TITLE

"Buckling Resistance of Tubular Steel Column Infilled with ECC Strengthened with Carbon Fiber Reinforced Epoxy Composite"

Project/Thesis ID. 2023

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Project Supervisor: Dr. Muhammad Tahir Lakhair

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Certification

This is to certify that Izzat Ullah (352755), Khazran (351492), Waqar Ahmed (287214) and Abdur Rehman (346947) have successfully completed the final project **“Web Buckling Resistance of Tubular Steel Column infilled with ECC Strengthened with Carbon Fiber Reinforced Epoxy Composite”,** at the **NUST**, to fulfill the partial requirement of the degree **BECE (Bachelor of Engineering in Civil Engineering).**

External Examiner	**Project Supervisor**
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Project Title: "Buckling Resistance of Tubular Steel Column Infilled with ECC Strengthened with Carbon Fiber Reinforced Epoxy Composite"

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	→ SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	→ SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	→ SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

This project fulfills three SDGs which are:

- SDG No. 9 (Industry Innovation and Infrastructure: Enhancing the Web- Buckling Capacity),
- SDG No. 11 (Sustainable Cities and Communities: Durable and Long Standing)
- SDG No. 13 (Climate Action: ECC is environmental friendly , adoption of ECC in infrastructure development leads to significant carbon emission reduction and cost savings, globenewswire.com)

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	

5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Abstract

This study examines the web buckling resistance of tabular steel columns reinforced with carbon fibre reinforced epoxy composite (CFRP) and filled with engineered cementitious composites (ECC). While CFRP offers improved strength and stiffness, the use of ECC as an infill material gives special ductility and energy dissipation properties. In seismically vulnerable areas, the combination of these materials satisfies the demand for resilient structural systems and promotes effective space utilisation in buildings. To evaluate the performance of ECC-infilled steel columns under axial and lateral loading circumstances, experimental and analytical approaches are used in the research. The structural behaviour, load-carrying ability, and deformation characteristics of the columns are assessed by a series of laboratory tests.

It is anticipated that the results of this study will reveal the significant enhancement in the overall structural performance of tabular steel columns infilled with ECC and strengthened with CFRP. The combination of these materials effectively delays web buckling, increases load-carrying capacity, and enhances energy dissipation capacity, making them a promising solution for improving the seismic resilience of structures. The research findings contribute to the advancement of sustainable and resilient construction practices, with potential applications in a wide range of civil engineering projects.

Keywords: web buckling, tubular steel, ECC, CFRP, strengthening

Undertaking

I certify that the project "Buckling Resistance of Tubular Steel Column Infilled with ECC Strengthened with Carbon Fiber Reinforced Epoxy Composite" is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

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List of Acronyms

ECC	Engineering Cementitious Composites
CF	Carbon Fiber
CF-REC	Carbon Fiber Reinforced Epoxy Composite

Chapter 1

1) Introduction

Columns act as a structural element that transfers loads from the slab, (i.e., roof, beam, upper floor) to the foundation and finally to the soil beneath a structure. In construction, columns are used in trusses, building frames, and structure support for bridges.

Why ECC ?

- Standard cement only has a strain capacity of around 0.01 percent
- Bendable concrete's strain capacity can be as much as 7 percent, meaning it is hundreds of times more flexible.
- Fibrous structure also means it breaks in a safer, slower way—generating many "microcracks" instead of the large cracks seen in traditional concrete.

Carbon fibre reinforced epoxy composite CFR-EC:

- Carbon Fiber (CF) is a material composed of fibers between diameter 50 to 10 micrometers, mainly conformed by carbon atoms.
- The properties of the carbon fiber, such as a high flexibility, high resistance, low weight, high-temperatures resistance and a low thermal expansion coefficient.
- It is a popular choice between aerospace, industries, engineering, military applications, etc.

Literature Review:

No.	Intext Citation	Aim	Experimental Setup	Findings
1.	(Teoh et al., 2023)	To investigate the flexural buckling behavior of self-compacting lightweight concrete-filled cold-formed built-up box section (CFBBS)	A total of 20 specimens were prepared and tested, including 9 LWSCC-filled CFBBS columns, 9 CFBBS columns for reference purposes, and 2 repeating specimens to verify test reliability. Breakstem rivets were selected as connectors.	The study found that the Column specimens with intermediate and long length experienced predominantly overall flexural buckling failure, while those with short length suffered from severe local buckling.
2.	(Lakhiar et al., 2023)	To study the web crippling performance of pultruded GFRP C sections strengthened by fiber-reinforced epoxy composite	The research used two sizes of pultruded GFRP channel sections, C1 and C2, to study their mechanical properties in both longitudinal and transverse directions.	The results showed that the proposed FEC strengthening method effectively enhanced the web crippling capacity of pultruded GFRP C sections. The study also found that an increase in bearing length from 20mm to 50mm significantly increased the average web crippling capacities of pultruded GFRP C sections up to 45%.

3.	(Dinis et al., 2014)	To investigate the strength, interactive failure and design of web-stiffened lipped channel columns exhibiting distortional buckling	This study involved 10 fixed-ended cold-formed steel web-stiffened lipped channel columns with 8 different geometries. The specimens had nominal lengths ranging from 2100 to 3000 mm and were brake-pressed from high strength zinc-coated grades G500 and G550 structural steel sheets.	The study concluded that the flange-triggered L-D interaction in web-stiffened lipped channel columns is mechanically different from its web-triggered counterpart.
4.	(Sharhan et al., 2021)	To analyse the Steady and transient state tests on local buckling of high strength Q690 steel stub columns	The tests involved eight stub columns with different width-to-thickness ratios. The ambient temperature experiments were conducted using a microcomputer-controlled electro-hydraulic machine.	Results show that buckling resistance decreases with temperature due to steel degradation. Temperature affects ultimate bearing capacity, with higher temperatures leading to greater loss.
5.	(Nguyen et al., 2021)	To predict Critical Buckling Load of Web Tapered I-Section Steel Columns Using Artifcial Neural Networks	The study developed a finite element model (FEM) of the WTIS column using ANSYS software. The model was verified with experimental. The steel column's constitutive material model was represented as a bi-linear stress-strain curve.	An ANN model was developed to predict the critical buckling load of WTIS columns using 269 simulated experiment data. The model outperformed existing formulas and parametric studies.
6.	(He et al., 2014)	To inspect Post-buckling behavior and DSM design of web-stiffened lipped channel columns with distortional and local mode interaction	The material properties of a specimen were studied using displacement transducers and strain gauges. The results were analyzed to determine the material's buckling critical stress and local deformation.	Results confirm the inadequacy of the current DSM distortional design curve and evaluate predictions made by NLD and NDL approaches. A DSM-based approach considering L-D interaction is proposed as an additional check.
7.	(Landesmann et al., 2016)	To investigate on the strength and DSM design of cold-formed steel web/flange-stiffened lipped channel columns buckling and failing in distortional modes	This study focuses on selecting cross-section dimensions and lengths of fixed-ended SLC and PLC columns for analysis using GBTUL and ANSYS shell finite element models.	The study aimed to develop a novel DSM distortional strength curve for web-flange stiffened lipped channel columns against distortional failure. The findings suggest that a more refined DSM design approach should involve the web-to-lip width ratio as a key parameter.

8.	(Tankova et al., 2018)	To study the experimental buckling behavior of web tapered I-section steel columns	The University of Coimbra conducted full scale tests to study the buckling behavior of web-tapered steel columns. The research project aimed to study the stability of non-uniform steel members, including flexural buckling, lateral-torsional buckling, and lateral-torsional buckling of beams.	The results provide a basis for calibration and validation of numerical models, and validate the design method proposed for web-tapered columns.
9.	(J. H. Zhang & Young, 2018)	To perform experimental investigation of cold-formed steel built-up closed section columns with web stiffeners	This study tested two types of built-up closed sections with inward and outward stiffeners at the web. The steel plates were zinc-coated and fabricated into V-section and O-section sections.	The results show that the direct strength method provides accurate and reliable design predictions.
10.	(Y. Zhang et al., 2007)	To conduct experimental study of hysteretic behavior for concrete-filled square thin-walled steel tubular columns	Nine CFTST columns were tested under cyclic lateral and constant axial loads to simulate seismic loading conditions. The tubes were made from cold rolled thin steel sheet and cold bent to lipped angles and C-sections.	Results show ductile failure, axial load level significantly influences hysteretic behavior, and four-stiffener columns have better ductility.
11.	(Wang et al., 2014)	To perform the experimental study on local buckling of axially compressed steel stub columns at elevated temperatures	The experiments tested 12 stub columns under load and temperature conditions, focusing on steel grade, buckling resistance, and temperature.	Tests on mild Q235 and high strength Q460 steel columns revealed decreased buckling resistance with temperature increase, with high strength columns experiencing more rapid degradation. Eurocode 3 provisions predicted higher buckling loads.
12.	(Naseem Baig et al., 2006)	To investigate the strength of Concrete Filled Steel Tubular Columns	Steel pipes made of grade 36 steel sheets from Pakistan Steel Mills and Maula Buksh Pipe Industries were tested for compressive strength. Concrete cylinders were tested for composite column strength. Design codes were consulted to prevent local buckling. Testing was conducted at the University of Engineering and Technology in	Experiments on hollow and filled steel tubular columns show circular columns have significantly stronger strength than square ones. Local wall buckling is observed in square columns. Further experiments on double-skinned short columns are needed.

			Peshawar, Pakistan, using a 200-t capacity machine.	
13.	(Ilanthalir et al., 2020)	To investigate concrete-filled steel tube columns of different cross-sectional shapes under axial compression:	Mild steel, cold-formed steel, and high strength structural steel are used in CFST columns. Tensile coupon tests determine material characteristics. ANSI/AISC 360 divides CFT columns into compact, non-compact, and slender sections. Hollow steel sections are classified into Classes 1-4, with Class 1-3 sections having thicker walls. Researchers propose slenderness limits for elliptical and octagonal sections, and extend code limits for rectangular and high strength steel.	The study reveals that circular hollow steel sections provide better confinement to the concrete core, with the strongest confinement at corners and centers. Slender CFST columns have stronger composite action. Codes should revise limits on concrete compressive strength and steel yield strength due to the use of high strength and ultra-high strength materials in construction.
14.	(Bahrami & Kouhi, 2020)	To investigate the Compressive Behavior of Circular, Square, and Rectangular Concrete-Filled Steel Tube Stub Columns	The study investigates the use of concrete filled steel tubes in CFSTS columns. The columns were tested under concentric load and modeled using ABAQUS for nonlinear three-dimensional finite element analysis. The model was validated using a concrete damage plasticity model and a bilinear steel material model. The concrete's behavior was influenced by the steel tube's confinement effect.	The study identifies that increasing load eccentricity reduces ultimate load-carrying capacity, energy absorption capacity, and stiffness, while enhancing steel tube thickness increases ultimate capacity.
15.	(Ayough et al., 2021)	To investigate the effects of cross-sectional shapes on the axial performance of concrete-filled steel tube columns	The study uses 8-node linear brick elements with reduced integration (C3D8R) for modeling the concrete core in CFST stub columns. The shell element type of S4R is used for modeling thin-walled steel tubes, but C3D8R can also be used for buckling analysis. Two layers of elements are considered to avoid premature buckling. The optimum mesh size is determined using mesh	Results show that circular CFST columns have better structural performance than polygonal columns, and octagonal and hexagonal columns show better ductility. Parametric studies show that ultimate axial strengths are enhanced with increased steel yield strength and concrete compressive strength.

			sensitivity analysis, and a refined element size of 30 × 30 is taken for the steel tube to better predict local instabilities.	
16.	(More & Subramanian, 2023)	To Investigate the Axial Compressive Behavior of Cold-Formed Steel-Concrete Composite Columns Infilled with Various Types of Fiber-Reinforced Concrete	This research used M40 grade concrete infills and various fiber-reinforced concretes like steel, carbon, glass, coir, jute, and sisal in composite columns. The concentric axial load-carrying capacity of rectangular steel tubular columns filled with concrete was ascertained using an experimental program involving 24 specimens. Cold-formed plain steel columns were used for the study.	This study examined three types of steel-concrete composite columns with varying slenderness ratios. Results showed that glass, steel, and sisal fiber-reinforced concrete infills can enhance the ultimate load of steel tubular columns, making them effective for structures with high loads. The load-carrying capacity of glass fiber-reinforced concrete-infilled steel tubular columns was higher than other types. The study also found that fiber-reinforced concrete-infilled steel tubular columns can take more deformations and strain before failure.

2) Statement of the problem

The column is the most critical structural element of any commercial building, skyscrapers, stadiums, and arenas, and in form of piers in case of bridges. Columns are used to support floor/roof beams and the columns of the floor above. The columns at the bottom floor of a tall building must carry the accumulative weight of all the floors above.

For making high rise buildings, it is important to use light weight material having high strength so as the load on bottom floors can be reduced due to above floors. For this reason, column cross section is also reduced. Hence column becomes strong against fracture or compression/material failure but may prone to buckling as it becomes slender.

Therefore, the column is at a great risk of buckling and this research aims to increase the buckling capacity of columns.

This research will help structural engineers, architects, and mega projects to making high rise buildings with safety.

3) Goals/Aims & Objectives

The goal is to increase the resistance of the web buckling behaviour in steel column by adding ECC as a filler to make it lighter, more ductile, environmental friendly and highly tensile strength concrete and adhering CFRP sheet as strengthening material.

Proposed solutions:

We use CFR-EC and ECC as in-filler to make the column more resistant to buckling , more durable, light weight, environmental friendly. It is very innovative idea and never practiced in industry yet before

Why it is better:

- CFR-EC has high strength to weight ratio that ultimately helps in tall buildings like bridges
- ECC as in-filler reduces the consumption of cement which ultimately reduces the carbon emission due to production of cement.
- By using these fibers, flexural strength, and ductility of concrete rises to 1.5-2%
- It also increases the load carrying capacity and higher energy dissipation at beam-column joint
- CFR-EC due to its unique characteristics, is resistant to corrosion and high fatigue resistance.

Final project output:

It is anticipated that the web buckling performance of columns will be increased to a great extent.

Equipment:

- For hardware, CFR-EC and in-filler ECC adopted
- For software, Abaqus is used

Why proposed solution is better:

It is a great innovation in the industry, environmental friendly, resistant to corrosion, high strength to weight ratio, high tensile strength, more ductile and will increase the web buckling performance of slender columns.

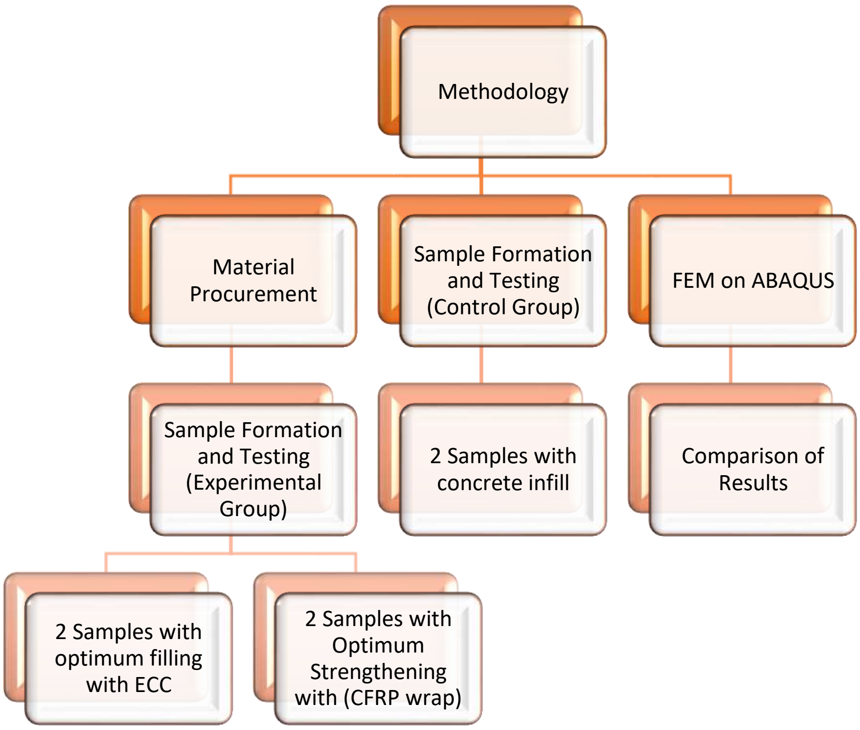
4) Motivation

Previous research just studied the buckling phenomenon of columns filled with normal concrete or self-compacting concrete and they used either built-up box section from commercially available steel sections or lipped sections. An extensive literature is also missing for the study of buckling of tubular column reinforced with Carbon Fiber and ECC. Therefore, this topic is selected to bring new innovation in the research field.

5) Assumption and Dependencies

The structural performance of tabular steel columns against buckling will be improved significantly when infilled with Engineered Cementitious Composites (ECC) and strengthened with Carbon Fiber Reinforced Epoxy Composite (CFRP). • The study may reveal that the ECC-CFRP composite system will provide superior resilience and ductility. • The project displays the environmental and sustainability of used materials . ECC is known for its durability and reduction of carbon footprint due to use of low cement content, while CFRP can increases the lifespan of structures, which reduces the need for maintenance, demolition and reconstruction. • By taking into consideration all the aspects of project, it can be depicted that the ECC and CFRP approach is cost-effective for long duration as seeing its potential to extend the service life of structures and diminish the maintenance costs.
It is anticipated that the web buckling performance of columns will be increased to a great extent.

6) Methods



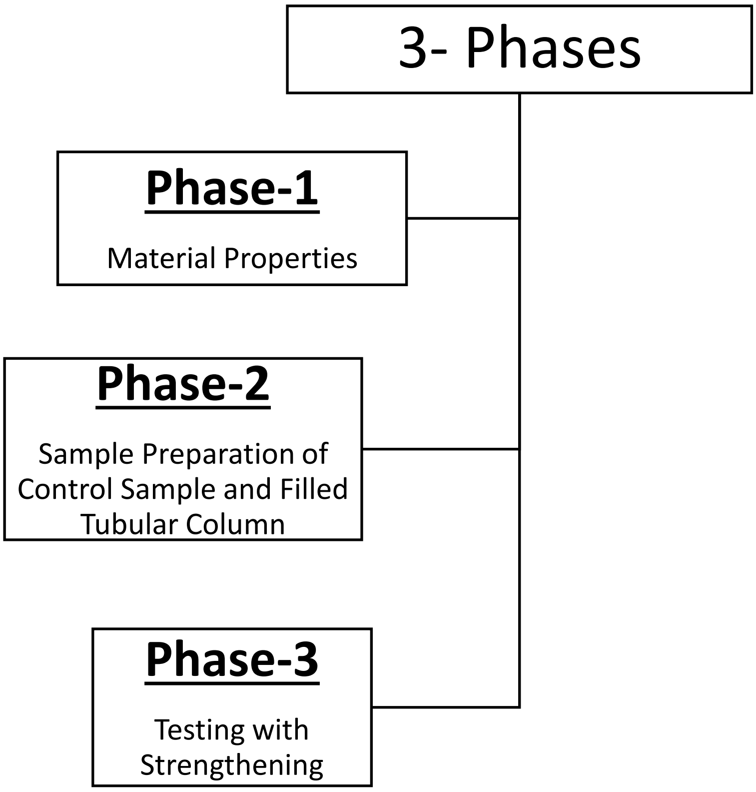
7) Report Overview

This study examines the web buckling resistance of tabular steel columns reinforced with carbon fiber reinforced epoxy composite (CFRP) and filled with engineered cementitious composites (ECC). While CFRP offers improved strength and stiffness, the use of ECC as an infill material gives special ductility and energy dissipation properties. In seismically vulnerable areas, the combination of these materials satisfies the demand for resilient structural systems and promotes effective space utilization in buildings. To evaluate the performance of ECC-infilled steel columns under axial and lateral loading circumstances, experimental and analytical approaches are used in the research. The structural behavior, load-carrying ability, and deformation characteristics of the columns are assessed by a series of laboratory tests. It is anticipated that the results of this study will reveal the significant enhancement in the overall structural performance of tabular steel columns infilled with ECC and strengthened with CFRP. The combination of these materials effectively delays web buckling, increases load-carrying capacity, and enhances energy dissipation capacity, making them a promising solution for improving the seismic resilience of structures. The research findings contribute to the advancement of sustainable and resilient construction practices, with potential applications in a wide range of civil engineering projects.

Chapter 2

1) Proposed Solution/Results

The proposed solution is completed in three phases. These phases are:



I. Phase-1 (Material Properties)

a. Specific Gravity and Water Absorption of Sand (ASTM C-128):

A = oven dry mass = 223g

B = pycnometer + water = 1275g

C = pycnometer + water + sand = 1492g

S = SSD = 300g

S.G = 2.7

Bulk S.G = 3.62

W.A = 1.69%

b) Specific Gravity and Water Absorption of Marble Dust (ASTM C-128) :

A = oven dry mass = 211g

B = pycnometer + water = 1275g

C = pycnometer + water + MD = 1489g

S = SSD = 300g

S.G = 2.455

Bulk S.G = 3.5

W.A = 2.74%

c) Moisture Content of Sand:

W! = Wt. of container = 221g

W2 = Wt. of container + Sample = 372g

W3 = Wt. of container + Oven Dry Sample = 370g

M.C = 0.54%

d) Dry Density of Sand:

Oven Dry Mass = 1.33 kg

Avg Dia = 88.9 mm

Avg Length = 140 mm

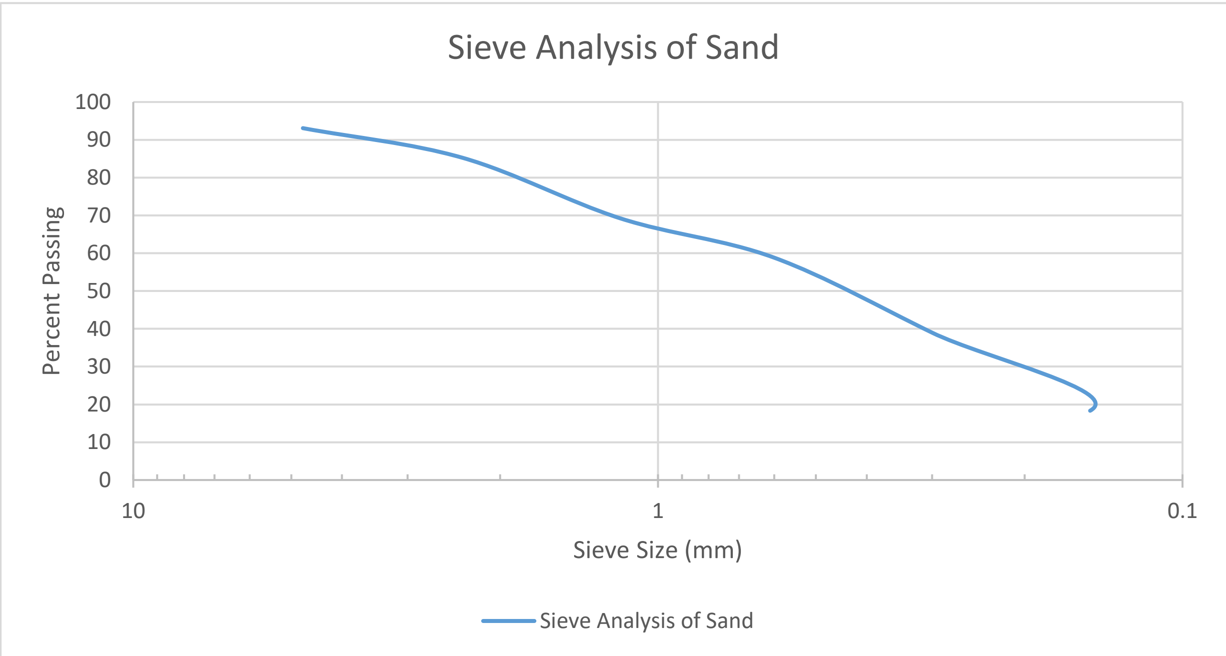
Volume = 0.000869 m^3

D.D = 1530.5 kg/m^3

e) Sieve Analysis and Fineness Modulus of Sand (ASTM C-136-06):

Total Sample = 1000g

Sieve #	Sieve # (mm)	Weight Retained (g)	Cumulative Weight Retained	% Cumulative Retained	% Passing
#4	4.75	69	69	6.91	93.09
#8	2.36	78	147	14.73	85.27
#16	1.18	160	307	30.76	69.24
#30	0.6	104	411	41.18	58.82
#50	0.3	198	609	61.02	38.98
#100	0.15	206	815	81.66	18.34
#200	0.75	105	920	92.18	7.82
pan	0	78	998	100.00	0.00
	Total	998	F.M	2.36	



II. Phase-2 (Testing of Control Sample and Filled Tubular Column)

For control:	For ECC :
Cement : sand 1:1	Cement: sand 1:1
Hard waste fiber 2% of cement	Replacement of cement about 20%
W/C = 0.4	Cool bottom ash (CBA): 15% of cement
	Marble Dust (MD): 5% of cement
	W/C = 0.4

To Check:

- Load Deflection
- Failure Pattern
- Stress and Strain Curve
- Ultimate Load

a) Samples Prepared

- 2 Samples Prepared filled with ECC without strengthening
- 2 Samples Prepared filled with ECC with Strengthening
- 2 Hollow steel column samples prepared for control test
- 3 Cubes of (4"X4"X4") prepared filled with ECC Ratio
- 3 Cubes of (4"X4"X4") prepared filled with Control Ratio

Hollow Steel

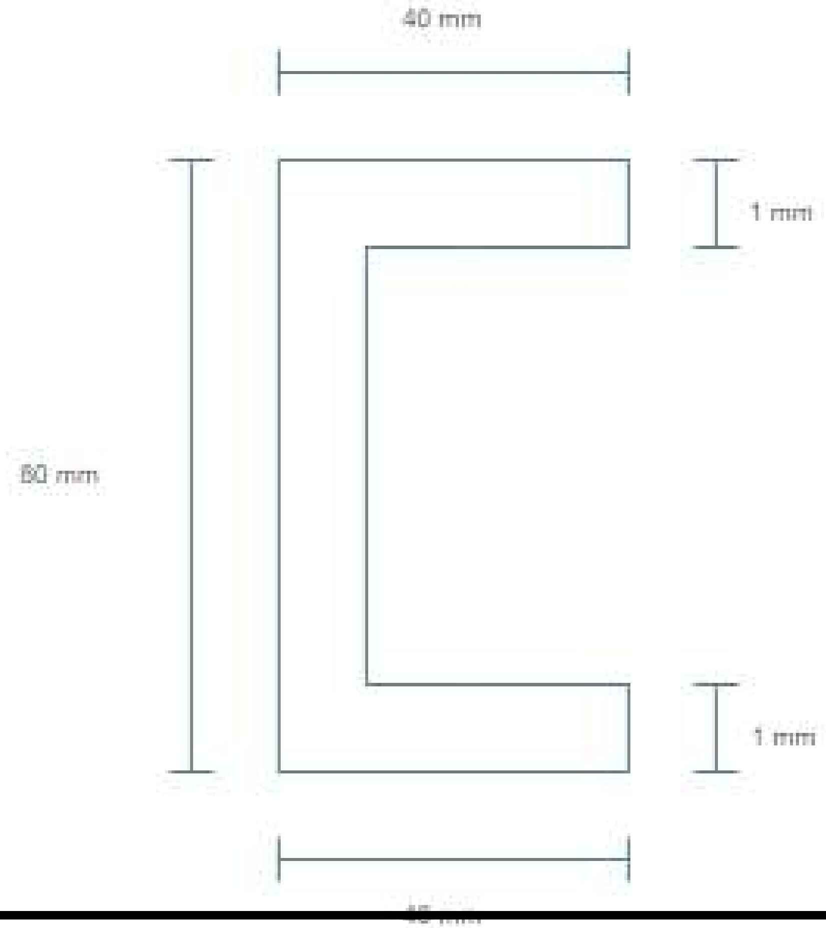
Cubes filled with ECC and Control Samples

Tubular Column filled with ECC

Tubular Column filled with ECC and Carbon Fiber Wrap

b) Dimensions of Tubular Column Sample

Specimen	Grade (ksi)	Height (mm)	Width (mm)	Thickness (mm)	Length (mm)
	22	501	20	1	80



Cross Section

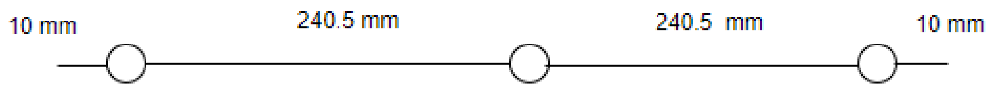
c) Rivet Arrangement

Rivet arrangement:

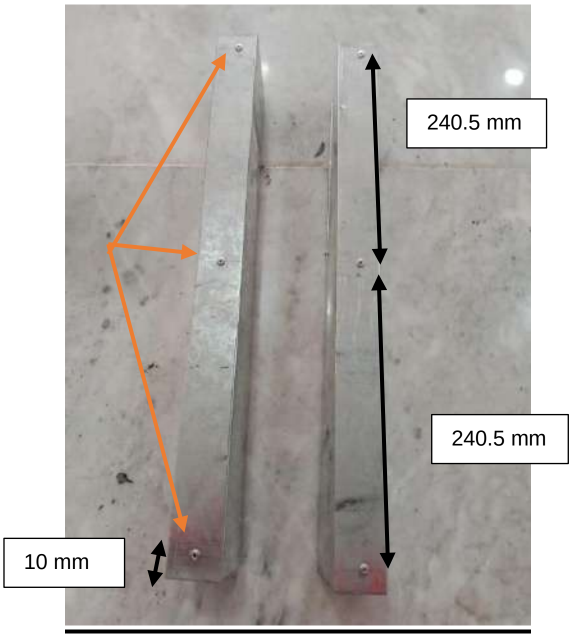
10 mm from top and bottom

And one placed in the middle.

4mm Rivet Diameter



Rivet Arrangement

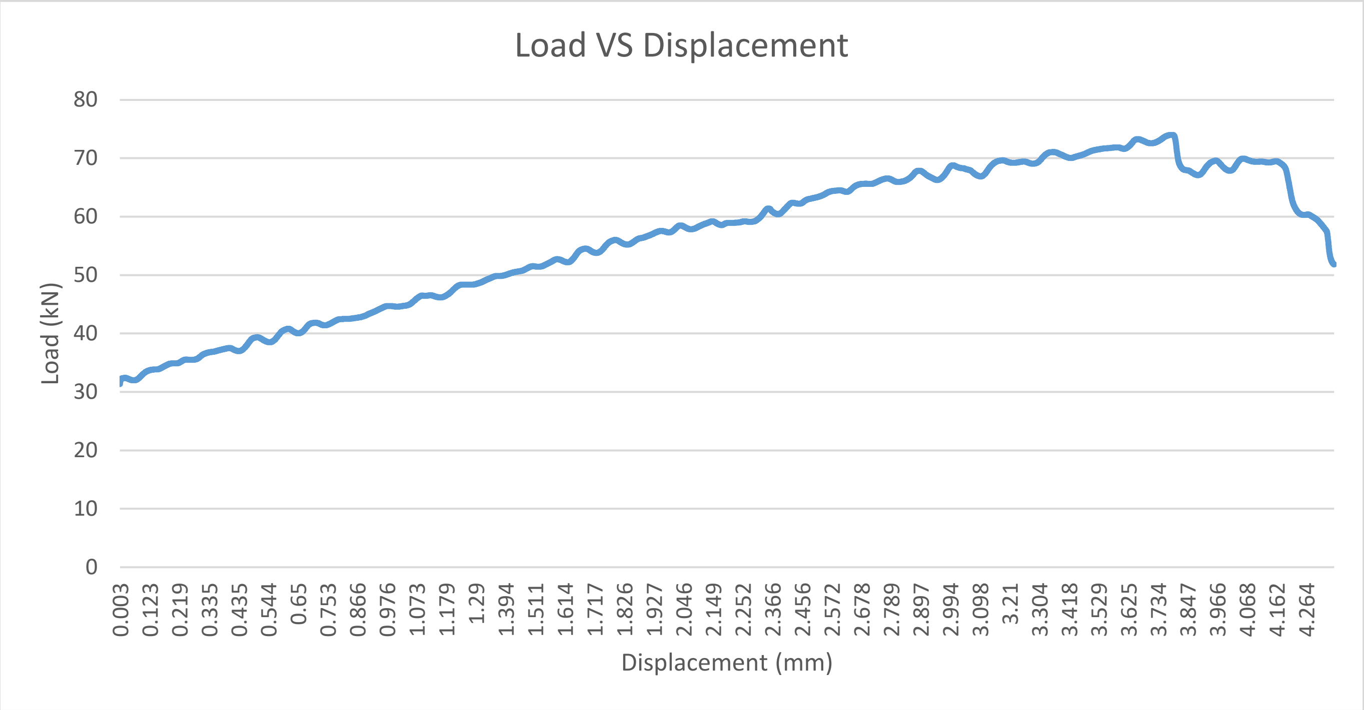


III. Phase 3 (Testing with Strengthening)

I. Results for Testing of Tubular Column with ECC infill:

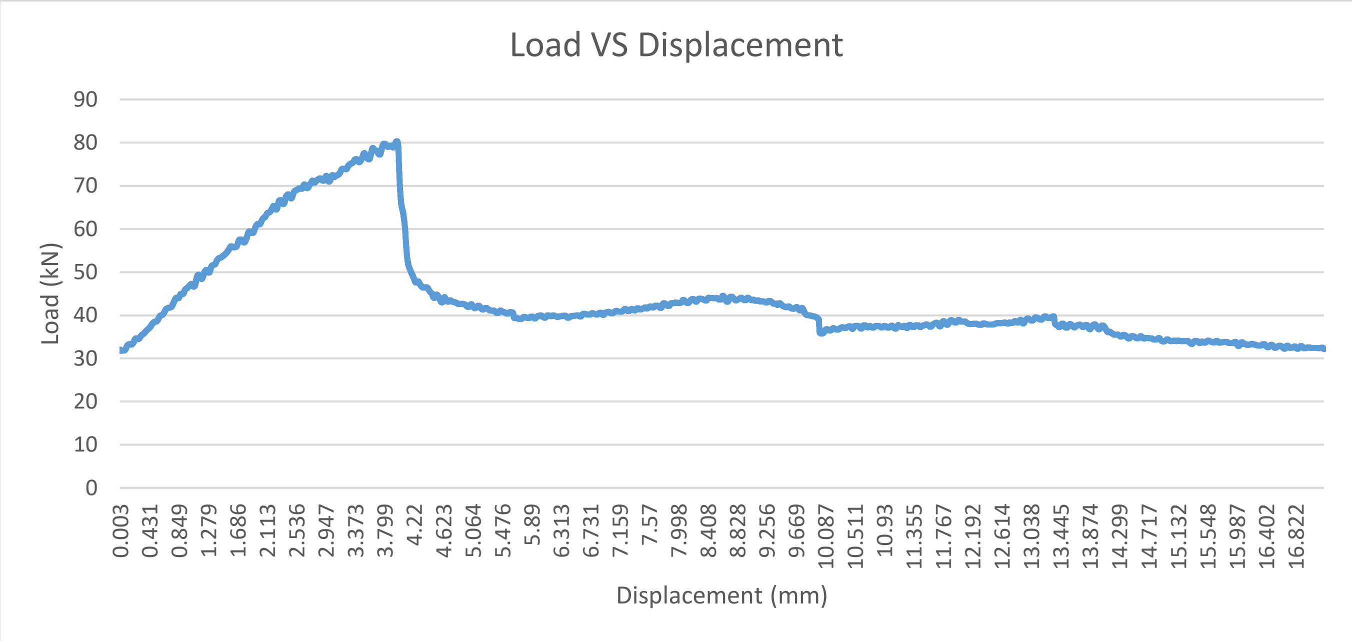
a) Sample 1

Loading Conditions	End Test Results
Rate: 0.500 mm/min	
Control: Deform. 1	Maximum load: 74.006 kN
Start load: 0.200 kN	Maximum strength: 23.127 MPa
Stop load: 30 %	Deform. 1: 3.789 mm
Area: 3200.000 mm²	



b) Sample 2

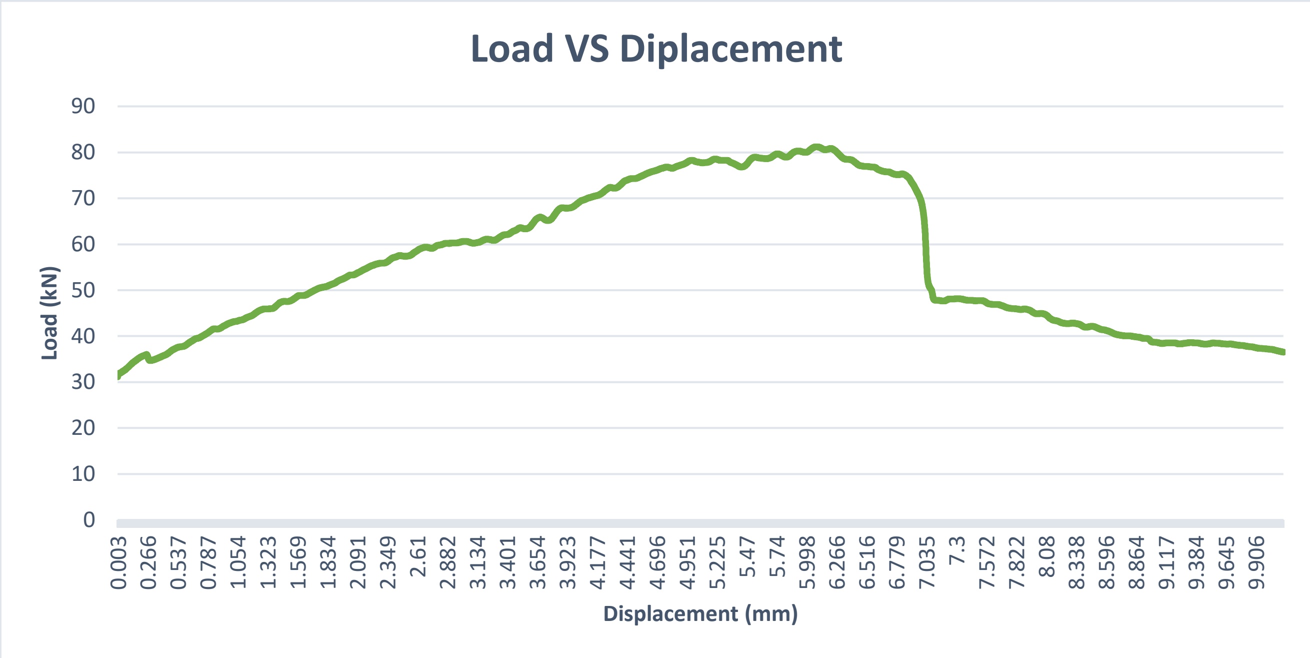
Loading Conditions	End Test Results
Rate: 0.500 mm/min	
Control: Deform. 1	Maximum load: 80.340 kN
Start load: 0.200 kN	Maximum strength: 25.106 MPa
Stop load: 60 %	Deform. 1: 3.974 mm
Area: 3200.000 mm²	



II. Results for Testing of Tubular Column with ECC infill strengthened with Carbon Fiber Reinforced Epoxy Composite:

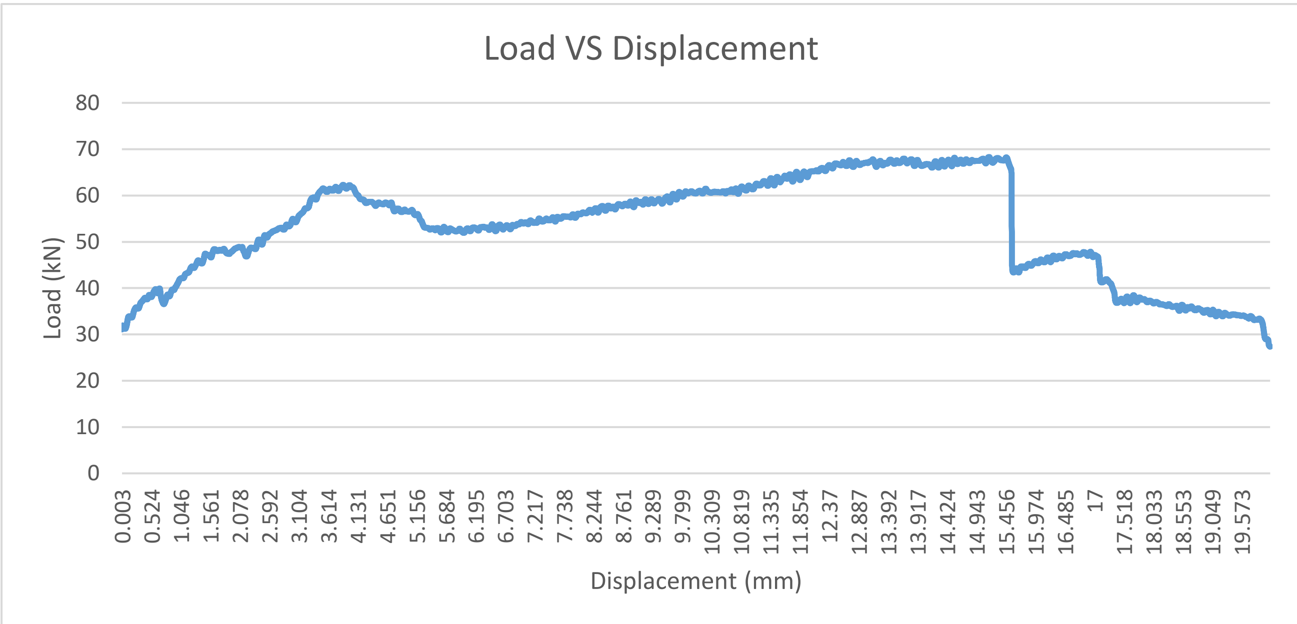
a) Sample 1:

Loading Conditions	End Test Results
Rate: 1.000 mm/min	
Control: Deform. 1	Maximum load: 81.212 kN
Start load: 0.200 kN	Maximum strength: 25.379 MPa
Stop load: 55 %	Deform. 1: 6.086 mm
Area: 3200.000 mm²	



b) Sample 2

Loading Conditions	End Test Results
Rate: 0.500 mm/min	
Control: Deform. 1	Maximum load: 68.301 kN
Start load: 0.200 kN	Maximum strength: 21.344 MPa
Stop load: 60 %	Deform. 1: 15.167 mm
Area: 3200.000 mm²	



2) Discussion:

Maximum Strength of the tubular column sample infilled with ECC is between 23MPa to 25MPa and maximum displacement calculated is between 3.8mm to 4mm respectively. On the other hand, the maximum strength calculated from the samples of tubular steel columns infilled with ECC and reinforced with CF-REC is between 25.4MPa and 21MPa and the maximum that it allowed is 6.1mm to 15.2mm.

Hence from these results we can see that reinforcing with CF increases the displacement meaning that it increases the buckling resistance of tubular columns.

Chapter 3

1) Summary and Future work

I. Summery:

The web buckling behaviour of the novel lightweight Engineered Cementitious Composites (ECC) with tubular steel columns wrap with Carbon Fiber was investigated in the present study. The Engineering Cementitious Composites (ECC) was used in placed of conventional concrete to examine the behavior of column in that material. An experimental program consisting of 6 column specimens of two different member of water to cement ratio infilled with ECC , two different column wrap of Carbon Fiber Epoxy and infilled with ECC and two different steel columns infilled with ECC was conducted. The experimental program encompassed material tests, fresh concrete properties tests, and fixed-ended column tests. The mechanical behaviours including failure modes, lateral deflections, flexural buckling resistances. The web buckling phenomenon was observed in every samples. To enhance the web buckling of the column the Carbon Fiber CF and steel are used to resist the web buckling of a column. Furthermore, the experimental data as well as the visual of columns are deep analyzed.

II. Future Work:

The future work will be to use different materials as well as different sections for the column to analyse the behavior of the column. Whereas the column is more prominently weaker in the buckling. Additionally, we have examine the buckling phenomena of a column. The further research can be done to check the flanges of the column and enhance by using the carbon fibre, as well as some other alternative materials to enhance the failure of the column.

Chapter 4

1) Conclusion & Recommendation

This study explores innovative methods for enhancing the web buckling resistance of tubular steel columns through the development and improvement of structural systems. Specifically, it investigates the application of Engineered Cementitious Composites (ECC) as infill material and their reinforcement with Carbon Fiber Reinforced Epoxy Composite (CFRP). These novel approaches promise substantial advancements in structural performance, with a strong emphasis on resilience and sustainability.

References and Citations

1. Ayough, P., Ibrahim, Z., Sulong, N. H. R., & Hsiao, P. C. (2021). The effects of cross-sectional shapes on the axial performance of concrete-filled steel tube columns. *Journal of Constructional Steel Research*, *176*. https://doi.org/10.1016/j.jcsr.2020.106424
2. Bahrami, A., & Kouhi, A. M. (2020). Compressive behaviour of circular, square, and rectangular concrete-filled steel tube stub columns. *Civil Engineering and Architecture*, *8*(5), 1119–1126. https://doi.org/10.13189/cea.2020.080538
3. Dinis, P. B., Young, B., & Camotim, D. (2014). Strength, interactive failure and design of web-stiffened lipped channel columns exhibiting distortional buckling. *Thin-Walled Structures*, *81*, 195–209. https://doi.org/10.1016/j.tws.2013.09.016
4. He, Z., Zhou, X., Liu, Z., & Chen, M. (2014). Post-buckling behaviour and DSM design of web-stiffened lipped channel columns with distortional and local mode interaction. *Thin-Walled Structures*, *84*, 189–203. https://doi.org/10.1016/j.tws.2014.07.001
5. Ilanthalir, A., Jerlin Regin, J., & Maheswaran, J. (2020). Concrete-filled steel tube columns of different cross-sectional shapes under axial compression: A review. *IOP Conference Series: Materials Science and Engineering*, *983*(1). https://doi.org/10.1088/1757-899X/983/1/012007
6. Lakhiar, M. T., Kong, S. Y., Bai, Y., Miah, M. J., & Syamsir, A. (2023). Web crippling performance of pultruded GFRP C sections strengthened by fibre-reinforced epoxy composite. *Composite Structures*, *316*. https://doi.org/10.1016/j.compstruct.2023.117047
7. Landesmann, A., Camotim, D., & Garcia, R. (2016). On the strength and DSM design of cold-formed steel web/flange-stiffened lipped channel columns buckling and failing in distortional modes. *Thin-Walled Structures*, *105*, 248–265. https://doi.org/10.1016/j.tws.2016.03.023
8. More, F. M. D. S., & Subramanian, S. S. (2023). Experimental Investigation on the Axial Compressive Behaviour of Cold-Formed Steel-Concrete Composite Columns Infilled with Various Types of Fibre-Reinforced Concrete. *Buildings*, *13*(1). https://doi.org/10.3390/buildings13010151
9. Naseem Baig, M., Jiansheng, F., & Jianguo, N. (2006). *Strength of Concrete Filled Steel Tubular Columns*. *11*(6).
10. Nguyen, T. H., Tran, N. L., & Nguyen, D. D. (2021). Prediction of Critical Buckling Load of Web Tapered I-Section Steel Columns Using Artificial Neural Networks. *International Journal of Steel Structures*, *21*(4), 1159–1181. https://doi.org/10.1007/s13296-021-00498-7
11. Sharhan, A., Wang, W., Li, X., & Al-azzani, H. (2021). Steady and transient state tests on local buckling of high strength Q690 steel stub columns. *Thin-Walled Structures*, *167*. https://doi.org/10.1016/j.tws.2021.108214
12. Tankova, T., Martins, J. P., Simões da Silva, L., Simões, R., & Craveiro, H. D. (2018). Experimental buckling behaviour of web tapered I-section steel columns. *Journal of Constructional Steel Research*, *147*, 293–312. https://doi.org/10.1016/j.jcsr.2018.04.015
13. Teoh, K. Bin, Chua, Y. S., Pang, S. D., & Kong, S. Y. (2023). Experimental investigation of flexural buckling behaviour of self-compacting lightweight concrete-filled cold-formed

built-up box section (CFBBS) columns. *Thin-Walled Structures*, *187*. https://doi.org/10.1016/j.tws.2023.110751

14. Wang, W., Kodur, V., Yang, X., & Li, G. (2014). Experimental study on local buckling of axially compressed steel stub columns at elevated temperatures. *Thin-Walled Structures*, *82*, 33–45. https://doi.org/10.1016/j.tws.2014.03.015
15. Zhang, J. H., & Young, B. (2018). Experimental investigation of cold-formed steel built-up closed section columns with web stiffeners. *Journal of Constructional Steel Research*, *147*, 380–392. https://doi.org/10.1016/j.jcsr.2018.04.008
16. Zhang, Y., Xu, C., & Lu, X. (2007). Experimental study of hysteretic behaviour for concrete-filled square thin-walled steel tubular columns. *Journal of Constructional Steel Research*, *63*(3), 317–325. https://doi.org/10.1016/j.jcsr.2006.04.014
17. Structural Steel Design, 5th Edition, Jack C. MacCormac and Stephen F. Csernak
18. https://www.sciencedirect.com/science/article/pii/S0950061823030064
19. https://www.sciencedirect.com/science/article/pii/S2214509523003960