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Original Article

Experimental Study of the Seismic Performance of Composite Frames Encased with Mild Steel under Cyclic Loading

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Abstract - *Concrete-filled steel tubes (CFT) have gained prominence in construction due to their exceptional earthquake resistance. The synergy between concrete and steel offers several advantages, including delaying local bulking of steel offers several advantages, including delaying local bulking of the steel tubes through concrete restraint and enhancing concrete strength via the confining effect of the steel. This research investigates portal frames encased in mild steel, which is crucial for shear connections that improve load-bearing capacity and ductility. The experimental assessment of the CFT frame's load-bearing capacity was conducted through horizontal cyclic load testing, where a force was applied along the axis of the portal structure. Mild steel plates, 1.2mm thick and presented in various widths, were used alongside M2% grade concrete. Specimens were equipped with shear connections to function cohesively and tested with the spacing of 125 mm, 100mm, and 75mm, applying a load increment of 0.1 tons per cycle. Notably, the strength and toughness of the shear connector unit were enhanced without requiring additional steel. The hysteresis curve illustrated the relationship between axial elongations and loads. CFT structures exhibited higher ductility, rigidity, and ultimate load capacity compared to regular concrete. The cyclic loading protocol involved ten cycles at a frequency of 0.5 Hz, simulating real-world seismic conditions. These findings suggest incorporating CFT elements in seismic-prone areas can optimize frame design. Specifically, shear connectors spaced 100 mm apart significantly enhanced load-bearing capacity without additional steel reinforcement. This research highlights the benefits of CFT in construction and provides guidelines for improving structural resilience against seismic activities, contributing to safer building practices in earthquake-prone regions. The analytical equation between spacing and load applied and deflection (obtained is proposed for the present model. For example, MSCFPF is used in curve fitting, which allows for the creation of equations that represent the relationship between load, deformation, and other key variable spacing.*

Keywords - *Concrete–Filled steel Tube (CFT), Load bearing, Hysteresis curve, yield strength, Cyclic loading frame, SP specimens (SP-75, SP-100, SP-125).*

1. Introduction

Composite Frames Encased with Mild Steel (CFEMS) emerged as a promising structural system for seismic-prone regions due to their enhanced strength, ductility, and strength capacity. However, a significant gap exists regarding the specific effect of shear connectors on the seismic performance of these frames, particularly in relation to their spacing. To evaluate the seismic performance of CFEMS, experimental studies under cyclic loading are crucial [1]. Various factors, such as material properties, structural configuration, and the presence of reinforcing elements, impact the seismic performance of composite frames. Specifically, incorporating mild steel around steel components is intimated to enrich composite frames for earthquake resistance [2]. The improved seismic performance achieved through the usage of mild steel encasement can lead to safer and more resilient buildings, reducing the risk of damage and loss of life during earthquakes [3]. Advanced technology plays a crucial role in the experimental study of the seismic performance of composite frames encased with mild steel. The study utilized Abaqus, a software suite for finite element Analysis (FEA) and computer-aided engineering. Abaqus enables detailed simulations of complex civil engineering problems, including nonlinear dynamic issues and varying boundary conditions. The software consists of three main stages: pre-processing modelling, processing the finite element analysis, and generating reports and visualizations from output files, which is the post-processing step. The use of advanced techniques and numerical modelling allows for a comprehensive understanding of the complex behavior of these frames under cyclic loading. This knowledge is essential for developing reliable design guidelines and enhancing the seismic safety of structures [4]. By providing additional confinement, strength capacity, and stability, mild steel encasement can expand the ductility, reduce demands on other structural components, and ensure the overall integrity of the frame under seismic loading [5]. The encasement increased the capacity, energy, ductility, and stiffness of frames. It also delayed the onset of failure and provided a more ductile failure mode [6].

Moreover, experimental studies have demonstrated the benefits of encasement in terms of improved ductility, energy dissipation, and joint behavior. These findings have contributed to developing more accurate numerical models and improved design guidelines for these structures, ensuring their safety and reliability under seismic loads [7]. The study has many limitations, including limited scale, material variability, boundary conditions, instrumentation and data acquisition, parameter studies, and numerical modelling [8]. The applications of this study include validating numerical models, optimizing design parameters, developing design guidelines, assessing retrofit strategies, and understanding failure mechanisms. The results of experimental studies contribute to the advancement of seismic-resistant construction and the safety of structures in earthquake-prone regions [9].

The present study validates the results of an earlier investigation regarding ductility and maximum load ability of steel-encased portal frames utilizing shear connectors within the sample. The study focuses on how varying spacing between shear connectors impacts the specimen’s overall strength and load-bearing capacity. The specimen's overall strength and load-bearing capacity can be significantly enhanced by incorporating shear connectors. A portal frame and a bare frame underwent a cyclic static stress test to understand the unique behavior further. Reducing the space among shear connectors is proven to enhance their maximum load capacity. The experiments included a hysteresis curve plot to thoroughly assess the failure process across all three portal frames. The significant objective of the present study is to investigate shear connectors located at different spaces from the frame.

2. Literature Review

The literature review presents a comprehensive study of cyclic loading of composite moving surfaces listed below, A comprehensive study was conducted on the seismic behaviour of two conventional reinforced concrete (RC) columns and six concrete-encased CFST columns in hysteresis curves. The research findings indicated a 74.8% rise in flexibility and a 162.7% increase in energy absorption in ultra-high-strength columns when compared to the conventional method. The enhancement in composite column flexibility and increment in the absorption capacity of energy has been enhanced by means of placing the pre-tensioned steel strip, which significantly improves structural performance [10]. Attaching web stiffeners to the end plate can help decrease the stress concentration on the fillet weld, enhancing the shear link's performance. The test samples have been showing an average over-strength factor of 1.9 and firm rotation capacity of 0.087 rad, significantly surpassing the defined values of 1.5 and 0.08 rad for Eccentrically Braced Frames (EBF) links in American Institute of Steel Construction (AISC) 341-16 regulations [11]. The frame's yield mechanism follows the design philosophy with the concept of "beam-column-node" as its basis. The full hysteresis curve has shown a high ability to absorb energy. The consistent weakening of strength continues, with a ductility factor surpassing 2.85 [12]. Once the inner steel plate buckles, it reaches its maximum yield capacity, contributing to load bearing and energy absorption by creating a tension field. The load capacity of concrete specimens is approximately 18% higher than that of specimens that lack concrete. The relationship between height and thickness significantly impacts the post-buckling behaviour of a Typical Steel Plate Shear Wall (SPSW). When fraction of height-thickness increases, structure's ultimate bearing capacity will also increase by 10% - 30%. Furthermore, for optimal performance of prefabricated SPSW with a Partially Encased Composite column, it was presented to maintain spacing between 120 mm and 60 mm [13].

The prefabricated joints had slightly weaker positive load-bearing capabilities than the cast-in-situ joints, with prefabricated joints' negative load capacity being between 73% and 90% of the cast-in-situ joints [14]. Samples' strength capacity has been depended primarily on structures. Different kinds of building enclosures significantly affect a building's lateral stiffness and strength capability. The ductility coefficient of all samples indicates that the structural system relies more on lateral stiffness and elastic deformation rather than structural ductility to withstand earthquakes [15]. A finite element model was developed and tested, with the results showing that samples practised flexural failure and their load-displacement graphs displayed a comparable outcome. PC-S specimen has exhibited a ductility coefficient of CIP specimen and bearing capacity, whereas the PC-C specimen had higher values [16]. Ductility, stiffness stability, and strength stability decreased. The damping index was between 0.281 and 0.414 near failure, with a ductility over 3.0. This demonstrated the potential use of columns in seismic areas for supporting structures. The Code AIJ-2001 was proposed for calculating the compressive bending capacity of columns under cyclic seismic loading, with a 1.15 enhancement factor for accurate calculation [17]. The steel RC beams have a higher carrying capacity and energy consumption [18]. Steel fibre frames were built with a 0.5% volume fraction as well. The objective of the study is to examine the mechanical characteristics, cracking behaviours, mode of failure, structural flexibility, and load-displacement response of Numerical Control (NC) and Precast hybrid steel Fibre concrete (SFC) frames. Based on the findings, there was an enhancement observed in the structural flexibility, which was attributed to the inclusion of steel fibres in standard concrete [19].

The structural performance of CFST columns connected to steel beams was experimentally evaluated under seismic loading using nine different connection details. It was discovered from the findings that joints through-beam details exhibited the most favourable seismic behaviour out of all the joints tested [20]. Finite element analysis was employed to find the best shape for efficient heat capacity. Five samples for testing were selected and designated as C, C1, C2, C3, and C4. The heat ability was examined, and structural elements were evaluated, showing that the reduced specimen has superior heat capacity compared to other specimens and ultimately sustains the stability of the specimen at any height [21]. The findings from the experiment indicate that besides CIFP2-0, all tested specimens have strength capacity ratios with a maximum ratio of 97.5%. This presented that Steel-Reinforced Concrete-Filled Steel Tubular (SRCFST) constituents could absorb significant amounts of input energy [22]. Factors were varied to analyze the performance of various rectangular columns.

Comparison was made between composite structures' projected maximum axial strengths and actual test results. Research has demonstrated that a numerical model effectively forecasts the performance of Centre of Futuristic Defence and Space Technology (CFDST) columns containing a stainless steel outer skin [23]. Various designs and materials of concrete-filled steel tubes were analyzed underneath adjacent impact loads. Previous researchers debated the techniques used based on geometric attributes, analytical approach, materials utilized and their characteristics, physical measurements, and limitations of concrete-filled steel tubes [24].

The analysis of square stub columns includes evaluation of axial compressive behaviour, encompassing failure mode, load-deformation relationship, and stress-strain relationship. Moreover, the aspect ratio of width to thickness is important in improving the failure mode and ductility of square stub columns, with steel ratio and hoop coefficient influencing the extent of the confinement effect [25].

Furthermore, incorporating advanced materials such as FRI (Fibre Reinforced Polymers) has been shown to enhance the seismic resilience of CFST structures in the future by improving their confinement and load-bearing capacity. Despite the advancements, challenges remain regarding the durability and long-term performance of CFST structures in aggressive environments.

The limitations, such as steel tube corrosion and concrete over-tie degradation, necessitate further research into protective measures and innovative design solutions to ensure longevity. Overall, while significant progress has been made in understanding and optimizing CFST systems for seismic applications, ongoing research is essential to address existing gaps in knowledge and improve design practices for enhanced structural resilience.

3. Research Methodology

3.1. Materials and Methods

According to Indian Standards of IS10262:2009 and IS456:2000, concrete could easily flow into the mould when placed at 200mm. The material properties and their appropriate description/ values are presented in Table 1. Mild steel rods in which shear connectors yield strength 250N/mm^2, 6mm diameter, and density 7850 kg /m3 and 150mm length.

Table 1. Material properties

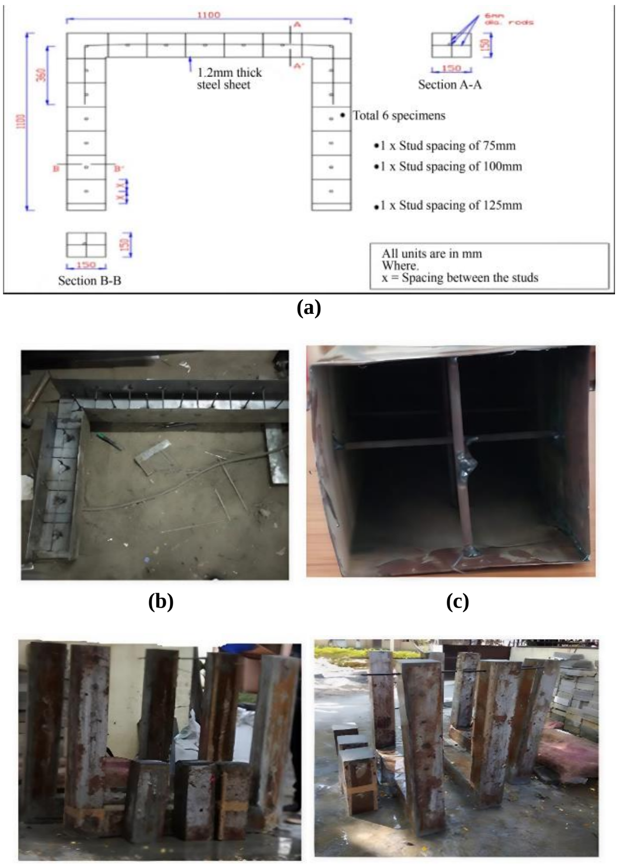
Materials	Description/values
Grade designation	M25 concrete
Type of the cement	OPC 53 grade
Maximum water-cement ratio	0.50
Maximum nominal size of aggregate	20mm
Minimum cement content	300kg/m3
Workability	75- 100mm
Cement Specific gravity	3.15
Fine aggregates of Specific gravity	2.68 (M sand)
Coarse aggregates specific gravity	2.74
Density (Shear connectors- 6mm diameter, 150 mm dimension)	7850kg/m^3
Density (Mild steel-1.2 mm thickness)	7850kg/m^3
Yield strength (Mild steel-1.2 mm wideness)	250N/mm^2

Material properties of the M25 concrete are described in Table 1. M25 concrete, a widely employed mix in construction, achieves a compressive strength of 25 N/mm² post 28-day curing. Key factors shape its properties: OPC 53 grade cement, selected for its robustness, ensures structural integrity. The water-cement ratio of 0.50 impacts both workability and strength, optimizing compaction with a 20mm maximum aggregate size to reduce voids. Maintaining a minimum cement content of 300kg/m³ enhances binding for structural stability, while a workability range of 75-100mm governs handling during placement. Cement-specific gravity (3.15) and aggregates (e.g., M sand at 2.68) influence density and strength, which is crucial for precise mix proportioning. Cumulative specific gravity (2.74) consolidates all aggregate weights. Shear connectors, 6mm diameter, 150mm length, offer density and yield strength, crucial for load-bearing capacities. Similarly, mild steel, 1.2mm thick, ensures structural robustness. In essence, meticulous consideration of these parameters ensures the formulation of M25 concrete meets requisite strength, durability, and workability criteria for diverse construction endeavours.

The steel casing was bent into a ‘C-shape’ structure so that the specimen’s end was evaluated widely openly. It was done to welded internal shear rods. Once shear rods were placed in that particular position, they were placed into the beam with development length, which goes into columns. Wide-opened steel was locked through welding a steel plate into it. Interior steel rods were attached to welded steel plates. Edges of steel plate are welded together to stop the concrete slurry and make it strong. Underneath the surface of the column is presented open for the first part of the specimen. The opening is filled with concrete to bind to it strongly. Different lengths and thicknesses with 1.2mm are utilized. The plate, which is retained on the concrete, fills the place and increases load-carrying capacity.

3.2. Portal Frame Specimen

The research aims to analyze the behaviours of portal frames by performing tests on three frame specimens filled with concrete and equipped with shear connections. Each frame section is 1.1 meters high and 1.1 meters wide and has a rectangular area of 150 mm x 150 mm. The frames are initially empty and then filled with M25 grade concrete, a common concrete mix in construction. After filling, the concrete is allowed to cure normally for 28 days to ensure optimal strength development. The frames are then subjected to static cycle pressure, likely simulating the various loads and stresses that frames might experience in real-world scenarios. This experimental setup allowed researchers to observe the frames structurally respond under different load conditions, providing valuable information about their performance and potential areas for improvement. Shear connectors are fixed at 75mm, 100mm, and 125 mm spacing.



(a)

(b) (c)

(d) (e)

Fig. 1 Fabrication of the structures: (a) General Schematic Diagram of the portal frame (all units in mm); (b) Bent mild steel sheets); (c) Column Bottom opening; (d) Concrete poured specimen; (e) Curing of specimen

A distinctive procedure is followed during the construction of the samples to ensure proper concrete compaction. The specimen is inverted, and concrete is poured while the casing is rotated and mixed. In addition, routine compaction was done with a 16 mm rod to promote compaction. After construction, the exposed sides of the concrete are allowed to cure naturally for up to 28 days, ensuring sufficient strength develops. The study focused on analyzing the effect of distance and the number of shear connections in the portal frame. Other parameters, such as beam and column dimensions, concrete quality, and steel bar profiles, remained constant during the study. Three portal frames, called SP-125, SP-100, and SP-75, were built with different spacing among shear connectors: 75 mm, 100 mm, and 125 mm, respectively. These shear connectors are welded with the frame section. The loading frame is designed per Indian standards, and base plates are made accordingly.

Table 2. Specimens names

Specimen ID	Spacing of Studs	No. of Specimens
Bare frame	-	1
SP-75	75mm	1
SP-100	100mm	1
SP-125	25mm	1

The data outlines a set of samples categorized by Sample ID, each with specific attributes denoting the number of samples and the spacing between studs, presented in Table 2. The samples, designated as SP-125, SP-100, and SP-75, each represent individual specimens with varying stud spacing of 125mm, 100mm, and 75mm, respectively. Such variations in stud spacing are likely intended to assess the structural performance or load-bearing capacity of materials under different configurations, reflecting real-world scenarios where studs or fasteners are positioned at different intervals. Additionally, including a "Bare frame" sample, denoted by a lack of specified stud spacing, implies a control or reference sample devoid of additional elements or modifications, serving as a baseline for comparison against the samples with defined stud spacing.

Fig. 2 Base plate

The base plates are designed with a 20mm space allowance in both dimensions to accommodate potential errors in the prototype. Additionally, 16mm-diameter interruptions are strategically drilled 50mm from the base to align with the perforations in the supports. However, adjustments are made to accommodate the specimen's perforations. The apertures presented on the cup are enlarged to a boundary of 31mm, as illustrated in Figure 2. This modification ensured more precise placement of lateral bolts. By allowing for these adjustments, the design not only addressed potential prototype cracks but also optimized functionality, streamlining the assembly process and enhancing the overall effectiveness of the system.

3.3. Experimental Test Setup

The experimental research setup, as depicted in Figure 3, allows for the detection of displacement on the column specimen's upper and centre surfaces.

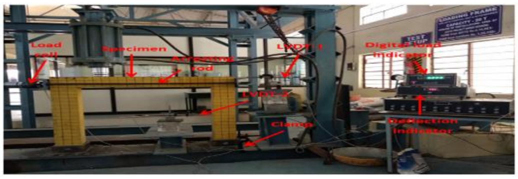


Fig. 3 Test setup of composite portal frame

All samples underwent rigorous testing on a 50-tonne cyclic loading frame to assess their response to static cyclic loading. Utilizing a hydraulic jack equipped with a load cell, the load is applied to the beam-column joint while measuring deflection. Each cycle applied a load of approximately 0.1 tonnes, with a loading gap of 1 kN. Loading is repeated three times for each specimen, totalling 10 loading cycles. Two LVDTs are employed simultaneously, one positioned at the middle of the top edge and the other at the middle of the column, enabling precise deflection tracking. Only LVDT-1 readings were utilized, with LVDT-2 serving as a control. Three samples, along with a "bare frame" sample, were cast and analyzed. The loading process is static and devoid of time-based intervals, with load control ensuring the observation of deflection at specific load levels. Initial connections are meticulously established, securing the sample to the base plate to prevent any upward movement during experimentation.

4. Results and Discussion

For all the specimens, horizontal load displacement was displayed in graphical representation. In graphs, when the hysteresis curve resulted in a straight line, it shows that elasticity has changed. After the frame had been unlocked, the loop presented in the particular region produced straight formation and lingering deformations. The material had reached a greater ductility value when loads were significantly increased. When the specimens resulted with no significant squeezing and with satisfactory performance, the hysteresis curve was smoothed out.

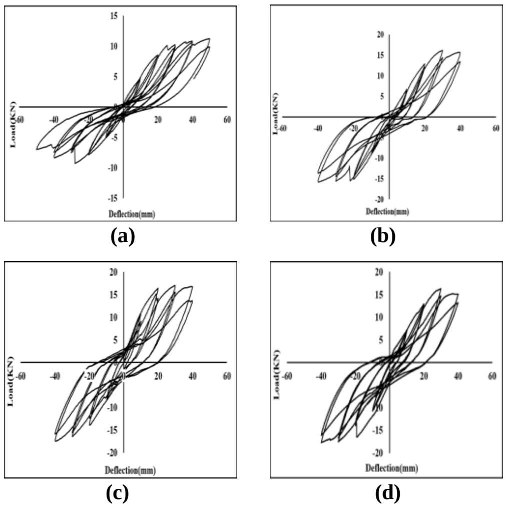


Fig. 4 Hysteresis curve: (a) Bare Frame (b) SP-75 (c) SP-100; (d) SP-125

Table 3. Specimen's Load-carrying competencies

Allotted Name	Stud Arrangement	Highest load (kN)	Load rise in % matched with a bare frame	Maximum observed deflection (mm)	Deflection decreases in % related to the bare frame
Bare frame	-	11	-	46.67	-
SP-75	75mm	16	38.86	39.06	25.08
SP-100	100mm	15	29.05	30.03	42
SP-125	125mm	14.3	20.11	39.81	18.15

Load-carrying capacities of the frames with shear connectors surpass those of the bare frame, as represented in Table 3. Specifically, the SP-75 spacing exhibited a notable result with the load value compared to the bare frame, indicating a significant enhancement in performance. The overall effectiveness of SP-75 increased by 38.86%, signifying a substantial improvement in load-bearing capability. Similarly, the corresponding percentages for SP-100 and SP-125 spacing's are 29.05% and 20.11%, respectively. These findings underscore the efficacy of frames in bolstering the structural integrity and load-bearing capacity of the frames. The observation shows that the increase in load-carrying capacities across different spacings presents a progressive enhancement in the structural performance of 75mm. Overall, the data presented in Table 3 highlight the positive impact of spacing on the load-bearing capabilities of the frames, indicative of their potential to enhance structural resilience and durability.

The provided data presents a comparative analysis of various stud arrangements' impact on load-bearing capacity and deflection in structural elements. The "Bare frame" serves as a baseline reference, featuring an initial load capacity of 11kN and a maximum observed deflection of 46.67mm. Subsequent samples are denoted as SP-75, SP-100, and SP-125, and the characteristics of stud spacing are 75mm, 100mm, and 125mm, respectively. As stud spacing widens, the load-bearing capacity tends to increase. For instance, SP-75 exhibits the highest load capacity at 16kN, followed by SP-100 at 15kN and SP-125 at 14.3kN. However, despite the higher loads, wider stud spacing results in decreased load rise percentages compared to the bare frame. Regarding deflection, the data presents that wider stud spacing correlates with reduced deflection. SP-100, with a 100mm stud arrangement, displays the most significant decrease in deflection at 42% compared to the bare frame, followed by SP-75 at 25.08% and SP-125 at 18.15%. Overall, the findings indicate a trade-off between load-bearing capacity and deflection, with wider stud spacing generally offering higher load capacities but lower deflections.

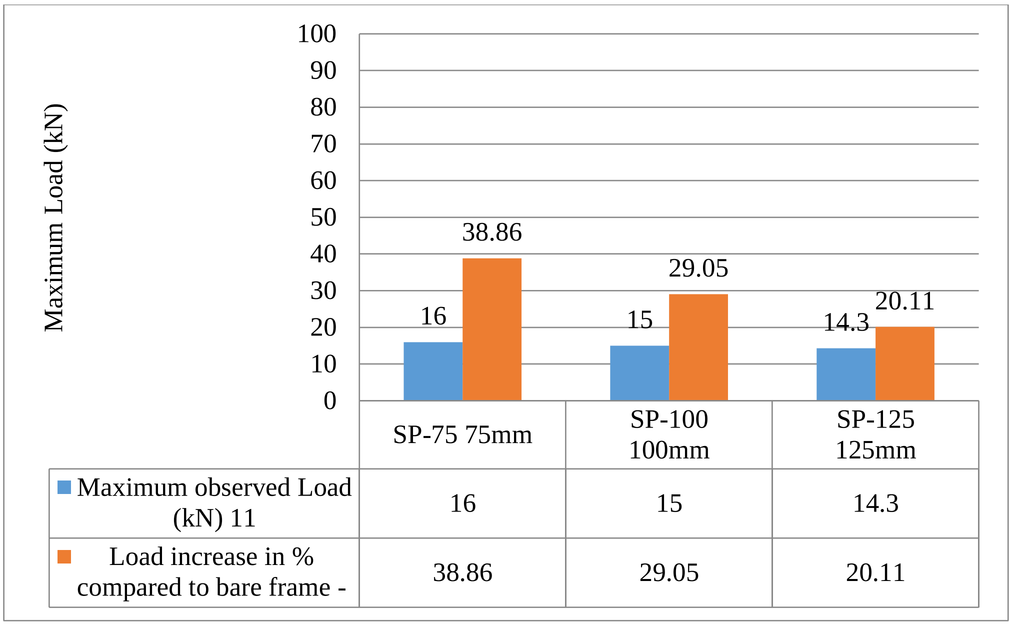


Fig. 5 a) Maximum load and percentage increment

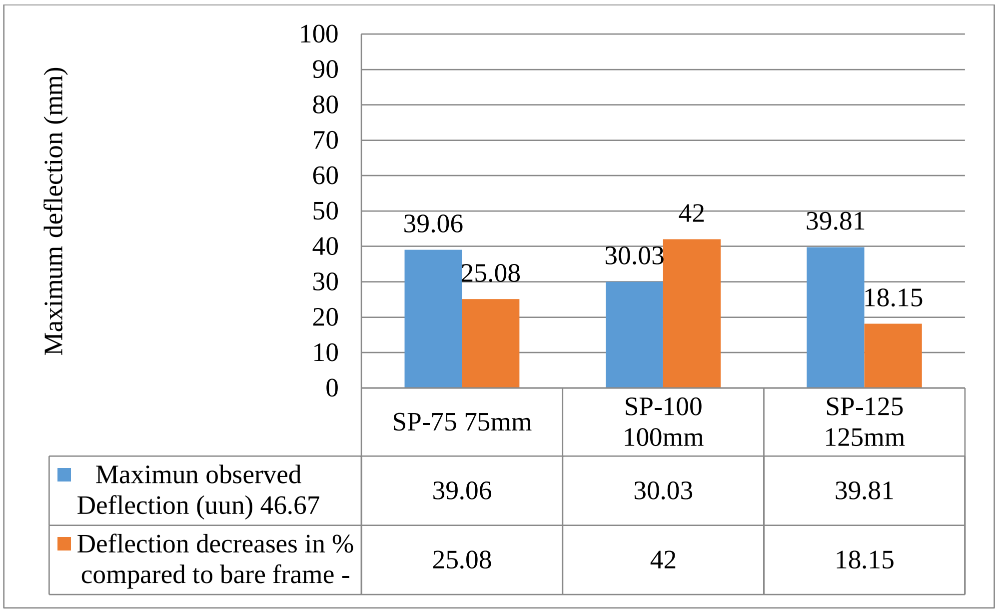


Fig. 5 b) Maximum Deflection and decrement of percentage

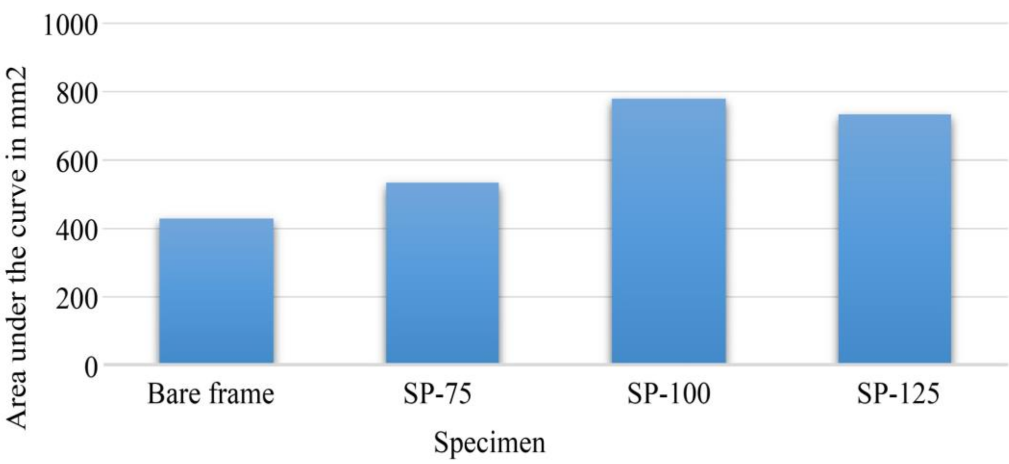


Fig. 6 Area under the curve of four specimens

The data presented in Table 3 demonstrate that the load-carrying capacities of the shear connectors frames surpass those of the bare frame. Notably, SP-75 exhibited a significantly greater load value than the bare frame, indicating a substantial increase in overall effectiveness by 38.86%. Similarly, SP-100 and SP-125 showed 29.05% and 20.11% corresponding increases. These findings underscore the efficacy of enhancing the load-bearing capacity of the frames. Progressive increases in load-carrying capacity across different spacing highlight the potential for improved structural resilience and durability with suitable spacing.

Table 3 and Figure 6 show the bare frame strength and SP-75 spacing with certain limitations. Although SP-75 spacing was used, strength remained the same. With further improvements, the presented data was enhanced with a bare frame and SP-75 to be robust. This acquaintance is necessary for advanced research and development to make frames stronger and more earthquake-resistant. By identifying the experimental limits, researchers can aim to optimize the strength of structural components, which ultimately improves their ability to withstand seismic forces and ensure the safety and stability of the built environment.

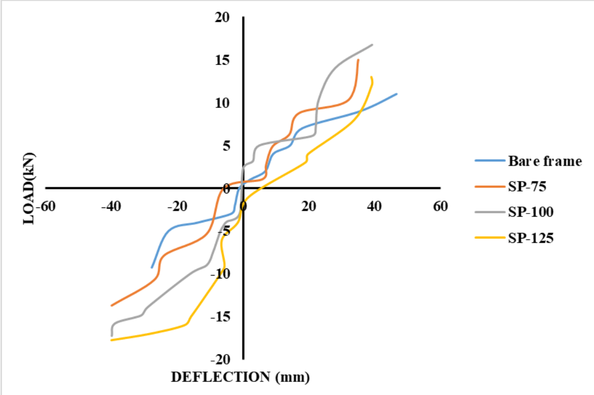


Fig. 7 Comparison of spacing: bare frame, S-75, SP-100, and SP-125

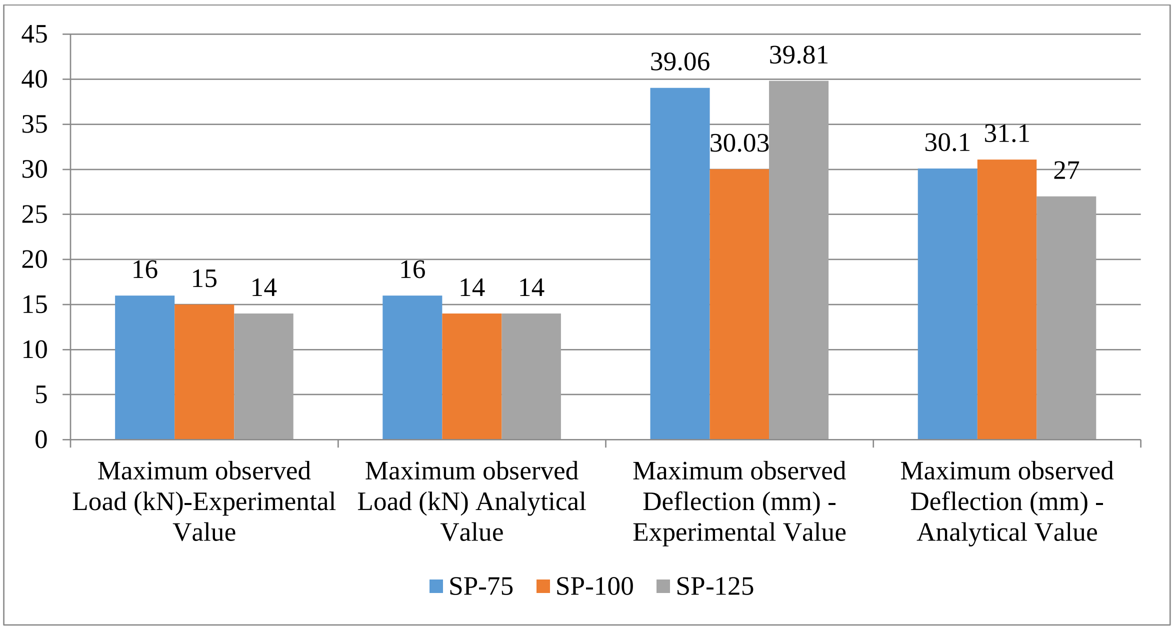


Fig. 8 MSCFPF's experimental value vs. Analytical value

The backbone curves illustrate the heightened straight ductility and load significance, indicating increased flexibility and lateral force compared to prior instances. These curves are pivotal for comprehending structural behaviour under horizontal loads, offering insights into strength, stiffness, and ductility. In Figure 7, negative loads depict expanding space below each line sequentially, signifying enhanced ductility with reduced shear connection separation. Consequently, greater spacing between connectors results in decreased material ductility. The inference drawn is that shear connection separation directly influences load-bearing capacity and displacement. Hence, a decrease in the distance between shear connections correlates with an increased maximum load capacity.

Figure 8. Illustrate the maximum observed load in (kN) and deflection in (mm) for three different samples, labelled SP-75, SP-100, and SP-125. Each sample is presented with both experimental and analytical values for comparison. The experimental values indicate that SP-75 has the highest load at 16kN, followed closely by SP-100 at 15kN, while SSP-125 remains at 14kN. Overall, the experimental and analytical loads are aligned closely with minor variations across samples. For deflection, experimental values reveal that SP-75 exhibits the largest deflection at 39.06 mm, followed by SP-125 at 39.81mm, SP-100 at 31.1 mm and SP-125 at 27mm.

5. Deflection of the Failure Mode

The field of civil engineering or material science begins with the observation of concrete damage on the bare frame of the test specimen, which shows significant crushing, as shown in Figure 8a. It should be noted that most of the concrete cracks are concentrated in a certain area, which indicates local stress concentration. Fracture is still observed at the SP-75 beam-to-column junction, illustrated in Figure 8b, which illustrates potential structural vulnerabilities. After analyzing, the beam-column junction of SP-100, which is moved to a certain region, was depicted in Figure 8c. Similarly, Specimen SP-125 showed failure developing just below the beam-column connection, as shown in Fig. 8d, highlighting possible failure modes in structural elements. Subsequent inspection of the internal concrete, facilitated by an opening in the steel tube after testing, was to assess internal damage or integrity problems. Despite significant tensile damage, the concrete appears to have suffered little additional damage. This highlights the common problem of these frames not working effectively either due to imperfections in the concrete or the shear bond. It is observed that the area under each curve increases for negative loads, indicating increased formability of the material as the shear connections decrease. As a result, increasing shear connection spacing makes the structure more susceptible to damage. These findings highlight the importance of understanding and addressing shear joint behaviour in CFTs to ensure structural integrity and durability.

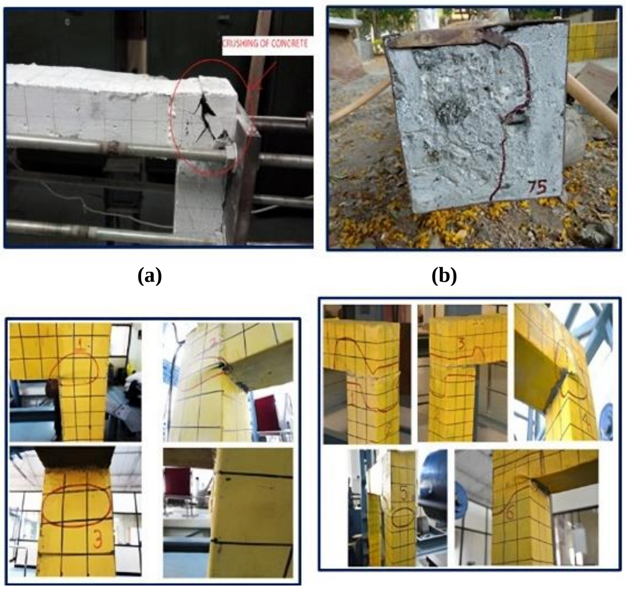


Fig. 9 Material Defects and Failures: (a) Bare Frame (b) SP-75 (c) SP-100 (d) SP-125

The study achieved superior results in the seismic performance of CFST compared to state-of-the-art techniques by implementing a comprehensive approach that optimized shear connector configurations and utilized advanced material. Specifically, the proposed method demonstrates that tighter shear connector spacing significantly enhances load-bearing capacities and ductility, with the SP-75 configuration spacing significantly enhancing load-bearing capacity compared to the bare frame. This improvement aligns with findings from existing studies, which emphasize the importance of the optimized shear connector arrangement in enhancing structural performance under cyclic loading. Additionally, the experimental setup incorporated precise displacement measurement techniques using dual LVDTs, allowing for reliable tracking of deflection and providing insights into the structural behaviour under applied loads. The maximum observed deflection was 39.06mm for SP-75, 30,03mm for SP-100, and SP-125, with a corresponding decrease in deflection of 25.08%, 42% and 18.15% relative to the bare frame. This methodology's rigor is complemented by M25 concrete, which has been shown to achieve robust performance characteristics, as detailed in existing standards. By integrating the advanced techniques and materials, the proposed method not only confirmed but enhanced existing knowledge regarding the efficacy of shear connectors in CFST structures, thereby contributing valuable insights for future design practice aimed at improving against seismic forces.

6. Conclusion

The research described the relationship between the structures of CFST, shear connectors spacing, ductility, and load-bearing capacity. Due to the increased confinement effects, the spacing that is present between the shear connectors enhances the load-bearing capacity. This was tested by looking at the load-deflection curves with different spacings on the large areas. Moreover, LVDTs and load cells have been intimated even after internal structure damage and concrete crushed, enriching safety and keeping the encasing steel intact. The prevailing research study explains that load-bearing capacity contributes to the steel's ability to hold the components firmly. The present study resulted in the outcome that less shear connection gap can highlight the shear links by the enhancement of load-bearing capacity. Various shear stud spacings were presented with high peaks in the load-displacement curves. This resulted in a decreased value in spacing, and ductility was increased. The research concluded with further analysis of the computer software highlighting the importance of the CFST frame structures in succeeding in cost-effectiveness and seismic resistance in construction projects. Finite Element Analysis (FEA) is the advanced numerical simulation that performs seismic performance of composite frames in future research. Under seismic loading, hybrid simulation and shake table testing are the experimental testing approaches that provide knowledge into the composite structures' behaviour. CFT offers a significant advantage for seismic resilience in construction, making high-rise buildings and bridges in earthquake-prone areas; the CFT technology contributes to safer building practices and improves structural integrity, which helps in real-world applications. The study’s limitations include using specific material and specimen sizes and fixed shear connector spacing of 75mm, 100mm and 125 mm. These could explore a broader range of materials, varying specimens and dimensions, and alternatively, spacing configurations to enhance the performance. Future investigation will focus on utilizing galvanized mild steel, which has been shown to provide better results in terms of performance and structural integrity.

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