JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Comparative Study on the Efficiency of Retrofitting Reinforced Concrete Columns by Concrete, Steel, and Fiber Reinforced Polymer Jacketing

A Research Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

By: Samrawit Girma

April 2023

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By: Samrawit Girma

Advisor: Dr. Kabtamu Getachew (Ph.D.)

Co-advisor: Eng. Besukal Befekadu (Msc)

April 2023

Jimma, Ethiopia

DECLARATION

I declare that this thesis entitled "**Comparative Study on the Efficiency of Retrofitting Reinforced Concrete Column by Concrete, Steel and Fiber Reinforced Polymer Jacketing**" is my original work, and has not been presented by any other person for an award of a degree in this or any other University.

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APPROVAL SHEET

This thesis has been submitted for examination as university supervisor. The thesis titled "**Comparative Study on the Efficiency of Retrofitting Reinforced Concrete Column by Concrete, Steel and Fiber Reinforced Polymer Jacketing** "by Samrawit Girma is approved for the Degree of Masters of Science in Structural Engineering.

Approved by board of examiner:

We, the undersigned, approve the master's thesis of Samrawit Girma.

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ABSTRACT

Structural members experience strength deficiencies for a variety of reasons, including improper design, faulty construction, inspection, change in structure use, older constructions that were not designed for earthquake actions, and so on. To overcome this problem, strengthening structural members when found deficient is necessary, and it can be applied before the hazard or after the hazard. The research that has been conducted so far mostly focuses on the behavior and axial capacity of single reinforced concrete columns that have been individually jacketed with FRP, steel, and RC jacketing. However, practically, retrofitting will be conducted for all columns of a building as a frame. To widen this gap, a reinforced concrete frame was modeled and analyzed using the three jacketing methods considered in the study to compare and select the most efficient jacketing technique.

This research is a comparative study, considering a symmetrical G+5 office medium-rise RC building under an earth quake load that is retrofitted with steel, reinforced concrete, and carbon fiber reinforced polymer jacketing; and RC columns under axial loads. The analysis program consists of a total of 20 specimen models using finite element software ABAQUS 6.14. The comparison was in terms of two critical parameters; story displacement and story drift for a retrofitted reinforced concrete frame.

In conclusion, the analysis result showed that RC jacketing gives greater axial load-carrying capacity than CFRP and steel jacketing for both short and slender columns. For retrofitted frames, the maximum reduction in both story displacement and story drift is found for reinforced concrete jacketed frames as compared to the other retrofitting systems considered in the study.

Keywords: *Steel jacketing, CFRP jacketing, RC jacketing, Eccentricity, Axial load, Retrofitting.*

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First and foremost, I would like to thank the Almighty God for every success in my life and the satisfactory accomplishment of this research paper.

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ACRONYMS/NOTATIONS

CAE	Computer-aided engineering
CFRP	Carbon fiber reinforced polymer
CDP	Concrete damage-plasticity model
dc	Damage variable
d_t	Damage variable in tension
E	Elastic modulus
E_{co}	Initial undamaged modulus of elasticity
E_{co}	Initial undamaged modulus of elasticity
FEA	Finite element analysis (FEA)
FE	Finite element
FEM	Finite Element Method
Fsu	Ultimate tensile strength
RC	Reinforced concrete
Mpa	Mega Pascal
u	Ultimate stress,
ε_t	Total tensile strain
$\varepsilon_{ot}{}^{el}$	Elastic tensile strain corresponding to the undamaged material
ε_{su}	ultimate strain
ε_c	Total compressive strain
$\varepsilon c^{\ in}$	In-elastic strain
εc	Compressive strain

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Concrete structures consist of several elements, the most important of which is the column. Columns are critical elements in many structures as local member failure may lead to a partial or complete collapse of the structure. If a column is structurally deficient due to damage, which may be caused by an earthquake, design or construction error, or from reinforcement corrosion, a retrofit can be a suitable option to bring it back into service.

When the column cannot sustain the applied loads because of an increase in load, a change in the use of the structure, or an initial poor design of the structure, the column must be strengthened. Jacketing is one of the preeminent and most commonly utilized strategies to retrofit R.C. columns. On the other hand, the structural usage of buildings sometimes changes, causing higher loads beyond the designed capacity of structures, which in turn results in structurally deficient members. Under such conditions, the strengthening of civil engineering structures becomes very important to enhance the ultimate capacity. In addition to this, after a hazard occurs on structures, the affected member needs to be repaired so that it can sustain loads.

There are different types of strengthening and retrofitting methods used, which affect the global or local member performance of a structural member under the given loading condition. Column jacketing enhances the axial capacity of the column. We can have different types of column jacketing. For reinforced concrete columns, there are mainly three methods of retrofitting. Reinforced concrete, steel, and fiber-reinforced polymer jacketing are commonly used before hazard and after the hazard occurred.

The retrofit strategy may involve targeted repair of deficient regions, providing systems to increase stiffness and strength, or providing redundant load-bearing systems. In general, a combination of different strategies may be used in the retrofitting of the structure. The selection of a specific rehabilitation technique should be based on the retrofit objectives as well as economic considerations.

1.2 Statement of the problem

The research that has been conducted so far mostly focuses on the behavior and axial capacity of reinforced concrete columns that have been individually jacketed with FRP, steel, and RC jacketing, both experimentally and analytically. However, practically, retrofitting will be conducted for all columns of a building as a frame. To widen this gap, a reinforced concrete frame was modeled and analyzed using the three jacketing methods to compare and select the most efficient jacketing technique.

1.3 Research question

- How does the axial eccentric load affect the capacity of RC columns jacketed with steel, fiber-reinforced polymer, and reinforced concrete?
- What is the significant effect of column length variation on the axial capacity of the retrofitted column considered in the study?
- Which of the three strategies used in the study for retrofitting is the most effective?

1.4 Objective of the Study

1.4.1 General Objective

The objective of this paper is to perform a comparative study on the efficiency of concrete jacketing, steel jacketing, and CFRP jacketing on retrofitting RC columns using the finite element package ABAQUS.

1.4.2 Specific objective

To investigate and compare:

- The axial capacity of a retrofitted RC column based on axially eccentric load and column length.
- The effect of eccentric loading on steel, CFRP, and RC-jacketed reinforced concrete columns.
- The efficiency of steel, CFRP, and RC jacketing on reinforced concrete frames is based on story displacement and story drift.

1.5 Significance of the study

This research is a finite element study on retrofitting columns using the three different methods of jacketing technique, which gives some information for the readers about the performance of each retrofit technique based on the comparative analysis result found from the FEM analysis. This model can also be used as a starting point for further research.

1.6 Scope and limitation of the Study

This research is limited to a five-bay by three-bay G+ 5 stories RC building, which is regular in plan and elevation. as well as a single column of 150x150x3650mm for the slender column and a square column of dimension 150x150x1200mm for the short column. Any other cross-sections, different depth-to-height ratios, and reinforcement variations are not considered. The frames are assumed to be firmly fixed at the bottom, and the soil–structure interaction is neglected. Four strengthened RC frames for lateral load and sixteen single columns for axial load capacity are analyzed. The analysis is completed using the finite element package ABAQUS 6.14-1.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Retrofitting is a technical intervention in the structural system of a building that improves the resistance to the earthquake by optimizing the strength, ductility, and earthquake loads. The strength of the building is generated from the structural dimensions, materials, shape, number of structural elements, etc. The ductility of the building is generated from good detailing, materials used, degree of seismic resistance, etc. Earthquake load is generated from the site seismicity, the mass of the structures, the importance of buildings, the degree of seismic resistance, etc. Due to the variety of structural conditions of the building, it is hard to develop typical rules for retrofitting. Each building has different approaches depending on the structural deficiencies. Hence, engineers are needed to prepare and design the retrofitting approaches. In the design of retrofitting approach, the engineer must comply with the building codes. The results generated by the adopted retrofitting techniques must fulfill the minimum requirements of the building codes, such as deformation, detailing, strength, etc. (*Structural Retrofitting - AMERICAN GEOSERVICES*, no date).

2.2 Decision for Retrofitting

Retrofitting is needed when the assessment of structural capacity results in the insufficient capacity to resist the forces of expected intensity and acceptable limit of damages. It is not merely the poor quality of materials and damage to structural elements that serve as the reasons to retrofit a building. Changes in the building's function, changes in environmental conditions, and changes in valid building codes could also be the reasons for retrofitting. Retrofitting must be conducted by experts from each field. In the most retrofitting process, an engineer plays the main role. An engineer must assess and analyze the structural capacity. An engineer must also design the best retrofitting techniques to strengthen the structural deficiencies.

Some factors that should be considered to decide whether to retrofit or not are:

a) The technical aspects include the testing of materials and structural analysis. These measures are important to understand the condition of the structures related to the recent building codes.

b) Cost intervention Cost and benefit analysis must be conducted before the decision is made.

c) Importance of building each building is built for its purpose. Some old buildings have extra values, such as historical values, that will strongly affect the final decision.

d) Availability of adequate technology some retrofitting techniques need “modern “technology to implement it. A decision of retrofitting must consider whether the region provides such technology.

e) Skilled workmanship to implement the proposed measures some retrofitting techniques need unusual construction methods to implement it. Skilled workmanship must be provided to implement the proposed measures.

f) Duration of works. Some retrofitting works will consume less time to finish, but others take more time to complete. Hence, it is important to take into consideration the duration of work (Shrestha *et al.*, 2009).

2.3 Steel Jacketing

(Issa *et al.*, 2010) conducted an experimental, theoretical and numerical investigation to evaluate the behavior of reinforced concrete columns strengthened externally with steel jacket or fiber composite under axial loads. The experimental program presented six rectangular reinforced concrete columns with the same dimension of 150 × 200 × 1200 mm. The steel jacket consisted of four vertical angles at column corners and horizontal steel plates welded to the corner angles and distributed along column height. The main parameter was the type of external strengthening method. For the steel jacket, the variables were the size of corner angles and the spacing between the steel plates. From the experimental study, it was concluded that increasing the area of corner steel angles and decreasing the spacing between the steel pattern plates of steel jackets increase the ultimate carrying capacity and ductility of strengthened columns.

(Adam *et al.*, 2009) performed experiments on axially loaded RC columns strengthened by steel cages as well as numerical models using the finite element method to verify the obtained experimental results. Also, a parametric study was carried out to analyze the influence of each of the parameters on the behavior of RC columns strengthened by steel cages. The study considered these parameters: the size of the angles; the yield stress of the steel of the cage; the compressive strength of the concrete in the column; the size of the strips; the addition of an extra strip at the ends of the cage; and the friction coefficient between the layer of mortar and the steel of the cage. The obtained results of this parametric study were that the slippage between the steel cage and the column can be reduced by increasing the size of the strips due to the greater stiffness of the steel cage in the transverse direction. This improvement in confinement would also result in a better transmission of loads between the cage and the column by the shear stress mechanism.

(Tarabia and Albakry, 2014) studied the behavior and efficiency of reinforced concrete square columns strengthened by steel angles and strips (steel cage). The main studied parameters were: the size of the steel angles, strip spacing, grout material between column sides and angles, and the connection between the steel cage to the specimen head. Two different concrete strengths 57.8 MPa and 47.5 MPa were also considered in this study. All the specimens were tested under concentric axial loads till failure. This study concluded that jacketing by steel angles and strips proved to be a very efficient strengthening method. The gain in the axial load capacity of the strengthened columns was obtained from 1.35 to 2.10 for the un-strengthened column. This gain was due to the confinement effect of the external steel cage, and the ability of the steel angle to resist an extensive part of the applied axial load. The failure in most of the strengthened specimens was due to the buckling of the steel angle followed by the crushing of the original columns. The axial ductility of the strengthened column was also obtained to be increased by 50%.

(Belal *et al.*, 2019) performed both experimental and numerical investigations on seven specimens under compressive axial loading. The specimens were strengthened with different steel jacketing configurations. Three different vertical steel elements (angles, channels, and plates) were chosen with the same total horizontal cross-sectional area. Three studied variables were: the shape of the main strengthening system (using angles, C-sections, and plates), size, and the number of batten plates. This study concluded that angles and channels proved to be performed similarly, but steel plates resulted in less capacity for the column, due to the thinness of the plate. Batten plates had variable results based on which cross-section was used. The jacketing system with channels resulted in higher strength than angles. But the angles were found to be benefited more from improved confinement stress due to the discrete thicker plates. Additionally, the columns with angles experienced less deformation than the other steel jacket/cage cross-sections. Additional consideration was recommended when using C-sections with batten plates or plates only, since their thinner thicknesses may present buckling problems.

(Ezz-eldeen, 2018) conducted both experimental and numerical investigations on fifteen-column specimens to evaluate the efficiency of steel angles and the strip jacketing method under eccentric loads. Four different eccentricities were used in the study. Then the twelve columns were divided into three groups and strengthened with three different angle sets (two same angles in each set) on the compression side and two same angles on the tension side separately. It was concluded that increasing the covered area of the steel jacket increased the load-carrying capacity of the strengthened columns. Finally, a parametric analysis was conducted using ANSIS finite element model for proposing practically used dimensions in strengthening columns subjected to different eccentricities. Columns with cross-sectional areas ranging from 25 × 35 cm to 25 × 120 cm were analyzed for this purpose and presented in a tabular form for practical application.

(Pasala N., Dipti R.& Durgesh C., 2018) uses steel caging techniques for the seismic strengthening of reinforced concrete (RC) columns of rectangular cross-sections. The steel cage consists of angle sections placed at corners and held together by battens at intervals along the height. In the study, a rational design method was developed to proportion the steel cage considering its confinement. An experimental study was also carried out to verify the effectiveness of the proposed design method and detailing of steel cage battens within potential plastic hinge regions. One ordinary RC column and two strengthened columns were investigated experimentally under constant axial compressive load and gradually increasing reversed cyclic lateral displacements. Both strengthened columns showed excellent behavior in terms of flexural strength, lateral stiffness, energy dissipation, and ductility due to the external confinement of the column concrete. The proposed model for confinement effect due to the steel cage reasonably predicted moment capacities of the strengthened sections, which matched with the observed experimental values.

(Khalifa and Al-Tersawy, 2014)developed a practical-based analytical model and designed an experimental program on seven low-strength reinforced concrete columns. Two series of strengthening procedures were considered in this study. The first series contained four steel angles and uniform intervals of strips. Steel casing by four plates connected with or without dowels was included in the second series. This study concluded that the load-carrying capacity could be enhanced up to 66% using steel angle and strip strengthening series. This capacity proved to be doubled with steel casing by four plate series. This study also concluded that the increase in strip thickness and reduction in strip spacing resulted in more effective strength and ductility than the increase in the steel angle dimensions. The presence of dowels exhibits the comparatively slower failure of the column in steel casing techniques. Finally, the experimental and analytical results were compared and showed to be obtained a good agreement in them. The proposed analytical model accounted for the composite action for concrete confinement and enhancement of the local buckling of the steel elements.

(Uy, 2002) investigated the behavior of steel plate jacketed reinforced concrete columns. Both short columns and slender columns were incorporated. The dimension of the columns was 150 mm x 150mm x450mm for the short column and 150 mm x 150mm x815mm for the slender column. All specimens were tested under concentric loading until failure. The failure mode for both short columns and slender columns was local buckling of the steel plates and local crushing of the concrete. The result showed that the ultimate strength of the bonded column was increased by around 90% to 110%.

(Li *et al.*, 2005) proposed a constitutive model based on experimental results to evaluate the behavior of concrete strengthened by externally bonded steel plates. To obtain sufficient data, an experimental program was first conducted. 60 concrete cylinders with a 300 mm diameter and 600mm length jacketed with different types and thicknesses of steel jackets were tested. The model is based on the stress and strain values of the intersection points and regression analysis was used to determine the parameters. The result showed that the steel plate jacketing is efficient for the uni-axially loaded column to increase strength and ductility.

Figure2.1: Steel jacketing retrofit for RC column (with steel angles, Chanel, and bands jacketing) (*FRP Jacketing VS Steel Jacketing - Structural Strengthening Method*, no date)

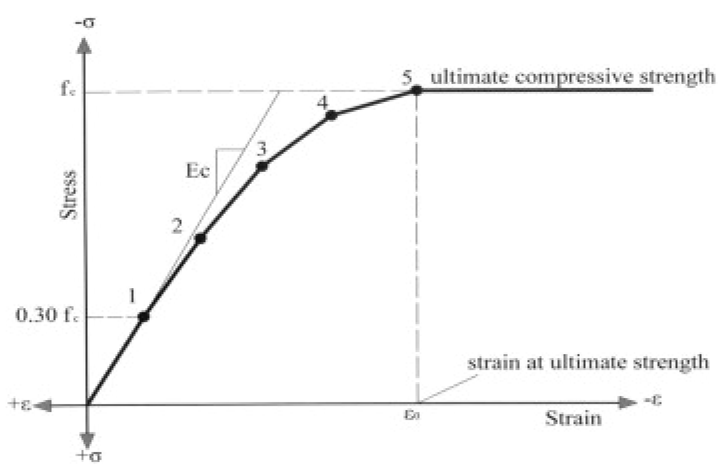


Figure 2.2: Stress-strain relationship strengthened by steel jacketing(Belal, Mohamed and Morad, 2015)

2.4 Fiber-reinforced polymer jacketing

Research on strengthening concrete columns with FRP had been developed dramatically in recent years.

(Bagus, Widiarsa and Hadi, 2013) presented the results of an experimental study on the performance of carbon fiber reinforced-polymer wrapped square reinforced concrete columns under eccentric loading. The influence of the number of CFRP layers, the magnitude of eccentricity, and the presence of vertical CFRP straps were investigated. The results of this study showed that CFRP wrapping enhanced the load-carrying capacity and ductility of the columns under eccentric loading. Furthermore, the application of the vertical CFRP straps significantly improved the performance of the columns with large eccentricity.

(Campione and Miraglia, 2003) FRP-reinforced concrete members with different shapes of the cross-section were analyzed and a model to evaluate the confining pressure and the ultimate strain was developed. The model was then examined with experimental data and showed good agreement.

Figure 2.3: Installation of FRP wraps(AL-ALAILY, 2011)

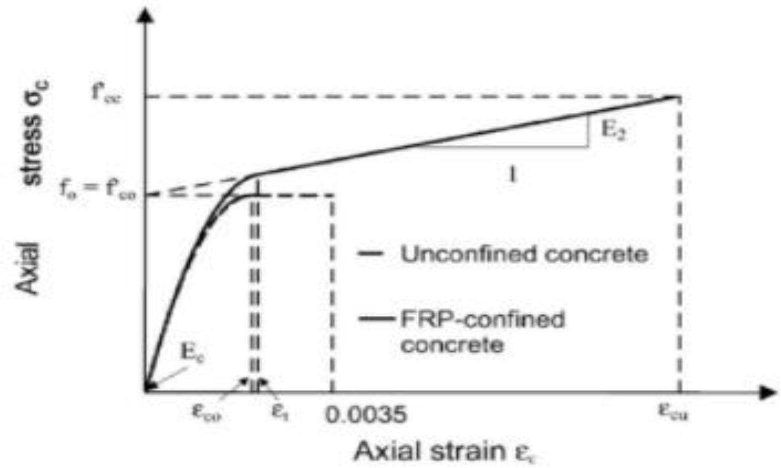


Figure 2.4: Stress-strain relationship for FRP confined concrete (Tahghighi and Gholami, 2018)

Muhammad N. S. Hadi et al. (2012) have conducted an experimental study on the performance of carbon-fiber-reinforced polymer (CFRP) wrapped square reinforced concrete (RC) columns under eccentric loading. The experimental program consisted in testing a total of 12 RC specimens under compression loading. The specimens had four 12 mm diameter deformed bars as longitudinal steel reinforcement and 8 mm diameter plain bars spaced at 100 mm as transverse steel reinforcement (ties). The tie rebar spaced at 50 mm was applied at both ends of the specimens to prevent premature failure at the locations. The specimens were divided into three groups: unwrapped, wrapped with one layer of CFRP, and wrapped with three layers of CFRP. Each group consisted of four specimens; one specimen was tested concentrically, one was tested under a 25 mm eccentric load, and one was tested under a 50mm eccentric load. Two different monitoring systems were used to measure the displacement of the columns. For concentric loading, one LVDT was connected directly to the testing machine to measure the axial displacement of the column during the test. Data read from this LVDT were recorded at the same time as load data were recorded by the testing machine. A second LVDT, a laser LVDT, was also used in addition to the first one for an eccentric load to measure the lateral deflection (δ) of the column. The second LVDT was placed horizontally near the mid-height of the column. When the specimen and the instrumentation were placed in position and initial calibration was done, the compression testing then started. The column was tested under displacement control with a loading rate of 0.5 mm/min, and the endpoint position was set at 50 mm. Based on the experimental work carried out in this study, the following conclusions were drawn:

- CFRP wrapping had a more significant effect on the maximum load of eccentrically loaded columns compared to concentrically loaded columns.
- The CFRP wrapping enhanced the performance of the columns by postponing the rupture of the concrete and reinforcement, which means it increased the column ductility.
- In columns with a large eccentricity, which means with a large bending moment, the presence of CFRP straps produced higher ductility than in columns wrapped horizontally with a similar number of CFRP layers.

(Abdel-Hay, 2014) conducted an experimental study on the behavior of R.C. square columns with poor concrete at the upper part, strengthened with CFRP. Ten square columns of height 2000 mm and a cross-section of 200 x 200 mm are tested. One of them is a controlled specimen and the other nine specimens are divided into three groups. All specimens had the same longitudinal reinforcement and stirrups. A high-strength carbon fiber fabric, SIKA WRAP 300 C, was used for jacketing the tested columns. The CFRP materials had a nominal thickness of 0.167 mm. surface of the concrete column is Prepared by using a hammer and blower to remove the weak element on the concrete cover. The column was chamfered by a radius of 20 mm. Then the epoxy paste is applied on the column surface to fill the uneven surface of the concrete. SIKA DUR 41 CF was used to bond the CFRP with a column, then rolling the CFRP was laminated by a special laminating- roller to ensure that the CFRP is saturated with epoxy resin and there are no air voids between the fibers and concrete surface. All columns were loaded with a 500-ton hydraulic machine in the material laboratory. The applied load was read out on the load cell scale. LVDTs were placed at the upper and lower part of the column to measure the longitudinal strains, and electrical strain gages of 20 mm gage length were used to measure the fiber strain. Conclusions: The following conclusions are drawn from this work. 1) Partial strengthening of square columns with poor concrete at the upper part can be used. It is significant to wrap the poor part only using one layer of CFRP. 2) Increasing the jacket height will provide a higher ductility for wrapped columns without a significant increase in the ultimate load of columns. 3) Confined part must be provided with a corner radius to increase concrete strength as the upper part is quite weak. 4) The ultimate load of the wrapped column increases as the concrete strength of the upper part increases, while the ductility decreases. 5) Increasing the top concrete height causes an increase in ductility, but the failure load decreases. 6) Ductile failure mode was achieved in specimens of the top concrete height of 500 mm, while in the case of 350 mm top concrete height, the failure mode was brittle.

(Jameel, Sheikh and Hadi, 2017) have carried out experimental work on the Behavior of circularized and FRP-wrapped hollow concrete specimens under axial compressive load. This paper investigates the suitability of the circularization technique for strengthening square hollow concrete specimens. A total of eight specimens were made from normal-strength concrete. The specimens were divided into two groups: solid and hollow specimens. All the specimens were 300 mm in height and 106 mm in cross-section. The hollow specimens had a central square hole of 35 mm sides. Each group consisted of four specimens. The first specimen in each group was the reference specimen. The second specimen was constructed with 20 mm round corners and was wrapped with two layers of CFRP, which simulates the conventional strengthening method.

The third specimen was circularized with full-length plain concrete segments and wrapped with two layers of CFRP. The fourth specimen was circularized with concrete segments which were 20 mm shorter than the length of the specimen and wrapped with two layers of CFRP. All specimens were tested under axial compression loading. For testing the universal Denison compressive testing machine with a maximum load capacity of 5000 kN is used. A transducer (LVDT) was used. For the circularized specimens, the LVDT was mounted onto a frame of two circular rings. For square specimens, a square test setup was designed. The travel linear variable differential transformer (LVDT) was mounted onto two box frames that were fixed at the top and bottom of the specimen by steel bolts. All specimens were tested under a displacement-controlled axial load at the rate of 0.5 mm/min. The data were recorded every two seconds. Conclusion: 1. Circularization proved to be an effective method in strengthening CFRP confined square hollow concrete specimens similar to CFRP confined solid concrete specimens. 2. The experimental investigations carried out in this paper demonstrated that the specimens circularized with full-length concrete segments confined with CFRP achieved higher ultimate axial load than the specimens circularized with short concrete segments confined with CFRP. 3. When the effect of circularization is compared with rounding the corners of the CFRP confined specimens, after excluding the contribution from section enlargement, the circularization technique contributed less to the yield stress of the hollow specimens than to the yield stress of the solid specimens.

(Sadeghian, Rahai and Ehsani, 2010) have conducted experimental work on the Study of Rectangular RC Columns Strengthened with CFRP Composites under Eccentric Loading. This paper presents the results of experimental studies on reinforced concrete columns strengthened with carbon fiber reinforced polymer (CFRP) composites under the combination of axial load and bending moment. A total of seven RC specimens were designed with a rectangular section (200 mm x300 mm). The test portion of each specimen had a height of 1,500 mm and each haunched head had a height of 600 mm. The specimens were tested under compression eccentric loading up to failure. Three different FRP thicknesses of 1.8, 2.7, and 4.5 mm (two, three, and five layers); four fiber orientations of 0°, 90°, +45°, and 45° concerning an axis perpendicular to the column axis; and two eccentricities of 200 and 300 mm were investigated. Two columns were un strengthen; two were strengthened with two longitudinal layers and one transverse layer of CFRP; two others were strengthened with four longitudinal layers and one transverse layer of CFRP, and the last column was strengthened with two diagonal layers of CFRP. One specimen of each group was tested under an eccentricity of 200 mm, and another was tested under an eccentricity of 300 mm. The specimen DD` was tested under an eccentricity of 300 mm only. All specimens were reinforced with 4ϕ 12 mm longitudinal ribbed bars (fy=465 Mpa) symmetrically placed. Transverse reinforcement was provided with rectangular ties ϕ 6.5@200 mm made of smooth bars (fy=325 Mpa). A hydraulic actuator was used to apply the axial load to the columns. A total of six linear variable displacement transducers (LVDTs) and 26 strain gauges were used for every specimen. The specimens were tested using a 600 kN capacity compression actuator under displacement control and the data were monitored using an automatic data collecting system. Displacements and strains were monitored by a digital data logger system. The tests were performed up to the failure of the specimens. Force, displacements, and strains were obtained during the test and were filed by computer software. The following conclusions are drawn: 1. The strengthened specimens had similar bilinear load-displacement curves as the un-strengthened specimens. The first part of all curves was approximately linear up to the yield point when the tension steel bars yielded. The axial secant stiffness and yield strength were improved with increasing axial stiffness of the FRP. After the yielding point, the FRPs were effectively activated, so the plastic region of all curves had limited stiffness degradation. The axial tangent stiffness was improved with increasing longitudinal stiffness of the FRP. The maximum load-carrying capacity of each specimen was reached at the FRP failure point when the longitudinal fibers of the FRP failed in tension. 2. The moment-curvature behavior showed that longitudinal layers improved the bending stiffness and moment capacity of the specimens, but curvature capacities were not generally improved. The behavior of the specimen with angle orientation was a little different. In this case, not only the bending stiffness and moment capacity were enhanced, but also the curvature capacity was improved. 3. When the strengthened columns fail in tension-controlled failure, the transverse layers could not make any improvement on the confinement of the compression side of the section. In this region, the concrete behavior is similar to the unconfined concrete. 4. The sine-shaped model for second-order deformation is in good agreement with experimental data for different levels of deformation from the linear region up to the failure point on the prismatic part of the specimens. The model can be used for the design calculation of RC columns strengthened with CFRP composites.

2.5 Concrete Jacketing

Concrete jacketing involves the encasement of the existing column with an additional layer of concrete plus additional longitudinal and transversal reinforcement. Concrete jacketing was widely used in Mexico City after the 1985 earthquake and was the most popular retrofitting method at the time. The technique was found experimentally to be effective. The stiffness of the retrofitted structural system was also significantly increased which could cause the structure to attract more seismic load (Wu, Liu, and Oehlers, 2016).

(Vandoros and Dritsos, 2008) evaluated the strengthening effect of concrete jackets in terms of different reinforcement welding techniques in the concrete jacket. The original reinforced columns were 250 mm x 250 mm in cross-section and 1800 mm in height with a foundation of 1400 mm by 780 mm by 650 mm to simulate full-scale ground floor columns. The thickness of the concrete covers was 75 mm and no special treatment was incorporated at the interface between the original column and the cover. The columns were concentrically loaded until failure. The result showed that the behavior of reinforced concrete columns can be significantly improved by concrete jacketing. They found that the load-carrying capacity can be increased by 3.44 times, and the stiffness by 2 times.

In conclusion, the result in this area showed that concrete cover jacketing can improve the load-carrying capacity of the concrete column by a significant amount.

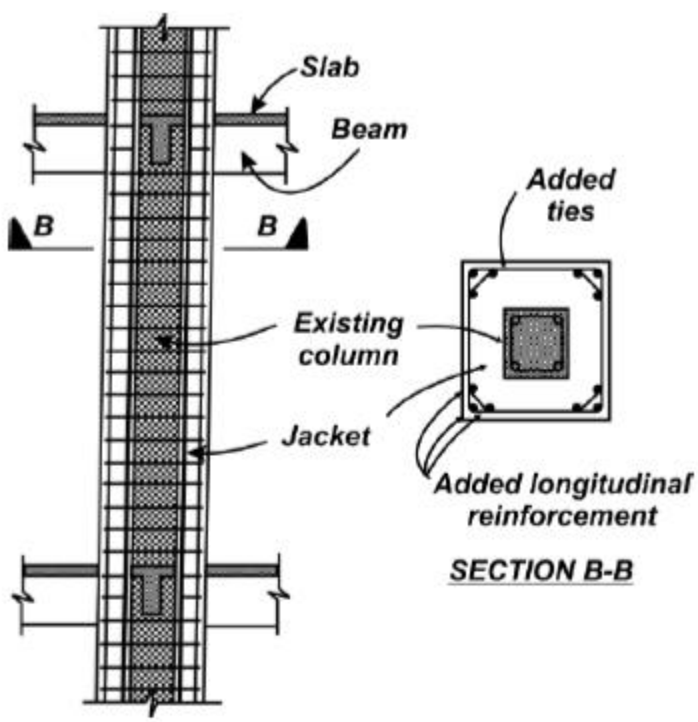


Figure 2.5: Construction techniques for column jacketing (*Safeguard your structure by Column Jacketing*, no date)

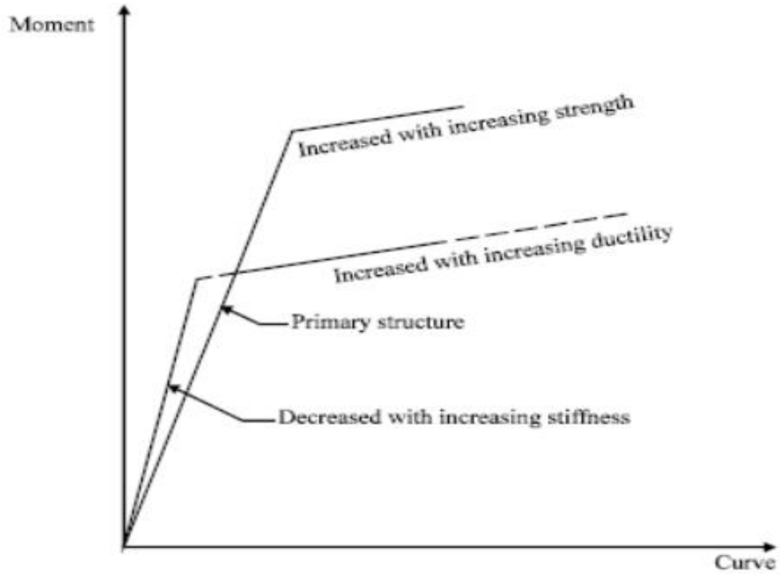


Figure.2.6: The relationship between the moment curve in different retrofitting approaches (Nasersaeed, 2011)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 General

This chapter presents and describes the approaches and techniques the researcher used to collect data and investigate the research problem.

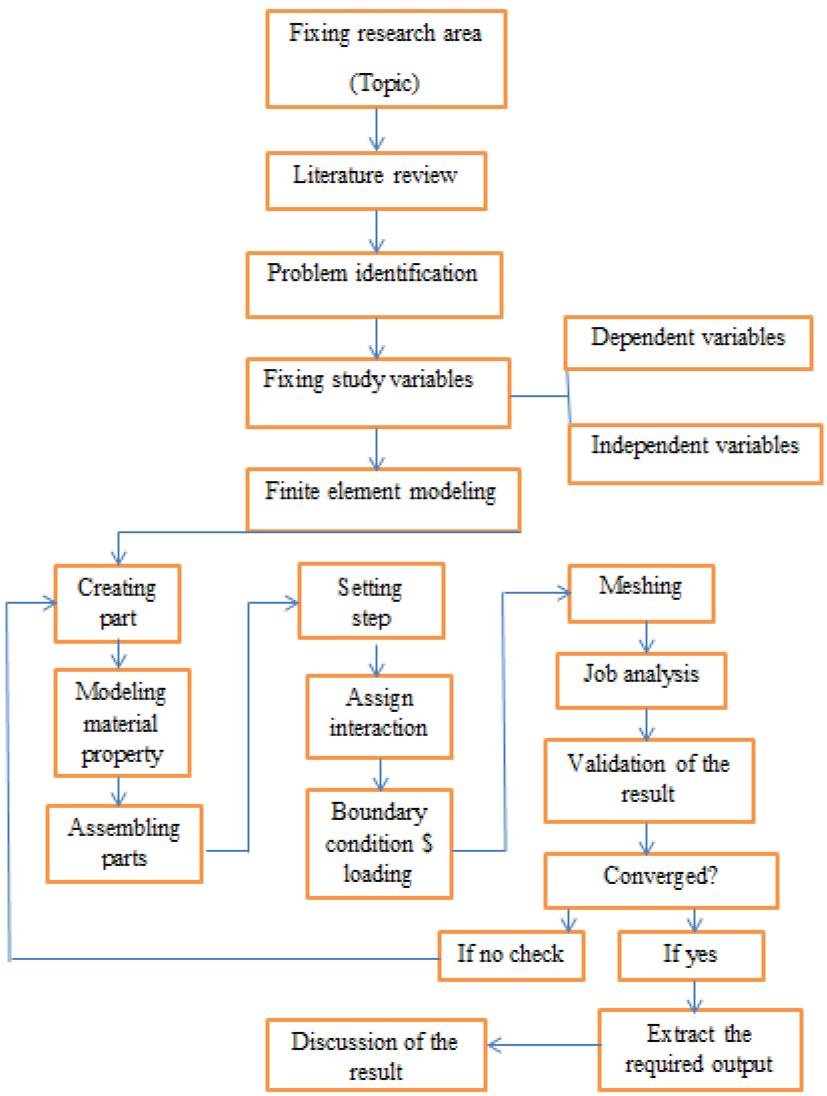


Figure3.1: Research design chart

3.2 Research Design

Various methods can be used to conduct research, and these can be either quantitative, qualitative, or a combination of both. Based on this, the paper has a quantitative nature (comparative), aiming to gather data from twenty modelings and analysis using ABAQUS software. The lateral load analysis of the study is based on the new code EBCS EN 1998-1:2015. The model for the lateral load analysis is a G+5 building with a plan dimension of 30m x 17.6m and a story height of 3.3m. To create 3D models, the finite element software Abaqus6.14 is used.

3.3 Study Variables

3.3.1 Dependent Variables

The dependent variables of this study are:

- Axial load resistance
- Story displacement
- Story drift

3.3.2 Independent Variables

The independent variables are,

- Eccentricity
- Column length
- Types of jacketing

3.4 Data Collection Process

The data used for this research is collected from existing literature related to retrofitting reinforced concrete columns with concrete, steel, and carbon fiber reinforced polymer jacketing. A finite element analysis (ABAQUS) software was used to perform several finite element Analyses to observe the behavior of columns with concrete, steel, and carbon fiber reinforced polymer jacketing. The observations from the finite element analysis were compared with the previous experimental results for validation purposes and the validated model for the parametric study of the research paper.

3.5 Finite Element Modeling

The Finite Element Method (FEM) is a procedure for the numerical solution of the equations that govern the problems found in nature. Usually, the behavior of nature can be described by equations expressed in differential or integral form. For this reason, the FEM is understood in mathematical circles as a numerical technique for solving partial differential or integral equations. When referred to the analysis of structures, the FEM is a powerful method for computing the displacements, stresses, and strains in a structure under a set of loads. Finite element analysis (FEA) is an extremely useful tool in the field of civil engineering for numerically approximating physical structures that are too complex for regular analytical solutions (*Introduction to the Finite Element Method for Structural Analysis*, 2009).

3.6 Geometric Modeling

For concrete, CFRP, steel angles, and strips the C3D8R elements are used in the model. The C3D8R element is an eight-node reduced integration brick element with three translational degrees of freedom at each node. Two-nodded truss elements designated as T3D2 have been used to model the longitudinal and tie reinforcements.

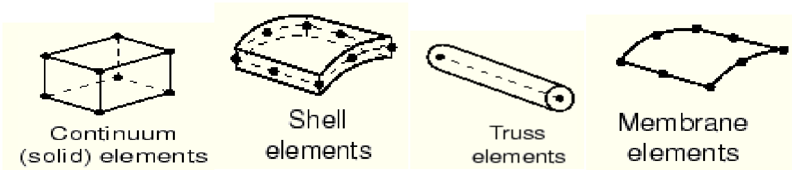


Figure 3.2: Solid and line elements used in the FEM (Simulia, 2014).

Table 3.1: Geometric Modeling

Type	Dimension(mm)
Short column	150*150*1200
Long column	150*150*3650
Frame ground floor	500*500*3650
Frame column 1nd-5th floor	500*500*3300
Frame beam	300*400
Steel jacket	40*40*2

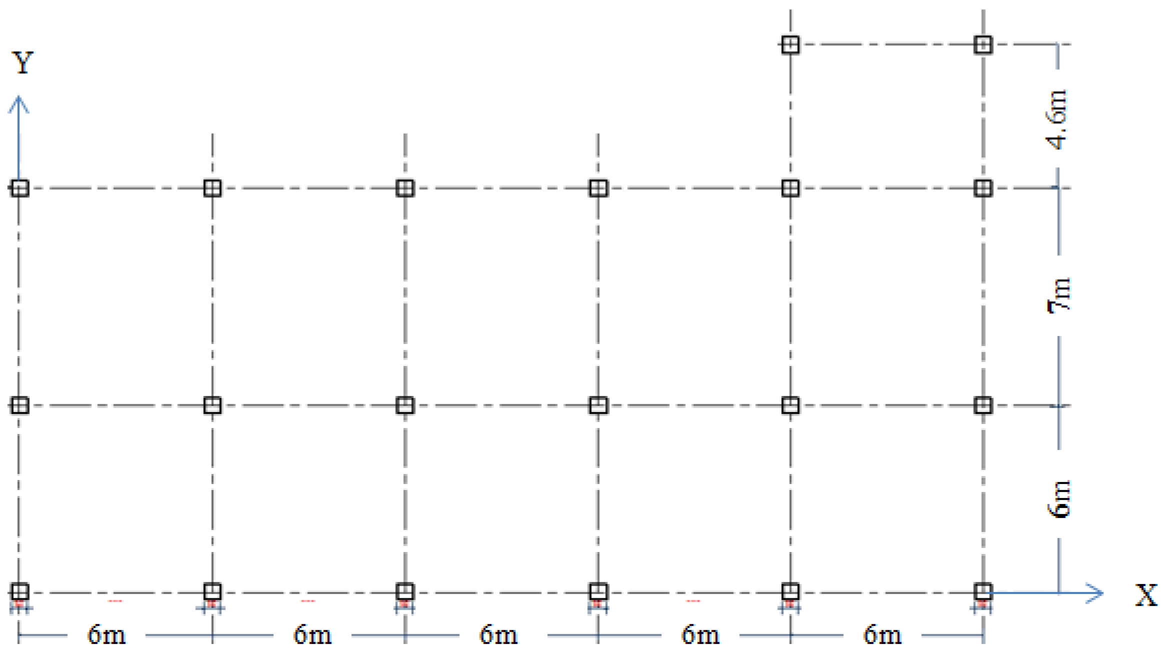


Figure 3.3: Plan of the building model

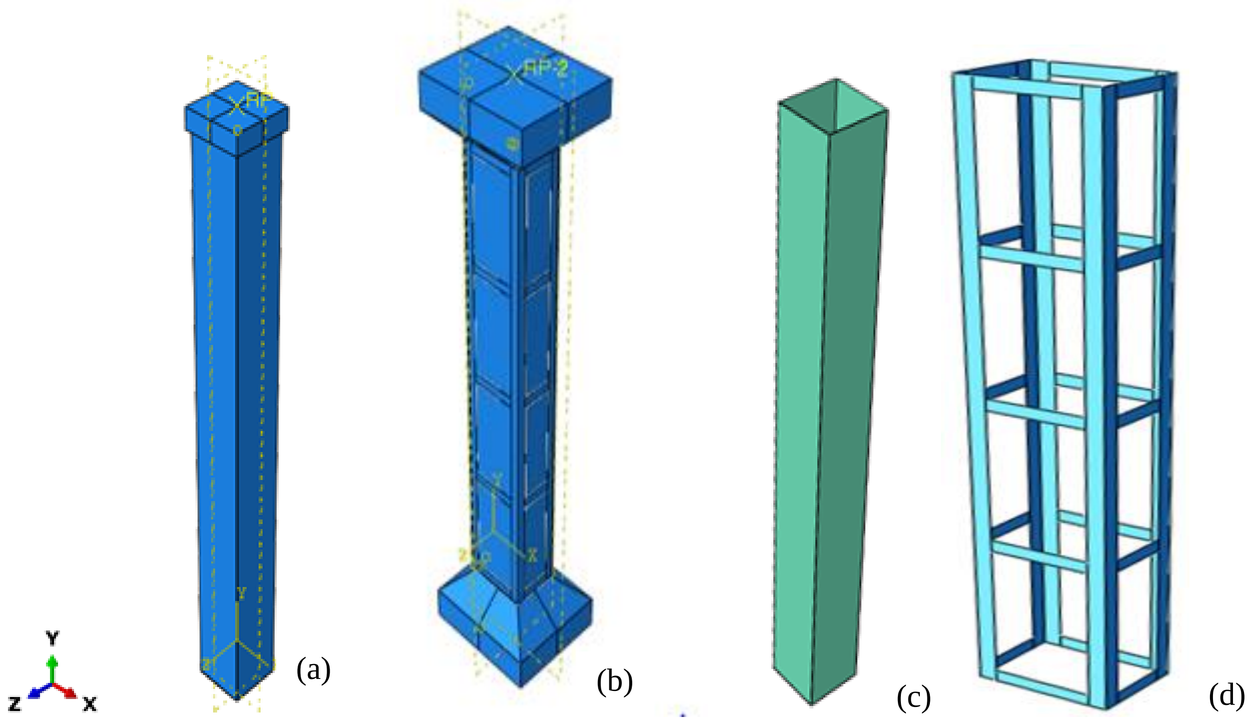


Figure 3.4: Sample Finite element models for (a) RC jacketed column b) steel jacketed column (c) CFRP d) steel strap

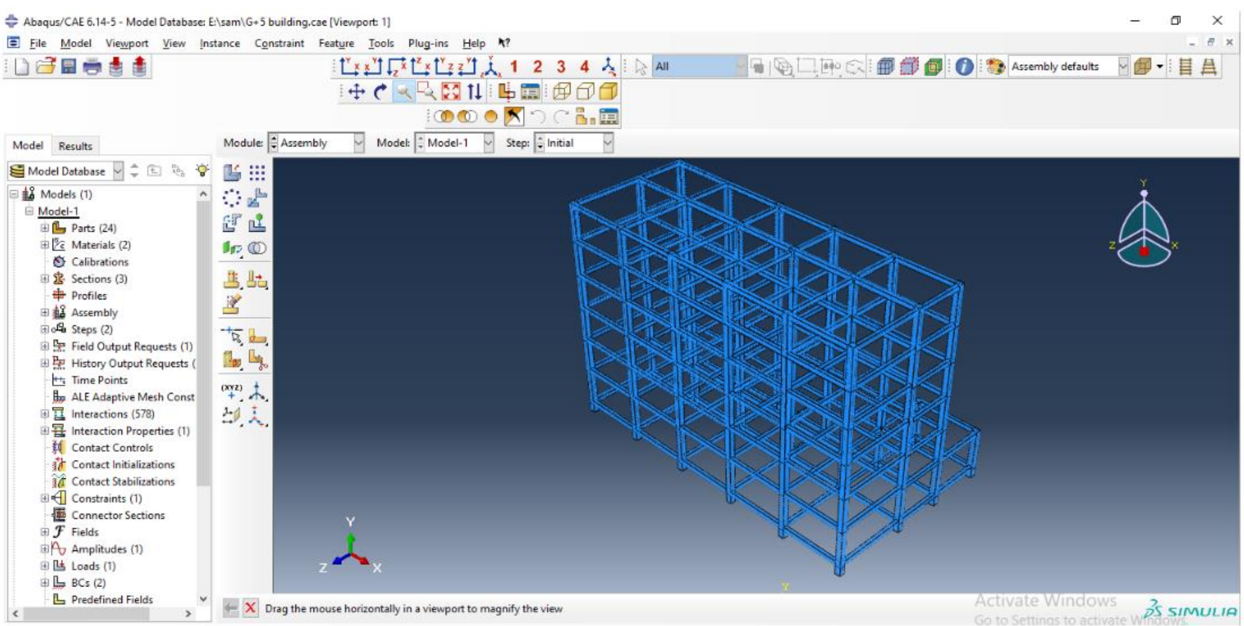


Figure 3.5: Sample finite element model for bare frames

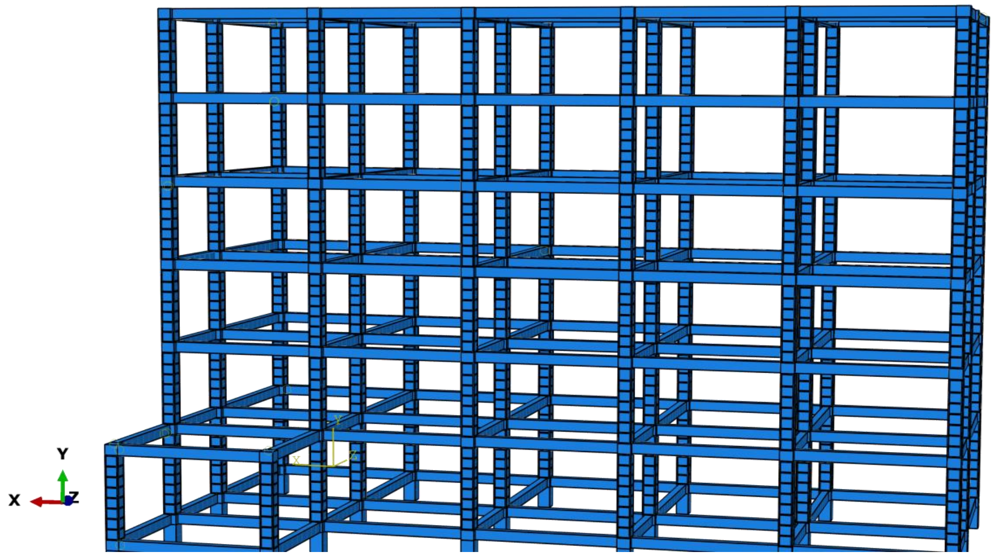


Figure 3.6: Sample finite element model for steel jacketed frames

3.7 Material properties used in the finite element model

3.7.1 Concrete

The material properties in the finite element method for concrete are compressive behavior and tensile behavior. The compressive stress-strain relationship for concrete is based on numerical expressions proposed by (Desayi and Krishnan, 1964)

$$f = \frac{E_{c*}\varepsilon}{\left[1+\left(\frac{\varepsilon c}{\varepsilon o}\right)^2\right]} \tag{3.1}$$

$$\varepsilon_o = \frac{2*fc}{Ec} \tag{3.2}$$

The modulus of elasticity of concrete for compression is calculated based on the ACI 318-14 equation.

$$E_c = 4730\sqrt{f'_c} \quad \text{where } f'_c \text{ in Mpa} \tag{3.3}$$

ABAQUS provides the concrete damage plasticity model which describes the compressive and tensile behavior of concrete and it is capable of representing the linear, plastic, and damage portion of the stress-strain curve for concrete.

3.7.1.1 Concrete damage plasticity model

The concrete damage plasticity (CDP) model uses a stress-strain relationship to define relative concrete damage. The model is a continuum, plasticity-based damage model for concrete that is capable of predicting both the compressive and tensile behavior of the concrete material. Compression hardening and tension stiffening models are used to define the complete behavior of concrete under loads. Therefore, the CDP model has been used to simulate the concrete material behavior in the FEM investigation of RC column jacketing using concrete jacketing, steel jacketing, and FRP Jacketing. In ABAQUS, the input for this model is stress-inelastic curves and converted to stress-plastic strain curves automatically using the damage variable (Le Minh *et al.*, 2021).

3.7.1.2 Concrete Compressive Behavior

The uniaxial compression stress-strain curve is defined in terms of the inelastic strain and the damage portion that is given by the parameter, d_c (damage parameter). d_c represents the degradation of the elastic stiffness of the material in compression.

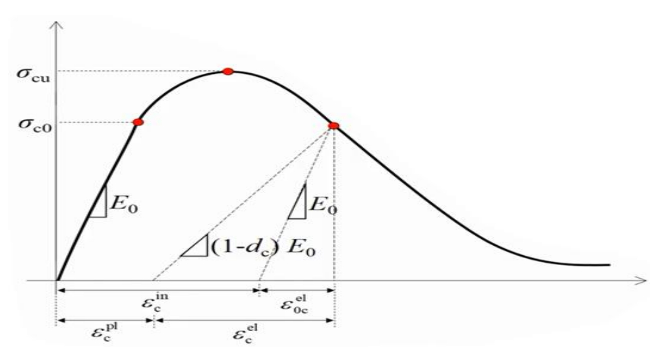


Figure 3.7: Concrete compression damage (Elkady, 2022)

The following equation calculates the inelastic strain and damage parameters.

$$\varepsilon_c^{in} = \varepsilon_c - \frac{f_c}{\varepsilon_c} \tag{3.4}$$

The compression damage parameter is calculated using the following formula

$$d_c = 1 - \frac{\sigma c}{E_o\ (\varepsilon_c - \varepsilon_c^{pl})} \tag{3.5}$$

The important parameters necessary for the concrete damage plasticity model are given below.

Table 3.2: CDP parameters used in the study(Elkady, 2022)

CDP Parameters	Values used in FEM
Dilation angle	40
Flow potential eccentricity	1.12
Stress ratio	1
Shape factor	0.6667
Viscosity Parameter	0.01

Table 3.3: Material properties(Krishna and Kumar, 2020)

Concrete grade	C-25
poison ratio of concrete	0.2
Density of concrete	24KN/m3
Grade of steel rebar	S-460
Grade of steel jacket	S-500
Density of steel	78KN/m3
Modulus of elasticity of steel	200GPa
Poison ratio of steel	0.3
density of CFRP	1.8g/cm3

3.7.1.3 Tensile Behavior of Concrete

The tensile behavior of concrete is characterized by a linear elastics tress–strain relationship before the concrete reaches its tensile strength, $f_{ct,}$ and a bilinear stress σ_t-crack width relationship for the post-peak softening behavior.

The uniaxial tensile strength of concrete, $f_{t'}$ is calculated based on the ACI 318-14 equation for normal-weight concrete.

$f_{t'} = 0.56\sqrt{f'c}$ (Where $f_{c'}$ in Mpa) (3.6)

Concrete tension properties for the damage model are defined in two stages: the linear elastic portion up to the tensile strength and the nonlinear post-peak portion, which is called tension stiffening. The first part is defined using the modulus of elasticity of concrete (Ec) and the yield stress of concrete in tension. After peak point, strain softening.

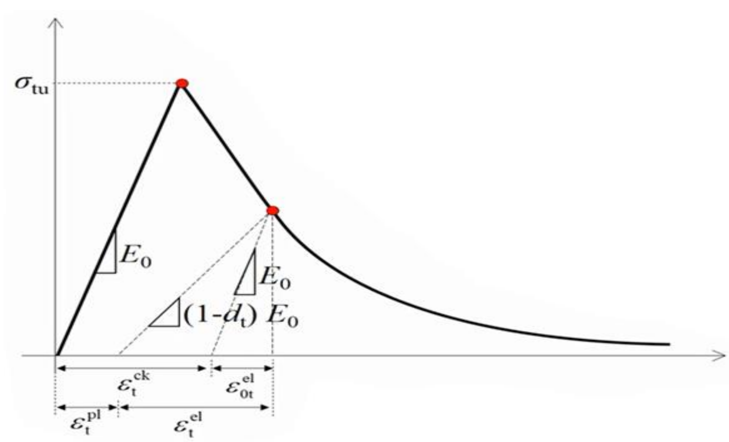


Figure 3.8: Concrete tension damage(Elkady, 2022)

The tensile damage parameter is calculated using the following equation

$$d_t = 1 - \frac{\sigma_t}{\sigma_{to}} \tag{3.7}$$

Once the damage parameter is calculated the cracking and yield strain is automatically calculated using the following equation

$$\varepsilon_t^{ck,h} = \varepsilon_t - \frac{\sigma_t}{\varepsilon_c} \quad (3.8)$$

$$\varepsilon_t^{pl} = \varepsilon_t - \frac{\sigma_t}{\varepsilon_o}\left(\frac{1}{1-d_t}\right) \quad (3.9)$$

3.7.2 steel

The steel for the finite element models has been assumed to be an elastic-plastic material and identical in tension and compression. It is based on a linear elastic response up to yielding and constant stress from the point of yielding to the ultimate strain. The steel property is approximated by the elastic region and plastic region. The elastic region is presented by young's modules and the plastic region by yield stress, ultimate stress, and plastic strain.

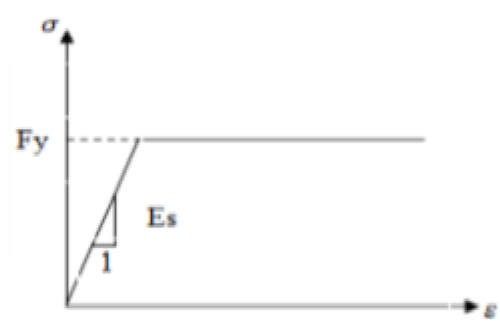


Figure 3.9: Elastic-plastic stress-strain response of steel

3.8 Assembling parts in Abaqus

A physical model is typically created by assembling various components. The assembly interface in Abaqus allows analysts to create a finite element mesh using an organizational scheme that parallels the physical assembly. In Abaqus, the components that are assembled are called part instances.

The mesh is created by defining parts and then assembling instances of each part. Each part can be used (instanced) one or more times, and each part instance has its position within the assembly. This organization of the model definition matches the way models are created in Abaqus/CAE, where the assembly can be created interactively.

3.9 Interaction of different components

Many engineering problems involve contact between two or more components. One of the most important factors that affect the accuracy of the results of simulation is modeling the interaction between assembled parts correctly. In the simulation analysis, choosing suitable contact conditions between different parts of the model must be carefully considered to allow the transfer of the forces between these parts. The ABAQUS library provides a wide range of contact models required to define the interaction between different parts of any model.

3.9.1 Concrete and Reinforcement Interaction

When modeling rebar as a wire, the rebar has to interact with the concrete beam. This can be modeled in multiple ways in Abaqus using constraints. Constraints in Abaqus allow the modeling of kinematic relationships between points and surfaces. One way to do it is to make a constraint so that the rebar becomes embedded in the concrete region. The embedded element technique is used to specify that an element or groups of elements are embedded in "host" elements. The embedded element technique can be used to model the interaction between the reinforcement and the concrete. Abaqus searches for the geometric relationships between the nodes of the embedded elements and the host elements. If a node of an embedded element lies within a host element, the translational degree of freedom at the node is eliminated, and the node becomes an "embedded node." The translational degree of freedom of the embedded node is constrained to the interpolated values of the corresponding degree of freedom of the host element. Embedded elements are allowed to have a rotational degree of freedom, but these rotations are not constrained by the embedding. To ensure bonding between the concrete and the reinforcing bars, the longitudinal bar and stirrup reinforcements were defined as “embedded” in the concrete, which effectively couple the behavior of the rebar with the adjacent concrete medium (Cheng, 1995).

To get the actual behavior of the steel-jacketed RC column in the FEM model, it is necessary to define proper interaction among these contact surfaces. In finite element study, “tie” and “embedded” constraints are used for combining different parts. In the “tie” constraint there is no relative movement between two surfaces and hence each node of the two surfaces moves together showing a perfect bond between them. It is necessary to define the master and slave surface for the „tie” constraint. The embedded constrained have been used in this research. The embedded constraint used for concrete reinforcement interaction allows bonding the nodes of reinforcing bars to the compatible degrees of freedom of the host region elements (concrete).

3.9.2 Concrete and Steel strip Interaction

In this research, a tie constraint is used. In each steel-strip interaction, the steel angle is defined as the master, and the concrete is defined as the slave. In the tie constraint, a perfect bond between the master and slave surfaces is assumed, and hence each node of the bodies in this constraint moves together and no slip occurs between the nodes of the master and slave.

3.9.3 Concrete and CFRP Interaction

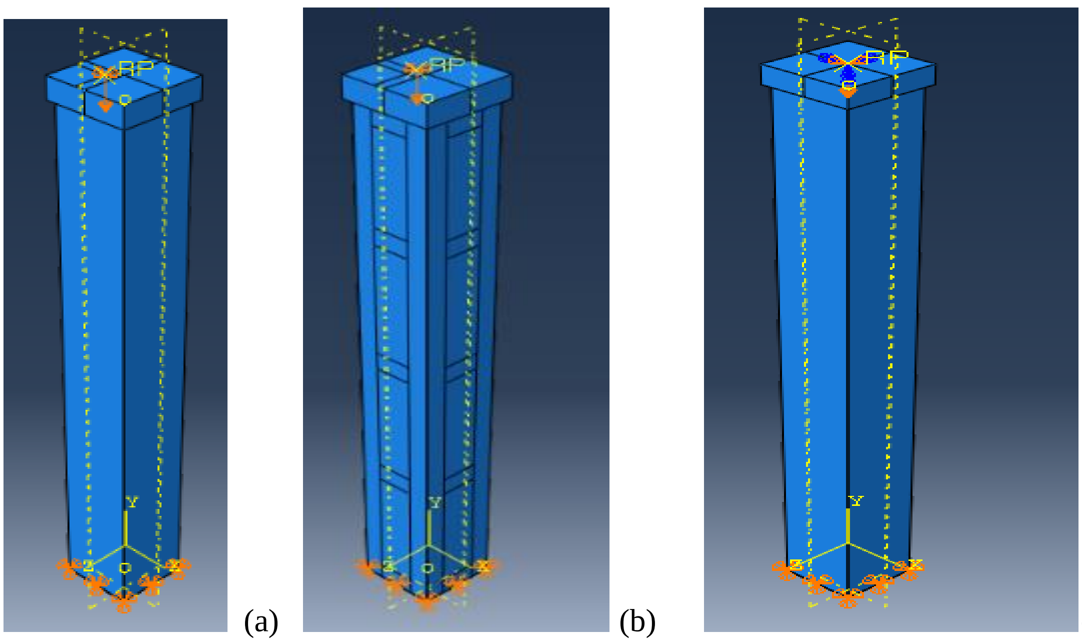
The tie constraint is used. CFRP is defined as master and concrete is defined as a slave in the interaction.

3.10 Boundary and Loading Conditions

After modeling and assembling the section, the appropriate boundary conditions were created using the boundary condition option. For the axially loaded column, pin support was applied at the bottom, and at the top, a vertical compressive load was applied on the top vertically downward by fixing the translation in X and Y directions, the loading was expressed in the form of displacement. The displacement was applied in small increments to overcome numerical instability difficulties that could be occurred when a large load had been applied suddenly.

Table 3.4: Boundary condition

Support type	U_1	U_2	U_3
Bottom	0	0	0
Top	0	-5	0



(a) (b) (c)

Figur 3.10: Loading condition (a) For reinforced concrete jacketing (b) For steel jacketing column (c) For CFRP jacketing

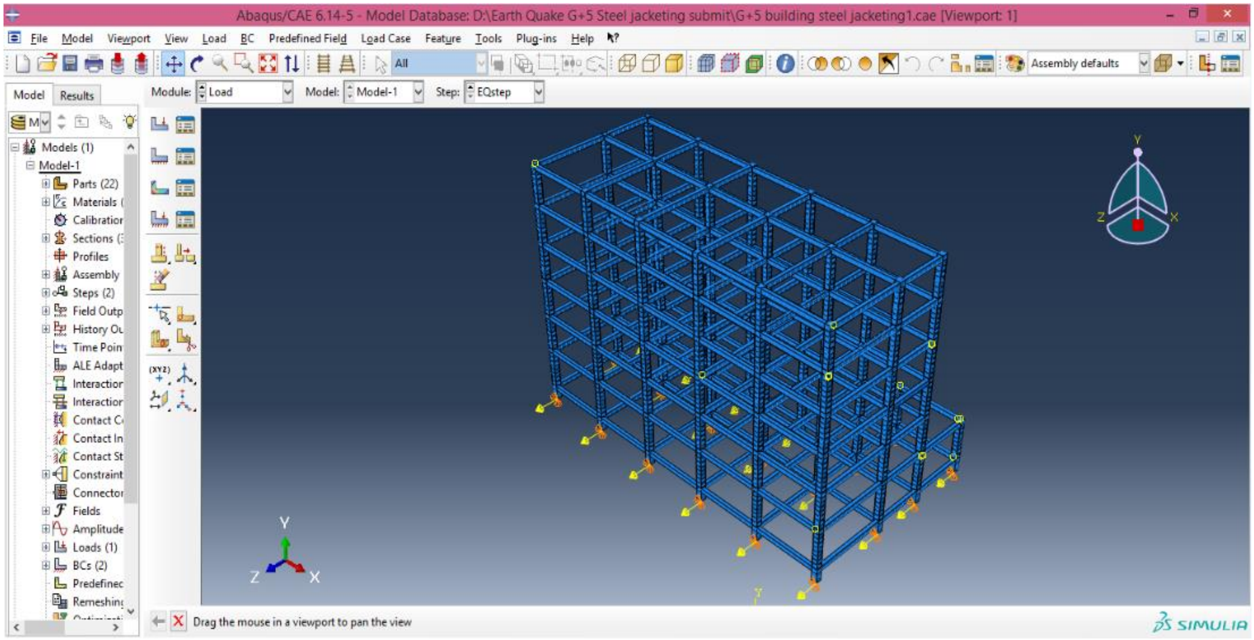


Figure 3.11: Sample Loading for CFRP jacketed frame

3.11. Load stepping

For the nonlinear analysis, automatic time stepping in the Abaqus program predicts and controls load step size. Displacement-controlled finite-element analyses were used in this research. the maximum and the minimum load step sizes are required for the automatic time stepping. In this particular study period, the maximum number of increments, the initial increment, minimum increment size, and maximum increment size were set to $3.5,1*10^{5}$, 0.005, $1E^{-05}$, and 1 respectively.

3.12 Meshing

Meshing is the process in which the continuous geometric space of an object is broken down into thousands or more shapes to properly define the physical shape of the object. Meshing, also known as mesh generation, is the process of generating a two-dimensional or three-dimensional grid; it involves dividing complex geometries into elements that can be used to discretize a domain.

Creating the most appropriate mesh is the foundation of engineering simulations. The mesh influences the accuracy, convergence, and speed of the simulation. Predictably shaped and mathematically defined volumes allow governing equations to be solved. Typically, the equations solved on these meshes are partial differential equations.

The Mesh module allows a generation of meshes for parts and assemblies created within Abaqus/CAE. Various levels of automation and control are available so that you can create a mesh that meets the needs of your analysis. As with creating parts and assemblies, the process of assigning mesh attributes to the model, such as seed mesh techniques and element types, is feature-based. As a result, you can modify the parameters that define a part or an assembly, and the mesh attributes that you specified within the Mesh module are regenerated automatically. In this research, hex meshing was used for all samples in this research paper.

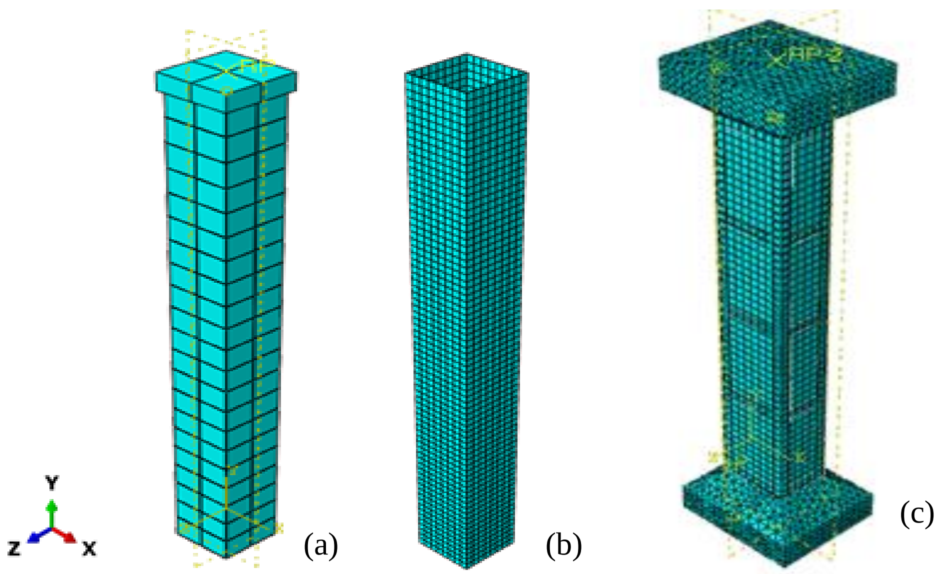


Figure 3.12: Sample meshing view for (a) Reinforced concrete jacketing b) CFRP jacketing c) steel jacketing of columns

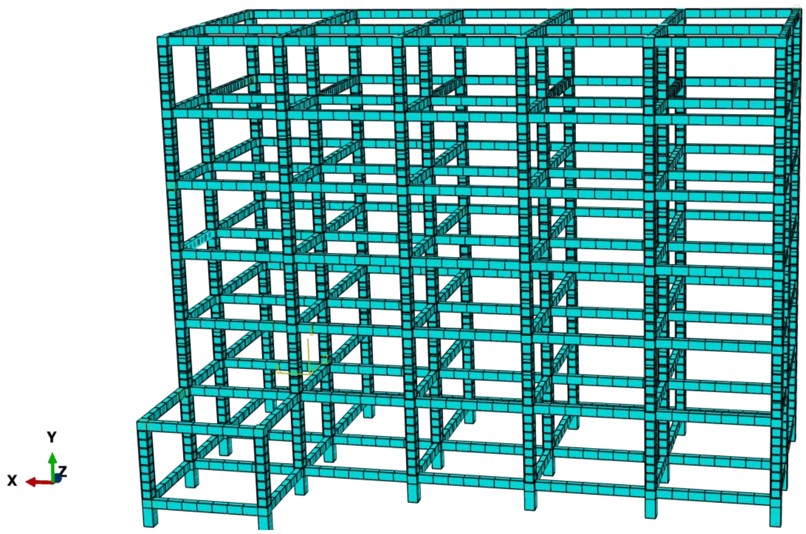


Figure 3.13: Sample meshing view of Steel strap jacketed RC frame

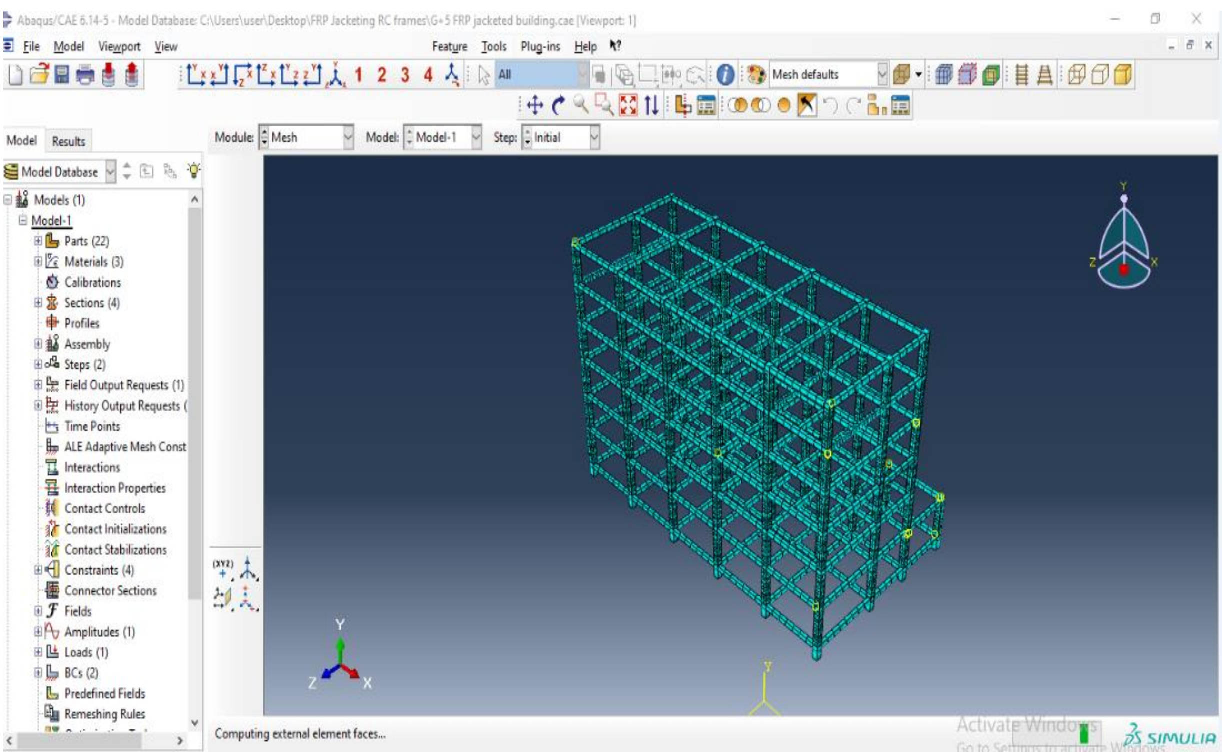


Figure 3.14: Sample meshing view of CFRP jacketed RC frame

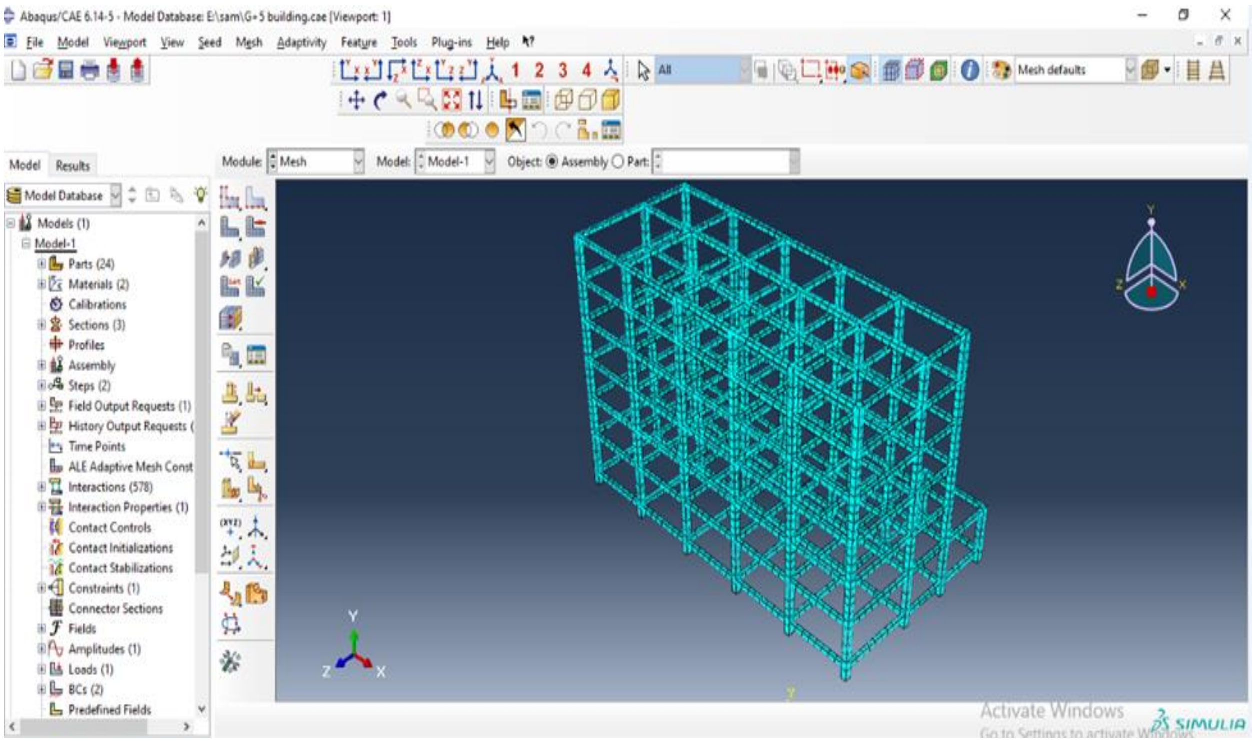


Figure 3.15: Sample meshing view of reinforced concrete jacketed RC frame

3.13 Mesh sensitivity analysis

The solutions obtained by solving a finite element model depend on the size of the elements used. By increasing the mesh density (reducing the size of elements and thus reducing the volume of elements), the numerical solution of the problem converges into a single solution. Of course, the smaller the mesh, the more physical memory is used to solve the finite element model, and the simulation duration increases. To investigate the influence of mesh sizes on the performance of a column, three models were used for each of four samples of bare RC column, steel jacketed RC column, reinforced concrete jacketed RC column and CFRP jacketed RC column with the same geometry and loading condition but different element sizes for sensitivity checks. The mesh size used for the single axial loaded column is 15 mm for all models for comparison purposes, and it is in good agreement with the results obtained in the experiment.

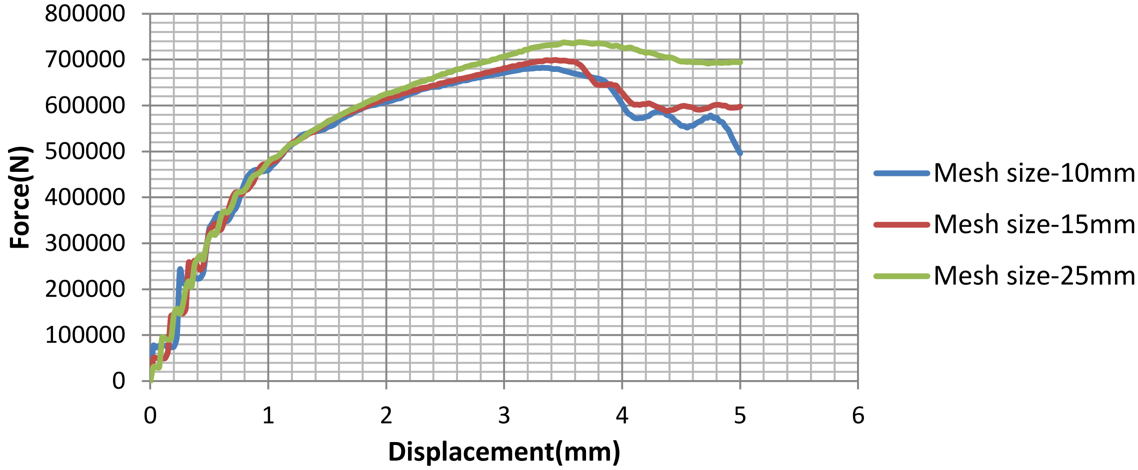


Figure 3.16: CFRP jacketing mesh sensitivity

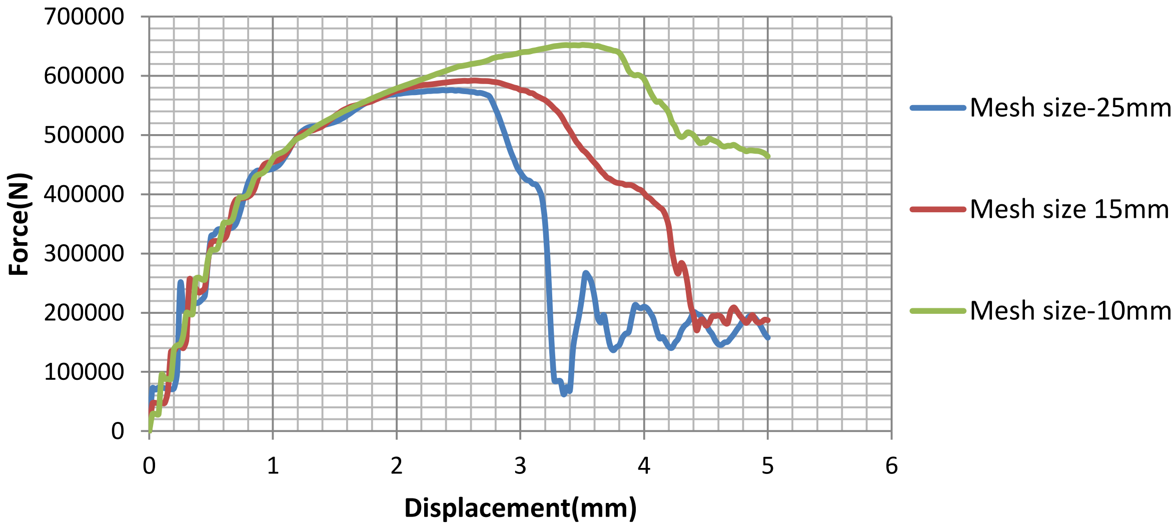


Figure 3.17: Reinforced Concrete jacketing mesh sensitivity

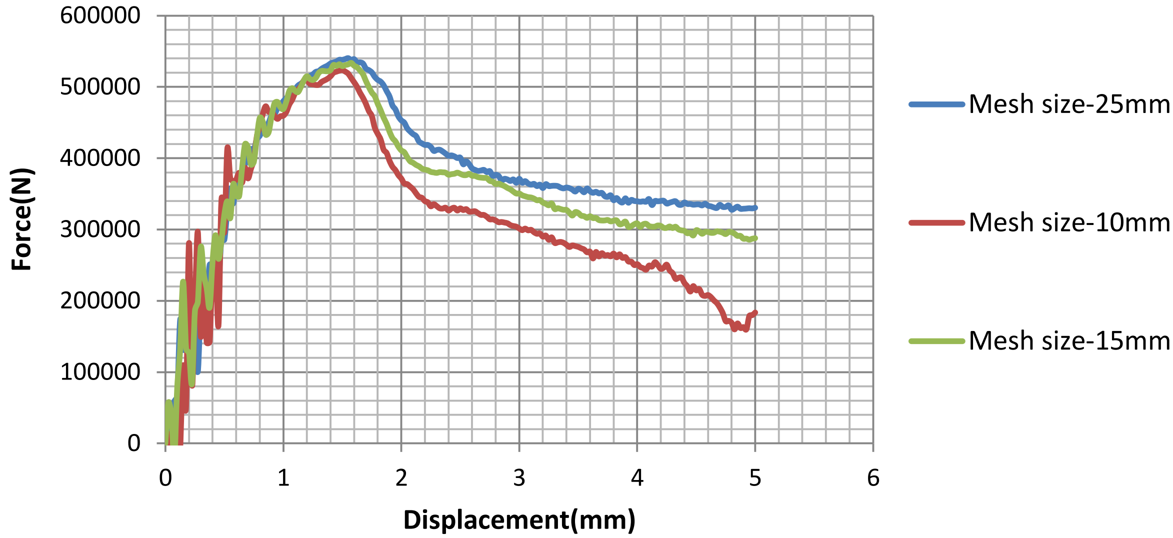


Figure3.18: Steel-jacketed mesh sensitivity

Table 3.5: Mesh sensitivity analysis comparison with experimental results

			ultimate load(KN)		
		Mesh size	Finite Element result	Experimental result	Difference from Experimental result (%)
(Krishna and Kumar, 2020)	CFRP Jacketing	10	682	743	8.2
		15	699		5.92
		25	738		0.67
(Tayeh *et al.*, 2019)	Concrete Jacketing	10	576	604	4.64
		15	592		1.99
		25	652		7.36
(Ezz-eldeen, 2018)	Steel Jacketing	10	524	554	5.4
		15	534		3.61
		25	540		2.53

Therefore, from the mesh sensitivity analysis 25mm mesh size was used for CFRP jacketing, and steel jacketed reinforced column, 15mm was used for concrete jacketing.

CHAPTER FOUR

ANALYSIS, RESULT, AND DISCUSSIONS

4.1 General

Finite element analyses were conducted using the software ABAQUS 6.14-1 to compare the performance of a single concrete column under axial load and reinforced concrete frame structure under earthquake loading with different retrofitting systems such as steel, CFRP, and RC jacketing. Results of Response Spectrum Analysis have been used to observe and compare the floor response of all the models in terms of the following parameters.

1) Story displacement
2) Story drift
3) Axial load

4.2 Validation of Finite Element Analysis by Experimental Result

Existing experimental data is used to validate the finite element models developed for columns under axial load. To investigate the performance of different jacketing systems for reinforced concrete, a lot of parameters have been considered in this study. Some of these are material models for steel, CFRP, and concrete, different loading rates, boundary conditions, mesh size, and element type for validation purposes. Validation is important to establish the reliability of the model's performance and, ultimately, the results of the research itself.

4.2.1 General description of data used in the experiment

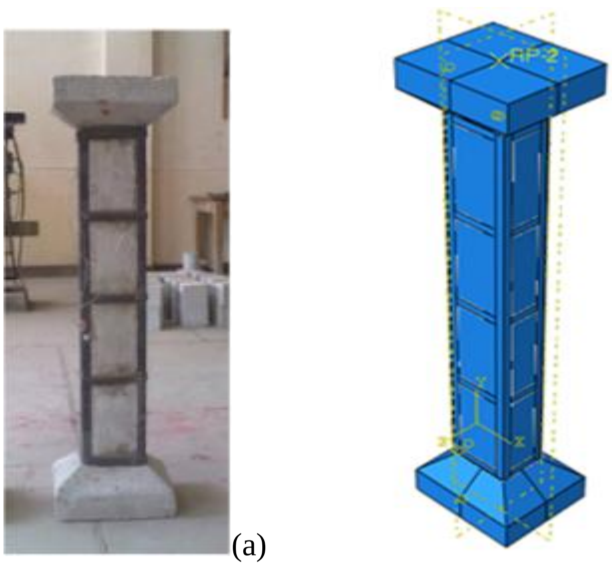
a) Steel jacketing

The concrete is defined as an isotropic material in the modeling and should be deliberately expressed in verification.

Table 4.1: Concrete properties of validity parameters (Ezz-eldeen, 2018)

Concrete properties	Magnitude
Elastic Modulus	37300
Poisson's Ratio	0.19
Compressive strength	25mpa

An experiment carried out by (Ezz-eldeen, 2018) was used to compare the FEM of the RC column. The dimension of the column was 120X160X1000 mm with a column head of 260X300 mm at the top and bottom. In the experiment, both the pure axial load and the eccentric load were considered with main reinforcement and stirrup at 120 mm. The yield strength of all reinforcements was 240 MPa and the steel jacket was 3.8x105 (kN/m2).



(a) (b)

Figure 4.1: (a) Steel stirrup strengthened column specimens (Ezz-eldeen, 2018) (b) Finite element model of steel strap

Figure 4.2 Experimental setup for the test used for steel jacketing (Ezz-eldeen, 2018)

The columns were tested under static load using a 1000 KN capacity hydraulic jack mounted on a steel frame. The result found was a failure load of 554KN for the control column and 643KN for the 10mm eccentrically loaded column.

b) CFRP jacketing

Table 4.2: Properties of CFRP sheet validity parameters (Krishna and Kumar, 2020)

Property	Details
Tensile strength	4900MPa
Elastic modulus	235000MPa
Nominal fiber Thickness	0.128mm
Grade of concrete for CFRP jacketing	M-20

Table 4.3: Reinforcement steel properties of validity parameters (Krishna and Kumar, 2020)

Steel properties	Magnitude
Diameter of the longitudinal bar	12mm
Diameter of tie bar	8m
Elastic Modulus	200000 Mpa
Poisson's Ratio	0.3
Yield Strength	500

Test specimens having a length of (L= 1500mm), depth (d=150mm), and width (b=150mm) were used. The columns are reinforced with 4 bars of 12 mm diameter as main reinforcement and 8 mm diameter ties are provided as shear reinforcement spaced at 150 mm c/c as medium scale RC column. Additionally, horizontal and vertical reinforcement was provided as shown in figure 4.3 (Krishna and Kumar, 2020).

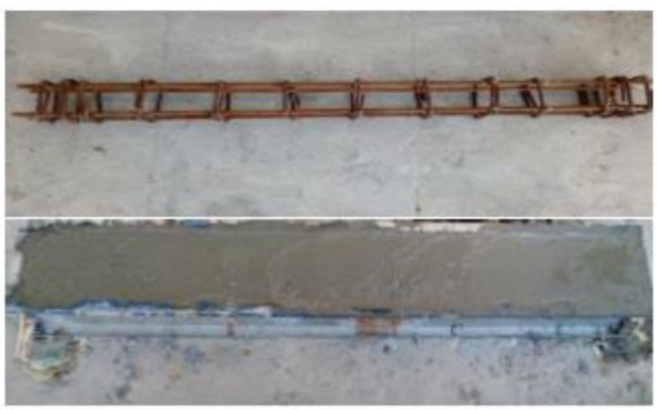


Figure 4.3: Mold of specified dimensions and reinforcement details(Krishna and Kumar, 2020).

The column specimens are tested on a 2000kN capacity loading frame under uni-axial compressive load. Steel plates were used as column caps to ensure parallel surface to columns which distribute the load uniformly with minimum eccentricity. The loading rate of the loading frame is maintained at 10kN and this rate is maintained constant up to cracks appearing on the surface of the column specimen(Krishna and Kumar, 2020).

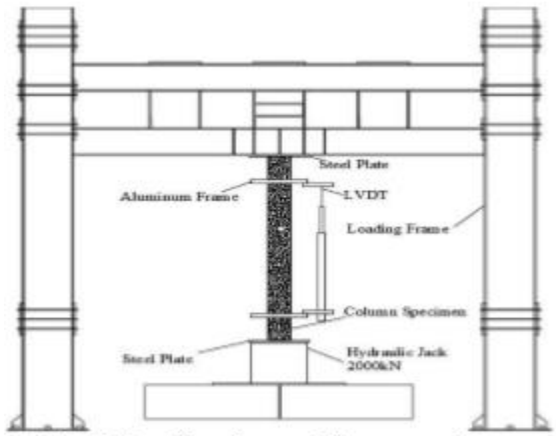


Figure 4.4: Loading frame with the test specimen (Krishna and Kumar, 2020)

The result obtained from this experiment was an ultimate load of 743KN for a retrofitted column wrapped with a single layer of CFRP.

c) RC jacketing

(Tayeh *et al.*, 2019) conducted an experimental study on Repairing and Strengthening Damaged RC Columns Using Thin Concrete Jacketing. The experimental programs included reinforced concrete column specimens with cross sections of 100 mm × 100 mm and a height of 300 mm. The thickness of jacketing applied was 25 mm with 4Ø8 mm main steel-reinforcing bars with a length of 280 mm and a diameter of 8 mm used at the four corners of the column cores. 3Ø2.5 mm transverse steel reinforcement ties are used and fixed to the longitudinal steel bars with a vertical spacing of 90mm. All the column specimens that are jacketed are loaded with approximately 90% of their actual axial capacity.

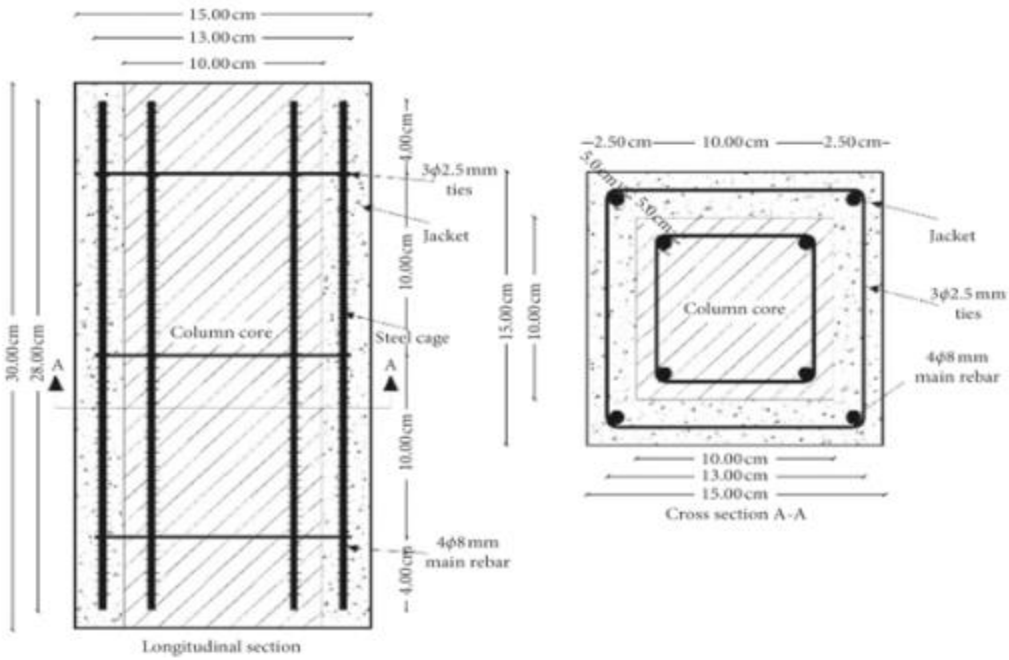


Figure 4.5: Geometry and reinforcement details of the experiment(Tayeh et al., 2019).

Figure 4.6: The A-B jacketed column specimens ready for testing(Tayeh et al., 2019).

The axial displacement of the specimens is measured using the compression testing machine. Three strain dial gauges with an accuracy of approximately 0.00254 mm are fixed at the mid-height of the column before testing. At each increment of 6kN axial compression load, the readings of axial displacement are recorded using the machine data acquisition system. The value obtained from this experimental research where from the average of three specimens is 604mpa.

4.2.2 Comparison of the Results

The results obtained from the laboratory test were used to compare with the results obtained from the finite element analysis. Hence, the finite element model was implemented based on the parameters and conditions used in the laboratory test. The load-deflection curve for both experimental and finite element analysis (ABAQUS Software package) has been presented in table 4.4.

Table 4.4: Comparison of experimental (Ammar, 2015) and finite element result

Type	Experimental result(KN)	Finite element result(KN)	Difference from Experimental result (%)	Reference
Concrete jacketing	604	592	0.67	(Tayeh *et al.*, 2019)
CFRP jacketing	743	738	0.5	(Krishna and Kumar, 2020)
Steel jacketing	554	554	2.53	(Ezz-eldeen, 2018)

The finite element model gives acceptable results for the ultimate load capacity with values less than 7% from the reference experimental values.

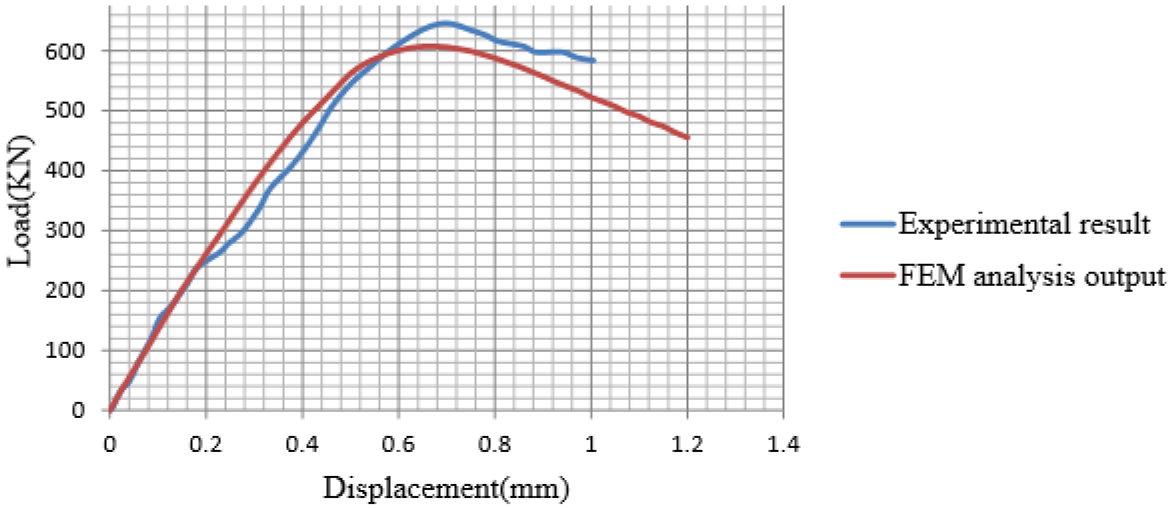


Figure 4.7: Comparison of experimental and finite element result

4.3 Effect of length

Column length greatly influences a column's ability to carry a load. Short columns fail by crushing due to material failure. Long, slender columns fail by buckling. Buckling is the sudden uncontrolled lateral displacement of a column at which point no additional load can be supported. Therefore, it is necessary to analyze the effect of jacketing methods as the length of columns varies. Figure 4.7 shows a slender column strengthened with reinforced concrete, CFRP, and steel. Figures,4.7 and table 4.5 indicates the axial load-carrying capacity of reinforced concrete columns strengthened with RC jacketing has been improved by 32.1%, CFRP by 31.2%, and steel jacketed by 5.62% compared to the control columns (bare reinforced columns). As figure 4.8 and table 4.6 depicts for short RC jacketed columns strength increased by 36.5% which is the most efficient method of strengthening and followed by the CFRP jacketing technique with 16.8% axial load carrying capacity enhancement and the steel jacketing technique increased by 2.2% contrast to the bare reinforced concrete column.

Table 4.5: Axial load capacity of a retrofitted slender column

Type	Length(mm)	Ultimate load	% Increase for bare column
Bare RC column	3650	564.5	0
CFRP jacketed column	3650	598.1	5.62
Steel jacketed column	3650	820.7	31.22
RC jacketed column	3650	831.52	32.1

Table 4.6: Axial load capacity of retrofitted short column

Type	Length(mm)	Ultimate load	Increase for bare column (%)
Bare RC column	1200	612.2	0
CFRP jacketed column	1200	736	16.8
Steel jacketed column	1200	625.8	2.2
RC jacketed column	1200	964.1	36.5

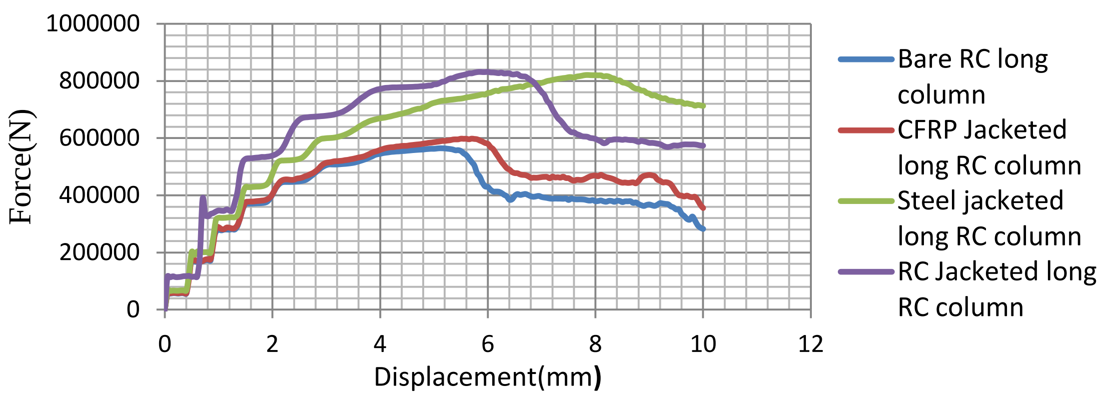


Figure 4.8: Effect of length for long column

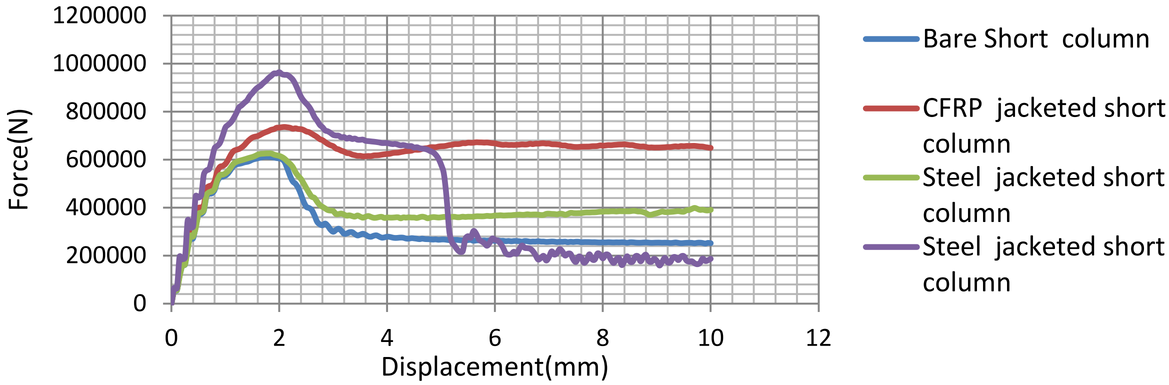


Figure 4.9: Effect of length for short column

4.4 Effect of eccentricity

Eccentrically loaded columns are subjected to moment, in addition to axial force. The moment can be uniaxial, as in the case when two adjacent panels are not similarly loaded. Biaxial bending of columns occurs when the loading causes bending simultaneously about both principal axes. To study the performance of a strengthened RC column both Uni-directional and Bi-directional load eccentricities are considered.

4.4.1 Uni-Directional Eccentricity

The capacity for different values of eccentric was obtained from FEM analysis. Displacement eccentric loading was applied on a loading plate 50mm thick with 20mm, 35mm, and 45mm eccentricity, and the force-displacement response is drawn for each eccentric loading jacketed column. The ultimate loading capacity was obtained from the outputs of the FEM analysis.

The force to displacement curve in Figures(4.9,4.11,14) and table 4.7 assures that for uni-directional eccentrically loaded strengthened slender reinforced concrete column RC jacketing technique shows better improvements in ultimate load carrying capacity by 33% for 20mm eccentricity, 34% for 35mm eccentricity and 35.74% for 45mm eccentric loading. Next to reinforced concrete jacketing steel strengthening technique enhanced the ultimate load-carrying capacity by 32% for 20mm eccentric loading,29.15% for 35mm load eccentricity, and 30.78% for 45mm eccentricity. CFRP jacketing holds the third rank in improving the capacity of the eccentrically loaded column. As the eccentricity length of the load increase, the steel jacketing technique will be a good alternative to use next to the reinforced jacketing technique. Figure (4.10,4.12,4.13) and table 4.4 strengthened short column loaded with uni-axial eccentric loading showed that reinforced concrete jacketing raise the axial load carrying capacity with 33.32% when the eccentricity length is 20mm,34.93% for 35mm eccentricity and 36.33% 45mm eccentricity, and followed by CFRP jacketing and lastly steel jacketing.

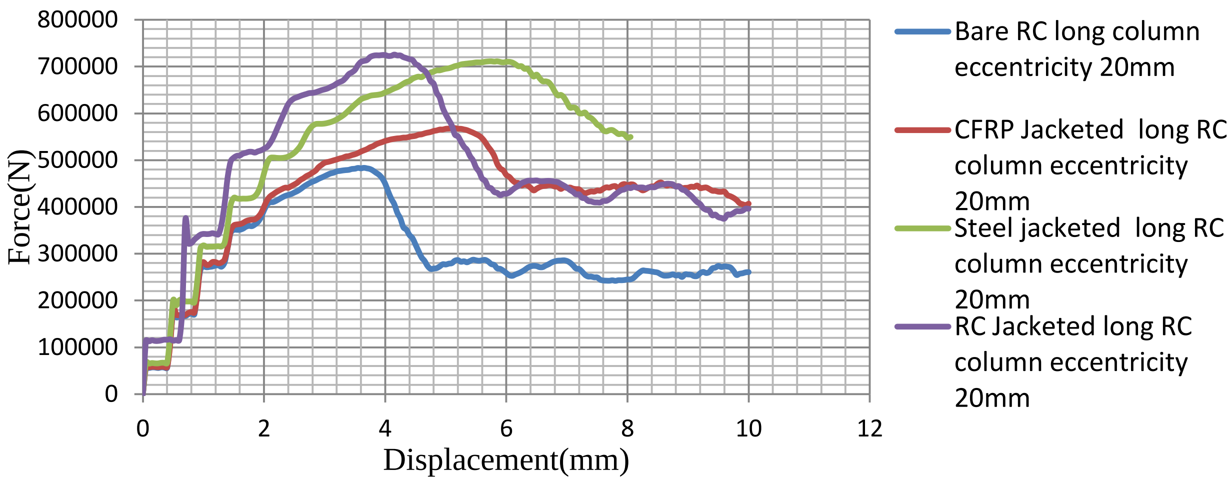


Figure 4.10: Comparison of the efficiency of uni-directionally loaded strengthened slender column with an eccentricity of 20mm.

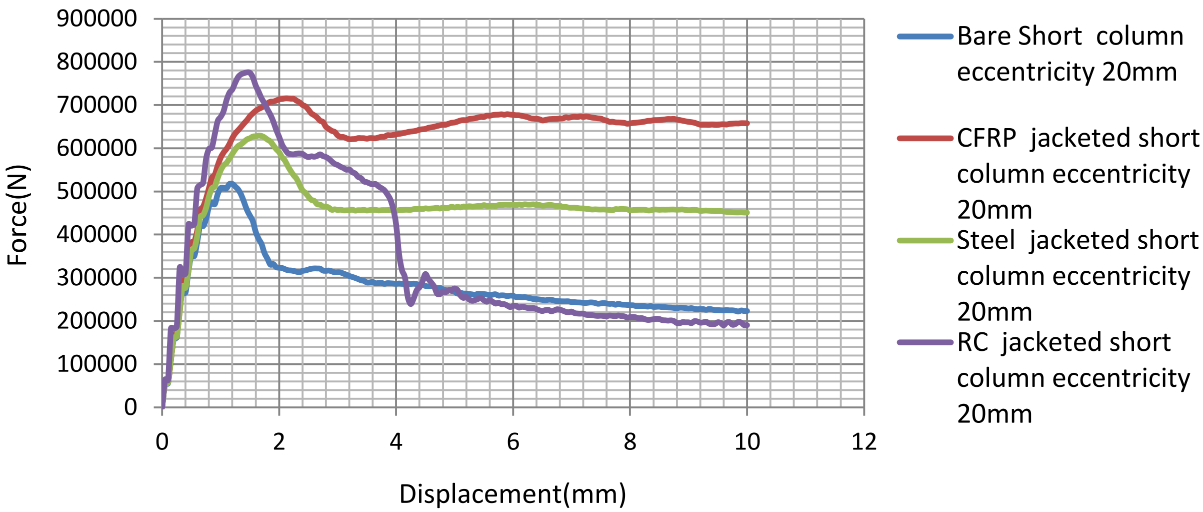


Figure 4.11: Comparison of the efficiency of uni-directionally loaded strengthened short column with an eccentricity of 20mm.

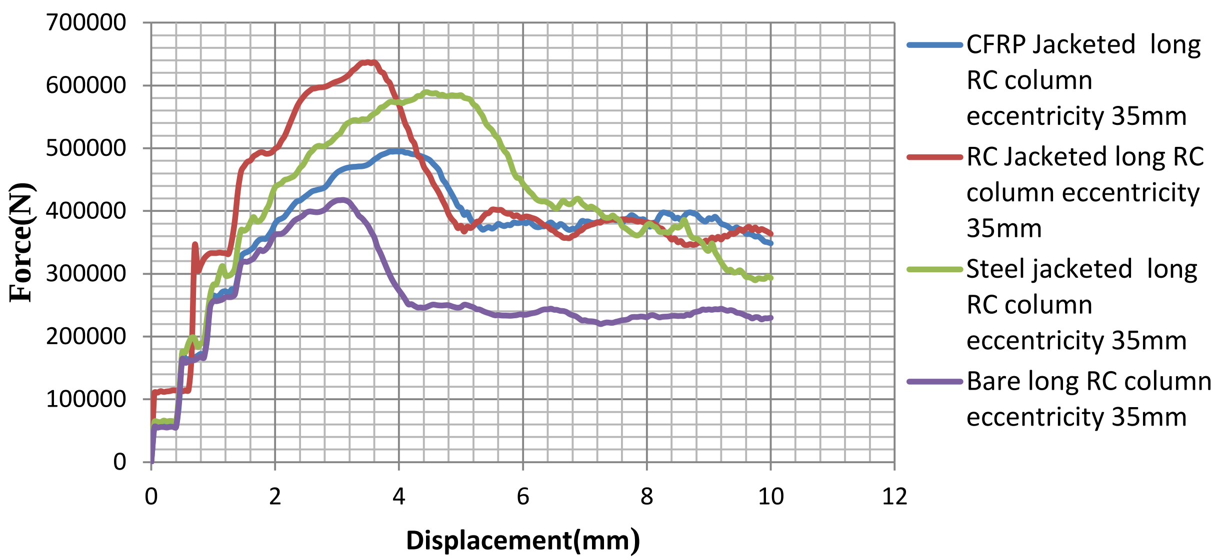


Figure 4.12: Comparison of the efficiency of uni-directionally loaded strengthened slender column with an eccentricity of 35mm.

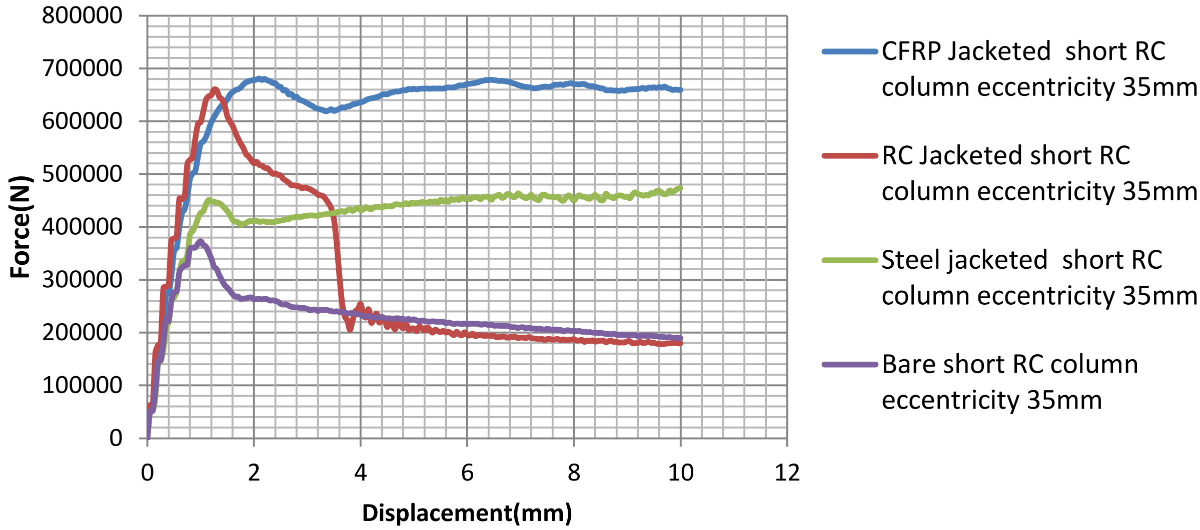


Figure 4.13: Comparison of the efficiency of uni-directionally loaded strengthened short column with an eccentricity of 35mm.

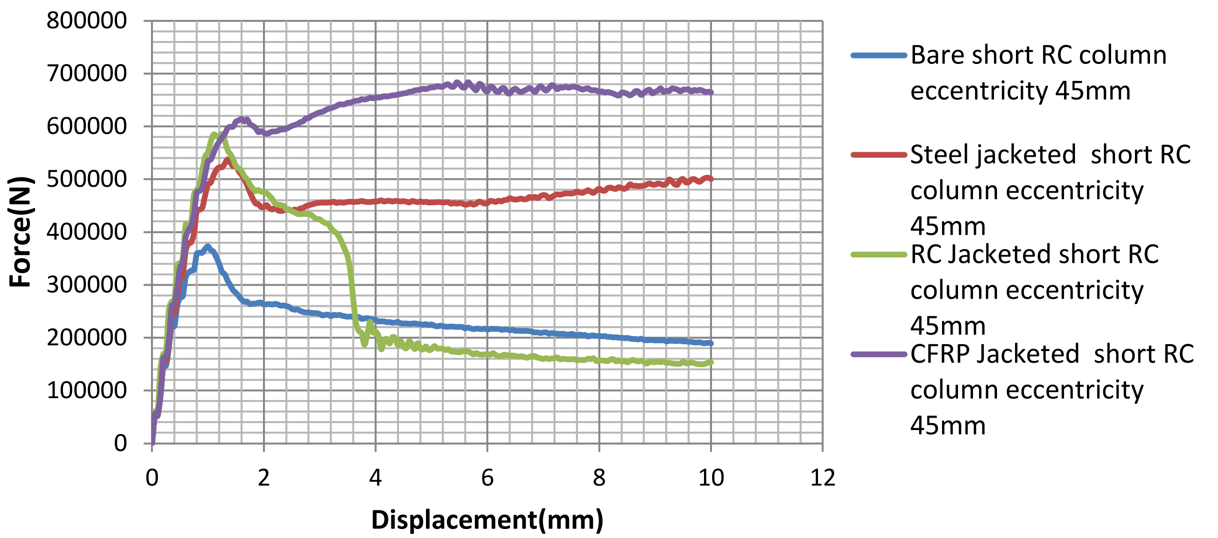


Figure 4.14: Comparison of the efficiency of uni-directionally loaded strengthened short column with an eccentricity of 45mm

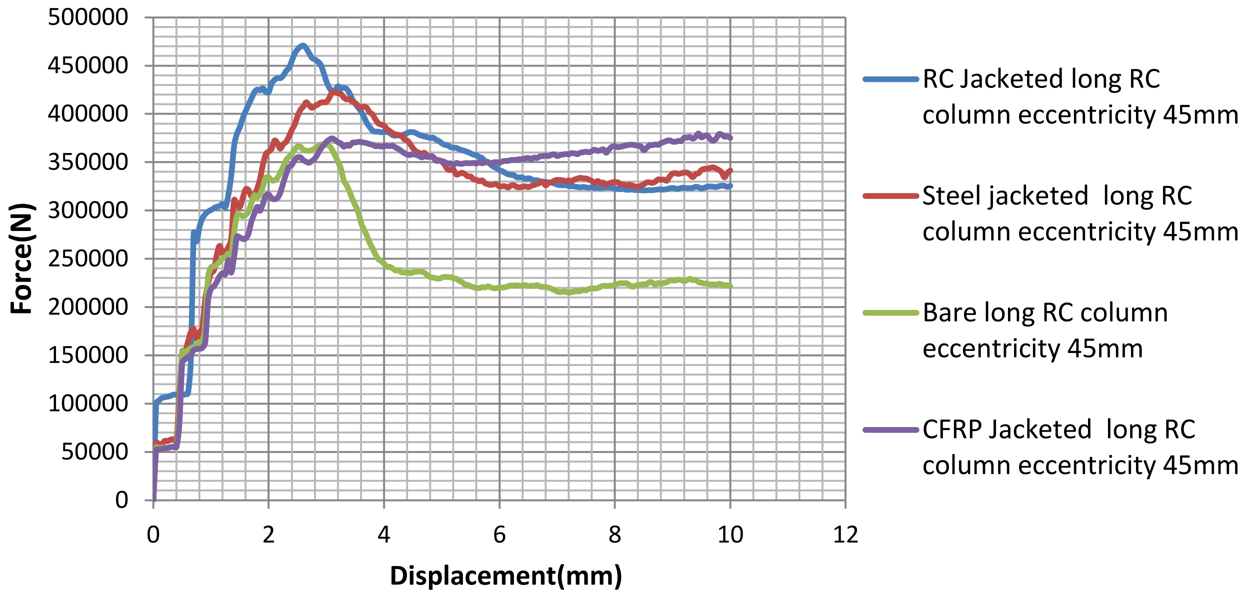


Figure 4.15: Comparison of the efficiency of uni-directionally loaded strengthened slender RC column with an eccentricity of 45mm.

Table 4.7: Results for Uni-directional Eccentricity for Bare and Retrofitted Slender RC Columns.

Eccentricity	Ultimate load(KN)				The increase compared to the bare column (%)		
	Bare frame	CFRP jacketed frame	steel jacketed frame	RC jacketed frame	CFRP	steel	RC jacketed frame
20	483.6	676.79	711.3	725.6	28.55	32	33.4
35	417.64	495.06	589.44	637.21	25.73	29.15	34.5
45	368.12	449.87	531.85	572.9	18.2	30.78	35.74

Table 4.8: Results for un-directional eccentricity for bare and retrofitted short RC columns.

Eccentricity (mm)	Ultimate load (KN)				The increase compared to the bare column (%)		
	Bare frame	CFRP jacketed frame	Steel jacketed frame	RC jacketed frame	CFRP	Steel	RC jacketed frame
20	517.34	715.4	629.5	775.8	27.7	17.82	33.32
35	429.46	680.79	577.97	660	15.6	25.7	34.93
45	372.83	583.59	537.46	585.58	36.46	30.63	36.33

4.4.2 Bi-directional eccentricity

In column members, it is common to find a bi-directional eccentricity (ex & ez). The FEM analysis gives the maximum load-carrying capacity for different values of combined eccentricity. The increase of load carrying capacity of a reinforced concrete column with the three techniques of jacketing loaded with bi-directional eccentricity is shown in Tables 4.9 and figure (4.15,4.17 and 4.18) for slender columns and Tables 4.10 and figure (4.16,4.19 4.20) for a short column. The load-carrying capacity of the reinforced concrete jacketed column loaded with a bi-directional eccentricity of 20mm enhanced by 52.4%, steel jacketed by 27.92%, and CFRP jacketed column by 16.02% compared to the bare column for the slender column. As table 4.10 reveals when the length of eccentricity increase CFRP jacketing perform well relatively for the slender column, for less eccentricity reinforced concrete jacketing gives a better axial load resistance. For 45mm eccentricity, CFRP jacketing gives a 60.2% increase in axial load carrying capacity, reinforced concrete jacketing 40.9%, and steel 30.63% contrast to the bare frame.

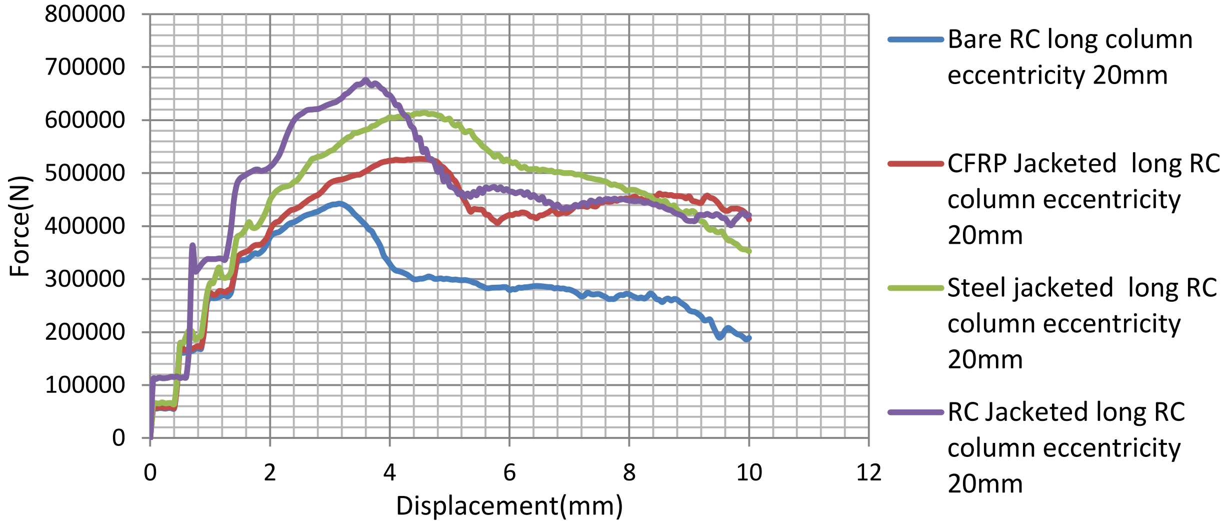


Figure 4.16: Comparison of the efficiency of bi-directionally loaded strengthened slender RC column with an eccentricity of 20mm.

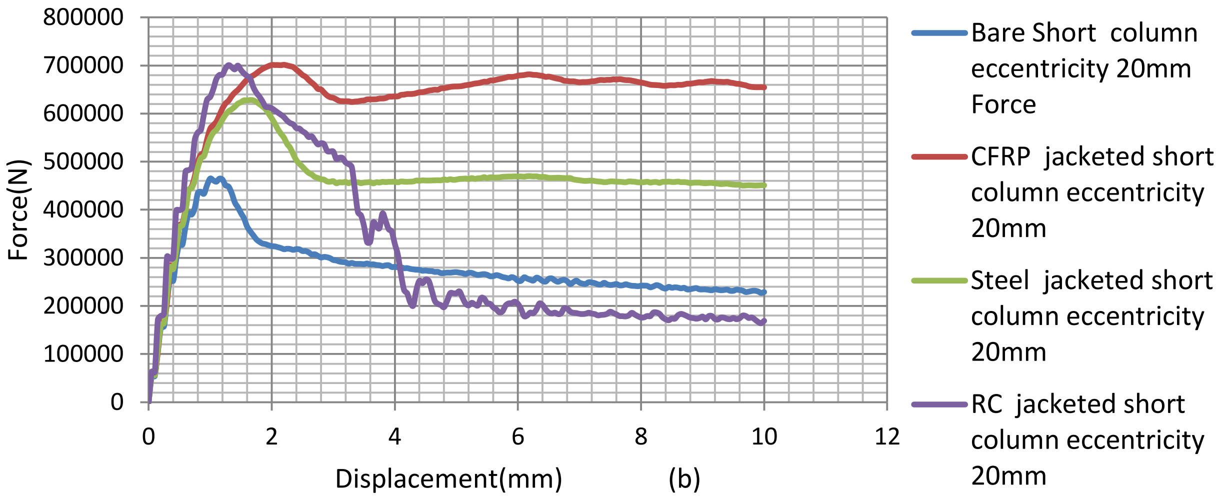


Figure 4.17: Comparison of the efficiency of bi-directionally loaded strengthened short RC column with an eccentricity of 20mm.

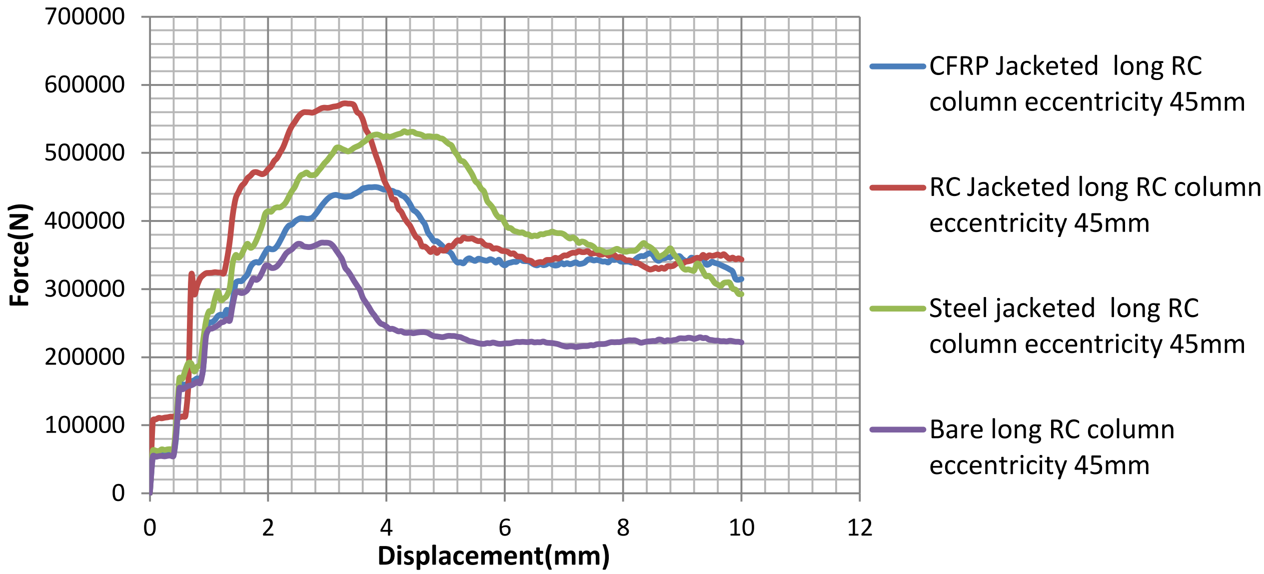


Figure 4.18: Comparison of the efficiency of bi-directionally loaded strengthened slender RC column with an eccentricity of 45mm.

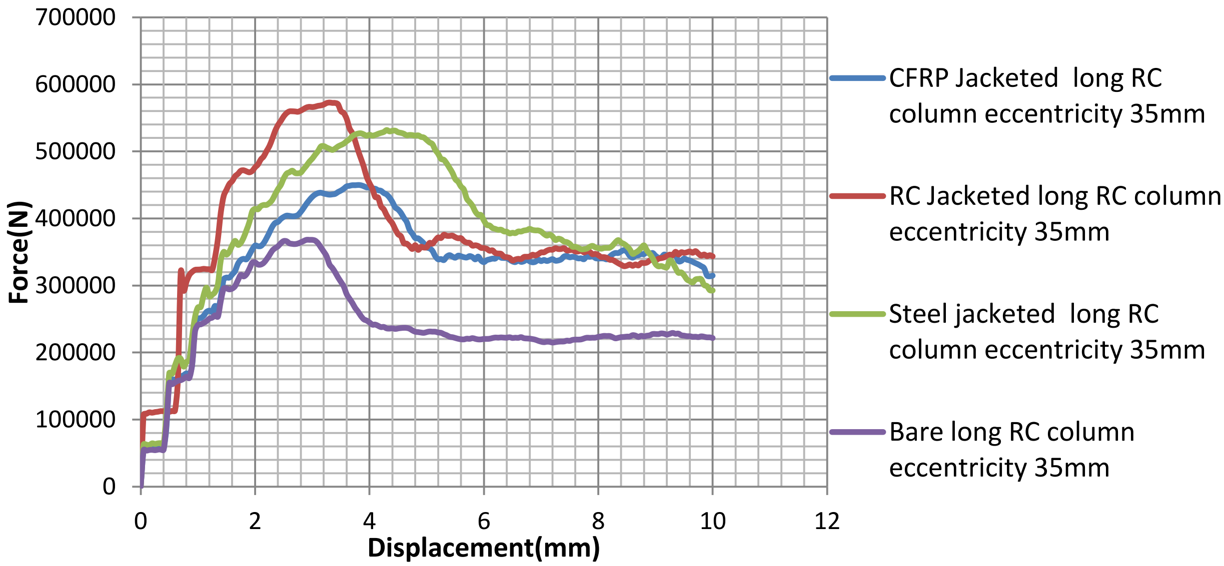


Figure 4.19: Comparison of the efficiency of bi-directionally loaded strengthened slender RC column with an eccentricity of 35mm.

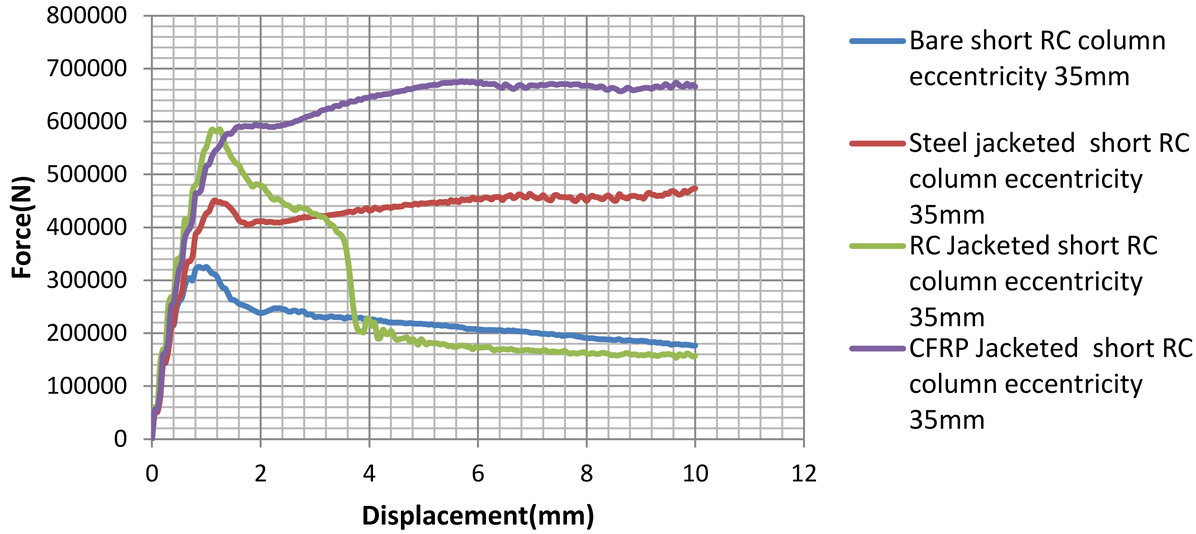


Figure 4.20: Comparison of the efficiency of bi-directionally loaded strengthened short RC column with an eccentricity of 35mm.

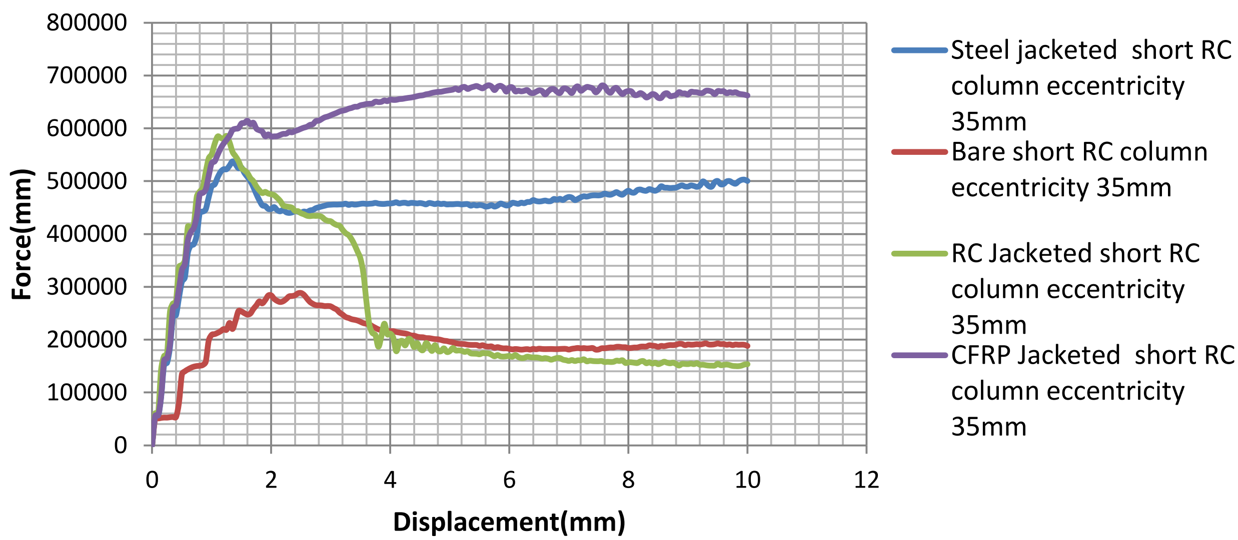


Figure 4.21: Comparison of the efficiency of bi-directionally loaded strengthened short RC column with an eccentricity of 35mm.

Values for reference and strengthened columns under Bi directional eccentricities are given below.

Table 4.9: Results for Bi-directional eccentricity for bare and retrofitted slender RC columns.

Eccentricity	Ultimate load(KN)				The increase compared to the bare column (%)		
	Bare frame	CFRP jacketed frame	steel jacketed frame	RC jacketed frame	CFRP	steel	RC jacketed frame
20	442.45	526.9	613.8	676	16.02	27.92	52.4
35	315.97	468.2	486.9	536.55	32.5	35.11	41.11
45	282.27	427.83	413.36	462.42	34	31.71	38.96

Table 4.10: Results for bi-directional eccentricity for bare and retrofitted short RC columns.

Eccentricity	Ultimate load (KN)				The increase compared to the bare column (%)		
	Bare frame	CFRP jacketed frame	Steel jacketed frame	RC jacketed frame	CFRP	Steel	RC jacketed frame
20	464.9	701.4	628.2	702	33.72	17.82	33.8
35	298.36	670.94	488.32	525.76	55.53	25.7	43.25
45	265.9	668.00	475.4	449.94	60.2	30.63	40.9

4.5 Story Displacement

Figure (4.21- 4.27) and table 4.11 shows the numerical result of the finite element analysis of story displacement vs time of strengthened columns using reinforced concrete, CFRP, and steel jacketing is presented. As table 4.11 results show the reinforced concrete jacketed column gives a greater decrease in story displacement by 40.6% for the top floors and next steel jacketing showed a decrease in story displacement by 27.37% and CFRP jacketed column decreased by

16.8% in story displacement relative to the control RC frame. Hence, RC jacketing has been found the most efficient in terms of story displacement reduction of the three jacketing techniques considered in this study. For further information see table 4.11.

Based on (ESA, 2015) the allowable lateral displacement for a structure having non-structural elements of brittle materials attached to the structure is limited to H/200 where H is the height of the structure so in this case by considering of height of the structure which is equal to 21 meters the allowable lateral displacement becomes 105mm.

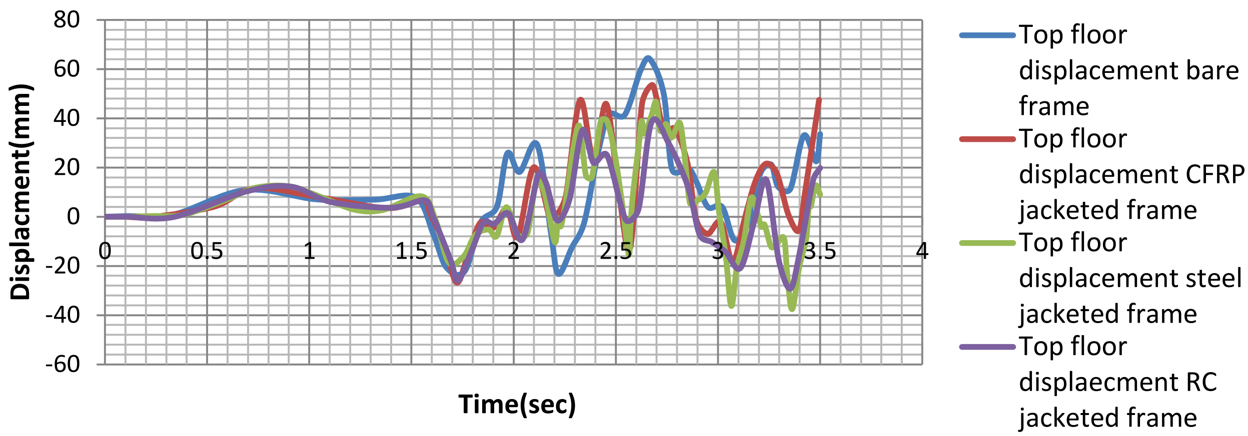


Figure 4.22: Maximum Story Displacement comparison of bare, CFRP, steel and RC jacketed frame for the top floor.

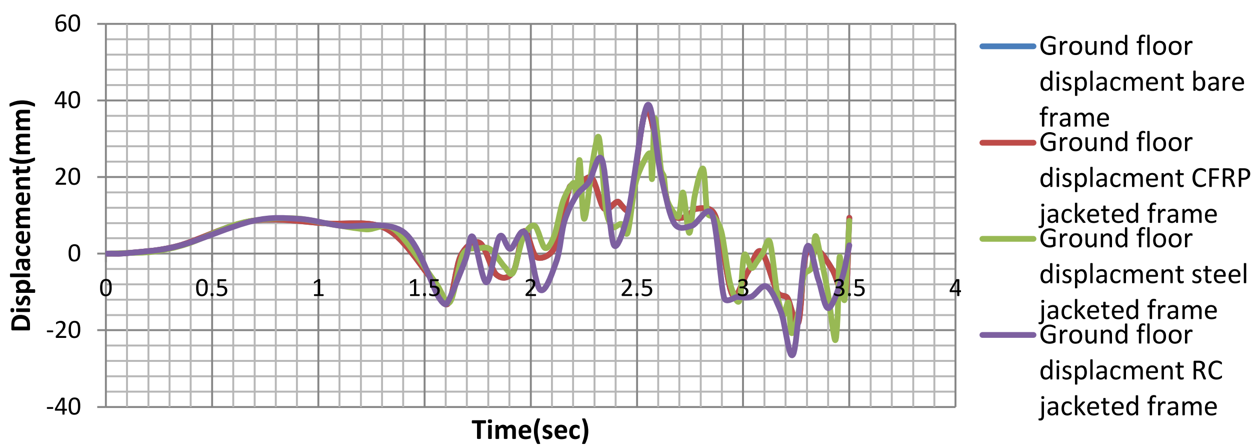


Figure 4.23: Maximum Story Displacement comparison of bare, CFRP, steel, and RC jacketed frame for ground frame.

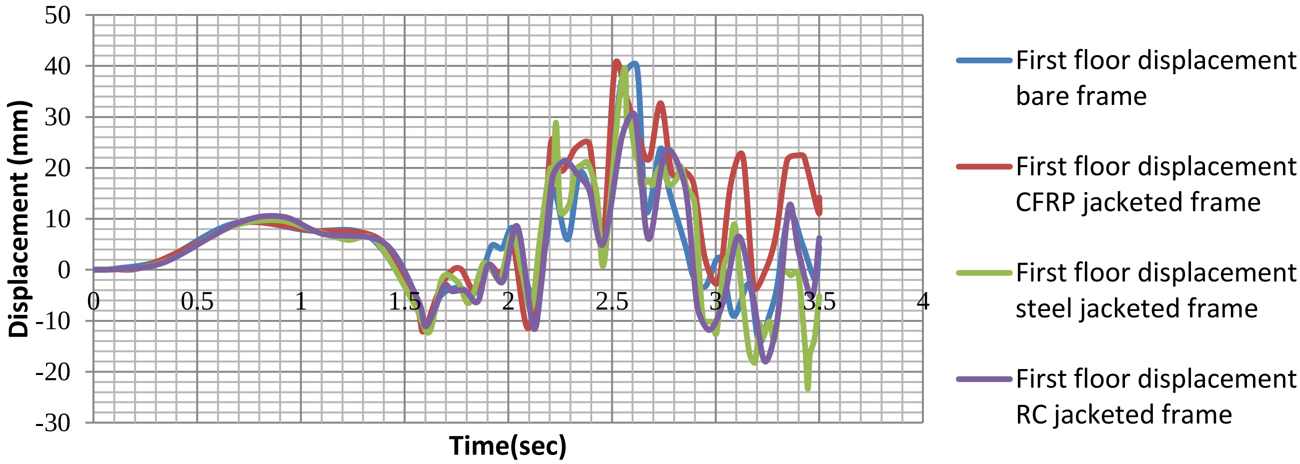


Figure 4.24: Maximum Story Displacement comparison of bare, CFRP, steel and RC jacketed frame for the first floor.

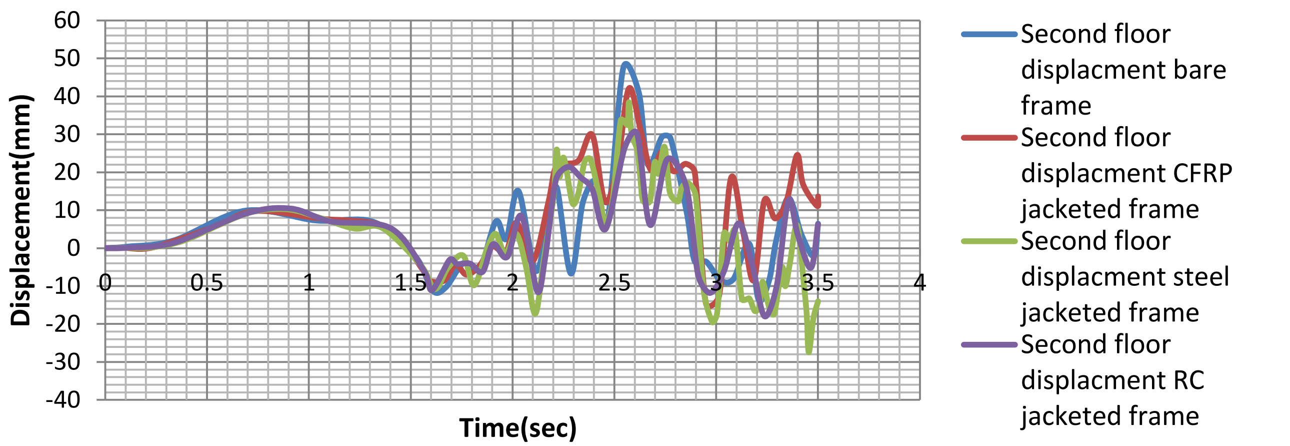


Figure 4.25: Maximum Story Displacement comparison of bare, CFRP, steel and RC jacketed frame for the second floor.

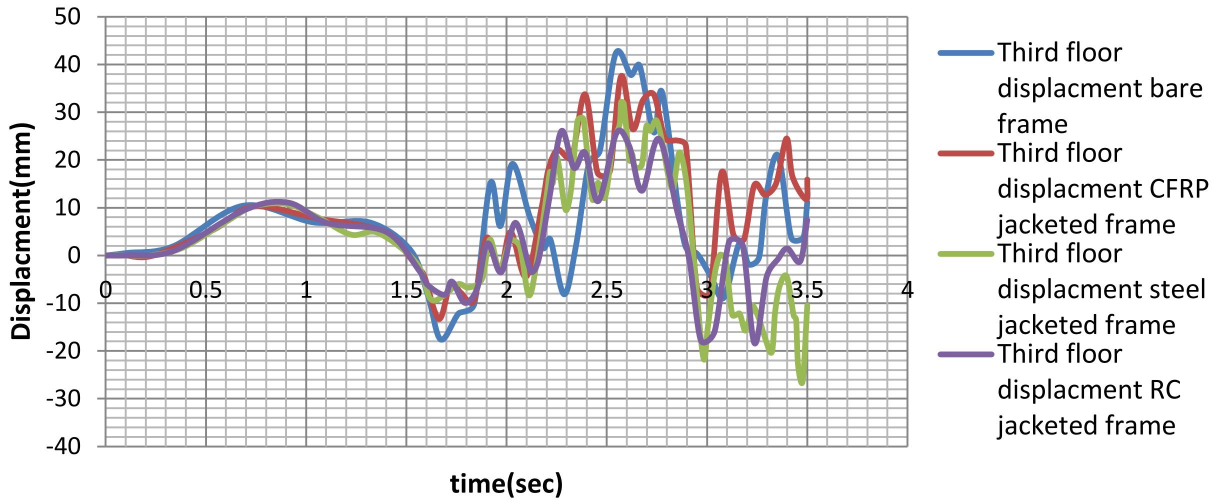


Figure 4.26: Maximum Story Displacement comparison of bare, CFRP, steel and RC jacketed frame for the third floor.

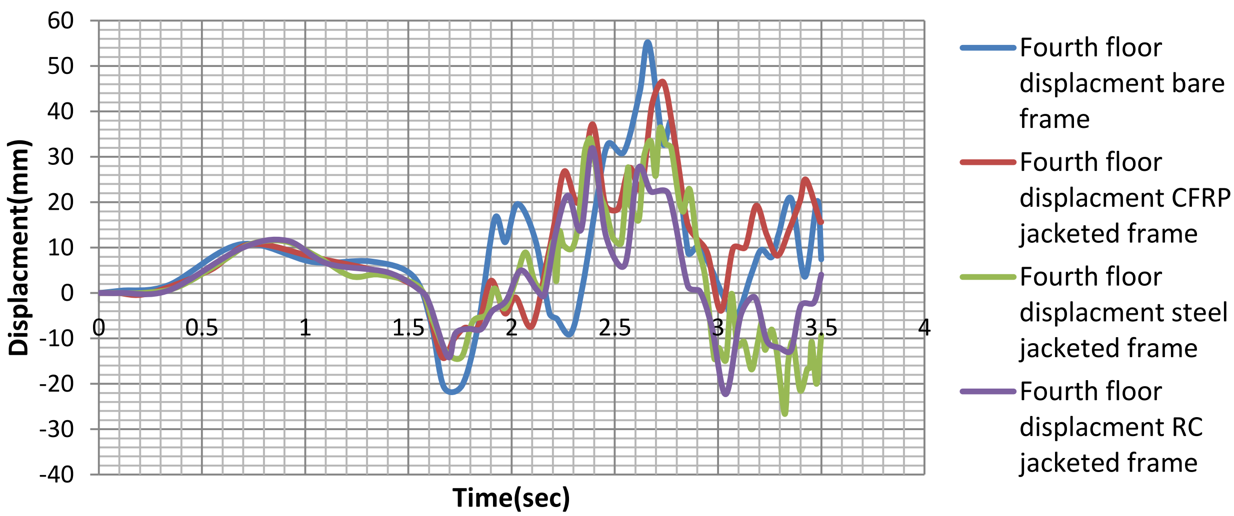


Figure 4.27: Maximum Story Displacement comparison of bare, CFRP, steel and RC jacketed frame for the fourth floor.

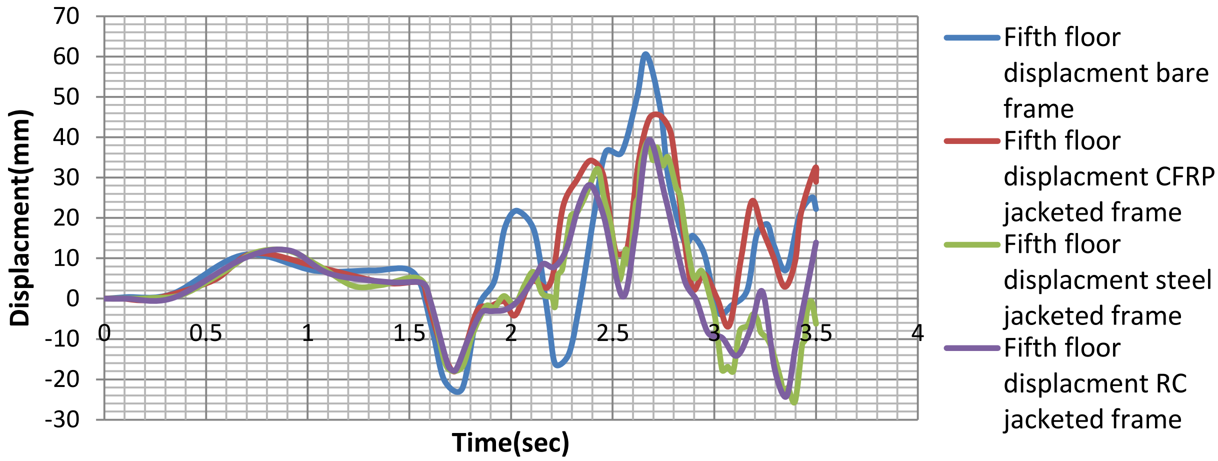


Figure 4.28 Maximum Story Displacement comparison of bare, CFRP, steel and RC jacketed frame for the fifth floor.

Generally, the following table 4.11 compares the reduction of -story displacement in percentage as compared to the bare frame for the three retrofitting systems considered in this study.

Table 4.11: Summary story displacement results in percent of retrofitted RC frame

Story	Bare frame	CFRP jacketed frame	steel jacketed frame	RC jacketed frame	Reduction of story displacement (%)		
					CFRP	steel	RC
Top	64.3	53.5	46.7	38.5	16.8	27.37	40.6
Ground	38.7	37.5	35.3	34.9	3.1	8.8	10.6
1st	40.1	39.51	39.6	30.2	1.5	1.25	24.7
2nd	47.5	42.1	38.4	30.2	11.4	19.16	36.4
3rd	42.3	37.5	32.2	26.1	11.35	23.88	38.3
4th	55	46.4	46.4	36.3	15.64	15.64	34
5th	60.6	45.3	39.2	39.1	25.25	35.31	35.5

4.6 Story drift

The story drift versus time curve shown in figure 4.4-figure 4.9 and Table 4.5 point out that the maximum reduction in story drift is found when the bare frame is jacketed with reinforced concrete and followed by a steel jacketed frame. For the top story, the reduction in story drift for the reinforced concrete jacketed column is 39%, steel jacketed 36.3% and CFRP jacketed 12.1%. In the first story, the reinforced concrete jacketed frames story drift decreased by 51%, steel jacketed by 40.5% and CFRP decreased by 32.68%. Hence, reinforced concrete jacketing is found the most efficient in terms of story drift reduction from retrofitting techniques considered in this study.

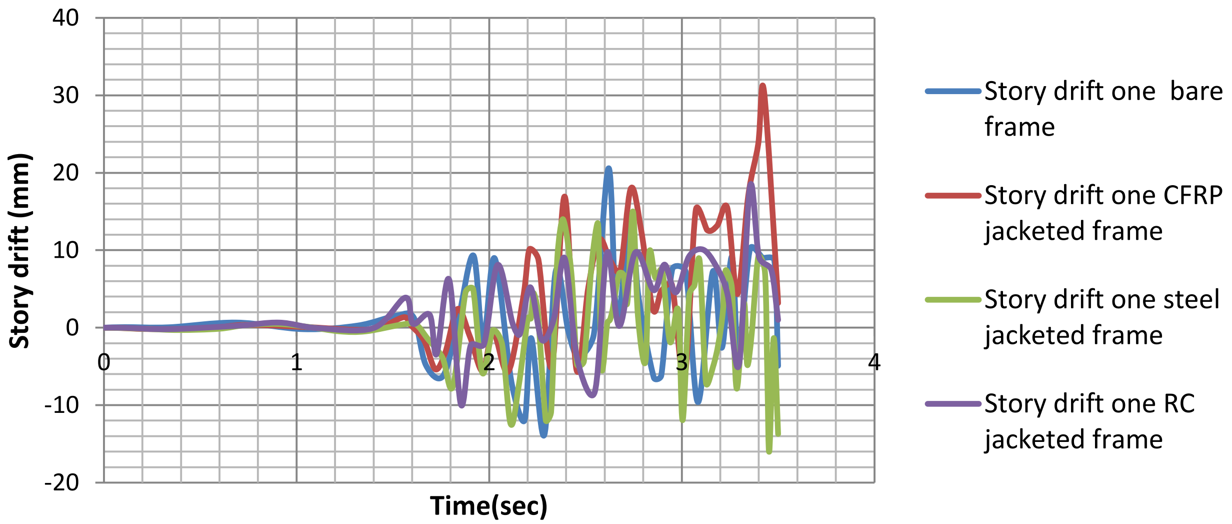


Figure 4.29: Maximum Story drift comparison of bare, CFRP, steel, and RC jacketed frame for story one

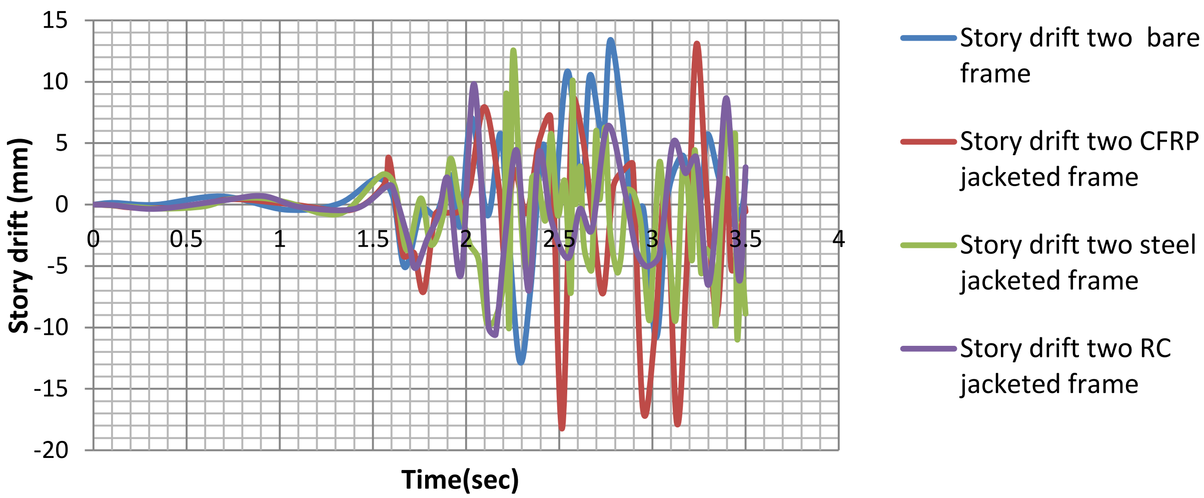


Figure 4.30: Maximum Story drift comparison of bare, CFRP, steel, and RC jacketed frame for story two.

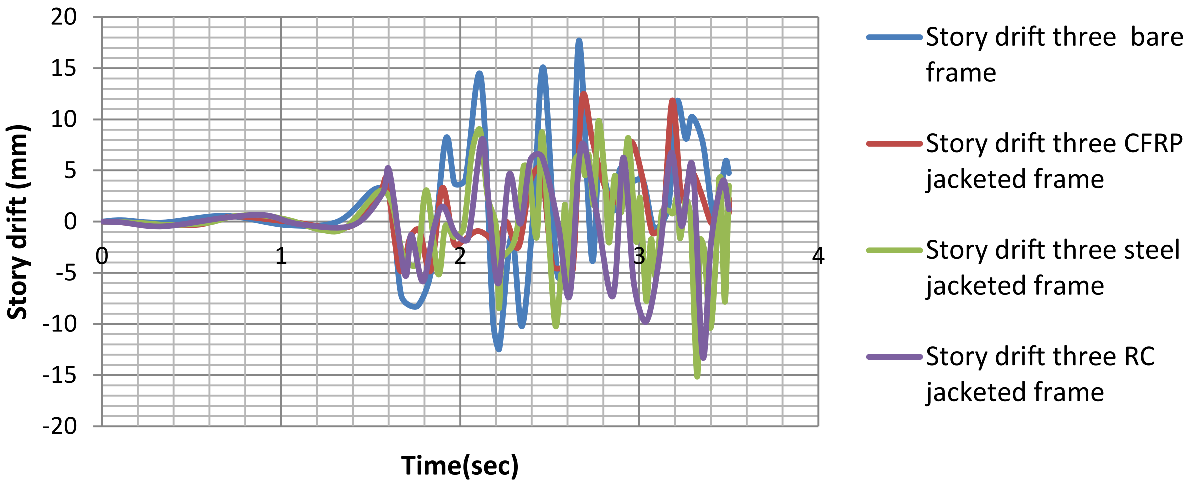


Figure 4.31 Maximum Story drift comparison of bare, CFRP, steel, and RC jacketed frame for story three.

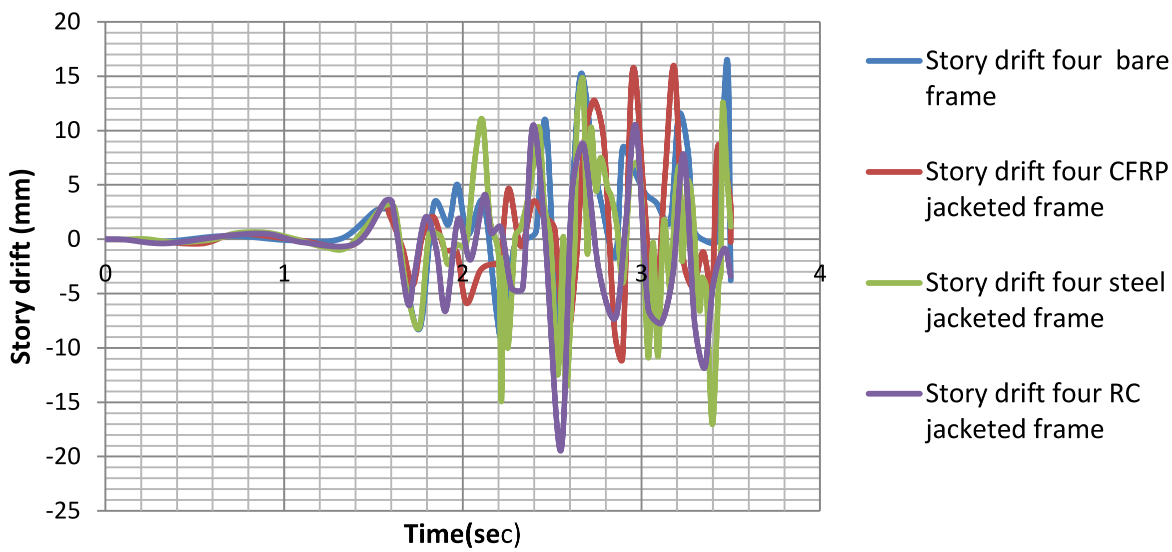


Figure 4.32 Maximum Story drift comparison of bare, CFRP, steel, and RC jacketed frame for story four.

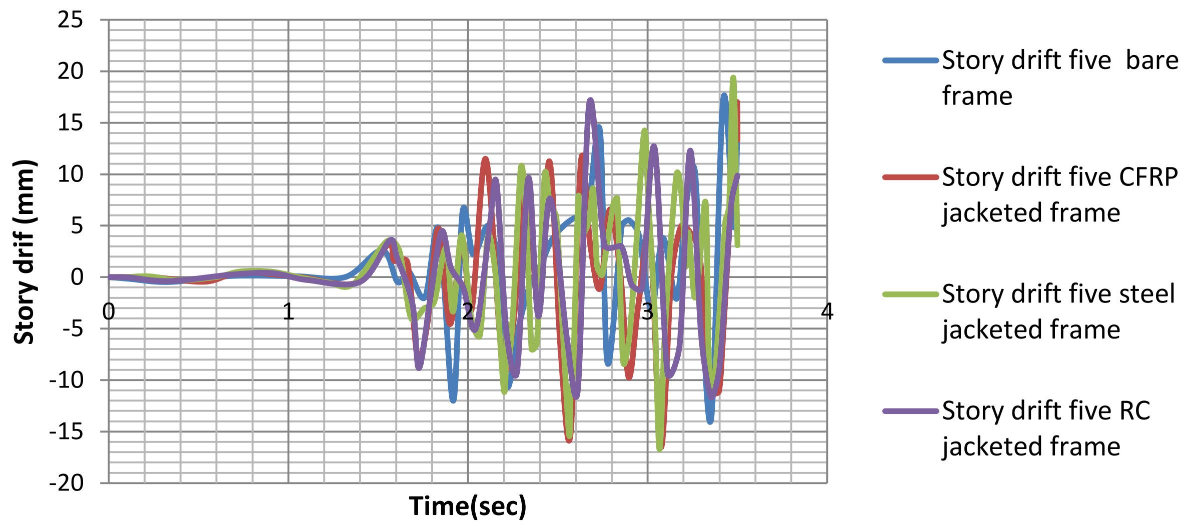


Figure 4.33: Maximum Story drift comparison of bare, CFRP, steel, and RC jacketed frame for story five.

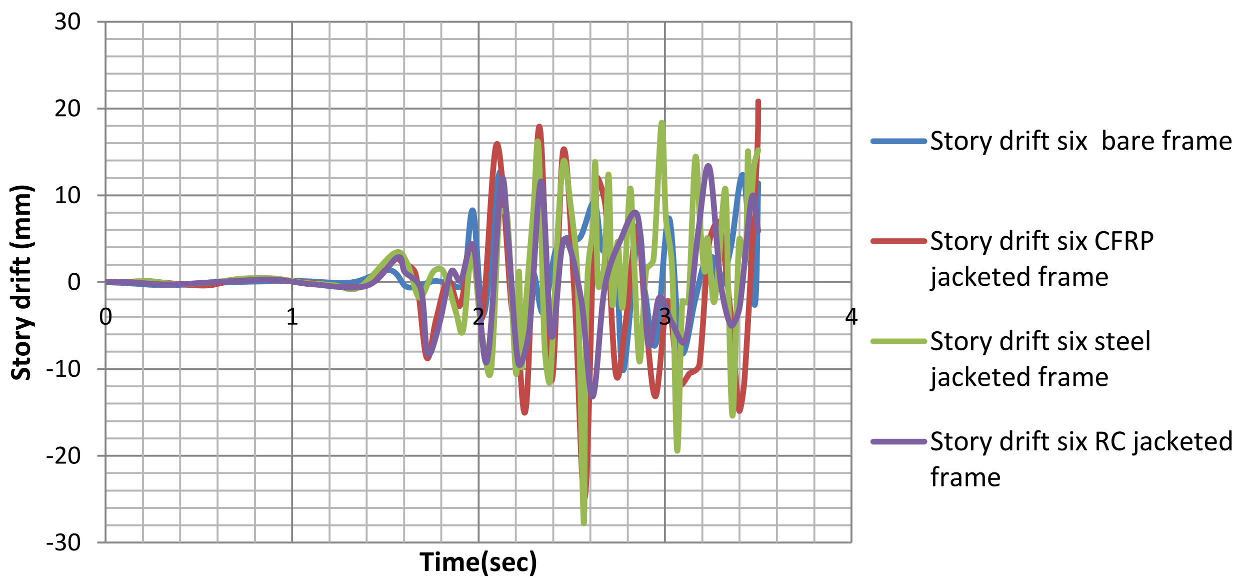


Figure 4.34: Maximum Story drift comparison of bare, CFRP, steel, and RC jacketed frame story for six.

Generally, the following table compares the reduction of story drift in percentage as compared to the bare frame for the different lateral load-resisting systems considered in this study.

Table 4.12: Percentage reductions in maximum story drift of different lateral load resisting systems compared to the bare frame.

Story	Bare frame	CFRP jacketed frame	steel jacketed frame	RC jacketed frame	Reduction in story drift compared to the bare frame (%)		
					CFRP	steel	RC
Top	20.82	18.3	13.27	12.71	12.1	36.3	39
1st	30.57	20.58	18.2	15	32.68	40.5	51
2nd	13.41	13.03	12.44	9.8	2.83	7.2	26.9
3rd	17.71	12.03	9.84	8.03	32.1	44.44	54.7
4th	16.5	15.83	14.51	10.41	4.1	12.1	37
5th	19.36	17.24	16.94	16.44	10.95	12.5	15.01

According to (ESA, 2015) inter-story drift is evaluated as the difference in the average lateral displacements ds at the top and bottom of the story under consideration. For buildings having non-structural elements of brittle materials attached to the structure of the code provide the following inter-story drift limit

$dr. \nu \leq 0.005h$

Where dr is the design inter-story drift and h is the story height v is the reduction factor which takes into account the lower return period of the seismic load associated with the damage limitation requirement. The recommended values of ν are 0.4 for importance classes III and IV and ν = 0.5 for importance classes I and II. Therefore, the drift limitation for the study will be

$dr \leq 0.005h/0.4=0.0125h$

Based on the above criteria, for all models considered in the study, story drift values are within the permissible limit.

4.7 Story drift ratio

The drift ratio is defined as the difference in horizontal displacement over one

Story (floor) divided by the story height.

As seen in Table 4.13 the top floor drift ratio decreased by 38.2% for CFRP jacketed frame, 36.5% for reinforced concrete jacketing, and 12.04% for steel jacketing techniques compared to the bare frame. On the first floor, the steel jacketed columns drift ratio decreased by 51%, reinforced concrete jacketed columns decreased by 41.64% and CFRP jacketed columns decreased by 33.33%. On average reinforced concrete jacketing is the most efficient technique of retrofitting for drift ratio reduction.

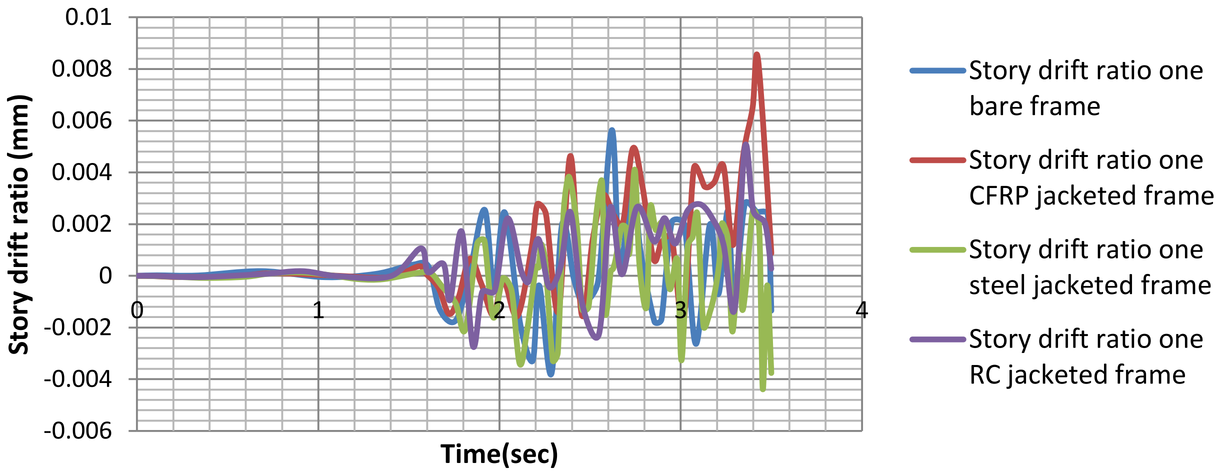


Figure 4.35: Maximum Story drift ratio comparison of bare, CFRP, steel, and RC jacketed frame for story one

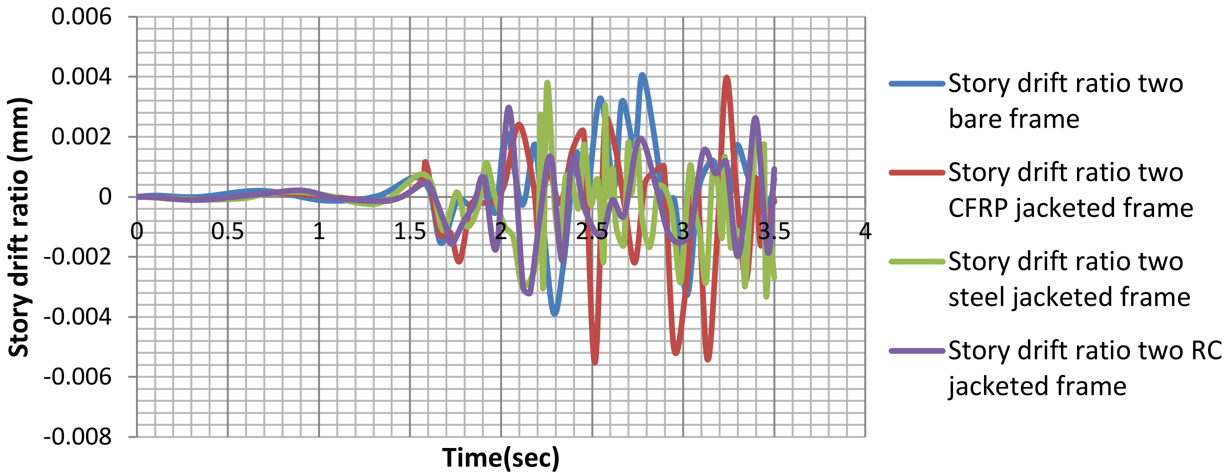


Figure 4.36: Maximum Story drift ratio comparison of bare, CFRP, steel, and RC jacketed frame for story two.

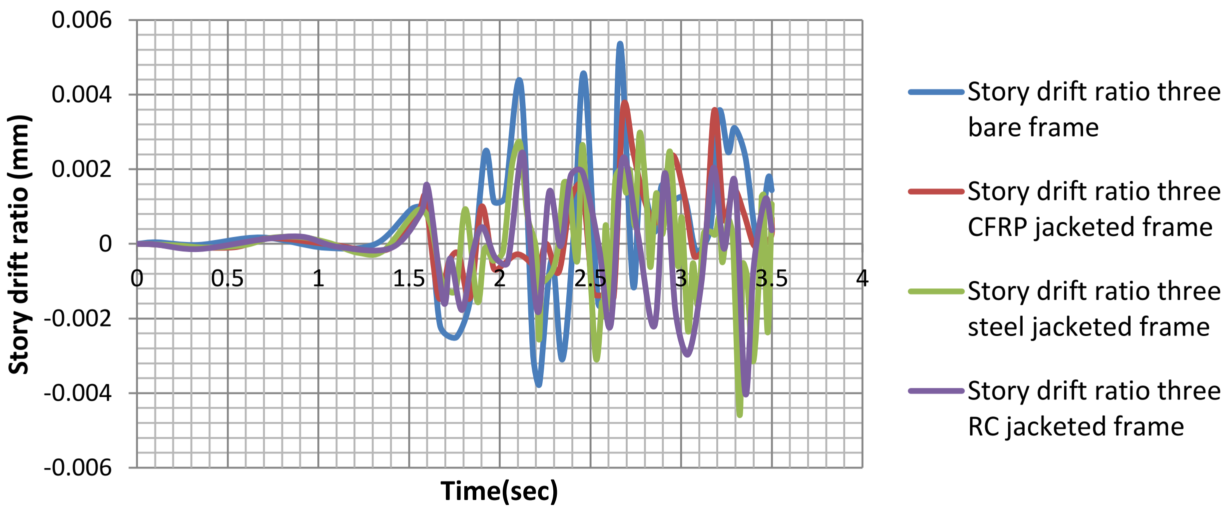


Figure 4.37: Maximum Story drift ratio comparison of bare, CFRP, steel, and RC jacketed frame for story three

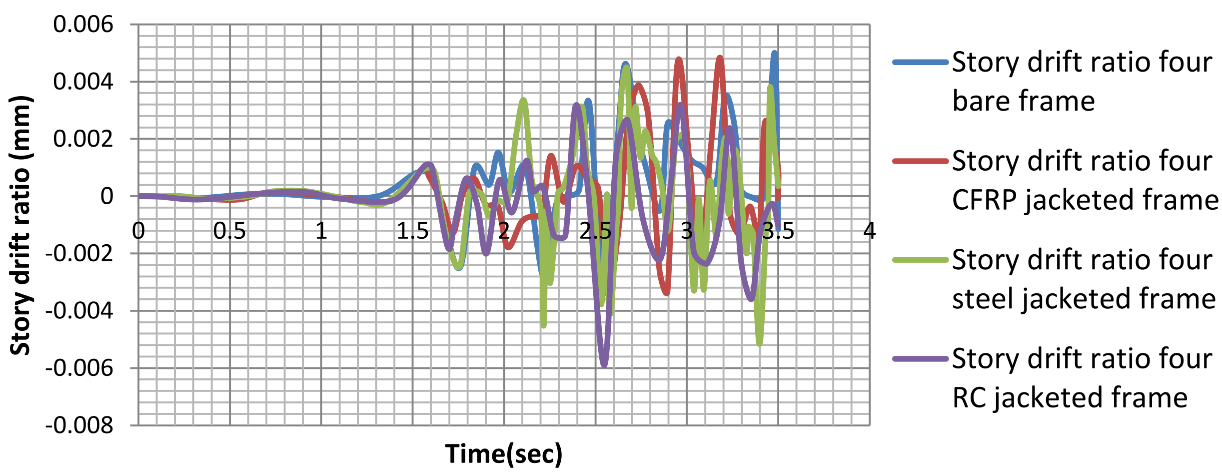


Figure 4.38: Maximum Story drift ratio comparison of bare, CFRP, steel, and RC jacketed frame story four.

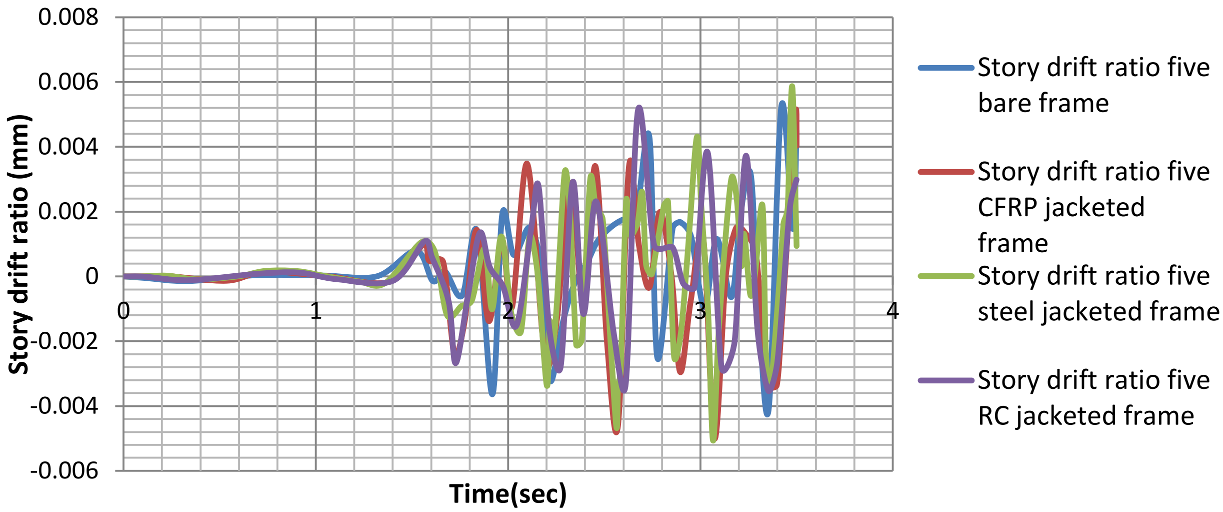


Figure 4.39: Maximum Story drift ratio comparison of bare, CFRP, steel, and RC jacketed frame for story five

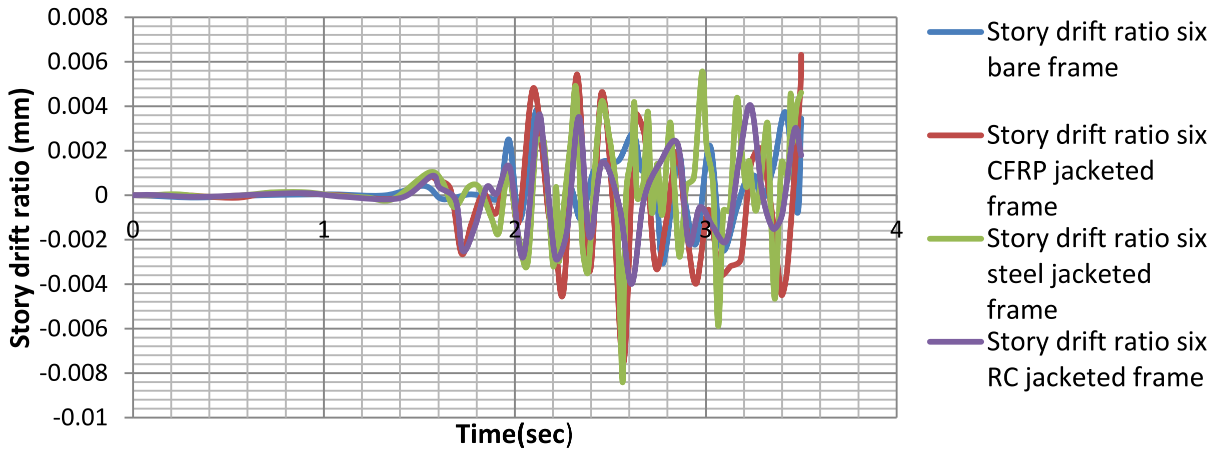


Figure 4.40: Maximum Story drift ratio comparison of bare, CFRP, steel, and RC jacketed frame for story six.

Table 4.13: Percentage reductions in maximum story drift ratio of different lateral load resisting systems compared to the bare frame.

Story	Bare frame	CFRP jacketed frame	steel jacketed frame	RC jacketed frame	Reduction in drift ratio compared to a bare frame (%)		
					CFRP	steel	RC
Top	0.0063	0.0039	0.0055	0.004	38.2	12.04	36.51
1st	0.0084	0.0056	0.0041	0.0049	33.33	51.2	41.67
2nd	0.0041	0.0039	0.0037	0.0029	10.98	8.04	29.3
3rd	0.0054	0.0036	0.0029	0.0024	32.41	44.8	55.6
4th	0.005	0.0048	0.0043	0.0031	4	14	38
5th	0.0059	0.005	0.0052	0.0051	14.51	11.9	13.6

4.8 Failure modes of columns from the FE analysis

Figure 4.41 show that failure on the Short RC jacketed column occurred at the upper edge of the middle height of the column by crushing or yielding the materials. Both the concrete column and RC jacketing materials failed at the same time. A shorter and wider column normally fails under compression failure when the axially loaded stress exceeds allowable stress. From Figure 4.42 and Figure-4.43, the steel and CFRP jacketed column have the same failure mode as RC jacketed short column, as the concrete material bulge the stress on the steel and CFRP jacketing to increases and cause the yielding of the steel straps and cracking of CFRP that leads to failure of the column. From Figure 4.44 - 4.46, the failure mode for long RC, steel, and CFRP jacketed columns is buckling. As the vertical load increases the bending stress also increases that leading to bending failure in the middle of the columns.

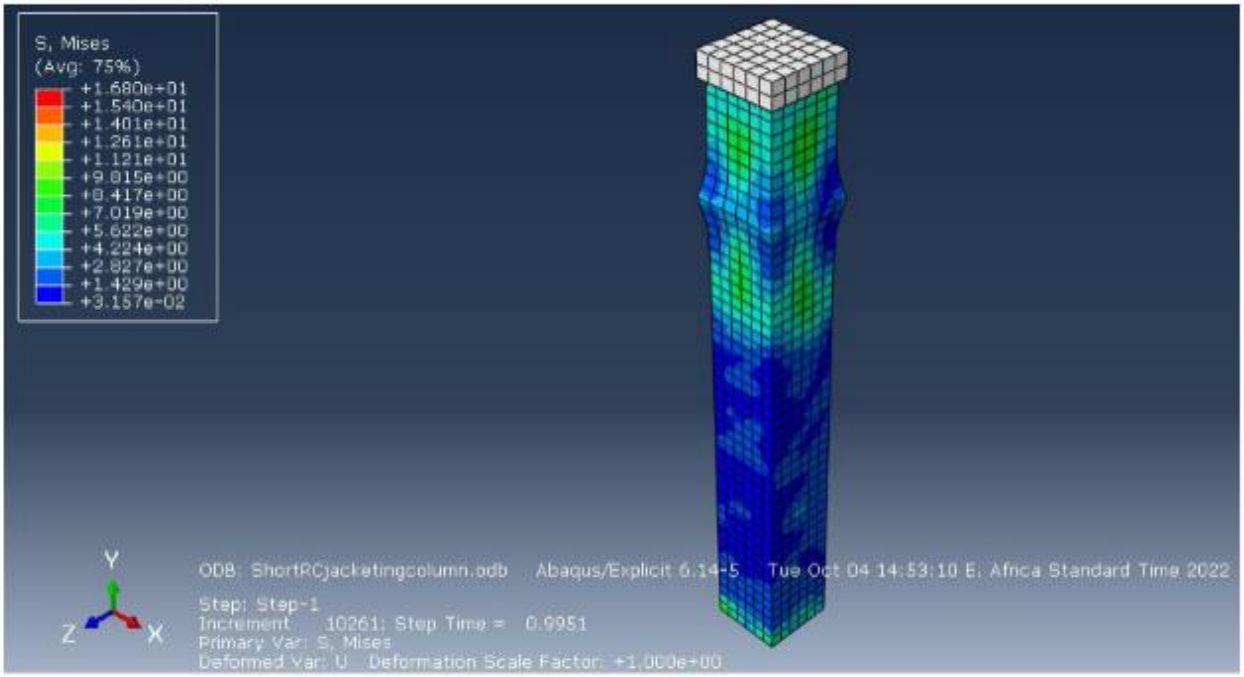


Figure 4.41: Failure mode of short RC jacketed column.

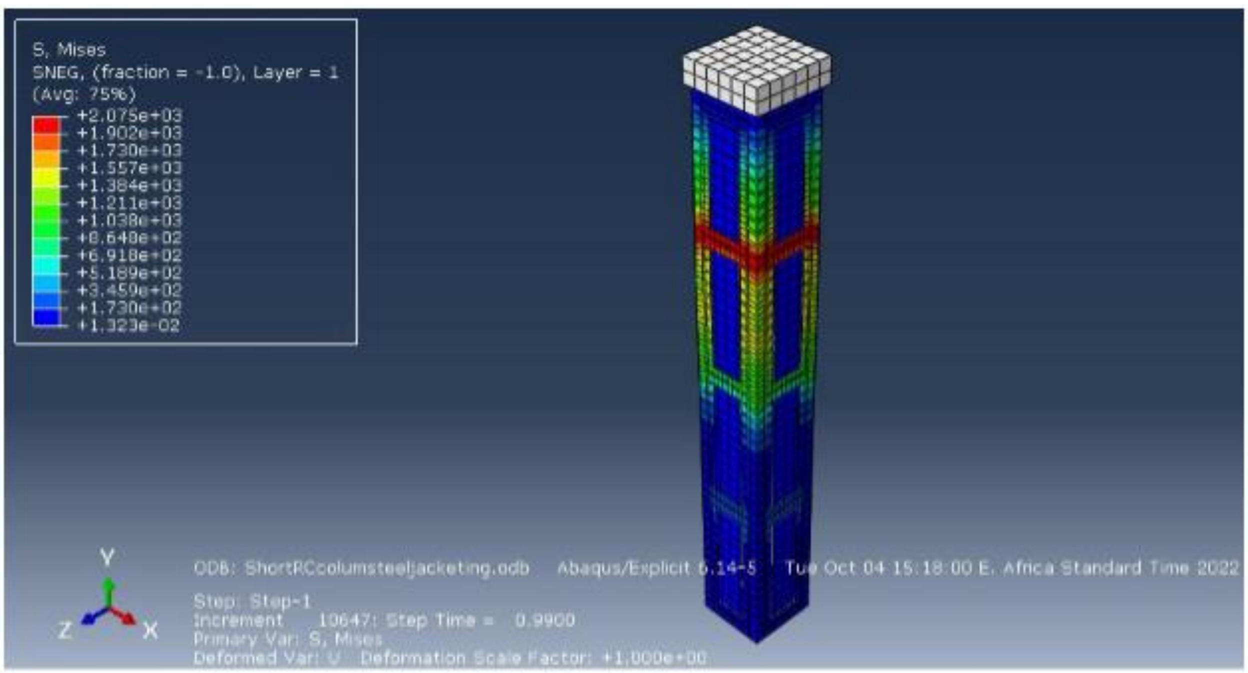


Figure 4.42: Failure mode of steel jacketed reinforced concrete column.

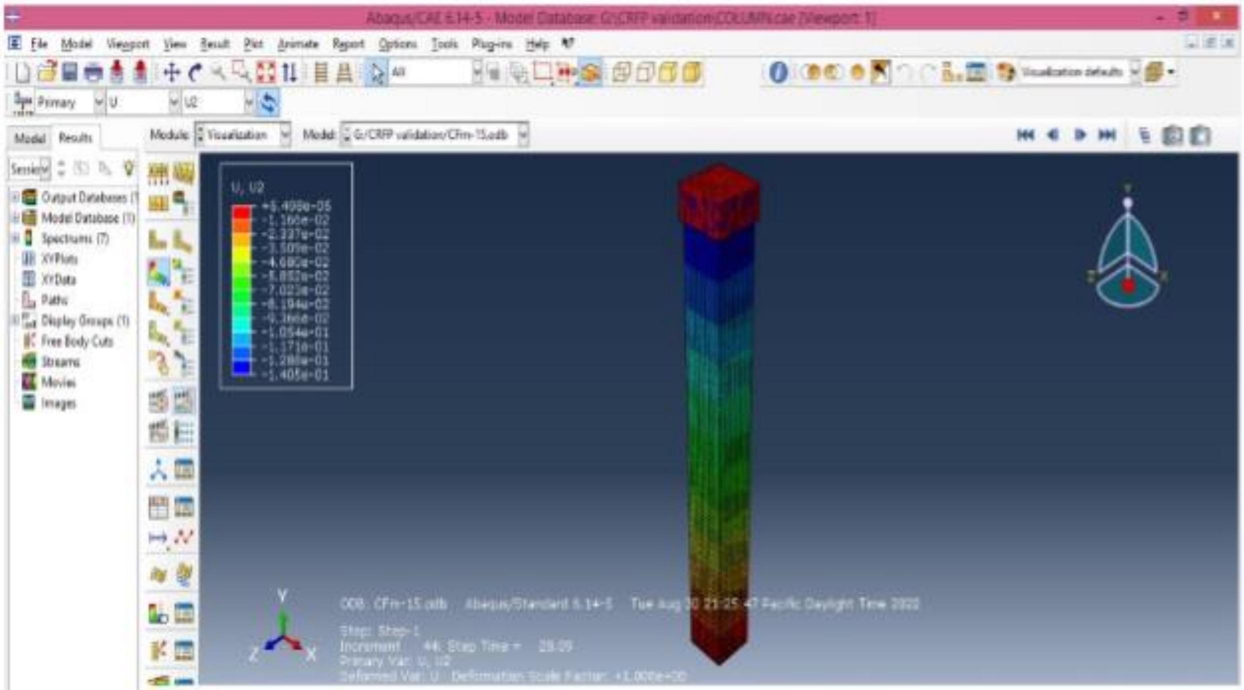


Figure 4.43: Failure mode of CFRP jacketed Reinforced concrete column

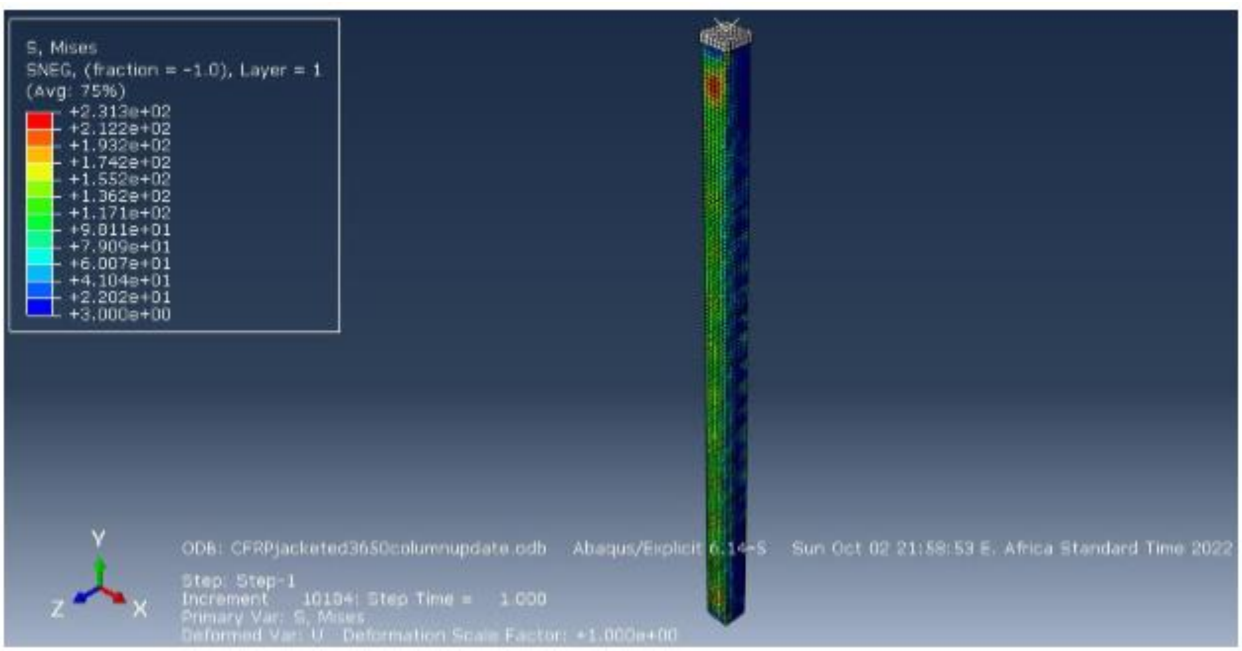


Figure 4.44: Failure mode of CFRP jacketed long reinforced concrete column.

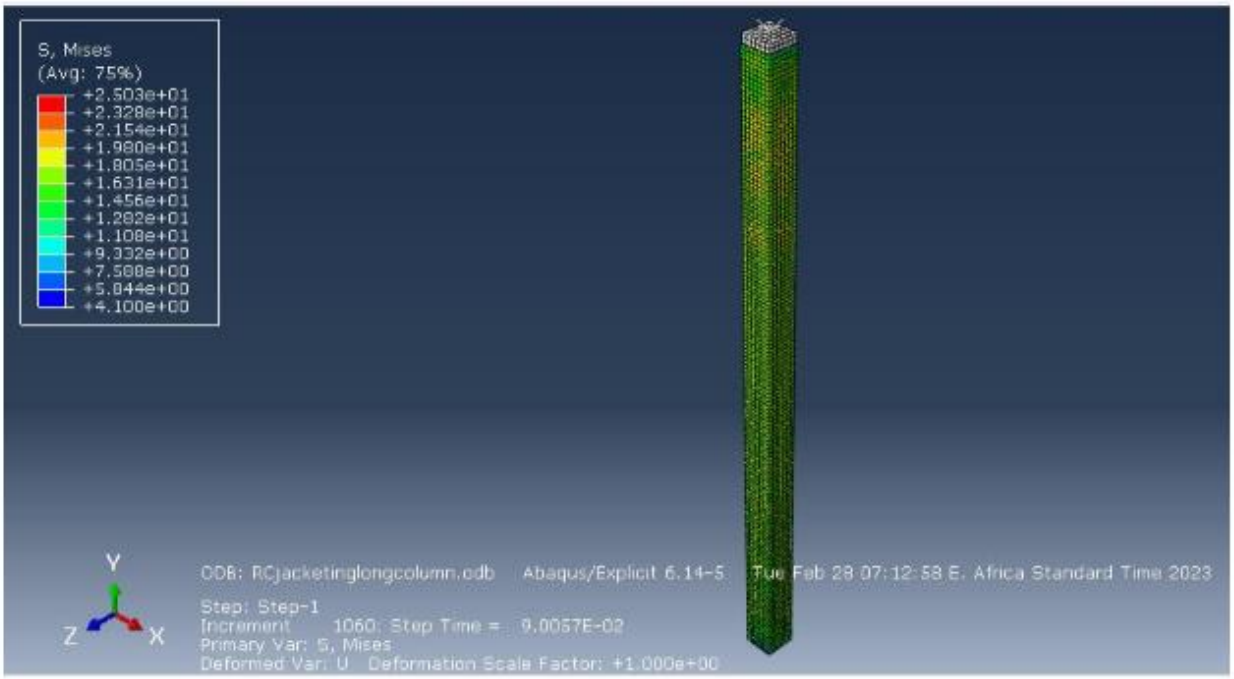


Figure 4.45: Failure mode of RC jacketed long reinforced concrete column.

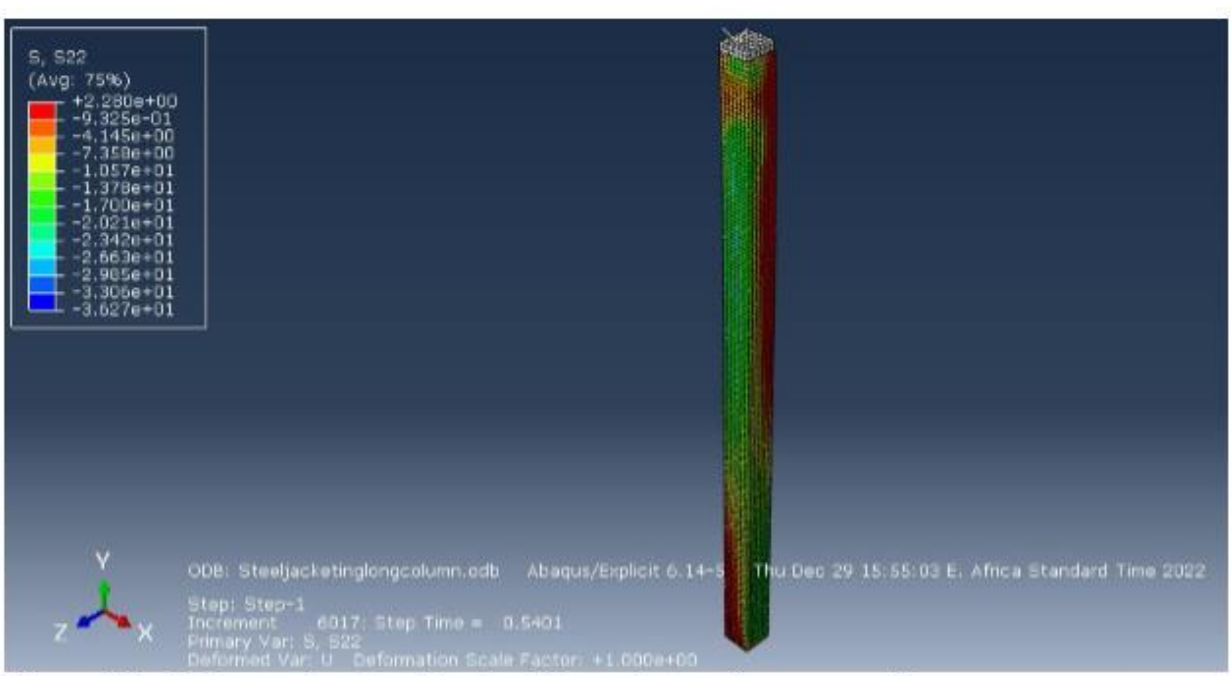


Figure 4.46: Failure mode of steel jacketed long reinforced concrete column.

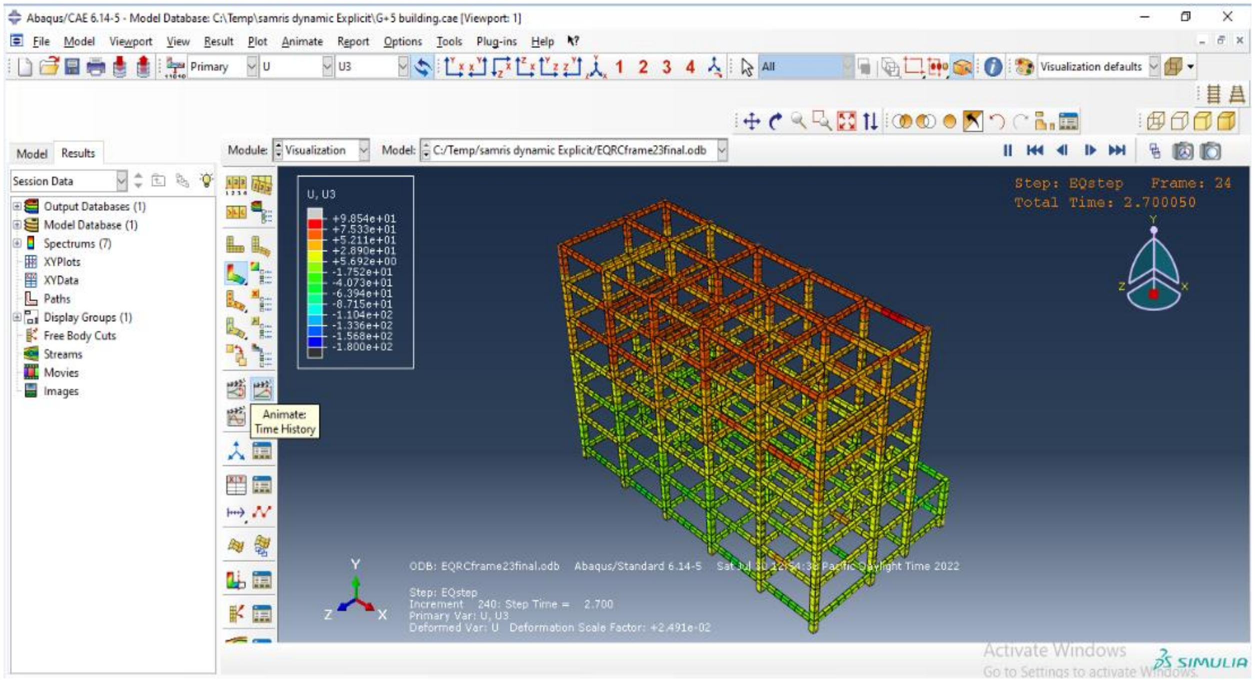


Figure 4.47: Bare reinforced concrete Frame Abaqus output.

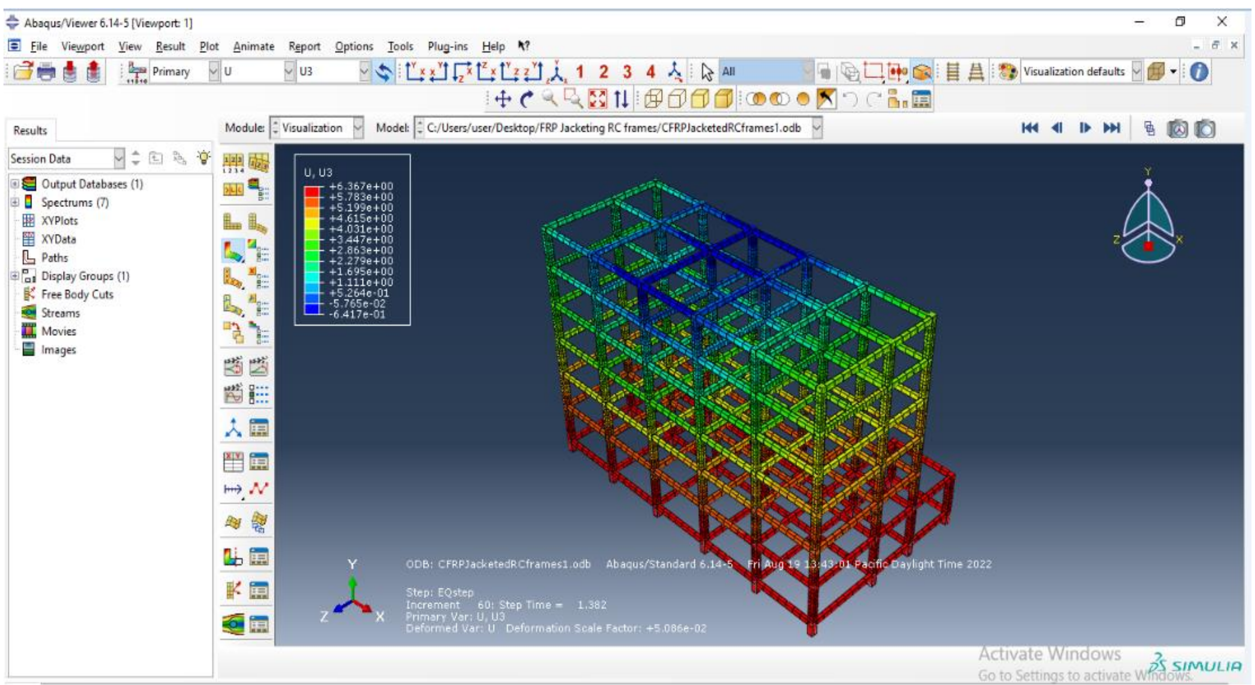


Figure 4.48: Failure mode of carbon Fiber reinforced polymer jacketing Reinforced concrete FrameAbaqusoutput.

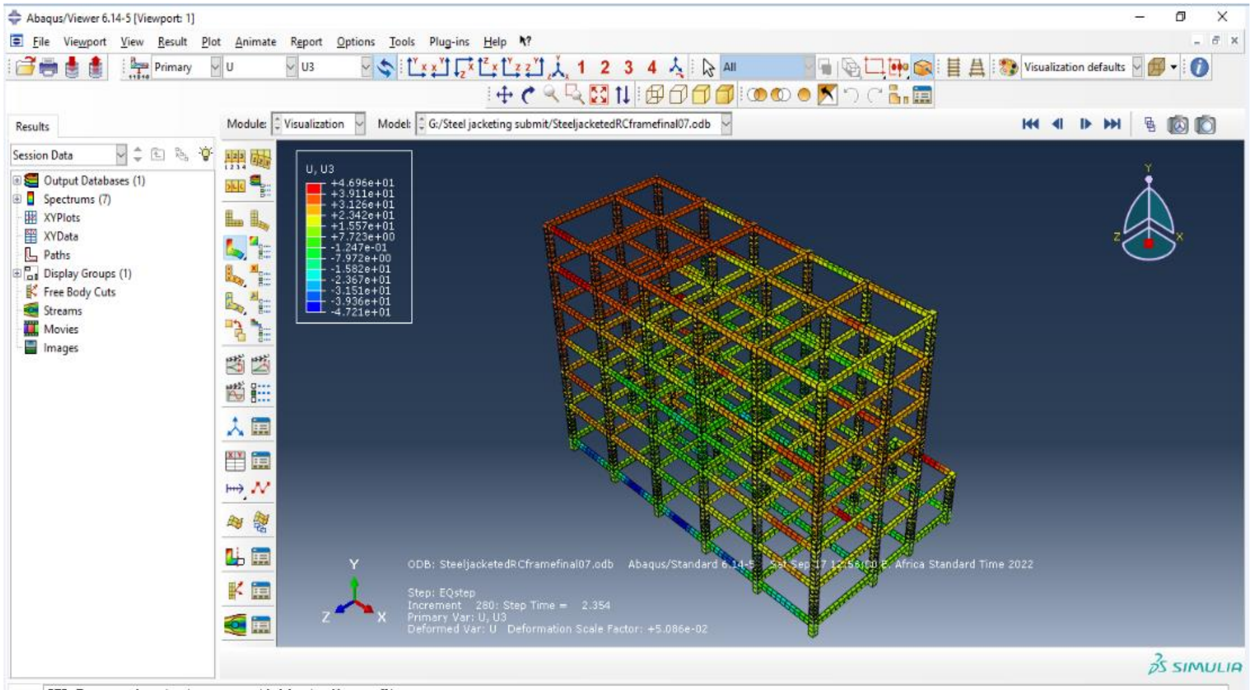


Figure 4.49: Failure mode of steel jacketed Reinforced concrete Frame Abaqus output.

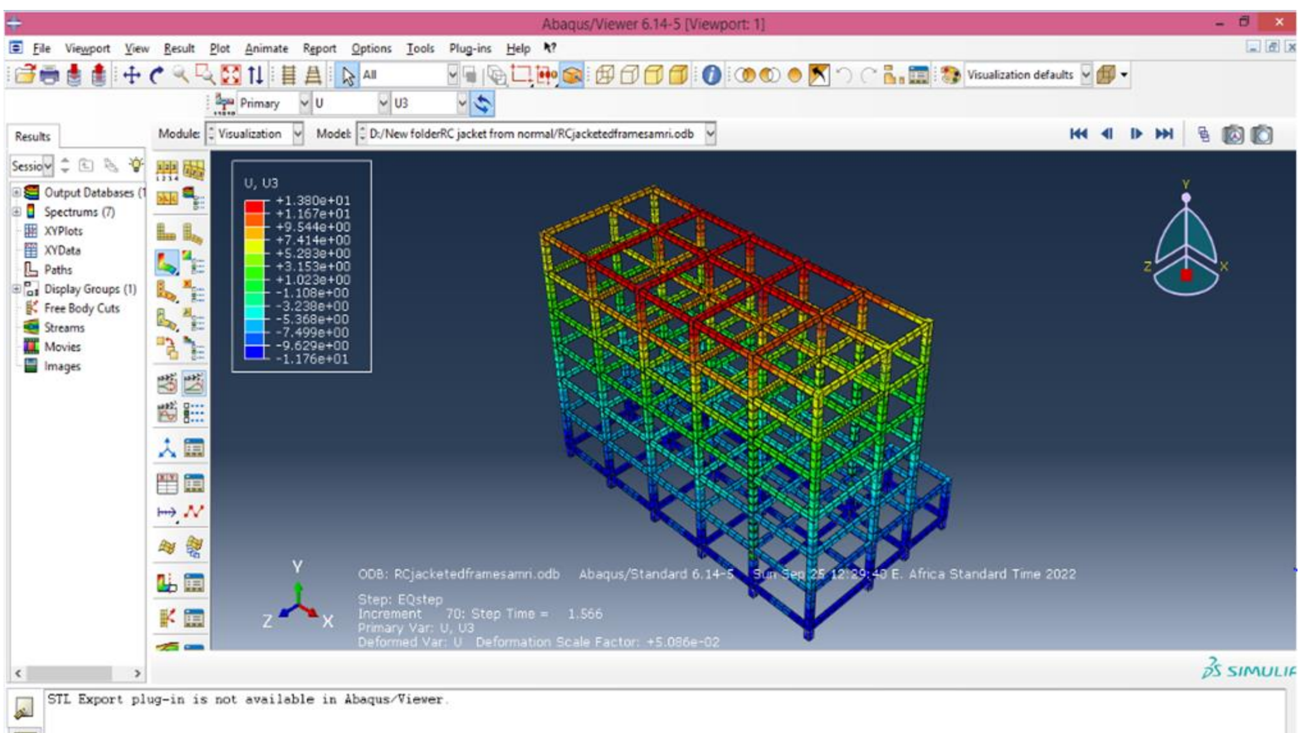


Figure 4.50: Failure mode of RC jacketed Reinforced concrete Frame Abaqus output.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

A finite element analysis using Abaqus has been conducted to study and compare the efficiency of reinforced concrete, CFRP, and steel jacketing systems on RC frame structures subjected to seismic load and on single columns under axial load. The comparison was in terms of two critical parameters; story displacement and story drift for a retrofitted reinforced concrete frame. For a single column, the study variables of axial load eccentricity and length of the column have been taken to evaluate the load versus displacement results. From the numerical analysis result extracted from the finite element program, the following result as well as some recommendations presented.

5.1 Conclusion

- The performance of the RC jacketing method was found to be very efficient. In this study, the enhancement in ultimate axial capacity of short RC column strengthened by RC jacketing increased by 36.5% and followed by the CFRP jacketing technique with 16.8% axial load carrying capacity enhancement and steel jacketing technique by 2.2%, compared to the bare column. RC Jacketing of columns gives a higher ultimate load result due to the added concrete with longitudinal and transverse reinforcement around the existing columns that increase the cross-sectional area of the concrete.
- For slender columns the axial load-carrying capacity of reinforced concrete columns strengthened with RC jacketing has been improved by 32.1%, CFRP by 31.2%, and steel jacketed by 5.62% compared to the control columns.
- Numerical analysis results from the finite element program indicate that both uni and bi-directional eccentrically loaded column strengthened with RC jacketing technique shows

a greater improvement in ultimate load-carrying capacity followed by steel and CFRP strengthening techniques.

- The reinforced concrete jacketed column gives a greater decrease in story displacement by 40.6% for the top floors and followed by steel jacketing with a decrease in story displacement by 27.37% and CFRP jacketed column decreased by 16.8% t relative to the control bare frame.
- The maximum decrease in story drift occurs on the first floor; the reinforced concrete jacketed frames story drift decreased by 51%, steel jacketed by 40.5% and CFRP decreased by 32.68%.
- The failure mode of the RC jacketed column is crushing while jacketing the column with steel changed the failure mode to ductile behavior. The failure in the steel jacketed specimens is due to the buckling of the steel angle followed by the yielding of steel angles and crushing of concrete. The columns strengthened with CFRP sheet failed by rupture occurring in the sheet fibers and followed by concrete failure.
- RC jacketing has been found the most efficient technique for strengthening columns relative to CFRP and steel jacketing techniques.

5.2 Recommendations

This research considers regular frames, column dimensions, stiffness, constant concrete grade, steel grade, and loading conditions therefore, further research is required on the following areas.

- The structure considered in this study fulfills plan and elevation regularity, the behaviors for irregular structures under those retrofitting types can be considered for future study.
- The comparative study was carried out under earthquake load, a comparison under wind and blast load can be considered for future researchers.
- The effects of varying column shape and dimension, stiffness, concrete grade, and steel grade on the frame structure jacketed with the three techniques can be study area.

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APPENDIX-A

Material properties

Table A.1: Summary of concrete and steel properties

Material	Density (ton/mm3)	Youngs modulus of elasticity (Mpa)	Poisson‟s ratio
Concrete	2.54e-9	31848	0.2
Steel	7.85e-9	202405	0.3
	7.85e-9	195733	0.3

Table A.2: Concrete damaged plasticity parameters used in the proposed ABAQUS model

Plasticity parameter	Dilation angle	Eccentricity	Stress ratio	Shape factor	Viscosity Parameter
Thevalue used in the model	38	1.12	1	0.6667	0.01

Table A.3 Compressive behavior of concrete damage plasticity for C-25

Yield Stress	Inelastic Strain		Damage Parameter	Inelastic Strain
12.5	0		0	0
14.779363	1.50E-05		0	1.50E-05
16.897181	4.00E-05		0	4.00E-05
18.815096	7.90E-05		0	7.90E-05
20.499689	1.32E-04		0	1.32E-04
21.925443	0.000202		0	0.000202
23.076855	0.00029		0	0.00029
23.949385	0.000396		0	0.000396
24.549184	0.00052		0	0.00052

24.891777	0.000661		0	0.000661
25	0.000816		0	0.000816
24.901601	0.000985		0.003936	0.000985
24.626862	0.001166		0.014926	0.001166
24.206509	0.001356		0.03174	0.001356
23.670071	0.001553		0.053197	0.001553
23.044731	0.001756		0.078211	0.001756
22.354643	0.001964		0.105814	0.001964
21.620626	0.002174		0.135175	0.002174
20.860155	0.002386		0.165594	0.002386
20.087539	0.002598		0.196498	0.002598
19.314226	0.002811		0.227431	0.002811
18.549152	0.003023		0.258034	0.003023
17.799119	0.003235		0.288035	0.003235
17.069142	0.003445		0.317234	0.003445
16.362775	0.003653		0.345489	0.003653
15.682397	0.00386		0.372704	0.00386
15.029454	0.004065		0.398822	0.004065
14.404665	0.004268		0.423813	0.004268
13.80819	0.004469		0.447672	0.004469
13.23977	0.004669		0.470409	0.004669
12.698832	0.004866		0.492047	0.004866
12.184584	0.005062		0.512617	0.005062
11.69608	0.005257		0.532157	0.005257
11.232271	0.005449		0.550709	0.005449
10.792054	0.005641		0.568318	0.005641
10.374298	0.00583		0.585028	0.00583
9.977867	0.006019		0.600885	0.006019
9.601643	0.006206		0.615934	0.006206
9.244531	0.006392		0.630219	0.006392

8.905476	0.006576		0.643781	0.006576
8.583462	0.00676		0.656662	0.00676
8.277519	0.006942		0.668899	0.006942
7.986728	0.007124		0.680531	0.007124
7.710212	0.007304		0.691592	0.007304
7.5	0.007448		0.7	0.007448

Table A.4 Tensile behavior of concrete damage plasticity for C-25

Yield Stress	Cracking Strain		Damage Parameter	Cracking Strain
3	0		0	0
1.664354	0.000281		0.445215	0.000281
1.179148	0.000507		0.606951	0.000507
0.923358	0.000718		0.692214	0.000718
0.76383	0.000923		0.74539	0.000923
0.654173	0.001124		0.781942	0.001124
0.573836	0.001324		0.808721	0.001324
0.512265	0.001522		0.829245	0.001522
0.463463	0.00172		0.845512	0.00172
0.423761	0.001917		0.858746	0.001917

Table A.5 Time vs. acceleration (time-history)
(https://www.google.com/search?q=accel0.005.xlsx&oq)

Time	Acceleration (mm/s^2)
0	-0.00058642
0.005	-0.0001926
0.01	0.0015497
0.015	0.00050873

0.2	-0.00386
0.205	0.007519
0.21	-0.00616
0.215	0.000113

0.4	-0.00315
0.405	0.002018
0.41	0.004725
0.415	0.001965

0.6	-0.00652
0.605	-0.00495
0.61	0.000196
0.615	-0.00254

0.02	0.0011702
0.025	-0.00060372
0.03	0.0030347
0.035	-0.00018351
0.04	-0.0016621
0.045	-0.0029422
0.05	0.0035594
0.055	0.00068148
0.06	-0.0004265
0.065	0.0045153
0.07	-0.00052157
0.075	-0.002987
0.08	0.0028889
0.085	-0.0046055
0.09	-0.0084664
0.095	0.0078378
0.1	0.0043367
0.105	-0.00035865
0.11	-0.0015216
0.115	-0.0032504
0.12	-0.0086723
0.125	-0.0048807
0.13	0.0018469
0.135	0.0042954
0.14	0.0014322
0.145	0.0040518
0.15	-0.0014169
0.155	8.92E-05
0.16	-0.00048918
0.165	0.00087565
0.17	0.0069997
0.175	0.0047491
0.18	0.0078769
0.185	0.0014488
0.19	0.0052096
0.195	-0.0078563

0.22	0.004427
0.225	-0.00071
0.23	5.39E-05
0.235	0.00035
0.24	0.000252
0.245	-0.00297
0.25	0.002037
0.255	0.006321
0.26	0.004922
0.265	0.002481
0.27	-0.00876
0.275	0.002992
0.28	0.00042
0.285	0.001729
0.29	0.001697
0.295	-0.00297
0.3	0.003425
0.305	-0.00114
0.31	0.002857
0.315	-0.00653
0.32	0.000644
0.325	-0.00601
0.33	0.000396
0.335	0.001899
0.34	0.001927
0.345	0.000736
0.35	-0.00285
0.355	0.002735
0.36	0.000246
0.365	0.000284
0.37	0.00608
0.375	0.003085
0.38	0.000248
0.385	0.005873
0.39	-0.00172
0.395	-0.00061

0.42	0.006094
0.425	-0.0005
0.43	0.001131
0.435	-0.00401
0.44	0.004306
0.445	0.002539
0.45	-0.0032
0.455	-0.00016
0.46	-0.00108
0.465	-0.00671
0.47	-4.50E-05
0.475	-0.002
0.48	-0.00022
0.485	-0.00042
0.49	0.000962
0.495	0.003149
0.5	-0.00084
0.505	0.001073
0.51	0.001952
0.515	-0.00783
0.52	0.005668
0.525	-0.00431
0.53	0.003579
0.535	0.003664
0.54	0.0011
0.545	-0.00071
0.55	-0.00233
0.555	-0.00029
0.56	-0.00099
0.565	0.005743
0.57	-0.00842
0.575	0.002443
0.58	0.000611
0.585	-0.00248
0.59	-0.00702
0.595	0.003435

0.62	-0.00207
0.625	0.001274
0.63	0.001142
0.635	-0.00109
0.64	0.00555
0.645	-0.00479
0.65	0.003872
0.655	-0.0024
0.66	-0.00837
0.665	-0.00309
0.67	0.002651
0.675	0.00248
0.68	0.00394
0.685	-0.00093
0.69	-0.00127
0.695	0.002803
0.7	-0.01109
0.705	0.000597
0.71	-0.00142
0.715	-0.00231
0.72	0.004114
0.725	0.004029
0.73	0.004611
0.735	-0.00852
0.74	8.28E-05
0.745	-0.00328
0.75	-0.0006
0.755	-0.0023
0.76	0.004861
0.765	-0.00713
0.77	0.003791
0.775	-0.00551
0.78	-0.00031
0.785	-0.00021
0.79	-0.00071
0.795	0.006701

1	-0.021452
1.005	-0.0030461
1.01	-0.0007462
1.015	0.0034019

0.8	0.001327
0.805	-0.00295
0.81	-0.00149
0.815	0.000415

1.4	-0.01809
1.405	-0.02174
1.41	-0.04006
1.415	-0.02189

1.2	-0.01189
1.205	0.002891
1.21	-0.00479
1.215	0.003868

1.02	0.015462	0.82	-0.00222	1.42	-0.01882	1.22	0.002728
1.025	-0.020349	0.825	-0.0008	1.425	-0.00712	1.225	0.000824
1.03	0.026679	0.83	-0.00577	1.43	-0.01046	1.23	0.007435
1.035	-0.026249	0.835	0.008213	1.435	-0.01299	1.235	-0.00943
1.04	0.0082934	0.84	0.002085	1.44	0.005394	1.24	0.006411
1.045	-0.0081082	0.845	-0.00946	1.445	-0.00012	1.245	0.00223
1.05	-0.0001726	0.85	-0.00044	1.45	-0.01052	1.25	-0.00619
1.055	0.0066366	0.855	-0.01085	1.455	-0.02975	1.255	0.010252
1.06	-0.0011336	0.86	-0.00307	1.46	-0.04708	1.26	0.005605
1.065	0.013324	0.865	0.0111	1.465	-0.0429	1.265	0.008165
1.07	-0.014378	0.87	0.002478	1.47	-0.01299	1.27	-0.00379
1.075	0.011963	0.875	0.005338	1.475	-0.00252	1.275	-0.00805
1.08	-0.011801	0.88	-0.00095	1.48	0.037413	1.28	0.013514
1.085	0.0064862	0.885	-0.00835	1.485	0.051147	1.285	-0.01316
1.09	-0.005083	0.89	-0.01293	1.49	0.097297	1.29	-0.0011
1.095	0.0036288	0.895	-0.01256	1.495	0.081157	1.295	0.008846
1.1	0.0007198	0.9	0.007769	1.5	0.003006	1.3	-0.01576
1.105	0.0063406	0.905	0.011607	1.505	-0.05118	1.305	0.016781
1.11	-0.012546	0.91	0.007996	1.51	-0.12842	1.31	-0.00901
1.115	-0.0050683	0.915	-0.00211	1.515	-0.09446	1.315	-0.0066
1.12	0.0055655	0.92	-0.01039	1.52	-0.06007	1.32	-0.00413
1.125	-0.017858	0.925	-0.01502	1.525	0.09707	1.325	-0.00883
1.13	0.016955	0.93	-0.00662	1.53	0.18942	1.33	-0.00279
1.135	-0.0081347	0.935	0.009633	1.535	0.18859	1.335	-0.00413
1.14	0.012131	0.94	-0.00597	1.54	0.06338	1.34	0.009579
1.145	-0.0001296	0.945	0.013241	1.545	-0.17734	1.345	0.011057
1.15	0.0059931	0.95	0.013288	1.55	-0.33758	1.35	0.011427
1.155	0.0037933	0.955	-0.00497	1.555	-0.30528	1.355	0.010248
1.16	0.001384	0.96	-0.007	1.56	-0.02622	1.36	-0.00939
1.165	-0.0057997	0.965	0.008815	1.565	0.15556	1.365	-0.00647
1.17	0.010618	0.97	-0.00632	1.57	0.3063	1.37	-0.02418
1.175	0.0001951	0.975	0.00205	1.575	0.34465	1.375	-0.02702
1.18	-0.000379	0.98	-0.00227	1.58	0.051933	1.38	-0.01874
1.185	-0.003387	0.985	0.014005	1.585	0.093786	1.385	0.006827
1.19	-0.0037736	0.99	-0.01549	1.59	-0.1836	1.39	0.009505
1.195	0.0062107	0.995	0.018949	1.595	-0.21969	1.395	0.013792

1.6	-0.12375		1.8	0.30849	2	-0.16404	2.2	0.34525
1.605	0.1467		1.805	-0.4897	2.005	0.093863	2.205	1.0396
1.61	0.28739		1.81	-0.76007	2.01	-0.01943	2.21	0.34266
1.615	0.35335		1.815	-0.80747	2.015	-0.82644	2.215	0.24921

1.62	0.20179	1.82	-0.3425	2.02	-0.6933	2.22	-0.08999
1.625	0.14716	1.825	-0.06015	2.025	-0.59133	2.225	-0.62182
1.63	-0.14012	1.83	0.90416	2.03	0.59363	2.23	-0.61806
1.635	-0.18637	1.835	1.1735	2.035	0.65824	2.235	-0.32444
1.64	-0.26117	1.84	0.82991	2.04	0.92672	2.24	-0.18262
1.645	-0.15043	1.845	-0.45769	2.045	0.80232	2.245	0.046797
1.65	-0.03262	1.85	-0.37106	2.05	0.74243	2.25	0.64952
1.655	0.1534	1.855	-0.86459	2.055	-0.23269	2.255	0.86035
1.66	0.19135	1.86	-1.1043	2.06	-1.1047	2.26	0.52686
1.665	0.17472	1.865	-0.15999	2.065	-1.3659	2.265	0.019809
1.67	-0.23853	1.87	0.24253	2.07	-0.95694	2.27	-0.00547
1.675	-0.49894	1.875	0.18789	2.075	-0.37481	2.275	-0.18629
1.68	-0.41107	1.88	1.0485	2.08	1.4082	2.28	0.01788
1.685	-0.04649	1.885	0.51679	2.085	1.5254	2.285	0.33116
1.69	0.23218	1.89	0.001995	2.09	1.8226	2.29	-0.57325
1.695	0.52692	1.895	-0.08664	2.095	0.74492	2.295	-1.1765
1.7	0.54571	1.9	-0.87428	2.1	-1.211	2.3	0.018566
1.705	0.50615	1.905	-0.83276	2.105	-1.8576	2.305	0.63352
1.71	-0.16515	1.91	-0.25266	2.11	-1.3322	2.31	1.2725
1.715	-0.70246	1.915	0.34346	2.115	-0.31601	2.315	0.33513
1.72	-0.63244	1.92	0.67633	2.12	0.83323	2.32	-0.87866
1.725	-0.41874	1.925	0.82812	2.125	1.3994	2.325	-2.0392
1.73	-0.47251	1.93	0.24674	2.13	1.1116	2.33	-1.5874
1.735	0.1489	1.935	-0.16556	2.135	0.38102	2.335	-0.06536
1.74	0.81961	1.94	-0.11238	2.14	0.11628	2.34	1.2187
1.745	0.71654	1.945	0.20715	2.145	-1.6983	2.345	1.2576
1.75	0.55461	1.95	0.065992	2.15	-1.7054	2.35	0.85658
1.755	0.1056	1.955	-0.07142	2.155	-0.65631	2.355	0.51881
1.76	-0.42343	1.96	-0.39554	2.16	0.2367	2.36	-0.49614
1.765	-1.3818	1.965	-0.58781	2.165	1.4475	2.365	-0.41141
1.77	-0.89231	1.97	-0.10576	2.17	2.5803	2.37	-0.76992
1.775	-0.12709	1.975	0.50911	2.175	0.94194	2.375	-0.91569
1.78	0.45977	1.98	0.29837	2.18	-1.1471	2.38	0.27388
1.785	0.7725	1.985	-0.16069	2.185	-1.7653	2.385	0.78958
1.79	1.044	1.99	-0.09726	2.19	-1.1335	2.39	0.70573
1.795	0.35477	1.995	-0.11582	2.195	-0.56801	2.395	1.3264
2.4	-0.16048	2.6	-0.15087	2.8	0.13218	3	-1.4472
2.405	-0.59712	2.605	0.25928	2.805	-1.7242	3.005	-0.48084
2.41	-0.89225	2.61	0.5406	2.81	-1.9936	3.01	-0.77372
2.415	-0.7453	2.615	-0.39961	2.815	-0.27624	3.015	-0.41479
2.42	-0.01147	2.62	0.45606	2.82	-0.37567	3.02	0.63917

2.425	0.78833
2.43	0.086504
2.435	0.208
2.44	-0.12803
2.445	0.20736
2.45	0.1146
2.455	0.46865
2.46	0.19345
2.465	-0.76334
2.47	-0.5596
2.475	0.22588
2.48	0.87686
2.485	1.2463
2.49	0.51593
2.495	-0.12521
2.5	-0.58335
2.505	-1.7804
2.51	-1.3812
2.515	-0.5817
2.52	0.48821
2.525	1.246
2.53	1.9931
2.535	1.3042
2.54	-1.3297
2.545	-2.3384
2.55	-1.6094
2.555	-0.9119
2.56	0.35684
2.565	2.7869
2.57	2.0378
2.575	0.1261
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2.585	-1.2484
2.59	-1.0596
2.595	-0.54444

2.625	0.34178
2.63	-0.21716
2.635	-0.20617
2.64	0.36373
2.645	-0.01937
2.65	0.072266
2.655	-0.04984
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2.665	-0.05206
2.67	-0.13925
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2.69	-0.21603
2.695	0.74049
2.7	-0.13877
2.705	0.63617
2.71	0.73516
2.715	-0.62475
2.72	-0.46063
2.725	-0.78818
2.73	-1.112
2.735	0.23726
2.74	0.69019
2.745	0.60288
2.75	1.1615
2.755	0.78596
2.76	-0.43327
2.765	-0.73717
2.77	-1.832
2.775	-0.60927
2.78	0.10309
2.785	1.7027
2.79	1.6241
2.795	0.82398

2.825	0.10989
2.83	1.7252
2.835	1.0838
2.84	-0.04616
2.845	-0.6475
2.85	-0.69044
2.855	-1.2489
2.86	-0.61796
2.865	0.69001
2.87	1.2045
2.875	0.44208
2.88	0.81992
2.885	-0.07771
2.89	-1.3602
2.895	-1.2837
2.9	-0.10733
2.905	0.23189
2.91	0.53051
2.915	0.53704
2.92	0.70265
2.925	0.11495
2.93	0.078012
2.935	-0.02814
2.94	-0.19428
2.945	-0.14477
2.95	0.31649
2.955	0.37666
2.96	-0.66248
2.965	-1.2932
2.97	-0.06882
2.975	0.12641
2.98	0.93818
2.985	1.7867
2.99	1.3225
2.995	-1.0146

3.025	1.0141
3.03	-0.32958
3.035	-0.13456
3.04	0.58311
3.045	-0.43794
3.05	-0.54441
3.055	0.44596
3.06	0.69572
3.065	-0.12552
3.07	0.56473
3.075	-0.46098
3.08	-0.71326
3.085	-0.97587
3.09	-0.53973
3.095	0.54726
3.1	0.9824
3.105	1.1504
3.11	0.48288
3.115	-0.60107
3.12	-0.59927
3.125	-1.4916
3.13	-1.1024
3.135	0.20701
3.14	0.64622
3.145	0.80951
3.15	1.5416
3.155	-0.38483
3.16	-1.0017
3.165	-0.1039
3.17	-0.40165
3.175	-0.34421
3.18	1.0014
3.185	1.4228
3.19	0.17637
3.195	-0.6719

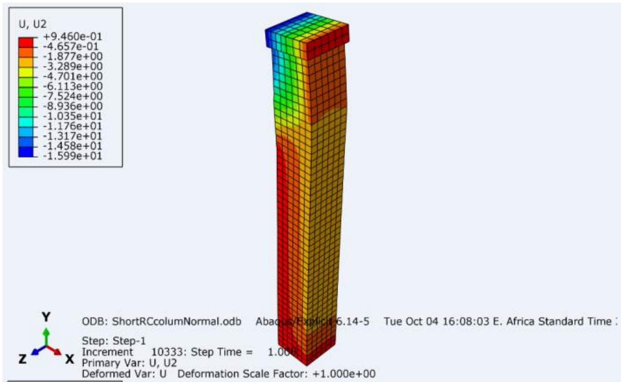
3.2	-0.7365
3.205	-0.73832
3.21	-0.68846
3.215	-0.30153
3.22	1.2169

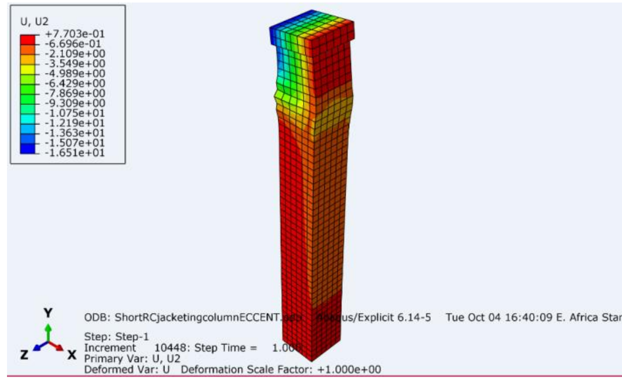
3.4	0.85763
3.405	-0.98574
3.41	-1.5245
3.415	-1.4107
3.42	-1.5762

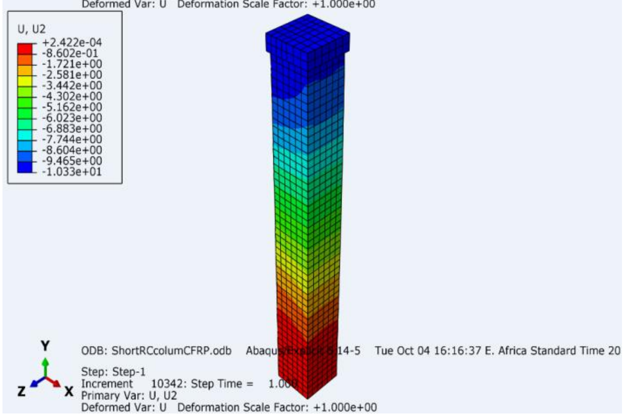
3.225	0.88687		3.425	1.0836
3.23	0.66428		3.43	2.4074
3.235	0.69907		3.435	1.4221
3.24	-0.02876		3.44	0.8116
3.245	-1.6979		3.445	0.51095
3.25	-1.2923		3.45	-0.99533
3.255	-0.40934		3.455	-1.2875
3.26	1.1844		3.46	-0.95385
3.265	0.62051		3.465	-0.92016
3.27	1.2088		3.47	-0.20192
3.275	1.0103		3.475	1.5005
3.28	-0.31022		3.48	1.7211
3.285	-0.5509		3.485	0.5399
3.29	0.34358		3.49	0.50525
3.295	-1.0384		3.495	-1.1422
3.3	-1.023		3.5	-2.8068
3.305	-0.69435		3.505	-1.4673
3.31	-0.29312		3.51	0.6974
3.315	0.32761		3.515	1.7739
3.32	1.2935		3.52	1.4823
3.325	1.0115		3.525	1.378
3.33	-0.02509		3.53	-0.42712
3.335	-0.78209		3.535	-1.1379
3.34	-1.1401		3.54	-0.64481
3.345	-0.19992		3.545	-0.2982
3.35	0.40965		3.55	-0.35775
3.355	0.3671		3.555	0.66074
3.36	0.33587		3.56	-0.66925
3.365	0.60952		3.565	0.40753
3.37	-1.1995		3.57	0.38208
3.375	-0.90494		3.575	0.29146
3.38	-0.0565		3.58	0.21076
3.385	-0.16811		3.585	0.20582
3.39	0.41768		3.59	-0.79502
3.395	2.0726		3.595	-0.19929

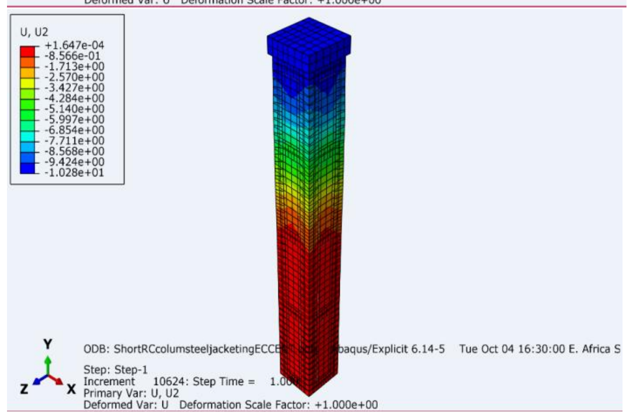
APPENDIX-B

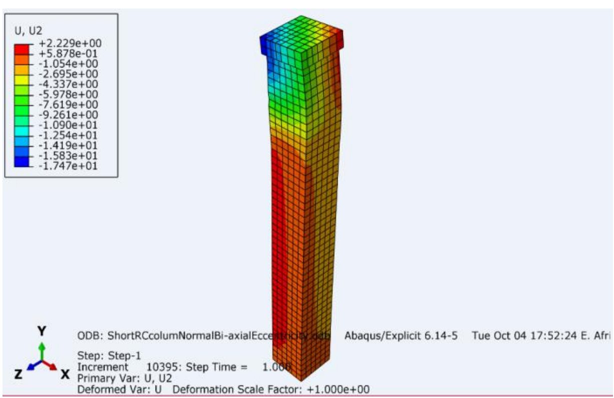
The output of eccentricity and length of the column.

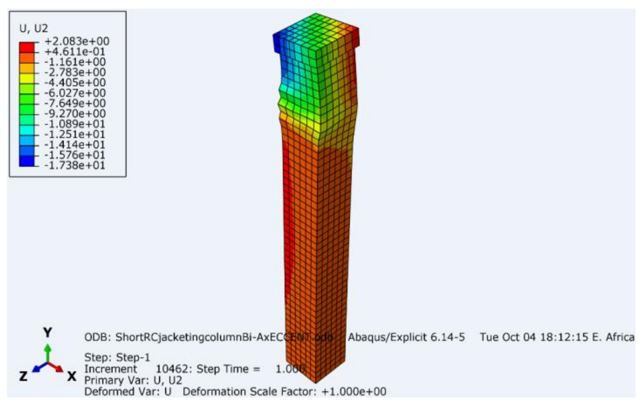


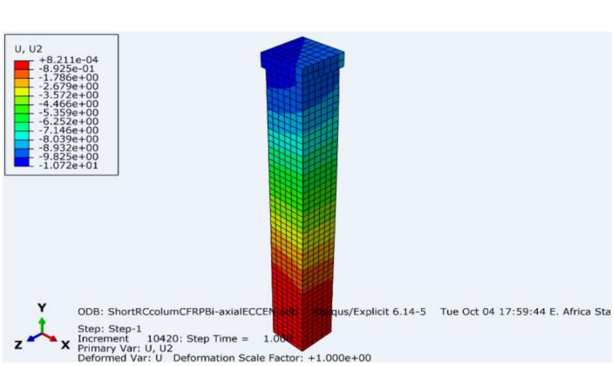


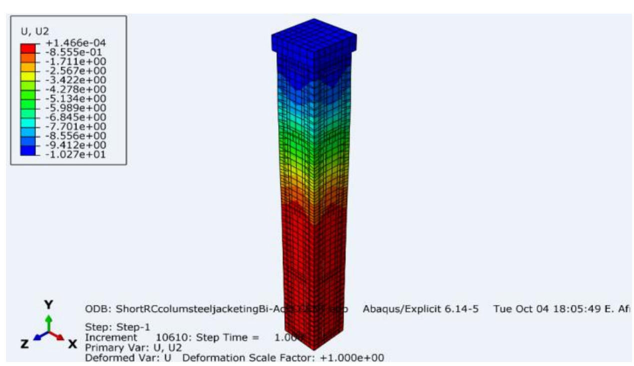


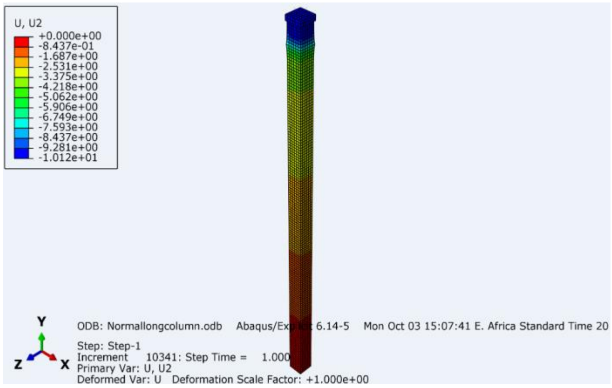








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-1.687e+00
-2.531e+00
-3.375e+00
-4.218e+00
-5.062e+00
-5.906e+00
-6.749e+00
-7.593e+00
-8.437e+00
-9.281e+00
-1.012e+01
ODB: Normallongcolumn.odb Abaqus/Ex 6.14-5 Mon Oct 03 15:07:41 E. Africa Standard Time 20
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Increment 10341: Step Time = 1.000
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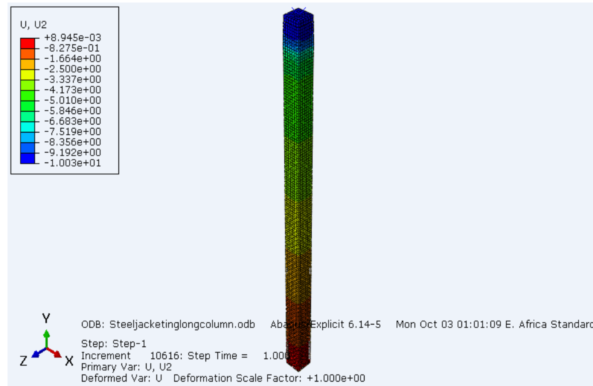
Deformed Var: U Deformation Scale Factor: +1.000e+00
Y
Z
X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-3.337e+00
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-6.683e+00
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Increment 10616: Step Time = 1.00
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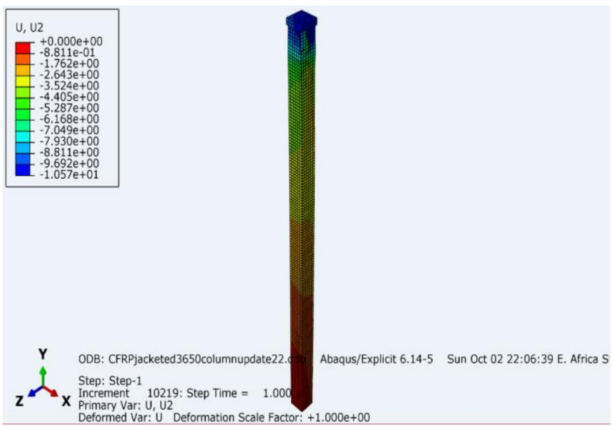
Deformed Var: U Deformation Scale Factor: +1.000e+00
Y
Z
X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-9.692e+00
-1.057e+01
ODB: CFRPjacketed3650columnupdate22. Abaqus/Explicit 6.14-5 Sun Oct 02 22:06:39 E. Africa S
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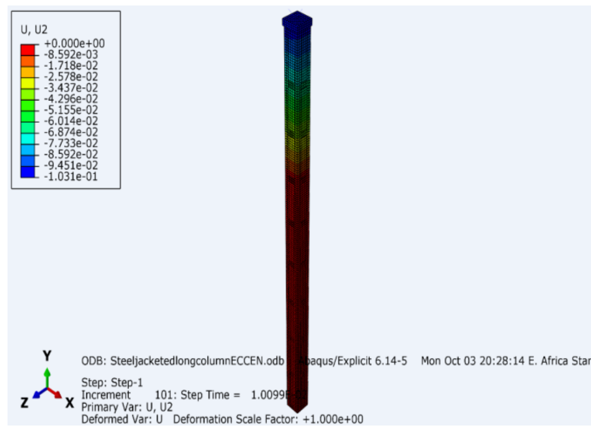
Increment 10219: Step Time = 1.000
Primary Var: U, U2
Deformed Var: U Deformation Scale Factor: +1.000e+00
Y
Z
X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-3.437e-02
-4.296e-02
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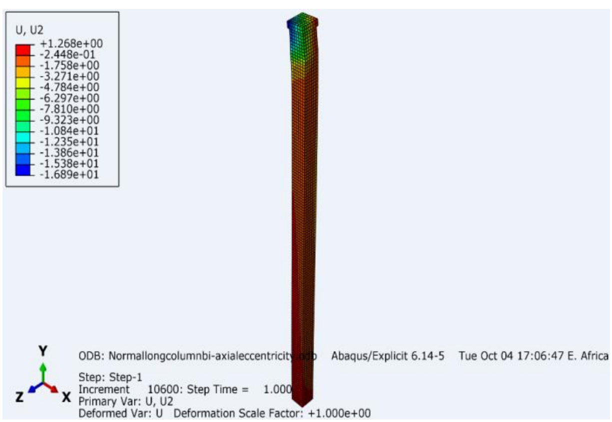
-6.874e-02
-7.733e-02
-8.592e-02
-9.451e-02
-1.031e-01
ODB: SteeljacketedlongcolumnECCEN.odb aqus/Explicit 6.14-5 Mon Oct 03 20:28:14 E. Africa Stan
Step: Step-1
Increment 101: Step Time = 1.0099
Primary Var: U, U2
Deformed Var: U Deformation Scale Factor: +1.000e+00
Y
Z
X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ODB: Normallongcolumnbi-axialeccentricity Abaqus/Explicit 6.14-5 Tue Oct 04 17:06:47 E. Africa
Step: Step-1
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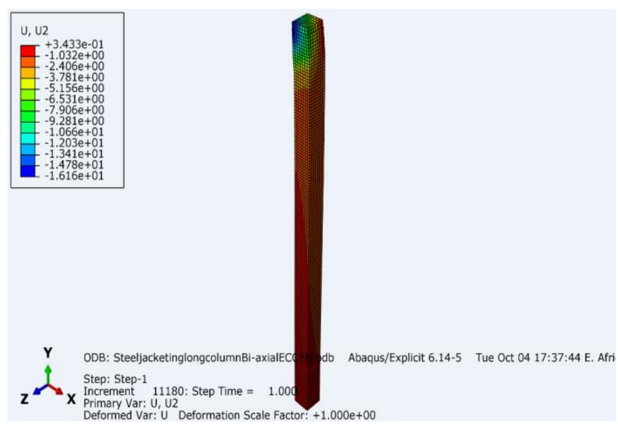
Primary Var: U, U2
Deformed Var: U Deformation Scale Factor: +1.000e+00
Y
Z
X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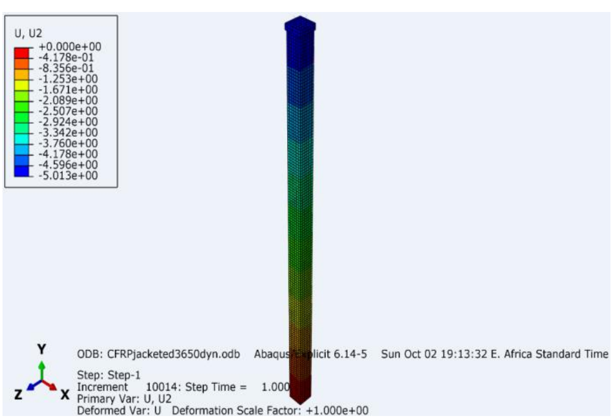
ODB: SteeljacketinglongcolumnBi-axialEC db Abaqus/Explicit 6.14-5 Tue Oct 04 17:37:44 E. Afri
Step: Step-1
Increment 11180: Step Time = 1.000
Primary Var: U, U2
Deformed Var: U Deformation Scale Factor: +1.000e+00
Y
Z
X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-2.089e+00
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-2.924e+00
-3.342e+00
-3.760e+00
-4.178e+00
-4.596e+00
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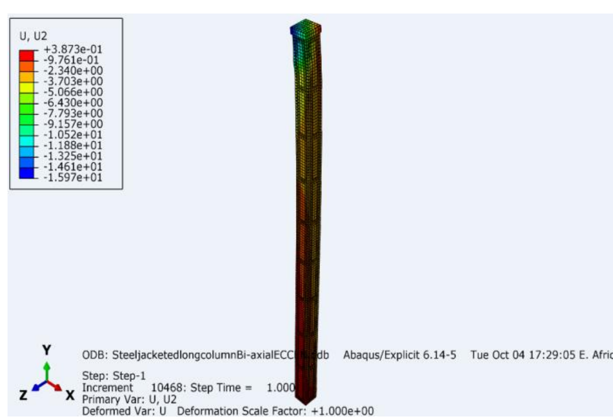
ODB: CFRPjacketed3650dyn.odb Abaqus licit 6.14-5 Sun Oct 02 19:13:32 E. Africa Standard Time
Step: Step-1
Increment 10014: Step Time = 1.000
Primary Var: U, U2
Deformed Var: U Deformation Scale Factor: +1.000e+00
Y
Z
X


U, U2
+3.873e-01
-9.761e-01
-2.340e+00
-3.703e+00
-5.066e+00
-6.430e+00
-7.793e+00
-9.157e+00
-1.052e+01
-1.188e+01
-1.325e+01
-1.461e+01
-1.597e+01
ODB: SteeljacketedlongcolumnBi-axialECC db Abaqus/Explicit 6.14-5 Tue Oct 04 17:29:05 E. Afric
Step: Step-1
Increment 10468: Step Time = 1.000
Primary Var: U, U2
Deformed Var: U Deformation Scale Factor: +1.000e+00
Y
Z
X

APPENDIX-C

Displacement versus force for Long and Short column.

Table C.1: Displacement versus force for Bare, CFRP, RC and steel jacketed column.

Bare RC long column		CFRP Jacketed long RC column		Steel jacketed long RC column	
Displacement	Force	Displacement	Force	Displacement	Force
0	0	0	0	0	9.89E-07
0.050995	57564.55	0.050995	59084.71	0.050995	68527.73
0.10099	56257.82	0.10099	57643.88	0.10099	65733.07
0.150985	57657.98	0.150985	58945.42	0.150984	67057.75
0.20098	57412.9	0.20098	58621.53	0.200979	66423.86
0.250972	56238.41	0.250973	57793.66	0.250972	66415.31
0.300963	57651.26	0.300963	58958.38	0.300961	67612.44
0.350953	57503.3	0.350953	58756.17	0.350951	67673.15
0.400943	56728.16	0.400943	58068.38	0.400941	67183.05
0.450934	120544.4	0.450933	111030	0.450931	125722.1
0.50092	181896.1	0.50092	191495.9	0.500917	202440.3
0.550906	168825.2	0.550905	172983.9	0.550903	191865.7
0.600892	168327.5	0.600891	170639.4	0.600889	203101.6
0.650877	168911.5	0.650877	168207.5	0.650875	205207.3
0.700861	169183.3	0.700861	170117.2	0.700859	201500.1
0.750842	172716.3	0.750841	175267.4	0.750792	201349.7
0.800823	173897	0.800822	176672.7	0.800444	200925.7
0.850804	172226.3	0.850803	176144.7	0.850416	198900.6
0.900786	243226.7	0.900785	229472.9	0.900394	253639.1
0.950219	272862.7	0.950761	289390.9	0.950371	314823.7
1.000036	279476.8	1.000737	288250.2	1.000238	321351.8
1.05083	277364.6	1.050712	282272.5	1.050204	321076.9
1.100647	279995.3	1.100688	281589.1	1.100081	321301.7
1.150464	280415.4	1.150663	287361.6	1.150974	321915.1
1.20028	279858.9	1.200637	286574.8	1.200869	323155.7
1.250097	281238.2	1.250609	284081	1.250764	323241.9
1.300891	280535.3	1.30058	285779.8	1.300654	323392.8
1.350708	293098.4	1.350551	296495.4	1.350605	331781.6
1.400815	322310.4	1.400521	320705.6	1.400574	362695
1.450785	353083.8	1.45049	355446.4	1.45047	408439.6
1.500752	370570.2	1.500457	375393.5	1.500379	429116.3
1.550719	370997.3	1.550423	377792.8	1.550346	428423.9
1.600685	370873.1	1.60039	377966.6	1.600177	428878.7
1.650652	371403.3	1.650357	378398.8	1.650994	429581.2
1.700618	371948	1.700323	379695.3	1.700815	430227.1

1.750581	372349.5	1.750286	380454.8	1.750635	430498.8
1.800541	372979.9	1.800237	381609.4	1.80032	431602.9

RC Jacketed long RC column		Bare Short column		CFRP jacketed short column	
Displacement	Force	Displacement	Force	Displacement	Force
0	0	0	0	0	0
0.050173	116790.5	0.050995	53432.9	0.050995	58715.29
0.100158	113533.4	0.100988	54812.84	0.100988	58670.9
0.150142	116853.2	0.150978	116261.7	0.150978	117771.1
0.200131	114018.4	0.200963	157880.6	0.200964	168735.5
0.25012	114108.3	0.250947	162488.9	0.250947	172075.3
0.300109	115214.4	0.300927	237557.4	0.300927	236645.1
0.35009	117303.8	0.350903	270367.3	0.350498	301925
0.400308	117397.8	0.400225	271261.2	0.400205	298386.7
0.450268	118362.8	0.450375	320714.2	0.4504	333839.6
0.50023	114868	0.500525	370383.1	0.500593	397605
0.550191	116012.2	0.550385	373092.7	0.550024	400248.5
0.60015	115336.5	0.600037	386852.5	0.600201	411157.4
0.65011	185083	0.650376	447977.2	0.650848	480172.8
0.700837	386529	0.700492	457342.2	0.700967	489677.1
0.750678	332341.6	0.750107	459533.2	0.750913	493696.8
0.800332	326373.1	0.800376	473533.9	0.800407	510555.3
0.850139	334624.5	0.850042	508956.3	0.850668	551441.8
0.900797	338077.7	0.900675	526403	0.900296	570065.9
0.95059	343488.5	0.950813	528769.6	0.950153	573344.8
1.000397	346957.3	1.000807	533483.6	1.000464	582019.8
1.050256	345926.4	1.050716	543169.4	1.050735	599035.2
1.100782	345924.5	1.10006	558681.9	1.1001	620227.1
1.150534	350590.1	1.150521	573204.5	1.150689	635318.9
1.200329	347054.1	1.200369	579560.3	1.200465	640518.6
1.25012	346106.3	1.250283	582163.1	1.250002	643982.5
1.300876	375924.2	1.300097	584722.9	1.300895	650755.3
1.350814	414457.3	1.350611	588539.3	1.350086	659901.9
1.400379	480603.7	1.400107	590543.8	1.400099	672950.3
1.450157	516830.8	1.450108	594046.1	1.450276	683816.5
1.500281	527319.9	1.50031	599643.3	1.500485	691936.1
1.55068	529492.9	1.550601	602774.6	1.550471	695658.2
1.600139	529464.9	1.600529	605485.6	1.600342	698152.3
1.650786	530741	1.650625	608515.9	1.650361	703843.4
1.700439	531762.4	1.70012	610816.5	1.700492	709899.2
1.750063	532475.3	1.750686	612243.3	1.750353	714611.6

1.800668	534203.8		1.800685	611366.6		1.800764	718953.2

Steel jacketed short column	
Displacement	Force
0	0
0.050995	56110.57
0.100988	56131.06
0.150977	112637.2
0.200963	158525.7
0.250946	163045.4
0.300926	225498.6
0.35089	282982.3
0.400168	279051.7
0.450932	316866.4
0.500748	373741.9
0.550568	378895.5
0.600668	390104.5
0.650579	452641.1
0.700976	463988.3
0.750586	467385.8
0.800421	479132.2
0.850931	514721.3
0.900565	535870.8
0.950889	537380.3
1.00008	542669.2
1.050442	552859.7
1.100509	567571.1
1.150313	582643.5
1.200227	590189.6
1.250624	594463.1
1.30083	597505.3
1.350873	600885.8
1.400704	604336.9
1.450467	607795.8
1.500222	610902.9
1.550301	615022.5
1.600088	620756.6
1.65026	623732.8
1.700427	624593.1
1.750485	625539.3
1.800358	625801.3

RC jacketed short column	
Displacement	Force
0	0
0.050996	65597.19
0.100989	63511.64
0.150979	196056.1
0.200965	184938.1
0.250948	190975.2
0.300929	346417.2
0.350891	317210.5
0.400166	320613.1
0.450086	448351.3
0.500395	441657.2
0.550788	451068.6
0.600811	538952.1
0.650323	555293.6
0.700375	561050.1
0.750507	602875.1
0.800488	648134.2
0.850142	657130.9
0.900757	670399.9
0.95031	700651.6
1.000112	733908.4
1.050767	744879.3
1.100745	754978.3
1.150664	772035.8
1.200939	792694
1.250451	817051.4
1.300083	825817
1.350087	836607.6
1.400683	846508.3
1.4504	864572.1
1.500185	877155.6
1.550209	890827.1
1.600215	900761.8
1.650074	907686.1
1.700805	919024.2
1.750546	928233.3
1.800033	940112.3

Table C.2: Displacement versus force Uni and Bi-directional eccentricity for Bare, CFRP, RC, and steel jacketed column.

CFRP Jacketed long RC column eccentricity 20mm	
Displacement	Force
0	0
0.050994	58815.4
0.100986	57430.96
0.150979	58366.91
0.200971	58167.14
0.250963	57374.33
0.300953	58474.89
0.350943	58438.19
0.400933	57726.74
0.450922	105476.5
0.500902	185423.2
0.55088	170020.6
0.600836	168816.5
0.650807	166982.3
0.700783	169175.7
0.75076	173438.2
0.800737	175559.6
0.850712	174351.6
0.900687	214645.6
0.950393	278755.5
1.000215	282212.4
1.050036	276079.6
1.100797	277101.6
1.150619	282409.1
1.20044	282014.3
1.250261	279616.6
1.300079	281507.9
1.350126	288069.4
1.400559	313652.2
1.450383	349478.7
1.500474	360411.7
1.550306	362609.3
1.600905	363366.9
1.650022	365562.4
1.7006	369579.2

RC Jacketed long RC column eccentricity 20mm	
Displacement	Force
0	0
0.050843	114471.8
0.100795	112782.8
0.150742	115168.5
0.200724	113653.8
0.250701	113651.5
0.300669	114682.4
0.350644	116334.4
0.400133	116208
0.450916	117260.6
0.500704	114115.3
0.550491	115419.6
0.600276	115058.7
0.650061	178614.5
0.700144	371105
0.750479	322425
0.800688	322910.2
0.850871	330300.8
0.900177	335747
0.950395	340737.6
1.000613	342359.9
1.05083	341974.2
1.100148	342396.9
1.150363	343846.5
1.200578	342215.1
1.250793	341971.6
1.300111	364050.8
1.350637	408176
1.400638	464415.3
1.450238	497529.9
1.500009	505230.5
1.550753	509201.8
1.600861	509922.9
1.650172	513836.9
1.70077	515720.9

Steel jacketed long RC column eccentricity 20mm	
Displacement	Force
0	-24.3804
0.050994	65247.78
0.100985	65629.55
0.150973	65337.52
0.200959	67410.58
0.250945	65400.44
0.30093	66045.34
0.350914	66069.95
0.400899	64133.26
0.450883	112362.5
0.500705	178772.4
0.55027	178649.6
0.600847	192776.5
0.650381	203433.9
0.700017	200745.1
0.750649	186286.7
0.800007	190341.4
0.850418	193635.3
0.900651	232493.5
0.950699	272643.8
1.000766	292420.2
1.050605	292305.7
1.100545	309167
1.150463	322076.3
1.200302	304690
1.250141	302294.9
1.300938	304834.7
1.350777	314539.5
1.400616	350445.2
1.450588	379232.5
1.500251	382866.4
1.550122	387820.7
1.600437	396782.7
1.650273	407689
1.700105	397855.9

1.75006	371716.2
1.800776	372834.3
1.850069	373698.8
1.900348	378470.5
1.950905	386806.9
2.000011	400319.1
2.050397	414375.3
2.10077	422641.2
2.15077	427148.5
2.200566	431601.6
2.250474	435286.6
2.300159	438560.2
2.350334	441239.1
2.40052	441071.5
2.450706	444554.7
2.50089	448079.9
2.550104	451883.3
2.600431	457631.7
2.650307	461202.8
2.700693	466040.2
2.750164	469033.4
2.80062	473432.2
2.850724	477586.1
2.900797	484936.5
2.950631	489896.5
3.000792	494477
3.050447	496094.7
3.100497	497698.1
3.150446	499640.2
3.200235	501431.4
3.250269	503644.4
3.300371	505210.7
3.35033	507883.3
3.400078	508662.8
3.450939	510828.5
3.500095	512517.6
3.550115	515119.9
3.600087	518352.5
3.650104	521021.2
3.700027	523583.3
3.750656	527459.5

1.750508	517821.6
1.800245	517780.5
1.850011	516160.9
1.900666	518933.1
1.950401	520900.9
2.000137	524423.1
2.050242	528189.4
2.100361	536420.7
2.149987	547854.8
2.200495	562556.1
2.250021	577455.3
2.300002	591944.9
2.35031	606739.8
2.400881	620080.9
2.450417	627543.8
2.500589	632161.9
2.550136	634539.3
2.600737	637267.3
2.650076	639479.6
2.700556	641414.6
2.75056	643410.1
2.800673	643652.2
2.850728	645004.4
2.900707	647219.8
2.950613	649567
3.000155	651253.7
3.050326	653303.3
3.100745	656675.5
3.150487	659463.3
3.200826	663815.5
3.25043	667025.7
3.300737	669961.3
3.350692	676129.9
3.400598	683868
3.450134	687602.1
3.500785	692795.7
3.550589	703049.7
3.600176	710048.9
3.650628	712106.6
3.700182	713951.5
3.75067	720311.8

1.750139	396354.4
1.800917	400546.6
1.850752	409265
1.900591	419909.9
1.95043	432524.3
2.000434	449101.7
2.050876	458283.9
2.100695	465273.5
2.150552	469479.5
2.200687	472925
2.250371	474281.1
2.300204	475609.5
2.350011	478091
2.400783	483547.6
2.450589	486271.5
2.50048	493526.7
2.550225	501401.5
2.600143	509964.6
2.650753	517937.8
2.700257	526334.8
2.750754	528408.8
2.800292	530813.6
2.850613	531986.9
2.900249	534553.2
2.950801	537751.1
3.000428	541505.2
3.050959	543441.4
3.100753	548666.2
3.15034	553603.5
3.200129	558802.9
3.250365	563066.1
3.300774	567499.6
3.350193	569266.7
3.400466	575500.3
3.450737	575880.6
3.500822	577962.3
3.550958	580007.1
3.60046	582071.9
3.650854	583303.7
3.700251	588403.6
3.750474	589834.8

3.800337	529991.4
3.850919	533849.9
3.900724	536494.3
3.950335	538545.5
4.000109	541055.9
4.050094	542759.9
4.100725	544496.7
4.150514	545576.6
4.200249	546541.6
4.250678	547080.6
4.300619	548198.2
4.350401	548353.5
4.400081	549899.4
4.450543	551008.3
4.50015	551948.9
4.550098	554349.7
4.600464	555076
4.650905	557287.2
4.700406	558835.9
4.750723	560112.6
4.800318	562362.9
4.850702	563465.1
4.90045	565430.8
4.95097	565463.9
5.000728	567083.9
5.050334	567526.3
5.100659	568196.4
5.150532	568536.8
5.200808	567154
5.25024	567024.8
5.300867	565618.3
5.350674	564126.9
5.400472	561367.9
5.450446	558781.6
5.500418	555480
5.550586	552118.4
5.600739	546537.4
5.65043	538435.3
5.70021	528445.4
5.750506	520154.8
5.800437	508971.1

3.800121	723029.6
3.850431	724075.4
3.900012	723875.6
3.95054	724690.1
4.00015	724536.4
4.050237	722617.8
4.100709	722975.3
4.150142	725620.5
4.200761	723759.1
4.249986	723771.4
4.300151	720172.6
4.350045	718112.9
4.400193	715895.6
4.450799	714110.5
4.500591	705811.1
4.550604	701979.2
4.600198	694992.6
4.65044	691233.4
4.700626	682689.8
4.750472	668700.4
4.80084	663505.6
4.850379	643936.6
4.900366	633618.6
4.950121	611902.6
5.000382	597645.7
5.050726	585688.9
5.100154	573843.1
5.150336	554623.8
5.200315	551100.4
5.250009	539987.6
5.300579	528827.6
5.350368	521985.1
5.400755	508661.9
5.450091	499572.5
5.500372	484181.3
5.550506	475141.1
5.600639	460561.4
5.650773	455812
5.699978	442445.3
5.750112	439899.3
5.800246	431932.4

3.800721	593506.8
3.850118	597465.7
3.900445	599643.6
3.950888	602143.6
4.000251	605514.4
4.050393	604487.5
4.10057	605156.2
4.150743	606570.4
4.200257	605673.1
4.250162	608112.4
4.300584	609829.1
4.350088	608316.6
4.400594	610836.9
4.450148	612556.6
4.500532	612069.3
4.550833	613642.1
4.600393	613833.1
4.650853	611205.8
4.70049	611871.1
4.750903	610972.4
4.800521	608875.1
4.850136	607960.9
4.900611	601736.4
4.9505	601439.4
5.000351	602583.8
5.050124	593190.1
5.100358	589471.8
5.15063	592446.8
5.200571	584397.8
5.250333	577200.8
5.300948	578786
5.350822	579006.7
5.400658	569099.9
5.450675	563008
5.500896	557900.7
5.550344	550851
5.600113	547014
5.650286	541489.4
5.70036	537015.1
5.750588	530616.1
5.800187	534456.1

5.850707	491752.2	5.850379	429898.5	5.850735	530174.9
5.900394	482379.1	5.900133	425031.9	5.900455	522291.9
5.950306	477873.3	5.95012	428079.6	5.95032	525818.4
6.000058	468253.2	6.000107	428184.2	6.000851	522172.1
6.051007	464056	6.050094	430942.6	6.050359	518737.8
6.100869	456897	6.10008	436507.8	6.100129	520477.7
6.150924	451936.6	6.150067	441362.3	6.150687	514002.8
6.200106	451143.3	6.200045	445145.8	6.200084	509501.8
6.25028	445928.5	6.250005	450797.9	6.250503	512166.3
6.300885	447848.1	6.299966	453405.8	6.300847	507695.7
6.350286	445914.7	6.349926	455928.7	6.35068	507316.7
6.400668	441008.6	6.399887	456235	6.400824	507605.8
6.451049	435309.1	6.449848	456164.3	6.450701	507898.6
6.500384	438956.7	6.499808	456699.5	6.500403	504642.8
6.55061	442394.3	6.550677	455016.1	6.550595	506750.5
6.600809	444496.8	6.600626	454860.5	6.600814	505687
6.65088	445171.4	6.650584	455478	6.650925	504234.7
6.700852	446688.7	6.700519	455764.4	6.700655	504784
6.750438	446191.4	6.750453	455096.6	6.750656	501612.2
6.800365	443599.7	6.800387	454118.1	6.800318	502286.1
6.850155	443013.9	6.850322	452877.9	6.850828	501691.4
6.900388	438478.7	6.900256	449181	6.900393	500260.5
6.950313	442537	6.950191	445656.3	6.950735	500000.4
7.000386	440577.8	7.000125	441495.6	7.000234	500138.5
7.05067	441508.5	7.050059	436295.3	7.050194	499775.8
7.10103	439179.3	7.099994	432368.1	7.100241	497310.3
7.150291	438157.6	7.149947	426883.7	7.150086	497494.9
7.200475	437644.5	7.199907	427005.3	7.200265	496513.5
7.250801	432173.6	7.249868	419613.8	7.250269	493968.3
7.300178	429137.2	7.299829	418370.3	7.300597	491564.7
7.350542	431149	7.34979	412828.7	7.350471	490529.8
7.400882	433096.4	7.39975	411840.8	7.40023	489256.2
7.450172	432719	7.449711	409803.7	7.450211	487927.9
7.500526	435216.9	7.499671	409662.3	7.500652	487308.6
7.550798	434748.8	7.549632	409467.3	7.5504	485482.6
7.60096	439027.5	7.599593	412800.4	7.600245	484389.7
7.651033	441984	7.649553	412938.5	7.650662	481297
7.700434	441332.3	7.700422	416287.7	7.700577	477727.6
7.750799	443811.8	7.75038	421216.5	7.750725	478864.2
7.800198	444483.2	7.80032	427201.5	7.800545	476780.1
7.850523	439860	7.850254	431954.5	7.850082	475228.8

7.900894	446909.1
7.950235	448883.9
8.000428	446159.3
8.050839	448266.8
8.101089	447487
8.150578	441716.9
8.200316	439039.4
8.25058	435431.9
8.300879	437864
8.351032	441719.3
8.40048	443936.2
8.450916	444558.1
8.500336	449995.8
8.550774	452355.3
8.600883	448450
8.650175	445703.3
8.700294	447536.7
8.750668	445854.6
8.801102	444454.5
8.85054	444102.8
8.900831	440338
8.951098	440820.4
9.000424	441241.9
9.050867	443247.9
9.100363	442812.6
9.150822	445753.4
9.2011	440289.2
9.251005	441086.3
9.300285	441573.2
9.350477	438367.3
9.400176	434661.3
9.450392	434287.2
9.500631	432493.5
9.550875	432341.6
9.601053	432845.4
9.650967	425253.3
9.700436	422777.3
9.750919	419413.8
9.800432	414935.8
9.850931	408202.5
9.900469	405758.3

7.900188	436005.9
7.950123	437555.7
8.000057	441574.1
8.049992	440206.2
8.099926	442802.4
8.14986	441631
8.199795	441571.6
8.250118	441673.5
8.299804	439969.4
8.350041	441898.8
8.399933	442242.7
8.449756	442169.5
8.499634	445448.2
8.549566	447517.9
8.599501	448392
8.649435	449697.5
8.699369	449422.9
8.749294	448286.6
8.799109	443335.5
8.849043	444296.3
8.899609	437409.9
8.949539	435204.4
8.999429	429388.9
9.049363	423934.9
9.099298	417172.5
9.149204	410536.2
9.199139	406215.4
9.249032	397607.4
9.298966	393783.8
9.348901	392565.1
9.398835	382194.2
9.44877	383730
9.498704	378311.8
9.549546	376524.3
9.599481	374981.8
9.64942	383673.2
9.699381	383472.7
9.749341	386998.6
9.799302	391008.3
9.849262	390884.6
9.899223	392035.9

7.900239	471638.2
7.95006	467139.7
8.000534	468156.7
8.050273	468549.4
8.10076	468001.3
8.150157	465373.2
8.200267	462926
8.250849	461566.7
8.300798	457964.6
8.350941	456679.1
8.400745	450800.1
8.450232	447671.8
8.500496	447618.8
8.550452	446557.8
8.600345	447847.4
8.650994	440749.6
8.700679	437178.9
8.750038	439076.4
8.800916	430939.3
8.850585	426485.9
8.900571	423469.2
8.950952	428351.5
9.000332	425467.7
9.050469	428664.6
9.100617	424944.8
9.150922	413022.8
9.200265	409591
9.250813	406837.8
9.300477	397374.6
9.350896	392778.6
9.400403	394160.8
9.450056	389150.4
9.50035	388423.5
9.550226	389867.1
9.600794	380212.1
9.650826	373288.1
9.700266	372109.7
9.750119	368237
9.80014	365245.6
9.850195	359040.4
9.900307	356163.2

9.950977	403893.4	9.949104	396398.3	9.950062	355703.1
10.00013	406974.4	9.99855	396174.6	9.999973	352630

CFRP jacketed short column eccentricity 20mm		Steel jacketed short column eccentricity 20mm		RC jacketed short column eccentricity 20mm	
Displacement	Force	Displacement	Force	Displacement	Force
0	0	0	0	0	0
0.050994	58161.32	0.050994	56637.72	0.050994	63638.9
0.100987	58020.17	0.100986	56628.59	0.100986	62384.12
0.150976	110835.9	0.150976	111533	0.150975	171514.7
0.200958	167756.9	0.200957	160873.2	0.200855	179597.5
0.250939	170457.7	0.250935	164548.9	0.250179	183893.2
0.300919	223689	0.300905	221862.1	0.300633	302692.9
0.350762	292815.9	0.350708	280749.4	0.350384	297779
0.400619	288872.7	0.400031	276796.9	0.400003	300158.7
0.450281	324333.7	0.450717	317671.3	0.450032	398661.8
0.500749	380839.9	0.500643	364362.2	0.500184	399076.6
0.550143	384761.5	0.550161	367951.5	0.550263	403313.2
0.600589	409335.6	0.600057	396378.1	0.600114	479469
0.650246	455917.8	0.650568	440892.2	0.650117	482324
0.700458	464795.3	0.700315	444922	0.700435	488300.2
0.75014	482951.9	0.75032	461407.3	0.750001	545339.5
0.800928	507550.9	0.800018	488324	0.80073	560993.3
0.850641	531736.4	0.850665	507399.4	0.850302	565983.9
0.900273	538756.4	0.900089	511631.4	0.900486	599745
0.950461	559973.1	0.950324	531356.6	0.950311	628825
1.000617	578064.2	1.000236	548691.1	1.000914	634341.9
1.050886	590065.3	1.050701	560166.8	1.050895	650591.1
1.100744	598598.4	1.100309	566011.2	1.100529	671606.6
1.150757	609844	1.150485	575815.8	1.150007	680163.2
1.200255	623679.8	1.200873	587610.3	1.200389	681130.9
1.250751	634358.7	1.250747	597475.8	1.250771	693867.8
1.300478	641799.3	1.300436	604899.3	1.300363	700660.9
1.350682	649492.7	1.350223	608910.3	1.350808	696493.8
1.400594	657739.4	1.400562	614268.1	1.40043	691907.1
1.450778	665108.3	1.450117	620437.6	1.45006	699742.3
1.500813	674088.1	1.500745	623632.3	1.500005	690747.4
1.550092	680728.3	1.550313	627551.1	1.550936	683176.1
1.600065	686740.8	1.600515	627100.2	1.600801	678086.5
1.650039	691122.9	1.6503	628210.6	1.650478	672818.6

1.700792	694286.3
1.750117	699060.3
1.800465	704078.1
1.850455	707736.6
1.900535	708290.7
1.95009	710335.4
2.000757	713451.9
2.050031	714046.9
2.100632	715443.1
2.150374	715419.1
2.200694	714724
2.250537	714411.3
2.300091	709991.1
2.350833	706226.8
2.400588	700359.9
2.450944	696774.8
2.500133	689597.4
2.550132	680762.6
2.600547	676380.8
2.650722	671074.2
2.700212	663932.7
2.750563	660745.1
2.800086	649748.6
2.850626	644676
2.900116	640253.6
2.950622	637703.4
3.000131	629858.2
3.050683	626258.1
3.100918	625858
3.150457	623186.3
3.200828	620862.4
3.250058	621143.5
3.300502	621496.9
3.350021	623489.4
3.400491	623278.1
3.450732	623229.3
3.500218	622161.4
3.550602	623419.5
3.600056	623274.4
3.650467	623043.8
3.7	624969.4

1.700757	627511.8
1.750219	624066.3
1.800071	619762.8
1.850884	614657.1
1.900735	609084.4
1.950315	599928.6
2.000131	590180.3
2.050665	579352.4
2.100658	567501.5
2.150457	558033.6
2.200333	549629.8
2.250124	537010.1
2.30005	528946.1
2.35088	515373.5
2.400098	503220.8
2.450898	495568.3
2.500825	489341.1
2.550583	482490.4
2.600463	476665.5
2.650419	473384
2.700226	468368.7
2.750075	466098.2
2.800076	463436
2.850065	462653.5
2.900066	458891
2.950037	458246.8
3.000038	459486.8
3.050029	455180.7
3.100029	457124.3
3.150023	456850.5
3.200006	457901.9
3.250008	455308.9
3.300009	457676.3
3.350008	456866.5
3.399984	457212.4
3.449986	455320.2
3.499985	456569.8
3.549986	457087.9
3.599984	457425.6
3.649973	454941.9
3.700794	457331.8

1.700523	655231.6
1.75058	643408.5
1.800633	635236
1.850691	625200
1.90086	614303.6
1.950022	613290.3
2.000058	610952.6
2.05033	606630.9
2.100462	601965.9
2.150327	597534.3
2.200271	592500.3
2.250173	585176.4
2.300161	580264.4
2.350294	577323.3
2.400699	569626.9
2.450052	568770.3
2.500214	563207.3
2.550491	559059.1
2.600535	551139.6
2.65069	552747.2
2.700102	543987.7
2.750568	535936.5
2.800812	538342.8
2.85051	536379.4
2.900958	522347.2
2.950101	521114.3
3.000187	520956.5
3.050341	505566.4
3.100557	508197.7
3.150618	507568.2
3.200706	498449.8
3.250789	494661.9
3.300886	488938.1
3.350924	442034.4
3.400842	395286.3
3.450424	388411.7
3.500151	365867
3.55025	332641.5
3.600344	333414.7
3.650238	373587.9
3.700432	365624.3

3.750354	626483.9
3.800778	626793.9
3.850066	630239.7
3.900406	630046.3
3.949992	630779.9
4.000517	632154.2
4.049918	633239.6
4.100316	634429.2
4.150726	635835.9
4.199976	637441.8
4.250444	638767.3
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4.399971	643039.6
4.450373	644028.1
4.499852	644711.7
4.550345	647358.7
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4.800456	654414.6
4.849802	654466.4
4.90028	656938.2
4.949721	658936.3
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5.099809	664308.7
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5.200392	665149.3
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5.450048	672425.3
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5.549889	675524
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5.650703	676765.9
5.7001	677626.2
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3.750795	456649.3
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3.899856	458072.6
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4.15074	458351.3
4.200741	458117.2
4.250742	458481
4.2998	458879.6
4.350628	460816.3
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4.450631	461155.6
4.50063	460810.3
4.550632	460771.9
4.600633	461001.3
4.650618	461215.9
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4.75062	461273.3
4.800579	463071.3
4.850581	461962.1
4.900582	463463.5
4.950583	462219.3
5.000544	462820.7
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5.100433	464440.3
5.150434	464958.2
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5.300438	464166.2
5.350386	465506.7
5.400361	465778.9
5.450353	467783.5
5.500354	465794.4
5.550251	467579.3
5.600157	467125.4
5.650165	467014.2
5.700167	467321.9
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3.800508	392413.1
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3.950307	354780.2
4.000407	329040.5
4.050506	305768
4.100462	265902.8
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4.200633	226248.6
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4.300733	201019.8
4.350632	233893.5
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4.450378	247185.4
4.500601	255004.3
4.550301	252388.7
4.600143	232308.6
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4.800227	197565
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4.950076	226456.4
5.000326	226220.1
5.050669	230311.9
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5.300165	203139.4
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5.55037	204360
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5.799799	678613.6
5.85027	677624.6
5.900678	678850.4
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6.000394	677346.3
6.050651	676505.8
6.100039	676480.9
6.150453	675059.3
6.200294	673598.3
6.25017	671940.2
6.300279	669336.6
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6.400683	668011.6
6.450104	667132.8
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6.550507	665435.6
6.6003	667006.9
6.650776	667578.4
6.700662	667918.5
6.750649	668117.9
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6.900415	671683.5
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7.000378	672094.3
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7.10065	672232.9
7.150596	673806.3
7.200494	672446.4
7.250578	673738.3
7.300593	672380.4
7.350512	670994.2
7.400334	670183.4
7.450474	669204.2
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7.600355	664017.9
7.650302	661056.3
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7.750422	659930.9
7.800369	659789.3

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5.900155	469154.3
5.950169	469491.4
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6.050189	469326.7
6.100066	468717.5
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6.200016	469957.3
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6.300005	469653.9
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6.449926	467879.6
6.499918	466312.3
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6.599908	466375.3
6.6499	466639.2
6.699876	466280.8
6.74987	465989.2
6.799875	465623.7
6.849872	465903.3
6.899881	463202.6
6.949869	462104.9
6.999882	461353.4
7.049896	460390
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7.149924	460357.6
7.199927	460576.6
7.249934	459676.5
7.299949	458838.3
7.349962	458418.9
7.399961	457372.3
7.449975	457814.3
7.49999	458917.5
7.550004	458907.3
7.600018	458368.8
7.650032	458251.7
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7.799998	458927.8

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5.900738	206082.3
5.950088	208943.8
6.000837	204206
6.050611	193518.7
6.100134	179008.2
6.150391	180265
6.19991	186268.7
6.250102	184909.2
6.300001	192583.9
6.349983	205262.5
6.400077	201940.4
6.45013	193245.3
6.500762	186446.1
6.55048	184340.9
6.600226	186126.5
6.650775	183254.4
6.700194	184569.1
6.750347	195053.6
6.800485	194492.8
6.850573	188206.1
6.90044	185864.1
6.950747	185291.7
7.000344	183701.4
7.05089	183322.7
7.100868	183962.6
7.150804	186005.7
7.200338	184163.2
7.250276	183076.8
7.300143	180471.9
7.350211	181428.2
7.400638	181946.3
7.450279	183756.3
7.500297	188054.4
7.550723	185164.9
7.600917	182507
7.650002	179144.3
7.700423	178882.6
7.750271	178280
7.800105	180399.1

7.850474	659337.1	7.850012	458542.7	7.850152	185759.6
7.900202	658736.8	7.900026	458178.3	7.900747	181994.6
7.950378	656817.6	7.95004	457027.5	7.950478	178591
8.000409	657706.4	8.000054	457095.8	8.00061	175942.9
8.050394	658519.4	8.050065	457383.4	8.050791	176500
8.100447	659240.7	8.100079	458275	8.100755	179200.8
8.150606	659871.7	8.150093	456572.9	8.150157	178831.7
8.200416	660648.4	8.2001	457565.8	8.200635	186287
8.250312	661724	8.250106	457677.8	8.250712	186584.7
8.300231	663293.9	8.300119	455990.8	8.300548	183570.5
8.350323	663731.4	8.350134	458088.6	8.350503	176268.3
8.400201	664951.8	8.400148	457965.8	8.400693	172219.3
8.450168	665230.1	8.450158	458565.6	8.450316	170401.3
8.500206	665416.5	8.500172	457775.9	8.500398	173902.9
8.550125	666098.1	8.550186	457795.1	8.550027	173568
8.60004	666828.3	8.600201	458574.2	8.600182	180772.5
8.650104	667713.6	8.650214	457435.2	8.650281	183559.3
8.699963	667474	8.700228	457533.1	8.700603	181626.4
8.750811	667941.7	8.750242	456832.5	8.750572	178691.1
8.799966	666292.4	8.800191	455480.9	8.800859	175747.9
8.850058	665277.2	8.850205	456316.3	8.850821	174852
8.900179	663714.6	8.900219	456431.6	8.90007	173549.5
8.950305	662355.1	8.950207	456385.1	8.950451	175048.8
9.000383	661206.5	9.00022	455576.4	9.000809	178065.1
9.050414	660402.1	9.050235	455177.6	9.050582	172228.7
9.100608	659042.3	9.100248	455803.9	9.100069	179085.6
9.150681	656804.1	9.150199	455803.6	9.150803	179055.8
9.200857	654524.8	9.200212	455001.4	9.200758	172876.2
9.250862	654363.6	9.250227	454321.3	9.250123	172010.6
9.300041	654343.5	9.30024	453394.2	9.30052	176175.1
9.350183	654059.8	9.350253	453936.3	9.350972	175563.9
9.400326	654815.3	9.400267	454186.2	9.400211	173131.5
9.45043	654011.5	9.450281	453235.7	9.450129	172613.9
9.500526	654084.9	9.500287	452441.6	9.500953	175118.7
9.550373	655106.6	9.550293	451937	9.550442	172516.2
9.600327	655534.8	9.600307	451974.4	9.600883	174526
9.650208	654850.8	9.650321	450338.4	9.650598	180122.3
9.70035	656463	9.700335	450628	9.700976	179216.8
9.750414	656919.2	9.750348	450943.3	9.750202	175039.9
9.800321	657447.1	9.800223	450694	9.800333	176192.5
9.850335	657362.5	9.850238	450399.4	9.850761	171812.9

9.900381	658035.7	9.900251	450561.6	9.900864	166914.5
9.950823	657962.1	9.950266	450998.5	9.950605	164122.6
9.999991	657878.8	9.999886	450828.7	10.00007	169188.8

APPENDIX-D

Inter Storey displacement and Drift versus Time

Table D. 1: Inter Storey displacement in the Y-direction versus Time.

First-floor displacement bare frame		Third-floor displacement bare frame		Sixth-floor displacement bare frame	
displacement	time	Displacement	time	Displacement	time
0	0	0	0	0	0
0.109209	0.260356	0.109209	0.539845	0.109209	0.265102
0.337662	2.038937	0.337662	1.937867	0.337662	0.917667
0.687662	9.200632	0.687662	10.43798	0.687662	10.87338
1.037662	7.69817	1.037662	6.933176	1.037662	7.039536
1.318756	6.798332	1.318756	6.903047	1.318756	6.939003
1.521658	-4.21366	1.521658	1.066247	1.521658	7.74756
1.608357	-11.8405	1.608357	-8.49508	1.608357	-7.29915
1.671551	-5.25756	1.671551	-17.6061	1.671551	-20.6558
1.760606	-3.44267	1.760606	-12.1335	1.760606	-22.1242
1.838864	-4.56855	1.838864	-10.1409	1.838864	-2.34851
1.918156	4.642878	1.918156	15.06985	1.918156	4.093139
1.969187	4.173144	1.969187	6.162071	1.969187	25.7567
2.028799	7.997228	2.028799	19.18997	2.028799	18.16674
2.115464	-5.1445	2.115464	8.143912	2.115464	29.26605
2.18326	5.421201	2.18326	1.53365	2.18326	-6.97159
2.2183	15.92435	2.2183	3.354968	2.2183	-23.2414
2.286384	5.978225	2.286384	-8.12242	2.286384	-12.2962
2.345506	19.06186	2.345506	1.892002	2.345506	-2.33513
2.411061	13.07126	2.411061	19.44284	2.411061	25.11087
2.465458	7.753321	2.465458	21.98901	2.465458	41.38547
2.543911	36.69989	2.543911	42.27024	2.543911	41.37541
2.620096	39.9482	2.620096	37.78932	2.620096	59.24836
2.664094	11.5077	2.664094	39.73031	2.664094	64.27508
2.734442	23.79541	2.734442	25.79092	2.734442	50.0225
2.775977	15.50582	2.775977	34.1786	2.775977	19.04274
2.855309	4.59304	2.855309	10.40957	2.855309	19.52267
2.893638	-1.3853	2.893638	1.780136	2.893638	14.37464
2.950725	-3.26969	2.950725	0.335439	2.950725	3.949635
3.020791	2.33726	3.020791	-4.49499	3.020791	3.937688
3.084255	-9.02593	3.084255	-8.83328	3.084255	-9.68154
3.161462	-2.82071	3.161462	2.553296	3.161462	0.027952
3.207933	-14.1089	3.207933	-1.89776	3.207933	17.72466
3.259751	-8.88565	3.259751	-0.36261	3.259751	21.26622

3.294079	-3.7958
3.354141	10.90984
3.420213	4.809409
3.480352	-1.85496
3.5	4.447128

3.294079	12.17935
3.354141	20.94416
3.420213	3.712331
3.480352	3.76518
3.5	11.19529

3.294079	12.22362
3.354141	11.30895
3.420213	33.03421
3.480352	22.48466
3.5	33.59373

First-floor displacement RC jacketed frame	
displacement	time
0	0
0.109209	0.113817
0.340905	1.457942
0.690905	9.10372
0.910298	10.43419
1.107876	7.025423
1.400851	5.282048
1.5656	-6.00574
1.604233	-11.0726
1.691113	-3.06619
1.727255	-4.18301
1.791589	-4.0746
1.852951	-6.24929
1.90428	1.049853
1.973611	-2.32642
2.043894	8.497451
2.121071	-11.3649
2.158761	-3.04042
2.21344	18.06226
2.273088	21.43195
2.335974	18.567
2.391531	15.51328
2.457102	5.058462
2.54876	26.14616
2.611319	30.18603
2.675454	6.111617
2.759344	23.42356
2.853505	16.09518
2.910788	-6.9968
2.969232	-11.8165
3.037667	-6.14294
3.109843	6.544484

Third-floor displacement RC jacketed frame	
Displacement	time
0	0
0.109209	0.04465
0.340905	0.999135
0.690905	9.499256
0.910298	11.06665
1.107876	6.763834
1.400851	4.921942
1.5656	-3.27272
1.604233	-6.09938
1.691113	-8.24493
1.727255	-5.46433
1.791589	-9.92557
1.852951	-6.93569
1.90428	2.534141
1.973611	-3.50785
2.043894	6.852103
2.121071	-3.33178
2.158761	-1.03323
2.21344	12.03157
2.273088	26.04041
2.335974	18.36261
2.391531	21.53763
2.457102	11.37961
2.54876	25.68613
2.611319	22.96052
2.675454	13.55296
2.759344	24.4436
2.853505	8.847796
2.910788	-0.7265
2.969232	-17.7927
3.037667	-15.9285
3.109843	2.828592

Sixth-floor displacement RC jacketed frame	
Displacement	time
0	0
0.109209	0.010841
0.340905	-0.02977
0.690905	10.24172
0.910298	12.22607
1.107876	5.94528
1.400851	3.665626
1.5656	6.686046
1.604233	0.432748
1.691113	-17.4953
1.727255	-26.011
1.791589	-14.4083
1.852951	-2.28752
1.90428	-2.92132
1.973611	1.417068
2.043894	-9.1981
2.121071	17.2639
2.158761	13.70578
2.21344	-1.48342
2.273088	6.970083
2.335974	35.11464
2.391531	21.90031
2.457102	25.01699
2.54876	-1.27529
2.611319	3.124099
2.675454	38.49859
2.759344	29.74224
2.853505	12.1356
2.910788	-7.42098
2.969232	-10.2552
3.037667	-14.3482
3.109843	-20.8483

3.177863	-4.65458
3.236767	-17.9453
3.297239	-9.88916
3.353865	12.47126
3.400829	3.451907
3.464593	-5.21022
3.5	6.24396

3.177863	2.074761
3.236767	-18.3798
3.297239	-4.46886
3.353865	-0.75421
3.400829	1.471753
3.464593	-1.24044
3.5	7.44788

3.177863	-1.7693
3.236767	14.99031
3.297239	-17.5418
3.353865	-29.2649
3.400829	-14.1907
3.464593	14.54422
3.5	19.81582

First-floor displacement CFRP jacketed frame	
displacement	time
0	0
0.091328	0.116662
0.236993	0.488747
0.535799	5.859246
0.736684	9.312397
1.058174	7.741483
1.381924	5.923681
1.556926	-7.05077
1.589675	-12.1384
1.662464	-4.46497
1.720641	-0.4431
1.772672	0.112081
1.836084	-3.99197
1.900053	1.060306
1.966807	-0.65742
2.020123	5.269608
2.098098	-11.4645
2.17625	10.67889
2.209314	25.50212
2.255977	19.38474
2.325239	23.86955
2.391599	24.67879
2.453625	5.177457
2.514872	40.12209
2.570957	33.73399
2.628441	25.99181
2.68033	21.77712
2.735448	32.69075
2.789321	18.88918
2.850299	19.34205

Third-floor displacement CFRP jacketed frame	
Displacement	time
0	0
0.091328	0.020861
0.236993	-0.0198
0.535799	5.351659
0.736684	10.24917
1.058174	7.737811
1.381924	4.992557
1.556926	-2.49741
1.589675	-4.34442
1.662464	-13.3089
1.720641	-5.92353
1.772672	-7.8486
1.836084	-9.56548
1.900053	3.690891
1.966807	-3.29307
2.020123	4.905882
2.098098	-4.43729
2.17625	10.39147
2.209314	18.07664
2.255977	22.18117
2.325239	20.66858
2.391599	33.76312
2.453625	17.33568
2.514872	17.59843
2.570957	37.52055
2.628441	26.49008
2.68033	32.51734
2.735448	33.64301
2.789321	24.65822
2.850299	24.08277

Sixth-floor displacement CFRP jacketed frame	
Displacement	time
0	0
0.091328	-0.0333
0.236993	-0.05698
0.535799	4.119686
0.736684	11.6043
1.058174	7.749412
1.381924	3.46187
1.556926	6.617899
1.589675	1.743802
1.662464	-11.7292
1.720641	-26.7389
1.772672	-16.6086
1.836084	-2.52816
1.900053	-4.55685
1.966807	3.276532
2.020123	-8.13641
2.098098	20.08324
2.17625	-0.06955
2.209314	0.586781
2.255977	8.709917
2.325239	47.43727
2.391599	22.95011
2.453625	45.84299
2.514872	9.960486
2.570957	-12.3748
2.628441	45.91076
2.68033	53.47588
2.735448	34.83841
2.789321	35.80247
2.850299	21.95927

2.894529	16.74517		2.894529	23.00607		2.894529	-1.40154
2.949319	2.140851		2.949319	-6.72786		2.949319	-7.0019
3.014076	-2.24643		3.014076	-7.96091		3.014076	-2.18194
3.072836	16.77913		3.072836	17.40085		3.072836	-18.3333
3.131622	22.23607		3.131622	4.361704		3.131622	-0.46593
3.184475	-3.36782		3.184475	3.409287		3.184475	14.67108
3.235999	-0.52481		3.235999	14.74943		3.235999	21.58612
3.288888	6.375851		3.288888	12.7		3.288888	17.4232
3.345021	21.45728		3.345021	15.12467		3.345021	0.777288
3.396756	22.44216		3.396756	24.50529		3.396756	-5.62133
3.426689	22.15346		3.426689	16.47071		3.426689	10.2391
3.49496	11.36595		3.49496	11.73067		3.49496	47.50751
3.5	14.2039		3.5	15.90942		3.5	49.77428

First-floor displacement steel jacketed frame			Third-floor displacement steel jacketed frame			Sixth-floor displacement steel jacketed frame	
displacement	time		Displacement	time		Displacement	time
0	0		0	0		0	0
0.091328	0.126843		0.091328	0.03681		0.091328	-0.00391
0.226727	0.394257		0.226727	0.052323		0.226727	0.275046
0.387359	2.333546		0.387359	1.680745		0.387359	0.858806
0.595734	7.171952		0.595734	6.933475		0.595734	6.950866
0.735568	9.250128		0.735568	10.22872		0.735568	11.75577
0.902432	9.648953		0.902432	10.77717		0.902432	12.34541
1.060681	7.771092		1.060681	7.945552		1.060681	7.906113
1.223125	5.873166		1.223125	4.374033		1.223125	2.814145
1.360384	5.772735		1.360384	4.708175		1.360384	2.7475
1.549255	-6.93051		1.549255	-1.50587		1.549255	8.282774
1.61857	-12.2504		1.61857	-9.01114		1.61857	-1.50022
1.682662	-1.50142		1.682662	-8.52979		1.682662	-18.5805
1.757253	-2.45564		1.757253	-6.00889		1.757253	-15.9073
1.811363	-6.51589		1.811363	-6.71682		1.811363	-7.53336
1.877234	1.102416		1.877234	-4.91826		1.877234	-5.22202
1.91688	0.02037		1.91688	3.338032		1.91688	-7.8613
1.964713	-1.5682		1.964713	-2.9431		1.964713	3.871331
2.018444	6.934961		2.018444	3.112849		2.018444	-7.37414
2.066995	-0.63195		2.066995	1.764505		2.066995	-6.76434
2.111169	-7.66527		2.111169	-8.33818		2.111169	14.3955
2.152545	6.080555		2.152545	-0.8671		2.152545	9.285229
2.200936	19.73863		2.200936	12.93129		2.200936	-10.275
2.216414	16.90847		2.216414	17.51004		2.216414	-0.75801

2.230503	28.83033
2.252091	11.30319
2.294099	12.80914
2.321757	19.30554
2.353955	20.61412
2.383256	20.97983
2.426893	14.75081
2.455973	0.706573
2.491848	13.59433
2.531259	31.87163
2.563126	39.56858
2.57149	28.41312
2.584423	29.94939
2.613434	22.55548
2.6264	21.22321
2.640492	16.57588
2.674448	17.63181
2.697537	16.66371
2.717387	19.1742
2.746217	20.4246
2.77245	16.71346
2.811522	17.79288
2.831386	20.2815
2.862864	16.00961
2.898577	12.99537
2.938693	-9.59201
2.981447	-10.1639
3.00448	-12.3987
3.038587	0.468334
3.065269	3.387744
3.092733	8.770495
3.125758	-4.0476
3.161862	-16.0984
3.189304	-18.1905
3.212946	-10.8715
3.227819	-13.3188
3.259859	-10.1488
3.285148	-13.6373
3.323075	-0.36849
3.339531	-0.21846
3.363124	-1.08966

2.230503	15.14575
2.252091	20.52617
2.294099	9.583658
2.321757	13.86281
2.353955	28.18821
2.383256	28.5541
2.426893	11.93573
2.455973	15.23462
2.491848	12.27236
2.531259	23.5347
2.563126	27.28988
2.57149	32.17084
2.584423	31.82642
2.613434	19.92326
2.6264	21.2511
2.640492	18.43159
2.674448	18.96594
2.697537	27.12055
2.717387	26.11262
2.746217	28.33529
2.77245	24.52859
2.811522	15.67104
2.831386	13.97227
2.862864	21.60642
2.898577	14.86101
2.938693	-3.09855
2.981447	-21.431
3.00448	-14.838
3.038587	-3.79255
3.065269	0.144103
3.092733	-0.79746
3.125758	-12.3995
3.161862	-12.1415
3.189304	-15.7338
3.212946	-12.9836
3.227819	-10.5107
3.259859	-13.3316
3.285148	-16.702
3.323075	-20.2721
3.339531	-11.8707
3.363124	-6.28839

2.230503	-3.92504
2.252091	4.560543
2.294099	28.82821
2.321757	36.85385
2.353955	16.71853
2.383256	16.15427
2.426893	38.94535
2.455973	39.15099
2.491848	27.04974
2.531259	5.113356
2.563126	-15.326
2.57149	-4.22492
2.584423	9.37846
2.613434	29.88373
2.6264	38.85653
2.640492	33.72577
2.674448	41.06396
2.697537	46.67334
2.717387	34.96545
2.746217	37.64803
2.77245	32.1585
2.811522	38.28819
2.831386	29.16775
2.862864	5.556182
2.898577	6.565532
2.938693	9.559269
2.981447	18.15186
3.00448	2.460707
3.038587	-16.2893
3.065269	-36.27
3.092733	-20.2802
3.125758	-10.1927
3.161862	7.49284
3.189304	2.284783
3.212946	-4.12107
3.227819	-3.1852
3.259859	-12.1751
3.285148	-11.3504
3.323075	-8.72162
3.339531	-23.983
3.363124	-37.5518

3.397396	-0.581
3.431883	-15.2836
3.444466	-23.3542
3.454402	-16.7404
3.477293	-13.4001
3.5	-5.13393

3.397396	-4.40402
3.431883	-12.5246
3.444466	-13.4559
3.454402	-23.1031
3.477293	-26.3002
3.5	-10.4948

3.397396	-20.5932
3.431883	-8.82589
3.444466	4.679186
3.454402	4.165524
3.477293	12.67529
3.5	8.976274

Table D.2: Inter Storey Drift in the Y-direction versus Time.

Story drift one bare frame	
Displacement	time
0	0
0.109209	0.072208
0.337662	0.049694
0.687662	0.660162
1.037662	-0.19506
1.318756	0.275293
1.521658	1.571508
1.608357	1.319284
1.671551	-4.82753
1.760606	-6.23542
1.838864	0.937401
1.918156	9.320167
1.969187	-1.70742
2.028799	8.955493
2.115464	-6.9773
2.18326	-11.9956
2.2183	-1.34892
2.286384	-13.8386
2.345506	7.293449
2.411061	-0.49685
2.465458	-3.86198
2.543911	-0.79578
2.620096	20.57796
2.664094	1.169173
2.734442	14.13264
2.775977	3.852836
2.855309	-6.48333
2.893638	-6.16673
2.950725	7.556098

Story drift three bare frame	
Displacement	time
0	0
0.109209	0.13946
0.337662	-0.09104
0.687662	0.566537
1.037662	-0.34504
1.318756	0.021802
1.521658	3.163899
1.608357	2.75154
1.671551	-7.24182
1.760606	-8.26905
1.838864	-4.7504
1.918156	8.013273
1.969187	3.710572
2.028799	4.131729
2.115464	14.17867
2.18326	-9.66114
2.2183	-12.4287
2.286384	-1.41782
2.345506	-10.2162
2.411061	1.557278
2.465458	15.00824
2.543911	-5.27308
2.620096	-3.15814
2.664094	17.71433
2.734442	-3.59024
2.775977	5.263439
2.855309	1.068658
2.893638	5.183577
2.950725	3.900383

Story drift six bare frame	
Displacement	time
0	0
0.109209	-0.1124
0.337662	-0.34676
0.687662	0.001261
1.037662	0.119681
1.318756	-0.03484
1.521658	1.373262
1.608357	-0.47161
1.671551	-0.46435
1.760606	0.110773
1.838864	-0.12139
1.918156	-0.28173
1.969187	8.244795
2.028799	-3.64007
2.115464	12.7072
2.18326	-2.07756
2.2183	-6.98364
2.286384	1.174784
2.345506	-3.51975
2.411061	3.471647
2.465458	5.029758
2.543911	5.144676
2.620096	9.162109
2.664094	3.68132
2.734442	2.97797
2.775977	-10.1452
2.855309	5.817383
2.893638	-1.2441
2.950725	-7.09172

3.020791	7.180329
3.084255	-9.61505
3.161462	7.263011
3.207933	-2.59511
3.259751	9.154528
3.294079	-3.34447
3.354141	10.16769
3.420213	8.999294
3.480352	8.650008
3.5	-4.91993

3.020791	3.99096
3.084255	-0.66452
3.161462	1.365487
3.207933	11.66099
3.259751	8.103226
3.294079	10.26299
3.354141	7.718442
3.420213	0.40125
3.480352	5.848745
3.5	4.747648

3.020791	7.361004
3.084255	-8.00593
3.161462	-2.06424
3.207933	1.973255
3.259751	2.788689
3.294079	-0.80044
3.354141	4.12667
3.420213	12.22904
3.480352	-2.62444
3.5	11.38236

Story drift one RC jacketed frame	
Displacement	time
0	0
0.109209	-0.01886
0.340905	-0.18931
0.690905	0.245692
0.910298	0.656782
1.107876	-0.04414
1.400851	-0.03619
1.5656	3.882069
1.604233	0.506914
1.691113	1.673188
1.727255	-3.40165
1.791589	6.238745
1.852951	-9.89024
1.90428	-2.28831
1.973611	-2.09192
2.043894	8.105191
2.121071	0.601355
2.158761	-0.85449
2.21344	5.221598
2.273088	-1.57285
2.335974	1.143463
2.391531	8.992027
2.457102	-4.02543
2.54876	-8.2529
2.611319	9.636484
2.675454	0.211742
2.759344	9.71967

Story drift three RC jacketed frame	
Displacement	time
0	0
0.109209	-0.06917
0.340905	-0.45881
0.690905	0.395536
0.910298	0.632453
1.107876	-0.26159
1.400851	-0.36011
1.5656	2.733012
1.604233	4.973251
1.691113	-5.17874
1.727255	-1.28132
1.791589	-5.85097
1.852951	-0.68641
1.90428	1.484288
1.973611	-1.18143
2.043894	-1.64535
2.121071	8.033099
2.158761	2.00719
2.21344	-6.03069
2.273088	4.608456
2.335974	-0.20439
2.391531	6.024347
2.457102	6.321144
2.54876	-0.46003
2.611319	-7.22551
2.675454	7.441339
2.759344	1.020041

Story drift six RC jacketed frame	
Displacement	time
0	0
0.109209	0.02632
0.340905	-0.26468
0.690905	0.135802
0.910298	0.289876
1.107876	-0.24256
1.400851	-0.42114
1.5656	2.855576
1.604233	1.160192
1.691113	-0.82961
1.727255	-8.26352
1.791589	-4.60806
1.852951	1.209279
1.90428	0.182904
1.973611	4.111247
2.043894	-9.19044
2.121071	11.48133
2.158761	5.044582
2.21344	-9.34843
2.273088	-5.3705
2.335974	11.60839
2.391531	-6.23398
2.457102	4.820267
2.54876	-1.78563
2.611319	-13.1872
2.675454	-0.7473
2.759344	4.740961

2.853505	4.836892
2.910788	8.143951
2.969232	4.54803
3.037667	9.188545
3.109843	10.08037
3.177863	7.95758
3.236767	4.373119
3.297239	-4.75072
3.353865	18.1964
3.400829	9.172994
3.464593	7.466454
3.5	1.005703

2.853505	-7.24739
2.910788	6.270306
2.969232	-5.97621
3.037667	-9.78561
3.109843	-3.71589
3.177863	6.72934
3.236767	-0.43444
3.297239	5.420294
3.353865	-13.2255
3.400829	-1.98015
3.464593	3.969785
3.5	1.20392

2.853505	7.568738
2.910788	-7.14156
2.969232	-1.77864
3.037667	-4.67936
3.109843	-6.67747
3.177863	5.765736
3.236767	13.2684
3.297239	0.05666
3.353865	-5.00319
3.400829	-2.80091
3.464593	9.68282
3.5	5.900041

Story drift one CFRP jacketed frame	
Displacement	time
0	0
0.091328	-0.04513
0.236993	-0.17594
0.535799	-0.11358
0.736684	0.368644
1.058174	0.068724
1.381924	-0.21512
1.556926	1.351901
1.589675	0.414848
1.662464	-1.65913
1.720641	-5.37462
1.772672	-3.1837
1.836084	2.418832
1.900053	-1.14266
1.966807	-5.62057
2.020123	-0.52397
2.098098	-5.70735
2.17625	3.812533
2.209314	10.13125
2.255977	8.750332
2.325239	-5.06176
2.391599	16.93252
2.453625	-5.46813
2.514872	5.208874
2.570957	11.37902

Story drift three CFRP jacketed frame	
Displacement	time
0	0
0.091328	-0.04015
0.236993	-0.2484
0.535799	-0.30082
0.736684	0.500837
1.058174	-0.03193
1.381924	-0.49184
1.556926	3.002413
1.589675	4.174266
1.662464	-4.7114
1.720641	-1.5625
1.772672	-0.8774
1.836084	-4.79789
1.900053	3.302229
1.966807	-2.16282
2.020123	-1.81222
2.098098	-0.92047
2.17625	-1.78338
2.209314	-2.87048
2.255977	0.015652
2.325239	-2.50528
2.391599	3.937162
2.453625	5.113679
2.514872	-4.28395
2.570957	-4.5387

Story drift six CFRP jacketed frame	
Displacement	time
0	0
0.091328	-0.02678
0.236993	0.061974
0.535799	-0.38943
0.736684	0.383851
1.058174	0.016074
1.381924	-0.44261
1.556926	2.665483
1.589675	2.247318
1.662464	0.922365
1.720641	-8.66089
1.772672	-4.24785
1.836084	0.245723
1.900053	-2.72051
1.966807	3.988951
2.020123	-4.01758
2.098098	15.9114
2.17625	-2.7458
2.209314	-6.01783
2.255977	-14.1294
2.325239	17.90759
2.391599	-11.3102
2.453625	15.16082
2.514872	-1.63462
2.570957	-24.7207

2.628441	8.66069
2.68033	7.350302
2.735448	17.96943
2.789321	12.5655
2.850299	2.341448
2.894529	4.777962
2.949319	5.514396
3.014076	-6.4496
3.072836	15.20436
3.131622	12.5958
3.184475	13.19554
3.235999	15.49809
3.288888	4.338206
3.345021	17.01741
3.396756	23.70514
3.426689	30.56646
3.49496	5.402513
3.5	3.176157

2.628441	-4.71631
2.68033	12.03021
2.735448	8.167368
2.789321	4.372358
2.850299	1.855762
2.894529	2.970863
2.949319	7.815763
3.014076	4.589247
3.072836	-1.10484
3.131622	-0.06346
3.184475	11.84178
3.235999	2.248124
3.288888	4.868988
3.345021	2.75966
3.396756	-0.00547
3.426689	-0.31741
3.49496	0.598348
3.5	2.27599

2.628441	11.66694
2.68033	8.771099
2.735448	-10.497
2.789321	-4.54142
2.850299	6.481164
2.894529	-3.80639
2.949319	-13.1528
3.014076	-2.15883
3.072836	-11.6541
3.131622	-10.5146
3.184475	-9.47609
3.235999	4.430918
3.288888	6.883205
3.345021	-2.16209
3.396756	-14.7716
3.426689	-11.0664
3.49496	15.21974
3.5	20.81833

Story drift one steel jacketed frame	
Displacement	time
0	0
0.091328	-0.03667
0.226727	-0.15778
0.387359	-0.30199
0.595734	-0.14315
0.735568	0.330871
0.902432	0.485076
1.060681	0.102903
1.223125	-0.4729
1.360384	-0.46727
1.549255	0.416552
1.61857	0.442686
1.682662	-1.48805
1.757253	-3.84216
1.811363	-7.58708
1.877234	4.54683
1.91688	4.980506
1.964713	-5.83787
2.018444	-0.35166

Story drift three steel jacketed frame	
Displacement	time
0	0
0.091328	-0.03811
0.226727	-0.14015
0.387359	-0.32178
0.595734	-0.098
0.735568	0.525999
0.902432	0.596434
1.060681	0.077423
1.223125	-0.79916
1.360384	-0.5938
1.549255	2.987238
1.61857	1.782989
1.682662	-3.31154
1.757253	-4.06768
1.811363	3.075381
1.877234	-5.1255
1.91688	-0.43294
1.964713	-1.49416
2.018444	-0.64436

Story drift six steel jacketed frame	
Displacement	time
0	0
0.091328	-0.01251
0.226727	0.133737
0.387359	-0.22929
0.595734	0.040602
0.735568	0.413354
0.902432	0.42341
1.060681	-0.0633
1.223125	-0.34492
1.360384	-0.60107
1.549255	3.346064
1.61857	2.109224
1.682662	-1.7828
1.757253	1.209789
1.811363	1.227323
1.877234	-3.36578
1.91688	-5.544
1.964713	3.214937
2.018444	-5.9744

2.066995	-2.11895
2.111169	-12.3991
2.152545	-7.66952
2.200936	1.268074
2.216414	1.169238
2.230503	4.463634
2.252091	2.215262
2.294099	-11.9706
2.321757	-10.8465
2.353955	9.051404
2.383256	13.99838
2.426893	7.013576
2.455973	-4.7364
2.491848	-4.34486
2.531259	7.966898
2.563126	13.50295
2.57149	8.749956
2.584423	-5.35829
2.613434	0.626213
2.6264	0.956629
2.640492	2.273026
2.674448	6.970854
2.697537	6.823763
2.717387	3.256603
2.746217	15.0022
2.77245	1.480952
2.811522	-4.37949
2.831386	9.649915
2.862864	6.443597
2.898577	7.441701
2.938693	-1.83476
2.981447	2.220452
3.00448	-11.9364
3.038587	4.180786
3.065269	5.427841
3.092733	8.613094
3.125758	-7.09878
3.161862	-5.06554
3.189304	-2.16429
3.212946	1.982677
3.227819	7.413556

2.066995	6.893575
2.111169	8.956482
2.152545	2.505453
2.200936	-0.6071
2.216414	-8.43552
2.230503	-3.60406
2.252091	-3.21387
2.294099	-2.27008
2.321757	-0.27164
2.353955	5.408562
2.383256	5.206326
2.426893	-1.54575
2.455973	8.755456
2.491848	-0.47899
2.531259	-10.1627
2.563126	-5.19447
2.57149	-6.26521
2.584423	1.667774
2.613434	-5.73479
2.6264	2.166798
2.640492	5.942604
2.674448	6.582531
2.697537	4.51277
2.717387	6.531612
2.746217	1.640875
2.77245	9.839797
2.811522	3.396297
2.831386	-2.05033
2.862864	4.461723
2.898577	0.904208
2.938693	8.166866
2.981447	-1.88819
3.00448	2.265451
3.038587	-7.72094
3.065269	-1.72383
3.092733	-5.40992
3.125758	0.963052
3.161862	1.085649
3.189304	0.849069
3.212946	2.412561
3.227819	-1.63523

2.066995	-10.1411
2.111169	7.781427
2.152545	7.96159
2.200936	-10.5361
2.216414	1.232816
2.230503	-9.76155
2.252091	-2.81558
2.294099	8.376972
2.321757	15.62984
2.353955	-7.42517
2.383256	-11.3883
2.426893	6.772236
2.455973	13.95802
2.491848	9.157505
2.531259	0.372313
2.563126	-27.4973
2.57149	-13.1026
2.584423	0.736572
2.613434	6.356606
2.6264	13.70621
2.640492	-0.28804
2.674448	1.992535
2.697537	12.35536
2.717387	-2.55737
2.746217	4.657928
2.77245	-2.87593
2.811522	10.64139
2.831386	3.620255
2.862864	-9.15201
2.898577	1.347097
2.938693	2.695228
2.981447	18.31424
3.00448	7.38458
3.038587	1.425585
3.065269	-19.4119
3.092733	-2.29759
3.125758	-2.27963
3.161862	14.2876
3.189304	6.155648
3.212946	1.185688
3.227819	5.049787

3.259859	5.186339
3.285148	-7.86848
3.323075	3.172897
3.339531	-4.76247
3.363124	-0.76583
3.397396	9.194671
3.431883	7.168021
3.444466	-6.60981
3.454402	-15.9532
3.477293	-1.35116
3.5	-13.7212

3.259859	2.237325
3.285148	0.54038
3.323075	-15.1463
3.339531	-1.82045
3.363124	-2.80839
3.397396	-10.3952
3.431883	-2.15792
3.444466	4.183568
3.454402	4.350464
3.477293	-7.83708
3.5	3.524121

3.259859	-2.25089
3.285148	1.459566
3.323075	10.7591
3.339531	-1.18939
3.363124	-15.3199
3.397396	4.80101
3.431883	2.563876
3.444466	15.02092
3.454402	7.771792
3.477293	13.33677
3.5	15.2124