



## Composite Columns in Building Structure - A Analytical Study

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### Abstract

Present-day construction is greatly influenced by steel-concrete column composites. Steel-concrete composite gained extensive attention around the globe, which made steel-concrete composite utilization in construction more attractive than conventional reinforced cement concrete design. Different architectural culture has introduced inexhaustible diversification of different columns. One of the most widely used is concrete-encased columns. These columns are those in which steel is encased in reinforced concrete. Combining these two materials leads to less cross-sectional area, high rigidity, and improved lateral resistance. However, some construction difficulties are evident. A comprehensive overview of the state of the art of evolution of composite columns in building structures based on experimental numerical and analytical studies is emphasized in the paper. Moreover, replacing concrete with various materials such as cement aggregates, limestones, fly ash, and industrial waste is suggested to deal with the high cost of the construction.



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### Introduction

Construction history is a pillar for developing the modern-day construction strategies proposed by engineers. The authors have demonstrated several reports and ideas to make construction easy and reliable worldwide. Composite columns are built involving different blends of underlying steel and cement to utilize the beneficial properties of every material. The integral and interactive way of behaving of concrete and the primary steel components makes the composite segment an

exceptionally stiff, cost-effective, better ductility and thusly a basically effective part in building and bridge developments. The use of concrete and steel composite bodies is reported to be used widely worldwide. However, its use is considerably low in developing countries around the globe due to its high cost. The concrete and steel composite mixtures offer a significant role in the economic aspect of the construction field, specifically in high rise buildings. Another aspect of its viability is the reduced speed of erection in steel-concrete composite structures.

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In modern construction, steel-concrete composite columns have influenced the field, which has reduced the use of conventional methods such as reinforced cement concrete and other steel construction structures. Reinforced cement concrete structure is most economical and suitable for low rise buildings, so it is preferred to frame the system in most building structures. However, under seismic conditions, steel-concrete composite frames perform better due to the inherent characteristics of ductility, making them better than conventional reinforced cement concrete bodies. Also, the effect of seismic conditions on composite structures is significantly less due to low dead weight than reinforced cement composite. In present-day high rise buildings construction, engineers are considering strategies with more stiffness taking into account the advantage of steel and concrete reinforcement. These characteristics directly affect the high capacity and axial compressibility of composite columns composed of both materials.

In this structure, under earthquake conditions, bearing high magnitude concrete section possibly tends to crack, resulting in reducing the flexural strength of the overall beam and composite column. The steel part plays the role of a backup system, providing shear strength to the structure. It also provides plasticity to forestall brittle which can lead to failure modes. However, all characteristics such as ductility, flexural stiffness, and strength capacity can be improved by cross ties and by offering less spacing of the hoops.

Construction cost is very high today with conventional materials because of unavailability of the natural elements. The problem is suggested to sort out by replacing concrete with different low-cost types of materials, including waste materials. Cement is a binder substance that hardens and sells and binds alternating materials along with it. The origin of the word cement comes from Romans, which the UN agency termed 'opus caementiciumto'. It describes brick walls reassembled to modern concrete made of rock with a mixture of calcined lime as a binder. The mixture was a dictionary added up with small-grained bricks and volcanic ash to make it rigid, which were brought up as cimentum, cāment and cement.

Cement is the widest substance used by humans and the second-largest substance to be used after water. It has been reported from the recent surveys that during the 2012 financial year, 247 MT of cement was used, which was increased to 550 MT in the financial year 2020.<sup>1</sup> Moreover, cement is reported to be highest in China, and India is the second one. Furthermore, the engineers suggest using some other materials such as aggregates, limestone, Jype cement, and mixed concrete.

The present paper is concerned with different types of composite columns used in building frames. More specifically, this paper provides a comprehensive overview of the state of research in composite columns, including experimental and analytical studies emphasizing recent work by engineers using conventional and advanced strategies. The replacement of concrete with other materials also has been analyzed. Further use of composite columns in USA architecture has been elaborated.

#### Different types of Composite Columns

The column is one of the most integral elements in building materials and interiors. It can be seen through history to modern-day construction expressions for functional structural, symbolic and esthetic requirements. Composite Columns offer economic advantages by providing the benefit of carrying large loads with smaller cross-sectional areas. Specifically for high rise structures, these kinds of columns are reported to be used widely. They benefit from reduced column size, increase in utility space for the ground floor, good behaviour under seismic conditions and good rigidity of building structure. They also provide better protection against fire.

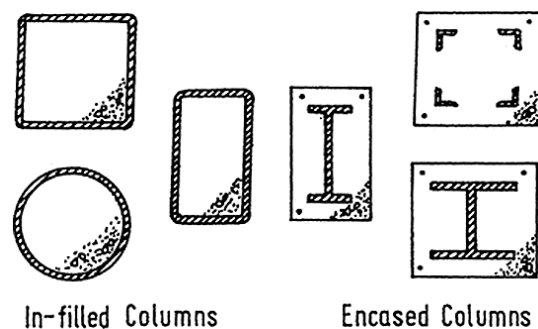


Fig. 1: illustrates the basic form of a composite column.<sup>2</sup>

The most commonly used composite columns in building structures are encased steel-concrete (where the steel section is encased in concrete) and in-filled steel-concrete composite (where the steel section is in-filled with concrete).

There are three basic types of concrete composite reported in the literature.

- Sections-completely encased.
- Sections-partially encased.
- Fully concrete filled hollow columns.

Steel composite performs better than conventional reinforced concrete cement under seismic activity due to inherent characteristics of ductility than reinforced concrete cement structures. The early evolution in the construction era, specifically for the usage of steel in building structures, was due to its property of fire resistance. However, in 1960 researchers showed that wrapping or encased concrete could increase load resistance in steel columns. The economic aspect of construction can be improved by utilizing high-quality concrete and implementing a composite section in the column designs. Steel concrete column composites are reported to be infrequently used in World War II and continued to use till the start of the 20th century. The fire protection was provided using encased concrete, whereas steel was combined with concrete as reinforcement.

Some earlier tests were performed on composite columns by Burr and were followed over the period by many researchers and engineers in both experiment and theoretical aspects.<sup>3</sup> The effect of steel and concrete strengths, the ratio of steel section, the cross-sectional dimensions of steel and concrete section and the reinforcement effect on composite columns strength were investigated in the work. Several parameters, including slenderness ratio and eccentricity, were varied to study the effects. The results indicated that the statistical properties of short composite beam columns in the reliability study are influenced by steel ratio, concrete strength and end eccentricity ratio. The end eccentricity ratio should be greater than 0.5 because it considerably affects beam-column strength.<sup>4</sup>

In current modern construction needs, the volume of steel is proposed to be increased. Composite

structures in construction comprised many structural systems, including framed structures with all composite parts and mechanisms, including composite beams, columns, and joints. Moreover, it includes the sub-grouping of steel and reinforced concrete elements. A relative analysis of conventional reinforced concrete cement, steel-concrete, and composite structures is proposed. The reinforced concrete cement structure is suggested not to be economically viable due to the unsafe framework and increased building load. ETABS analysis was performed to study different parameters such as story drifting and story displacement. This paper also compiled different reviews about the suitability of composite structures for high-rise buildings compared to other structures such as conventional reinforced concrete cement structures. Composite columns act as an integral element in the building structure combined with different elements to add beneficial properties to each material. The primary properties of composite columns for high-rise buildings, such as increased strength, stiffness and buckling resistance due to cross-sectional dimensions and protection in the case of an embedded section against corrosion, are highlighted in the work. The work concluded that conventional reinforcement concrete cement structures are less beneficial than composite structures as they offer more resistance to structure forces and produce less displacement.<sup>5</sup> Another analysis was performed to study a G+14 residential multi-stories building. The study includes the advantage of composite column structure over the reinforcement concrete cement structure. Advantage is such as easy renovation, lighter construction, lower stiffness of steel and good resistance against load are demonstrated. The study used the static and response spectrum method to examine building construction parameters, such as period, base shear, deflection, and story drift. The work proposed that the lightweight composite column makes it economically viable and more time period than reinforced concrete cement structure. However, reinforced concrete cement structure has the advantage of less displacement.<sup>6</sup> Kumawat *et al.* used Indian standards to study G+9 story building of composite structures under seismic conditions. They used equivalent static method, response spectrum analysis, and SAP2000 software for modelling. It is settled from their work that dead weight from the composite structure is 15% to 20%

less than reinforced concrete cement structure, which is reduced to 15% to 20% under vibration activity. The stiffness is also reported to increase almost 6% to 10% in the longitudinal direction for composite structures while 12% to 15% increment in the transverse direction compared to reinforced concrete cement structures. So finally, it can be said that composite structures are better than reinforced concrete cement in terms of structure.<sup>7</sup>

Another study was performed for partially Encased composite columns. The load-carrying capacity of the columns tends to have minor axis bending. Different variables such as eccentricity ratio and concrete strength effects were analyzed. A load failure beyond 70% was absorbed in all the experiments, leading to tension cracks. This work utilized Newmark's technique of numerical integration to estimate the maximum strength of the columns.<sup>8</sup> In-filled steel-concrete rectangular shape Composite column of 3m length was analyzed. Three different loading conditions, uniaxial bending, biaxial bending and viz. axial, were considered for the experiment. It was concluded from the work that yield strain was reached in compressive zones at a high load between 80%-90% leading to failure load, which subsequently tends to high bending moments due to large lateral displacement. Furthermore, no sign of local buckling of the steel section was noticed due to the overall buckling mode.<sup>9</sup> Another group performed experiments on rectangular shape in-filled steel-concrete columns. Their work proposed that concrete filling in columns enhances the load capacity of the columns. They also investigated concrete cube strength, the effect of varying steel strength design, and column section variation.<sup>10</sup>

A further demonstration of the factors of failure load and load-displacement relationships of 3m and 5m long composite was presented. They used ABAQUS

software to analyze the experiment.<sup>11</sup> The elastic-plastic behaviour of the reinforced steel-concrete composite was experimentally studied. A sharp peak was noticed on the load-deflection curve of the short column due to concrete crush. P- $\nabla$  the effect was more prominent in the long column than the short column, and unloading was observed.<sup>12</sup> The induction of steel ratio specifically for in-filled steel-concrete column composite is considered better due to high tensile strength, high flexural, better fire resistance and lower shrinkage. The addition of steel fibre into concrete composite adds better mechanical performance under tensile load because of the interaction of steel with matrix and the high strength of steel. Steel fibre also provides better ductility and delays crack occurrence and prolongation.

However, some construction difficulties such as concrete pouring quality or attachment between reinforcing bar and steel structure are reported. Several studies on encased steel-concrete structures are experimentally analytically and numerically conducted. An analytical model was proposed to study the capacity of an axial load of a composite column. The concluded results suggested that raised axial load capacity was due to the concrete confinement effect resulting from confining stress originating from transverse reinforcement and steel structure.<sup>13</sup>

Under seismic activity, another investigation was conducted. The work concluded that composite column components exhibit better ductility and cyclic strength when prevention from buckling is provided for longitudinal bars.<sup>14</sup> A summary of experiments based on encased steel-concrete and in-filled steel-concrete columns over the period are tabulated below.

**TABLE 1: ENCASED COMPOSITE COLUMN TESTATION.**

Sr no	Section Shape	Parameters studied	Remarks	References
1	Square and Rectangular	Unconventionality of applied load of both concrete and steel.	Columns were 4.57 m long and loaded Unconventionality along the weak axis.	[15]
2	Rectangular	Unconventionality	Demonstrated strength	[16]

3	Square	of applied load, slenderness ratio. Length, slenderness, strength of concrete and steel.	calculation method and procedure design. Experiment performed with longitudinal reinforcement.	[17]
4	Square	Length, strength of concrete and steel.	Demonstrated interaction equation and procedure design.	[18]
5	Square	Slenderness and eccentricity ratio, concrete strength, steel ratio.	Comparison with proposed design and ACI standards.	[19]
6	Square	Concrete strength, effective length, slenderness ratio.	Demonstration of calculation route.	[4]
7	Square	Concrete and steel strength, concrete confinement ratio, shear resistance mechanism.	ACI and AISCLRFD comparison.	[20]
8	Square	Concrete and steel strength, eccentricity and moment ratio.	Proposed BS 5950 based design procedure.	[21]

**TABLE 2: IN-FILLED COMPOSITE COLUMN TESTATION.**

Sr no	Section Shape	Parameters studied	Remarks	References
1	Circular	D/t and slenderness ratio, concrete, and steel strength.	Suggested computerized numerical method	[4]
2	Circular	Concrete, and steel strength, Slenderness, and effective length.	Short section columns were aligned to uniaxial moments.	[22]
3	Circular	Slenderness, effective length, concrete, and steel strength.	53 MPa -63 MPa concrete. was used	[23]
4	Rectangular	Effective length, concrete, and steel strength, eccentricity ratio.	Proposed BS 5950 and BS 5400 provisions.	[10]
5	Square	Steel tube thickness, Axial force ratio, concrete, and steel strength.	Demonstrated strength estimation method for confinement effect.	[24]
6	Circular	Steel strength, Wall thickness, effective length.	Demonstrated calculation method for strength.	[25]
7	Square	Effective length applied load eccentricity.	Numerical method predictions.	[26]
8	Rectangular	Concrete, and steel strength, eccentricity and moment ratio in both directions.	Design Procedure based on BS 5950.	[21]

### Replacement of Concrete in the building structure

Cement as a concrete replacement is reported in the literature as an effective route due to its less cost and intensive energy production. However, cement produces CO<sub>2</sub> emissions at a large scale resulting in severe environmental effects. One ton of cement production is estimated to generate one ton of CO<sub>2</sub> in the environment. The researchers have suggested some routes to cope with replacing concrete with less toxic materials.

Type cement is one of the alternates due to its refined nature, optimal phase composition, suitable particle size distribution, high strength to structure and better physical and chemical lab properties.

Fly ash is another commonly used alternative to use in concrete as a replacement by adding 0% to 30% of cementitious material. Fly ash is an industrial material created by burning coal to produce electricity. The materials which make up fly ash are pozzolanic, meaning that they can be used as a binder or as a supplement to the binding material. Usage of Fly ash as replacement or addition to binding material requires low invasive mining, uses less energy and reduces CO<sub>2</sub> emission and recourse consumption.

Limestone is another primary binding material formed at the bottom of the sea and lakes rich in calcium and accumulated from shells and bones. It is very cost-effective and the best solution to cement demands in modern-day construction.

Aggregates, one of the major ingredients of concrete-based structures, also act as an economical space filter and provide rigid skeletons to building structures.

Concrete mixed design is widely reported to use in building structures. Some factors that need to be considered for concrete mixers designs are 1) selection of cement type, which can influence the rate of enhancement of compressive strength of concrete. 2) Ratio of cement content should be limited from cracks, creeps and shrinkages. 3) The size and shape of the concrete section at the right place and compaction influence the workability. 4) Reinforcement spacing and quantity. 5) Strategy for transportation of material and its placing and

compaction. 6) Use of aggregates within the limitation of IS 456:2000.

A non-cement binder using palm oil fuel, rice rusk ash and slag was fabricated. The activation of the material was carried out by using 2.5%, 5%, and 7.5% of sodium hydroxide by the weight of the non-cement binder. A further mixture of different ratios of palm oil fuel, rice rusk ash and slag was presented for non-cement binder fabrication. The prepared samples were tested for setting time, consistency, compressive strength and flexural rate. The results from XRD, FTIR and SEM analysis revealed that setting time, flow strength and consistency of the prepared samples are considerably affected by mixed proportion and confinement of added materials.

The highest compressive strength of 40.68 MPa and flexural strength of 6.57 MPa were achieved for 42% slag, 30% rice rusk ash, and 5% sodium hydroxide.<sup>27</sup>

Another group from Madras, which is one of the leading cities in the development of energy and low carbon construction resources in the United Arab Emirates, proposed a renewable energy pathway to reduce its environmental footprint. They investigated 13 types of concrete mixed with the high volume of grounded slag cement with varying ratios of 50%, 60%, 70% and 80% as replacements for ordinary cement to reduce carbon emissions. They concluded significant carbon emission reduction to meet Madras city requirements with mixed salt concrete. This work showed a pathway for engineers for future sustainable and environmentally friendly construction routes.<sup>28</sup>

A survey was presented by Thelma Ramos *et al.* about Granitic quarry sludge, which is abundant waste material from granite rock processing. This material is considered a hazardous source to cause severe environmental concerns. An investigation was conducted to analyze Granitic quarry sludge effects as a partial replacement of cement in mortar in order to add durability and strength in Portugal. The survey involved SEM, chemical analysis and laser particle size distribution study. Moreover, mechanical strength and chloride penetration resistance on mortars containing different ratios of cement replacement by Granitic quarry sludge to the different number



of confinement levels were also analyzed. The sufficient confinement of Granitic quarry sludge waste originated dense matrix to promote a 38% reduction in expansion because of alkali-silica reaction and resistance to chloride improvement by 70% without compromising strength, and work efficiency was concluded.<sup>29</sup>

### Composite columns utilization in USA

Steel-concrete composite columns in horizontal structures are used often in the USA construction field. In low rise metal buildings, 95% of the floor systems are based on this type of construction design. Back in the 1890's number of bridges were built based on the strategy presented by J. Melan (Austrian engineer). Over a century ago, Melan's technique was the first composite implemented for bridges and buildings and gained significant attention to practices in the USA within a short period. A great impetus was received in the early 1950s on investigating composite columns in the University of Illinois and the American Association of Highway Officials Road Test Project.<sup>30</sup> The result concluded from their work was a comprehensive treatment of shear strength between both the materials involved steel and concrete.

Further, this study led to the development of performance and installation of the system and requirement of interstate highway system leading to bridge and then to the building structures designs through the number of platforms such as seminars, books and series of articles.<sup>31</sup> The utilization of composite columns in vertical systems is limited to high rise buildings or the use of concrete on the lower floor and steel design implementation on the upper floor.



**Fig. 2: illustrates the transition zone from the lower floor to the upper floor.<sup>32</sup>**

Lately, composite beam provisions have been introduced, but engineers are conscious of their simplicity and applicability to building structure designs. Some modifications were made in composite column provisions but with minimal updating at large scale research. However, in the 1990's, some new developments were made to modernize provision composite designs by Building Seismic Safety Council.<sup>33</sup>

Some of the basic requirements for USA based composite columns are elaborated here.

- The limitation of the use of materials where significant change was the removal of the strength to calculate the stiffness of the concrete. Also, the discouragement of using high-strength steel and concrete is recommended.
- Unnecessarily, local buckling limitations should be removed because both concrete-filled and unfilled were almost identical.
- The distribution of forces between the steel and concrete away from connection regions needs considerable attention.
- In beam-column interaction equations for steel cage actual shape of interaction, concrete composite is very close to the reinforced concrete structure, which is not ignorable.
- Under axial or flexural forces, most of the composite cross-sections do not adequately get to their full plastic capacity indicated calculated by test data.
- Little information about shear strength can originate problems in short column utilization in building designs leading to seismic deformation.

### Future Prospects

Considerable progress has been made in the steel-concrete column composite investigation in recent times. Beyond the rapid growth of composite column designs in construction for more facilities and comfort, history plays a significant role in the development of the field, leading to advanced innovations and revolutions. At the same time, hazardous effects on the environment are not ignorable. So after reviewing all the research work reported in the paper, we concluded that encased composite columns showed better structural

performance than conventional reinforced design. The addition of steel ratio further enhanced the shear, tensile and flexural strength, leading to delay and prolongation of the cracks. Moreover, locally available industrial wastage or other cost-effective materials as a partial concrete replacement could be added to prove the field more viable and economical. Additionally, introducing pollution-free or less pollutants such as renewable resources leading to soothing surroundings could be helpful. The work also concluded some of the background, development, and type of composite columns used in USA buildings. Furthermore, some basic requirements need to consider for USA building designs.

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#### Conflict of Interest

There is no conflict of interest.

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