

A Review on the Torsional Behavior of Lightweight Concrete-Filled Steel Tubular Composite Members

Maryam Qassim Mohammed*

Civil Engineering Department, Engineering College, Al-Iraqia Science University, Baghdad, Iraq

* **Corresponding Author:** maryamqassim@baghdadcollege.edu.iq

Abstract: Based on prior published experimental, numerical, and analytical research, this review paper offers a thorough examination of the torsional behavior of lightweight concrete-filled steel tubular (CFST) composite elements. Using material properties, cross-sectional configuration, and interaction between steel and concrete components as key variables, this study aims to systematically evaluate the structural performance of composite systems under torsional loading. The available literature generally addresses three main aspects, including the behavior of hollow steel sections filled with lightweight concrete, the response of composite beams under combined bending and torsion, and the stress distribution as well as failure mechanisms under torsional loads. From reviewing these studies, it can be observed that the interaction between steel and concrete plays a significant role in improving the overall structural performance. Greater strength, tougher, ductile, and better able to eject energy are only a handful of ways this enhancement appears. In addition, the concrete core is mainly liable for transmitting compressive forces and enhancing stability, and the steel tube enclosing the object and aiding it in its ability to withstand tensile stresses. However, most previous studies have mainly focused on normal-weight concrete, with greater attention given to axial and flexural behavior. In contrast, pure torsional behavior has not been sufficiently investigated. Although lightweight concrete offers important advantages, such as reducing the self-weight of the structure and improving efficiency, its use in steel tube systems is still limited in the literature. Another point that can be noticed is the lack of experimental work compared to numerical studies. Because of this, researchers' analytical models tend to be less easy to verify. In addition, while there have been a few of studies examining into the ways that bending and torsion interact, very few have taken lightweight to account. composite elements filled with concrete. It is also clear that there is no unified design approach or well-established guidelines that specifically address torsional behavior in lightweight CFST members. Based on this, it can be said that the understanding of torsional performance in such systems is still incomplete. Therefore, further experimental and analytical investigations are required to develop more reliable prediction models and to improve design methods, especially for practical engineering applications that involve complex loading conditions.

Keywords: Lightweight concrete, Concrete-filled steel tubes (CFST), Steel tubular members, Composite structures, Torsional behaviours, Pure torsion, Torque resistance.

1. Introduction

One of the most effective structural solutions in contemporary engineering is composite steel tube members, which combine the benefits of steel and concrete [1][2]. The combination of concrete and steel in composite systems provides a clear advantage in structural performance. Concrete mainly contributes through its compressive strength and stability, while steel offers high tensile strength and ductility. Because of this interaction, concrete-filled steel tubular (CFST) members have received considerable attention in recent years. These members are well known for their ability to absorb energy, as well as their improved stiffness and load-carrying capacity [2][3]. They are therefore widely used in practical engineering applications such as bridges, infrastructure systems, and high-rise buildings [3][4]. Among different loading conditions, torsion is considered one of the most critical factors affecting structural behavior and safety. Because the structural member twists, complicated stress distributions may emerge[5][6].It is possible to disregard torsional effects, particularly in complicated loading scenarios or with irregular geometries, even though many structural parts are mainly designed to resist axial and flexural loads[6]. Because the steel tube interacts with the concrete core, the torsional behavior of composite elements is relatively complex. When compared to more traditional structural parts, this interplay makes the reaction harder to achieve. More care must be made when CFST members employ lightweight concrete. It may alter the structure's stiffness and strength and reduce its total self-weight[7][8]. Lightweight composite members filled with concrete require additional research on their torsional behavior. This newly acquired study can enable us to construct improved designs and develop structural applications that are safer for use in real-world loading scenarios[3].

2. Methodology

The primary objective of this review is to analyze and evaluate previous research concerning torsional behavior in lightweight composite elements composed of concrete-filled steel tubular (CFST)[2][3]. A large body of literature has focused on torsion in composite structural systems; this study aims to synthesize, categorize, and assess that literature. Some of the most critical variables influencing torsional stiffness and strength are the properties of lightweight concrete, the thickness of the steel tube, and the cross-sectional shape. In addition, the purpose of this review is to highlight the discrepancies and missing data in previous research, especially when it comes to lightweight concrete that has been tested under pure torsional loading. The main purpose of the study is to compare different results and approaches in order to shed light on the behavior of composite members that are exposed to torsion. This effort also intends to point the way in potential future research directions and highlight significant knowledge gaps that must be addressed. The long-term objective is to improve the structural performance of lightweight composite materials used in engineering and to help create more trustworthy design methodologies [2].

3. Stress and Failure Analyses of Members Subjected to Torsion

3.1 Behavior of Hollow-Core Steel-Concrete-Steel Columns Subjected to Torsion Loading

The reaction of HC-SCS columns under pure torsional loading was the subject of a study by Anumolu et al. (2016)[9], which targeted to enhance knowledge of their torsional behavior. The columns are built from a composite material that has a hollow interior, where a concrete shell resides within a steel tube structure. This configuration not only reduces total body weight, but it also offers great strength and rigidity. There were six specimens tested experimentally in the study, all subjected to torsional loading. Numerical simulations were conducted using LS-DYNA finite element models to further reproduce the structural reaction. With an average disparity of 4.8%, the results from the numerical and experimental methods were in accord, which supports the proposed model technique. Based on the findings, a variety of aesthetic aspects of creativity significantly affected creative torsional capacity. When it comes to stress confinement and distribution, the concrete shell's thickness is crucial. The whole structural behavior was also shown to be significantly affected by the steel tubes' thickness and stiffness. The tested columns showed higher torsional resistance, delayed buckling, and increased ductility when compared to traditional methods. A simplified analytical model was also introduced for predicting torsional strength, and its results were consistent with the experimental data. However, some limitations can still be identified. The experimental program may have undervalued the heterogeneity in structural behavior due to the minimal number of specimens used. The research also did not take advantage of any except normal-weight concrete; it didn't are limited to older lightweight composite technologies which do not incorporate lightweight concrete applications. There was also a lack of research into the bond interaction between concrete and steel, as well as combined loading circumstances. Therefore, to evaluate the suggested models across a broader range of parameters, more research is required. Research lightweight concrete-filled systems subjected to torsional and combination loading scenarios might also yield valuable insights.

4. *Hollow Steel Section Members Filled with Lightweight Concrete*

4.1 Flexural Behaviour of Concrete-Filled Steel Hollow Section Beams

Research by Soundararajan and Shanmugasundaram[10], "Flexural Behaviour of Concrete-Filled Steel Hollow Section Beams," examined how steel hollow sections behaved under bending loads when filled with concrete. The primary goal the goal was to learn how concrete and steel work together to increase stiffness, flexural capacity, and structural efficiency. The basic idea behind this composite member type is that the concrete core increases compressive strength and aids in preventing local buckling of the steel walls. At the same time, the steel section provides confinement and resists tensile stresses[18]. To investigate this behavior, an experimental program was carried out using beam specimens with different configurations of hollow steel sections. A pure flexural response occurred by testing these specimens under four-point bending

circumstances. Steel section geometry, concrete filling, and their interplay were among all of the variables considered into account in the research. substances during transporting. The structural behavior was evaluated by carefully documenting the load-deflection response. Thorough documentation of the load-deflection behavior allowed for evaluation of rigidity, ductility, and maximum load capacity. According to the findings, flexural strength is much strengthened when concrete is used to fill hollow steel parts as opposed to leaving them empty. Greater stiffness, less mid-span deflection, and improved resistance to local buckling were additionally properties of the composite beams. Because of the enhanced ductile behavior and increased energy absorption brought about by the concrete, these members are well-suited for uses where deformation control is crucial[11]. The report went on to say that composite action between concrete and steel improves overall performance by distributing stresses more efficiently across the segment. Despite these positive outcomes, there are a number of caveats to be aware of. Because of its lower self-weight and seismic advantages, lightweight concrete is finding more and more applications in current structural systems; nevertheless, this study primarily focused on normal-weight concrete and did not include it. In addition, the study only took flexural behavior into account, not the more typical torsional impacts or combination loading events the actual structural parts face. There was also limited attention given to the bond interaction between steel and concrete, which can affect long-term behavior. A full-scale analytical model was also not created for use in the design process under various loading situations. Research on the flexural behavior of steel hollow sections filled with concrete is helpful, however the study falls low when it comes to more complicated structural situations.. In particular, there is still a lack of research on lightweight concrete and torsional loading. Therefore, the present research aims to address this gap by focusing on the torsional behavior of lightweight concrete-filled steel tube composite members [12].

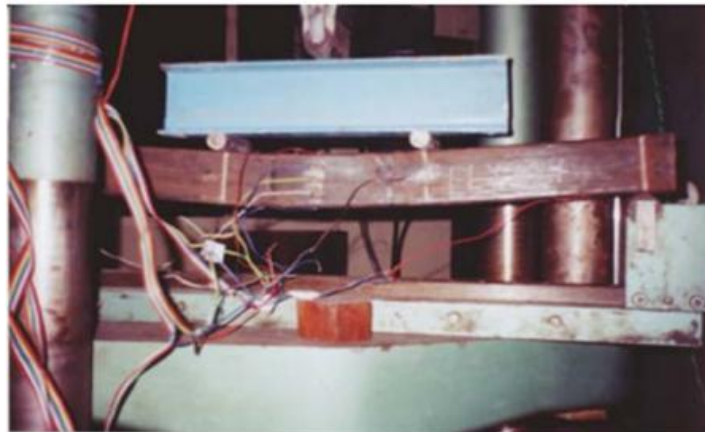


Figure 1. Testing Arrangement of Beam Specimen (**Soundararajan and Shanmugasundaram, 2008**).

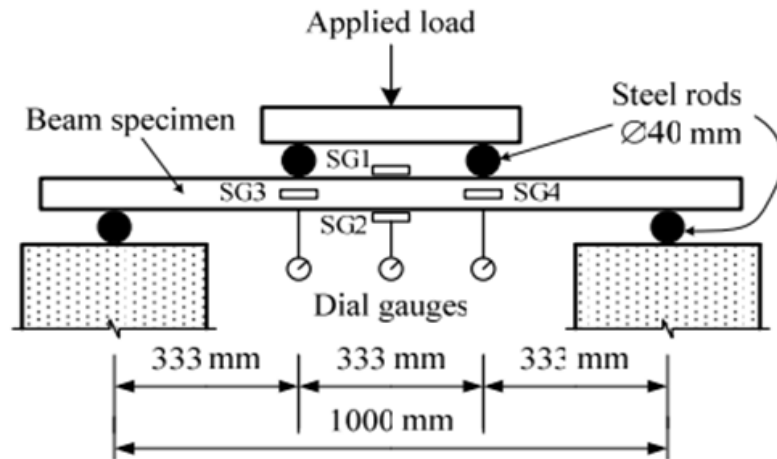


Figure 2. Details of Loading System for Beam Specimens (Soundararajan and Shanmugasundaram, 2008).

4.2 Ultimate Behaviour of Lightweight High Strength Concrete Filled Steel Tube

How well it performed structurally when filled with lightweight high-strength concrete under ultimate loading conditions[13]. Composite materials, which include lightweight concrete and steel tubes, were the main objective of this investigation due to their load-carrying capacity, failure mechanisms, and interplay. Lightweight concrete has the ability to reduce structural sections' self-weight while keeping them stiff and strong enough to meet engineering goals, according to the study. Experimental specimens were loaded up to failure with axial loads using concrete-filled steel tubes (CFSTs) containing lightweight high-strength concrete. Important specs that were investigated in the study included concrete strength, composite interaction quantity, and steel tube confinement. Impairment to ductility, ultimate load capacity[13][15], stiffness, and stiffness was evaluated using recording the load-deformation response. The use of lightweight high-strength concrete considerably decreases the structural parts' self-weight without compromising structural performance, according to the research. The post-peak behavior and post-cracking start were enhanced as a result of the steel tube's higher strength and ductility through enclosing the concrete core. The research shows that the members' ability to absorb energy and their ultimate load capacity are both greatly improved when steel and lightweight concrete are used together. The composite system's excellent structural efficiency was preserved by the confinement effect of the steel tube, even though the density was reduced. The study neglected to consider axial compressive behavior, which is a more significant loading situation, and instead focused on torsion and combined stress. The study also failed to offer a universal framework for analysis or design that could account for various building configurations. We also neglected to solve the specifics of the interaction's behavior under more nuanced stress scenarios. With the constraint that it only examines axial loading, this study does illustrate that steel tube systems employing lightweight high-strength concrete are conceivable. Not having access to torsional behavior analysis is a big negative, especially for constructions that are vulnerable to torsion. Due to the lack of investigation into combined loading conditions and long-term performance, the results will also not be applicable to practical engineering problems. In light of the review's

objective, this work addresses a substantial knowledge gap by investigating the response of lightweight concrete-filled steel tubular members to torsional loads[15].

4.3 Experimental Behaviour of Concrete-Filled Steel Tube Composite Beams

The writers of this piece are Farhan Khawla and Shahled Shahal. The study named "Experimental Behaviour of Concrete-Filled Steel Tube Composite" investigated the load-carrying capacity, stiffness, and failure modes of CFST composite beams[19]. "Beams" subjected to experimental loads. Beam members' enhanced structural performance was the primary focus of the study, which examined the composite action of steel tube and concrete filling. Parameters' effects on CFST beams' flexural response and general behavior were also investigated. As part of the experiment, many beam specimens were loaded with flexural stresses. Using a four-point bending configuration, the region of the constant moment was computed. To study how changes in geometrical parameters and material combinations affected structural reactivity, the specimens were subjected to a battery of experiments. The test method meticulously recorded the material's rigidity, longevity, and response to load deflection. operating at full capacity when loaded. Filling steel tubes with concrete increases their flexural strength compared to leaving the tubes empty. This enhancement is made possible by the synergy between the steel and concrete. The concrete core offers tensile resistance in this configuration, while the steel tube transfers compressive loads and confines the material. The composite beam strengthened, local buckling was reduced, and loading stability was enhanced as a consequence of this interaction. In comparison to standard steel beams, they exhibited much better ductility and energy absorption efficiency. Nonetheless, the research has a number of flaws. Because it was solely concerned with flexural behaviour, it ignored torsion and coupled loads, two common loading scenarios in real-world structural applications. Even though lightweight concrete is becoming more important due to its reduced self-weight and seismic advantages, normal-weight concrete was still extensively utilised. Even though the research overlooks more complex structural explanations, the experimental insights into CFST beams undergoing bending are priceless. Because structural components are often finalised in practice, the absence of torsional analysis is very worrisome. The results do not directly address lightweight composite systems; thus, more research is needed in this area as well [18].

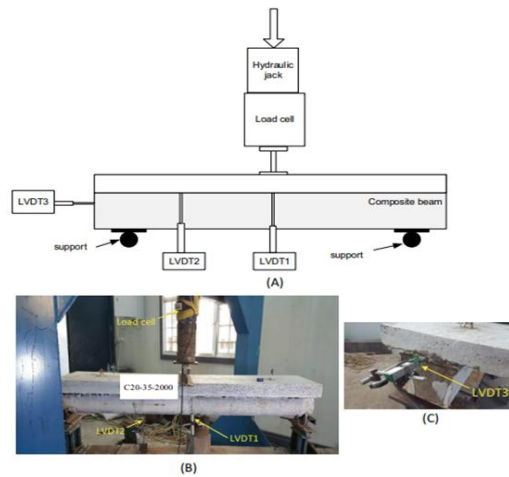


Figure 3. Scheme of Universal Test Machine and Measurement Settings (Shallal and Farhan, 2020)

5. Composite Beams Under Torsion

5.1 Experimental Study on Straight Composite Beams Subjected to Combined Flexural and Torsion

“E.L. Tan[] and B. Uy1” The study titled “*Experimental Study on Straight Composite Beams Subjected to Combined Flexural and Torsion*” investigated the behavior of straight composite beams under the simultaneous action of bending and torsion[16]. Study goals includes elucidating the relationship between bending and torsion and its effects on structural performance parameters as stiffness, strength, and failure modes. Steel composite beam systems were a major emphasis. is mixed with concrete, bringing out the best in the mutually beneficial impact that increases output. An experimental program was devised that incorporated flexural and torsional loads on several beam specimens. Testing conditions, including simultaneous bending and twisting moments, may be replicated by to the well-thought-out design of the test apparatus. The loading ratio, material qualities, and cross-sectional design were among the many things that were noted. The structural reaction was then evaluated by looking for symptoms of load-deformation behavior, decreased stiffness, fracture development, and identified failure modes. According to the findings, beam behavior is significantly affected by the connection between bending and torsion. For example, it was found that torsion reduces flexural capacity and increases cracking and localized damage speed. The composite action of concrete and steel also helped distribute loads more evenly than non-composite structures. Results revealed enhanced energy dissipation, ductility, and failure delay in experiments performed under combined stress settings. The primary function of steel is to withstand stresses, whereas concrete provides additional stability and compressive strength. However, those benefits could not be realized since the study's focus was too narrow. It merely only into account straight composite beams, completely disregarding differences in materials and more complicated geometries, such as lightweight concrete. Furthermore, we focused on combined flexural-torsional loads rather than isolating torsional behavior. As a result, the response when subjected to torsion becomes more complex and challenging to understand. The findings are not

directly applicable to practical engineering design because of weak analytical models and design formulations. From a critical point of view, the study provides useful insight into the behavior of composite beams under combined loading. However, it does not address the torsional performance of lightweight concrete-filled steel tubular members, which represents the main focus of the present review. Consequently, this study fills a significant knowledge vacuum regarding the effects of lightweight concrete on torsional resistance in composite systems, particularly when subjected to pure torsional loading [18].

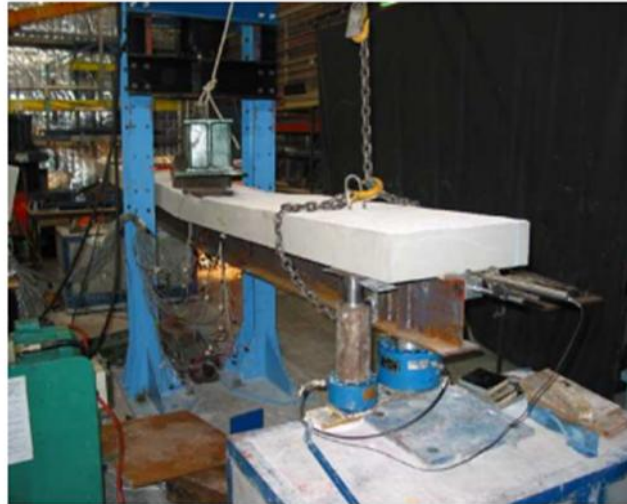


Figure 4. Cross-Sectional View of Test Specimen with FSC, CBF-1(Uy and Tan 2009).

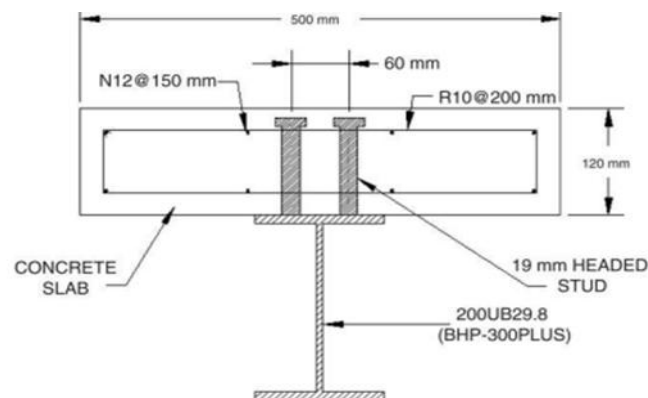
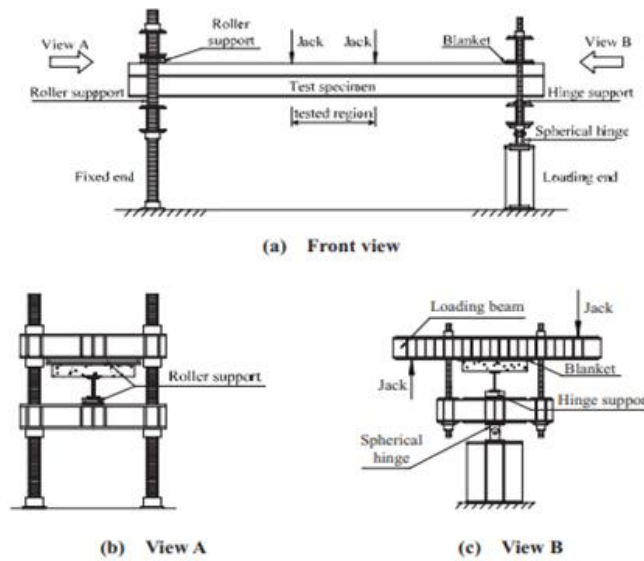


Figure 5. Composite Steel-Concrete Beam Experimental Set-Up (Uy and Tan 2009).

5.2 Performance of Steel-Concrete Composite Beams Under Combined Bending and Torsion

The Research on Steel-Concrete Composite Beams' Performance in Concurrent A study conducted by Jianguo Nie, Liang Tang, and C. S. Cai examined the behavior of steel-concrete composite beams during the period that they loaded with bending and torsional stresses[17] at the same time. The primary goal was to learn how stiffness, load-carrying capacity, and failure processes vary by flexure and torsion interactions. The study emphasizes that combined loading conditions are closer to real structural behavior in engineering applications compared to isolated bending or torsion. For this reason, analysing such interaction is important for a more realistic understanding of structural An experimental program was carried out using steel-concrete composite beam specimens. The beams were tested under controlled conditions where bending and torsion were applied at the same time. Different loading ratios were considered to observe their effect on the overall structural response. Several parameters were taken into account during the study, including material properties, cross-sectional geometry, and the level of composite interaction between steel and concrete [17]. By analysing the beams' responses to load deformation, stiffness loss, fracture advancement, and final failure modes, we were able to assess their performance. Flexural and torsion performance were found to be directly correlated, according to the findings. When combined, they reduced the material's strength and accelerated the cracking process compared to situations where bending alone was adequate. Whatever the reason, using concrete and steel together made the loads more evenly distributed and, in many cases, stopped the building from collapsing completely. Ductility and energy absorption were enhanced by combining the compressive strength of concrete with the tensile resistance and confinement of steel. Despite its many flaws, the study did make a few good points. The effects of lightweight concrete on composite beam behaviour under combined stresses were neglected due to the primary emphasis on normal-weight concrete. There was a lack of comprehensive analytical or numerical models produced due to the exclusive focus on experimental analysis. Because the behaviour wasn't totally isolated, it's possible that individuals who leaned more towards one side or the other weren't included in the results. The research, however limited in scope, does provide light on bent and torsionally coupled steel-concrete composite beams. Lightweight steel tube members exposed to concrete loading under complicated loading conditions have received very little attention in the literature. In order to evaluate the beams' performance, we tracked their stress-deformation response, stiffness decrease, fracture propagation, and final failure modes. The results show that flexural strength is greatly affected by torsional stiffness. Torsion, in contrast to straight bending, increases the rate of crack formation and reduces the load-carrying capacity. Steel and concrete, when combined, improved load distribution and, in certain cases, delayed failure. Contained energy absorption and ductility were enhanced in mixed loading situations by the synergy of compressive strength of concrete and tensile resistance of steel. However, you shouldn't let the study's limitations fool you. The effects of lightweight concrete on the behaviour of composite beams under combined loads were not examined in the study because its primary emphasis was on normal-weight concrete. In addition, experimental analysis was the only tool used in the study

process; no generalisable analytical or numerical models were created. Because pure torsional behaviour was not isolated, the study has limited direct application to structural elements dominated by torsion. Despite their growing importance in contemporary lightweight construction, lightweight concrete-filled steel tube constructions are not utilized in the study. implementation in building. The study only deals with normal-weight concrete, but it does give useful information about how steel-concrete composite beams react to bending and twisting at the same time. This highlights a gap in the existing literature that needs to be addressed. on the topic of how lightweight concrete affects the torsional resistance of composite elements, particularly if subjected to



complicated loading scenarios [6].

Figure 6. Schematic of Test Setup (Cai, Tang and Nie, 2009).

6. Overall Discussion

Taken as a whole, the research that were evaluated show how torsional loading greatly affects the structural behavior of composite elements, especially steel-concrete systems. Torsion, whether alone or in conjunction with bending, is clearly an important factor in controlling stress distribution, cracking patterns, and the processes of failure in the end. Composite According to the literature, the interaction between concrete and steel generally improves the structural performance compared to non-composite systems, particularly in terms of ductility, stiffness, and load-carrying capacity. Experimental comparisons between hollow steel sections and concrete-filled steel tubular members have shown that the steel tube confinement contributes to increased strength and helps delay local buckling. At the same time, the concrete core mainly plays a role in providing compressive resistance and enhancing energy absorption. However, most of the existing studies are still based on normal-weight concrete and tend to focus on flexural or axial behavior, while torsional effects have received much less attention. Studies on composite beams subjected to combined bending and torsion also indicate that torsion can reduce flexural capacity and accelerate the development of damage in structural members. Composite interaction, however, increased ductility and structural stability under complicated loading situations by attenuating some of these effects. As an alternate material system, these trials fail to adequately analyze lightweight concrete or isolated pure torsion situations. On the other hand, torsional movements might speed up damage development and significantly decrease flexural capability, according to the research. studied composite beams' responses to simultaneous bending and twisting Although composite interaction mitigated some of these effects, it enhanced ductility and structural stability in complex loading scenarios. Such analyses scarcely really explored a surface of lightweight concrete or isolated pure torsion scenarios as potential different material systems.

7. Research Gaps

Despite several research studying the behavior of steel-concrete composite elements under different load conditions, there are still notable gaps in our knowledge. Lightweight concrete proved promise in enhancing help with reducing the self-weight of composite tube structures and improve seismic performance. However, most of the existing studies still focus mainly on normal-weight concrete. Another important point is that torsion, although it plays a significant role in many structural applications, has not been widely studied. In fact, the majority of research tends to concentrate on axial or flexural behavior, while pure torsional loading is often neglected. In addition, the development of analytical models is still limited, mainly because there is a lack of comprehensive experimental work compared to the large number of numerical studies available in the literature. This makes it difficult to fully validate existing theoretical approaches. Moreover, coupled effects such as bending–torsion interaction have not been sufficiently investigated for systems using lightweight concrete. Most available studies deal with individual loading cases rather than combined conditions. At present, there are no well-established design guidelines or predictive models specifically for lightweight concrete-filled steel tubular members subjected to torsional loading. This

suggests that, from a design practice standpoint, the topic is far from finished. To address this information gap, further studies on the torsional behavior of lightweight composite components are needed. Design approaches that are more practical and dependable could be created with the help of research like this.

8. Conclusion

The torsional behavior of lightweight composite members made of concrete-filled steel tubes (CFSTs) has been studied experimentally and numerically. The primary results and a summary of the relevant literature are presented in this study. Research has demonstrated that steel-concrete composite-reinforced structures have superior performance in many loading scenarios, including those involving bending and torsion stresses acting simultaneously. The concrete tubes in which mostly resist loads, while the steel tubes absorb energy. The ductility, stiffness, and overall strength of the steel tube are all improved by its constrained design. The majority of studies have focused on regular-weight concrete, although lightweight concrete alternatives have gotten less attention. Similarly, torsional reactivity alone has received very less focus compared to axial and flexural behavior. When it comes to the torsional behavior of lightweight CFST members, there is a clear dearth of comprehensive testing procedures and design models. So far, this means that our knowledge of their torsional performance is incomplete. To further understand the torsional behavior of lightweight composite systems and to promote more reliable design approaches, additional analytical and experimental study is still necessary. Their utility in modern structural engineering would thus be amplified. Lightweight concrete-filled steel tubular members subjected to torsional loading still necessitate further investigation. This would help in developing more reliable prediction models and design guidelines that properly account for torsional effects.

References

- [1] L. H. Han, *Concrete-filled steel tubular structures: Behavior and design*, CRC Press, 2016.
- [2] Z. Tao, L. H. Han, and X. L. Zhao, "Behaviour of concrete-filled steel tubular members under different loading conditions," *Journal of Constructional Steel Research*, vol. 60, no. 10, pp. 1547–1565, 2004.
- [3] J. Y. R. Liew, M. X. Xiong, and D. X. Xiong, "Design of concrete-filled steel tubular members: A review," *Journal of Constructional Steel Research*, vol. 112, pp. 1–18, 2015.
- [4] B. Uy, "Strength of short concrete-filled steel box columns incorporating local buckling," *Journal of Structural Engineering*, vol. 127, no. 11, pp. 1297–1304, 2001.
- [5] X. L. Zhao and L. H. Han, "Torsional behaviour of concrete-filled steel tubular members," *Thin-Walled Structures*, vol. 39, no. 2, pp. 147–160, 2001.
- [6] M. A. Bradford and B. Uy, "Torsion of composite steel–concrete members," *Engineering Structures*, vol. 19, no. 7, pp. 567–573, 1997.
- [7] H. B. Ge and T. Usami, "Strength of concrete-filled thin-walled steel box columns using lightweight concrete," *Journal of Structural Engineering*, vol. 118, no. 11, pp. 3036–3054, 1992.

- [8] K. Sakino, H. Nakahara, S. Morino, and I. Nishiyama, "Behavior of centrally loaded concrete-filled steel-tube short columns," *Journal of Structural Engineering*, vol. 130, no. 2, pp. 180–188, 2004.
- [9] S. Anumolu, A. Kumar, and K. M. Rao, "Behavior of hollow-core steel–concrete–steel composite columns under torsional loading," *Journal of Constructional Steel Research*, 2016.
- [10] A. Soundararajan and K. Shanmugasundaram, "Flexural behaviour of concrete-filled steel hollow section beams," *Journal of Constructional Steel Research*, vol. 64, no. 7–8, pp. 718–725, 2008.
- [11] F. Ding, L. Wang, and Z. Yu, "Flexural performance of concrete-filled steel tubular beams: Experimental and numerical investigation," *Engineering Structures*, 2020.
- [12] Z. Chen, Y. Zhang, and D. Li, "Mechanical behavior of concrete-filled steel tubular beams under combined loading," *Thin-Walled Structures*, 2021.
- [13] Z. Yu and J. G. Teng, "Behaviour of concrete-filled steel tubular columns with lightweight concrete under axial compression," *Journal of Constructional Steel Research*, vol. 67, no. 3, pp. 476–490, 2011.
- [14] L. H. Han, W. Li, and R. Bjorhovde, "Developments and advanced applications of concrete-filled steel tubular structures," *Journal of Constructional Steel Research*, 2019.
- [15] Q. Wang and Z. Tao, "Structural performance of lightweight concrete-filled steel tubular columns under compression," *Engineering Structures*, 2020.
- [16] E. L. Tan and B. Uy, "Experimental study on straight composite beams subjected to combined flexural and torsion," *Journal of Constructional Steel Research*, 2007.
- [17] J. Nie, L. Tang, and C. S. Cai, "Behaviour of steel–concrete composite beams under combined bending and torsion," *Engineering Structures*, 2007.
- [18] J. Y. R. Liew, M. X. Xiong, and D. X. Xiong, "Behaviour of concrete-filled steel tubular members under combined loading actions," *Journal of Constructional Steel Research*, 2018.
- [19] F. Khawla and S. Shahal, "Experimental Behaviour of Concrete-Filled Steel Tube Composite Beams," *Journal of Structural Engineering / Constructional Steel Research*, n.d.

