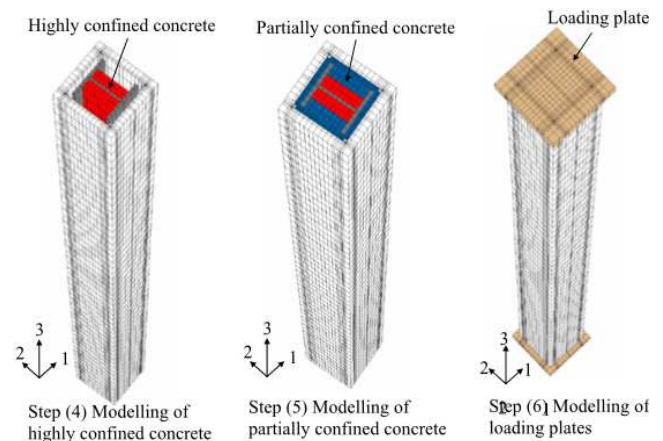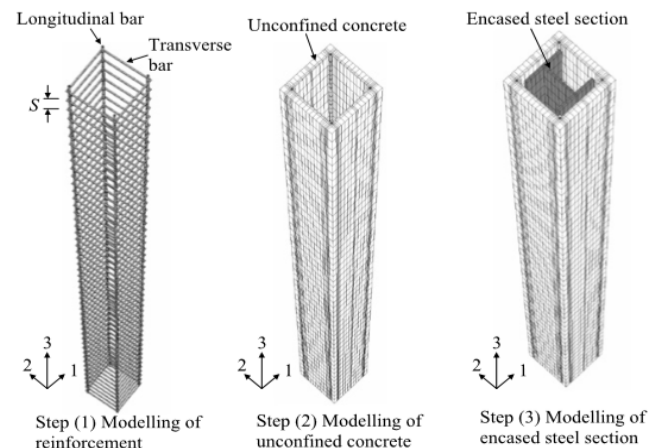
For

$$\frac{Pu}{\varphi c\, Pn} \geq 0.2$$

$$\frac{Pu}{\varphi c\, Pn} + \frac{8}{9}\left(\frac{Mux}{\varphi bMnx} + \frac{Muy}{\varphi b\, Mny}\right) \leq 1.0$$

2.4. Beam-Column Joints

Liang described in his studies that the column beam connection zone is one of the most important areas in earthquake resistance structure design principles. By increasing the construction of the high-rise buildings, big span bridges, heavy load industrial structures, indoor stadiums and deep piers, the usages of the concrete encased composite and concrete filled steel tubular columns have been extensive recently. Due to sufficient structural behaviors such as high strength, good stiffness, great ductility and large strain energy absorption capacity concrete encased composite columns are preferred in modern structures especially in high seismic zone areas. [20]

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, see Figure 5.

Figure 3. *Modelling Steps-II.*
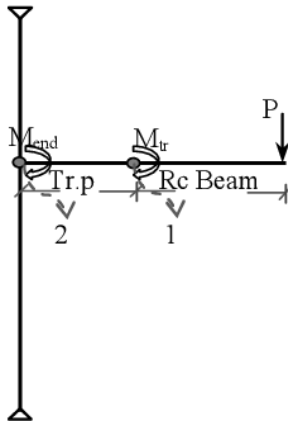

Figure 4. *Modelling Steps-I.*

Figure 5. *Model Static System.*

3. Methodology

3.1. Selection of Building

A R.C.C commercial structure selected for the study, is located in Islamabad. Islamabad exists in seismic zone 2B (Building Code of Pakistan 2007). The dimensions of the commercial building are 160 *ft.* x 78 *ft.* Building comprises of one basement of 10 *ft* in height which will be used for car parking. The ground floor, first floor and second floor are used for commercial purposes such as mall and shops having height of 14 *ft.* each. The remaining floors from third to tenth story have height of 12 *ft.* The third, fourth and fifth floor will be used for offices. The stories from sixth to tenth will be reserved for residential purposes. The total height of building including basement and mumty is 170 *ft.*

3.2. Architecture Drawings and Modeling

Drawings for building are produced using AutoCAD 2009 shown in figure 6. Plans are drawn along with side and front elevations. The building has been modeled in ETABS 2017 in seismic zone 2B using soil profile S_D UBC (Code 1997) as bare frame structure as per design provision of building code of Pakistan, ACI-318, UBC-97, Euro code 4 and AISC-LFRD. [26, 27]
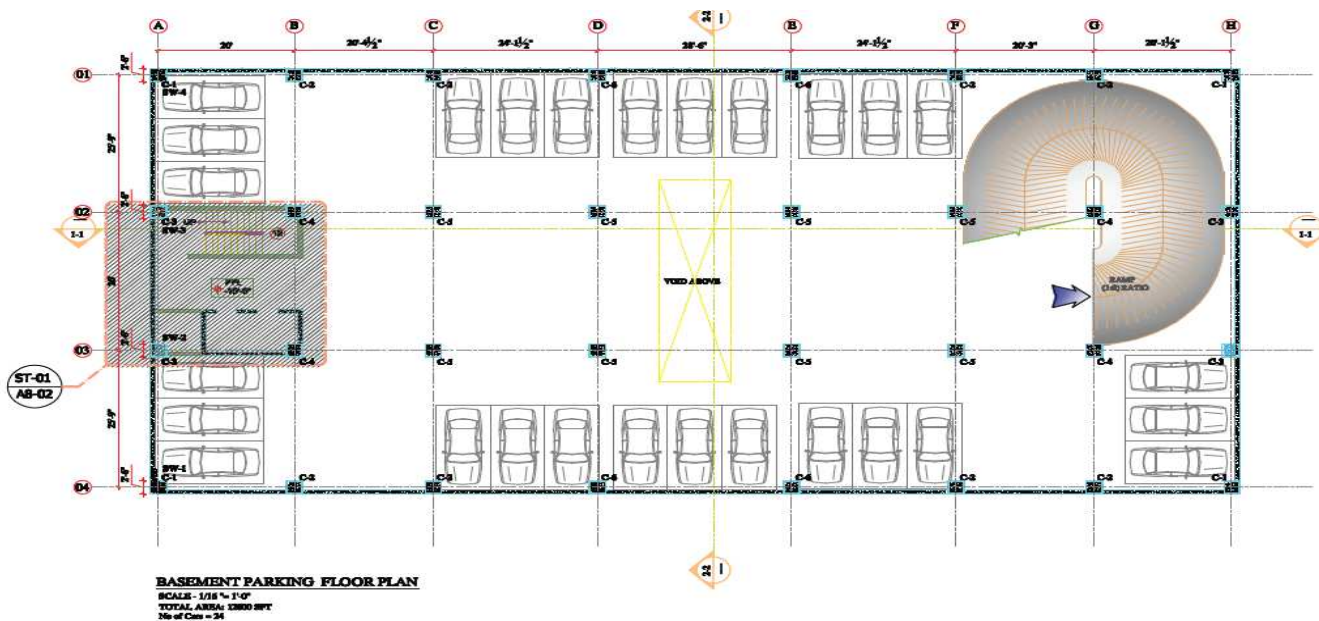

Figure 6. *Basement Plan of Building.*

3.3. Modelling and Analysis Specifications

The parameters used to demonstrate the procedure for computer-aided seismic analysis and design of basement, ground and eleven-story building which is a frame structure, located in *seismic zone 2B* and soil type *SD* are given below. FPS System is used for the project. Modelling and analysis has been done using ETABS 2017.

3.3.1. Concrete Compressive Strengths

The concrete compressive strength used for design is
R.C.C Columns: 4000 psi
R.C.C Beams: 3000 psi
Slabs: 3000 psi
Lean Concrete 800 psi

3.3.2. Dead Loads

Dead loads of structure are calculated from respective sizes of structural members and densities of materials used. Material used in structure and their load per square foot is given below:
Reinforced Cement Concrete (R.C.C): 150 lb/ft^2
Plain Cement Concrete (P.C.C): 144 lb/ft^2
Brick Masonry: 120 lb/ft^2
Soil: 110 lb/ft^2
Structural Steel: 490 lb/ft^2

3.3.3. Superimposed Dead

Superimposed dead loads of structure are calculated

from respective sizes of structural members and densities of materials used. It includes dead loads from floor finishes and *partition walls*, *exterior walls* of brick masonry.

Floor Finishes: 35 lb/ft^2
Exterior walls: 25 lb/ft^2

3.3.4. Live Loads

Live Loads are applied as per *Table 4* of *Design of Concrete Structures*, (Page # 11, Arthur H. Nilson; 14th edition).

Roof Live Load: 20 lb/ft^2
Assembly Area: 100 lb/ft^2

***Table 4.** Minimum Uniformly Distributed Loads.*

Occupancy or Use	Live Load, psf[a]	Occupancy or Use	Live Load, psf[a]
Offices	50	Schools	
Corridors above the first floor	80	Classrooms	40
Penal institutions		Corridors above first floor	80
Cell blocks	40	First-floor corridors	100
Corridors	100	Sidewalks, vehicular driveways, and yards subject to trucking[e]	250
Residential		Stadiums and arenas	
Dwellings (one and two- family)		Bleachers[c]	100
Uninhabitable attics without storage	10	Fixed seats (fastened to floor)[c]	60
Uninhabitable attics with storage	20	Stairs and exit ways	100
Habitable attics and sleeping area	30	One and two-family residence only	40
All other areas except stairs and balconies	40	Storage areas above ceilings	20
Hotels and multifamily houses		Storage warehouses (shall be designed for heavier loads if required for anticipated storage)	
Private rooms and corridors serving them	40	Light	125
Public rooms and corridors serving them	100	Heavy	250
Reviewing stands, grand stands, and bleachers[c] Roofs		Stores	
Ordinary flat, pitched, and curved roofs	20	Retails	
Roofs used for promenade purposes	60	First floor	100
Roofs used for roof gardens or assembly purpose	100	Upper floors	73
Roofs used for other special purposes[f]		Wholesale, all floors	125
Awnings and canopies		Walkways and elevated platforms (other than exitways)	60
Fabric construction supported by a lightweight rigid skeleton structure[g]	5	Yards and terraces, pedestrians	100
All other construction	20		

3.3.5. Earthquake Loads

Earthquake Loads are applied as Building Code of Pakistan Seismic Provisions 2007 and UBC-97.
The following parameters are used in design.
Seismic Zone: 2B (Ref. BCOP 2007)
Site Class (Geotechnical): SD (Geotechnical Report)
Response Modification Coefficient (R): 8.5
Importance Factor (I): 1

3.3.6. Load Combinations

Orthogonal effects have been applied in load combinations by considering 100% EQ in one direction and 30% EQ in perpendicular direction as per clause of *UBC-97. (UBC-97 1633.1 General).*

3.4. Equivalent Static Analysis

Design analysis has been performed using ACI 318 and Eurocode 4 provisions for R.C.C and Composite columns. Finite element model prepared in ETABS 2017.
Economic comparison will be done by preparing bill of quantities (BOQ) using present material construction cost. These will then be presented in the form of table.
The equivalent static method is a simplified lateral force

procedure to inculcate the seismic (dynamic) loading in design process. It uses static force procedure to distribute the effect of lateral load V in two main axis i.e. X-axis and Y-axis direction. It includes following steps:

1) First step is to calculate the lateral force V acting on structure. The lateral force depends upon the soil type, importance factor of building, fundamental and natural time period of building, design ground acceleration (depends upon seismic zone), system that is resisting lateral force and the overall weight of structure including dead some or full live load.
2) The vertical seismic force distribution is determined along the height of structure. The height and force magnitude are proportional to each other.
3) Considering that the diaphragm is rigid, the overall distribution of forces on each level horizontal and resisting vertical elements.
4) Calculation of the additional forces from the inherent and accidental torsion to be added to the forces resulting from the horizontal distribution of the level forces.
5) Determination of the drift, overturning moment, and P-Delta effect that are the direct results of the action of the lateral seismic forces.
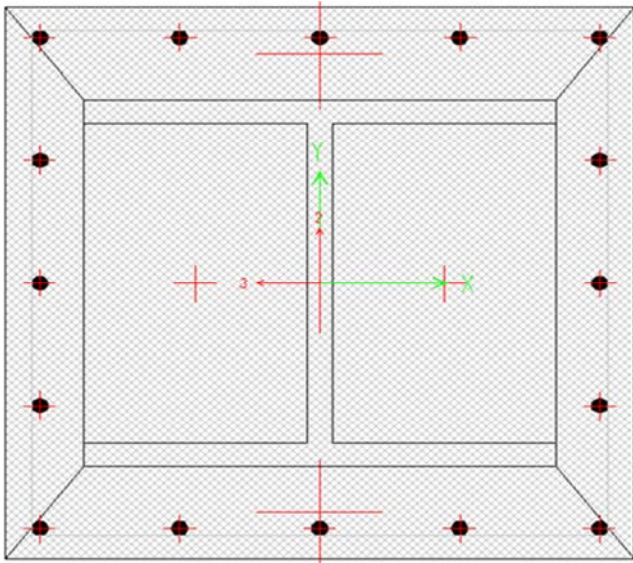
Figure 7. Cross Section of Composite Column.

3.5. 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 the functionality, safety, and economy. 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 past 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. Composite columns have been modeled using Eurocode 4 and AISC provisions. Columns are modelled in ETABS 2017 shown in figure 8 and the cross section of composite column is shown in figure 7.

3.6. R.C.C Design of Building

R.C.C design of building has been done using ACI-318 and UBC-97. The material properties were taken as per ASTM standards. Finite element was modelled using ETABS 2017 software shown in figure 8.

Column sizes for given structure are shown in Table 5.

Table 5. Columns Sizes.

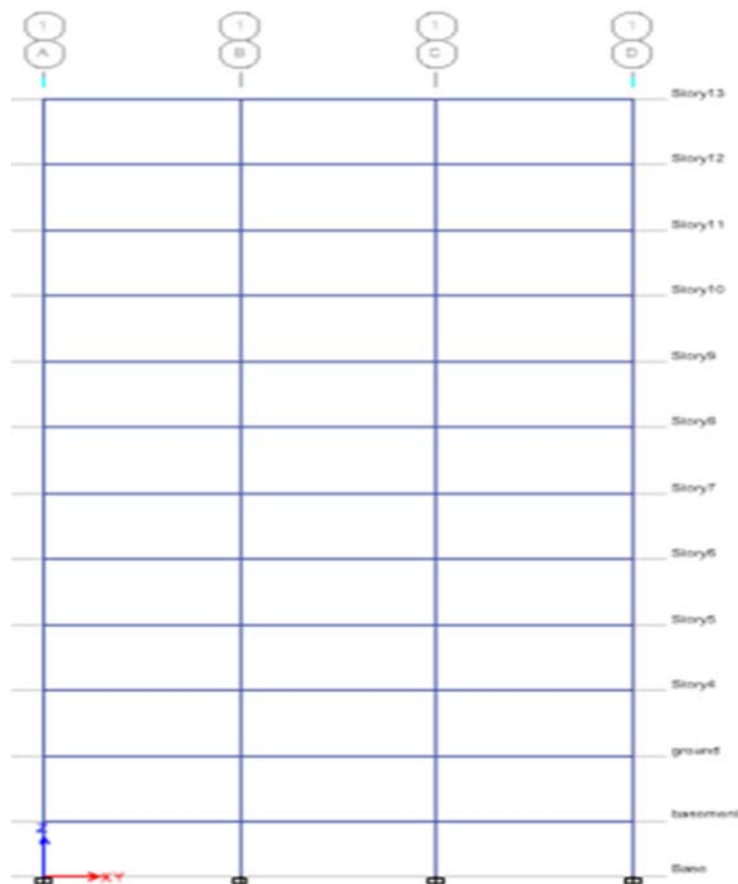| Column	Size of column of R.C.C	Expected Composite Column Size
C1	30"x30"	18"x18"
C2	36"x36"	21"x21"
C3	36"x36"	18"x18"
C4	24"x24"	15"x15"
C5	42"x42"	21"x21"

Figure 8. ETABS Model.

3.7. Result Comparison

The behavior of Composite column and R.C.C structure has been compared. The result comparison has been done for the following.

3.7.1. Structure Displacement

Structural displacement has been checked by using results from ETABS model of both R.C.C and steel concrete composite column.

3.7.2. Story Drift

Change in story drift of a normal R.C.C structure and steel concrete composite column structure has been compared

from ETABS model:

3.7.3. Base Shear

Base shear has been compared in the form of table for both R.C.C and composite column structure.
Similarly following has also been compared.
Yield Strength.
Economic Comparison.
Effect on functionality of Building.

3.8. Beam Column Connection

Concret beam and column joints are modelled as shown in figure 9.

Figure 9. *Proposed Connection Technique.*

All beams are connected to the column in the same way; the steel beam is welded to an end plate which is connected to the column by using bolts. The beam is considered 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 beam and columns have the same connection details which are shown in figure 10.
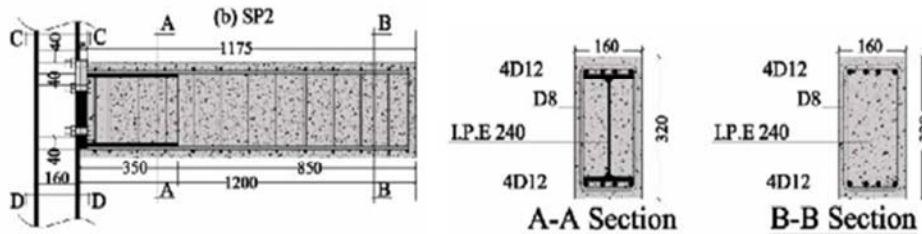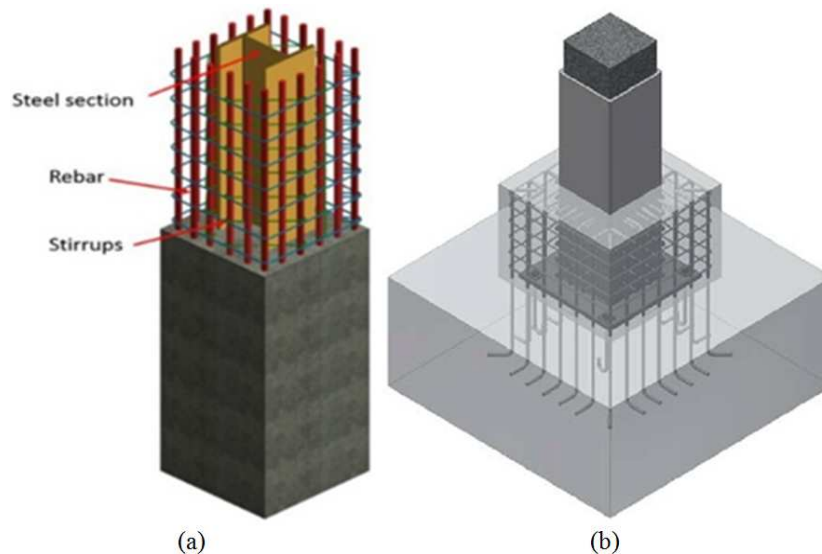

Figure 10. *Elevation and Cross Section.*

Figure 11. *Column Cross-section and Foundation Detail.*

3.9. Foundation Connection of Composite Column

The proposed way to connect the column to the foundation is shown in figure 11(a) and figure 11(b). This method is used around the world to connect steel column to foundations. The size of base plate and foundation is dependent of load acting at foundation.

4. Result and Discussion

Equivalent static analysis was performed on R.C.C and Composite Column building in ETABS. A R.C.C commercial structure, selected for the study, is located in Islamabad. Islamabad exists in seismic zone 2B (Building Code of Pakistan 2007). The dimensions of the commercial building are 157.5 *ft.* x 78 *ft*. Building comprises of one basement of 12 *ft* in height which will be used for car parking. The ground floor, first floor and second floor are used for commercial purposes such as mall and shops having height of 12 *ft.* each. The remaining floors from third to tenth story have height of 12 *ft*. The third, fourth and fifth floor will be used for offices. The stories from sixth to tenth has been reserved for residential purposes. The total height of building including basement and mumty is 160 ft. The results are of base shear; displacement, ground over-turning moment, storey drift, storey shear, ductility, mode shape, model period, quantities and floor area ratio which are compared between R.C.C structure and Composite column structure.

4.1. Results for Zone 2B (X & Y Direction)

The results are shown in figure 12 and figure 13. According to the building code of Pakistan, 2007, the peak ground acceleration is 0.2g against which the building has been designed. Results in X and Y-direction between comparison of 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 comparison, floor area ratio and column sizes.
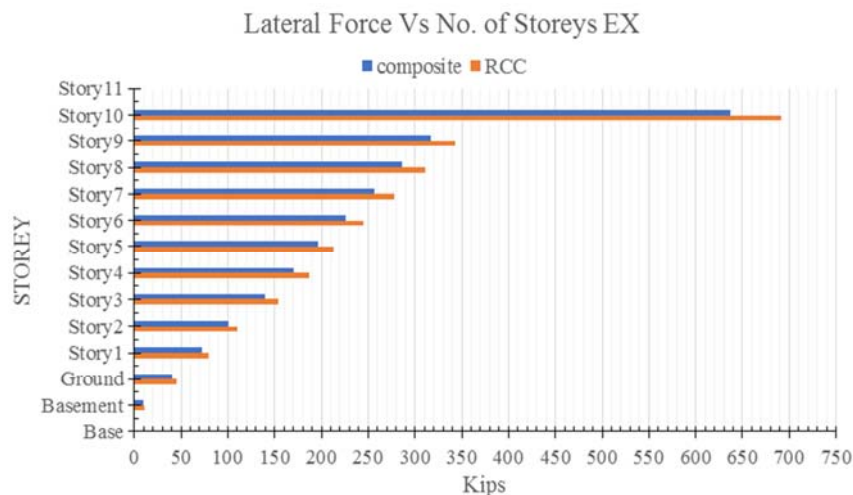

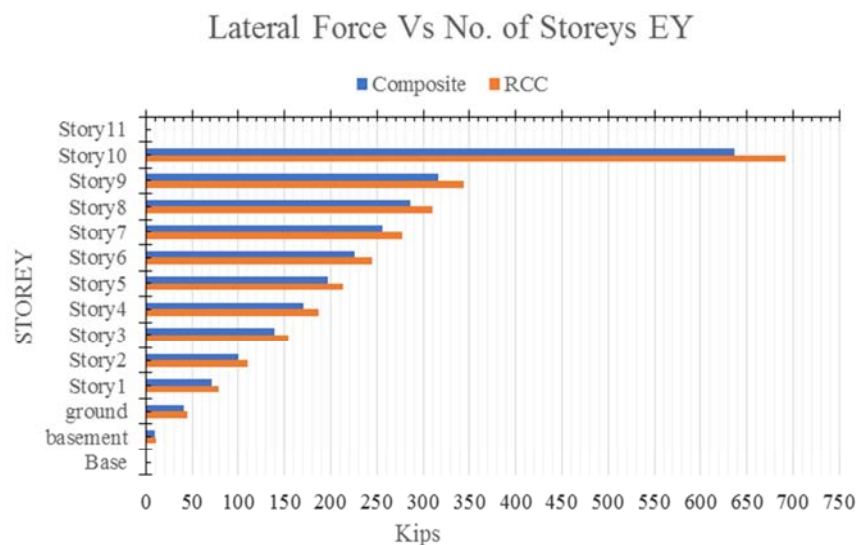*Figure 12. Lateral Force Comparison (X-Direction).*

Figure 13. Lateral Force Comparison (Y-Direction).

4.1.1. Lateral Force Comparison

In Figure 12, lateral force versus storey level is plotted for both R.C.C and Encased Composite Column for X and Y direction, the values gradually increase as storey level increases. The graph shows that lateral force for R.C.C is greater than as compared to Composite structure. The difference between frames with encased composite column and R.C.C is 7.943%. Storey lateral forces decreases in encased column structure.
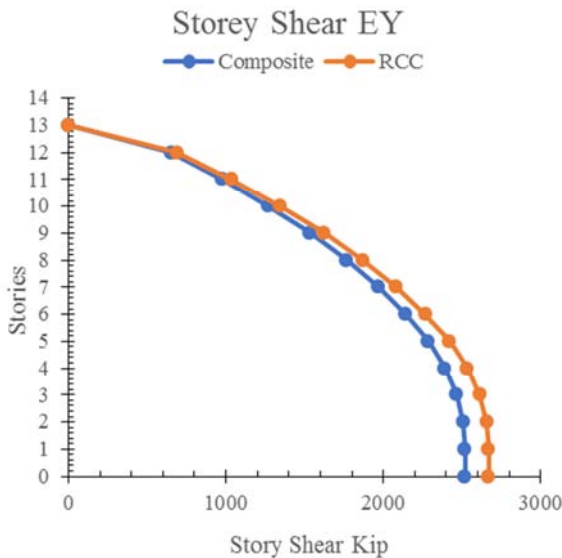
4.1.2. Storey Shear Comparison

Figure 14. *Storey Shear EY.*

Figure 15. *Storey Shear EX.*

In figure 14 and figure 15, Shear Force and storey level is plotted for both R.C.C and Encased Composite Column for X and Y direction, the values gradually decrease as storey level increases. The graph shows that shear force for R.C.C is greater than as compared to Composite structure. The difference between frames with encased composite column

and R.C.C is 5.67%. There is less shear acting on Encased composite column than R.C.C and the reason is due to overall less dead weight acting on structure.
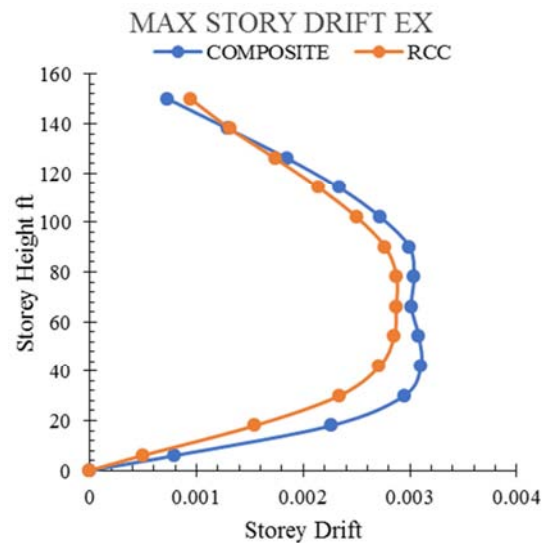

Figure 16. *Storey Drift Comparison EX.*

4.1.3. Storey Drift Comparison

Storey drift gradually increases at first from base to ground storey. As the no. of storey increases, somewhere around fifth story the storey drift of both frame reaches their maximum values with Encased Composite having larger storey drift value than that RCC structure. Storey drift for both structures gradually decreases as it moves along the top storey. The trend of graphs in Figures 16 and 17 respectively shows that the storey drift for encased composite column structure is more as compared to R.C.C structure. This is due to small sizes of columns in Encased Composite column structure when compared to R.C.C (see Table 6). The storey drift in EY direction is more as Figure 16 shows, this is because of building orientation i.e., in EY direction building spans only 78 *ft* as compared to EX where it spans for 157.5 *ft*.
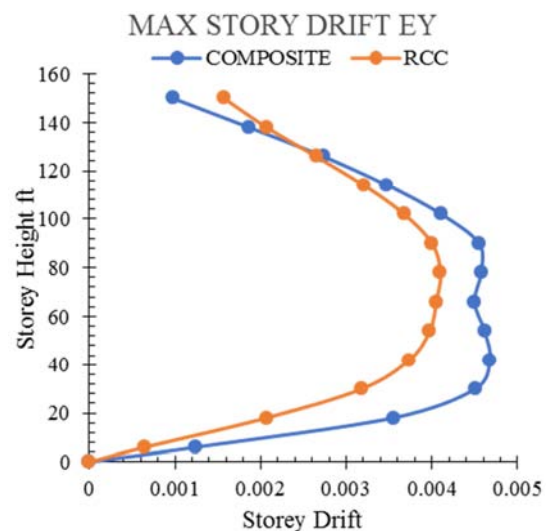

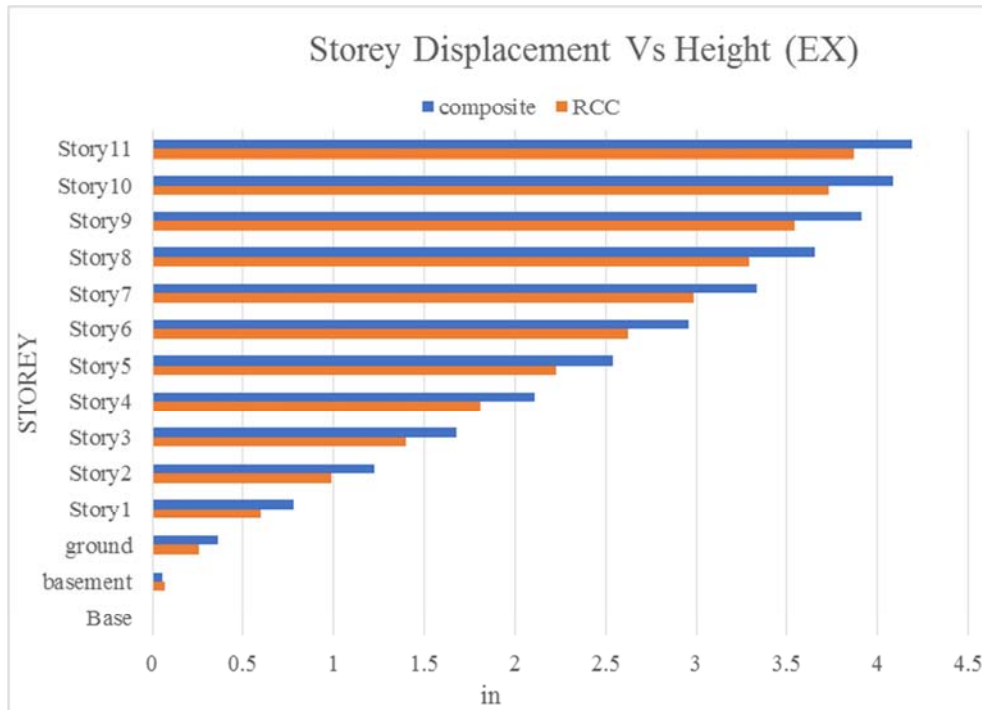**Figure 17.** *Storey Drift Comparison EY.*

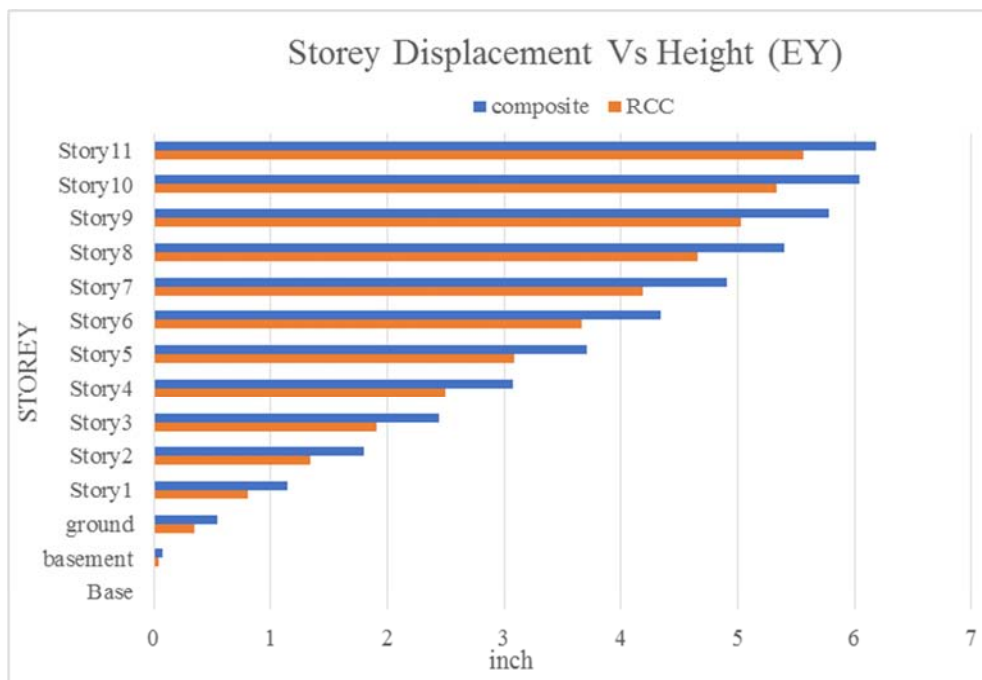**Figure 18.** *Story Displacement (EX-Direction).*

Figure 19. *Story Displacement (EY-Direction).*

4.1.4. Storey Displacement Comparison

Above figures shows the graphs of displacement versus storey level. The graph in X-direction is discussed first. In Figure 18, encased composite column shows more displacement than R.C.C Structure and the difference is 7.73%. Composite column structure displays more displacement and less base shear.

Now in figure 19, graph shows displacement Y-direction.

In Figure 19, encased composite column shows more displacement than R.C.C Structure and the difference is 10.17%. Composite column structure displays more displacement and less base shear in both directions.

More displacement is due to small sizes of columns in encased composite column structure so this result in less dead weight of structure which alternately result in less base shear.

4.1.5. Overturning Moment Comparison

In figure 20, 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%.
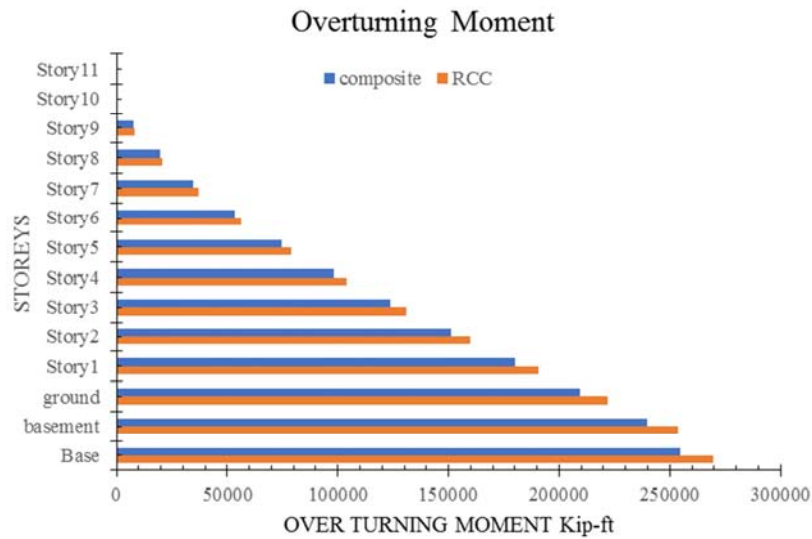

Figure 20. Overturning Moment.

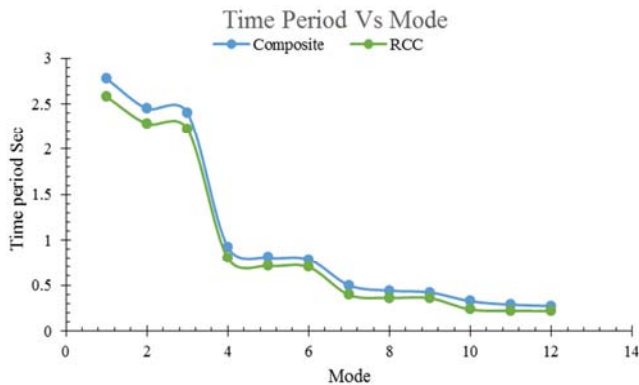### 4.1.6. Mode Period and Frequency Comparison
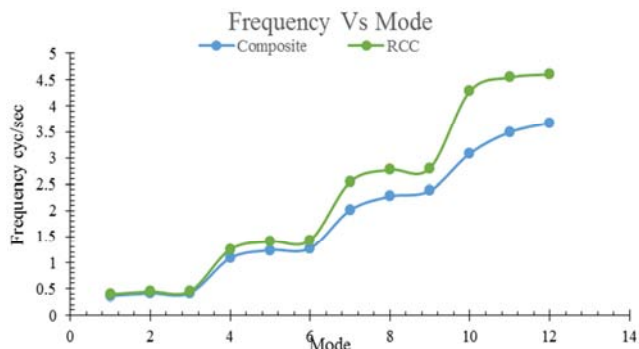

Figure 21. Time Period Comparison.

Figure 22. Frequency Comparison.

In figure 21, 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%

In figure 22, the frequency of composite column structure is less than R.C.C structure and the difference is 20.255%.

4.1.7. Moment Curvature/ Ductility
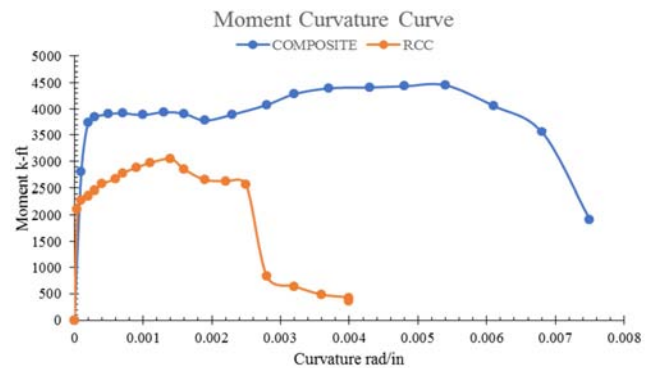
1) Columns Comparison

Figure 23. 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 23 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 24 columns 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.
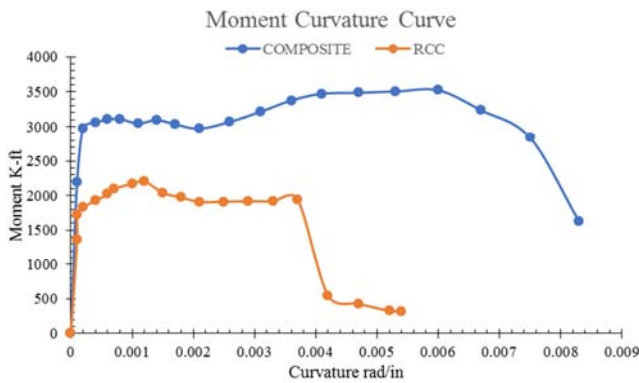
Figure 24. *Moment Curvature Comparison.*

2) Column Sizes Comparison

Table 6. *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.

4.2.4. Cost Comparison

It can be seen in table 6, 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.

4.2. Quantities and Cost Comparison

4.2.1. 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.

4.2.2. Encased Composite Column Structure
The total steel required for the construction of super structure i.e., from base to mumty is 747.6616 tons. The total concrete require for construction of super structure is 198701 cft.

4.2.3. Floor Area Ratios
Floor area for R.C.C structure is 147182.22 ft^2 and for encased composite Column structure it is 159452.5 ft^2. The floor area for composite column structure is 12270.25 ft^2 more than R.C.C structure that is 7.7%.

Table 7. *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

5. Conclusion

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:

i. 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.
ii. Storey drift for the R.C.C is less than encased composite column structure in both X and Y direction.
iii. 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.
iv. The overturning moment of R.C.C structure is 5.5% more than encased composite column structure.
v. 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.
vi. 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.
vii. Inner columns are reduced by 18 inches for encased section. This means that a lot of valuable space can be saved in structure.
viii. The floor area for encased composite column structure is increased by 7.7%, i.e. 12170.55 ft^2.
ix. 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.

6. Recommendation

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 then 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.

List of Abbreviations and Symbols

Ac, Ar: area of concrete and longitudinal reinforcement, respectively

As, Aw: area of steel shape and web of steel shape, respectively

B1: moment magnifier suggested in AISC-LRFD specification

Ec: elastic modulus of concrete

Em:: modified modulus of elasticity

Fcr: critical stress of column

Fmy: modified yield stress

Fy: specified yield strength of steel shape

Fyr: specified yield strength of longitudinal reinforcement

fc':: specified compressive strength of concrete

h1: width of composite cross section perpendicular to the plane of bending

h2: width of composite cross section parallel to the plane of bending

Ig: gross section moment of inertia

KL: effective length

Mn: nominal moment capacity without axial load

Mu: factored moment

Mu1, Mu2: the smaller and the larger required moments applied at both ends of the column, respectively

P0: composite column capacity under uniaxial compression

Pc: critical load of column

Pn: nominal axial compressive capacity

Pu:: factored axial load

r: radius of gyration

rm: modified radius of gyration

Z: plastic section modulus of steel shape

δ:: moment magnifier suggested in ACI-318 code

φb: resistance factor for bending, taken as 0.9

φc: resistance factor for compression, taken as 0.85

λc: slenderness parameter

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