DESIGN AND ANALYSIS OF STEEL TUBULAR SECTION FILLED WITH CONCRETE

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Abstract—: Reinforced cement concrete is a highly versatile and widely used construction material, essential for its ability to enhance tensile strength through the incorporation of twisted steel bars of varying diameters. Structural hollow steel sections, when filled with concrete, offer numerous advantages, such as increased load-carrying capacity and reduced sectional dimensions, leading to more slender and efficient members. These sections eliminate the need for formwork during casting and installation, reducing labor and cost as they do not require reinforcement fabrication. Additionally, while concrete is protected from fire hazards by being encased in steel, the steel itself is prone to corrosion; however, this can be mitigated with appropriate anti-rust or anti-corrosive coatings. Precast elements have become increasingly popular in modern construction, particularly in housing, and are valuable for repairs and retrofitting in cases of structural damage due to natural disasters or the need for rehabilitating old structures. This project focuses on confining concrete within hollow steel tubes, enhancing the elements' load-carrying capacity, flexural stiffness, and rigidity. These concrete-filled tubes are then evaluated against hollow tubes of the same dimensions, comparing their flexural and compressive strengths through finite element analysis and corresponding graphical representations.

Keywords: Reinforced cement concrete (RCC), Twisted steel bars, Tensile strength, Structural hollow sections, Load-carrying capacity, Reduced sectional dimensions

1. INTRODUCTION

Reinforced cement concrete (RCC) has become a cornerstone in construction due to its enhanced tensile strength provided by steel reinforcements. Typically, steel TMT or HYSD bars, varying from 8mm to 32mm in diameter, are embedded within the concrete to counteract its poor tensile strength. This combination of concrete and steel creates a material capable of withstanding diverse stresses, making RCC one of the most versatile and widely used construction materials available today.

Concrete itself is a composite material composed of four main components: Ordinary Portland Cement (OPC), fine aggregates (ranging from 600 microns to 4.75mm), coarse aggregates (ranging from 4.75mm to 12.5mm), potable water, and admixtures. Self-Compacting Concrete (SCC) represents a significant advancement in concrete technology. SCC can flow and consolidate under its own weight without the need for mechanical vibration, which not only reduces labor requirements by over 50% but also enhances the quality of the finished structure by minimizing defects like bugholes and honeycombing (RILEM, 1999).

In modern construction, particularly in the housing sector, structural hollow steel sections filled with concrete are increasingly favored. These sections serve as efficient compression members and eliminate the need for traditional reinforcement and formwork. Filling these hollow sections with concrete improves their load-bearing capacity and reduces the overall section diameter, offering practical advantages such as increased durability and fire resistance. Moreover, these sections protect the concrete from environmental exposure, although the steel itself may require protective coatings to prevent corrosion. This method finds extensive applications in precast elements, maintenance, repair, rehabilitation, and retrofitting projects, providing a robust solution that simplifies construction processes and enhances structural integrity.

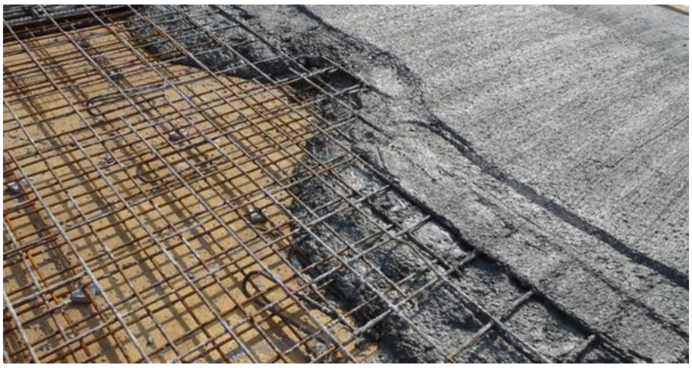


Fig.1 RCC

The need for this study arises from the numerous benefits of concrete-filled tubular sections, including eliminating formwork, negating the need for reinforcement fabrication, and protecting the concrete from environmental exposure. Furthermore, while concrete is vulnerable to fire hazards, confining it within steel tubes enhances its resistance compared to conventional methods. The scope of the work is confined to experimenting with hollow rectangular steel sections of 1 gauge measure and one grade of SCC concrete of M20. The study focuses on testing the flexural and compressive strengths and comparing experimental results with analytical predictions to validate the effectiveness of this construction approach.

2. LITERATURE REVIEW

Brian Uy et al. explores the renewed global interest in concrete-filled steel box columns, attributing their resurgence to the substantial benefits offered by this construction method. The paper delves into the strength behavior of short columns subjected to both axial compression and bending moments, focusing on how the slenderness limits of steel plates influence this behavior. A comprehensive series of experiments were conducted, complemented by the calibration and enhancement of a pre-existing numerical model. Additionally, a straightforward model for determining the strength-interaction diagram was validated against both experimental results and the developed numerical model. Although the rigid plastic method of analysis used in international codes of practice does not consider local buckling effects, these effects are shown to be significant, especially with larger plate slenderness values and higher axial forces. Consequently, the paper suggests modifications to include slender plated columns in design calculations.

Kenji Sakino et al. conducted a five-year research project as part of the U.S.–Japan Cooperative Earthquake Research Program, focusing on concrete-filled steel tubular (CFT) columns. The study aimed to elucidate the synergistic interaction between steel tubes and the concrete they encase and to establish methods for characterizing the load-deformation relationship of CFT columns. In the experimental phase, 114 specimens were tested under central loading conditions. The research examined various parameters, including tube shape, tensile strength, diameter-to-thickness ratio, and concrete strength, to develop a broadly applicable design method for CFT columns. Based on the test results, design formulas were proposed to estimate the ultimate axial compressive load capacities for both circular and square CFT columns.

W. F. Chen and C. H. Chen investigated the elastic-plastic behavior of pin-ended, concrete-filled steel tubular columns subjected to symmetrical and asymmetrical loading. The study utilized the Column Curvature Curve method to analyze columns with circular and square cross-sections. Three stress-strain relationships for concrete were considered: uni-axial stress, tri-axial stress (increasing ductility but not strength), and tri-axial stress (increasing both ductility and strength). Using these stress-strain curves, the researchers developed interaction curves relating axial force, end moment, and slenderness ratio for maximum load capacity. The results showed good agreement with previously reported experimental data.

Arivalagan S. and Kandasamy S. examined the flexural and cyclic behavior of steel hollow beam sections filled with various types of concrete, including normal mix, fly ash concrete, quarry waste concrete, and low-strength brick-bat-lime concrete. Strain and deflection measurements were taken under two-point loading conditions. A theoretical model was developed to predict the moment-carrying capacity of the beams, and the results were compared with international standards (EC4-1994, ACI-2002, and AISC-LRFD-1999). The study found that the moment-carrying capacity of the beams increased with the compressive strength of the filler materials, and the energy absorption capacity was also enhanced. The analytical results closely matched the experimental findings.

Yaohua Deng et al. conducted an analytical investigation into the flexural behavior of concrete-filled steel tubes (CFTs) and post-tensioned CFTs. The study employed finite-element analysis (FEA) using an elastic-perfectly plastic uniaxial material model for steel and the Drucker-Prager plasticity model for concrete. The theoretical sectional analysis (TSA) involved dividing the cross-section of circular CFT members into horizontal layers parallel to the axis of bending. The study applied the elastic-perfectly plastic uniaxial material model to the steel tube and incorporated confined concrete theory for the concrete core. The results highlighted the composite nature of CFTs, which leverage the strengths of both concrete and steel.

3. EXPERIMENTAL STUDIES

3.1 Material used

1. Cement:

Any cement meeting Indian Standards is suitable for concrete. The choice depends on strength requirements, durability exposure class, and the minimum fines needed for the mix.

2. Fine Aggregates:

Sand fills voids between powders and coarse aggregates, ensuring cohesion and resistance to segregation. Well-graded sand, including particles finer than 150 microns, enhances mix stability.

3. Coarse Aggregates:

Concrete uses normal concreting aggregates, with a maximum size of 40mm, adjusted for reinforcement and formwork. For this project, the size is limited to 12.5mm. Natural aggregates use less water than crushed ones; elongated aggregates are unsuitable.

4. Water:

Potable borewell water, compliant with Indian Standards, is used for mixing and curing concrete.

5. Admixtures:

Admixtures control flow and workability. Super plasticizers are crucial for SCC. Other types include Viscosity Modifying Agents (VMA) for stability, Air Entraining Admixtures (AEA) for freeze-thaw resistance, and retarders for setting control. Additional admixtures like ultra-fine silica or air-entrainers may be needed for segregation control.

Fig. 2 Material Used

3.2 Role of Superplasticizers:

Superplasticizers enable the creation of flowing concretes with slumps up to 250mm without significant bleeding, provided an adequate cement factor is used. Originating in the 1970s, these admixtures allow for highly flowable and cohesive concrete, reducing segregation and bleeding. The key to effective SCC and other flowable concretes is combining superplasticizers with a high content of powder materials, including Portland cement, mineral additions, ground filler, and fine sand. Partial cement replacement with fly ash enhances rheological properties, segregation resistance, strength, and crack prevention in mass concrete structures subject to thermal stresses. Coarse aggregates smaller than 20mm are preferred for optimal performance.

4. TEST PERFORMED

4.1 Tests on Self-Compacting Concrete

Various test methods have been developed to characterize the properties of SCC, but no single method has gained universal approval. Each test targets different workability aspects, so multiple tests are needed for a comprehensive evaluation. For SCC with a maximum aggregate size up to 20mm, typical acceptance criteria are summarized in below Table 1

Table 1 List of Test Methods for Workability Properties of SCC

Sr. No.	Method	Property
1	Slump Flow by Abrams Cone	Filling Ability
2	T50 Cm Slump Flow	Filling Ability
3	J-Ring	Passing Ability
4	V-Funnel	Filling Ability
5	V-Funnel At 5 Minutes	Segregation Resistance
6	L-Box	Passing Ability
7	U-Box	Passing Ability
8	Fill-Box	Passing Ability
9	Gtm Screen Stability Test	Segregation Resistance
10	Orimet Test	Filling Ability

Table 2 Acceptance Criteria for SCC

Sr. No.	Method	Unit	Minimum Value	Maximum Value
1	Slump Flow by Abrams Cone	mm	650	800
2	T50 Cm Slump Flow	Sec	2	5
3	J-Ring	mm	0	10
4	V-Funnel	Sec	6	12
5	V-Funnel At 5 Minutes	Sec	0	+3
6	L-Box	h2/h1	0.8	1.0
7	Fill-Box	%	90	100

4.2 Slump Flow Test and T50cm Test:

The slump flow test measures the horizontal free flow of self-compacting concrete (SCC) without obstructions, originally developed in Japan for underwater concrete. The test involves assessing the diameter of the concrete circle to evaluate filling ability. This simple, rapid test requires two people for measuring the T50 time and is widely used for assessing filling ability, though it does not indicate the concrete's ability to pass through reinforcement. It helps maintain consistency in ready-mix concrete supply. The equipment includes a truncated cone (200mm base, 100mm top, 300mm height), a base plate (700mm square), a trowel, a scoop, a ruler, and optionally a stopwatch. The procedure involves using 6 liters of concrete, moistening the base plate and slump cone, placing the cone centrally on a leveled base plate, filling the cone without tamping, striking off the excess, removing surplus concrete, lifting the cone to let the concrete flow, starting the stopwatch to measure the time to reach a 500mm spread (T50 time), measuring the final diameter in two perpendicular directions, calculating the average diameter (slump flow in mm), and noting any segregation at the edge of the concrete pool. The slump flow (SF) value indicates the concrete’s filling ability, with a minimum of 650mm required for SCC and a tolerance typically ±50mm. The T50 time indicates flowability, with acceptable ranges of 3-7 seconds for civil applications and 2-5 seconds for housing. Significant segregation is shown by coarse aggregate clustering in the center, while minor segregation shows a mortar border.

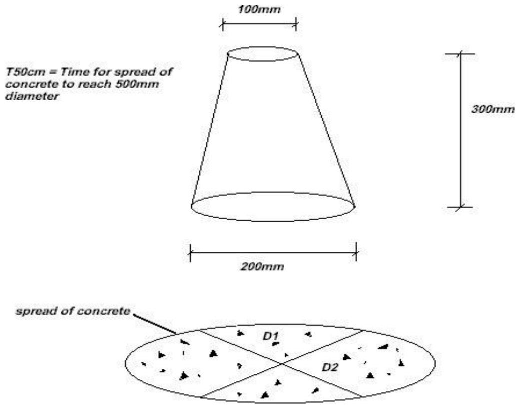


Fig. 3 Slump Flow and T50cm Test

4.3 V-Funnel Test And V-Funnel Test At 5 Minutes

The V-Funnel test, developed in Japan and used by Ozawa et al., measures the filling ability (flowability) of concrete with a maximum aggregate size of 20mm. The test uses a V-shaped funnel to determine the time it takes for about 12 liters of concrete to flow through the apparatus, indicating its flowability. After the initial flow time is recorded, the funnel can be refilled and left for 5 minutes to check for segregation, which would increase the flow time. Although designed to measure flowability, the result is influenced by other concrete properties like aggregate content and paste viscosity. The test's simplicity is offset by unclear effects of the funnel angle and wall effects on concrete flow. Equipment needed includes a V-Funnel, a 12-liter bucket, a scoop, and a stopwatch. The procedure involves moistening the funnel, filling it without compacting, and timing the concrete flow once the trap door is opened. The flow time at 5 minutes follows a similar process but without re-moistening the funnel. Shorter flow times indicate better flowability, with 10 seconds considered appropriate for SCC. Prolonged flow times can indicate potential blocking issues or segregation after settling, reflected in increased flow time and less continuous flow.

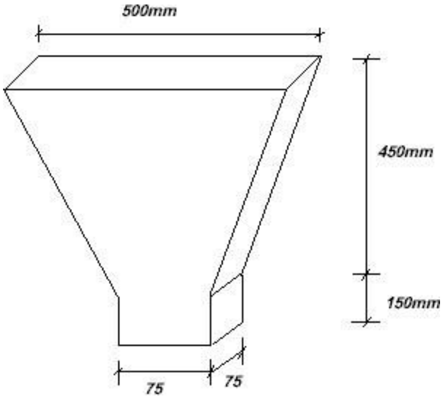


Fig. 4 V Funnel Test

5. EXPERIMENTAL PROCEEDINGS

5.1 Flexure Test

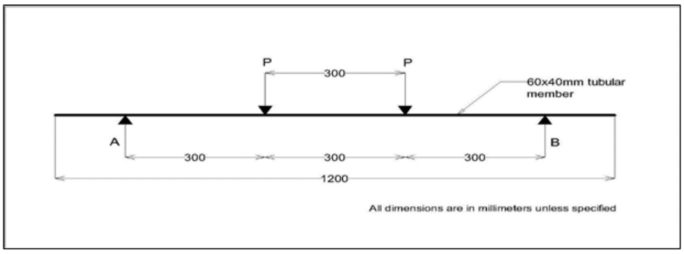


Fig 5 Setup for Flexure Test

For the preparation of the experimental set-up for the flexure test, SS tubes of length 1.2m were prepared to be tested for flexural strength. Two-point loading configuration was used for applying the load, facilitating the application of pure bending theory for simplified calculations. Four specimens were prepared: two hollow and two filled with SCC of grade M20. These specimens were tested using the two-point load configuration as depicted in Fig 5. The following graphs were plotted based on the test results: Stress-Strain Curve, Moment-Curvature Curve, and Load Deflection Curve.

Fig 6 Picture of Flexure Test

Table 3 Shows Flexure Test Results

Specimen	Ultimate Load	Ultimate Stress	Ultimate Moment
Hollow specimens			
1.	25.05 kN	118.75 N/mm^2	3757.5 N-m
2.	27.05 kN	156.25 N/mm^2	4057.5 N-m
3.	22.18 kN	138.63 N/mm^2	3327 N-m
4.	26.97 kN	168.58 N/mm^2	4046 N-m
In-filled specimens			
1.	32.93 kN	205.81 N/mm^2	4939 N-m
2.	34.37 kN	212.5 N/mm^2	5155 N-m
3.	32.07 kN	200.42 N/mm^2	4810 N-m
4.	33.00 kN	206.26 N/mm^2	4950 N-m

Fig 7 View of the test set-up

Fig. 8 Bending of the specimen.

Fig 9 Specimen after removal of load.

Fig 10 Bending of hollow specimen with slight crimping at points of application of load.

Fig 11 Bending at mid span in In-filled specimen.

Note: No crimping nearpoints of load application

Fig 12 Local buckling of hollow specimen

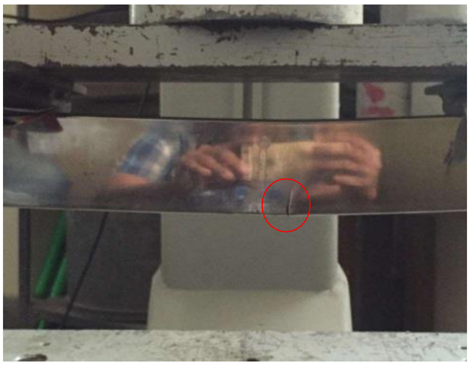
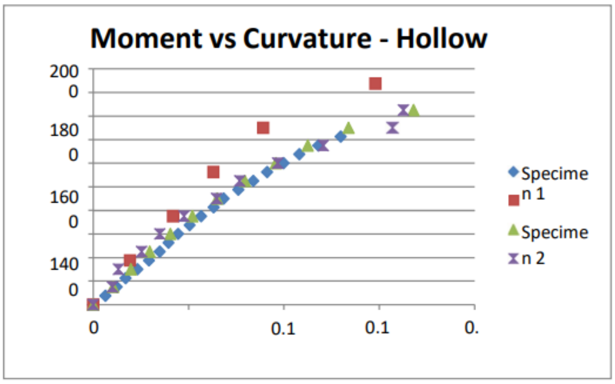
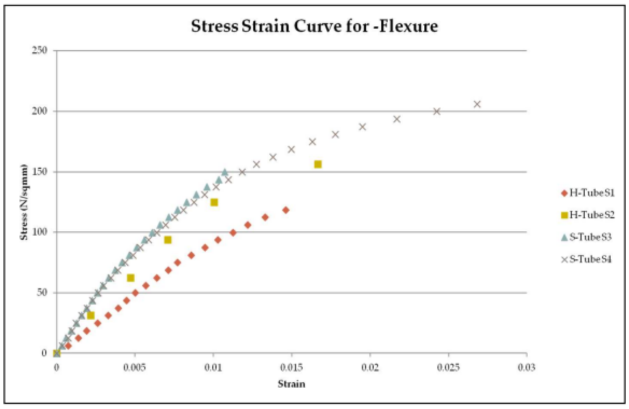


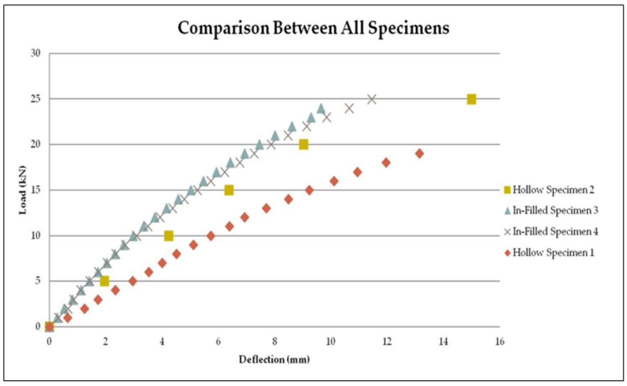
Fig 13 Failure crack in In-filled Specimen



Graph 1 Plot of moment vs. Curvature for hollow specimens subjected to flexure loading



Graph 2 Comparison of plots of stress strain for all specimens subjected to flexure loading



Graph 3 Plot of load vs. deflection for all specimens subjected to flexure loading

5.2 Compression Test

Fig. 14 illustrates the experimental set-up for the compression test to determine compressive strength and other parameters. The preparation involved leveling the specimens to ensure axial loading. Two indents were made on one face of each specimen for attaching the De-mech dial gauge. Loads and corresponding deflections were recorded, and parameters such as stress and strain were calculated (Appendix B). The following graphs were plotted: Stress vs. Strain and Load vs. Deflection.

Fig. 14 Experimental set-up for compression testing.

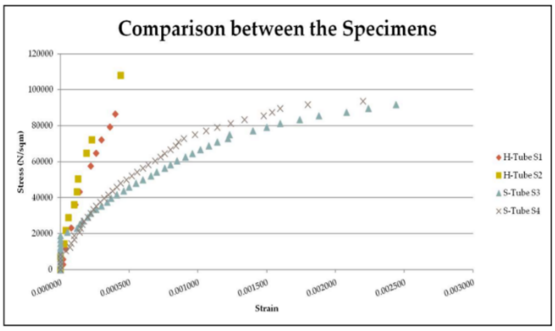
Table 4 Shows Compression Test Results

Specimen	Ultimate Load	Ultimate Stress
Hollow Specimen		
1.	120.00 kN	50.00 N/mm^2
2.	123.43 kN	51.43 N/mm^2
3.	147.50 kN	61.46 N/mm^2
4.	156.00 kN	65.00 N/mm^2
In-Filled Specimen		
1.	237.00 kN	98.75 N/mm^2
2.	227.00 kN	94.58 N/mm^2
3.	228.00 kN	95.00 N/mm^2
4.	235.50 kN	98.13 N/mm^2

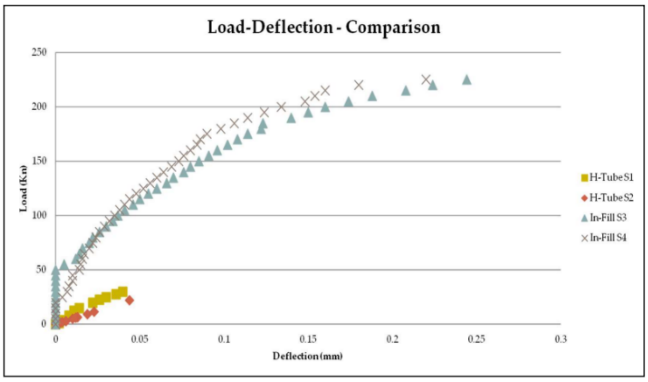
Fig. 15 Failure in Filled Section

Fig 16 Buckling of Specimen

Fig 17 Splitting of Specimen



Graph 4 Comparison of plots of Stress vs. Strain curve for specimens subjected to axial compression loading.



Graph 5 Comparison of plots of Load vs. Deflection for all specimens subjected to axial compression

6. CONCLUSION

The study revealed that both hollow and in-filled specimens possess distinct advantages and disadvantages. In-filled specimens exhibited a significantly higher load-carrying capacity compared to hollow specimens, indicating their superior performance in structural applications. During flexure testing, the failure mode of in-filled specimens was characterized by cracking on the tensile face, showcasing their ability to withstand tensile stresses better than their hollow counterparts. On the other hand, hollow specimens primarily failed due to local buckling at the points of loading, a behavior well-documented in the photographs taken during the testing process. This comparison highlights that while in-filled specimens are more robust in terms of load-bearing, hollow specimens may be more susceptible to deformation under localized stress, emphasizing the need to consider the specific application requirements when choosing between these two types of structural elements.

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