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To Study Behavior of Concrete Filled PVC Tubes by using ANSYS

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Abstract

This study investigates the structural behavior of Concrete Filled Polyvinyl Chloride Tubes (CFPTs) subjected to axial loading, aiming to evaluate their potential as an economical and sustainable alternative to traditional steel tubular columns. Experimental and analytical analysis were conducted to assess the load-bearing capacity, deformation characteristics, and strength-to-weight ratios of three types of specimens - Concrete Filled PVC Tubes (CFPT), Concrete Filled Double Skinned PVC Tubes (CFDPT), and Concrete Filled Double Skinned Hollow PVC Tubes (CFDHPT). M30 grade concrete was used as the infill material, and testing was performed using a Universal Testing Machine (UTM) in accordance with Indian Standard codes. Analytical simulations were carried out using ANSYS Workbench to validate experimental findings. Results indicate that CFPT and CFDPT specimens exhibit comparable load-carrying capacities, while CFDHPT provides a lighter configuration with moderate strength. The analytical results closely matched experimental outcomes, with variations within 5–10% for load capacity and 10–20% for deformation. The study concludes that PVC tubes offer a durable, corrosion-resistant, and cost-effective solution for composite columns, promoting sustainable and efficient construction practices.

Keywords: Concrete Filled PVC Tubes (CFPT), Axial Loading, ANSYS Analysis, CFPT Columns, Composite Columns, PVC Tube.

1. Introduction

Modern Composite columns, where mostly the concrete-filled tubular types play an important role in modern architecture and structures, are not fully researched. PVC pipes are used in construction because of their toughness, versatility, and capacity to endure environmental challenges. PVC can be an alternative to steel. They can act as molds in construction projects, lowering expenses. Due to its durability and strength-to-weight ratio, PVC is utilized in infrastructure for its cost-effectiveness and enduring properties. This research assesses load-bearing capability and deformation under axial loading to solve economic and environmental problems for the building sector.

Vinyl chloride can be polymerized to create PVC, or polyvinyl chloride, a polymer. PVC is utilized in various items, including pipes, doors, cables, and windows, among others. Because of its unique properties, it can be used in lightweight construction to improve structural members like columns. Composite columns have been thoroughly investigated and utilized, particularly steel tubes filled with concrete. FRP sheets improve column reinforcement by increasing compressive strength, ductility, and durability. However, FRP's high cost limits its usage in lightweight structures. Column confinement with PVC is affordable. PVC tubes are widely used as formwork and permanent structural elements due to their strength, flexibility, and resistance to climatic conditions. PVC is perfect for pilings and poles since it is lightweight, impermeable, and has a 50-year lifespan.

The main goal of this project is to investigate the benefits, structural behavior, and real-world uses of CFPTs. To maximize their application in architectural and engineering projects, it also looks into design concerns, material choices, and building procedures. The research intends to add to the expanding body of knowledge about CFSTs and their function in promoting resilient and sustainable infrastructure by exploring experimental analyses and real-world case studies. Additionally, using an ANSYS, concrete-filled steel tubes with different hollow steel tube geometries are modeled and analyzed. Additionally, perform experimental analysis, compare the results of analytical and experimental analysis, and perform a cost-benefit analysis.

2. Objectives:

1. To study current scenario of CFPT’s material and its design properties.
2. To perform experimental analysis of CFPT based on properties.
3. To conduct structural investigations on concrete filled PVC tubular columns.
4. To develop design specimen and perform analysis of CFPT by using ANSYS.
5. To compare outcomes of experimental and analytical analysis along with its cost benefit analysis.

3. Methodology

The procedure describes in this chapter includes materials, mix designs, details of specimen, experimental and analytical experimental procedure. Where in experimental procedure includes preparation, concrete mixing, casting of specimens, compacting, curing of specimens, and testing of specimen using Universal Testing Machine while in Analytical procedure includes Ansys software, project setup, model generation, material defining, meshing, loading and solutions. Each step has been carefully planned and executed to meet the technical requirements of the project.

To study and gather information on the present situation of CFPT with Research papers and Literature review.

1. To select the CFPT material as per the design requirements.
2. To develop CFPT specimen, Design and cast the specimen as per the structural and functional requirements.
3. To perform experimental analysis, by placing CFPT specimen under loading.
4. To develop design model and perform analytical analysis using ANSYS software.
5. To compare the outcomes of experimental analysis with analytical analysis to evaluate results and conclusion.

6. Drafting of report.

3.1. Materials

For the Concrete Filled PVC Tube specimens concrete is used as composite due to its strength, durability and versatility. Where the primary material used in concrete cement, coarse aggregate, fine aggregate (river sand) and water as well as Polyvinyl Chloride (PVC) Tubes are used for external cover of the specimen.

3.1.1. Cement

Here used Ordinary Portland Cement (OPC) of 53 grade that met the IS:12269-1987. The cement must to be uniform sized. The material should not be used if there is any indications of lumps or other materials are present. For a short period as possible, the cement should be kept under dry conditions.

3.1.2. Coarse Aggregate

In this experimental studies, the coarse aggregate with crushed angular in shapes of 20 mm, 10 mm and 6 mm sizes were used. The aggregates are used in concrete, the aggregates are dust-free and meet IS 383- 1970 specifications.

3.1.3. Fine Aggregate

The fine aggregate is high quality sand with particle size are of less than 4.75mm sizes. Hence in the river sand is used in this experimental investigation. The fine aggregates are cleaned and dust-free before used in the concrete and conforming to the requirements of IS 383-1970.

3.1.4. Polyvinyl Chloride Pipes (PVC)

Pipes made from the polymerization of vinyl chloride monomers, PVC is known for its excellent strength, durability and chemical resistance. These pipes are lightweight, easy to use, one of the major advantages of PVC pipes is their resistance to corrosion, chemicals and biological degradation. This experimental investigation used PVC pipes made of Polyvinyl Chloride with diameter of 110 mm and 50 mm pipes as shown below in figure. Where the external PVC pipe with diameter 110 mm and internal secondary PVC tubes with dimeter 50 mm. And cleaned before use in specimen without dust.

3.2. Experimental Procedure

Testing of Concrete Filled PVC Tubes is essential to evaluate their structural behaviour, particularly under axial compressive loads. The primary objective is to determine parameters such as load carrying capacity, deformation behaviour and stress strain response. The most common test performed is axial compression testing, conducted using a Universal Testing Machine (UTM). The 200 KN capacity Universal Testing Machine (UTM) is used to test the specimen. And for cubes Compression Testing Machine (CTM) is used to test cube specimen.

Test of compressive strength for concrete specimen are conducted as per IS 516:1959 clause number 5. This clause procedure and determining the compressive strength of concrete specimen as shown below.

3.2.1. Mix Design for Concrete

In order to create concrete with the required strength, durability, and workability, the mix design process involves choosing the right materials and figuring out their proportions. For this investigation concrete mix design done by Indian Standard method (IS 10262:2009). These methods consider factors such as target mean strength, workability requirement, exposure conditions size of aggregates and type of cement. And concrete mix ratio for M30 grade is 1:2.03:2.83 employed with water-cement ratio of 0.5 in order to increase the mix workability.

3.2.2. Specimen Design

For this experimental study there the total nine concrete filled PVC tube specimens are prepared with three groups where every group contains three number for specimens as well as three cube specimens also prepared for compressive test of concrete as per details.

Total number of three cubes with dimensions 150 mm × 150 mm × 150mm. and M30 grade of concrete is used as per concrete design. As per IS 456:2000 clause 15.3, Total number of three cubes where casted of size 150 mm × 150 mm × 150 mm.

Total Concrete Filled Specimen divided into three groups according to its different types and filled with M30 grade of concrete, Concrete Filled PVC Tubes (CFPT's), Concrete Filled Double Skinned PVC Tube (CFDPT), and Concrete Filled Double Skinned Hollow PVC Tube (CFDHPT). Every group contains three specimens. The specimen typically consists of the circular PVC pipes, there are total nine specimens as shown in Table.

Table 1**:** Specimen Details

Sr. No.	Name of Specimen
Group - 1	CFPT - 1
	CFPT - 2
	CFPT - 3
Group - 2	CFDPT - 1
	CFDPT - 2
	CFDPT - 3
Group - 3	CFDHPT - 1
	CFDHPT - 2
	CFDHPT - 3

Concrete Filled PVC Tubes (CFPT), Concrete Filled Double skinned PVC Tube (CFDPT) and Concrete Filled Double skinned Hollow PVC Tube (CFDHPT) specimen are designed to observe the structural behaviour of composite system under axial loading. For CFPT specimen consist of the circular PVC pipes filled with the concrete without internal reinforcement as shown in Figure 1.

And CFDPT specimen typically consist of the two circular PVC pipes filled with the concrete, by replacing internal reinforcement with secondary PVC tube, this both primary and secondary PVC tubes filled with M30 grade of concrete as per designed for CFDPT specimens as shown in Figure 2.

Also CFDHPT specimen typically consist of the two circular PVC pipes, where only gap between primary and secondary tube filled with the M30 grade of concrete, as shown in Figure 3.

and the core of the specimen kept hollow.For study PVC tube with 110 mm diameter and 450 mm depth were selected as primary which is work as external casing and the secondary tube with 50 mm diameter

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and 450 mm depth were selected based on the commercially available sizes. The height to diameter ratio was maintained at approx. 4:1, this PVC tubes filled with M30 grade of concrete as per designed.

Figure 1: Section of CFPT

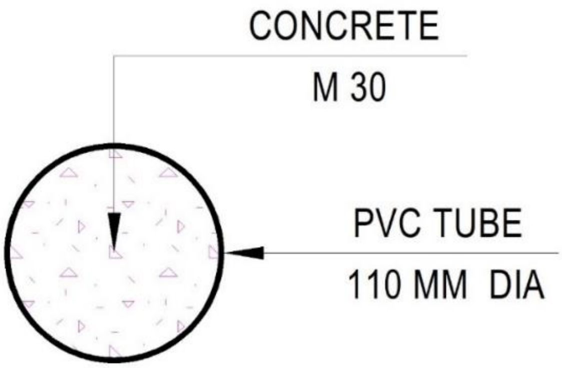


Figure 2: Section of CFDPT

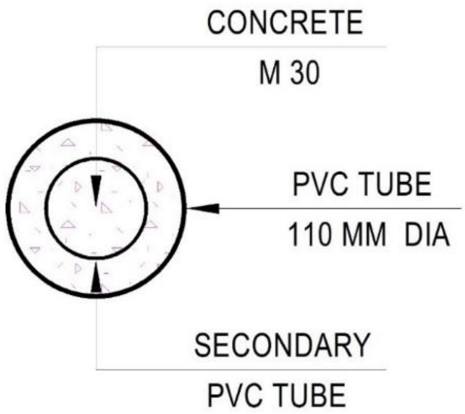
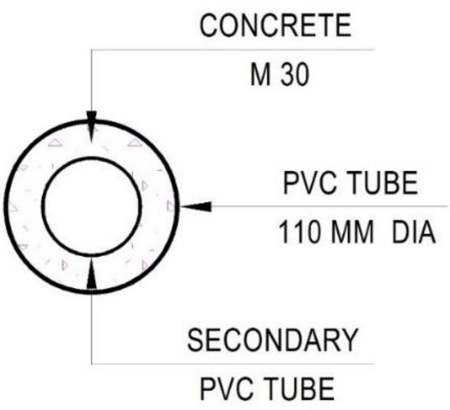


Figure 3: Section of CFDHPT



3.2.3. Specimen Casting and Curing

Each sample must have three test specimens created for testing within 28 days, per IS 456:2000 clause 15.3. The primary three PVC Tubes with 110 mm diameter and 450 mm depth as well as secondary 50 mm diameter tubes with equal height have been cleaned of dust particles and secondary tubes placed into the center then the concrete mix is poured into the specimens (PVC tubes). Three layers of well-mixed, uniformly spaced concrete are poured into the PVC tubes, followed by the concrete is tamped. Using a trowel, excess concrete is removed, and the top surface is leveled off. In that case here PVC tubes itself work as a formwork.

Figure 4: Concrete Cube

Figure 5: CFPT, CFDPT & CFDHPT specimen

For best results cubes and concrete filled PVC specimens should be kept undisturbed for the first 24 hours after casting. Then cubes and concrete filled PVC specimen placed inside water for curing purpose, the specimens were cured for 28 days.

Figure 6: Curing of Cubes

Figure 7: Curing of CFPT specimens

3.2.4. Test Program

Testing of Concrete Filled PVC Tubes is essential to evaluate their structural behaviour, particularly under axial compressive loads. The primary objective is to determine parameters such as load carrying capacity, deformation behaviour and stress strain response. The most common test performed is axial compression testing, conducted using a Universal Testing Machine (UTM). The 200 KN capacity Universal Testing Machine (UTM) is used to test the specimen. And for cubes Compression Testing Machine (CTM) is used to test cube specimen. Test of compressive strength for concrete specimen are conducted as per IS 516:1959 clause number 5.

Figure 8: Cube specimen Test Setup

Figure 9: CFPT specimen Test Setup

3.3. Analytical Procedure using ANSYS

ANSYS Workbench process involves creating a 3D model, assigning material properties to concrete and PVC applying boundary conditions including fixing the bottom face and applying an axial load on the top face to replicate compression and generating a mesh for finite element analysis. ANSYS computes stress distribution, deformation and failure patterns. This method helps to visualize behaviour, validate experimental results and optimize design parameters, offering a cost effective and efficient approach for evaluating complex structural system like CFPT.

Figure 10: ANSYS Procedure

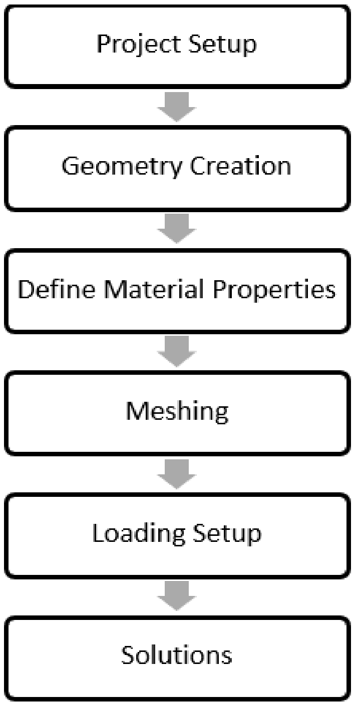


Figure 11: Project Setup

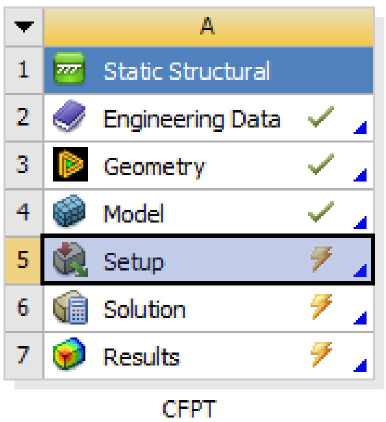


Figure 12: Geometry of CFPT

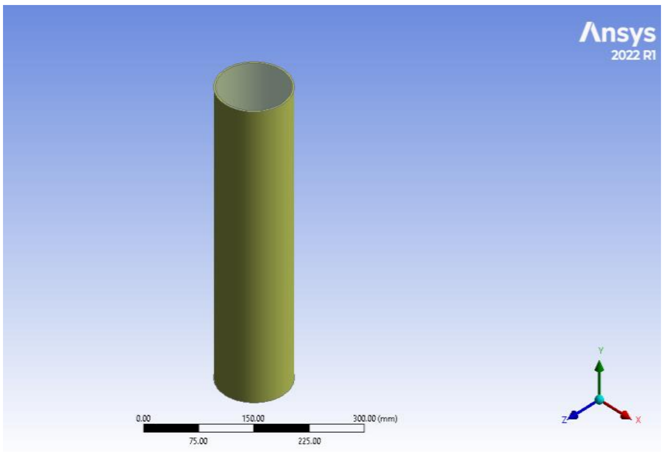
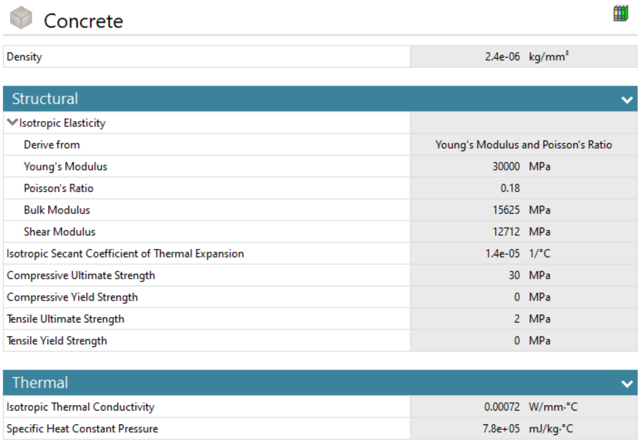


Figure 13: Properties of Concrete



Concrete	
Density	2.4e-06 kg/mm³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	30000 MPa
Poisson's Ratio	0.18
Bulk Modulus	15625 MPa
Shear Modulus	12712 MPa
Isotropic Secant Coefficient of Thermal Expansion	1.4e-05 1/°C
Compressive Ultimate Strength	30 MPa
Compressive Yield Strength	0 MPa
Tensile Ultimate Strength	2 MPa
Tensile Yield Strength	0 MPa
Thermal	
Isotropic Thermal Conductivity	0.00072 W/mm·°C
Specific Heat Constant Pressure	7.8e+05 mJ/kg·°C

Figure 14: Meshing the CFPT model

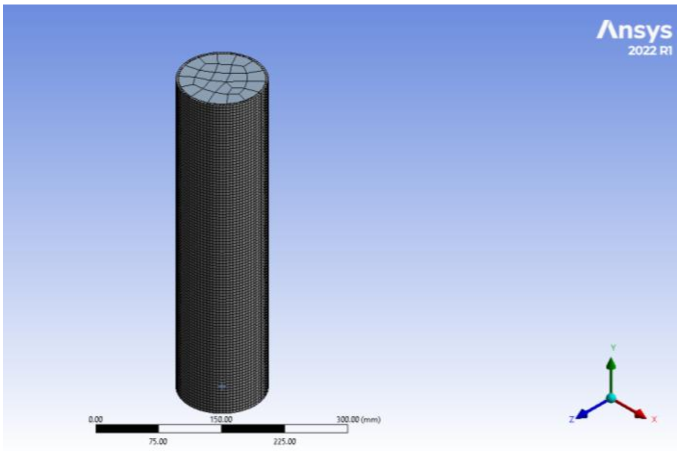
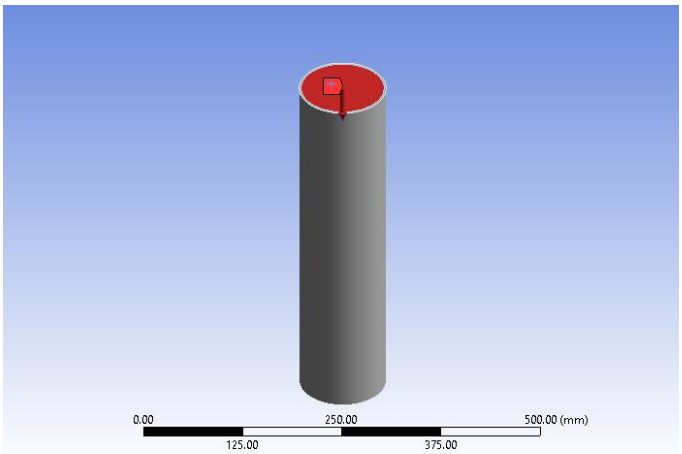


Figure 15: Loading on the CFPT model



4. Results and Discussion

4.1. Cube Testing

This cube was put in a Compression Testing Machine (CTM) after it had cured. Once the load is applied consistently at a given rate, the maximum load at which failure occurs is noted. The failure load is divided by the cross-sectional area of the cubes to determine the compressive strength. Important details regarding the strength, durability, and quality of concrete are provided by this test. The results are displayed in the table.

Figure 16: Cube under Compression

Table 2: Compressive strength of cubes after 28 days of curing

Sr. No.	Curing (Days)	Weight of Cube (Kg)	Dimensions of Cube (mm)	Density of Cube (kg/m^3)	Failure Load (KN)	Average Compressive Strength (N/mm^2)
S1.	28	8.24	150×150×150	2443.22	690	29.92
S2.	28	8.16	150×150×150	2419.62	670	
S3.	28	7.9	150×150×150	2342.42	660	

4.2. Weight of Specimens

Before testing each CFPT specimen is carefully weighed using a digital weighing scale after 28 days curing period. The weight includes mass of PVC tube and the concrete core. Then the weight is used to calculate strength to weight ratio of specimens. Weight of each specimen recorded and shown in f table

Table 3: Weight of Concrete Filled PVC Tube Specimen

Sr. No.	Name of Specimen	Weight (Kg)
Group - 1	CFPT - 1	10.34
	CFPT - 2	10.37
	CFPT - 3	10.39
Group - 2	CFDPT - 1	10.44
	CFDPT - 2	10.45
	CFDPT - 3	10.47
Group - 3	CFDHPT - 1	8.47
	CFDHPT - 2	8.49
	CFDHPT - 3	8.52

4.3. Experimental and Analytical Results

4.3.1. Concrete Filled PVC Tubes (CFPT)

Table 4: Experimental results of CFPT specimens

Sr. No.	Name	Failure Load (KN)	Deformation (mm)	Average Strength (KN)
1.	CFPT-1	203	8.29	207.7
2.	CFPT-2	216	12.69	
3.	CFPT-3	204.10	9.70	

Table 5: Analytical results of CFPT specimens using ANSYS

Sr. No.	Name	Failure Load (KN)	Deformation (mm)	Average Strength (KN)
1.	CFPT-4	220	6.94	220

Figure 17: Comparison of Experimental and Analytical results of each CFPT

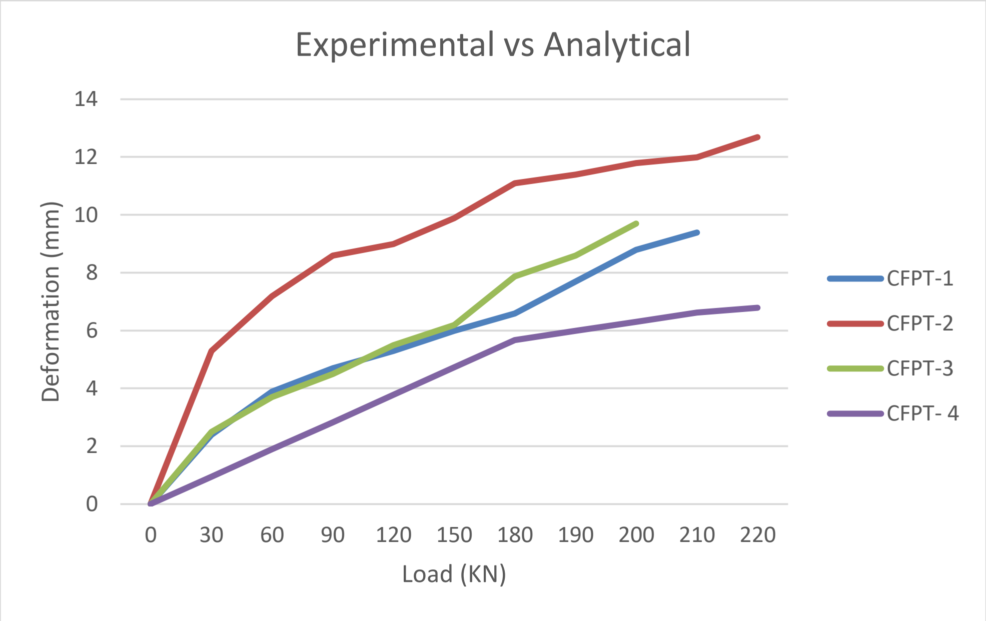


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Figure 18: Deformation of CFPT-1, CFPT-2, CFPT-3

Figure 19: Deformation of CFPT using ANSYS

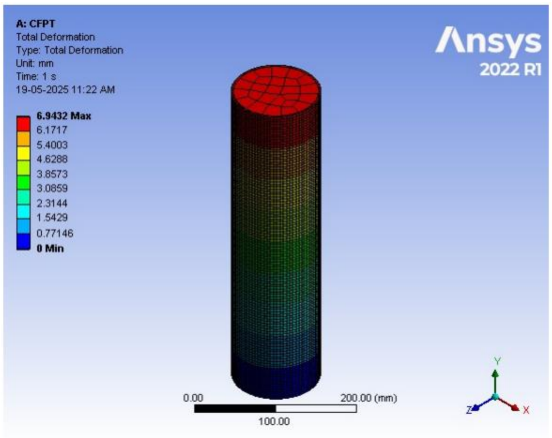
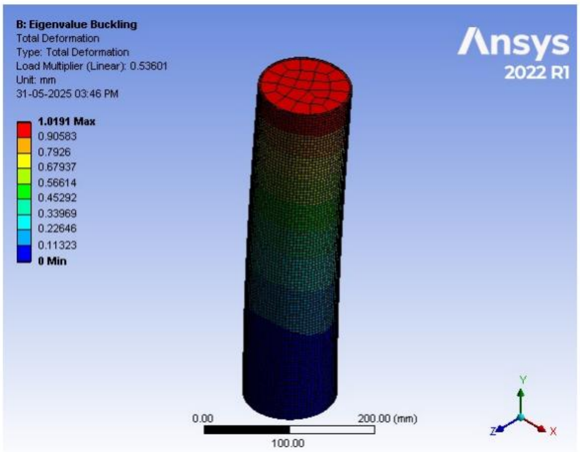


Figure 20: Buckling of CFPT using ANSYS



4.3.2. Concrete Filled Double skinned PVC Tubes (CFDPT)

Table 6: Experimental results of CFDPT specimens

Sr. No.	Name	Failure Load (KN)	Deformation (mm)	Average Strength (KN)
1.	CFDPT-1	205.47	10.99	206.30
2.	CFDPT-2	210.45	10.79	
3.	CFDPT-3	203.00	14.49	

Table 7: Analytical results of CFDPT specimens using ANSYS

Sr. No.	Name	Failure Load (KN)	Deformation (mm)	Average Strength (KN)
1.	CFDPT-4	220	9.29	220

Figure 21: Comparison of Experimental and Analytical results of each CFDPT

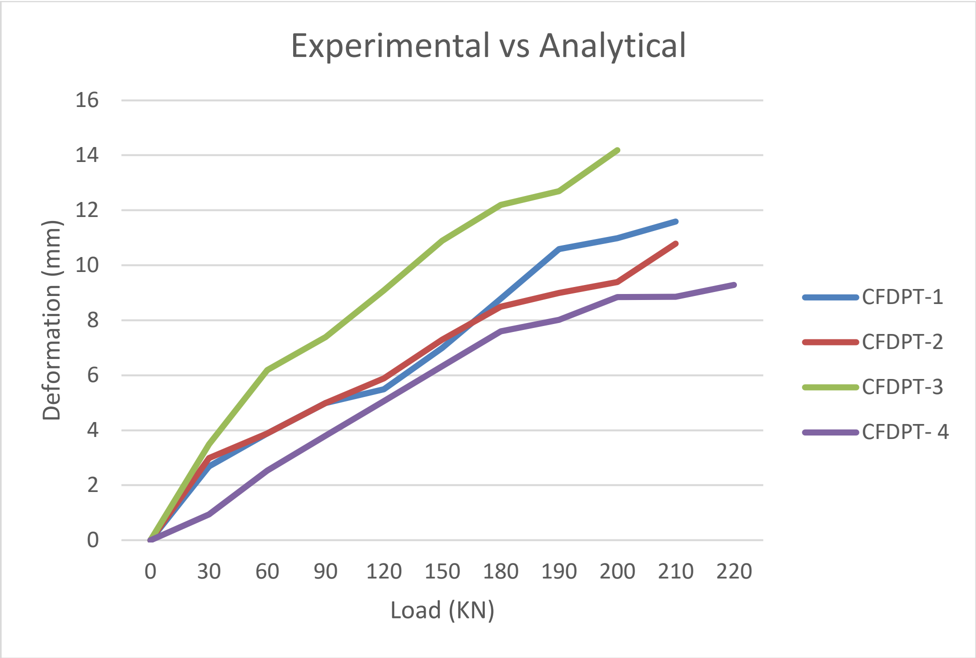


Figure 22: Deformation of CFDPT-1, CFDPT-2, CFDPT-3

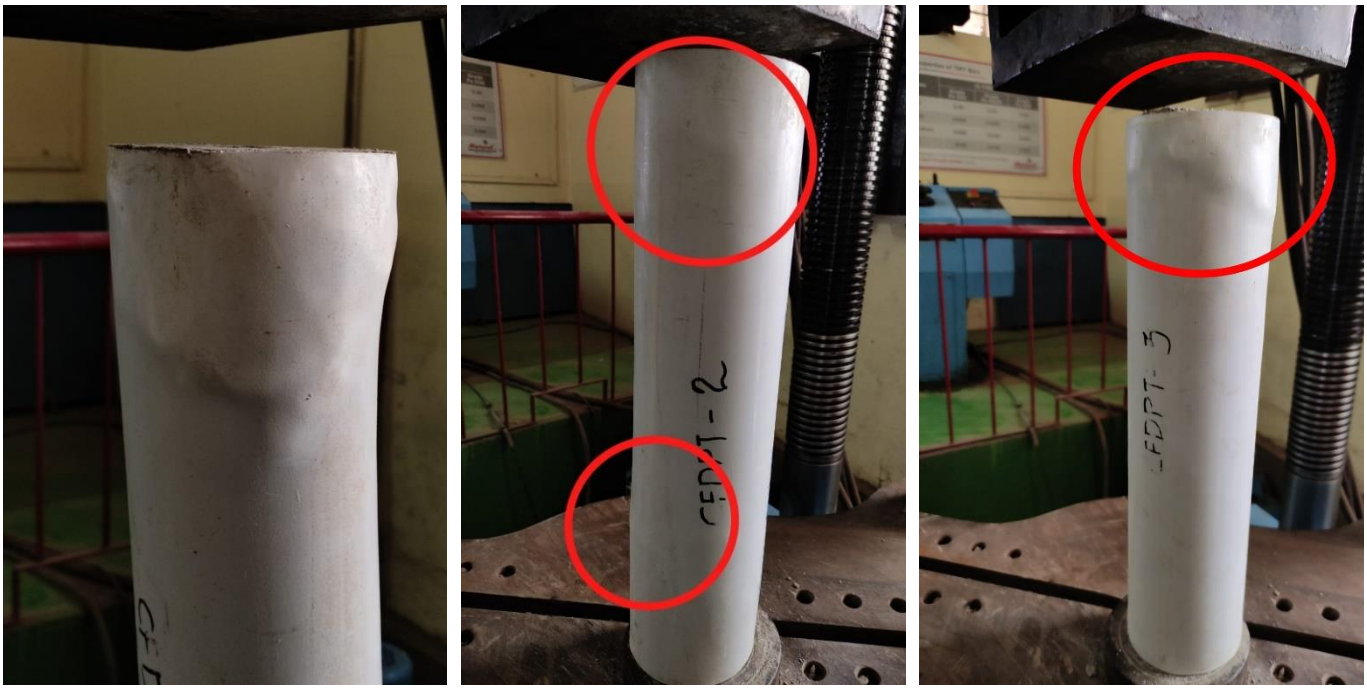


Figure 23: Deformation of CFDPT using ANSYS

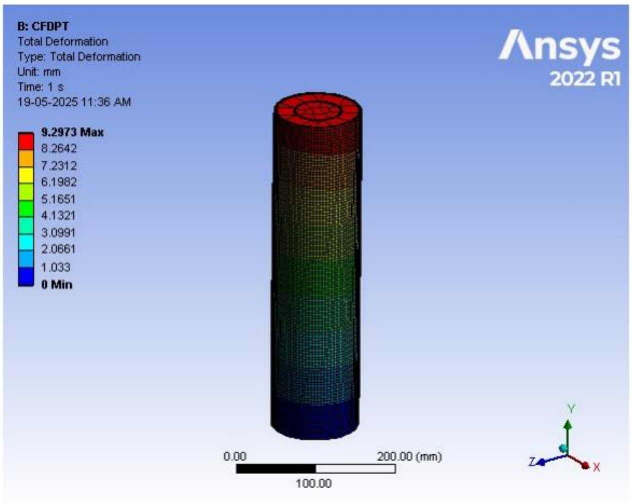
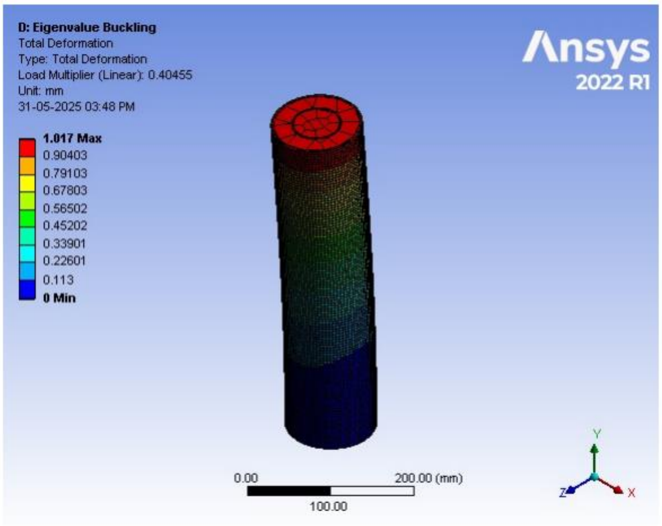


Figure 24: Buckling of CFDPT using ANSYS



4.3.3. Concrete Filled Double skinned Hollow PVC Tubes (CFDHPT)

Table 8: Experimental results of CFDHPT specimens

Sr. No.	Name	Failure Load (KN)	Deformation (mm)	Average Strength (KN)
1.	CFDHPT-1	154.38	8.59	144.27
2.	CFDHPT-2	148.45	7.29	
3.	CFDHPT-3	130.00	9.69	

Table 9: Analytical results of CFDHPT specimens using ANSYS

Sr. No.	Name	Failure Load (KN)	Deformation (mm)	Average Strength (KN)
1.	CFDHPT-4	160	7.97	160

Figure 25: Comparison of Experimental and Analytical results of each CFDHPT

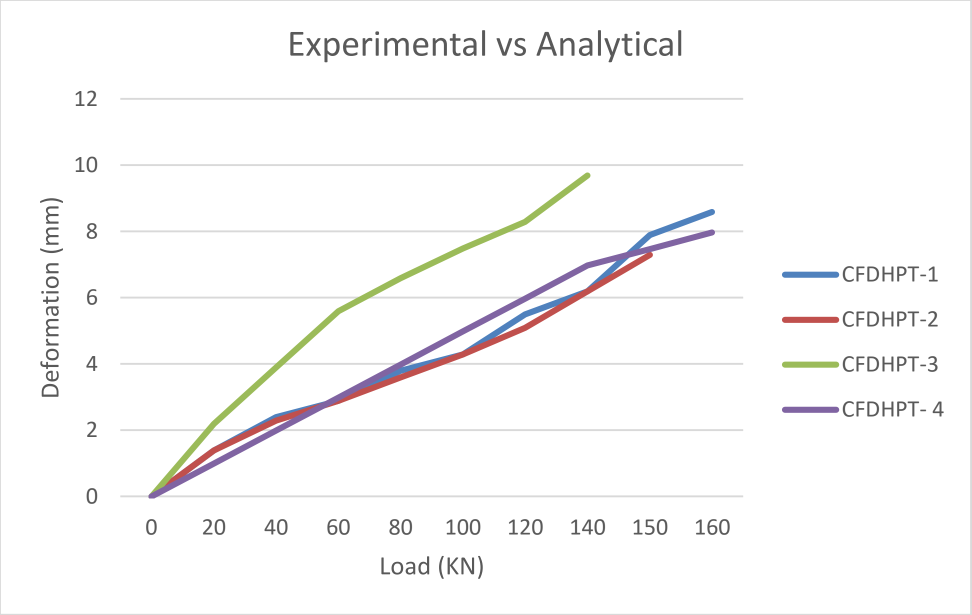


Figure 26: Deformation of CFDHPT-1, CFDHPT-2, CFDHPT-3

Figure 27: Deformation of CFDHPT using ANSYS

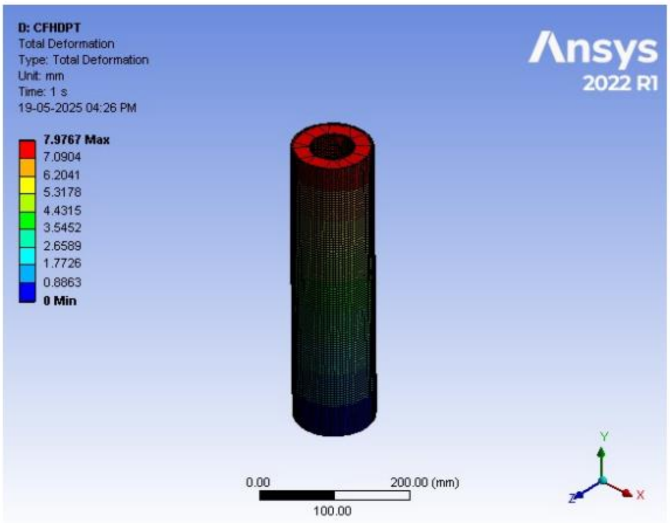
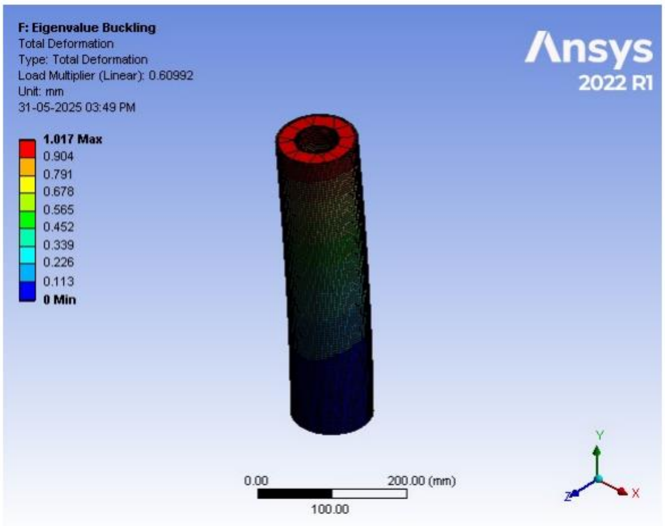


Figure 28: Buckling of CFDHPT using ANSYS



4.4. Comparison of Strength-to-Weight ratio of CFPT specimens

Table 10: Concrete Filled PVC Tube specimen's Strength to Weight ratio

Name of Specimen	Weight (Kg)	Load (KN)	Strength-to-Weight ratio	Average
CFPT - 1	10.34	203.00	19.63	20.03
CFPT - 2	10.37	216.00	20.82	
CFPT - 3	10.39	204.10	19.64	
CFDPT - 1	10.44	205.47	19.68	19.81
CFDPT - 2	10.45	210.45	20.13	
CFDPT - 3	10.47	194.23	18.55	
CFDHPT - 1	8.47	154.30	18.21	17.13
CFDHPT - 2	8.49	148.45	17.48	
CFDHPT - 3	8.52	134.00	15.72	

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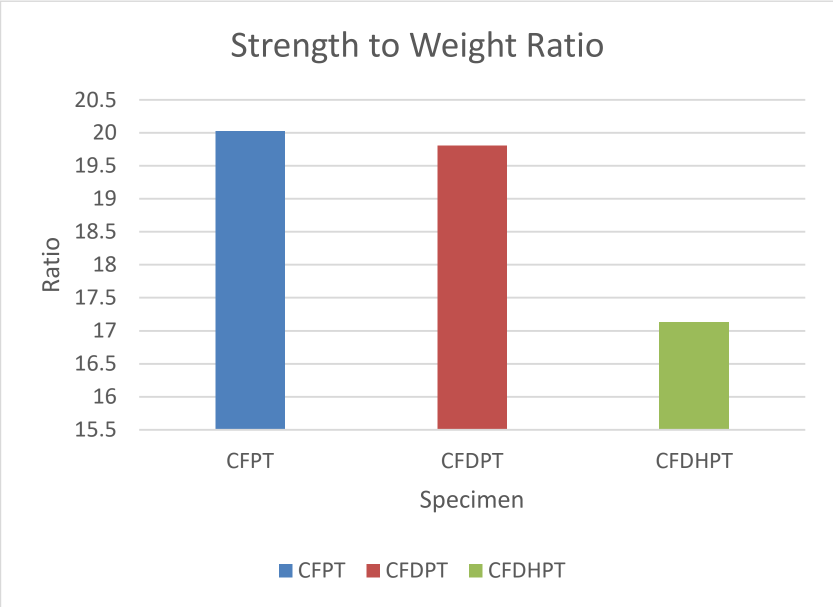
Figure 29: Average Strength to Weight ratio comparison of CFPT specimen



CFPT, CFDPT and CFDHPT have unique advantages. While CFPT offers maximum strength, CFDPT also shows the similar results as CFPT specimen but CFDHPT provides a lighter solution with satisfactory strength. Hollow space reduces weight and cost-efficiency but also reduces the strength of specimen as compared to CFPT and CFDPT.

5. Conclusion

To observe the behaviour of Concrete Filled PVC Tube, a detailed study has been carried out by using experimental method as well as analytical method using ANSYS software. And following conclusions are drawn based on the test results and observations.

1. This study shows that Polyvinyl Chloride (PVC) tubes can be building alternative material for cost effectiveness.
2. Research shows that Concrete Filled PVC can withstands axial stress and resist sudden failure.
3. CFPT and CFDPT shows similar results in load carrying capacity, where CFDPT has capacity to undergoes more deformation than CFPT because of double PVC tubes which helps to resist sudden failure of the member.
4. Strength to weight ratio gives CFDHPT good advantage, but as compare to CFPT and CFDPT. CFDHPT has less loads carrying capacity.
5. Deformation results obtained from ANSYS software varied from 10% to 20% when compared with experimental results.
6. When compared to experimental results, the load bearing capacity results using ANSYS software ranged from 5% to 10%. The outcomes from experiments and those from ANSYS software are almost the same.
7. Experimental data combined with ANSYS simulation provides complete understanding of the Concrete Filled PVC Tubes.
8. Also report shows CFPT environmental resistance, lightweight, and ability to minimize construction difficulties.

By examining PVC's flexibility in structural uses, this study aids in advancing sustainable building methods.These findings can help structural industry to adopt sustainable and cost-effective techniques.

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