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ORIGINAL ARTICLE

Experimental Investigation on Flexural Behaviour of Encased Cold Formed Steel Section in Reinforced Concrete Beams

H. Thanya Gayathri[1]*, **R. Baskar**[2], **N. Pannirselvam**[3]

1 Research Scholar, Department of Structural Engineering, Annamalai University, Tamil Nadu, India
2 Professor, Department of Structural Engineering, Annamalai University, Tamil Nadu, India
3 Associate Professor, Department of Civil Engineering, SRM Institute of Science and Technology, Tamil Nadu, India

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* **Corresponding author**.

thanyayagamur@gmail.com

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Abstract

Objectives: This research investigates flexural behaviour by comparing the experimental findings of two sample specimens: encased Cold Formed Steel (CFS) concrete beams and conventional reinforced concrete beams. Understanding the failure modes seen in encased CFS is critical for developing a safe and efficient composite system. **Methods:** The flexural behaviour of CFS encased in typical concrete beams was assessed using Four Point Bending Test. Compressive strength, flexural strength, deflection, stiffness, failure modes, load-carrying capacity, and structural performance are determined by the conventional testing methods. Crack patterns, load-deflection response, and failure mechanisms are among the observations made during the testing process. **Findings:** According to the experimental findings, the encased CFS beam's yield load and ultimate load are 45.32% greater than those of the reinforced concrete beam. Likewise, the encased CFS beam's deflection at yield and ultimate load is 17.73% and 14.10% lower than that of the traditional reinforced concrete beam, respectively. **Novelty:** Although the idea of encased steel concrete composite is not new, the use of CFS sections in concrete to improve flexural performance is a new application. It demonstrates a creative and promising method in the Civil Engineering sector.

Keywords: Cold Formed Steel; Flexural behaviour; Load-deflection; Encased beam; Stiffness

1 Introduction

Modern architecture and structural engineering frequently use CFS, an affordable and widely accepted building material. Thin steel sheets are pressed at room temperature to create CFS. CFS section is encased inside the beam and acts as a homogenous material. It increases strength, flexibility, and ease of fabrication. The construction industry has been demanding lightweight construction material that are easy to transport and allow for more design flexibility in recent years, one such material is CFS sections. Encased steel composite beams were found to be more than 40% to 50% higher than the bare steel beam section in a study by Md. Imran Kabir(1). The flexural behaviour of CFS composite beams with rectangular box geometry and various packing materials was examined by A.R. Dar. According to the data, cardboard and wood performed substantially better than PVC packing. Additionally, it prevents distortional buckling, which improves performance(2). Samadhan G. Morkhade conducted research on corrugated steel beams with and without apertures. According to the investigation, the ultimate load carrying capability of the beam with corrugated web increased by 18%(3). Ten specimens were examined by Xuhong Zhou to determine the flexural behaviour of a novel kind of cold-formed U-shaped rebar. Large deformability, substantial plastic bending capacity, and improved integrity are among the results. A numerical analysis is recommended for additional validation, along with design advice. Predictions of bending capacity agree well with test findings(4).

The results of Ashraf A. Rayan's study on perforated CFS sections in lightweight concrete indicated a 30% increase in load capacity. Furthermore, better resistance to failure is eventually the result of decreased distortional buckling and lateral displacement. Additionally, they examined the flexural behaviour of CFS hollow tubular flanges and discovered that, when tested without encasement, there is a problem with local buckling(5). According to Divahar's research, perforated CFS sections have a 75% higher load carrying capability than hot rolled steel, which highlights their usefulness in contemporary design and construction. Additionally, under two-point loading, they evaluated encased beams with corrugations at 0°, 30°, and 45°. The findings demonstrated that the 30° and 45° corrugated beams were able to support more weight than the 0° corrugated beams(6). A common type of beam, consisting of encapsulated flat and perforated CFS beams, was examined by Ashraf A. Rayan. The strength and load capacity are greatly increased by perforated CFS. It is challenging to employ in real-world applications, though. For the flexural behaviour, it is enclosed by a cold-formed steel section beam that is flat and perforated. The flexural behaviour of the CFS was examined and compared using eight different position types. When compared to the traditional RC beam, it is discovered that the CFS beam in back-to-back position, both perforated and flat, exhibits noteworthy outcomes(7). Lin Cao chose a composite beam that was subjected to two-point loading and had a U-shaped CFS section outside of the concrete beam. According to their findings, HUCB has outstanding flexural performance and great ductility(8).

Liu investigated restrained prestressed beams that incorporated a U-shaped cold-formed steel (CFS) section on the exterior of the concrete beam. It has been discovered that CFS encasement limits lateral deformation and saves construction costs. Its ductility and load-bearing capabilities are enhanced when CFS is added to the outside(9). The behaviour of the encased perforated steel cold-formed column in lightweight concrete was examined by Omar M. Lotfy. The axial compression capacity improvement is affected by the lightweight concrete encasement in a range of 19.5 to 154.6%. The U-shaped CFS portion in the enclosed prestressed RC beam has been investigated. By using shear studs, ductility and load capacity have been increased by 5–10%. Under loading, the composite section improves structural performance by absorbing the stress from the concrete(10). Babu examined the flexural behaviour of CFS I beams with hollow tube flanges. The beams' load-bearing capability was raised by strengthening them with polymer cement and wood waste, and this was also verified against the Egyptian Code(11). Composite columns with perforated CFS sections were studied by H. Taufiq. According to the test results, the C sections did not buckle locally until they were almost ready to fail. To boost load carrying capability, numerous researchers attempted to jacket the CFS portion on the outside of the concrete beam(12).

Most of the literature focused on corrugated, perforated, and closed cold-formed steel (CFS) sections, highlighting their role in enhancing the performance of composite beams. CFS sections are widely used in the lightweight construction. Interaction between CFS load bearing RC elements is not well explored. Few studies analysing the buckling and axial performance of bare CFS but did not give much attention to the performance of the encased RC beams under flexural loading. Very few experimental analyses have been carried out to investigate the flexural performance of RC beams with embedded CFS profile.

This paper directly addresses the above issues through the following novel contributions: it investigates reinforced concrete (RC) beams encased with cold-formed steel (CFS) sections under flexural loading. A C-channel section with lips is used as the encasement, and the study examines its impact on crack patterns, load-deflection behavior, and failure modes.

The precise interaction between cold-formed steel and concrete is not as well understood as classic composite systems, such as reinforced concrete beams with integrated steel reinforcement. Understanding the structural behaviour of these enclosed CFS beams under bending, shear, and flexural loading—including the strength of the steel-concrete bond, long-term performance under service loads, and failure modes. The key contributions of this study include the investigation of the flexural behaviour of RC beams encased with CFS channel sections, demonstrating enhanced flexural strength and improved energy dissipation capacity. The CFS channel section with lips encased in the reinforced concrete beam has been studied in an effort to boost its load carrying capacity without posing many challenges during the encased concrete beams' casting process. The uniqueness of this study lies in the utilization of open CFS section within the RC beams for flexural applications, which is not previously examined

2 Methodology

2.1 Materials

Both conventional and encased CFS beams were bound together using ordinary Portland cement (OPC) of grade 53. River sand, which belongs to zone II and has a specific gravity of 2.65, was used as fine aggregate in this investigation. In both kinds of beams, coarse aggregate with a specific gravity of 2.74 is utilised. Concrete of grade M25 is used with the ratio of 1:1.7:2.9. The mix proportion of M25 grade concrete is given in the Table 1. HYSD bars of Fe 415 grade were used to reinforce both beam specimens. Together with the above components, CFS section with Poisson's ratio of 0.3, yield strength of 340 N/mm^2, ultimate strength of 455 N/mm^2 and modulus of elasticity of 2.07 x 10^5 N/mm^2. Physical properties of CFS section are given in the Table 2.

Table 1. Mix Proportion of M25 Grade Concrete

Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (l)	W/C Ratio
380	717	1170	190	0.5

Table 2. Physical Properties of CFS Section

Grade of CFS	Section	Breadth(b)	Depth(d)	Depth of Lip(dl)	Thickness(t)
Fe 340	C-Channel	60 mm	150 mm	25 mm	2.5 mm

2.2 Testing Methods

2.2.1. Compressive Strength Test

Conventional concrete specimens' compressive strength was determined using electro-hydraulic pressure servo testing equipment. The specimen (150 mm x 150 mm x 150 mm) was tested at a loading rate of 0.5 MPa/s. For each proportion of the HFRC combination, six specimens were tested—three on seven days and three on twenty-eight days—and the final experimental result was derived by averaging the test results.

2.2.2. Flexural Strength Test

The prism specimens were tested using a loading frame with the capacity of 100 kN. The specimens used were 150 x 150 x 500 mm. The test span was fixed as 400 mm. The results for each type of specimen were calculated using an average of six replication specimens—three on seven days and three on twenty-eight days.

2.2.3. Modulus of Elasticity Test

An axial compressive load was applied to the cylindrical specimens of size 150 mm diameter and 300 mm height, using a digital CTM with a 2000 kN capacity. A dial gauge with a minimum count of 0.01mm was used to observe deformations at intervals of 10kN until the maximum load was reached. To determine the modulus of elasticity, the initial tangent modulus—that is, the slope of the stress-strain curve generated from the origin—was determined. A total of six specimens were used to assess the M25 grade concrete modulus of elasticity.

2.2.4. Flexural Behaviour of Beams

To analyse the flexural characteristics of encased CFS concrete beam and conventional reinforced concrete beam. For the present study, three beams were cast for each mixture. Totally six number of beams were cast and tested in three sets such that two beams in each set. Figure 1**(a)** shows the reinforcement details of the CFS encased concrete beam, **(b)** shows the CFS channel section with lip, **(c)** shows the reinforcement details of the conventional concrete beam and **(d)** Elevation of the beam.

A four-point bending test under static load conditions was carried out. The length of the beams is measured and split into three equal sections, each of which has a length of L/3, before the beam specimen is placed into the loading frame. In order to determine the crack pattern, grid patterns are then drawn inside the beam's flexural area. The hinged and roller supports of the loading frame are positioned differently depending on the length of the beam specimen. The beam is then positioned above the loading frame. A two-point loading condition was used to determine the simply supported beams' load-bearing capacity. Figure 2 shows loading setup for the beam. Using a steel spreader (I-section) and a hydraulic jack with a 500kN capacity and a 0.83kN minimum count, the load is gradually imparted to the beam specimen. Dial gauges positioned beneath the load and

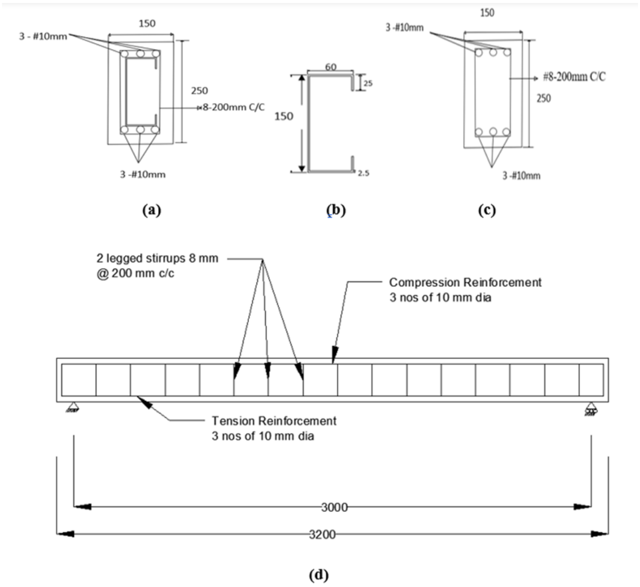


Fig 1. (a) Encased CFS beam Reinforcement detail (b) CFS Channel Section with lip (c) Conventional beam Reinforcement Detail (d) Elevation of the beam

mid-span with a least count of 0.01 were used to detect deflection for a 2.5kN load increment. The beam showed deflection and flexural cracks along its span as the applied load was gradually increased. Along with determining the failure mode for every test specimen, measurements of crack width and crack propagation were also documented. With a precision of 0.02 mm, the crack width was measured.

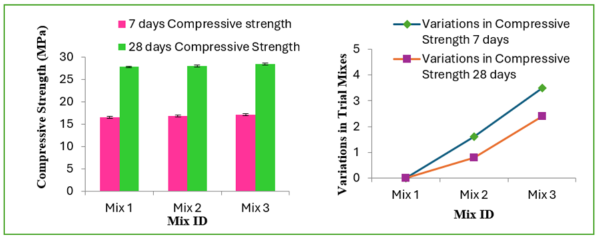
Fig 2. Loading Setup for the Beams

3 Results and Discussion

3.1 Compressive Strength

As shown in Figure 3, variations in the compressive strength at 7 days of the trial mixes of M25 grade concrete compared to the trial mix 1, mix 2 and mix 3 shows 1.61% and 3.49% variations in the compressive strength which is considered as a marginal deviation. Similarly at 28 days mix 2 and mix 3 shows variation of about 0.8% and 2.40% compared to the mix 1. The differences in the compressive strength fall within the expected range of experimental variations in the concrete hence considered it as negligible.

Neville found differences between ± 5% is not a significant problem in concrete due to its heterogeneity and testing procedure(13). He suggested that compressive strength variations below 5% are not statistically significant in most of the structural applications when the mix design lies within the quality control limits. Based on the above observations, variation in the trial mixes shows consistent and comparable across all the three mixes.

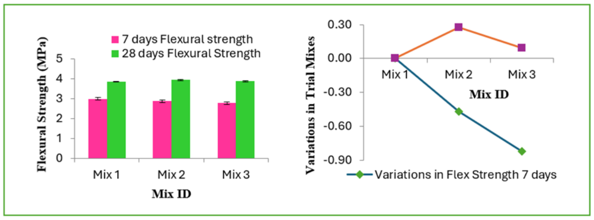


(a) Compressive Strength **(b) Variations in Compressive Strength**

Fig 3. Variations in the Compressive Strength of Trial Mixes

3.2 Flexural Strength

Figure 4 illustrates variations in the flexural strength at 7 days of the trial mixes of M25 grade concrete compared to the trial mixes 1, 2, and 3, which indicate 0.47% and 0.82% variations in the flexural strength, respectively, which is regarded a marginal deviation. Similarly, at 28 days, mix 2 and mix 3 vary by roughly 0.27% and 0.09%, respectively, compared to mix 1. The flexural strength variances are within the predicted range of experimental fluctuations in concrete; hence they are regarded inconsequential.



(a) Flexural Strength **(b) Variations in Flexural Strength**

Fig 4. Variations in the Flexural Strength of Trial Mixes

3.3 Modulus of Elasticity

The young's modulus values of trial mixes of M25 grade concrete are tabulated in the Table 3. The test results are also showing similar trend of the variation as compared to the compressive and flexural strength. 'E' value observed in the different trial mixes of grade M25 concrete. Variation in the modulus of elasticity of the trial mix 1, is showing variation of about 0.38% and 1.18% respectively compared to the Mix 2 and Mix 3.

Table 3. Modulus of Elasticity of M25 Grade Concrete

Sl No	Mix ID	Days	Modulus of Elasticity (GPa)
1	Mix 1	28	26.35
2	Mix 2	28	26.45
3	Mix 3	28	26.66

The observed difference in Young's modulus between trial mixes is modest and consistent with the compressive and flexural strength measurements. This demonstrates the dependability and consistency of your mixture designs and testing techniques. The strength difference is minimal; the modulus variation will be smaller due to the square root relationship as per IS 456:2000. This also explains the low percentage differences of about 0.38% and 1.18% as per trial mixes.

3.4 Flexural Load – Deflection Behaviour

The flexural load deflection behaviour of conventional and encased CFS beams are shown in the Figure 5. The effect of using CFS within the reinforced concrete can be visualized from the same. The influence of the encased CFS C-channel section helped load distribution effectively, which significantly improved the load-bearing capacity and flexural strength. The C-channel section is more efficient for resisting bending moments and shear forces than hot-rolled steel. The presence of cold-formed steel section beams resists delayed failure. The C-channel section along with reinforcement show lower deflection values. The encased CFS section significantly shows higher load-bearing capacity compared to conventional concrete. The ductile failure characteristic develops initial cracking and deflection before ultimate failure in gradual distortion. In contrast, conventional concrete has more brittle behaviour with post-cracking stiffness degradation. In economic and practical applications, cold-formed steel sections have faster construction and less formwork than conventional concrete.

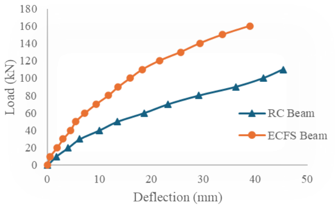


Fig 5. Load Versus Deflection

The encased CFS beam exhibited a yield load of 125.44 kN, representing an approximate 45% increase compared to the conventional reinforced concrete beam, which had a yield load of 86.32 kN. Similarly, the ultimate load of the encased CFS beam was 156.8 kN—also about 45% higher than that of the conventional reinforced concrete beam, which recorded an ultimate load of 107.9 kN. Figure 6 showing the crack pattern of the failed beam. A. M. Abou-Rayan et al., observed two failure modes in tested specimens, with local buckling governing failure. Strengthening the compression flange with wood waste or lightweight concrete increased ultimate load by 26.19% to 61.1%. minimal impact had observed when shear connectors were used however it is contrast to the present study without any connectors CFS encased beam improved load carrying capacity by 45% compared to the conventional RC beam(7). A. Abou-Rayan et al., found back-to-back channel CFS section significantly improved load capacity by 158% while face to face increased it by 107.65%, half depth and full depth CFS arrangements also improved its performance significantly. However, in the present study single channel section tried and it also performed significantly as rayan et al found(5). A recent study indicated that plate girders with concrete filled CFS tubular flanges offer higher flexural and torsional strengths compared to the ones with flat flanges. Local buckling was prevented by avoiding free edges in CFS channel beams by developing rectangular hollow flanges, riveted to the web through intermittent rivet fastening. However, in the present study lips were provided instead of flat flanges which helps to take care of both flexure and torsion. (2). Similar trend was seen in the study by Kharoob et al., have used closed built up box sections for encasement which is contrast to their work. In this study open C- Shaped channel CFS section also demonstrating that significantly enhance the beam performance(14).

Fig 6. Failure Pattern of ECFS Beam

The yield deflection of encased CFS section was 31.14mm and conventional concrete is 37.85mm. These results showing that encased CFS beam reduced deflection of about 17.73% compared to the conventional reinforced concrete beam. The ultimate deflection of encased CFS section was 38.93mm and conventional concrete is 45.32mm. These results showing that encased CFS beam reduced deflection of about 14.10% compared to the conventional reinforced concrete beam. Nabil S. Mahmoud et al., studied that Deflection increases with embedded height and shear connector spacing. Group B shear connectors performed better(15). M. Lofty et al., confirmed that encasing cold-formed web beams in concrete significantly enhances flexural performance. Concrete improves lateral-torsional buckling resistance, increasing load capacity by 80–85% and reducing deflection by 85–90% compared to unstiffened sections. Beams with web stiffeners also showed 40–45% higher strength and 65–70% lower deflection than unstiffened beams(10). CFS encased beam showed a delayed onset of cracking and changes the failure mode from brittle to ductile, which is contrast to the conventional RC beams. Uy et al., found that composite beams delay cracking and improves energy dissipation, but they have used hot rolled steel sections whereas in the present study, findings were related to the CFS sections(16).

3.4.1. Ductility

The encased Cold-formed steel section beam has a higher ductility factor than the Conventional concrete. The figure showed the comparison between ECFSWL-250 and C.C-250. The encasement of cold-formed steel section leads to improved energy absorption of 3052.11kN.mm has greater deformation capacity which confines encased cold-formed steel and suggests an increased strength-to-weight ratio and conventional concrete has 2079.71 kN.mm. The cold-formed steel and reinforcement bars increase ductile behavior, and an increment of loading covers yielding plateau which consistently distributes stress and resists cracking before failure. An Increase in stiffness resists buckling where encased cold formed steel beams have higher energy absorption than conventional concrete. low tensile strength contributes decrease in energy absorption. The proper design of novel composite concrete increases energy absorption. Figure 7 showing ductility factor of both ECFS beam and reinforced concrete beam.

$$\text{Ductility factor } = \frac{Ultimate\, deflection}{Yield\, deflection}$$

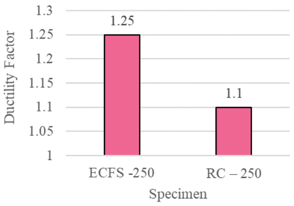


Fig 7. Ductility Factor of ECFS and RC Beam

Liu et al., found that improved compressive strength and Neutral axis shift occurs when the concrete refinement by encasement of CFS channel section in RC beams. In addition to this ductility and load carrying capacity also increased by 5 to 10 %. Provision of shear studs prevents buckling and enhance load bearing performance. However, in the present study with shear stud also the load carrying capacity and ductility increased but the percentage is slightly lower(9). Encased beams improve ductility and reduce the midspan deflection under service load compared to the conventional RC beams. This is similar to the findings by Li et al, where they found use of encased CFS enhance stiffness. However, their study was numerical simulation, and current work is purely experimental(17).

3.4.2. Stiffness

The encased cold-form steel section has higher stiffness than conventional concrete. where local buckling was resisted in novel encased steel sections and the moment of inertia is increased, concurrently the stiffness increases due to the interlace of concrete, cold-form steel, and reinforcement bars where section geometry and materials are used to exhibit an increase in stiffness. The conventional concrete has decreased stiffness due to loading conditions beam weakens its ability to resist deformation. Figure 8 showing stiffness values of ECFS and RC beam.

$$\text{Stiffness } = \frac{Ultimate\, load}{Ultimate\, deflection}$$

Babu and Selvan (include year) found that inclusion of cover plates increased the stiffness of the flexural members and prevents shear failure. Also found higher depth increases stiffness and strength. However, in this study without cover plates also stiffness increased to some extent(11).

Summary of the above discussion conclude that the previous studies give the potential of the steel concrete composites. However, in the present study, uniquely explaining the experimental flexural performance of the open profile CFS sections encased in the RC beams. This technique can be promising to provide light weight, cost effective and ductile structural designs.

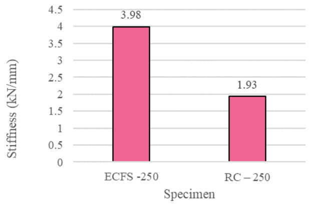


Fig 8. Stiffness of ECFS and RC Beam

3.4.3. Comparative Analysis with existing Studies

By comparing the present study and existing studies, highlighting the novelty and practical contributions discussed in the below table.

Aspect	**Present Study**	**Kharoob et al.** (14)	**Uy et al.** (16)	**Li et al.** (17)	**Han et al.** (18)
Steel Profile Type	Cold-formed steel (CFS), open section	CFS, closed box section	Hot rolled steel section	CFS section in numerical model	Concrete-filled steel tubes (hot rolled)
Flexural Capacity Increase	45% increase compared to conventional RC beams	30% increase	Not quantified, focused on crack behavior	Not validated experimentally	Enhanced ductility and energy absorption similar to current study
Failure Mode &Crack Pattern	Fine and widely distributed cracks, improved over conventional RC beams	Not explicitly mentioned	Similar crack distribution observed	Not investigated	Not directly comparable
Experimental Validation	Yes, full-scale experimental testing	Yes	Yes	No, only numerical analysis	Yes
Ductility & Load-Deflection	Improved ductility and energy absorption with lightweight CFS	Not detailed	Not the focus	Not analyzed	Similar ductile behavior, but using bulky hot-rolled tubes
Material & Construction Aspects	Lightweight, easy to fabricate, transport, and integrate	Not emphasized	Heavy and bulky	Only numerical efficiency considered	Bulky sections, higher material use and cost

4 Conclusion

The findings of this study demonstrate that encased cold-formed steel (CFS) sections significantly enhance the mechanical performance of structural concrete elements, making them a viable and efficient solution for modern construction applications.

Enhanced Structural Performance: Using cold-formed steel (CFS) sections in concrete beams enhances overall behaviour as compared to traditional RC beams. **Increased Load Capacity:** Yield and ultimate load capacities rose by around 45%, demonstrating significant strength improvement. **Reduced Deflections:** Yield and ultimate deflections fell by 17.73% and 14.10%, respectively, indicating increased stiffness and serviceability. **Improved Ductility:** The ductility factor increases from 1.10 (RC) to 1.25 (encased CFS), increasing energy absorption and lowering brittle failure risk. **Greater Stiffness:** Stiffness nearly doubled, from 1.93 (RC) to 3.98 (encased CFS), resulting in less cracking and longer service life. **Strain Hardening Behaviour:** Encased CFS beams exhibited strong post-yield performance and high deformation capacity.

Superior Mechanical Performance: The results show that encased CFS sections are an effective and novel reinforcement solution for modern concrete buildings.

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