BENDING BEHAVIOUR OF CONCRETE FILLED STEEL TUBE (CFST) WITH CARBON FIBRE REINFORCED POLYMER (CFRP)

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by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Ehsan Nikbakht Jargouyeh)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

January 2022

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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RAFELLINO RONNIE WISIL

ABSTRACT

The current work is focusing on the bending behaviour of concrete-filled steel tube (CFST) with carbon fibre reinforces polymer (CFRP) wrapping to minimize the environmental as well as cost-consuming problems on strengthening steel tubes. The process of cathodic protection to condition the steel tube may cause loss of adherence between metal substrates and cathodic coating occur due to a reduction reaction in the coating's interface. Hence, this research aims to propose a new method, which the CFRP will be wrapped around the CFST. CFRP has a very high, tensile strength when it comes to strength properties, so it can be the next solution to fix or prevent any steel deformation or corrosion. The testing is undergone by bending the middle part of the CFST wrapped with different layers of CFRP respectively. The results obtained in this research will highlight the bending behaviour of the CFST with CFRP wrapping. It is proven that the CFST wrapped with three-layered CFRP obtained a higher strength as well as a greater ductility compared to the CFST wrapped with two-layered CFRP.

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CHAPTER 1: INTRODUCTION

1. Background of Study

The growth of a population has an impact on the development of a region. All of these developments will contribute to the construction industry's rapid expansion. To keep up with the changes, the sector may require innovative and quick technologies. Enhancing the capabilities of materials used in the construction sector is one answer. Concrete and steel technology progress is one of the fields that is now being researched in order to create better constructed buildings in the future. Composite materials are made up of two or more materials, such as steel and concrete.

The concrete filled steel tube (CFST) is built of hollow steel with a concrete core inside. The steel's strength and performance vary depending on its cross section. The cross section can take the form of a circle or a rectangle. The only requirement is that the concrete structure be substantial and capable of carrying a heavier load. Because steel is lighter, the structure's weight can be reduced by using steel beams and columns.

The use of fiber reinforced concrete as infilling to improve the behavior of CFST columns has been studied for several decade. The CFST is wrapped with carbon fibre reinforced polymer (CFRP). It will be tested with various layers of CFRP to see how they affect the CFST behaviour. The varied layers of CFRP will improve the moment capacity, energy absorption capacity, and flexural stiffness of the CFST. Studies show various types of improvements that can be implemented to strengthen the CFST, however by adding layers of CFRP may improve the condition and performance of the steel tube.

1.1 Problem Statement

The behaviour of the composite material, which is concrete and steel, is still being studied through trials. To get the best strength and performance, CFST has undergone a lot of improvement and variety. Despite the fact that CFST has improved its performance by increasing ductility and stiffness, it still has a number of drawbacks.

The use of Carbon Fibre Reinforced Polymer can be reliable to strengthen the pipeline as it has a high strength material and superior fatigue performance. Only a few studies have looked at the response of steel pipeline or beams that have been strengthened in shear using CFRP laminate. This is because conventional ways have been used to overcome the corroded steel beams or pipeline.

A series of analytical and laboratory steps will be conducted, which determining the bending behaviour of the steel pipeline. The tests can be time consuming and the results may inaccurate despite the tests are basedon scientific theories.

1.2 Objectives

- To determine the bending behaviour of the CFST buckling.
- To identify the strength of the CFST that is wrapped with different CFRP layers.
- To investigate the effectiveness of CFRP for repairing and strengthening of CFST.

1.3 Scope of Study

For the project, a high-performance concrete filled steel tube will be used. HPC, or high-strength concrete, is commonly utilized in tall structures to sustain heavier loads. The purpose of the project is to determine the structural behaviour under bending of the CFST with an aid of Carbon Fibre Reinforced Polymer (CFRP). CFRP has a high tensile strength, so it will be paste at the middle part of the steel tube. A total of 3 and 5 layers of CFRP will be compared, and the result will be determined by comparing the forces, resistances, maximum deflections, and displacements of the pipeline.

CHAPTER 2: LITERATURE REVIEW

2.1 HIGH PERFORMANCE CONCRETE

High performance concrete, also known as HPC, is a type of concrete that is durable and stronger compared to conventional concrete. HPC is frequently used to construct not only tall buildings but also pavements, underground buildings and bridges. Marvila et al. (2021) studied that high performance concrete has a better and higher compressive strength (50-100 MPa) compared to conventional concrete (20-50 MPa).

Akhnoukh et al. (2019) stated that HPC is produced with high-quality mix ingredients, enhanced mix design, and low water-to-powder (W/CM) ratio. HPC is described as concrete that satisfies a unique set of qualities and uniformity standards that cannot be met using standard ingredients and mixing and curing techniques. HPC standards take into account the following features and requirements:

- Ease of placement
- High early strength
- Long-term mechanical properties
- Volume stability
- Extended life in severe environment

The mix design ingredients needed to produce HPC is cement, aggregates and water with the use of admixtures. The addition of mineral and chemical admixtures such silica fume and superplasticizer improve strength, durability, and practical qualities significantly.

In some cases, lowering the water/binder ratio below a certain point is not mechanically feasible because the strength of the HPC does not significantly exceed the compressive strength of the aggregate. When the coarse aggregate limits the compressive strength, the only way to increase strength is to use a stronger aggregate. However, while decreasing the W/B ratio does not increase compressive strength, it does increase matrix compactness and HPC durability. (Aitcin, 2003)

Furthermore, while HPC with high-strength steel fibres has strong ductility and resilience, the high-strength steel fibres account for around 35% of the total prices of high-performance concrete, resulting in a high initial cost of high-performance concrete. As a result, lowering the steel fibre content while maintaining or increasing flexural/tensile qualities is a difficulty (Du et. al., 2021). Despite the fact that the complete HPC has good durability, concrete buildings that are subjected to exterior service loads are prone to cracking.

2.2 CONCRETE FILLED STEEL TUBE

Concrete-filled steel tube (CFST) members maximise the use of steel and concrete components when compared to steel or reinforced concrete members. The steel tube keeps the concrete infill contained, and the concrete infill keeps the steel tube from bowing inward (Wei et. al., 2019). According to Wang et al. (2018), CFST members have been widely used in a variety of constructions all over the world. They have been used as follows:

- Mega-columns in high buildings
- CFST truss bridges
- Bridge piers
- Piles in floodwall structures
- Submarine pipeline structure

CFST can come into two cross sections, which are circular and rectangular. The axial strength of the infill concrete can be greatly improved because to the confinement offered by the steel tube. In addition, the infill concrete's restraining influence can avoid or at least delay local buckling of the steel tube. The interplay of the infill concrete and steel tube leads to the high strength and ductility of the structure. (He et. al., 2019).

Local buckling has long been an issue in steel buildings. This issue also occurred in CFST. To avoid local buckling, it is first necessary to estimate the dimensions of the steel box and adjust its length. If the concrete is in a steel pipe of the right width, good calculations can avoid local inward buckling. The researchers are also looking at CFST's axial strength capacity and cross-section analyses.

Due to the loss in mechanical behaviour induced by fire, chemical corrosion, and physical ageing, the usage of numerous CFST columns is considered insufficient to meet the essential safety and usability standards. (Yan et. al., 2021). To address the aforementioned issues, innovative materials and techniques were used in the retrofitting of CFST columns.

According to Gunawardena et. al. (2019), The number of studies looking into the behaviour of CFSTs under flexural loading in the literature is substantially lower than those looking into the behaviour of CFSTs under compression (columns) or simultaneous compression and bending (beam-columns).

2.3 STEEL

"Steel and concrete are by far the two dominant materials in terms of global energy requirement, and their increasing demand has never stopped since the industrial revolution." D'Amico et al. (2019).

Steel is the most important material used in the construction industry because it serves as the "skeleton" that holds the buildings together. Some of the main reasons for its use are its versatility, durability, and flexibility, as well as the fact that it is a very cost-effective material. Steel, due to its high strength-to-weight ratio, can frequently provide a solution when other materials are insufficient.

Steel is an alloy of iron and carbon with a minor amount of silicon, phosphorus, sulfur and oxygen. The carbon content of the steel is around 0.08 to 1.5 percent. Steel's tensile strength and yield point are at their maximum when carbon is at 1%. When steel is exposed to higher or extremely high temperatures, it deforms.

One of the most extensively used building materials in the construction industry is structural steel, which is also the most studied and well understood. Its behaviour is predictable, and its shape, cross-section, chemical composition, and mechanical qualities are all defined by numerous standards and norms created by agencies. The most common shapes of structural steel are beam and column.

Steel constructions include channel, angle, structural tubing, tee, sheet piling, and rails. The grade is determined by the steel's composite materials.

According to R. Weck (1965), there are six basic failure mechanisms: failure due to excessive plastic deformation as a result of static overload or impact, instability, creep, stress corrosion, fatigue, and brittle fracture. Steel with sufficient tensile strength, ductility, toughness, and elasticity can be used to avoid these failures.

2.4 CARBON FIBRE REINFORCED POLYMER

There are many ways to strengthen the offshore pipeline, which are coating, cathodic protection, etc. However, these methods may temporarilybenefit the strength and condition of the pipeline. In other words, the pipeline will eventually weaken and corroded. Worst case scenario, the pipeline has to be replaced to a newly conditioned pipeline, which is cost-consuming and not to forget, time consuming (shipping delivery).

Fibre Reinforced Plastics (FRP) can be the most efficient way to strengthen the offshore pipeline, as well as preventing it from any types ofcorrosions. FRPs are typically made up of a plastic matrix reinforced withfibres or fabrics. The interface is the area where the reinforcement and matrix meet. The chemical and mechanical interactions of the mixed materials influence the composite qualities (Saeed, 2015). The use of FRPhas a number of advantages, including the following:

- FRPs do not rust, corrode, or rot, and they are resistant to most industrial chemicals, allowing them to survive in difficult conditions.
- FRPs outperform aluminium and steel in terms of strength to weightratio.
- Under varied physical, environmental and thermal stressors, highstrength FRPs exhibit a high dimensional stability.

- FRPs' design flexibility is varied widely. They include anything from commercial fishing boat hulls and decks to sports car fenders, structural parts, and aerospace application.

The types, amount, and position of the fibre reinforcement contributesignificantly to the strength of FRPs. Based on Table 2-1, S-glass has a greater heat resistance and a higher tensile strength than E-glass. Aramid fibres have a high modulus, high strength, and low density. These fibres are widely utilised in high-impact applications and can be integrated into avariety of polymers. Carbon fibres combine small weight with high strength and elasticity modulus. These reinforcements work exceptionally well in high-strength situations, with a modulus of elasticity that rivals steel. FRP reinforced with carbon fibre provides exceptional fatigue characteristics.

Property	Glass		Carbon	Aramid
	E-glass	S-glass	T700SC	K49
Density (gm/cc)	2.58	2.46	1.80	1.45
Tensile strength (MPa)	3445	4890	4900	3000
Tensile modulus (GPa)	72.3	86.9	230	112.4
Comp. strength (MPa)	1080	1600	1570	200
Strain to failure (%)	4.8	5.7	1.5	2.4
Softening point (°C)	846	1056	>350	>150
Advantages	Low cost, easily available and more compatible		Low density, high strength and stiffness, low density and superior fatigue performance	High impact performance, flame resistant and resistant to chemicals
Disadvantages	Low modulus and susceptible to fatigue, creep and stress rupture		High cost, availability and compatibility	Low transverse and compressive strength, susceptible to UV and degrades in moisture

Figure 1 shows the summary of fibres properties from different materials (Hausrath & Longobardo, 2010)

CFRP has a tensile strength equivalent to normal steel and an elastic modulus comparable to it. CFRP sheets have demonstrated a great deal of promise in the reinforcement of various hollow steel constructions (Saini et. al., 2019). CFRP offers good fatigue and installation properties, as well as high strength, Young's modulus, and strength-to-weight ratio. In contrast to the anisotropy of concrete and the isotropy of steel, a CFRP jacket is a type of orthotropic material that can be used to encircle a concrete column. CFRP confinements are made of epoxy resins and can be combined with steel, concrete, or wood to make a composite. (Ostrowski et. al., 2020).

2.5 CFST-CFRP

In terms of bearing capacity, ductility, and construction flexibility, concrete filled steel tubes are well-known structural advantages. For two reasons, CFST wrapped in CFRP is projected to have improved structural qualities. To begin with, the CFRP can effectively restrict the CFST. Second, the CFRP may prevent corrosion in steel tubes (Wang et. al., 2020). Du et. al. (2021) agreed that because of its light weight, high tensile strength, and corrosion resistance, CFRP is increasingly being employed in reinforced constructions.

Xiao et al. (2005) presented a strengthening method for wrapping the CFST column in CFRP and conducted an experimental study to determine the effectiveness of CFRP confinement. According to the findings, CFRP can effectively prevent steel tube buckling. CFRP was used to improve the confinement to core concrete, which improved the bearing capacity and ductility of CFST columns.

Yan et. al. (2021) found out that the strengthened columns had good ductility, similar to the CFST columns, which could be due to the strengthened columns' progressive failure. In general, the CFRP textile grid's higher confining level resulted in lesser ductility. Some of the samples with additional CFRP fibre grid layers showed higher ductility because they did not tear layers of different fibres at the same time.

However, there are limited studies regarding on the performance of CFST wrapped with CFRP. According to Wang et. al. (2018), the setting of CFRP strip significantly increased the load carrying capacity of CFST members, according to all test findings. There was limited material on the behaviour of CFRP-strengthened CFST when partially enclosed or exposed to compression. Only Zand et al. (2017) and Sundarraja and Prabha (2012) investigated the behaviour of CFST members wrapped with CFRP.

2.6 MECHANICAL PROPERTIES

Compressive Strength

Compressive strength is commonly used to make decisions about the strength and serviceability of concrete members and structures for these reasons.

Other considerations must be made for mineral admixtures when compared to standard concrete. Tthe water/binder ratio is used for mix design. The water/binder formula is shown below:

$$x = \frac{\mathrm{w}}{\mathrm{c} + \mathrm{kf} + \mathrm{s}}$$

…where,

x = water/binder ratio

w = water content

c = cement content

k = efficiency factor

f = fly ash content

s = granulated blast furnace slag

For compressive strength, the formula to obtain the value is as shown below,

$$fc = Ax^{-B}$$

…where,

fc = compressive strength

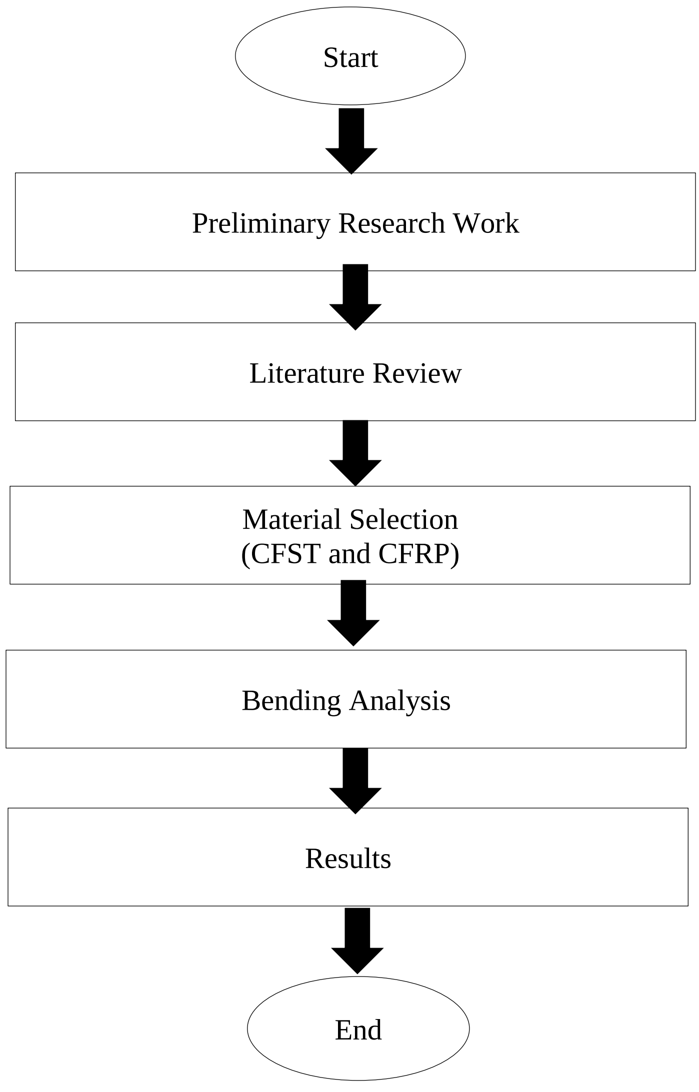
A = experimental factor for a given age

B = experimental factor for a given age

CHAPTER 3:
METHODOLOGY

3.1 FLOW CHART

Figure below shows the overall methodology of this project in a flow chartform:



3.2 MATERIALS USED

3.2.1 Mix Design

HPC was the material employed in the research. The mix design ratio has been computed. To attain varied compressive strengths of HPC, each mixture will have varying quantities of ingredients. This study will look at the effects of different compressive strengths on the structural behaviour of HPC-filled steel tube beams with various CFRP layers.

3.2.2 Concrete-filled Steel Tube

The dimensions of the steel tube beams are as below:

- Width = 100mm
- Height = 200mm
- Length = 1.5m
- Thickness = 5mm

The steel tube beams are filled with high performance concrete. Figures below show the drawing dimension of the steel tube.

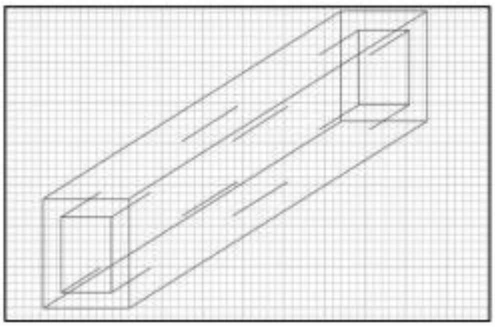


Figure 2 shows the Steel Tube Beams Diagram

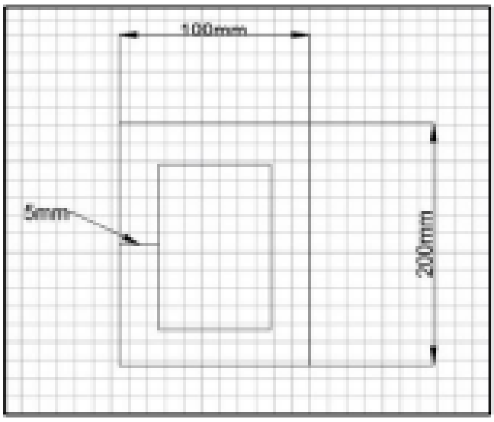


Figure 3 shows the Steel Tube Beams Dimension (Front View)

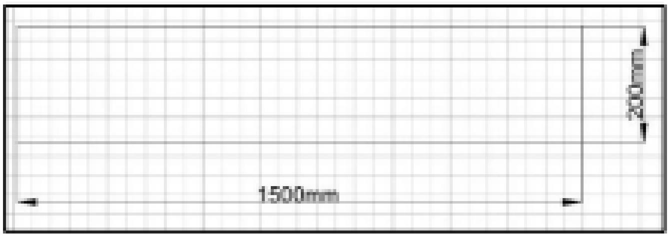


Figure 4 shows the Steel Tube Beams Dimension (Side View)

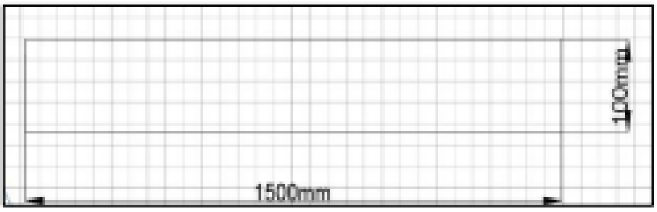


Figure 5 shows the Steel Tube Beams Dimension (Top View)

Figure 6 shows the Steel Tube Beams that will be used for the testing

3.2.3 Carbon Fibre Reinforced Polymer

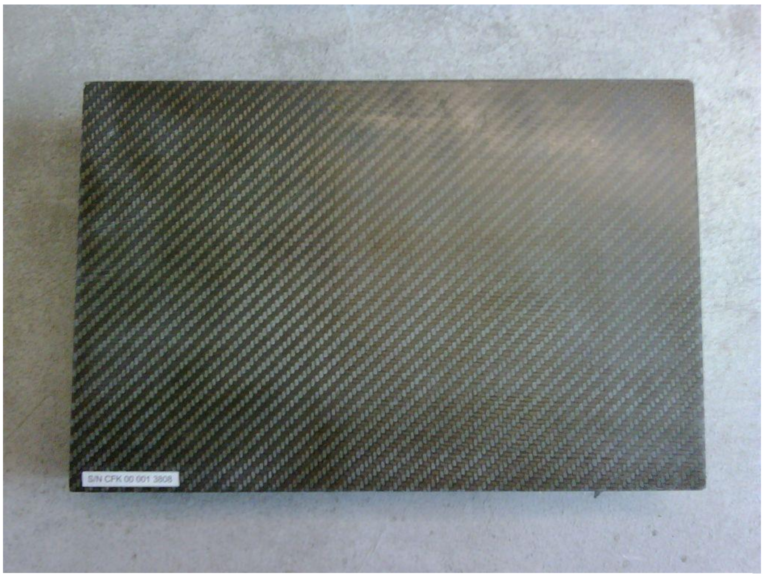


Figure 7 shows the carbon fiber reinforced polymer (CFRP)

Carbon Fibre Reinforced Polymer (or CFRP in short) is chosen due to its major properties' advantages as explained in literature review. A total of 5 layers of CFRP will be used for the experiment, where each steel tube will be wrapped with 2 layers and 3 layers of CFRP respectively.

3.3 EXPERIMENTAL SETUP

3.3.1 Procedures

HPC Filled Steel Tube Beams with CFRP Layers

1. The adhesive substance (epoxy) is mixed according to the manufacturer's instructions after making sure the steel tube surface is clean.
2. The adhesive material will be promptly applied to the steel tube's surface.
3. The first layer of CFRP is wrapped around steel tube beams in a parallel to the direction of the beam.
4. The second layer of CFRP will be applied perpendicular to the direction of the beam, as in procedures 1 to 3.
5. The air void between the CFRP and the steel tube beam is removed using a specific ribbed roller. Ascertain that the adhesive material thickness is distributed evenly over the beam.
6. At room temperature, the specimen is cured.

3.3.2 Testing

The purpose of the project is to determine the structural behaviour under bending of the CFST with an aid of Carbon Fibre Reinforced Polymer (CFRP). Different layers of CFRP wrapped on steel pipelines will be compared, and the result will be determined by comparing the forces, resistances, maximum deflections, and displacements of the pipeline.

Universal Testing Machine

The tensile and compressive strength of materials are tested using a universal testing machine (UTM), also known as a universal tester, materials testing machine, or materials test frame. The analysis for this project will be to determine the tensile strength, bending behaviour, compression and static test of the CFST wrapped with CFRP.

Figure 8 shows the set up for the testing of CFST wrapped with CFRP

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Physical Results

The results obtained from the testing consist bending behaviour of the CFST wrapped with CFRP.

Both of the steel tubes buckled when the ultimate load had been developed respectively (refer Figure 9). The bending occurred at the centre part of both steel tubes (major axis buckling). It is noticeable that the CFST-3L takes a slightly more time to bend compared to CFST-2L. There was no local buckling detected on both steel tubes throughout and after the testing. This shows that the layers of CFRP wrapped on the steel tubes can delay the bending of the steel tubes.

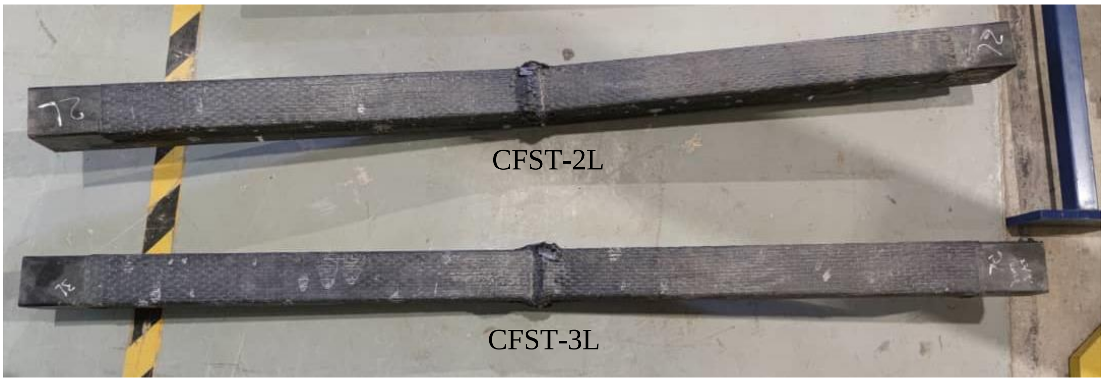


Figure 9 shows the physical results of both CFST after testing

Figure 10 shows the buckling failure of CFST-2L

Figure 11 shows the buckling failure of CFST-3L

The CFRP layers at the mid-part of both steel tubes were stripped after their peak loads had been attained. This small rupture is due to the load tension at the middle part during the testing of both steel tubes. It is also noticeable that the CFST-3L has a high CFRP rupture process compared to CFST-2L, which indicated the CFST-3L takes a slightly shorter time for the CFRP to rupture compared to CFST-2L. This shows that the more the layers of CFRP used, the more sudden the CFRP failure was.

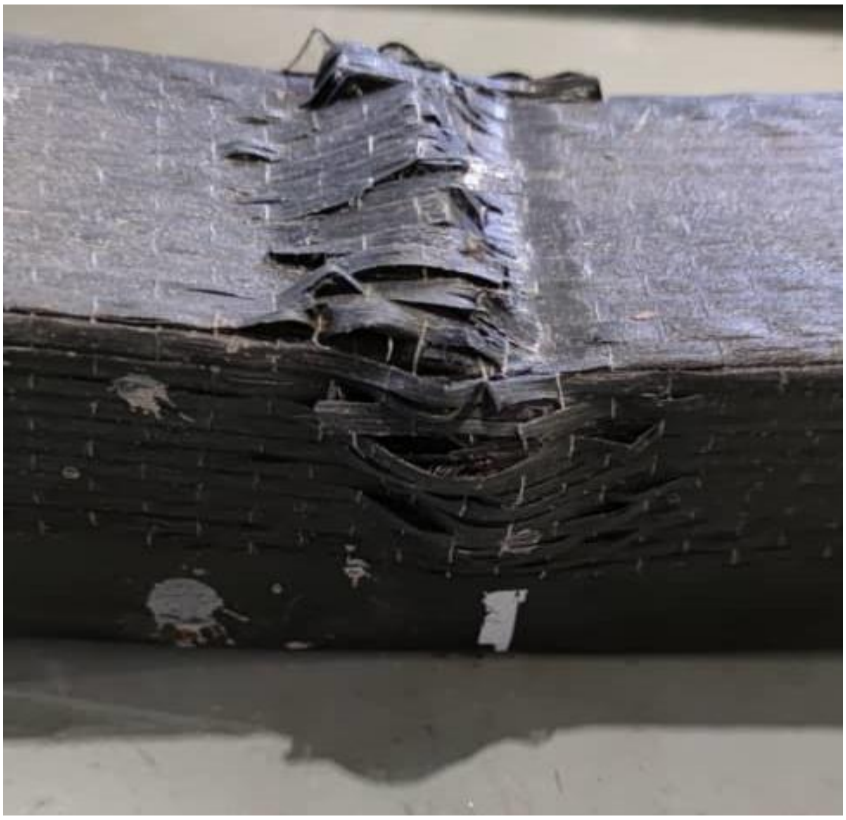


Figure 12 shows the CFRP rupture on CFST-2L

Figure 13 shows the CFRP rupture on CFST-3L

4.2 Data and Graphical Results

Displacement (mm)	Force Load of CFST-2L (kN)	Force Load of CFST-3L (kN)
0	0	0
0. 5	0. 4986	0. 9972
1	0. 9972	0. 9972
1. 5	1. 9944	1. 9944
2	1. 9944	2. 9916
2. 5	2. 9916	3. 4902
3	4. 4874	4. 4874
3. 5	6. 9804	7. 479
4	8. 4762	8. 9748
4. 5	10. 9692	11. 4678
5	14. 4594	14. 958
5. 5	16. 753	17. 592
6	19. 4454	19. 944
6. 5	19. 944	20. 9412
7	25. 9272	27. 9272
7. 5	29. 428	29. 428
8	30. 4146	31. 9104
8. 5	32. 9076	32. 409
9	38. 3922	39. 3894
9. 5	40. 8852	45. 381
10	47. 8656	49. 3614
10. 5	53. 3502	54. 846
11	59. 3334	60. 3306
11. 5	63. 3222	64. 3194
12	67. 311	67. 8096
12. 5	69. 3054	69. 804
13	71. 2998	74. 2914
13. 5	75. 7872	78. 2802
14	79. 776	80. 7732
14. 5	81. 7704	83. 7648
15	82. 669	86. 7564
15. 5	83. 5783	88. 7508
16	83. 7648 (UL)	89. 2494 (UL)
16. 5	83. 7648	89. 2494
17	83. 7648	89. 2494
17. 5	83. 7648	88. 7508
18	83. 7648	89. 2494
18. 5	83. 7648	89. 2494
19	83. 7648	89. 2494
19. 5	83. 135	89. 2494
20	83. 7648	89. 2494

Table 1 shows the data of force load for both steel tubes based on respective displacements

(Displacements were taken on every 5mm)

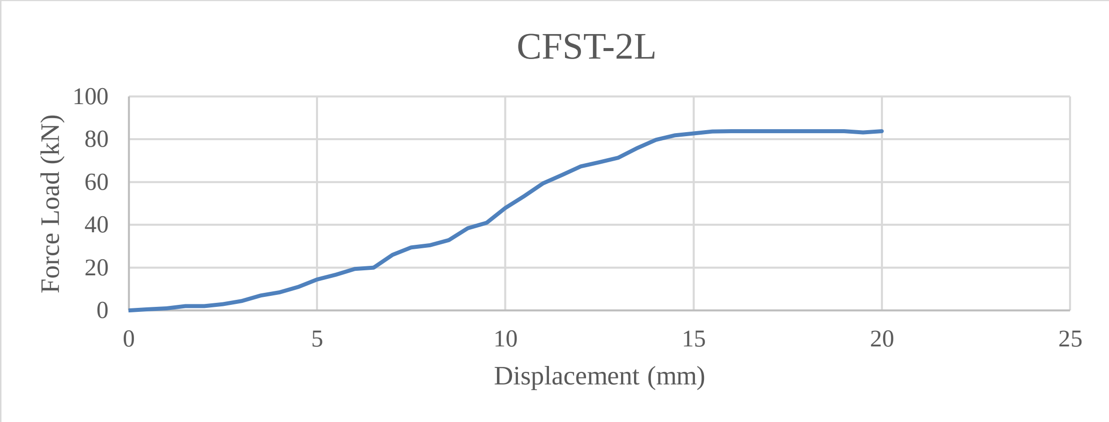


Figure 14 shows the graphical data of force load against displacement for CFST-2L (every 5mm)

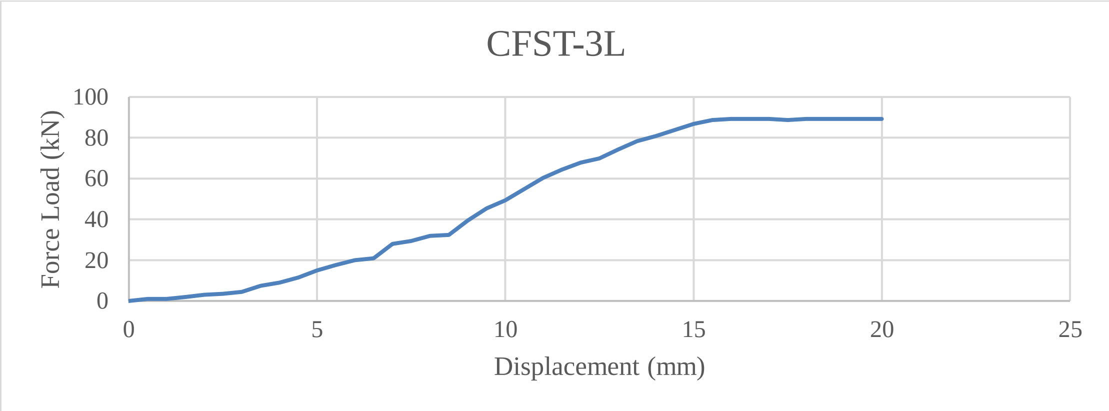


Figure 15 shows the graphical data of force load against displacement for CFST-3L (every 5mm)

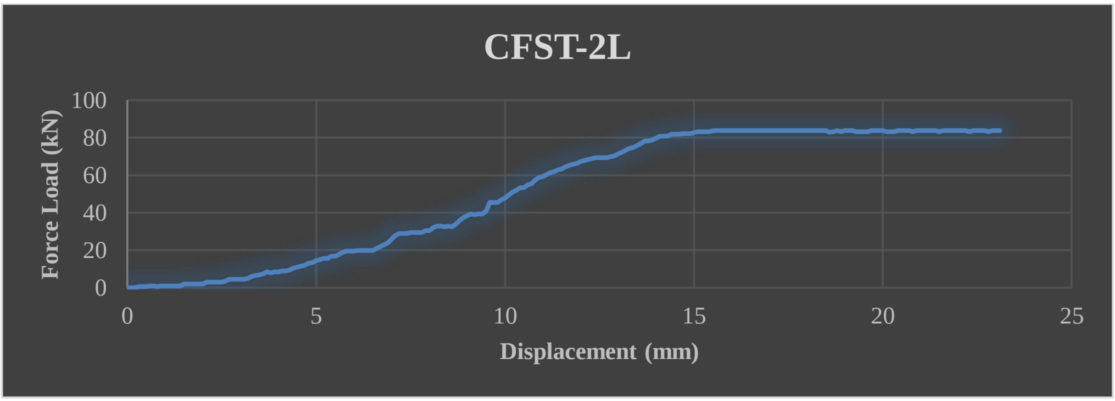


Figure 16 shows the graphical data of force load against displacement for CFST-2L (for all displacements)

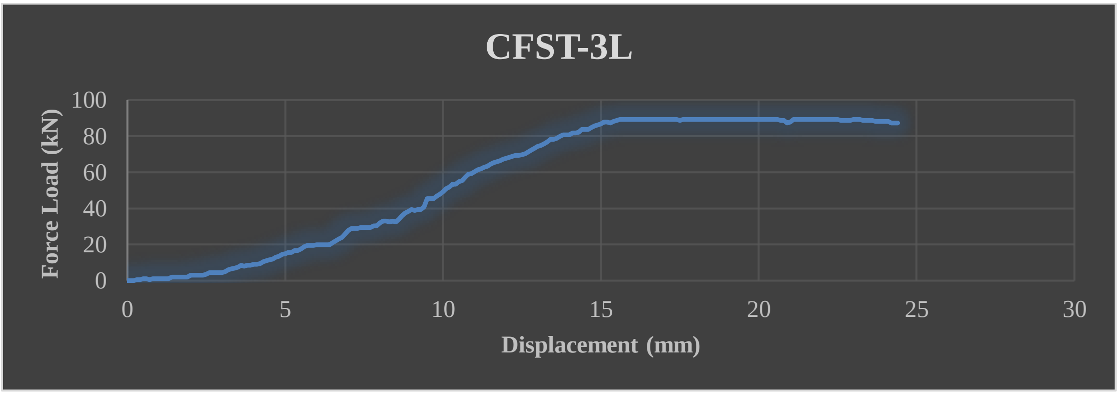


Figure 17 shows the graphical data of force load against displacement for CFST-3L (for all displacements)

Figure 14, Figure 15, Figure 16, and Figure 17 show the effect of CFRP when wrapped on the steel tubes. Both steel tubes were tested until it reaches its ultimate load respectively. For CFST-2L, the peak load that it exhibited was 83.7648 kN while for CFST-3L, the ultimate load experienced by this steel tube was 89.2494 kN (refer Table 1). By comparing the graphs, the load-carrying ability of CFRP wrapped specimens appears to increase as the number of CFRP layers increases.

Despite the buckling of both steel bars were visible, it is safe to say that CFST-3L exhibited a greater ductility compared to CFST-2L. CFST-3L showed a great result during the testing, which proves that more layers of CFRP can improve and strengthen the concrete filled steel tube.

4.3 Results Summary

Table 2 shows the summary of the results obtained

Types of Specimens	CFST-2L	CFST-3L
Layers of CFRP used	2	3
Bending Behaviour of steel tubes	Bending failure at the middle part of the steel tube	Bending failure at the middle part of the steel tube
Strength	Slightly Low	Slightly High
Ultimate Load (kN)	83.7648	89.2494
Ductility	Low	High

CHAPTER 5:
CONCLUSION

Conclusion

Based on the results obtained after the testing, the following conclusions can be drawn.

- There was no general failure that was observed except for the bending failure at the middle part of both steel tubes due to the load during the testing.
- The higher the number of layers of CFRP on the CFST, the steel tube can withstand a great amount of load.
- A concrete filled steel tube can obtain a higher ductility with condition, numbers of CFRP need to be wrapped. The more the layers of CFRP, the greater the ductility will be.

Recommendations

- The CFST wrapped with CFRP needs to be compared with the one without CFRP.
- More samples need to be tested to obtained more results.
- Instead of using the manual universal testing machine, the modern machinery of universal testing machine is suggested to obtained more graphical data and accurate results.

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