Palestine Polytechnic University

Deanship of Graduate Studies and Scientific Research

Master of Civil Engineering

The Effect of Applying Carbon Fiber Reinforced Polymer Cords on Reinforced Concrete Columns

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Thesis submitted in partial fulfillment of requirements of the degree Master of Civil Engineering

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The Effect of Applying Carbon Fiber Reinforced Polymer Cords on Reinforced Concrete Columns

Basil Issa Abusarhan

Abstract:

In the field of construction, reinforced concrete (RC) column is fundamental element that hold significant importance as essential load-bearing constituents. In some cases, there is need to strength and enhance load carrying capacity of the column for many reasons such as structural upgrades, aging and deterioration and seismic retrofitting. Using some strengthening and retrofitting techniques can reduce risk damage, increase the load capacity and raise the ductility. One of them is applying flexible near surface mounted –carbon fiber reinforced polymer (NSM-CFRP) cord.

This study will discuss this technique which is used by making grooves in the concrete cover and apply the desired material in, (CFRP will be used here), to examine the effects of used material on the strength of columns, which is a composite material comprising high-strength carbon fibers embedded in a polymer matrix. Analysis and investigation were conducted on strengthened (RC) column sample using CFRP cords from experimental test and comparing results with finite element (F.E) method using Abaqus program. The outcomes show good agreement of results between the proposed (F.E) model and the experimentally repaired columns. The parametric study in this research will include: different shapes of cross-sectional area of the column, classification of column short and long and the effect of applying CFRP on these types of (R.C) column.

أثر تطبيق أحبال الألياف الكربونية على الأعمدة الخرسانية المسلحة

باسل عيسى ابوسرحان

المستخلص

في مجال البناء، تعتبر الأعمدة الخرسانية المسلحة عناصر لها أهمية كبيرة كمقاوم للأحمال الرأسية والجانبية. في بعض الحالات، نحتاج إلى تقوية قدرة العمود على التحمل وتعزيزها لأسباب عديدة مثل الترقيات في البناء الحديث، والشيخوخة والتدهور ونتيجة الأحمال الزلزالية. يمكن أن يؤدي استخدام بعض تقنيات التقوية والتعديل إلى تقليل أضرار المخاطر وزيادة سعة الحمولة وزيادة الليونة للعمود. أحد هذه التقنيات هي تطبيق التقوية المثبتة بالقرب من السطح بواسطة احبال الألياف الكربونية.

ستناقش هذه الدراسة تطبيق هذه التقنية من خلال عمل بعض الفتحات محدودة الأبعاد في الغطاء الخرساني وتطبيق المادة المطلوبة بداخلها – وهي أحبال الألياف الكربونية - لفحص تأثير استخدامها على قوة الأعمدة. تتكون أحبال الألياف الكربونية من ألياف كربون عالية القوة مدمجة مع عناصر كيميائية أخرى. سيتم تحليل وفحص عينة العمود المقوى باستخدام حبال الألياف الكربونية من التجربة العملية، ومقارنة النتائج بطريقة القطع المحددة باستخدام برنامج اباكوس. أظهرت النتائج تقارباً كبيراً بين النتائج المخبرية مقارنة بنتائج النموذج المقترح. اشتملت الدراسة في هذا البحث على بعض المتغيرات مثل: أشكال مختلفة من المقطع العرضي للأعمدة الخرسانية المسلحة، تصنيف العمود قصير وطويل، وتأثير استخدام الألياف الكربونية على هذه الأنواع من الأعمدة.

Declaration

I declare that the Master Thesis entitled ”The Effect Of Carbon Fiber Reinforced Polymer Cord On Reinforced Concrete Columns” is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Student Name: Basil Issa Abusarhan

Signature: _______________ Date: _________________

Dedication

Thanks be to God Who is always helping us to success

To my loving parents who are the greatest support in the life

To my wife and daughter

To my brothers and sisters

To all friends and colleagues

To my teachers

To all of them

Acknowledgement

I would like to thank my supervisor Ph.D. Maher Amro for his continuous support and motivation while preparing this work. Ph.D. Belal Almassri the head of the Civil Engineering Department who worked hard to establish the plan for the Master's Degree in Civil Engineering. Ph.D. Haitham Ayyad, Ph.D. Abdulsamee Halahla and Ph.D. Naser Abboushi who I learned so much from their knowledge.

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Chapter 1: Introduction

1.1 Background:

As fundamental elements in construction, reinforced concrete (RC) columns serve as crucial load-bearing components. The combination of concrete's compressive strength and steel's tensile strength cooperatively reinforces the column, providing exceptional toughness and stability. This synergy ensures the safe and efficient transfer of vertical loads in various building structures.

In the ever-evolving field of civil engineering, the drive to enhance the structural integrity and durability of buildings has led to innovative advancements.

One of the most popular strengthening technique is applying Carbon Fiber Reinforced Polymer (CFRP) which is a composite material comprising high-strength carbon fibers embedded in a polymer matrix. Its remarkable properties include high strength-to-weight ratio, corrosion resistance, and excellent tensile strength.

CFRP is known for its low thermal expansion and electrical conductivity. Its benefits include enhanced structural performance, reduced weight, and increased durability in construction.

Property		Units	Value
Nominal thickness		mm	0.13
Maximum tensile strength		kN/m^2	3.5×10^6
Elastic modulus of elasticity	E_x	kN/m^2	2.3×10^8
	E_y	kN/m^2	1.79×10^7
	E_z	kN/m^2	1.79×10^7
Major Poisson's ratio	v_{xy}	–	0.22
	v_{xz}	–	0.22
	v_{yz}	–	0.30
Shear modulus	G_{xy}	kN/m^2	1.179×10^7
	G_{xz}	kN/m^2	1.179×10^7
	G_{yz}	kN/m^2	6.88×10^6
Maximum elongation at break		–	1.5%
CFRP density		kN/m^3	17.3

Figure 1: Properties of some types of CFRP material (Mahmoud et al. 2012).

However, CFRP can be costly and challenging to work with due to its brittleness.

Surface preparation and bonding complexities are some of its disadvantages. Despite these challenges, CFRP remains a popular choice for strengthening and repair applications where its unique properties outweigh its drawbacks.

The relationship between stress and strain of CFRP is linear and follows Hooke's Law within the elastic range. When subjected to an applied force (stress), CFRP exhibits proportional deformation (strain) up to its elastic limit.
Beyond this point, permanent deformation or failure occurs.

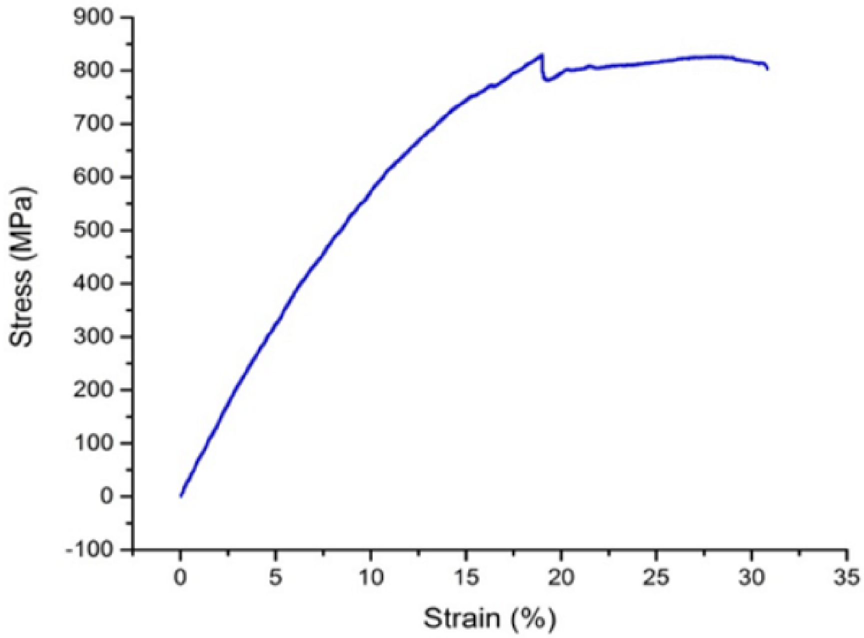


Figure 2: Stress-strain relationship of CFRP composite (Almitani et al 2021).

CFRP’s high tensile strength ensures it can withstand significant stress while maintaining its structural integrity within its elastic limit.

There are two types to implement CFRP material; externally bonded reinforcement (EBR) and near surface mounted (NSM). The NSM is faster and easier to apply than EBR technique.

The application of (CFRP) cords through the Near Surface Mounted (NSM) technique aims to strengthen (RC) columns.

The NSM technique involves embedding high-strength and lightweight CFRP cords into the cover of existing concrete elements, creating a strong bond that significantly improves the column’s load-bearing capacity and enhance the ductility.

This innovative approach offers several benefits, including increased resistance to environmental factors, seismic forces, and long-term degradation.

By reinforcing RC columns with CFRP cords via the NSM technique, engineers can efficiently extend the service life of structures while minimizing construction time and cost.

This cutting-edge method paves the way for safer, more sustainable, and solidifying its importance in modern construction practices.

1.2 Problem:

Columns can fail in different shapes: 1. Compression failure (crushing due to excessive load), 2. Buckling failure (sideways bending), and 3. Shear failure (diagonal cracking caused by lateral forces).

a b c

Figure 3: Modes of failure of RC column (a. Compression failure, b. Buckling failure, c. Shear failure).

This study aims to increase RC column load carrying capacity through the application of the NSM technique with CFRP cords.

1.3 Research Significance:

The majority of prior research on FRP confinement focused on using EBR-FRP sheets to strengthen or repair columns, with only a few studies exploring longitudinal NSM-CFRP strips. However, FRP strips' brittleness and lack of configurability limited their application as lateral confinement.

Implementing partial confinement and NSM-CFRP for improved column behavior remains a challenging area.

Recently, flexible NSM-CFRP cords have shown promise as a repair system, offering enhanced bond with concrete, higher load capacity, and better ductility. This study aims to investigate the behavior and capacity enhancement of damaged RC rectangular column repaired using flexible NSM-CFRP cords.

1.4 Methodology:

This study will utilize Numerical Analysis to explore multiple variables comfortably. ABAQUS software will model a loaded column, and Finite Element Method (FEM) will analyze its deformation. The results will be compared and validated against laboratory work by Obaidat et al. (2020), followed by further investigation of upgrades and various parameters.

Chapter 2: Literature Review

Obaidat et al. (2020) investigated the behavior of repaired and strengthened reinforced concrete (RC) rectangular columns by flexible near surface mounted –carbon fiber reinforced polymer (NSM-CFRP) cord. The study showed that significant enhance in axial strength can be achieved by using larger width to depth ratio and smaller spacing between CFRP cords.

The restoration of column strength through longitudinal and transverse CFRP repairs was mostly successful, except for the column with fractured bars near the base, which faced limitations in CFRP anchorage. For columns with fractured longitudinal bars, adding longitudinal and transverse CFRP in the plastic hinge region partially restored flexural strength. Ruili He et al. (2012).

Triantafillou and Deskovic et al. (2001) examined the NSM technique with CFRP strips for strengthening RC columns. The research revealed that NSM CFRP strips effectively enhanced column performance, providing efficient lateral confinement and enhanced load-carrying capacity.

Oguzhan Bayrak et al. (2003) examines the potential of retrofitting deficient and damaged square columns with CFRP jackets. The study finds that CFRP confinement improves ductility, energy dissipation, and strength in substandard members. Seismic behavior in degraded columns is positively influenced by CFRP jackets, but repair potential depends on the extent of damage.

The study by Najm et al. (2003) evaluated the application of CFRP fabrics as jacketing materials for RC columns. It demonstrated that CFRP jacketing significantly increased the axial and flexural strength of columns while improving their seismic performance.

Teng et al. (2005) presented a comprehensive review of hybrid strengthening techniques, including combinations of CFRP with other materials like steel plates or FRP wraps. The research emphasized the benefits of hybridization in optimizing the strengthening performance for different column configurations.

The study explored the use of steel reinforcement methods, such as steel jackets and steel bars, for RC column strengthening (Yu et al., 2009). It highlighted the potential of steel-RC composite columns to improve load-carrying capacity and ductility.

Improper repairs significantly reduced the lateral strength, stiffness, ductility, and energy dissipation of the columns. Concrete core damage in the later stages caused considerable stiffness reduction in strengthened columns. Lateral strengths remained mostly unchanged, but cumulative energy dissipation increased. Ductility improvement varied due to stiffness loss Hasan Elci et al. (2020).

l-Saikaly and Hamad (2012) investigated the use of concrete jacketing as a strengthening technique for RC columns. The research demonstrated that concrete jacketing effectively enhanced the axial and flexural capacity of columns, particularly for existing structures.

Shahawy et al. (2016) studied the effectiveness of CFRP wrapping on hollow RC columns. It indicated that CFRP wrapping significantly increased the load-carrying capacity and improved the confinement of hollow columns.

To assess CFRP-concrete bond behavior, José Manuel et al. (2004) pullout-bending tests. A fish spine crack pattern on epoxy adhesive was observed, attributed to CFRP-induced deformations and the average crack-CFRP angle was 33°.

Fang et al. (2018) analyzed the performance of CFRP grid reinforcement on RC columns. The study revealed that CFRP grid reinforcement effectively increased the ultimate strength and improved the ductility of the columns.

The study investigated the use of Fabric-Reinforced Cementitious Matrix (FRCM) composites for strengthening RC columns (Santarsiero et al., 2019). It demonstrated the potential of FRCM as a viable alternative to CFRP, providing enhanced resistance to concrete cover separation and better long-term performance.

AM Ashteyat et al. (2021) studied bond between concrete and NSM-CFRP cords and he founded that increasing NSM-CFRP cords' bonded length, concrete compressive strength, number of applied cords, and reducing cords' aspect ratio improved pull-out force and strengthening. Rupture was common for equal cord dimensions, while debonding occurred in multi-cord specimens with greater spacing.

Zhang et al. (2020) explored the application of CFRP cords for enhancing RC columns. The study indicated that CFRP cords effectively increased the load-carrying capacity and improved the seismic behavior of RC columns.

L. H. Sneed and Abdeldjelil Belarbi et al. (2014) studied CFRP sheets with fibers oriented in both the transverse and longitudinal directions on damaged RC columns, this study demonstrates that this method can be used to restore the torsional performance of severely damaged RC columns and they noticed that the repaired column exhibited CFRP system rupture at an average stress level below the CFRP's ultimate strength due to stress concentration. Rotational deformation capacity and ductility were notably improved compared to the original column.

Jamal. S. Makki et al. (2019) investigated and discussed the effects of groove shape, direction, and CFRP layers on the load carrying capacity, mid-span deflection, and failure mode of thirteen RC beams. The experimental results revealed that all externally strengthening techniques using CFRP sheets significantly improved the load carrying capacity of the tested RC beams. Specifically, the application of two transverse external layers of CFRP within grooves resulted in an impressive 103% increase in capacity, compared to only 42% with one CFRP layer of the same configuration.

In their study, Bedday et al. (2007) investigated the repair of damaged RC beams through the bonding of CFRP laminates. The results demonstrated that the load capacity and rigidity of repaired beams were notably higher compared to the control beam, regardless of the degree of damage. The authors observed that reinforcing with a CFRP laminate approximately half the width of the beam yielded satisfactory load capacity improvement. The use of CFRP laminates significantly enhanced the mechanical performance of repaired RC beams, making this technique effective in restoring the mechanical performance of cracked or damaged RC beams.

Chapter 3. Modeling

3.1 General

In a recent laboratory study conducted by Obaidat et al. (2020), columns were investigated. Now, this research aims to simulate two columns using ABAQUS Finite Element software. By comparing the results obtained from the software model with the data gathered in the laboratory, it can be established the accuracy and reliability of the simulation. This will enable us to explore additional aspects and enhance the model to analyze various parameters.

3.2 Geometry of Column

In order to validate the results obtained from Abaqus software against the real data mentioned in Obaidat et al. (2020), a rectangular column measuring (250×150×700) mm (length, width, and height respectively) was used as the reference sample. The column was reinforced with 4ϕ10 longitudinal steel bars and ϕ8/100 mm as transverse stirrups as shown in figure 4. To enhance its strength, CFRP cords were placed into grooves measuring (10×10) mm, with a spacing of 93 mm between cords.

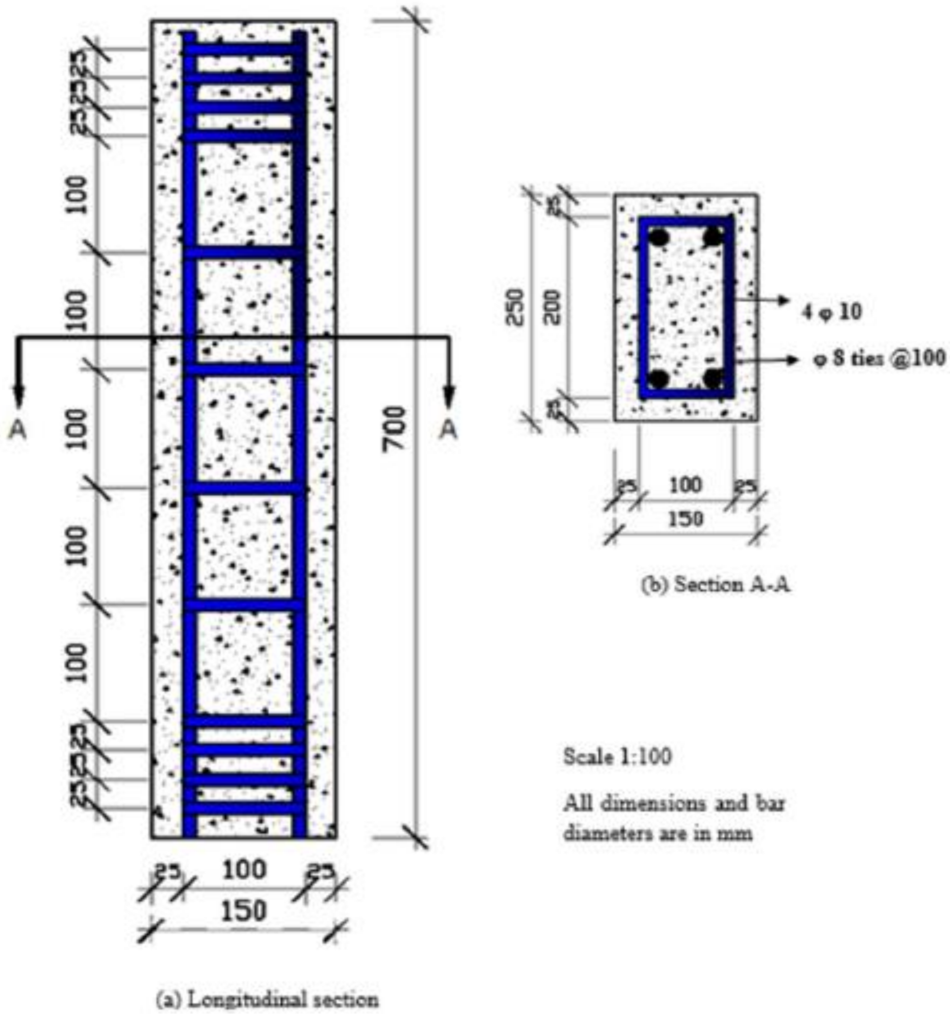
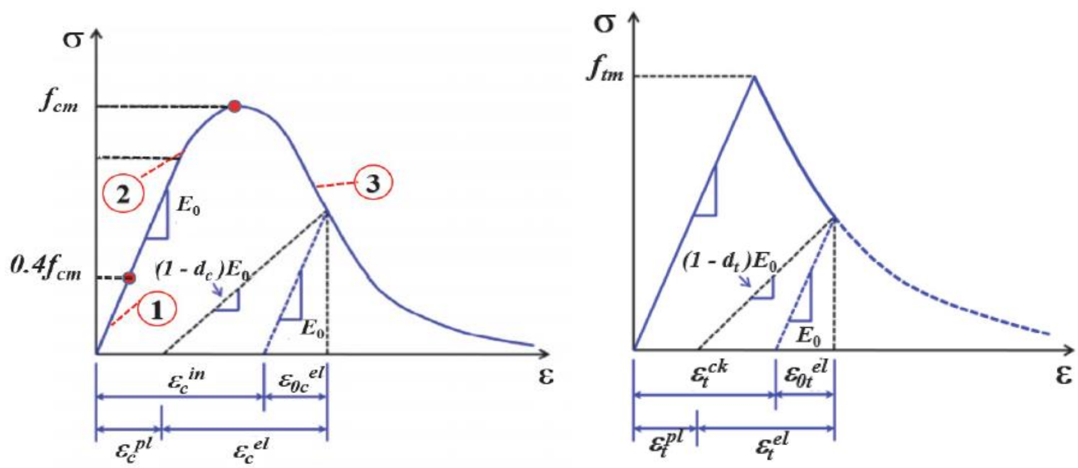


Figure 4: Layout and detailing of columns.

3.3 Material Properties

The concrete damage-plasticity (CDP) model is utilized to describe the plastic behavior of concrete, specifically in compression and tension. This model is suitable for analyzing compression zones, as it employs plasticity theory in such regions. The CDP model incorporates two fundamental failure criteria: compressive crushing and tensile cracking of concrete.

Furthermore, the plasticity model adopts the yield function initially proposed by Lubliner et al. (1989) and follows to a non-associated flow rule. Detection of strength or stiffness degradation in the CDP model relies on two parameters: dt and dc, representing tension and compression damage parameters, respectively.



a b

Figure 5: Damage variables: (a) behavior in compression, (b) behavior in tension. Le Minh et al. (2022).

The values of plastic damage parameters are shown in Table 1 as recommended by ABAQUS documentation for the definition of concrete material. The Poisson's ratio of concrete was chosen to be 0.2.

Table 1: Values of plastic damage parameters used for concrete model.

Parameter	Dilation Angle (Ψ)	Eccentricity (ϵ)	f_{b0}/f_{c0}	K	Viscosity Parameter
Value	30°	0.1	1.16	0.667	0.0001

Where:

(Ψ): the dilation angle.
(e): the flow potential eccentricity.
(f_{b0}/f_{c0}): the ratio of initial biaxial compressive yield stress to initial uniaxial compressive yield stress.
(K): the ratio of the second stress invariant on the tensile meridian to that on the compressive meridian.

Compression damage variable (dc):

This parameter is used to specify compressive stiffness degradation damage, dc is determined through plastic strain ε_c^{pl} and using a constant factor bc with $0 < bc \leq 1$.

$$d_c = 1 - \frac{\sigma_c E_c^{-1}}{\varepsilon_c^{pl}\left(1/b_c - 1\right) + \sigma_c E_c^{-1}} \qquad (1)$$

Tension damage variable (dt):

Similar to the compression damage variable dc, the damaged parameter in tension dt depends on ε_t^{pl} and an experimentally determined parameter bt = 0.1. So, unloading is assumed to return almost back to the origin and to leave only a small residual strain.

$$d_t = 1 - \frac{\sigma_c E_c^{-1}}{\varepsilon_c^{pl}(1/b_t - 1) + \sigma_t E_c^{-1}} \qquad (2)$$

To model the behavior of concrete in compression, the stress-strain curve of concrete for a given concrete characteristic compressive strength can be described using a suitable model, such as the one developed by Carreira and Chu et al. (1985), as follows:

$$f_c = \frac{f_c' \beta (\varepsilon / \varepsilon_0)}{\beta - 1 + (\varepsilon / \varepsilon_0)^{\beta}} \qquad (3)$$

$$\beta = \frac{1}{1 - \left(\frac{f_c'}{E_0 \varepsilon_0}\right)} \qquad (4)$$

$$E_0 = \frac{f_c'}{\varepsilon_0}\left(\frac{24.82}{f_c'} + 0.92\right) \qquad (5)$$

$$\varepsilon_0 = (1680 + 7.1 f_c') \times 10^{-6} \qquad (6)$$

where f_c is the concrete stress; $f'c$ is the maximum stress; β is a material parameter; ε is the concrete strain; ε_0 is the corresponding strain at maximum stress; and E_0 is the initial tangent modulus of elasticity.

For concrete under uniaxial tension, Carreira and Chu et al. (1985) proposed the following equations:

$$\frac{f_t}{f_t'} = \frac{\beta\,(\epsilon/\epsilon_t')}{\beta - 1 + (\epsilon/\epsilon_t')^{\beta}} \qquad (7)$$

Where:

f_t = the stress corresponding to the strain ε.

f_t' = the point of maximum stress, considered as the tensile strength.

$\varepsilon t'$ = the strain corresponding to the maximum stress.

β = a parameter that depends on the shape of the stress-strain diagram.

$$\epsilon_s E_s A_s + A_c f_t = P_b \qquad (8)$$

$$\epsilon_s = \epsilon_c = \epsilon_m \qquad (9)$$

$$f_t = \rho(f_s - \epsilon_m E_s) \qquad (10)$$

Where:

ε_s, ε_s: reinforcement and concrete strain, respectively.

ε_m: average strain (measured elongation divided by the gage length).

E_s: reinforcement elastic modulus.

A_s, A_c: reinforcement and concrete cross-sectional area, respectively.

$\rho = A_s/A_c$

P_b: the externally applied load to the reinforcement.

f_s: stress externally applied to the reinforcement.

f_t: average tensile stress in the concrete.

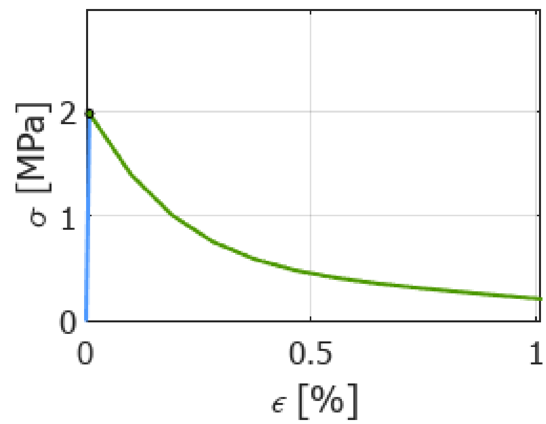


Figure 6: Tensile stress-strain diagram (Carreira and Chu model).

The material characteristics of normal concrete, steel reinforcement, CFRP cords and CFRP sheets can be summarized in Table 2, Table 2, Table 4 and Table 5 respectively.

Table 2: Mechanical properties of normal concrete.

Compressive strength (Mpa)	Modulus of elasticity (Mpa)
25	23500

Table 3: Mechanical properties of streel reinforcement.

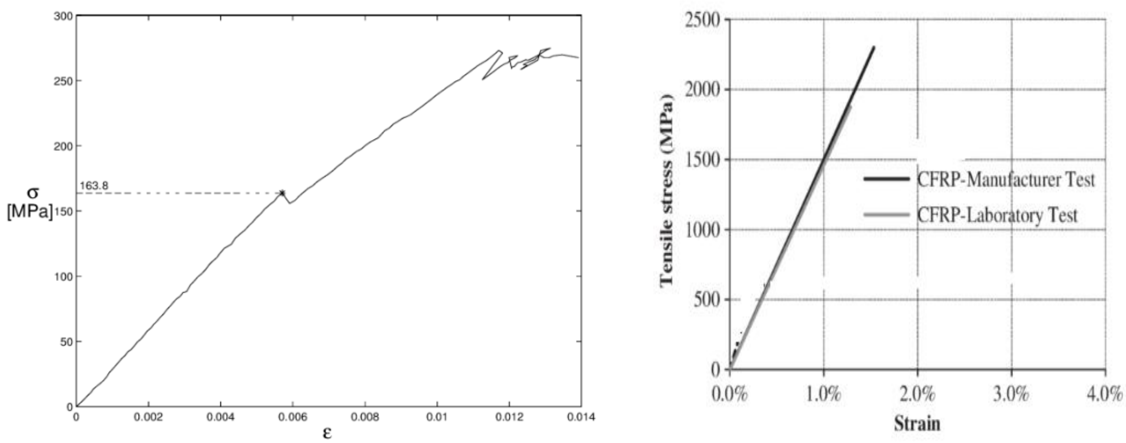
Property	Main Bars	Stirrups
Yeild Strength (Mpa)	421	570
Modulus of Elasticity (Mpa)	200000	200000

Table 4: Mechanical properties of CFRP cords.

Tensile Strength (Mpa)	Modulus of elasticity (Mpa)	Strain
2100	230000	0.016

Table 5: Mechanical properties of CFRP sheets.

Tensile Strength (Mpa)	Modulus of elasticity (Mpa)	Strain
3500	225000	0.017



a b

Figure 7: Stress-strain behavior of CFRP, (a) in compression and (b) in tension.

3.4 Numerical Modeling

This study was utilized a numerical approach to analyze the load carrying capacity and load-deflection relationship of reinforced columns. The main aim of this numerical modeling was to validate the experimental data, particularly focusing on load-deflection curves, failure loads, and cracking patterns. For this purpose, Abaqus finite element analysis software was employed to create the numerical models. The elements were defined in 3D, with steel reinforcement modeled as wire with two nodes and 3D truss elements, while normal concrete and CFRP cords modeled as solid extrusions with three nodes but CFRP sheet modeled as a lamina. The bond between concrete, reinforcement, and steel was represented as an embedded region, with the concrete acting as the host element. The bonding between normal concrete and CFRP cords and sheets was simulated as a tie-bond.

3.5 Finite Element Consideration

In the context of Abaqus analysis, the explicit dynamic technique emerges as a highly dependable method for applying loads. This technique is deemed successful due to two key factors. Firstly, it yields consistent and reliable results while minimizing convergence problems. Secondly, it proves to be particularly suitable for materials like concrete, as it effectively captures concrete fractures and overall failure behavior. In this study, all data obtained from the finite element model was compared with the experimental data, encompassing the load curve, ultimate failure load, and crack patterns.

3.6 Modeling of CFRP Cord

CFRP cord was modeled in Abaqus program such as normal concrete as a solid material with 3D dimensional with a tensile strength and modulus of elasticity of 2100 Mpa and 230000 Mpa respectively. Dimensions are (10×10 mm) and length of 250 mm and 150 mm for long and short side of column respectively.

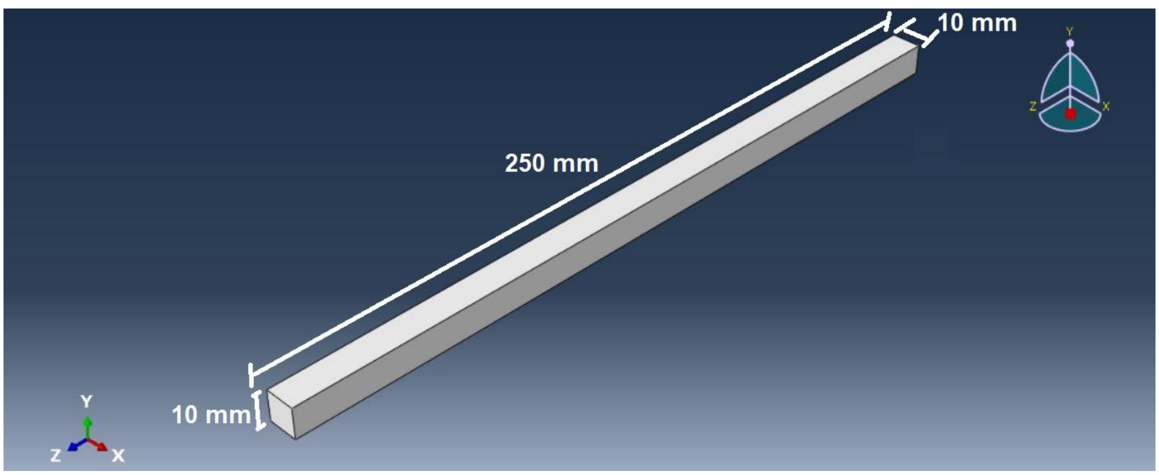


Figure 8: CFRP cord dimensions.

3.7 Loading and Boundary Conditions

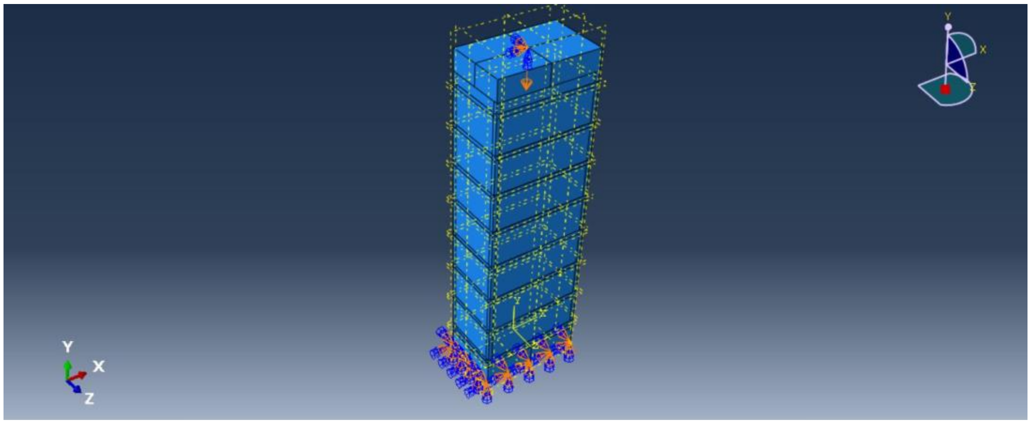


Figure 9: Detailing of boundary condition and loading.

The boundary conditions were utilized in modeling are the same ones that were used in experiments. Two load plates are placed at top and bottom of the column. Figure 8 shows the arrangement of boundary conditions, the bottom of the column has fixed support. The load applied as a displacement load (20 mm) and it applied at the center of top of the column. To measure the axial shortening of the experimental columns, two linear variable displacement transducers (LVDTs) set symmetrically at opposite sides of the column as shown in Figure 9.

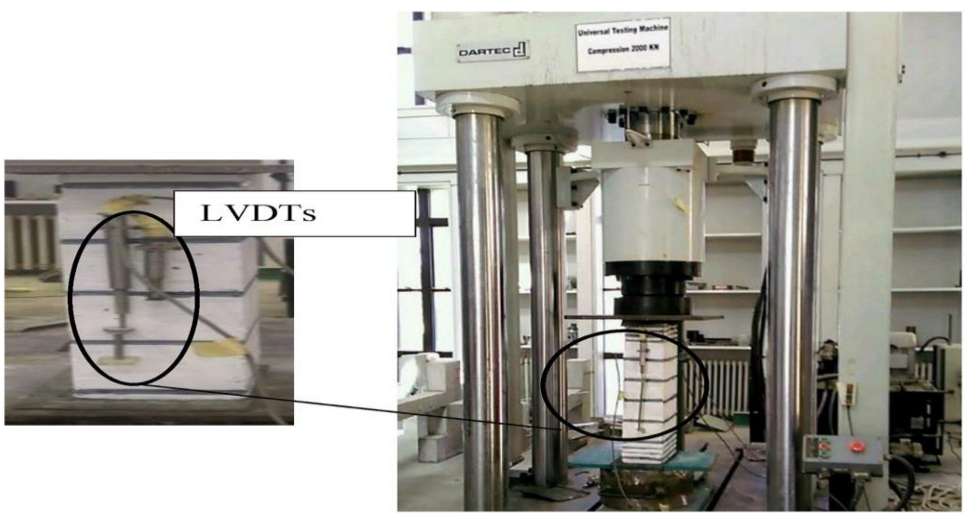


Figure 10: Instrumentation of the test specimens.

3.8 Verification of Model Data

3.8.1 Control Column (without CFRP)

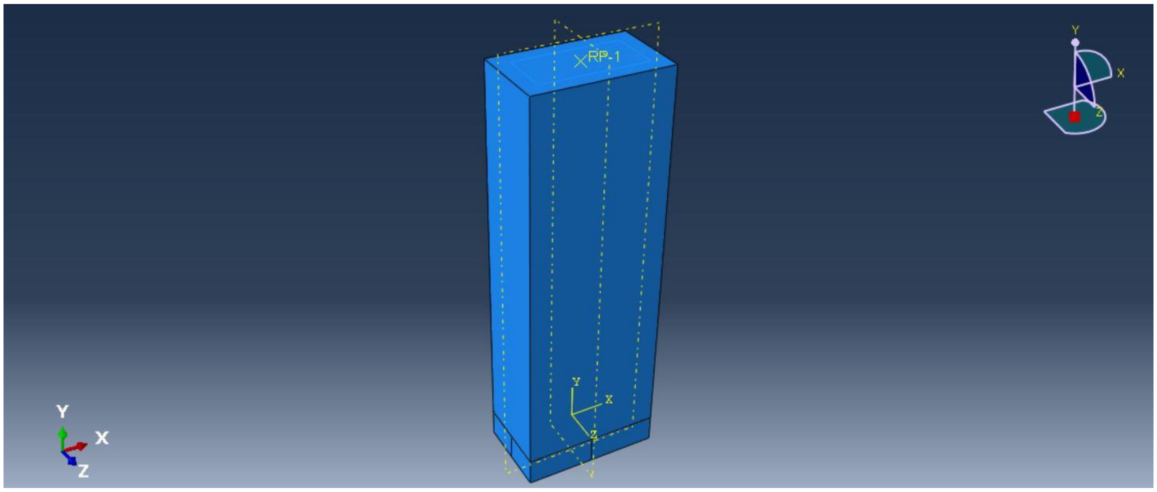


Figure 11: Control column without CFRP.

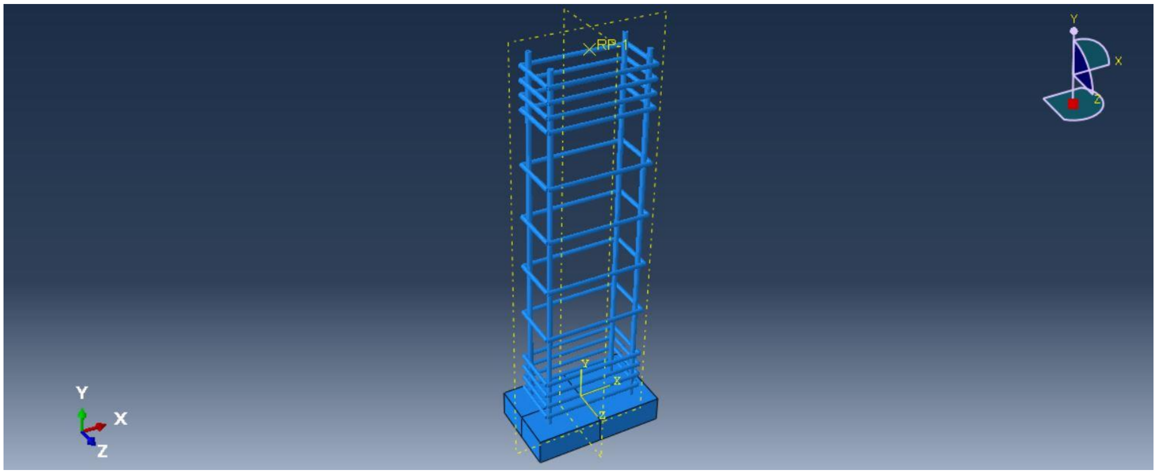


Figure 12: Steel of control column without CFRP.

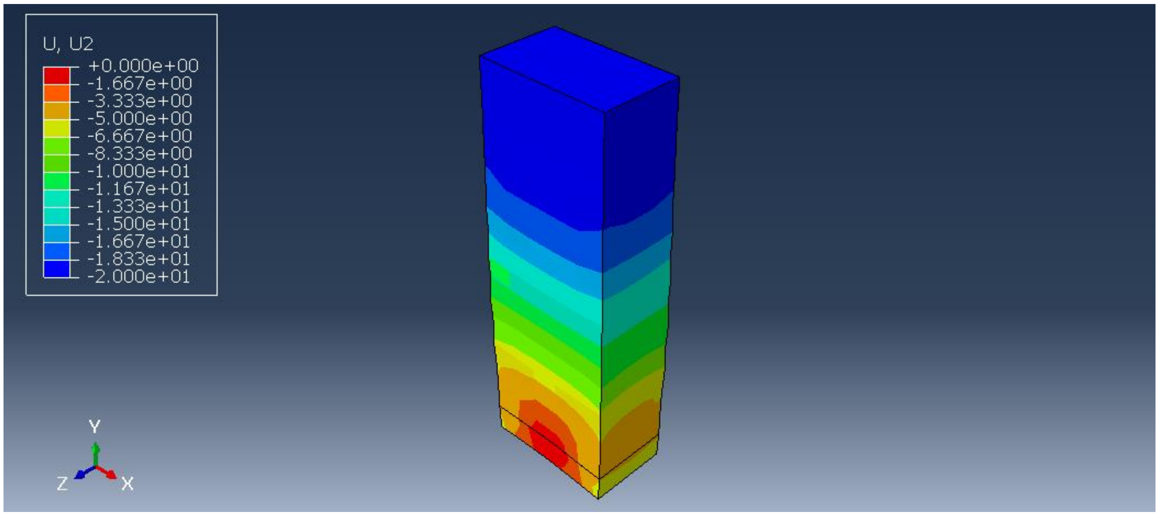


Figure 13: Without CFRP model – vertical displacement (U2).

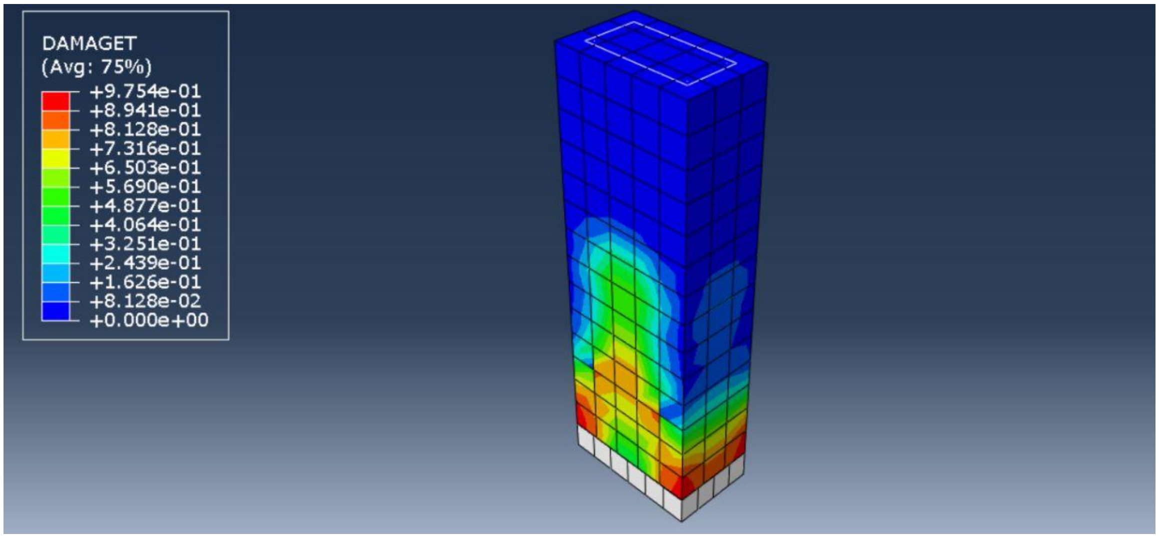


Figure 14: Without CFRP model – damage tension.

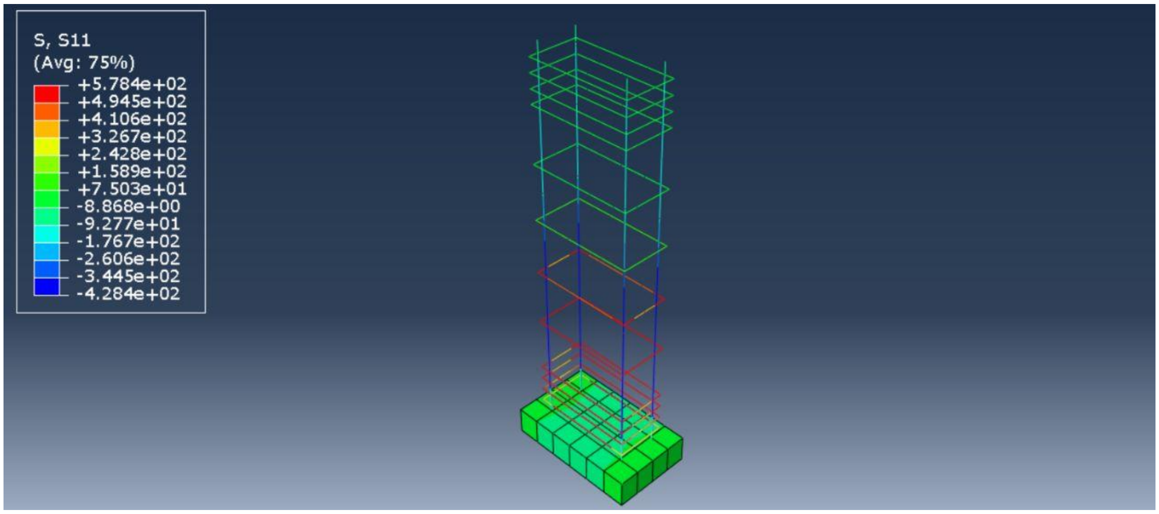


Figure 15: Without CFRP model – steel normal stress.

The diagram below presented illustrates the correlation between the load applied and the displacement observed in the column. The experimental data is sourced from a paper authored by Obaidat et al. (2020), while the numerical data is generated through the utilization of Abaqus software. The behavior and response of the experimental column closely align with the Abaqus model, showcasing a striking similarity. The numerical model achieved a peak load capacity of roughly 664 KN, whereas the experimental paper reported a value of approximately 698 KN. The variation between the maximum load capacities obtained from Abaqus and the experimental data amounts to a reduction of around 5%, an acceptable percentage.

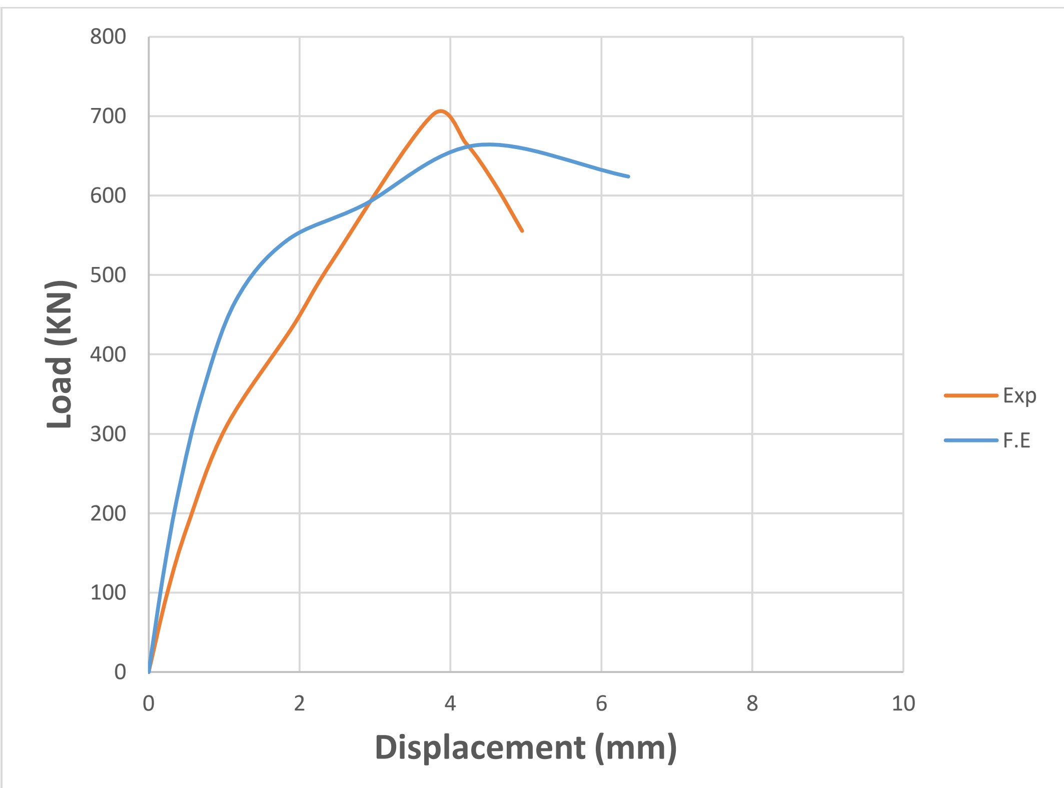


Figure 16: Load-displacement curve of control column.

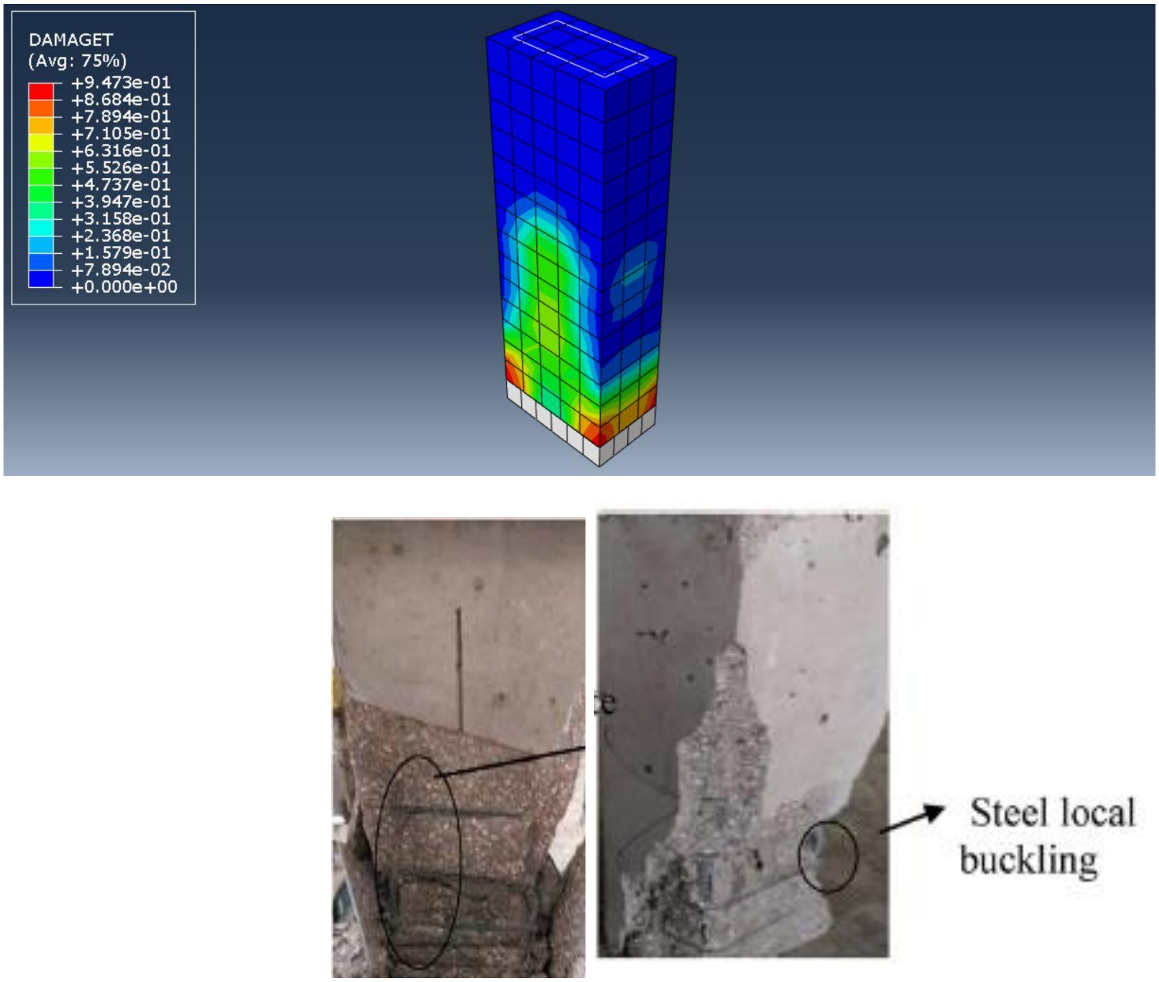


Figure 17: A failure mode (damage tension) of F.E model without CFRP and experimental sample.

3.8.2 Column with CFRP Cords

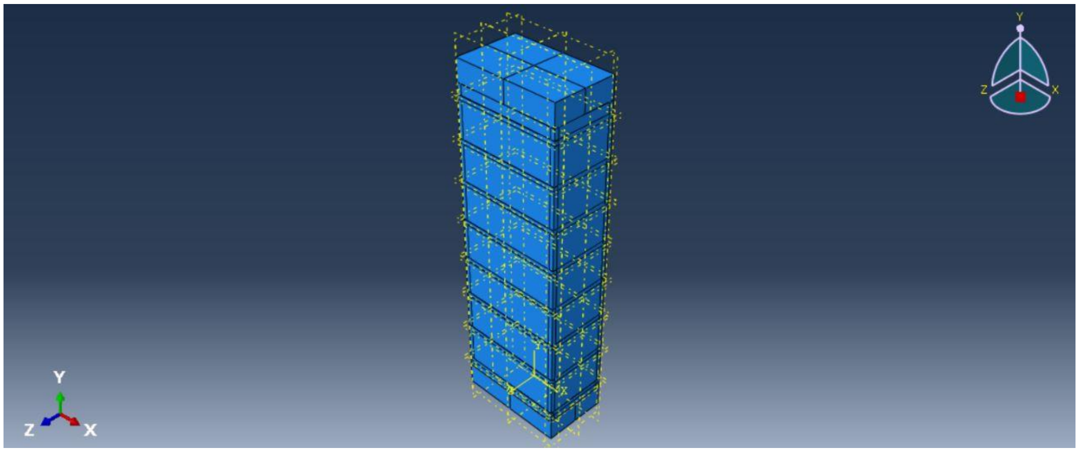


Figure 18: Column with CFRP cords

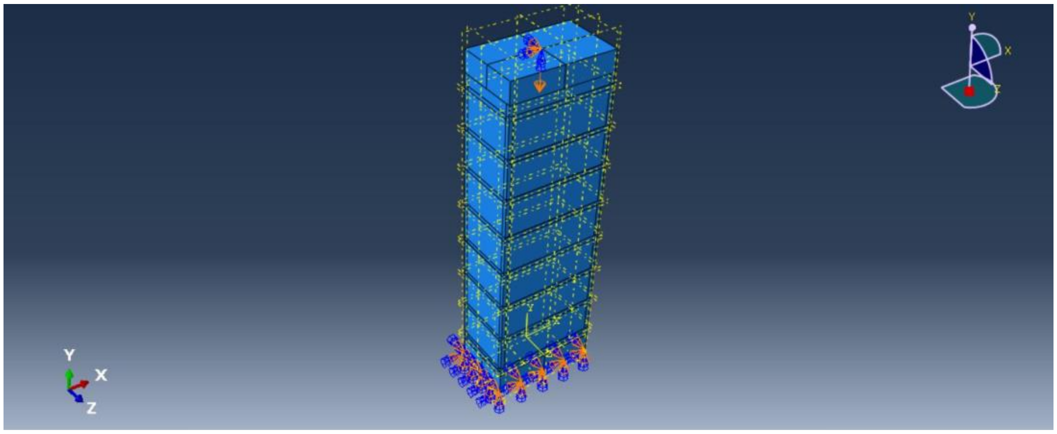


Figure 19: Load and support's location.

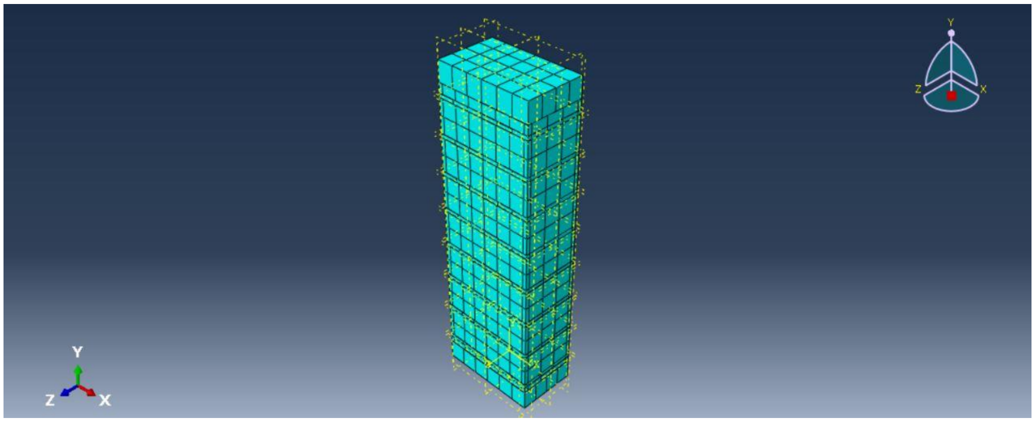


Figure 20: Meshing the whole model.

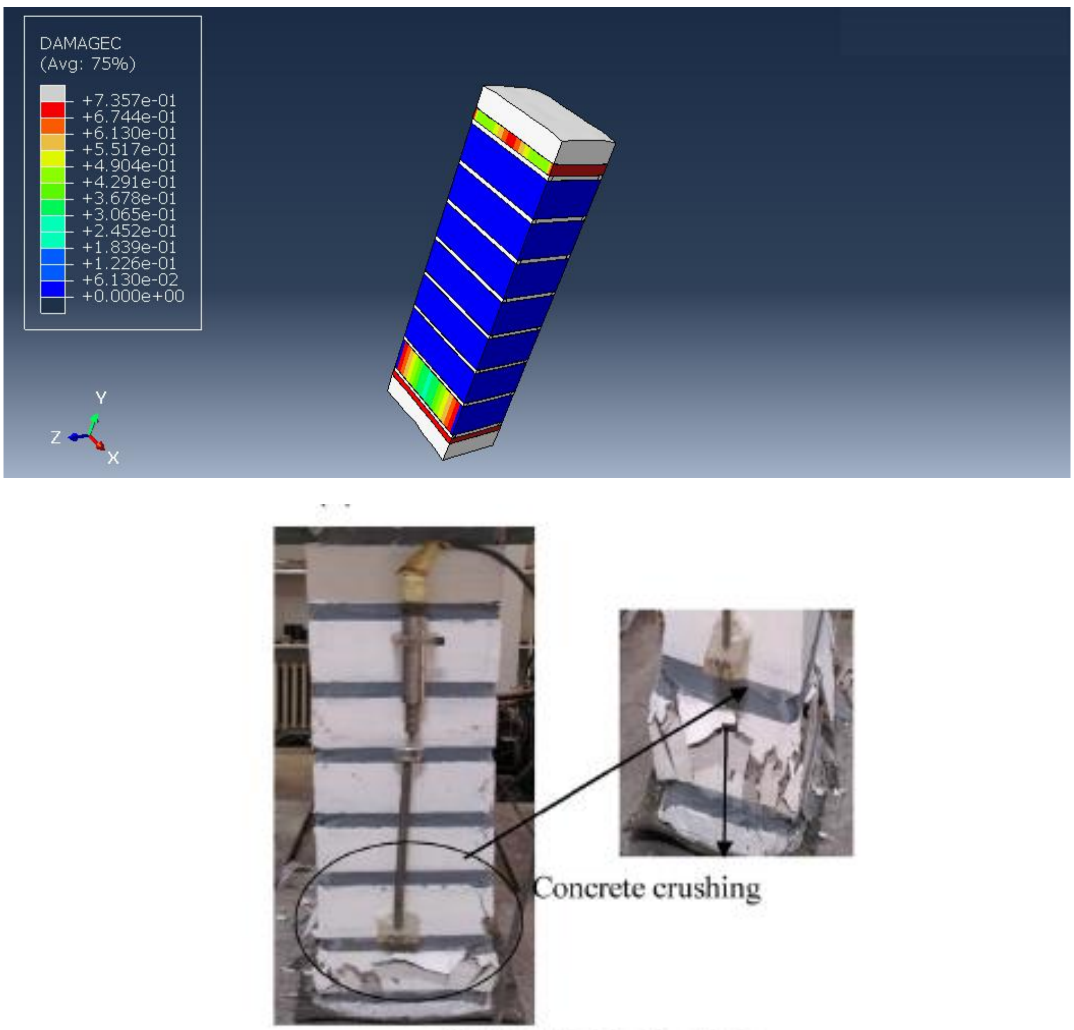


Figure 21: Failure mode (damage compression) of F.E model and experimental one with CFRP.

The diagram displayed below illustrates the connection between the applied load and the displacement observed in the strengthened reinforced column. The behavior and response of the experimental column closely mirror those represented in the Abaqus model. The numerical model achieved a peak load capacity of around 989 KN, whereas the experimental paper reported a value of approximately 1044 KN. The variance between the maximum load capacities obtained from Abaqus and the experimental data is about 5%, a deviation considered acceptable.

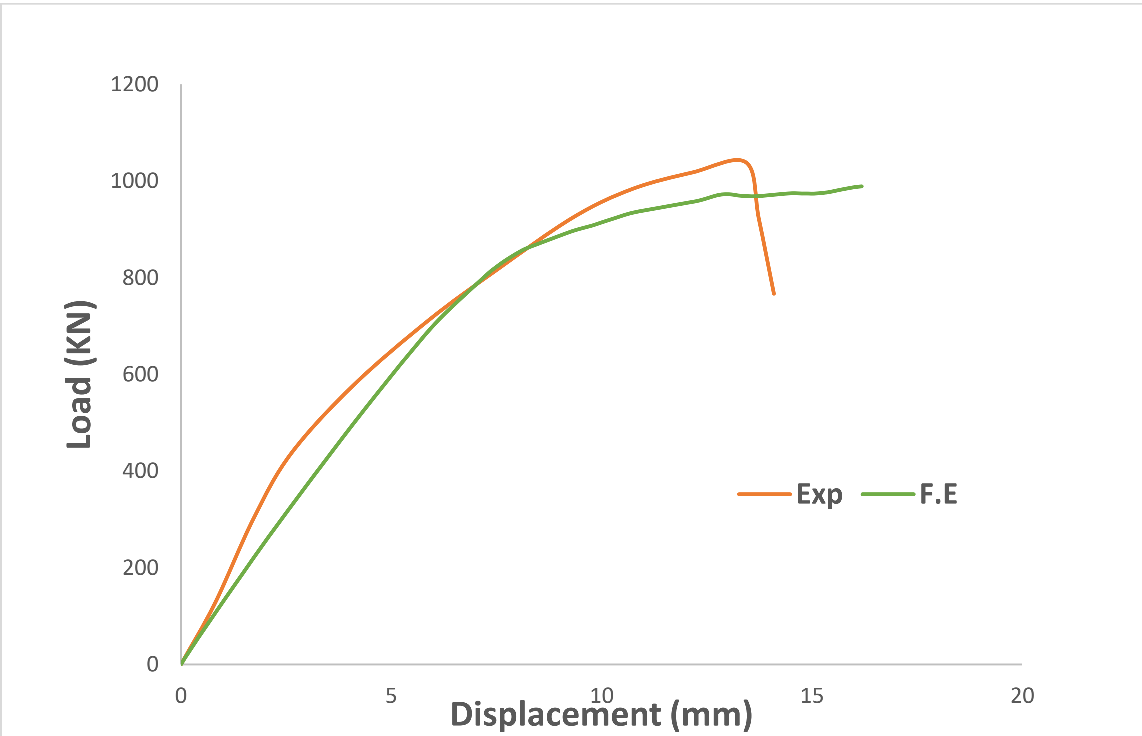


Figure 22: Load – Displacement Curve for CFRP model.

Clearly, the application of CFRP cords has the capacity to elevate the maximum load-carrying capacity to 1044 KN, signifying an advancement of 50%.

3.9 Parametric Study

A parametric investigation is carried out to explore into the behavior of reinforced concrete (R.C) columns that have been strengthened using CFRP (carbon fiber-reinforced polymer) using Abaqus. This study examines various factors such as, the shape of cross-sectional area of the column, classification of column short and long and the effect of applying CFRP sheet on (R.C) column.

The (RC) columns dimensions are (600×300) mm for rectangular and the diameter of 500 mm for circular. Both of them will reinforced with 8ϕ18 as longitudinal steel and ϕ10/100 mm as transverse stirrups reinforcement.

3.9.1: Short Column

In this parameter, a short column with 3.5 m height will be studied by simulation:

3.9.1.1: Rectangular Column

In this parameter, rectangular control column (without CFRP) and another with CFRP will be studied.

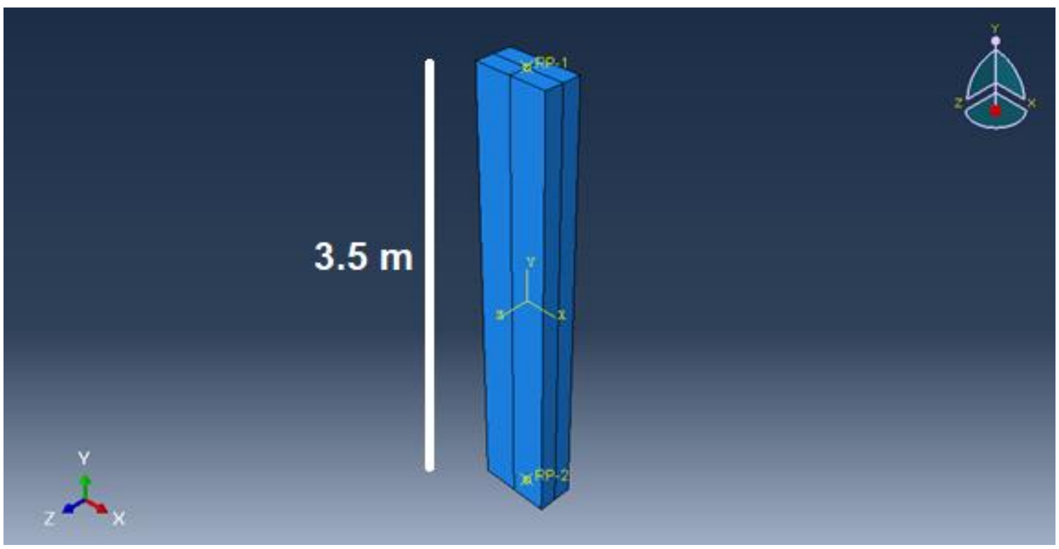


Figure 23: Short Rectangular Column.

3.9.1.2: Circular Column

In this parameter, circular control column and another with CFRP will be studied.

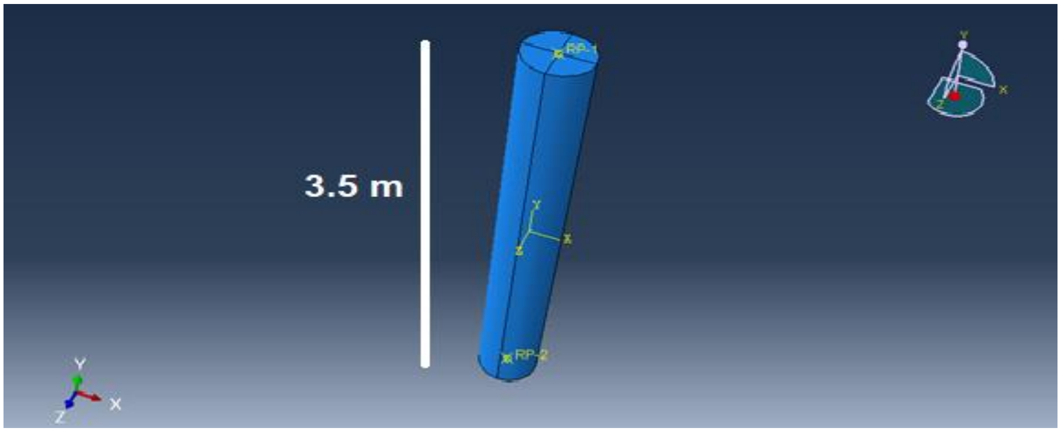


Figure 24: Short Circular Column.

3.9.2 Long Column

In this parameter, a long column with 5 m height will be studied by simulation:

3.9.2.1 Rectangular Column

In this parameter, rectangular control column and another with CFRP will be studied.

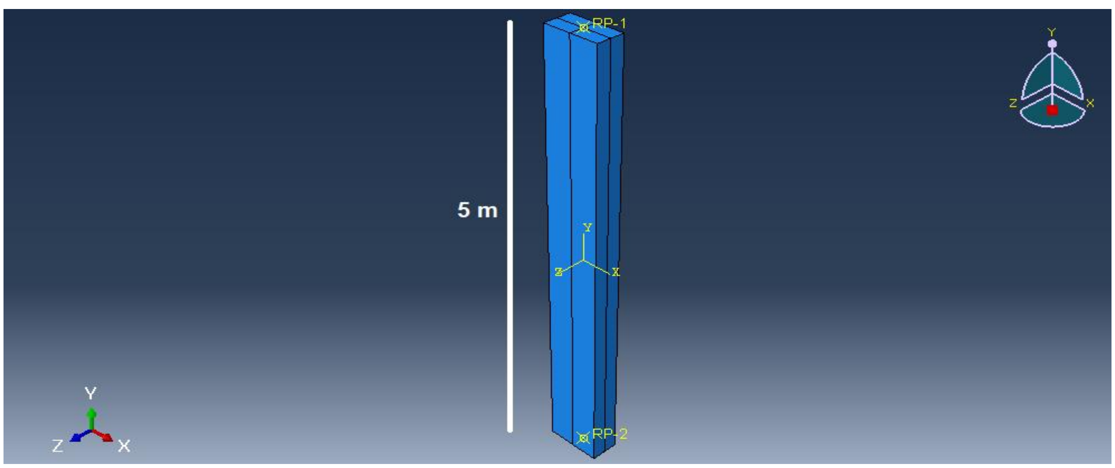


Figure 25: Long Rectangular Column.

3.9.2.2 Circular Column

In this parameter, circular control column and another with CFRP will be studied.

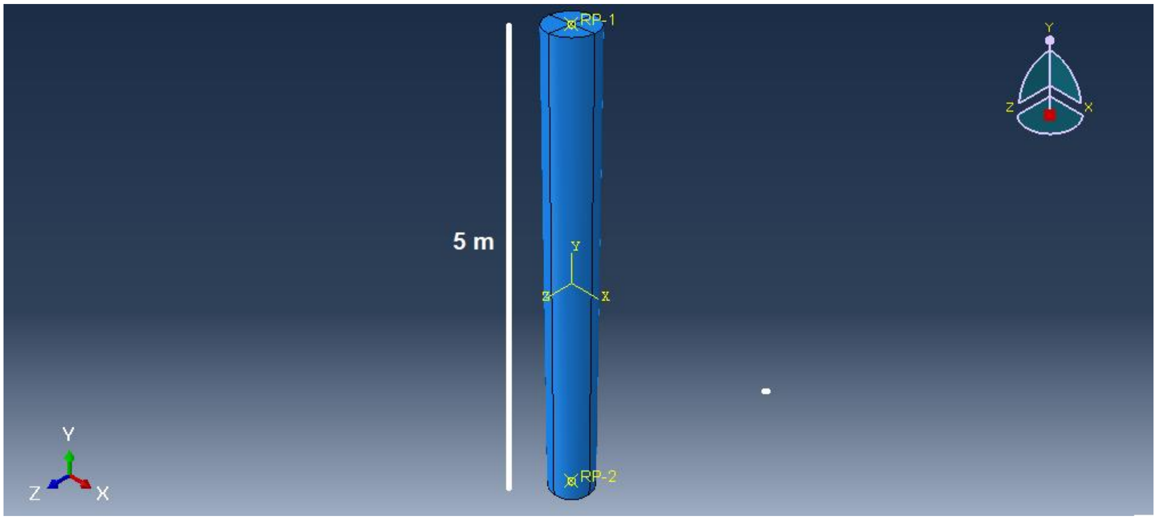


Figure 26: Long Circular Column.

Chapter 4: Results

Within this chapter, showing the primary outcomes derived from the examination of parameters outlined in Chapter 3 (3.9.1 and 3.9.2). Load-deflection curves will be displayed subsequently engage in thorough discussions of these curves.

4.1 Short Column

4.1.1 Rectangular Column

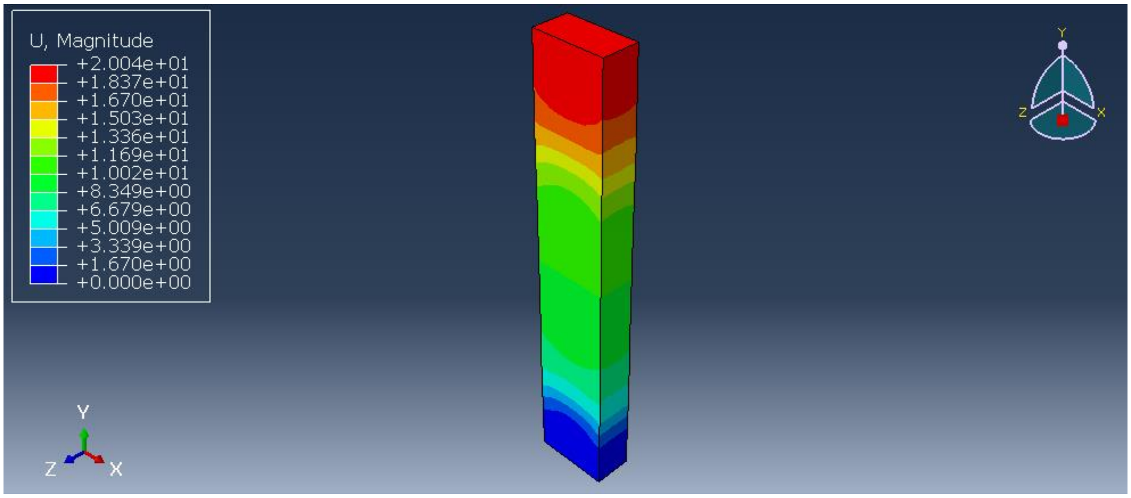


Figure 27: Short Rectangular Control Column – displacement.

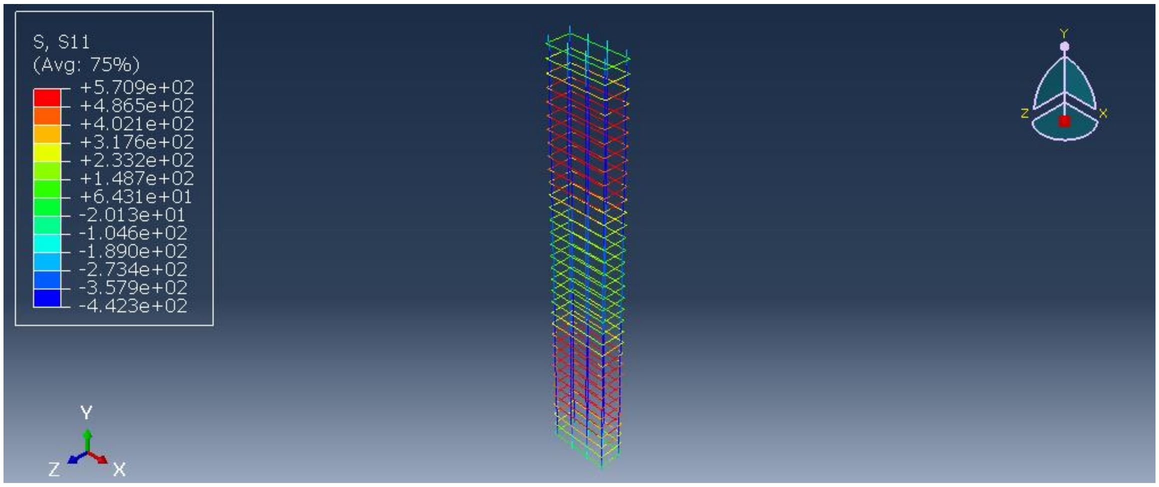


Figure 28: Short Rectangular Control Column – steel normal stress.

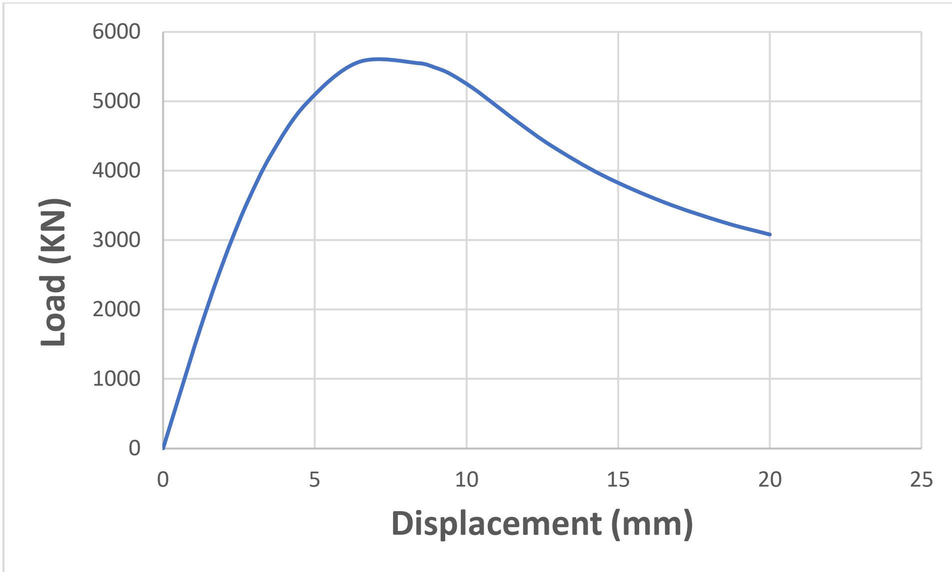


Figure 29: Short Rectangular Control Column – Load displacement curve.

The figure above showed that the maximum load capacity is about 5563 KN.

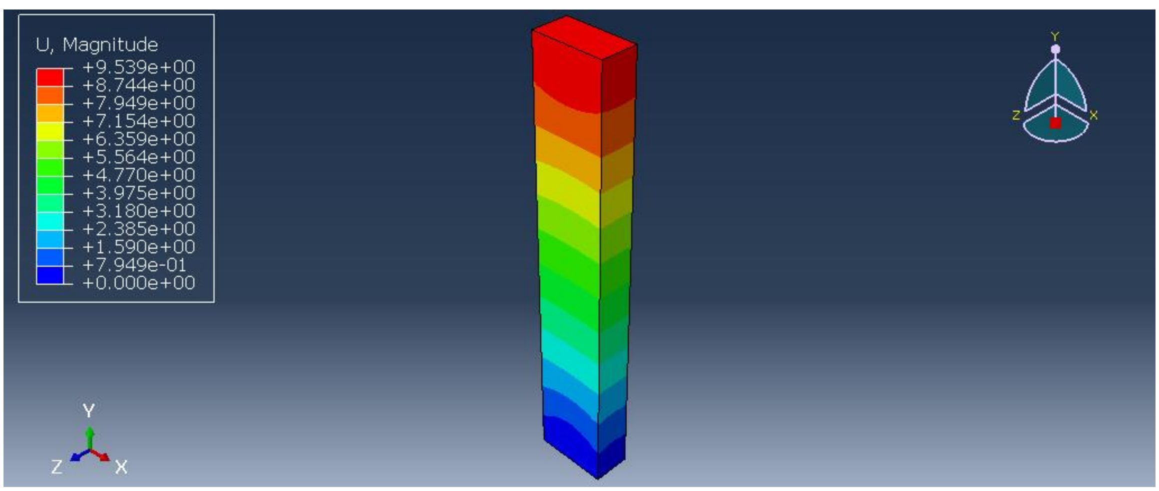


Figure 30: Short Rectangular Column with CFRP – displacement.

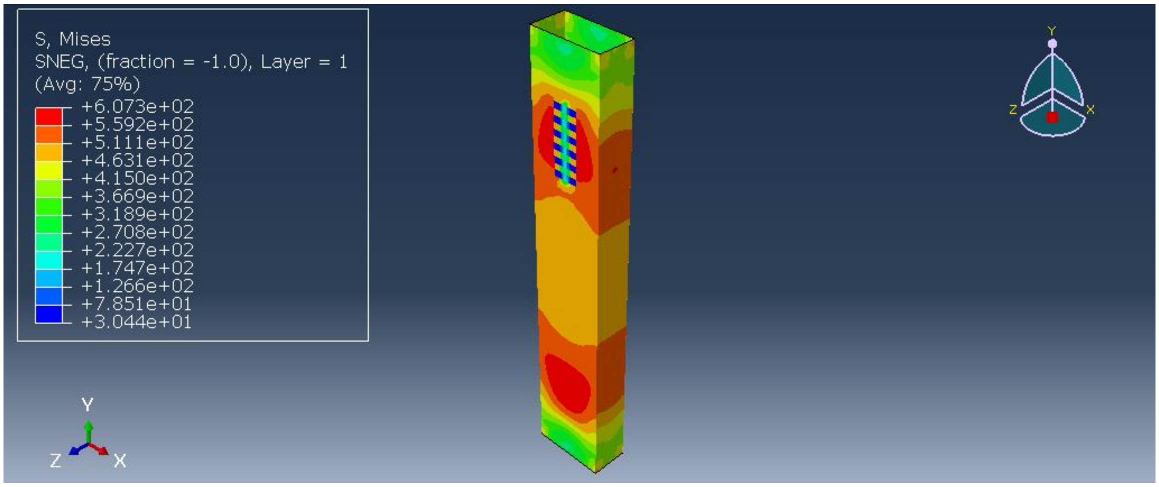


Figure 31: Short Rectangular Column with CFRP – stresses in CFRP.

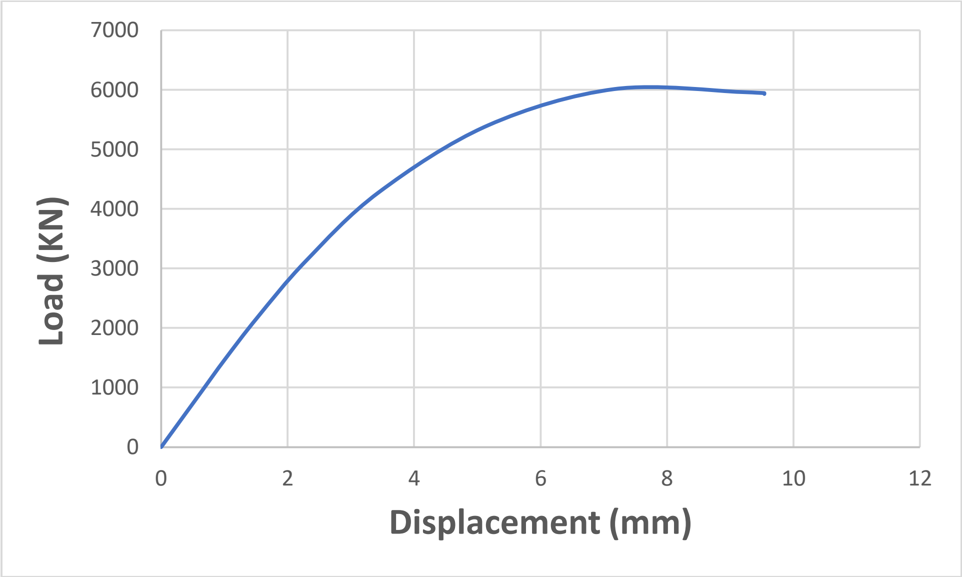


Figure 32: Short Rectangular Column with CFRP – Load displacement curve.

It is clear from the figure above, the maximum load capacity is about 6011 KN.

4.1.2 Circular Column

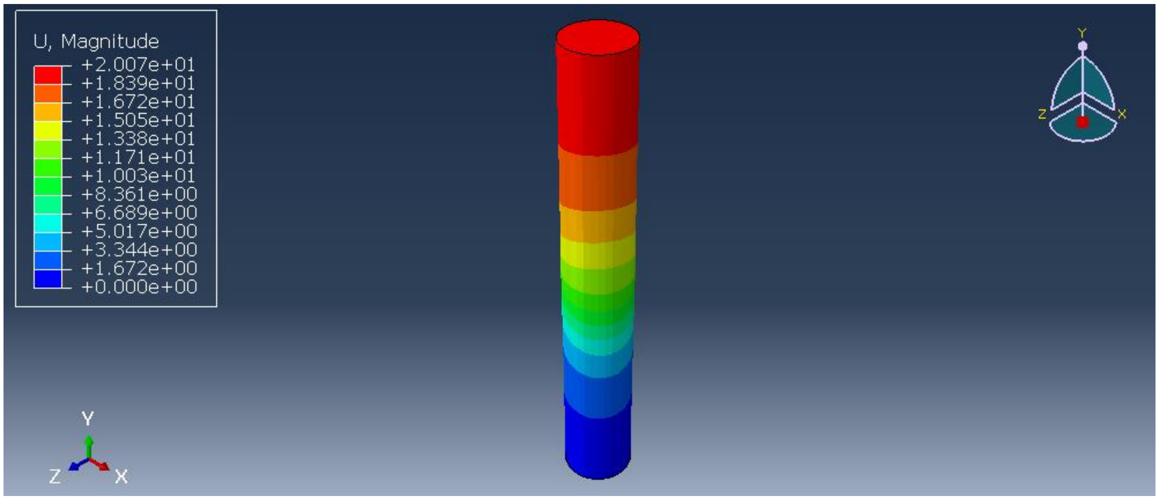


Figure 33: Short Circular Control Column – displacement.

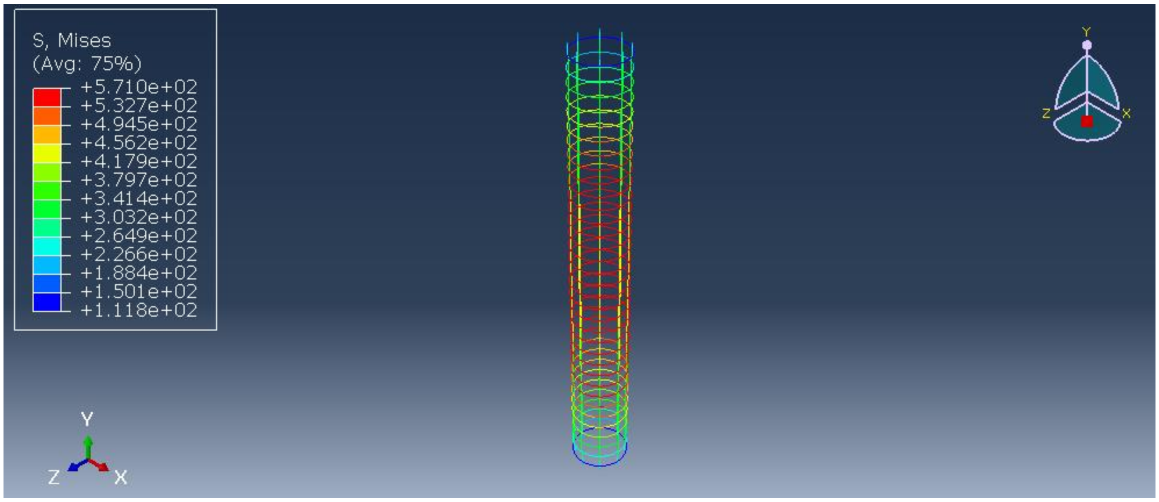


Figure 34: Short Circular Control Column – steel normal stress.

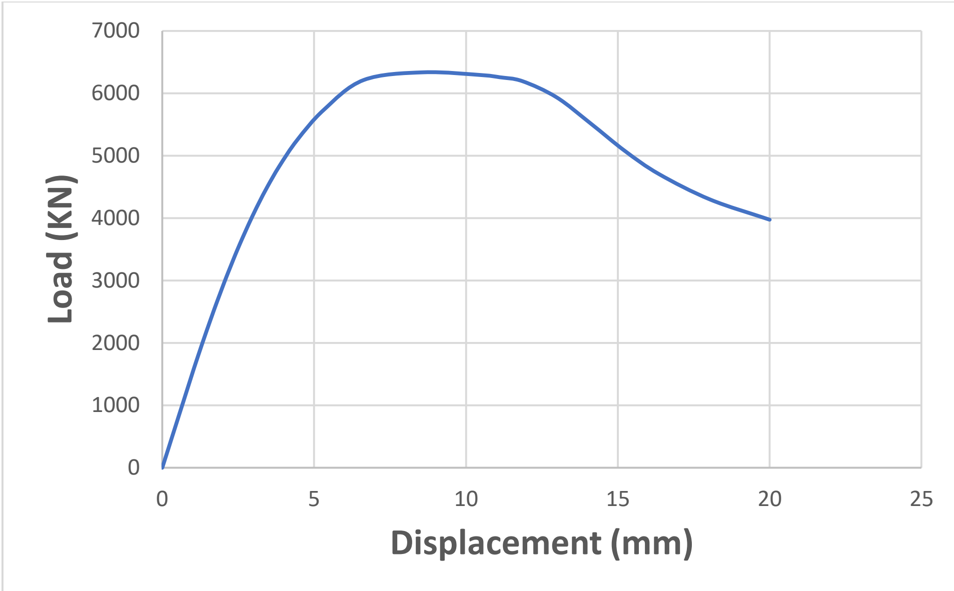


Figure 35: Short Circular Control Column – Load displacement curve.

From the curve above, the maximum load capacity is about 6335 KN.

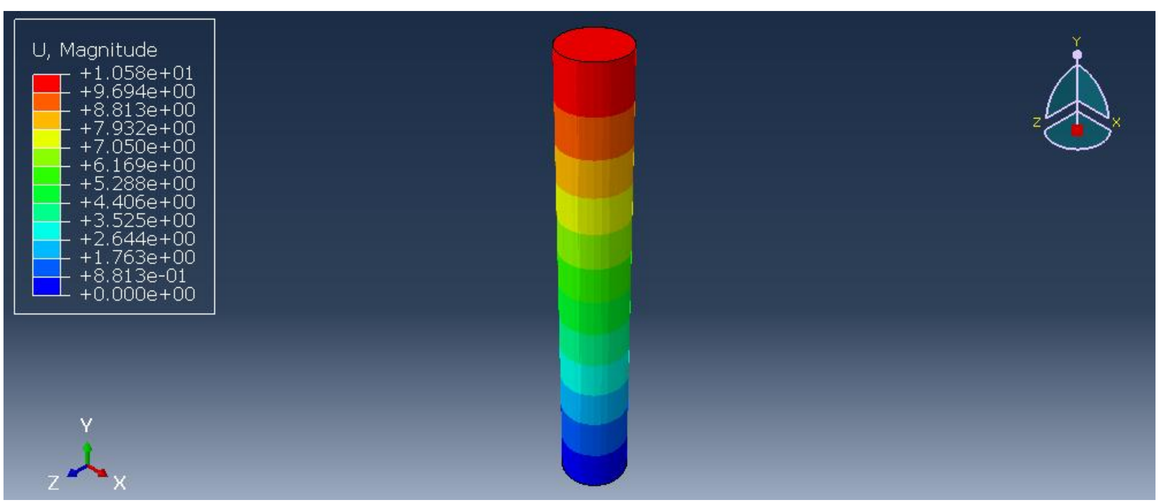


Figure 36: Short Circular Column with CFRP – displacement.

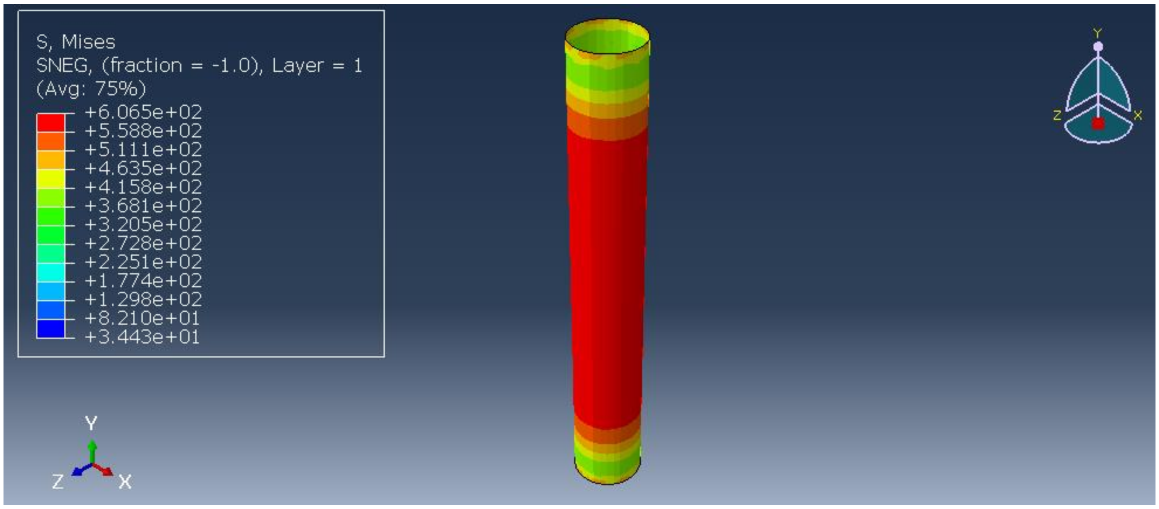


Figure 37: Short Circular Column with CFRP – stresses in CFRP.

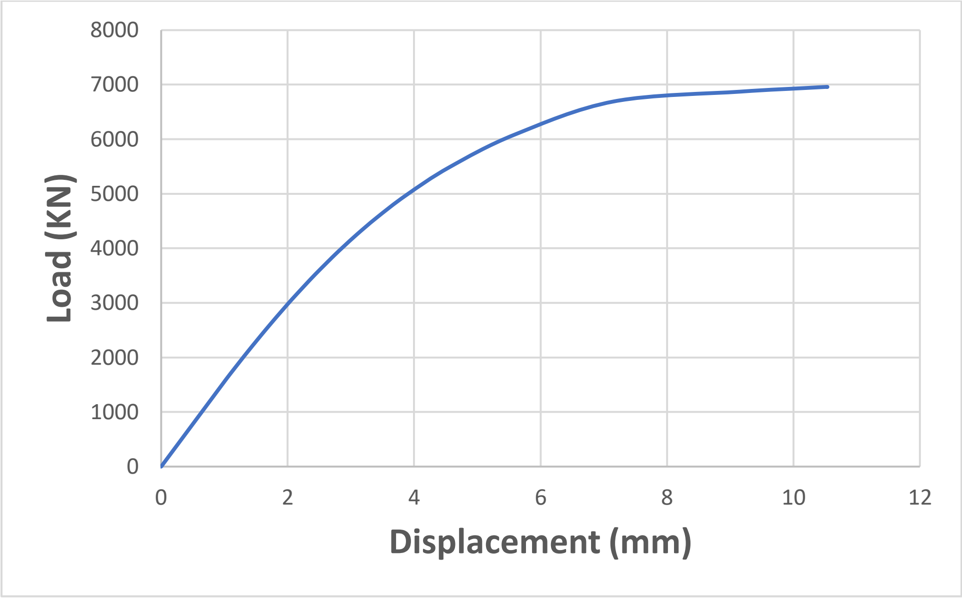


Figure 38: Short Circular Column with CFRP – Load displacement curve.

From the figure above, the maximum load capacity of circular column strengthened with CFRP is about 6958 KN.

4.2 Long Column

4.2.1 Rectangular Column

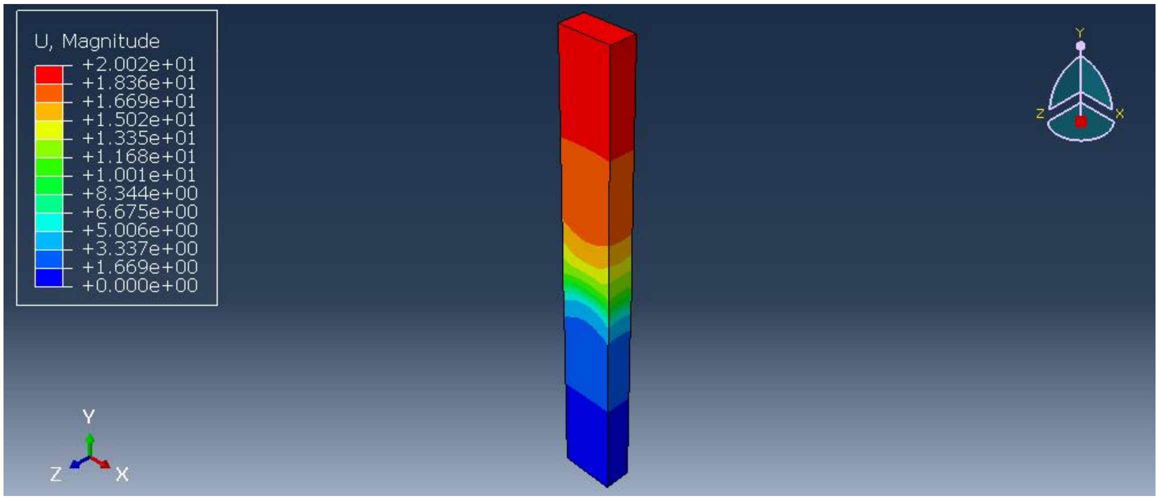


Figure 39: Long Rectangular Control Column – displacement.

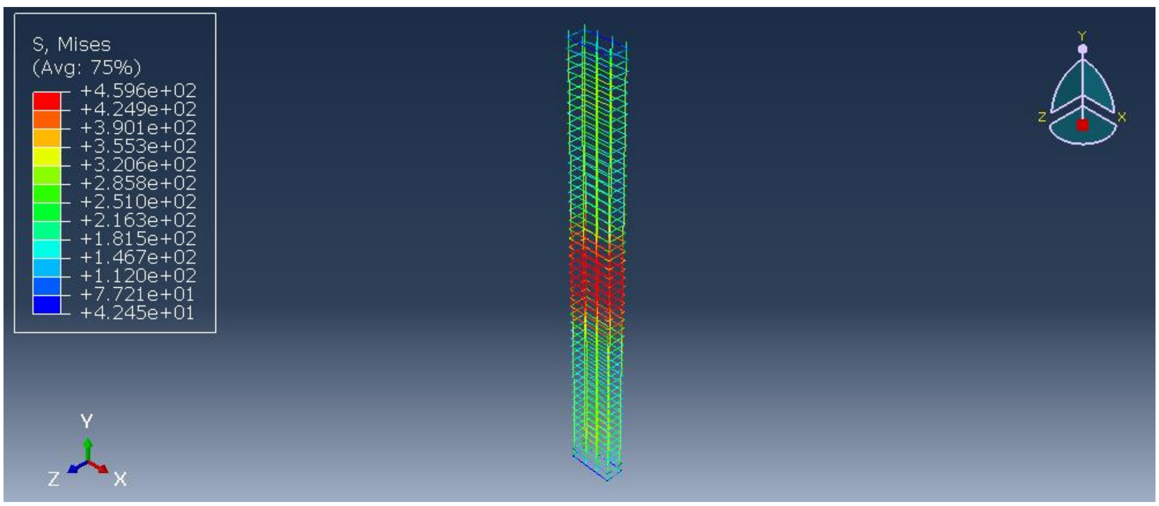


Figure 40: Long Rectangular Control Column – steel normal stress.

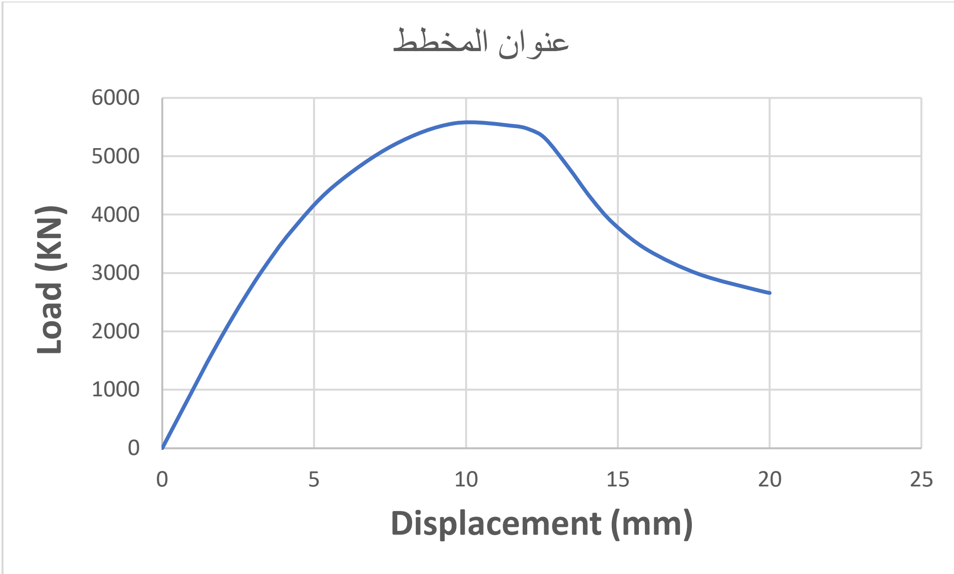


Figure 41: Long Rectangular Control Column– Load displacement curve.

From the figure above, the maximum load capacity is about 5563 KN.

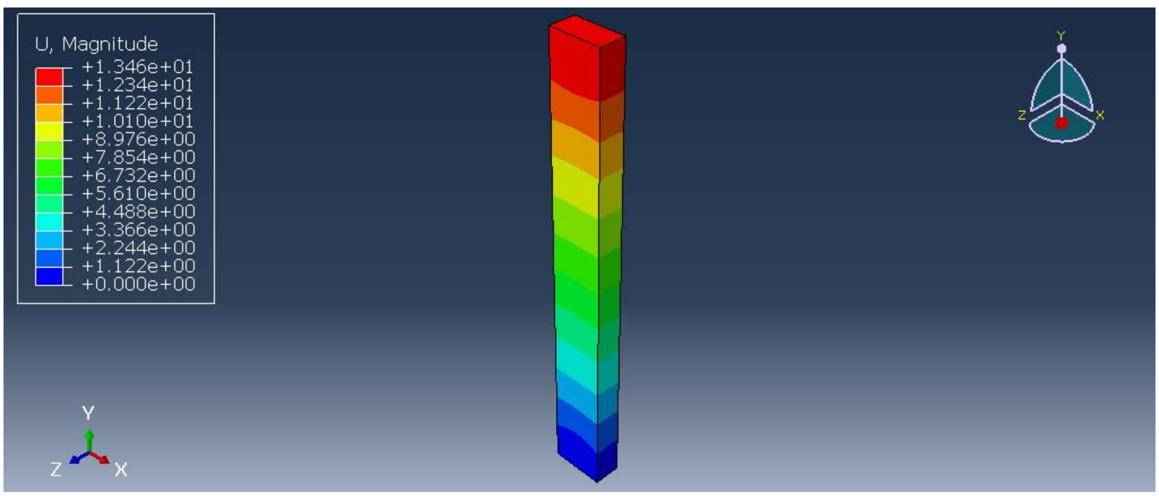


Figure 42: Long Rectangular Column with CFRP – displacement.

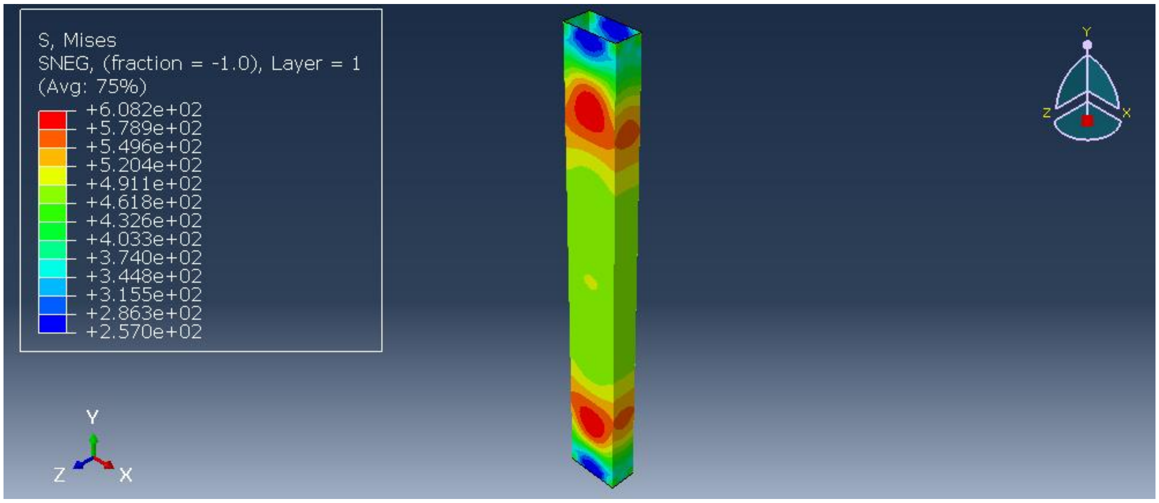


Figure 43: Long Rectangular Column with CFRP – stresses in CFRP.

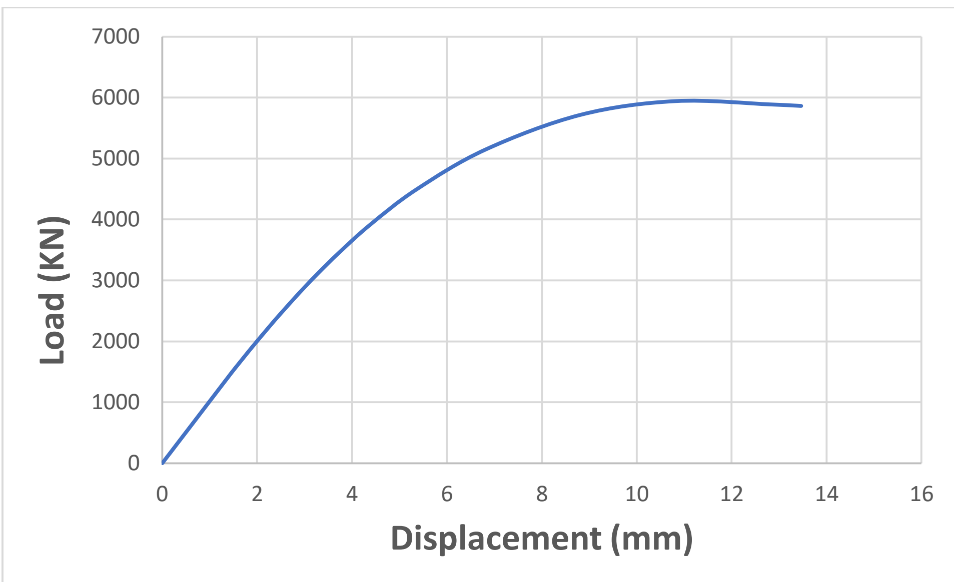


Figure 44: Long Rectangular Column with CFRP – Load displacement curve.

From the figure above, the maximum load capacity is about 5942 KN.

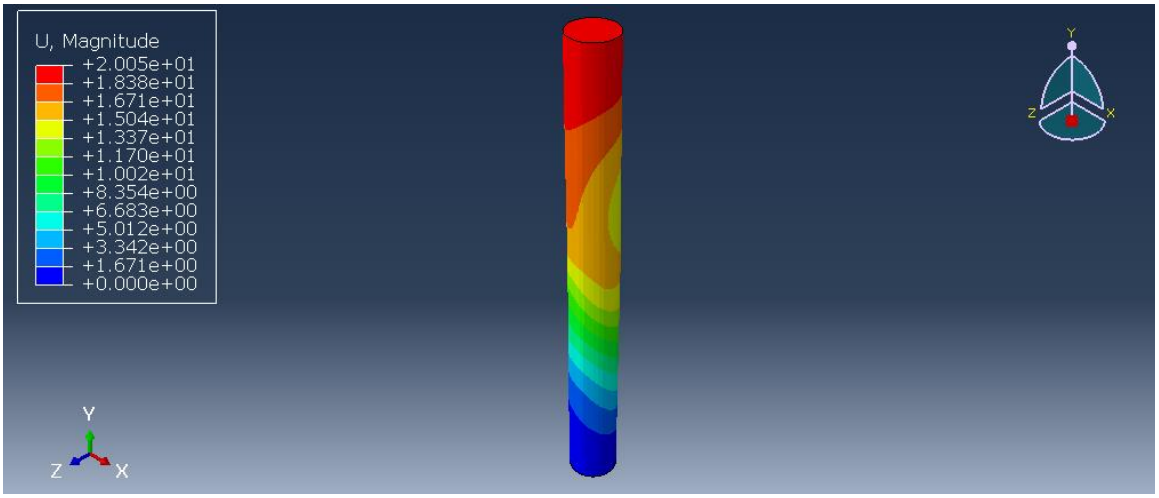


Figure 45: Long Circular Control Column – displacement.

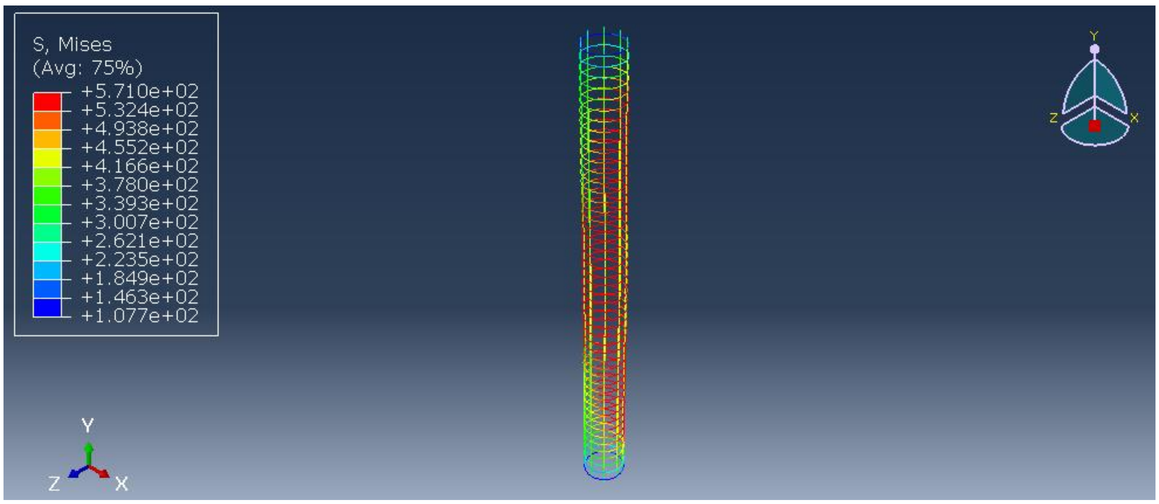


Figure 46: Long Circular Control Column – steel normal stress.

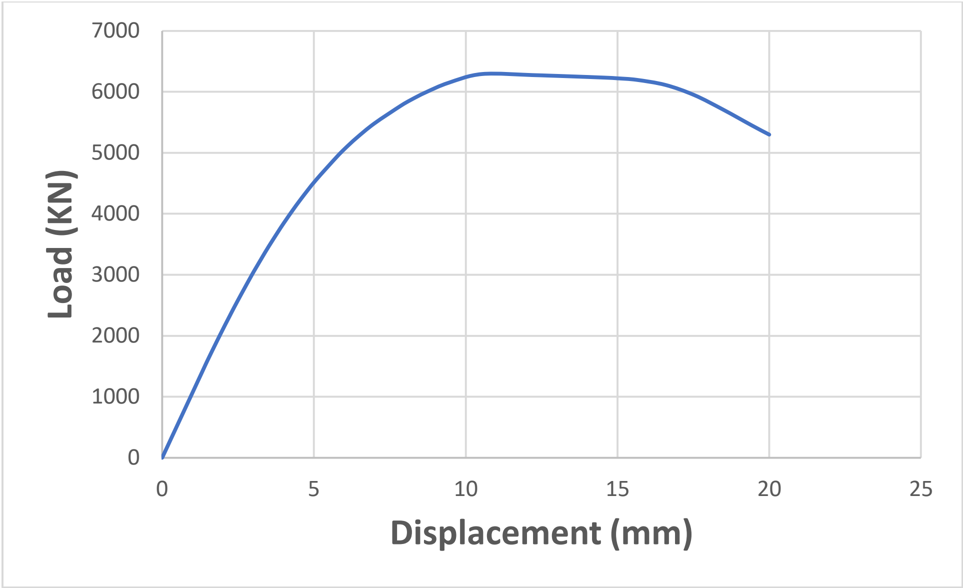


Figure 47: Long Circular Control Column – Load displacement curve.

From the figure above, the maximum load capacity is about 6291 KN.

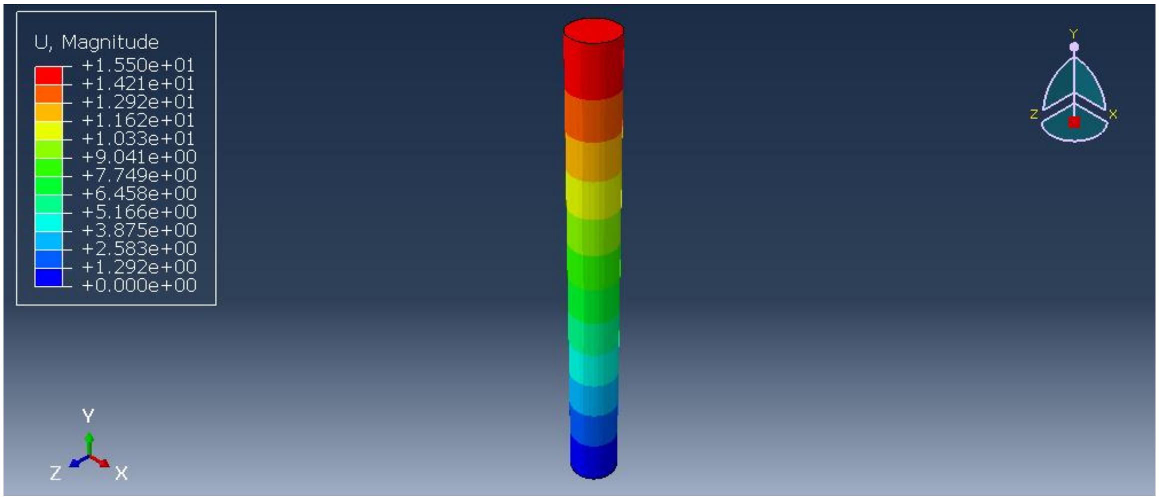


Figure 48: Long Circular Column with CFRP – displacement.

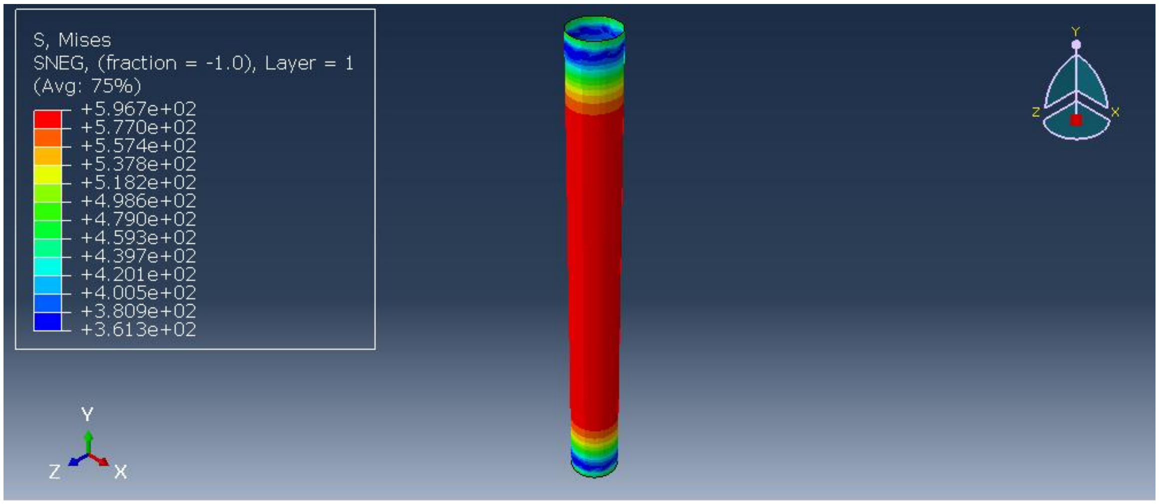


Figure 49: Long Circular Column with CFRP – stresses in CFRP.

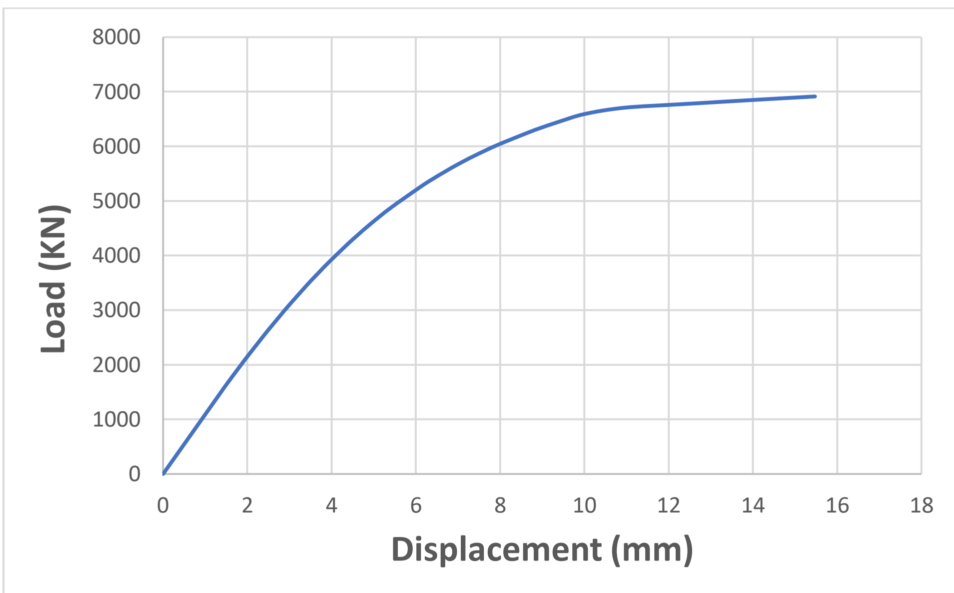


Figure 50: Long Circular Column with CFRP – Load displacement curve.

It is clear that from the figure above, the maximum load capacity is about 6912 KN.

Chapter 5: Discussion

5.1 Short Column

5.1.1 Rectangular column

Using the findings presented in chapter 4, where the finite element method is employed and compared load-displacement curves of control column and that strengthened with CFRP, it can be seen from the figure below that applying of CFRP enhances the load capacity of the short rectangular column by 8%.

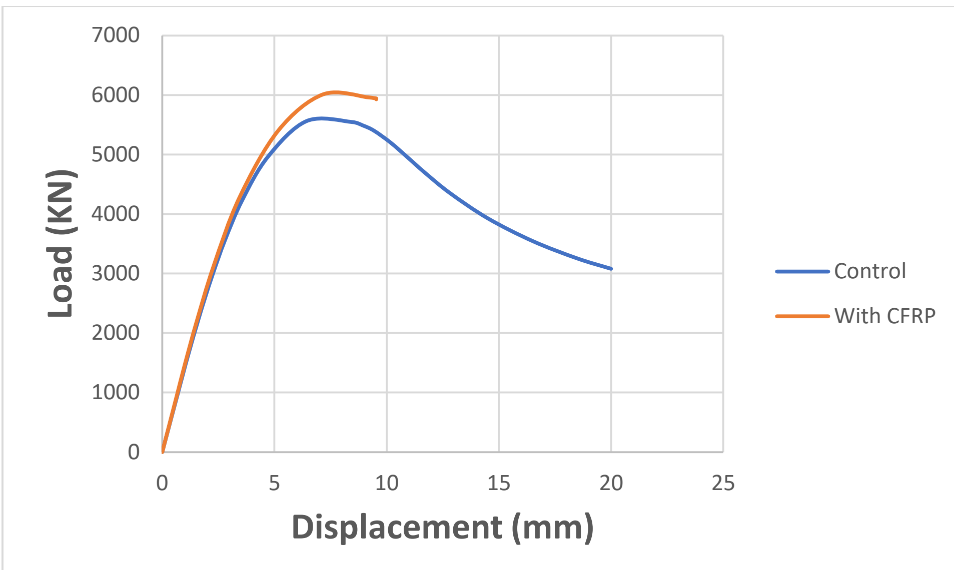


Figure 51: Comparison between load-displacement curve of rectangular control column and that strengthened with CFRP.

5.1.1.1 Circular column

Utilizing the results outlined in chapter 4, where the finite element method is utilized to analyze and load-displacement curves between the control column and the one strengthened with CFRP, it can be seen from the figure below that applying of CFRP increases the load capacity of the short circular column by 10%.

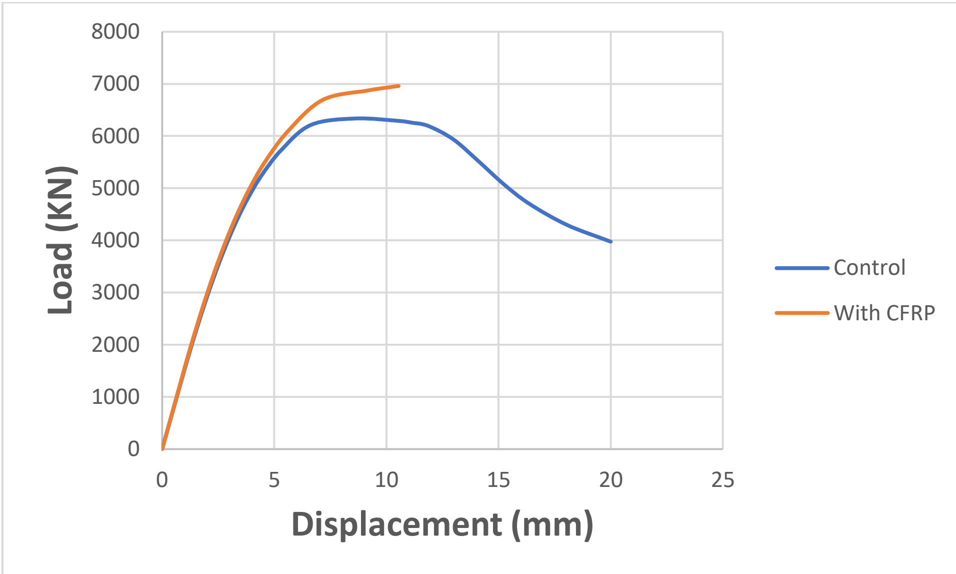


Figure 52: Comparison between load-displacement curve of circular control column and that toughened with CFRP.

5.2 Long Column

5.2.1 Rectangular column

Applying the insights revealed in chapter 4, which involve the utilization of the finite element method to analyze and compare the load-displacement curves of the control column and those featuring CFRP. The figure below illustrates that the application of CFRP raises the load capacity of the long rectangular column by 7%.

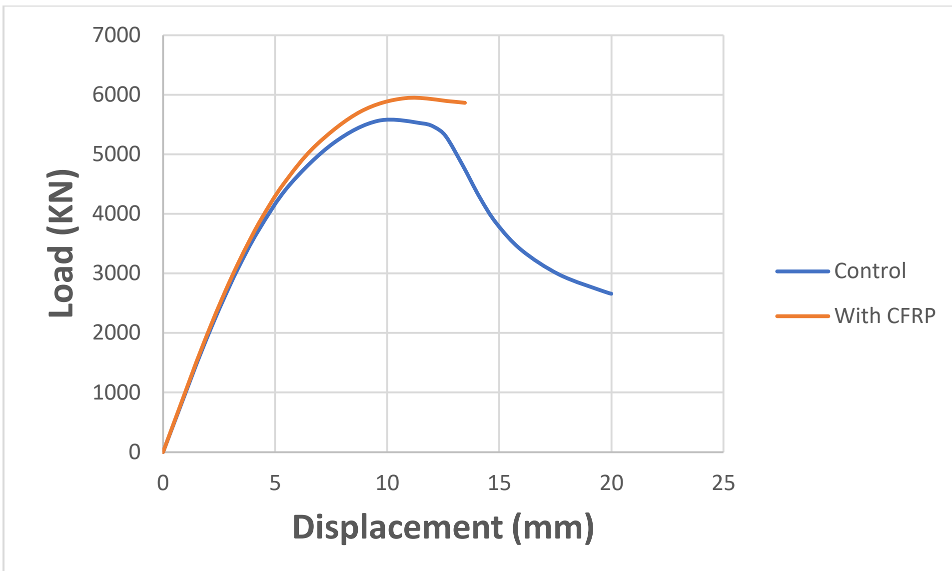


Figure 53: Comparison between load-displacement curve of long rectangular control column and that supported with CFRP.

5.2.2 Circular column

Depending upon the insights provided in chapter 4, where the finite element method is utilized to analyze and compare load-displacement curves of both the control column and the counterpart strengthened with CFRP. The figure below illustrates that the application of CFRP raises the load capacity of the long circular column by 9%.

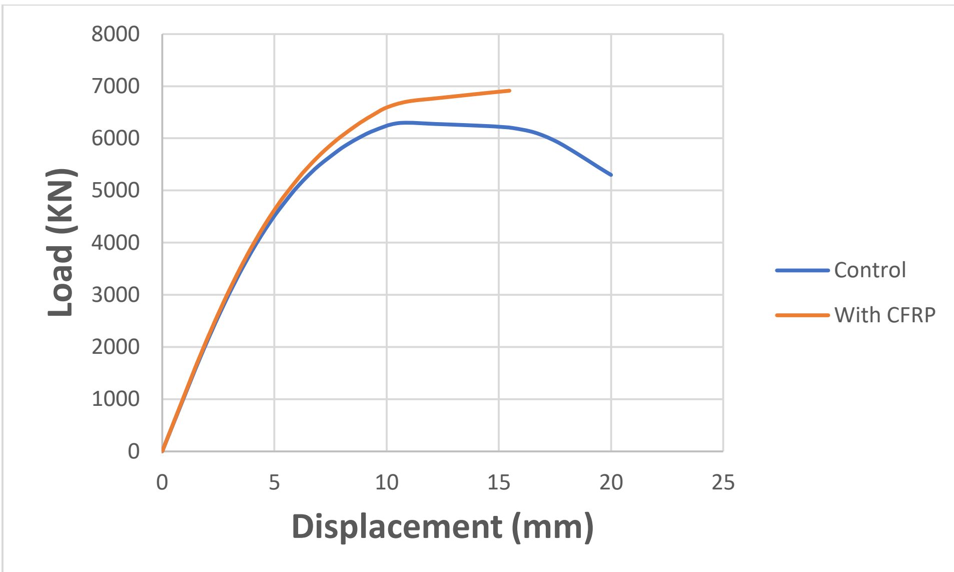


Figure 54: Comparison between load-displacement curve of long circular control column and that strengthened with CFRP.

Conclusion

- Applying CFRP cords by NSM technique increase the load carrying capacity.
- Reduce the spacing between cords give more enhancement in load capacity.
- Utilizing CFRP on (RC) columns can enhance the load capacity despite the column is a compression member.
- The circular section of (RC) column has more increasement in load capacity than the rectangular section when employing of CFRP on it.
- CFRP on circular columns has a stronger confinement than square and rectangular columns (where the corner radius is zero).

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