

A Comprehensive Review of the Design, Analysis, and Seismic Performance of Steel–Concrete Composite High-Rise Buildings

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Abstract : Steel-concrete composite structures have attracted much attention in current structural engineering due to their potential in improving the performance of structures, constructability and sustainability. These structures combine the high tensile strength of steel and the high compressive strength of concrete, so both materials can act together as a composite system. This paper reviews the existing research on the design and analysis of steel-concrete composite structures focusing on the structural behavior of composite beams and columns, load carrying capacity, stiffness, deflection and overall stability. The review includes design principles, analytical methods and code provisions relevant to the composite. The relative structural efficiency, material consumption, construction time, cost-effectiveness and environmental performance of steel, reinforced cement concrete (RCC) and composite structures are reviewed in the light of previous studies. The role of shear connectors is specially addressed to secure composite action and successful load transfer between steel and concrete components.

IndexTerms - Composite Structures, Steel–Concrete, Structural Design, Composite Beams, Composite Columns.

I. INTRODUCTION

Composite steel and concrete construction are a cutting-edge structural system that combines the advantageous qualities of concrete and steel to create a single, effective load-bearing unit. The fundamental idea behind composite construction is the efficient interaction of concrete and steel, which is accomplished by mechanical shear connectors that allow the two materials to function as one cohesive unit. Concrete's superior compressive strength and stiffness is further enhanced by steel's high tensile strength and ductility. Because of this combination, materials can be used more efficiently, leading to structures that are stronger, lighter, and more cost-effective. Composite structures are frequently utilized in high-rise buildings, bridges, industrial floors and infrastructure projects in contemporary civil engineering practice. Because of their increased stiffness-to-weight ratio, increased load-carrying capacity, and improved resistance to buckling and vibration, composite beams, columns, and slabs are becoming more and more popular. Furthermore, in-situ concrete casting and steel section prefabrication offer construction flexibility, expedited project completion, and less on-site labor. National and international standards like IS 11384:1985, Eurocode 4 (EN 1994), and AISC 360 regulate the design of composite members. These standards offer guidelines for assessing material interactions, figuring out effective section properties, and guaranteeing safety under a range of loading scenarios.

In addition to detailing shear connectors and interface slips, the design process entails comprehending how composite sections behave under flexure, shear, and axial loads. Additionally, by minimizing self-weight and optimizing material use, composite construction greatly aids in sustainable development by resulting in smaller foundations and lower carbon footprints. The design of composite steel and concrete structures has emerged as a critical area of structural engineering research and practice due to the increasing demand for strong and long-lasting structures. Over a century ago, this engineering and construction technique was widely used, with the steel-concrete connection playing a more prominent role. In order to overcome the effects of fire and ensure stability against axial and bending forces, concrete-encased steel sections were first developed as composites. To provide an integral and permanent formwork, composite columns with a reinforced concrete core and a steel pipe or steel tubular shell were introduced. This review paper summarizes the comparative performance of RCC, steel, and composite systems based on construction speed, structural behavior, foundation demand, and life cycle cost.

A. Components of composite structures

- Composite slab is a structural floor system that uses both concrete, and steel. Usually this is in the form of concrete poured on top of profiled steel decking. The steel decking acts as permanent formwork during construction and as reinforcement in the finished slab. The concrete provides compressive strength. This type of building results in a strong, flexible and often lighter-weight floor that can be built quickly
- Composite beams are structural members that consist of an I-shaped steel section fully or partially enclosed by concrete. This composite design combines the strength and rigidity of steel and the compression strength of concrete to form a member with higher load carrying capacity, more stiffness, and better fire and vibration resistance than conventional steel or reinforced concrete beams alone.

- A concrete encased steel column is a structural element that is composed of a steel section and a reinforced concrete section. The combination of the two materials results in extraordinary strength and ductility of these columns, which makes them perfect for high-rise structures and other applications where heavy load support is required.

B. Necessity of composite structure

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C. Limitations

- Prior to analysis, precise material properties (such as modular ratio, steel yield strength, and concrete grade) must be known.
- Without experimental data, it is challenging to accurately model the bond/slip behaviour between concrete and steel.
- The precise loading conditions (live load patterns, construction loads, and dynamic loads) might not be known before modelling.
- Prior to modelling, ideal supports and connections (pinned, fixed, or roller) are assumed; however, real-world field conditions frequently differ.
- For pre-analysis design, the composite section details (such as shear connectors, slab thickness, and deck profile) are frequently idealised

II. LITERATURE REVIEW

MD Tanvir Hasan Fahim (2022), he given an analytical review of steel-concrete composite columns, who emphasised the increasing use of these materials in seismic-resistant and contemporary high-rise buildings. According to the study, composite columns—whether in-filled or encased—offer greater stiffness, ductility, and load-bearing capacity than conventional reinforced concrete columns. The article also discusses elements like slenderness, eccentricity, and material strength while reviewing a number of analytical and experimental studies on encased and in-filled columns. In order to lower costs and CO₂ emissions, it also investigates environmentally friendly material substitutes like fly ash, limestone, and slag.

Binglin Lai , J.Y. Richard Liew, Akshay Venkateshwaran , Shan Li, Mingxiang Xiong (2020) stated in their review of developments in tubular composite members and connections, Lai et al. (2020) concentrated on how steel tubes can be integrated with fiber-reinforced polymers and concrete to enhance structural performance. The authors emphasised how fiber-reinforced polymer (FRP) confinement is increasingly being used to fortify tubular members and lessen corrosion. Notwithstanding notable advancements, they pointed out that more experimental and analytical research as well as thorough design guidelines are required to address intricate interaction mechanisms.

Chu Tuan Long, Pham Quoc Hoan, Doan Xuan Quy (2022) made a research work on Concrete's compressive strength and steel's tensile strength are combined in steel-concrete composite structures, which provide effective and affordable solutions for contemporary building. Because of their quick assembly and durability, composite systems have been used extensively in industrial facilities, high-rise buildings, and bridges over time. Growing interest in this technology is demonstrated by recent projects in Vietnam, including the Bitexco Financial Tower and Vietin bank Tower.

J.M. Aribert , Cr. Campian & V. Pacurar,(2021) they examined the seismic behaviour of fully encased steel-concrete composite columns using cyclic and monotonic tests on twelve specimens. Results indicate that concrete damage causes stiffness and strength to degrade quickly under cyclic loading, but that the material has a notable capacity for energy dissipation. Modified stiffness relations in analytical models better matched experimental data than those predicted by Eurocode 4. A seismic behaviour factor (q) of roughly 2.8 was calculated using an energy-based method, indicating good ductility for seismic design applications.

Dr. D. R. Panchal(2014) stated in this paper, VB.NET-based software for designing composite steel-concrete slabs, beams, and columns is presented in a simplified computational manner. The software incorporates full and partial shear connections, incorporates design checks from IS and Eurocode standards, and has a database of standard steel sections for automated selection. The study highlights that composite construction is perfect for high-rise structures because it is strong, lightweight, and quick to construct. Without requiring extensive experimental testing, the developed design tool allows for practical, economical analysis.

Russell Q. Bridge (2008) stated in this paper that he used Eurocode 4 and Australian Standards (AS 3600, AS 4100) to compare design philosophies for reinforced concrete, steel, and composite columns. It emphasises how the approaches are similar and fundamentally different, particularly in how they handle stability, slenderness, and second-order effects. The study demonstrates that, when used appropriately, steel- and concrete-based methods produce comparable outcomes despite having different theoretical foundations. Bridge comes to the conclusion that designing composite columns can be made more cost-effective and efficient by comprehending the design philosophy of each material.

Dinesh Kumar R, Manu S E, Saroj Kumar Yadav, Vetturaya Sudharsanan R. (2022) They uses both experimental and finite element methods (ABAQUS) to analyse the behaviour of steel composite columns that are concrete-encased and concrete-infilled under cyclic and monotonic loading. The study contrasts how strength, ductility, and post-buckling behaviour are affected by size, shape, and material configuration. According to the results, composite columns perform better than traditional reinforced concrete columns because they have greater stiffness, load capacity, and energy dissipation. The results demonstrate their appropriateness for high-load structural applications and seismic resistance.

P. Sasikumar, stated that, this study examines the buckling behaviour of fully encased composite columns (FECC) constructed with 80 MPa high-strength concrete through experimental, analytical, numerical, and statistical analyses. Three column specimens with different cross-sections were examined and compared to AISC 360 and Eurocode 4 predictions; the Eurocode results demonstrated a stronger correlation. The experimental results were validated by finite element analysis, which showed that buckling resistance could be accurately predicted. According to the study's findings, EC4 improves FECC design accuracy, and statistical validation backs up the increases in high-strength concrete composites' strength and stiffness.

Cao et al. stated that, this study examines the buckling behaviour of fully encased composite columns (FECC) constructed with 80 MPa high-strength concrete using experimental, analytical, numerical, and statistical analyses. Testing and comparison of three column specimens with different cross-sections against AISC 360 and Eurocode 4 predictions revealed a stronger correlation with Eurocode results. Reliable prediction of buckling resistance was demonstrated by finite element analysis, which validated the experimental results. The study comes to the conclusion that statistical validation backs up the strength and stiffness gains of high-strength concrete composites, and that EC4 offers improved accuracy for FECC design.

Hyeon-Jong Hwang mentioned that, in contrast to traditional concrete-encased steel (CES) columns, the Prefabricated Steel-Reinforced Concrete (PSRC) composite column, which is introduced in this chapter, uses steel angles at the corners to improve flexural performance and construction efficiency. PSRC columns provide better confinement, increased axial and flexural strength, and a quicker, safer installation because they are prefabricated, according to experimental and analytical research. However, ductility under cyclic loading may be impacted by problems like local buckling and cover concrete spalling. All things considered, PSRC columns show great promise for industrial and high-rise applications needing quick construction and high strength.

Xianhui Li, Yao Yin, Tieying Li, Xiang Zhu, and Rui Wang this study examines the buckling behaviour of fully encased composite columns (FECC) constructed with 80 MPa high-strength concrete using finite element modelling in LS-DYNA and experimental data, this study examines the lateral impact behaviour of reinforced concrete (RC) and different steel-concrete composite columns. According to the results, composite columns perform noticeably better than RC columns in terms of energy absorption, deformation control, and impact resistance. Solid concrete-filled double steel tube (S-DS) columns performed the best among the tested types, exhibiting lower mid-span deflection and higher plateau force. The study offers insightful information for impact-resistant composite structure design and optimisation.

Ali M. Memari and Mohammad, he examined in this chapter the use of structural fuse elements to regulate the interaction between masonry infill walls and structural frames under seismic loading. The nonlinear behaviour of infill-frame systems with fuse elements is simulated by finite element models created in ANSYS and verified against experimental data. According to the results, infill walls with fuses can provide stiffness during minor events and safely disengage under major loads to prevent wall and frame damage. The study recommends additional development for practical applications and concludes that the fuse concept is practical and effective for improving seismic performance.

Amarjeet Singh, discussed in recent studies emphasize the growing importance of composite structures in civil engineering due to their high strength-to-weight ratio, corrosion resistance, and durability. Nie et al. (2019) discussed innovations in steel-concrete composite systems, such as uplift-restricted and slip-permitted connectors and steel plate concrete composites, highlighting their efficiency and sustainability. Sharma et al. These studies collectively indicate that composite structures provide superior mechanical performance, design flexibility, and cost-effectiveness compared to traditional materials. However, they also require specialized analysis and design approaches to ensure safety and long-term performance in diverse civil engineering applications.

R.Thirumalai, S.Gobinath, K.S.Deva Prasanth, P.Gowtham, S.Gowtham Kumar examined experimentally in this work about the behaviour of concrete-filled steel tubular (CFT) columns under combined axial prestress and lateral loading. The performance of circular and square columns was compared using sixteen specimens with different shapes, thicknesses, and reinforcement. The findings demonstrated that, in comparison to square CFT columns, circular ones had a greater load-bearing capacity, less deflection, and delayed buckling. According to the study's findings, external prestressing and reinforcement improve stiffness and resistance to lateral loads.

III. CONCLUSION

- Combining both materials improves strength, stiffness, and overall performance, according to the design and analysis of composite steel-concrete structures.
- Composite sections make effective use of materials because concrete resists compression and steel resists tension, resulting in a balanced distribution of stress.
- Concrete's stiffness and steel's ductility allow for efficient control of deflection and vibration levels.
- Composite structures are more durable and fire resistant than traditional steel structures.
- The system is perfect for time-sensitive infrastructure projects because it facilitates quicker construction and simpler handling.
- The structure's self-weight is greatly decreased, which results in smaller foundation sizes and cheaper building expenses.
- The study attests to the fact that composite design achieves material economy, leading to sustainable and economical construction.

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