

**NUMERICAL INVESTIGATION OF CFST BRIDGE PIERS
UNDER LATERAL CYCLIC LOADING**

PROJECT REPORT

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of

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in

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DEPARTMENT OF CIVIL ENGINEERING

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DECLARATION

I undersigned hereby declare that the project report “Numerical investigation of CFST bridge piers under lateral cyclic loading”, submitted for partial fulfillment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Prof. Bushra M. A., Assistant Professor, Department of Civil Engineering. This submission represents my ideas in my own words and where ideas or words of others have been included; I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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CERTIFICATE

Certified that this report entitled 'NUMERICAL INVESTIGATION OF CFST BRIDGE PIERS UNDER LATERAL CYCLIC LOADING' is the report of project presented by ANJU G, Roll No: TKM20CESC04 during 2021-2022 in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Structural Engineering & Construction Management of the A P J Abdul Kalam Technological University.

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ABSTRACT

Concrete-filled steel tubular columns as bridge piers are appropriate for bridges with very tall piers in seismically active areas because they greatly slow down local buckling of the steel hollow section. Members made of concrete-filled steel tubular (CFST) columns as bridge piers combine the benefits of steel and concrete. Since concrete greatly reduces the ductility of the section and delays local buckling of steel hollow sections. Strength and ductility of the core are improved by the steel tube. Therefore, using CFST columns as bridge piers are more effective than normal RC columns.

This thesis paper is set out to study the effect of certain parameters such as Diameter to thickness ratio, concrete grade and slenderness ratio on the performance of CFST in bridge piers and its benefits under lateral cyclic loading conditions. The study on the behavior of CFST bridge pier and various parameters influencing their behavior are carried out using commercially available ANSYS, FEM software. Predicting the behavior of CFST using the modeling software has become economical and this is time saving. Also comparing their effect of shape of CFST bridge pier such as circular and square and results are in the terms of ultimate load carrying capacity. From the results, load-displacement graph is plotted to give a clear idea on the performance of CFST bridge pier under lateral cyclic loading. It also helps to analyze the variation of parameters like concrete grade, Diameter to thickness ratio and slenderness ratio under lateral cyclic loading.

Keywords: CFST, bridge pier, lateral cyclic loading, diameter to thickness ratio, concrete grade, slenderness ratio, shape comparison, ultimate load carrying capacity.

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ABBERRVIATIONS

CFST	-Concrete Filled Steel Tube
PTCFTs	-Posttensioned Concrete-Filled Tubes
CFTs	-Concrete Filled Tubes
FRCFT	-Fiber-Reinforced Concrete-Filled Tube
PDF	-Peak Dynamic Force
ESF	-Equivalent Static Force

NOTATIONS

Ecc	- Young's modulus of concrete
Es	- Young's modulus of steel
fs	- Yield Stress
fu	- Ultimate Stress
ftk	- Tensile Strength
fck	- Compressive Strength
δ	- Displacement

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete Filled Steel Tubular Columns are widely used in civil engineering structures due to its abundant structural benefits like excellent seismic behaviour, ultimate load bearing capacity, fire resistivity, excellent ductility and energy absorption capacity, particularly in zones of high seismic risk. Concrete-filled steel tubular columns are appropriate for bridges with very tall piers in seismically active areas because they greatly slow down local buckling of the steel hollow section.

Members made of concrete-filled steel tubular (CFST) columns as bridge pier combine the benefits of steel and concrete. They consist of a hollow steel segment that is either circular or rectangular and is filled with either regular or reinforced concrete. They are frequently utilized as columns and beam-columns in high-rise and multi-story buildings as well as beams in low-rise industrial buildings when a reliable and effective structural system is needed. Such structural systems have a variety of benefits in terms of both structural performance and order of construction. The inclusion of the concrete core either prevents or delays the inherent buckling issue associated with thin-walled steel tubes.

Prefabricated and delivered to the job site as a finished component, the steel tube is made in advance. The steel tube is lighter than precast columns and may be installed without the use of sizable cranes. By using CFST, the demands of shoring, erecting temporary formwork, and tying and inserting thin rebar cages are all avoided. If self-consolidating concrete is utilized, the concrete fill can be laid rapidly and without vibration because there is no intervening reinforcement inside the tube. Finally, because less material is needed to attain the same strength and stiffness created in a reinforced concrete (RC) component, CFST can provide lighter, more affordable buildings.

The use of CFST sections can be expected to further improve the inelastic behavior of the steel columns, especially for those with a large width thickness ratio and slenderness ratio. The advantages of the CFST sections are local buckling of plate panels can be delayed or prevented due to the presence of filled in concrete, ductility and strength

capacity can be significantly improved, reduction on use of steel makes the design more economical than standard bridge piers, since the cost of concrete is cheaper than that of steel and maximum displacement response during the shaking of residual deformation after the shaking can be reduced.

Members made of concrete-filled steel tubular (CFST) columns as bridge pier consist of a hollow steel segment that is either circular or rectangular and is filled with either regular or reinforced concrete. They are frequently utilized as columns and beam-columns in high-rise and multi-story buildings as well as beams in low-rise industrial buildings when a reliable and effective structural system is needed. Such structural systems have a variety of benefits in terms of both structural performance and order of construction. The inclusion of the concrete core either prevents or delays the inherent buckling issue associated with thin-walled steel tubes. The steel tubes and the concrete can work together well and the integrity of the steel- concrete interface is maintained. This composite column could also have higher fire resistance than the regular CFST columns, due to the inner tubes being protected by the sandwiched concrete during fire. The thickness of the steel tube wall can be reduced significantly when compared to the steel tube member by itself, and the self-weight is less when compared to the concrete-filled steel tube.

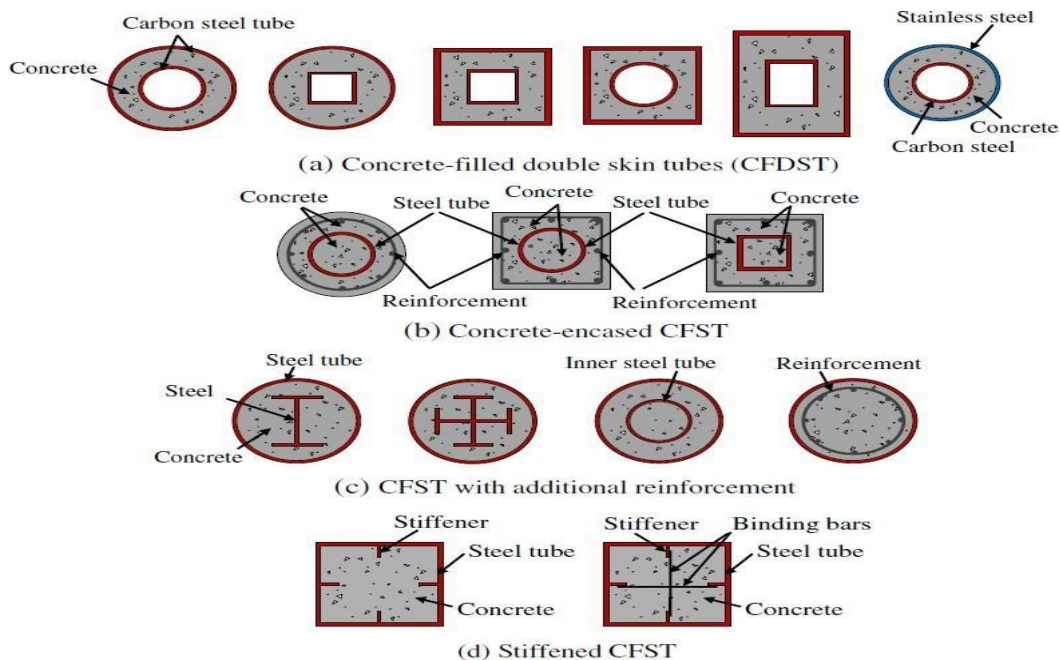


Fig.1.1 General CFST cross sections.

(Source: Han et al.,2014)

The concrete-steel interface is a region where most of the stress transfer takes place in a composite column. The combined action of steel and concrete in this region is integral as it contributes to high strength and ductility of the column. Steel provides lateral confinement to the infill concrete in a passive way and reduces shrinkage of concrete. Circular steel sections are found to provide the strongest confinement compared to rectangular/square, hexagonal and special-shaped sections such as triangular, Fan, D-shaped and semi-circular sections. The confinement of the square/rectangular steel tube to the core concrete is strongest at the corners than at the center. The confinement in elliptical CFST column lies between that in rectangular and circular tube and is a function of the aspect ratio of the section . The confinement effect is assumed to be between those of circular and rectangular CFSTs in hexagonal CFST column and the confinement effect is more at the corner regions than at the center of the core concrete. The confinement is greater at the corners and at the mid-point of the core concrete in octagonal CFST columns and is found to be superior to square CFST columns .

CFST bridge piers are simple, economical and rapidly constructed. The usage of concrete filled steel tube (CFST) piers is appealing because to their compact section dimension, high compressive strength, large stiffness, and superior deformation capacity, especially for high-pier and super-high-pier bridges located in mountains.

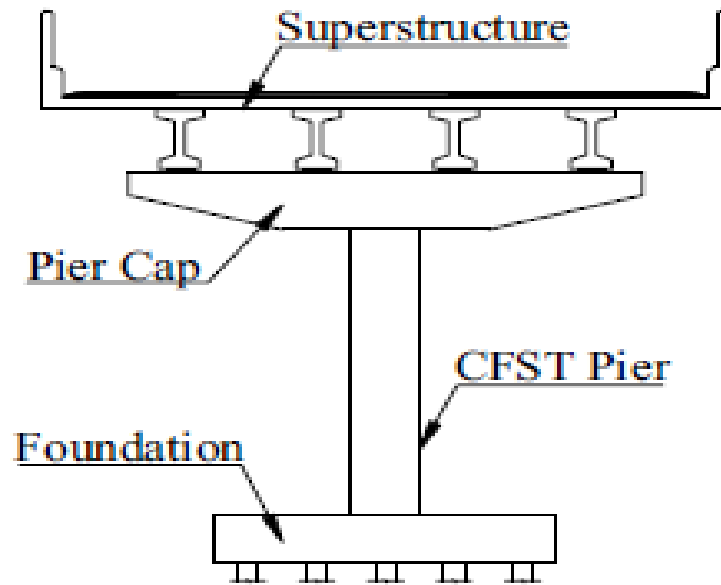


Fig.1.2 Cross section of bridge

Source: Yadav et al.,2017)

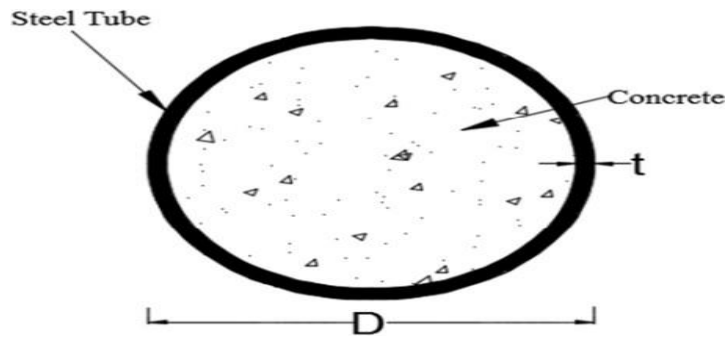


Fig.1.3 cross section of CFST bridge pier

1.2 SIGNIFICANCE OF THE STUDY

In earthquake-prone regions, lateral cyclic loading of CFST sections is important. It is crucial to research the ductility, strength, and stiffness characteristics of CFST sections in places with a high seismic risk. Concrete-filled steel tubes (CFSTs), one of many RC column substitutes, are gaining popularity due to their quick construction, low labor demand, and affordable material cost. By reducing the needed size of the column and expanding the floor surface, the usage of CFST columns results in significant cost savings. Tall structures and bridges in seismically active areas should use CFST columns. Columns made of CFST have been utilized in bridge piers that are impacted by traffic. Columns made of concrete-filled steel tubes (CFSTs) offer a reliable means of effectively resisting both horizontal and vertical ground vibrations. Concrete-filled steel tubes (CFSTs) are used in bridge applications as columns and shafts, providing superior structural performance and ease of construction. Such advantages are primarily because the CFST eliminates the need for embedded reinforcement and supporting formwork. From the standpoint of structural engineering, CFST columns have a higher load-bearing capacity than typical RC columns due to the composite action between the concrete core and surrounding steel tube. By making the column slenderer, the concrete core helps to prevent both local and global buckling. Analytical study on seismic behavior of CFST bridge piers gives proper understanding of actual behavior of CFST bridge pier under cyclic loading. CFST piers provide a superior performance under the vehicle impact forces. This has been confirmed by monitoring the strain in the steel tube, which always remains far below its critical level. Analysis of lateral load carrying capacity of CFST bridge pier under cyclic load condition by varying parameters gives idea about design of bridge piers in high seismic risk zone. Utilizing the CFST idea might result in a 60% overall steel savings when compared to a structural steel system. Steel tubes were also

employed as permanent formwork and to strategically place reinforcement that was evenly distributed. A higher flexural strength is obtained as a result of the concrete core's ability to postpone local buckling and drive the steel tube to buckle outward rather than inward. Because of this, tubes with thinner walls may attain the yielding strength prior to local buckling. The steel tube limits the concrete as it is compressed axially, increasing the CFST members' axial load resistance and ductility.

1.3 OBJECTIVES

Research objectives developed as follows:

1. To study the seismic behavior of CFST bridge piers under cyclic loading by using ANSYS.
2. To study the effect of Shape of CFST bridge pier having rectangular and circular cross sections.
3. To analyze the effect of lateral load carrying capacity of circular CFST bridge pier by varying Diameter to thickness (D/t) ratio, slenderness ratio and grade of concrete

1.4 SCOPE

The study is restricted to the following domains:-

- In this parametric study is about parameters such as Diameter to Thickness(D/t) ratio, grade of steel, grade of concrete and slenderness ratio.
- Shape comparison of CFST rectangular and circular column sections of bridge pier.
- Nonlinear static analysis
- Analytical study using ANSYS.

CHAPTER 2

LITERATURE REVIEW

2.1 CFST BRIDGE PIER

Ma et al. (2018) conducted parametric analysis to investigate the influence of various parameters on load-displacement (P-D) envelope curves based on CFST bridge piers. The parameters include the material strength, the steel ratio of inner CFST, the wall thickness to sectional width ratio, the longitudinal reinforcement ratio, and the axial load level. Finally, a simplified hysteretic model for the P-D relationship of a concrete encased CFST pier is proposed. It was found that the ultimate strength, ductility, and energy dissipation capacity of the members were improved with the increase of steel fibre content and volumetric stirrup ratio.

Roeder et al. (2018) conducted an experimental research study which included 19 CFST Pier-to-footing (or pile-cap) connection tests and 8 CFST pier column-to-precast pier cap tests was performed. These connections provide good performance under both seismic and gravity loads and address the concerns of US construction. From the comparison of cap beam experiments clearly demonstrates the different behaviours of the proposed connections as well as the influence of varying parameters on each connection type. The ER cap beam connections exhibited larger stiffness and strength than the WD and RC connections.

Deng et al. (2012) investigated the flexural behaviour of concrete-filled circular steel tubes under high-strain rate impact loading. Nine simply supported circular steel concrete-filled tubes (CFTs), two circular steel posttensioned concrete-filled tubes (PTCFTs), and one circular steel fiber-reinforced concrete-filled tube (FRCFT) have been tested in an instrumented drop-weight impact facility. The weight and the height of the drop-weight were varied to cause failure in some test specimens. Failure in the steel tubes was commonly tensile failure or rupture along the circumference. The use of prestressing strands and steel fibres significantly restrained the concrete tension cracks in the PTCFT and FRCFT specimens, respectively.

Saini et al. (2019) studied the performance of concrete-filled steel tube bridge columns subjected to vehicle collision. For this purpose, representative finite-element (FE) models are developed and validated with the experimental test results. The structural

performance is evaluated using a comprehensive set of measures, including peak dynamic force (PDF) and equivalent static force (ESF). They concluded that the maximum shear forces extracted from the simulations revealed that CFST piers can resist significantly larger lateral forces than RC piers of the same size.

Dagim et al. (2020) studied the behaviour of reinforced concrete hammerhead pier caps using finite element analysis software ANSYS. The parameters taken into consideration are important properties of both steel and concrete, shear span to depth ratio and flexural reinforcement ratio. The findings show that stress is decreased while change in steel grade has no significant effect on the behaviour of pier caps. The shear strength predictions using Strut and Tie models were found to be more conservative compared to the finite element method.

Han et al. (2014) studied the developments and advanced applications of concrete-filled steel tubular (CFST) structures. The characteristic of these concrete-filled steel tubular members is that the structural properties can be improved due to the “composite action” between steel tube and filled concrete. The concrete-filled steel tubular structure can be treated as an alternative system to the steel or the reinforced concrete system. The thorough comparison of advantages and disadvantages of the CFST system with the steel and RC system, the space truss structural system, the connection system, the hybrid system using high performance and sustainable materials as well as the life-cycle performance evaluation should be conducted in the future.

Wang et al. (2016) studied the seismic performance of concrete encased CFST piers. In this study, eight concrete-encased CFST box specimens and eight RC box counterparts were tested. The experimental parameters were the axial load level and cross-sectional type of the column. Results concluded that the CFST components can be used in a RC box pier to improve its performance, including lateral resistance, ductility, energy dissipation capacity, and stiffness degradation. The embedded corner CFST components also improve the integrity of the composite pier.

Ou et al. (2013) studied the practice of concrete filled steel tube piers to bridges. In study, it reviews available information concerning the application and development of CFST piers. Three bridge examples are then introduced, while the structural design and the construction methods of CFST column piers are described in detail. Furthermore, main parameters of CFST piers, such as slenderness ratio and material strength are

concluded. Finally, the future research direction of CFST column piers is viewed. Study concludes that CFST column piers, especially CFST laced column (or hybrid column) piers will have promising application prospects for the foreseeable future. In addition, CFST column piers can also be applied in railway bridges. For highspeed railway, CFST structures have large stiffness can be utilized to decrease the longitudinal and lateral vibration of bridges.

Kitada et al. (1998) studied the ultimate strength and ductility of state-of-the-art concrete-filled steel bridge piers in Japan. From the studies concluding that the stiffness, strength and ductility of a composite column are considered to be greater than those of thin-walled steel columns with the same cross-section as the outer steel plates of the composite column, because the encased concrete itself gives stiffness and strength, and also because the buckling deflection of the outer steel plates toward the inside of the box cross-section is prevented by the encased Concrete.

Yadav et al. (2017) experimentally investigated some scaled models of similar type of CFST RC pier are carried out under cyclic loading, the hysteretic performance of CFST RC columns, load displacement hysteretic curves, strength and stiffness degradation. Results shows that strength of CFST Reinforced concrete columns are increased, stiffness reduced, ductility of the specimen improved.

Badarlo et al. (2019) studied numerically on the effect of concrete grade on the CFST circular column's behaviour under axial Load. In this research, a CFST column with specific dimensions is modeled by using ABAQUS finite element software and CFST columns with C20, 30, 40 & 50 concrete cores were modeled with and without reinforcement, and the effect of concrete grade on the capacity of column was studied. In addition, MATLAB software was used to obtain beta index and load capacity design for the CFST column. The results demonstrated that the columns designed in accordance with the AISC have a good performance under the cyclic and static loading.

2.2 CONCRETE FILLED STEEL TUBES UNDER CYCLIC LOADING

Marson et al. (2004) investigated the adequacy as energy dissipating elements during earthquakes by conducting cyclic inelastic tests to determine the maximum strength and ductility of four concrete-filled circular steel piers joined to a foundation detail proposed to develop the full composite strength at the base of these columns. The ductility of all tested columns was found to be good, all columns being able to reach

drifts of 7% before a significant loss in moment capacity occurred as a result of cracks opening on the local buckles, suggesting that concrete-filled steel tubes can be effective as bridge piers in seismic regions.

Goto et al. (2012) develops and studied the FE model is to examine the behavior that enhances the seismic performance of RCFT columns. The main objective of developing the present accurate FE model is to examine the behavior that enhances the seismic performance of RCFT columns. Studies concluding that after local buckling occurs under alternate horizontal load, the axial force acting on the steel tube of RCFT columns gradually changes its centre of oscillation from compression to tension with the increase in horizontal displacement amplitude. This tensile axial force restrains the progress of local buckling deformation. At the same time, the compressive force is mostly resisted by in-filled concrete in which the compressive strength is enhanced by the confinement from the steel tube.

Fam et al. (2004) conducted an experimental work and analytical modeling for concrete-filled steel tubes subjected to concentric axial compression and combined axial compression and lateral cyclic loading. The objective of the study is to evaluate the strength and ductility of CFST short columns and beam-column members under different bond and end loading conditions. Both bonded and unbonded specimens were tested, including application of the axial load to the composite steel-concrete section and to the concrete core only. Research findings indicate that the bond and end loading conditions did not affect the flexural strength of beam-column members significantly. On the other hand, the axial strengths of the unbonded short columns were slightly increased, compared to those of the bonded ones, while the stiffness of the unbonded specimens was slightly reduced.

Usami et al (1997) studied the behaviour of partially filled concrete filled steel tubes under cyclic and dynamic loading. They conducted experiments on nine concrete filled steel tubes under static and dynamic loading and considered some parameters such as diameter to thickness ratio, no. of loading cycles, length of filled in concrete on the column behaviour are studied. To investigate the dynamic behaviour of concrete filled steel box columns, three specimens with different natural periods were tested by pseudo dynamic method. And the final results showed that concrete filled tube structures can be effectively used as bridge structures to resist severe earthquakes.

Sui et al. (2020) studied the hysteretic mechanical behaviour of an eccentrically loaded partially-concrete-filled steel tubular bridge pier under out of plane horizontal cyclic loading. To investigate the hysteretic behaviour of an eccentrically loaded partially-concrete-filled steel tubular (PCFST) bridge pier in an out-of-plane horizontal direction, a quasi-static experiment and finite element (FE) analysis of steel tubular columns were carried out. In this study, four PCFST column specimens were tested under constant eccentrically loaded and out-of-plane horizontal cyclic loading. The elasto-plastic behaviour and failure mode of these specimens were investigated. Finally, an empirical formula was proposed to describe the ultimate strength and ductility of such bridge piers for engineering application under complicated loading conditions.

Y. F. Yang et al. (2012) have examined the behaviour of CFST under partial compression by considering different parameters, namely cross-sectional shape, length to diameter ratio and partial compression area ratio. The study was carried out by testing twenty-six specimens of CFST by varying the above parameters and their behavior was also verified by developing a finite element model using ABAQUS software. The study shows that the behaviour of partial compressed CFST section is similar to the behaviour of fully compressed CFST section. Also, it is possible to predict strength of partial compressed CFST section using mathematical model proposed by researchers.

H. Eramma et al. (2014), studied the compressive behaviour of triangular and rectangular fluted reinforced circular CFST column with varying length to width (L/D) ratio. The compressive strength of CFST columns were obtained by experimentally and analytically. Analytical results of CFST column calculated using codes EC-4, ACI- 318 and AISC. In this study the experimental strength results of CFST columns were founds higher than the analytical strength results calculated from methods given in above codes; hence the researchers had suggested that the equations given in above codes cannot be directly used to calculate the compressive strength of the fluted CFST column.

Burak Evirgen et al. (2014), they investigated the compressive behavior of CFST section considering various cross-sectional shapes like circular, hexagonal, rectangular and square. Experimental study was carried out by varying B/t (Breadth to thickness) ratio and grades of concrete. The obtained results of experimental study were compared with software results calculated by developing a finite element model using ABAQUS software. In this study, researchers observed that the concrete core of CFST resists the

inward buckling of steel tube and steel tube provides better confinement to concrete core which results increase in the strength of CFST section. The study also shows that the ductility of the circular CFST section is more than hexagonal, rectangular and square CFST sections.

Zhang Huifeng (2012), studied the compressive behavior of circular CFST section with provision of the separation gap between inner concrete core and steel tube. Study is carried out with different parameters such as gap depth, strength of concrete, yield stress of steel, thickness of steel tube and eccentricity of the load. The Finite Element model is developed by using ABAQUS software and their results are compared with test results. The results indicate that the strength of CFST section decreases with increasing depth of the gap and eccentricity of the load. Also, it is observed that the thickness of steel tube helps to improve the strength of CFST section due to confinement effect.

2.3 EFFECT OF SHAPE ON PERFORMANCE ON CFST COLUMN

Yuan et al. (2018), they conducted a study of displacement ductility of staged construction-steel tube-reinforced concrete columns. An FE model was proposed for staged construction of ST-RC columns. The proposed FE model was able to predict the lateral stiffness, strength and deformation capacities. To improve the overall deformation capacity of the STRC columns, the key is to ensure the inner CFST and peripheral concrete encasement cooperate with one another to exert their respective advantages.

Han et al. (2009), they conducted a study on performance of concrete filled steel tube reinforced concrete columns subjected to cyclic bending. This paper reports nine test results of ST-RC columns, which were tested under constant axial load and cyclically increasing flexural loading. Axial load level and cross-sections were varied. Strength, ductility, stiffness and energy dissipation was investigated ST-RC columns are found to be showing good seismic performance.

Li et al. (2017), they carried out a study on “Concrete-encased CFST columns under combined compression and torsion: Experimental investigation”. The composite columns are subjected to combined compression and torsion under earthquake loads. A total of 26 tests were conducted on three types of specimens, i.e., concrete-encased CFST columns, hollow reinforced concrete (RC) columns without inner CFST components and conventional CFST columns. The tested concrete-encased CFST

columns under combined compression and torsion behaved in a ductile manner owing to the existence of the inner CFST component.

Sheta et al. (2016), they studied about experimental study on circular and square concrete filled steel tube columns subjected to axial compression loads. This paper investigates the behaviour of concentrically axially loaded circular and square high strength steel columns filled with different grades (M20, M30 & M40 etc.) of concrete. Performance indices such as Ductility index, Strength factor and Concrete contribution Ratio were also evaluated and compared. From the results, it has been noted that square columns have higher axial capacity. But the Ductility index for circular columns is better than square columns.

Hua et al. (2017), they conducted a study of experimental behaviour of tapered CFST columns under combined compression and bending. This paper researches on the structural performance of tapered composite columns under combined compression and bending. The test parameters included sectional type, tapered angle, slenderness ratio and load eccentricity. It is found that Tapered CFST columns behaved in a ductile manner when subjected to combined compression and bending.

Zhou et al.(2018), they conducted a study on concrete-encased CFST structures based on their behaviour and application. This paper initially reviews the recent research on concrete-encased CFST Structures. The major research findings on bond performance, static performance, dynamic performance and fire resistance are presented. This paper also outlines some construction considerations, such as the utilization of materials, the fabrication of the steel tube, and the methods of casting the inner and outer concrete some typical practical projects utilizing concrete-encased CFST members are presented and reviewed.

2.4 SUMMARY OF THE LITERATURE REVIEW

Based on the literature survey we understood that there are different parameters that can affect the performance of CFST specimens subjected to cyclic and axial loading. Based on the previous studies we found that thickness of steel tube, diameter of steel tube, length, concrete grade, steel grade etc can affect the behaviour of CFST specimens. And also, compressive behavior of circular CFST section is studied with provision of the separation gap between inner concrete core and steel tube. Strength, ductility, stiffness and energy dissipation of CFST specimens was studied and they were found to be showing good seismic performance.

2.5 RESEARCH GAPS

The research gaps identified from the literature survey are as follows: -

- There are few studies that Investigating the lateral load carrying capacity of CFST bridge pier under cyclic loading condition by changing the D/t ratio, steel grade ,concrete grade and slenderness ratio.
- Lesser number of literatures are available for the comparative numerical study on seismic behavior of CFST bridge piers having circular and rectangular cross sections.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

Concrete filled steel tube (CFST) columns are widely used in civil engineering structures due to its abundant benefits like excellent seismic behaviour, ultimate load bearing capacity, excellent ductility, fire resistivity and energy absorption capacity particularly in zones of high seismic risk. Therefore, the model for parametric study is built using ANSYS software. For conducting the analysis, the first step is the validation of ANSYS software based on the data from analytical study conducted by Yadav et al. (2017). For the fulfilment of the defined objectives, the steps followed are modelling of circular CFST bridge pier using codes GB50010 and GB50017, nonlinear static analysis, parametric study, shape comparison and development of load displacement curves and also comparative study. The parametric study provides better understanding of effect of parameter under lateral cyclic loading. Also, a comparative study on the effect of shape of CFST bridge pier having rectangular and circular cross sections under lateral cyclic loading. And also analyzing the effect of lateral load carrying capacity of circular CFST bridge pier by varying Diameter to thickness (D/t) ratio, slenderness ratio and grade of concrete. The methodology of the project is outlined as flowchart in the figure 3.1 shown below.

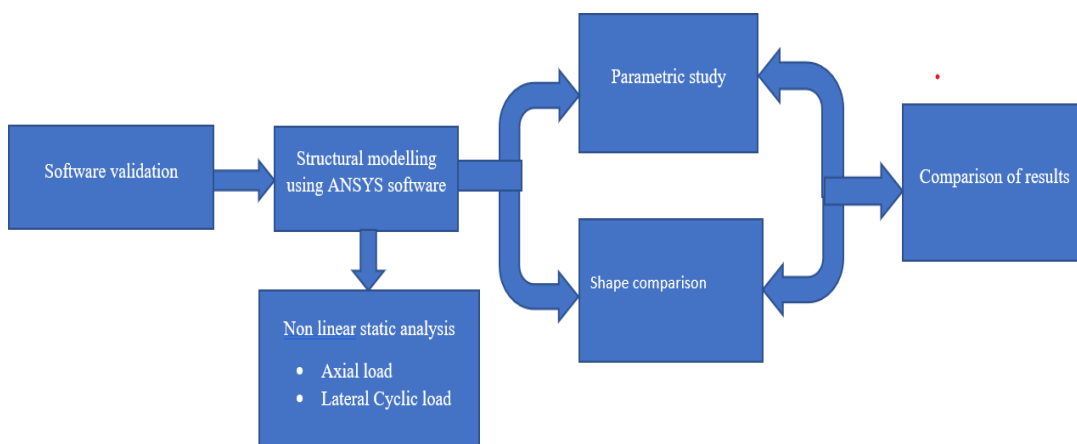


Fig.3.1 Flowchart of methodology

3.2 GEOMETRIC MODELLING

A finite element model using ANSYS software is used for obtaining analysis results. Finite element method considers to be the best tool for analyzing the structures properly. The most popular and the easiest software to learn is Ansys Workbench, it combines the strength of core product solvers with the project management tools necessary to manage the workflow. For the concrete, it's been used the Drucker Prager model is used for the 3-dimensional modelling of solids. Ansys is divided into modules where each module defines the aspects of modelling. The first stage of modelling is giving engineering data where the properties of CFST steel and concrete are added. Next stage is geometric modelling where the shape and size, material properties, coordinate systems, connections that whether it is bonded or non-bonded, meshing, giving supports and addition of forces that acts in the system are added and finally its solution in the form of deformation. The last stage will be the visualization and showing results in the form of hysteretic curves.

3.3 NON-LINEAR STATIC ANALYSIS

Concrete filled steel tube column is subjected to nonlinear static analysis. In ANSYS, the nonlinear solution process is based on the fundamental assumption of the Newton-Raphson algorithm that the nonlinear response of the composite structure is sufficiently smooth at both the global and local levels. However, in a progressive failure simulation, the nonlinear response of the composite structure is not smooth, especially at the local level where material failure results in an instantaneous reduction of material moduli. This non-smooth material response is one of the primary factors responsible for the difficulty in obtaining convergence in progressive failure simulations. In a nonlinear solution in ANSYS, there are three distinct levels: (1) Load Steps, (2) Sub steps, and (3) Equilibrium Iterations. The number of load steps is specified by the user. Different load steps must be used if the loading on the structure changes abruptly. In this study doing 31 sub steps to get equilibrium iterations and solving the solution. Here considered material and geometric non linearity to solve the CFST system under lateral cyclic loading. A load-step should be thought of as a set of constraints/loads that are being solved for while the sub-steps are how you transition from one loading environment to the next. To facilitate convergence, we consider sub-steps to apply load gradually. The NEQIT command is used to specify the minimum number of equilibrium iterations that must be performed before ANSYS evaluates the need for cutting-back

the size of the current sub step. Helius PFA significantly improves the overall convergence rate and robustness of progressive failure simulations of composite structures. However, to take full advantage of the superior convergence characteristics, you must change some of the default settings that govern the nonlinear solution process used by ANSYS.

1. Axial load: The top end of the column is free allowing displacements to take place in all directions. The constant compressive loading in axial direction is applied on the top of the column.
2. Lateral cyclic loads are applied. ATC-24 loading protocol was used for the cyclic loading.
3. From the results, load displacement graph is plotted to give a clear idea on the performance of CFST bridge pier under lateral cyclic loading. It also helps to carry out a comparative study between the performance of circular and rectangular bridge pier and its parameters like concrete grade, Diameter to thickness ratio and slenderness ratio.

3.4 SHAPE COMPARISON

Studying the effect of various sectional shapes of CFST bridge pier under lateral cyclic loading. For that, considering cross sections such as rectangular and circular for CFST bridge pier under lateral cyclic loading and obtaining load- displacement curves to find its lateral load carrying capacity.

3.5 PARAMETRIC STUDY

Hysteretic behaviour of CFST bridge pier is affected by the diameter to thickness ratio (d/t), concrete grade, slenderness ratio, concrete compressive strength. Here biaxial kinematic hardening property of concrete is considered for the parametric study. Three parameters are considered for the parametric study of CFST bridge pier.

3.5.1 Diameter to thickness ratio

The performance of concrete-filled steel tubular columns increases by increasing the thickness of steel tube.

3.5.2 Slenderness ratio

Greater flexibility, larger sideways displacement at the mid-height and lesser stiffness is observed in columns with large slenderness ratio.

3.5.3 Concrete grade

As the concrete grade increases the ultimate load carrying capacity also increases.

3.6 COMPARITIVE STUDY

In the visualization module the results of the analysis are displaced. By solving non linearities we get the solution in terms of deformation, lateral load carrying capacity. The load displacement graphs obtained during each parametric study and shape comparison are analyzed and results are compared in terms of lateral cyclic load carrying capacity.

CHAPTER 4

VALIDATION

4.1 GENERAL

The ANSYS software validated using the results published by Yadav et al. (2017). He conducted experimental and numerical studies to realize the behaviour of CFST columns under lateral cyclic load. He created five different models by using different thickness of steel to study the effect of increase in thickness of steel on behaviour of CFST column. Further give different columns are created by using different concrete cube to study the effect of concrete grade on behaviour of CFST column and another five different models are created to study the effect of slenderness on behaviour of CFST column. The failure studied criteria includes ductility, stiffness degradation and energy dissipation capacity.

4.2 HIGHLIGHTS OF ANSYS

Finite element method considers to be the best tool for analyzing the structure recently, many software's uses this method for analyzing and design. Ansys Workbench makes it easier to make more informed design choices by coordinating all your simulation data in one place. In ANSYS there many analyses can be done and one is static structural analysis in which it determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Static structural analyses are used for simple linear calculations as well as complex material, geometric and contact nonlinear calculations. The analysis results help to identify weak areas with low strength and durability. Ansys offers structural analysis software solutions that enable engineers of all levels and backgrounds to solve complex structural engineering problems faster and more efficiently.

4.3 VALIDATION OF SPECIMEN

CFST column was modelled and validated in the ANSYS software to predict its actual mesh size by mesh convergence study to get actual values and analyze its load displacement behavior.



Fig.4.1 Flowchart of validation

4.3.1 Modelling

The experimentally analysed model was simulated in ANSYS software. The overall height of the CFST column is taken as 5000mm and its diameter is 1000mm. Thickness of steel used for CFST column is 14mm. Material properties of the steel and concrete is mentioned in table 5.1.

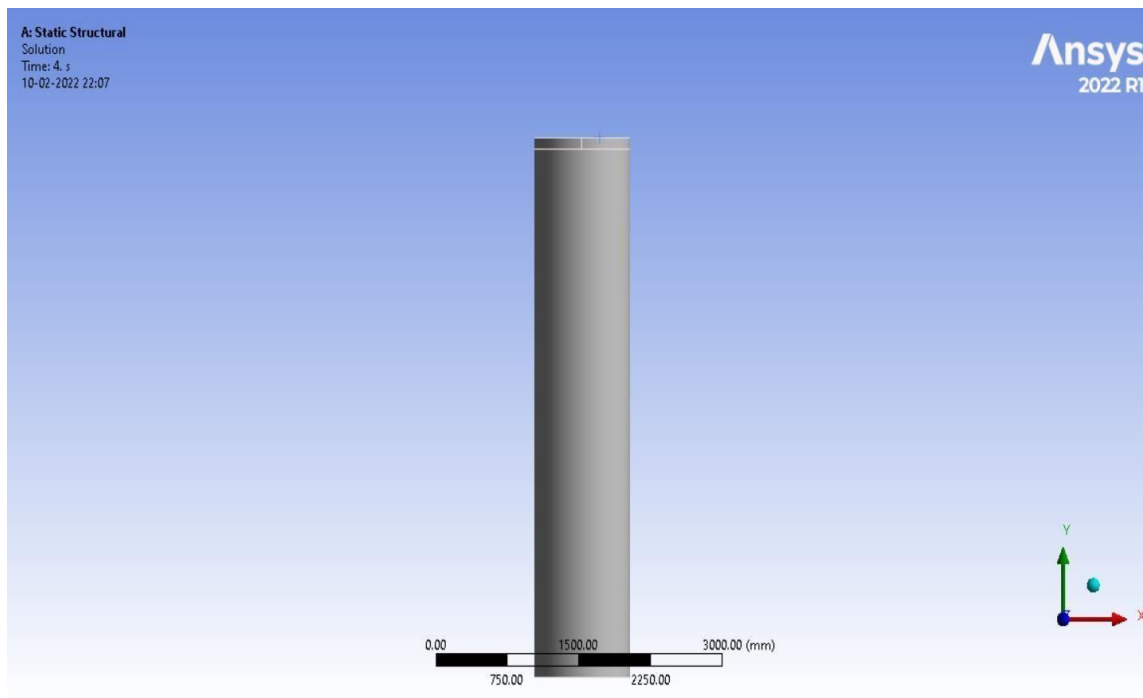


Fig.4.2 modelled CFST bridge pier

4.3.2 Assigning materials

The material used in the verification model was of steel grade Q345 and the concrete used are C30. For assigning materials, Drucker Prager model was used for assigning properties of concrete. Young's modulus (E_c), compressive strength (f_{ck}), Poisson's ratio and tensile strength (f_{tk}) of confined concrete are taken from GB50010. Different properties of steel such as, Young's modulus (E_s), yield stress (f_s), Poisson's ratio and ultimate stress (f_u) are taken from GB50017.

Table 4.1 Concrete properties of CFST column from analytical data

INPUT PARAMETER	CONCRETE (C30)
Young's modulus	26700MPa
Poisson's ratio	0.2
Uniaxial compressive strength	20.1 MPa
Biaxial compressive strength	2.01 MPa
Biaxial compressive strength	24.1 MPa

Table 4.2 Steel properties of CFST column from analytical data

INPUT PARAMETER	Steel (Q345)
Young's modulus	266000 MPa
Poisson's ratio	0.3
Yield strength	345 MPa

4.3.3 Contact behaviour

The contact behavior between different geometrical parts in the FEA model should be well considered. In this study, the interaction between the concrete core and the steel tube could be considered as bonded and considering there is no friction between concrete core and steel tube. First, the interaction between the steel tube and core concrete should be simulated. Here assumed that there no friction between the steel and concrete so value will be zero.

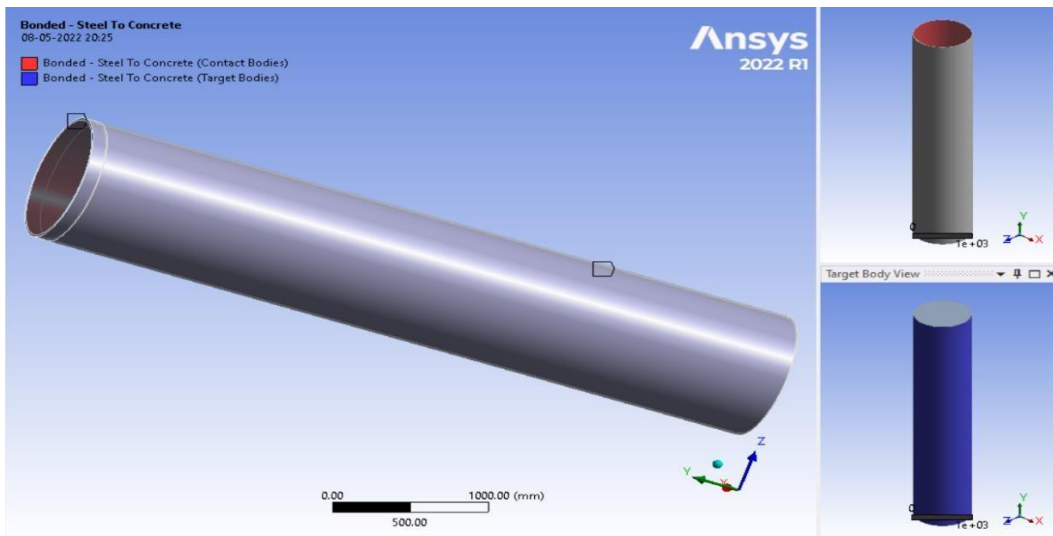


Fig.4.3 Connections between CFST steel and concrete

4.3.4 Meshing

The finite element model was verified through mesh convergence analysis. Mesh convergence analysis is carried out in order to verify the finite element models and obtain finite element mesh density. Tetrahedral solid elements were used for meshing. The figure below shows the meshed CFST column.

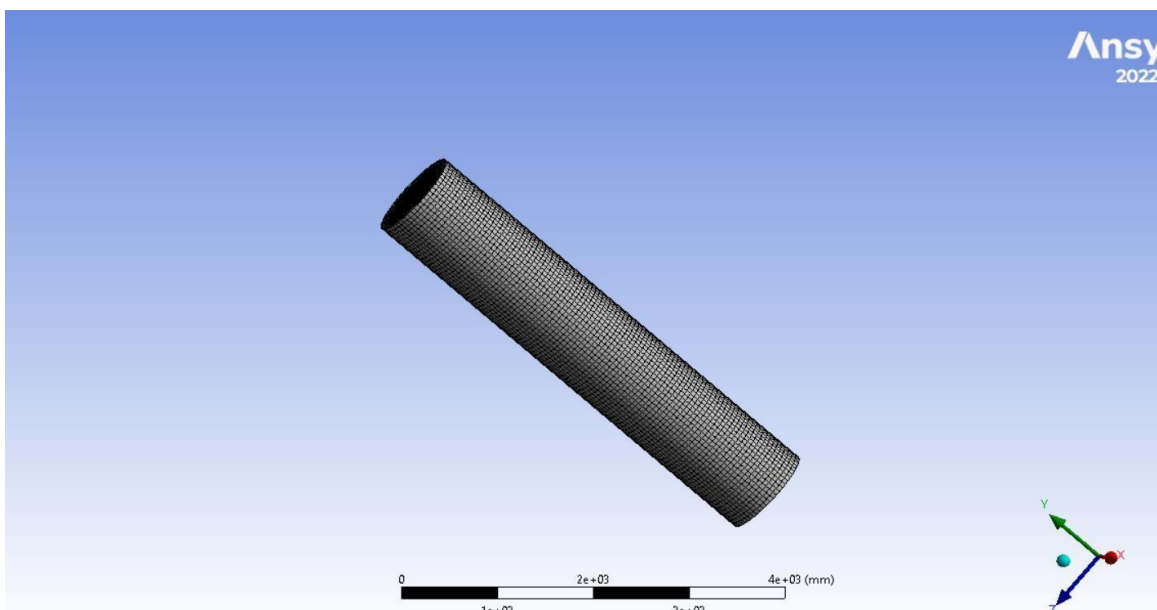


Fig.4.4 Meshed CFST column

4.3.5 Loading

For axial loading, a vertical load is applied on the top of the column. The load from the superstructure is taken as the 15% of the nominal axial capacity of the CFST pier. An arbitrary value of 0.5 KN load was given as the Y component in ANSYS. And the cyclic load was given to the CFST bridge pier using ATC-24 loading protocol (fig 5.5). Displacement controlled loading was used for the test. For the first load, 1mm was used, and three load step is applied before yield displacements. The displacements were denoted as δ , following the which the cyclic load steps were integer multiples of δ , such as 2δ , and 3δ , the loading cycle was repeated three times at each load step.

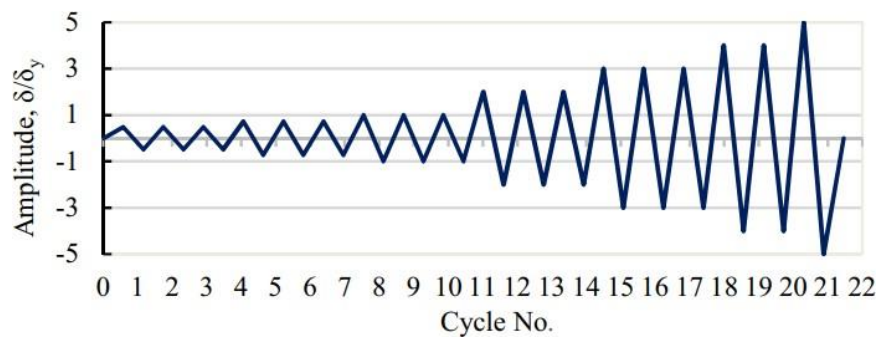


Fig.4.5 ATC-24 protocol

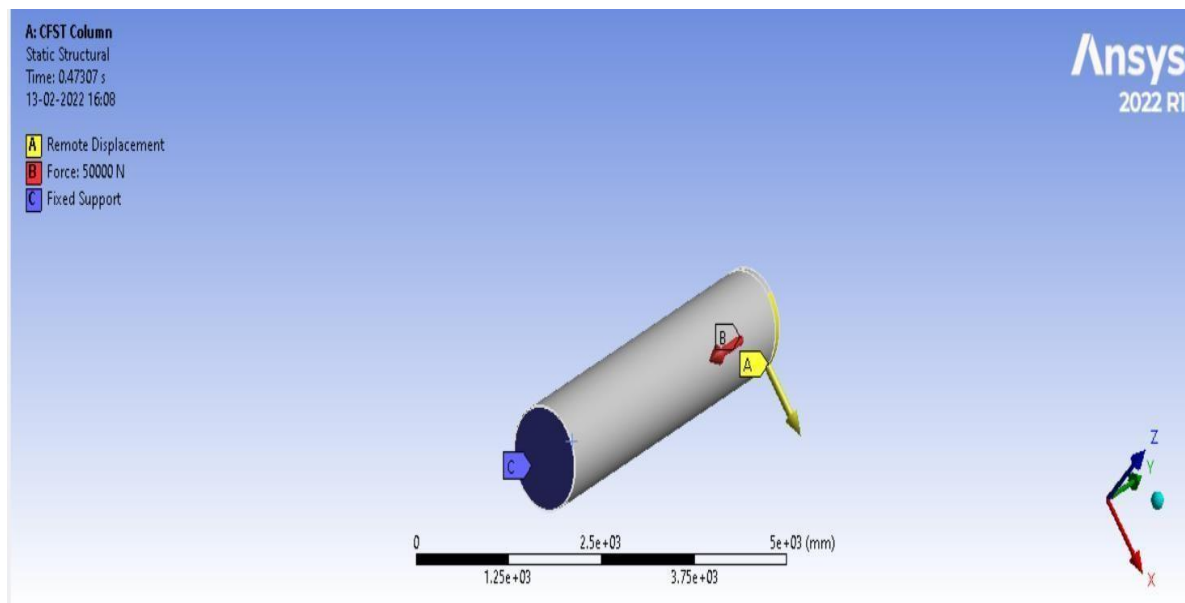


Fig.4.6 Load applied

4.3.5.1 cyclic pushover analysis

The main feature of the CPA is the cyclic approach adopted to manage the loading pattern. During the CPA the forces are applied in one direction (e.g., positive) and scaled until a predetermined displacement is attained. Then, the load distribution is reversed and starts to increase again until the second peak displacement is reached. This back-and-forth loading is repeated in cycles, according to the selected loading protocol. The goal of the loading protocol is to replicate the load and deformation histories induced in the structure and/or in its components by an earthquake. As a consequence, the seismic response thus obtained is cyclic. Based on this cyclic response, a backbone curve, which is characterized by a softening branch because of the cyclic degradation, can be obtained.

4.3.6 Boundary conditions

The bottom end of the column is fixed and another end is free. Free end is subjected to constant axial load and cyclically increasing lateral loading. Displacements in x, y and z directions are zero as boundary condition for bottom of column. The constant compressive loading in axial direction is applied on the top of the column. Lateral load is applied on the top of the column. The load from the superstructure is taken as the 15% of the nominal axial capacity of the CFST pier.

4.3.7 Results and discussions

The load and displacement value from the analytical analysis of reference journal (Yadav et al. (2017) and validated values are given below Fig 6.1.

Table.4.3 Comparison of lateral load and displacement values

Parameters	From analytical analysis (OPENSEES)	FE Modelling (ANSYS)	Percentage variation
Lateral Load (KN)	1091.73	1023.27	6%
Displacement(mm)	200.69	196.28	2.19%

Load-Displacement Graph

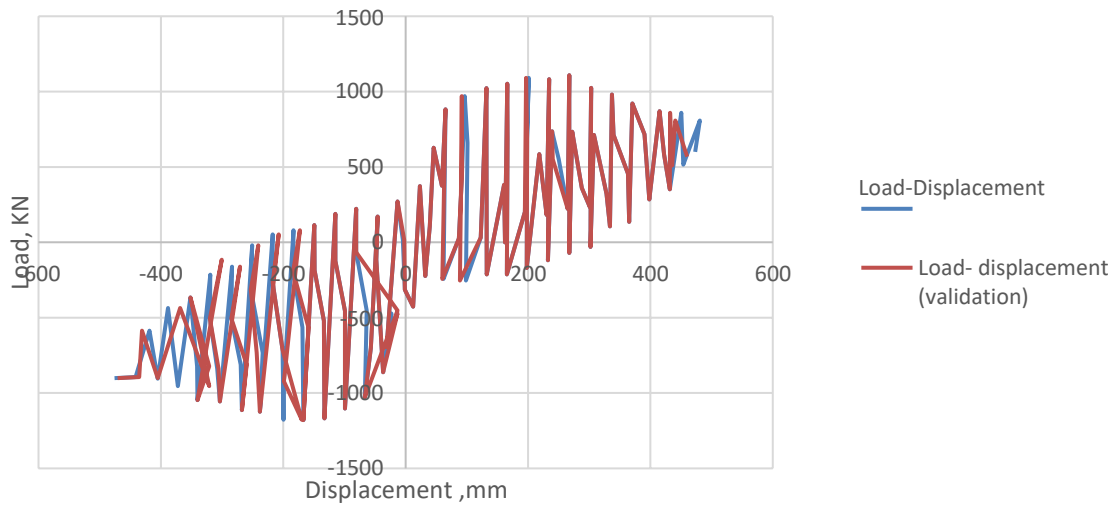


Fig.4.7 Load-Displacement graph

From the validation, there is a variation of 6% and 2.19% are observed in the load and displacement values respectively. Since the variations of values are less than 10%, the software can be used for analysis. However, some deviation from the reference analytical journal that done analysis in OPENSEES are due to the uncertainty in material properties and some unknown assumptions made due to the lack of data availability.

CHAPTER 5

GEOMETRIC MODELLING AND ANALYSIS

5.1 GENERAL

CFST bridge pier was modelled using ANSYS software . Analysis type is nonlinear and isotropic elasticity of steel is considered. Bilinear kinematic hardening property of steel and the concrete plasticity model of Drucker-Prager (DP) was employed to describe the behaviour of confined concrete.

Concrete used for the CFST bridge pier is of compressive strength 30 MPa and steel is of yield strength 345 MPa.

5.2 MATERIAL MODELLING

The Concrete filled steel tube (CFST) bridge pier is modelled in ANSYS workbench is shown in fig.5.1. The structural dimension is summarized having a circular bridge pier with a cross section of diameter 650mm and height 4500mm with a thickness of 14mm.

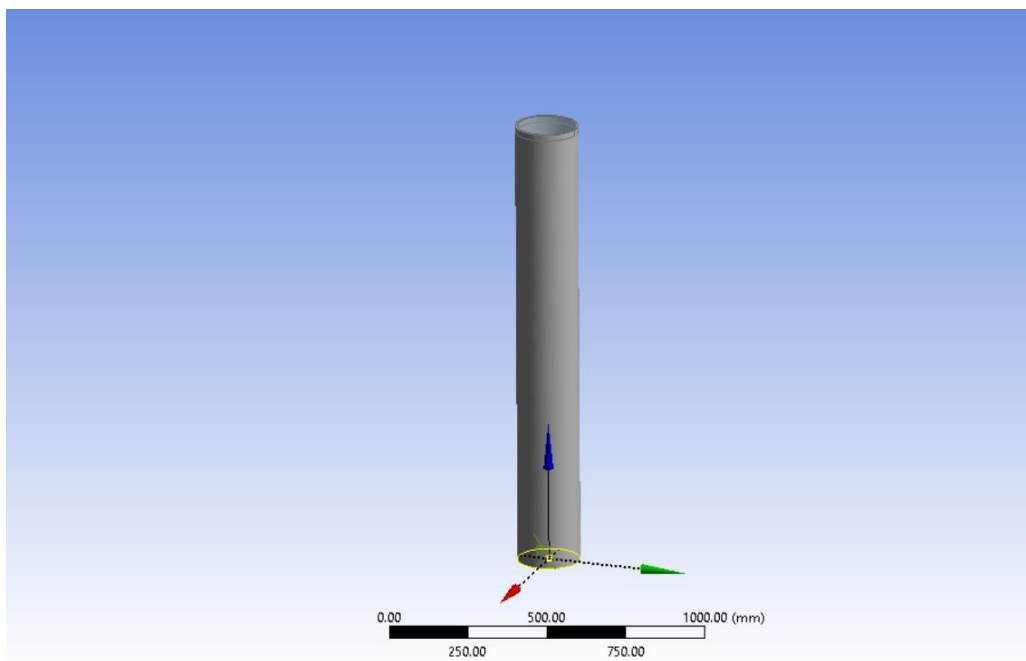


Fig.5.1 Model of CFST column developed using ANSYS

5.3 ELEMENT PROPERTIES

3D hexahedral elements with 8 noded elements are utilized for modelled of CFST column. ANSYS uses the Newton Raphson method to obtain solution for non-linear

problems. The Newton-Raphson approach available in the ANSYS software was employed to solve the non-linear problem. In this approach the applied compression displacement is subdivided into a series of load increments. Newton Raphson equilibrium iterations provide convergence at the end of each load increment with tolerance limit for all degrees of freedom in the model. Residual load vector, which is the difference between the internal forces(the load corresponding to element stresses) are analyzed by using Newton Raphson approach. Interaction between the concrete core and the steel tube could be considered as bonded and considering there is no friction between concrete core and steel tube. The material used in the verification model was of steel grade Q345 and the concrete used are C30. For assigning materials, Drucker Prager model was used for assigning properties of concrete. Young's modulus (E_c), compressive strength (f_{ck}), Poisson's ratio and tensile strength (f_{tk}) of confined concrete are taken from GB50010. Different properties of steel such as, Young's modulus (E_s), yield stress(f_s), Poisson's ratio and ultimate stress(f_u) are taken from GB50017. Properties of steel and concrete are shown in table 5.1 and 5.2.

Table 5.1 Properties of Concrete

INPUT PARAMETER	CONCRETE (C30)
Youngs modulus	26700MPa
Poisson's ratio	0.2
Uniaxial compressive strength	20.1 MPa
Uniaxial tensile strength	2.01 MPa
Biaxial compressive strength	24.1 MPa

Table 5.2 Properties of Steel

INPUT PARAMETER	Steel (Q345)
Youngs modulus	266000 MPa
Poisson's ratio	0.3
Yield strength	345 MPa

5. 4 LOADING AND BOUNDARY CONDITIONS

A constant axial load is applied on top of the circular column. This is followed by cyclic load applied on the lateral direction of the circular column as displacement control. The bottom end of the column is taken as fixed and the column behaves like cantilever column with fixed support in y direction. The connection between the CFST steel and concrete is shown in the fig.5.2 and loading and the boundary condition are shown in the fig.5.3.

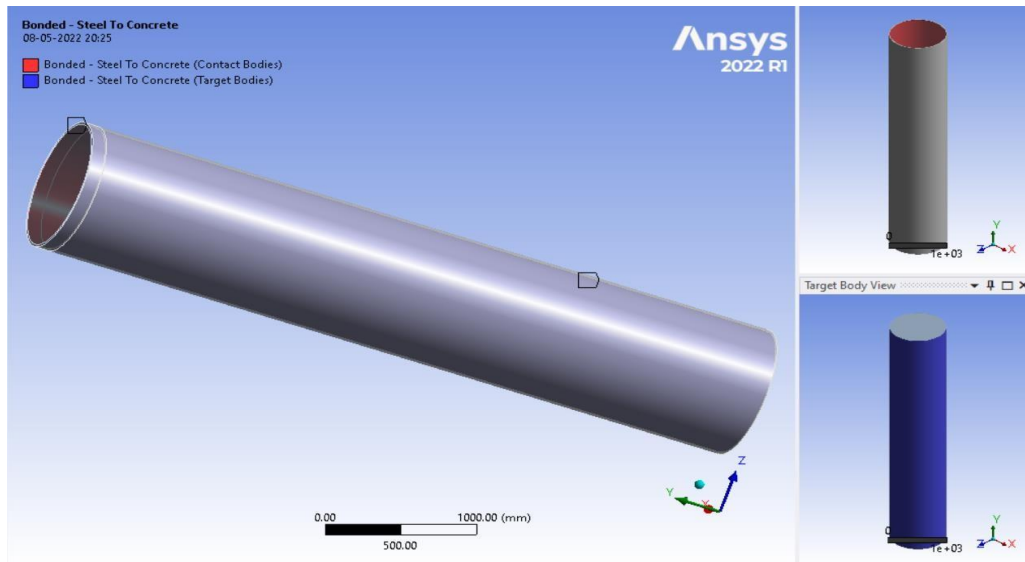


Fig.5.2 Connections between the CFST steel and concrete

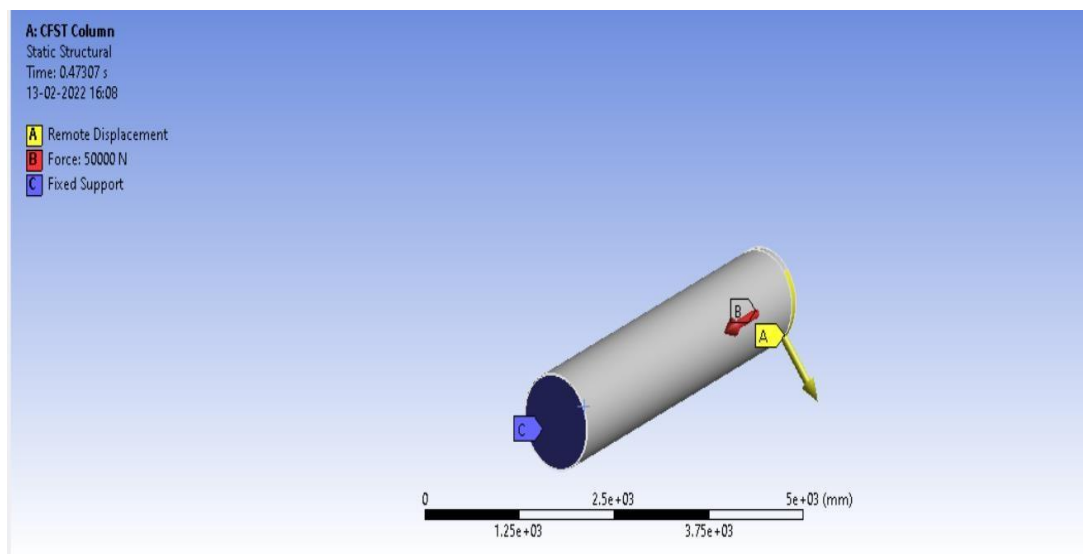


Fig.5.3 Loading and boundary condition of CFST circular bridge pier

5.5 MESH ARRANGEMENT

Meshing plays an important role in the engineering simulation where complex

geometries are divided into simpler elements that can be used as various local approximations of larger domain. The mesh arrangement for a model influences the accuracy, convergence and speed of the simulation. Meshing procedure consumes a significant part of the time it takes to get simulation. Better and more automated meshing tools, faster and accurate solution are needed. Meshed model of CFST circular column is shown in fig.5.4. Mesh size of 100mm taken for simulation of model.

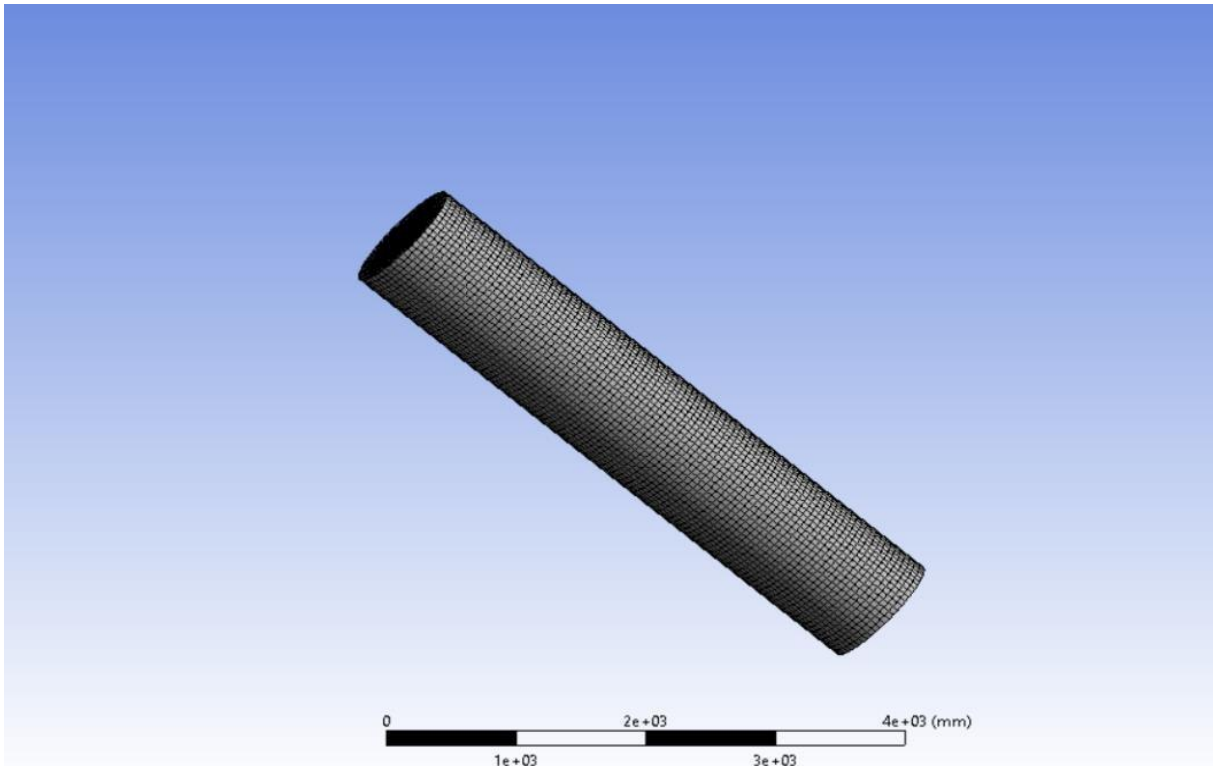


Fig.5.4 Meshed model of Concrete filled steel tubular circular bridge pier

5.6 RESULTS AND DISCUSSIONS

Displacement controlled cyclic loading according to ATC -24 protocol was given to the CFST circular bridge pier having diameter of 650mm and height 4500mm with a thickness of 14mm. Axial load of 50000N was given to the top end of the CFST bridge pier and lateral cyclic load along x direction.

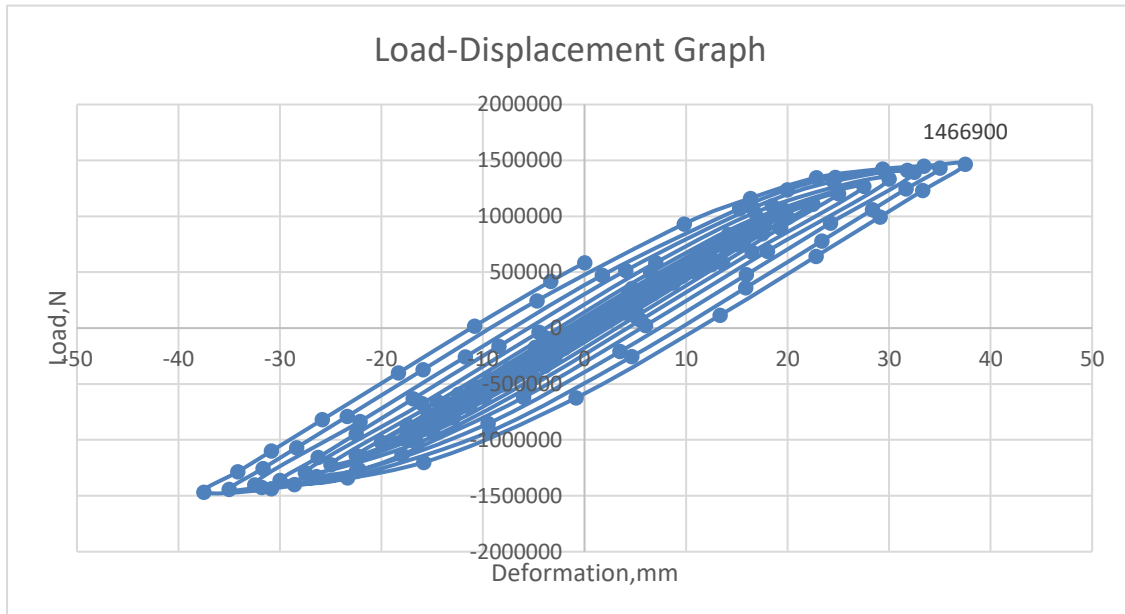


Fig.5.5 Load displacement graph of Circular CFST bridge pier

From the numerical analysis of CFST circular bridge pier under lateral cyclic loading, the ultimate load corresponding to maximum displacement 37.5 mm is 1466.9KN. Fig.5.5 represents the load displacement graph of circular CFST bridge pier under lateral cyclic loading.

CHAPTER 6 PARAMETRIC STUDY

6.1 GENERAL

Concrete-steel composite structures are very efficient in carrying high loads as they combine benefits of both these materials concrete and steel and that load carrying capacity affected by various parameters. By increasing load carrying capacity, the concrete core delays the local buckling in the steel tube and prevents inward buckling of the steel tube, while the steel tube enhances the strength of the concrete core through confinement. Parameters considered in this study were grade of concrete core, Diameter -thickness ratio and slenderness ratio etc. in this parametric study, Parametric study by varying parameters were done by using ANSYS. The effect of different parameters on CFST columns under cyclic loading are illustrated below:

6.2 Diameter to thickness ratio

This study is conducted on five circular CFST bridge piers to investigate the effect of thickness variation on the performance of bridge piers. The increase in D/t ratio may be either due to the increase in diameter or decrease in thickness of the section. Hence it is analyzed by keeping diameter constant and varying thickness. For this study the D/t ratio is ranging from 50 to 83. The increase in D/t ratio with increased thickness of steel tube for a constant diameter represents the improvement in cross section of the steel tube and hence produce greater section capacity. Details of specimen are shown below.

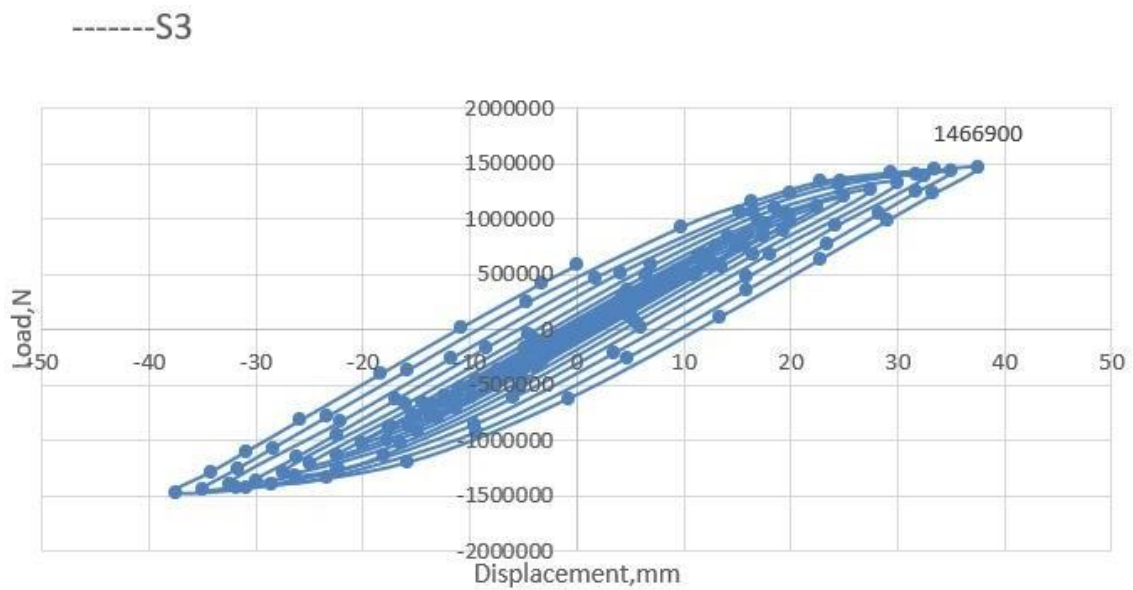
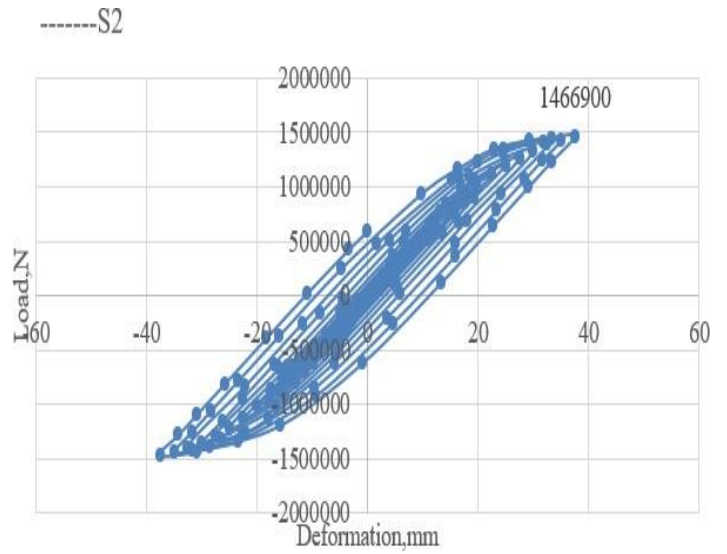
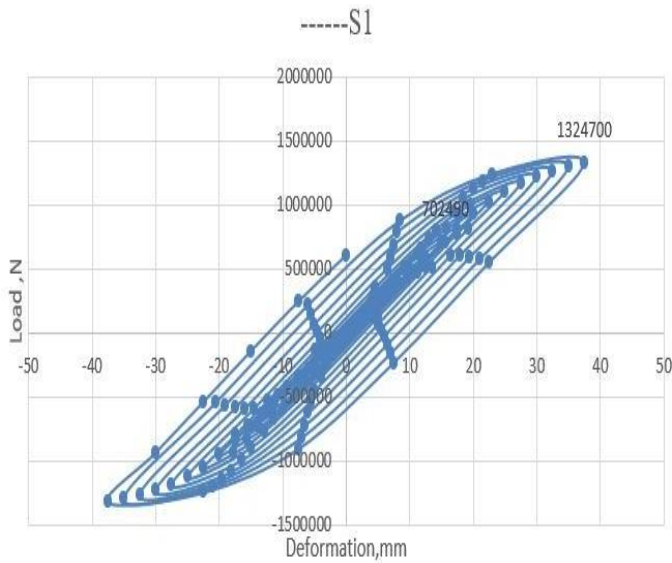
Table 6.1 Details of specimens considered for the analysis

Specimen No.	Diameter(D) mm	Thickness(t) mm	Steel Grade	Concrete Grade	Height mm	D/t ratio
S1	1000	12	Q345	C30	5000	83.3
S2	1000	14	Q345	C30	5000	71.4
S3	1000	16	Q345	C30	5000	62.5
S4	1000	18	Q345	C30	5000	55.6
S5	1000	20	Q345	C30	5000	50

6.2.1 Results and discussions

When the D/t ratio is decreased from 83 to 50, the ultimate cyclic lateral load of the

column is found to increase by 26.16% . From the results concluding that the cyclic lateral load capacity of a CFST column can be significantly increased by smaller D/t ratio. Here the thickness of the steel tube ranging from 12-20mm. The comparison and results of hysteresis behavior of the five different D/t ratio is shown in Fig 6.1(S1-S5) and Table 6.2.



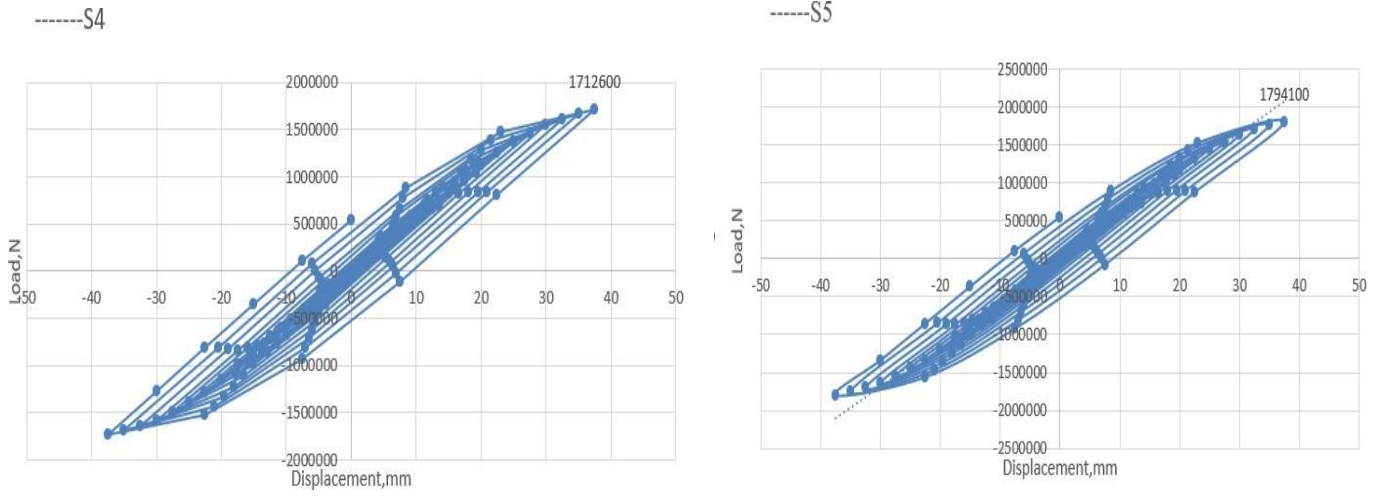


Fig.6.1 Comparison and results of hysteresis behavior of the five different D/t ratio (S1-S5)

Table 6.2 Ultimate load of the specimens corresponding to displacement 37.5mm

Specimen No.	D/t ratio	Ultimate Load KN
S1	83.3	1324.7
S2	71.4	1466.7
S3	62.5	1466.7
S4	55.6	1712.6
S5	50	1794.1

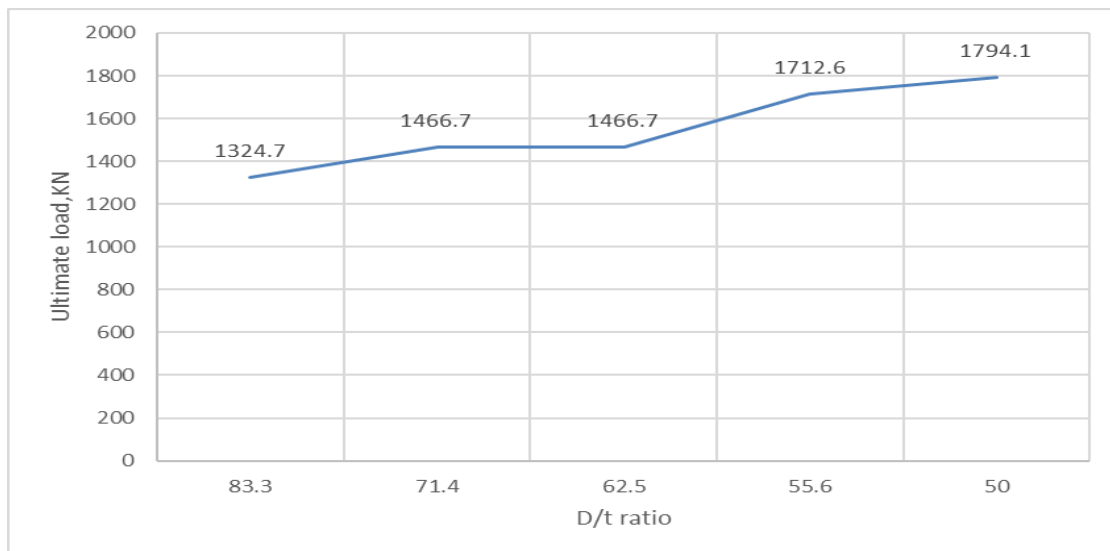


Fig 6.2 Graph representing Ultimate load and D/t ratio

When the D/t ratio is decreased from 83 to 50, the ultimate cyclic lateral load of the bridge pier is found to increase by 26.16%. From this study can be concluded by the cyclic lateral load capacity of a CFST bridge pier can be significantly increased by smaller D/t ratio.

6.3 Slenderness ratio

This study is conducted on five circular CFST bridge pier to investigate the effect of slenderness ratio on the performance of bridge pier. Effect of slenderness ratio is analyzed by changing length and keeping diameter constant. For this study the slenderness ratio is ranging from 10 to 18. Details of specimen are shown below table 6.3.

Table 6.3 Details of the specimens considered for analysis

Specimen No.	Diameter(D) mm	Thickness(t) mm	Steel Grade	Concrete Grade	Length mm	Slenderness Ratio
S1	500	14	Q345	C30	2500	10
S2	500	14	Q345	C30	3000	12
S3	500	14	Q345	C30	3500	14
S4	500	14	Q345	C30	4000	16
S5	500	14	Q345	C30	4500	18

6.3.1 Results and discussions

In this parametric study, the variation of slenderness ratio is in the range of 10 to 18 and here diameter and thickness of the steel tube are constant. The length of the CFST bridge pier is ranging between 2500 and 4500. The comparison and results of hysteresis behavior of the five different slenderness ratio is shown in Fig.6.3(S1-S5) and Table 6.4. Graph of ultimate load vs slenderness ratio corresponding to varying slenderness ratio are given in fig .6.4.

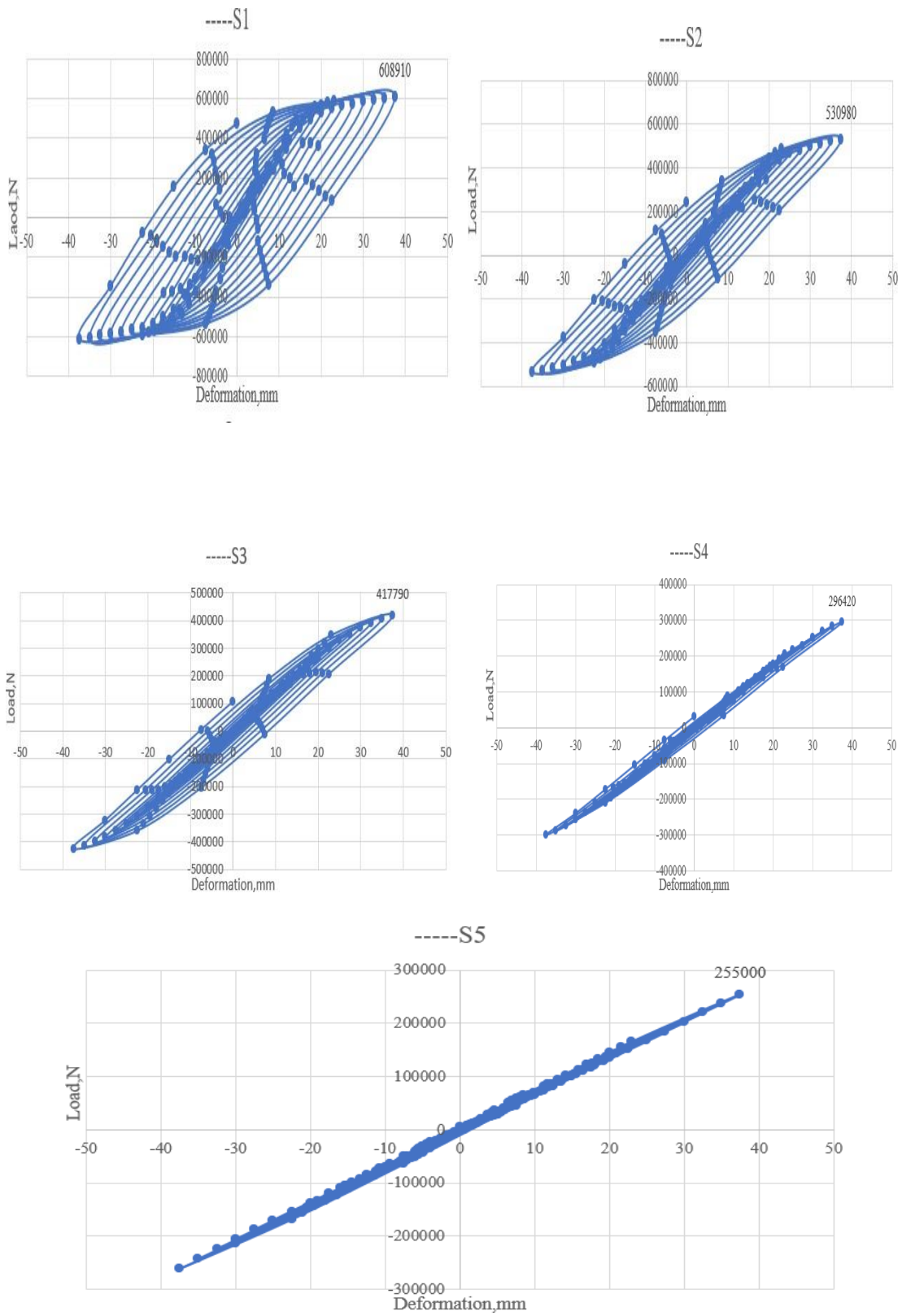


Fig.6.3 Hysteresis curve of CFST bridge piers under cyclic loading (S1-S5)

Table.6.4 Ultimate load of the specimens corresponding to displacement 37.5mm

Specimen No.	Slenderness Ratio	Ultimate Load KN
S1	10	608.91
S2	12	530.98
S3	14	417.79
S4	16	296.42
S5	18	255.0

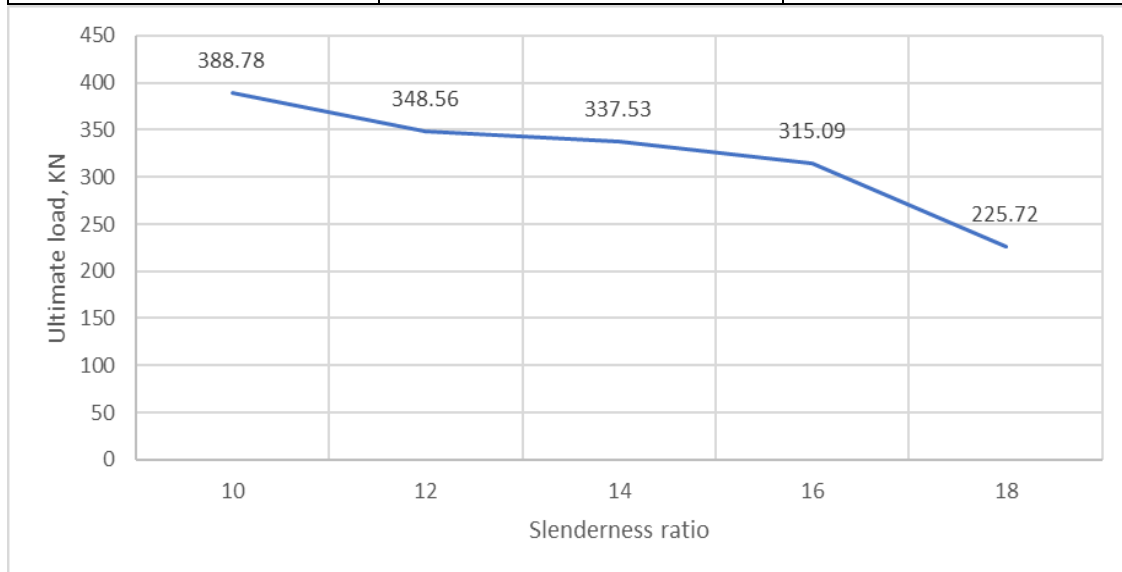


Fig.6.4 Graph of ultimate load vs slenderness ratio corresponding to varying slenderness ratio.

When slenderness ratio decreased from 18 to 10, ultimate load increases by 58.12%. From the analysis, the cyclic lateral load capacity of a CFST column can be significantly increased by smaller slenderness ratio.

6.4 Concrete grade

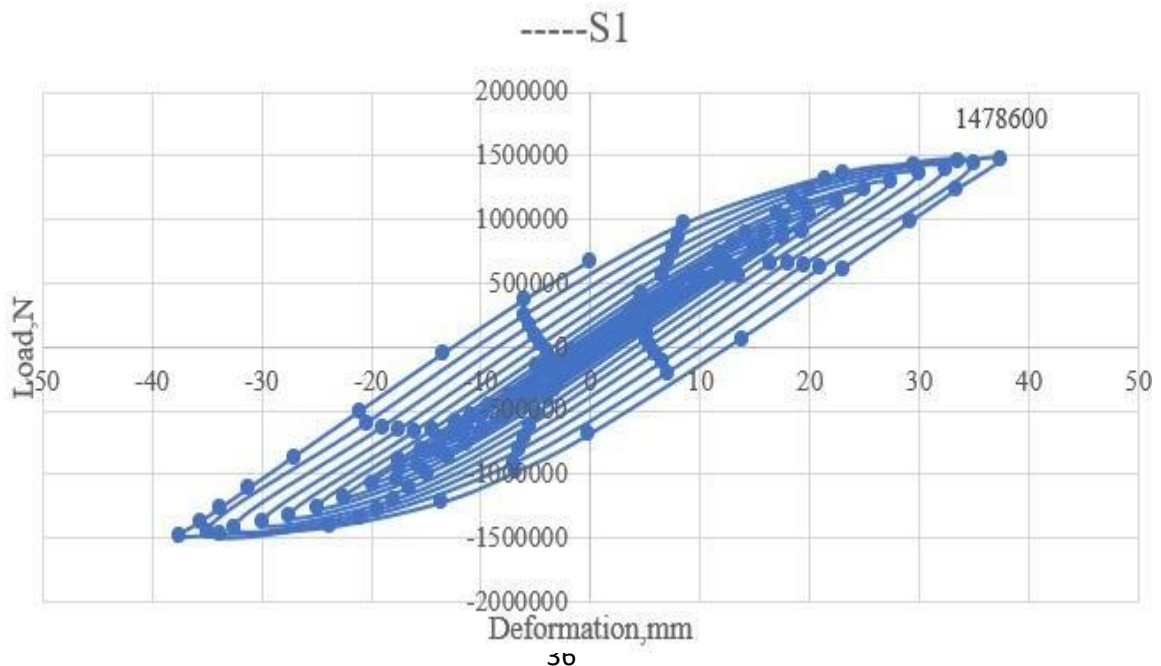
This study is conducted on five circular CFST columns to investigate the effect of concrete grade on the performance of column. Effect of increase in concrete grade is analyzed by keeping constant diameter and thickness. For this study the concrete grade is ranging from C30 to C50. Details of specimen are shown below table 6.5.

Table 6.5 Details of the specimens considered for analysis

Specime nNo.	Diameter(D)mm	Lengt hmm	Thickness(t)mm	Steel Grade	Concret eGrade
S1	1000	5000	14	Q345	C30
S2	1000	5000	14	Q345	C35
S3	1000	5000	14	Q345	C40
S4	1000	5000	14	Q345	C45
S5	1000	5000	14	Q345	C50

6.4.1 Results and discussions

In this parametric study, the compressive strength of concrete varying from 30MPa to 50MPa. In all five specimens the diameter, length of CFST bridge pier, thickness of the steel tube are constant. The comparison and results of hysteresis behavior of the five different concrete is shown in Fig.6.5(S1-S5) and Table 6.6. A Graph showing the variation of ultimate load corresponding to concrete grade are shown in fig.6.6.



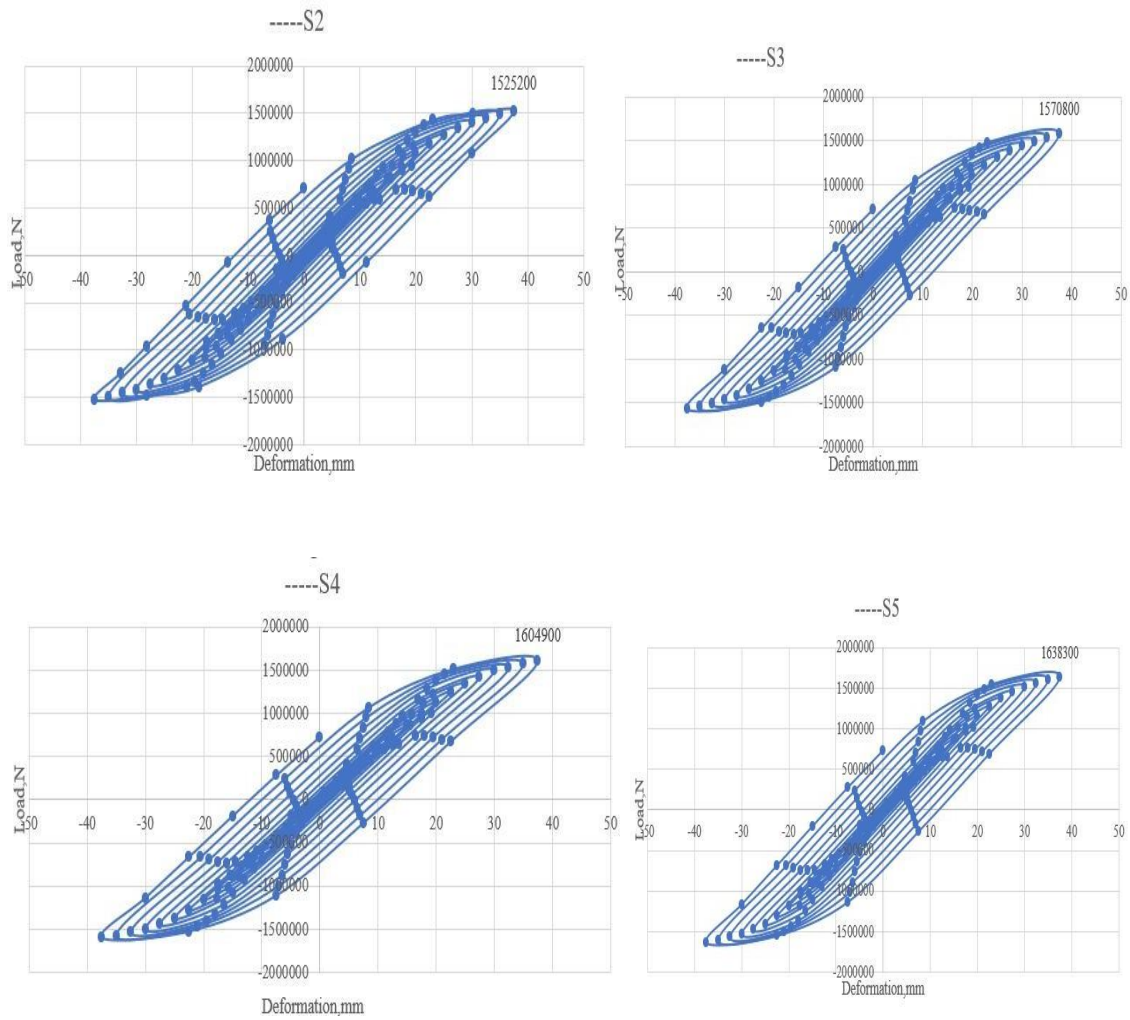


Fig 6.5 Hysteresis curve of CFST bridge piers under cyclic loading (S1-S5)

Table 6.6 Ultimate load of the specimens corresponding to displacement 37.5mm

Specimen No.	Concrete Grade	Ultimate Load KN
S1	C30	1478.6
S2	C35	1525.2
S3	C40	1570.8
S4	C45	1604.9
S5	C50	1638.3

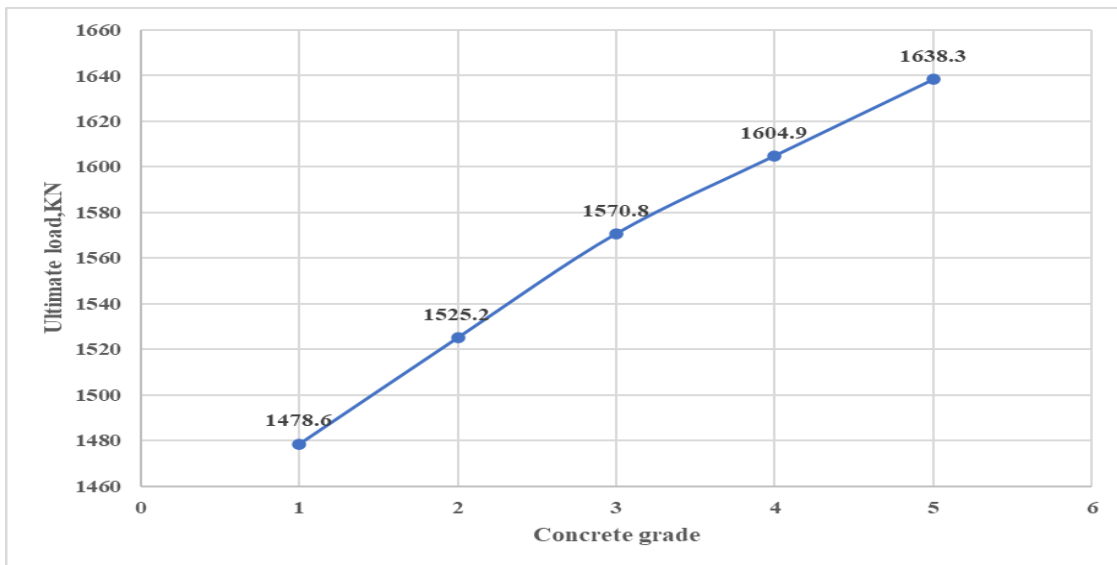


Fig.6.6 Graph corresponding to ultimate load and concrete grade of CFST bridge pier

When increasing the concrete compressive strength from 30MPa to 50MPa, found that increase in the ultimate load by 9.75%. From the analysis, the cyclic lateral load capacity of a CFST bridge pier can be significantly increased by larger concrete grade.

CHAPTER 7

EFFECT OF SHAPE OF CFST BRIDGE PIER HAVING SQUARE AND CIRCULAR CROSS SECTIONS UNDER LATERAL CYCLIC LOADING

7.1 GENERAL

Concrete-filled steel tubular (CFST) columns have been used in the construction of modern structures such as high-rise buildings and bridges as well as infrastructures as they provide better structural performance than conventional reinforced concrete or steel members. Different shapes of CFST columns may be needed to satisfy the architectural and aesthetic criteria. Steel tubes of circular, rectangular and square are the regularly employed cross-sections in CFST column construction. The square section is considered as an exceptional type of rectangular section. For architectural reasons, hexagonal, octagonal, elliptical and round-ended shapes are used in CFST. In this study, square and circular CFST columns were developed using FE software ANSYS .The verified FE models were used to investigate and compare the structural performance of CFST columns with different cross-section shapes by evaluating the overall load-deformation curves. The extent of the ultimate-axial-strength enhancement due to enhanced steel yield strength and concrete compressive strength was evaluated through the parametric studies.

7.2 SHAPE COMPARISON OF CFST BRIDGE PIER

This study is conducted on circular and square CFST bridge pier to investigate the effect of shape on the performance of bridge pier. It is analyzed by keeping same diameter and thickness for both square and rectangular bridge pier. Details of specimen are shown below.

Table 7.1 Dimensions of Circular and square bridge piers

Dimension	Type of CFST bridge pier	
	Circular bridge pier	Square bridge pier
Outer Dimension (mm)	200	177
Inner Dimension(mm)	172	149
Thickness of steel Tube (mm)	14	14
Grade of steel (fy) N/mm ²	345	345

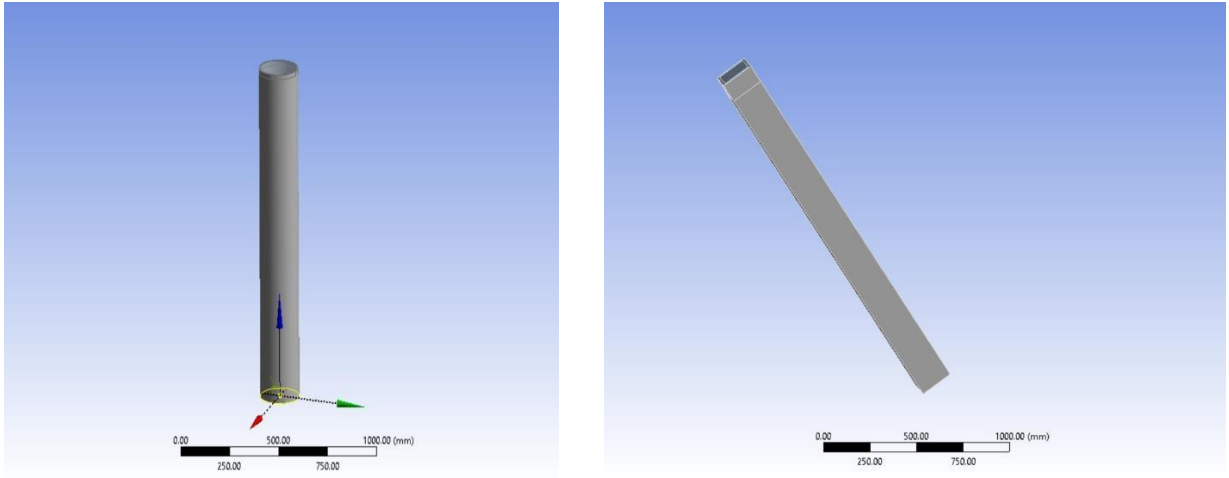
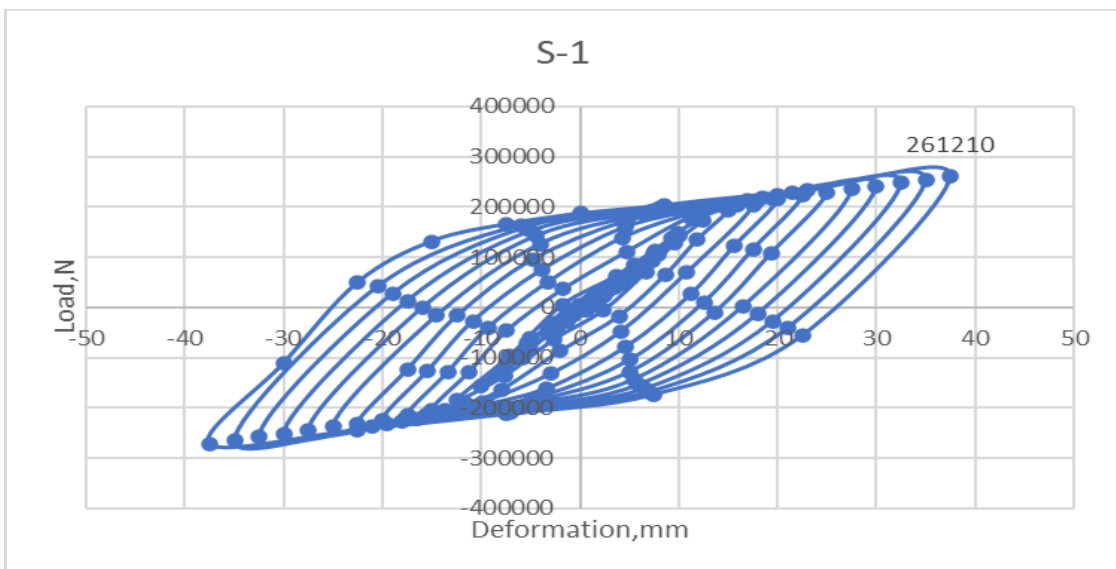


Fig.7.1 Modelled Circular and square CFST bridge pier

7.3 RESULTS AND DISCUSSIONS

In this study, 4 specimens were considered to study the effect of shape of CFST bridge pier by changing their lengths. The deformation in circular section is smaller compared to square section. From that study ,found that circular section takes more confining effect better than square section. When compared to ultimate load taken by circular and square CFST bridge pier, more load was taken by square CFST bridge pier. Stress concentration is more at the edges of square bridge pier while in circular bridge pier, due to confining effect stress concentration is almost equal throughout the whole section.



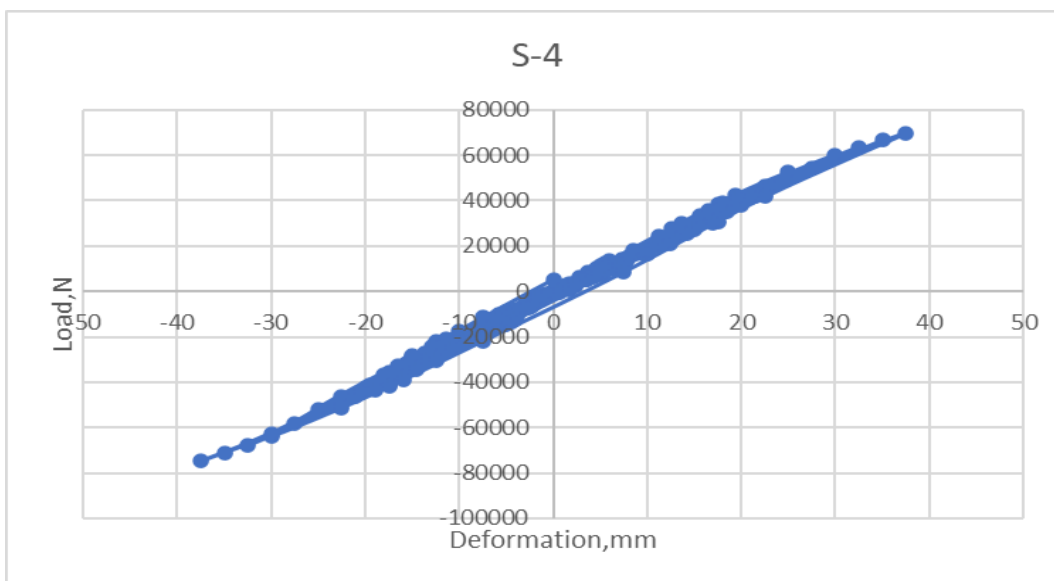
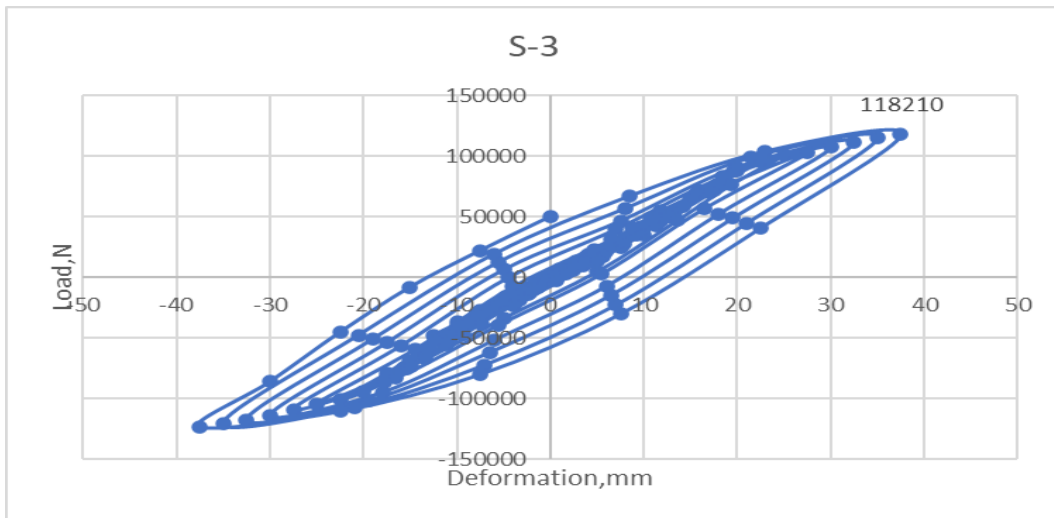
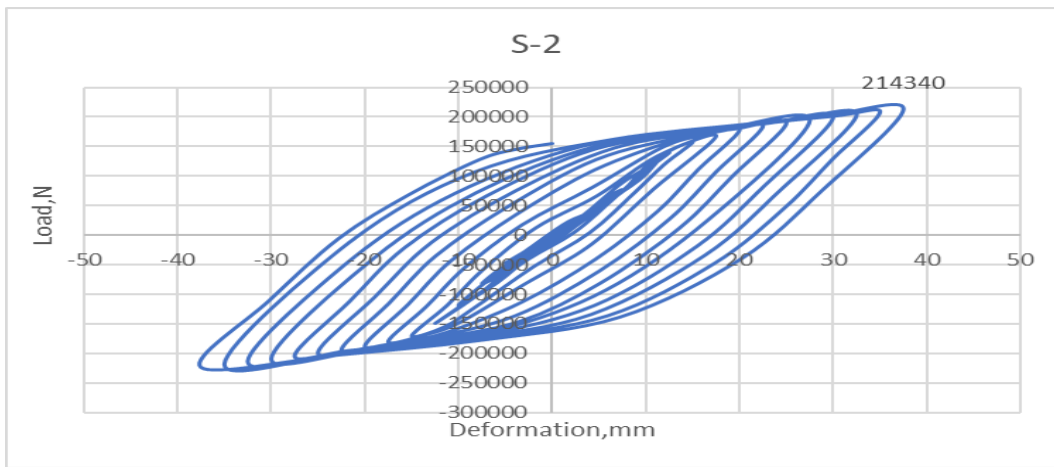
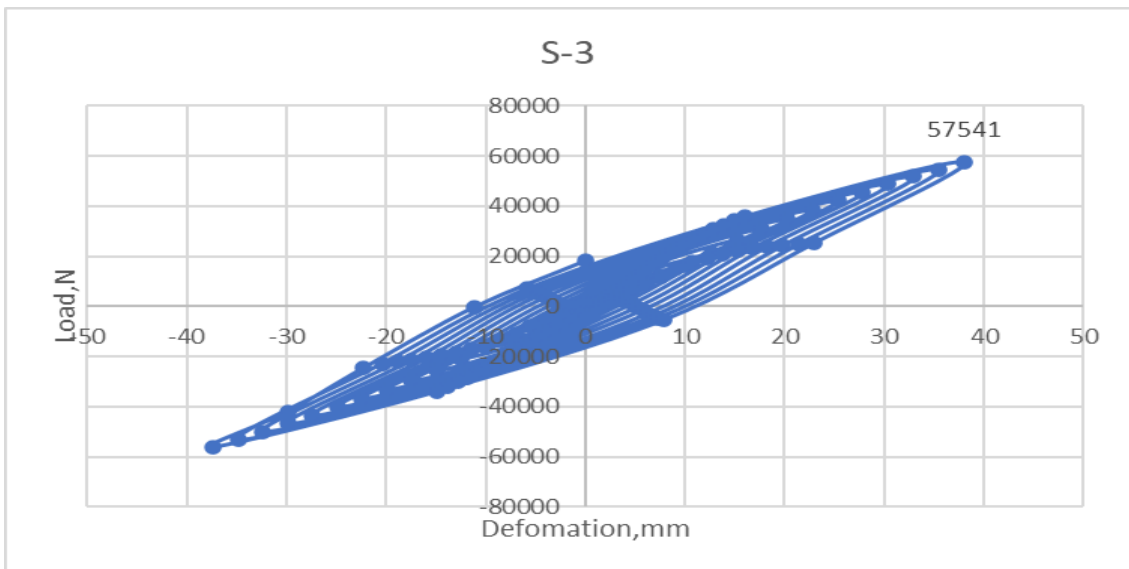
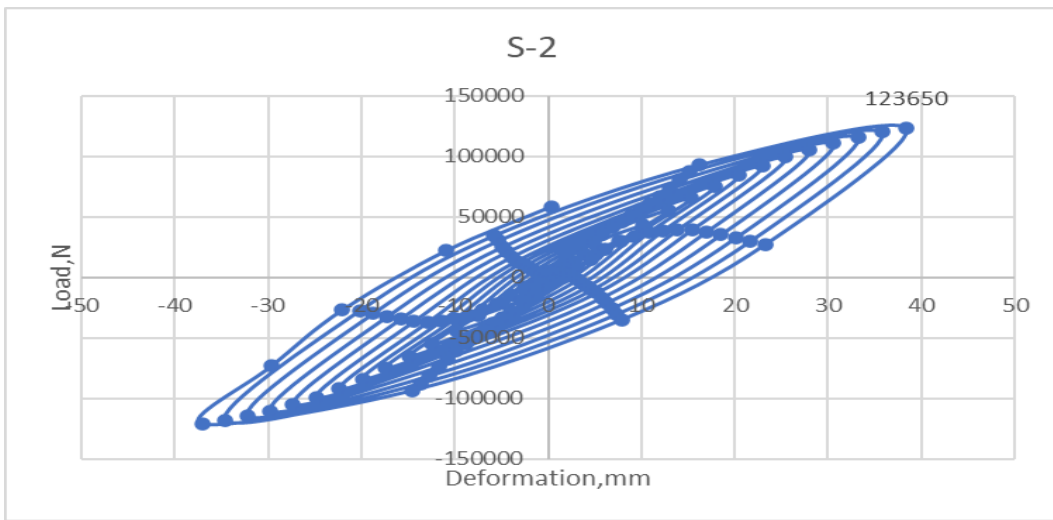
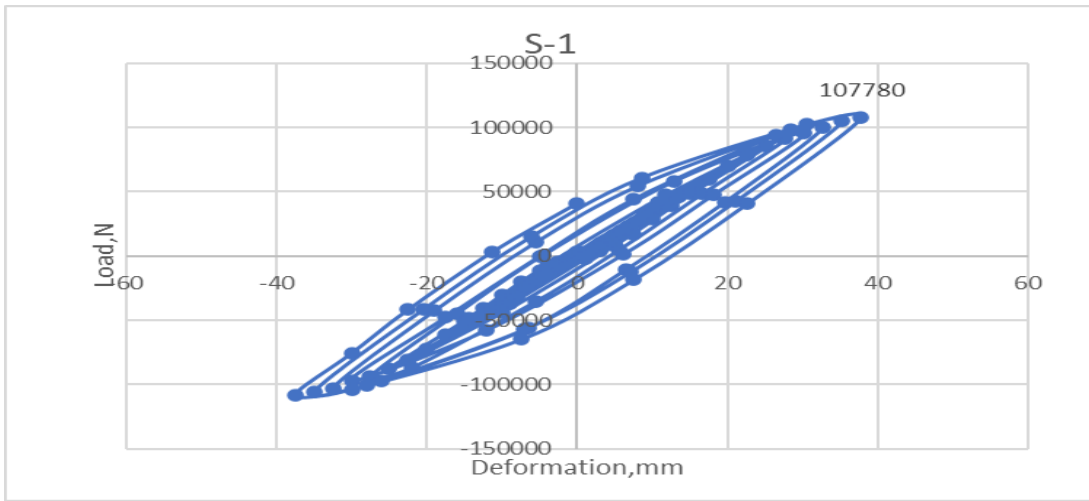


Fig.7.2 Hysteresis curves of Circular CFST bridge pier under cyclic loading



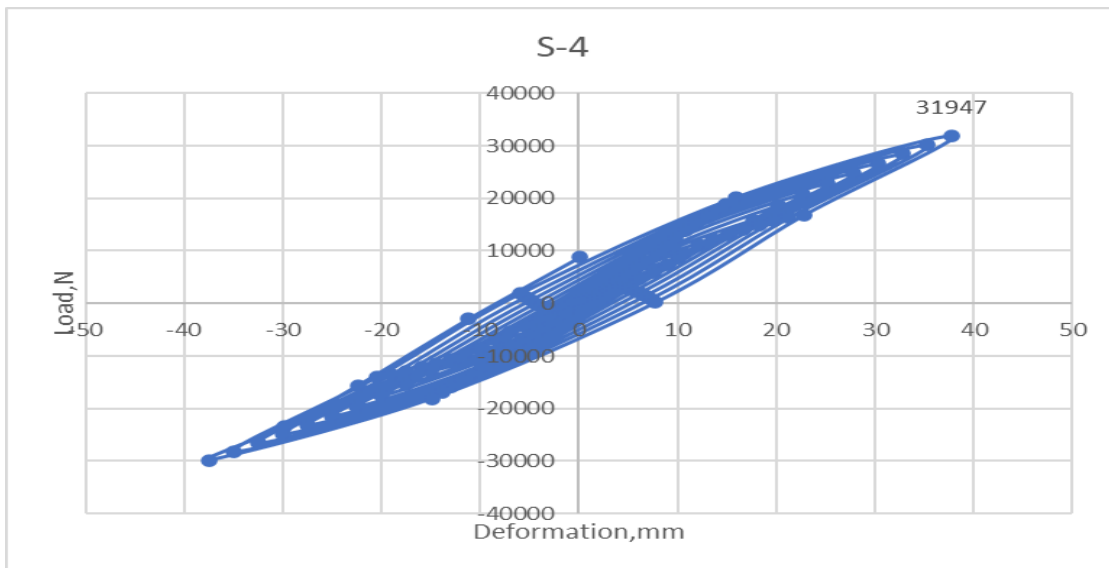


Fig.7.3 Hysteresis curves of Square CFST bridge pier under cyclic loading

Table.7.2 Ultimate load of Circular and square CFST bridge pier under lateral cyclic loading

	Specimens	Length(mm)	Ultimate load (KN)
Circular CFST bridge pier	S1	650	261.210
	S2	1000	214.340
	S3	1500	118.210
	S4	2000	47.278
Square CFST bridge pier	S1	650	199.690
	S2	1000	123.650
	S3	1500	57.541
	S4	2000	31.947

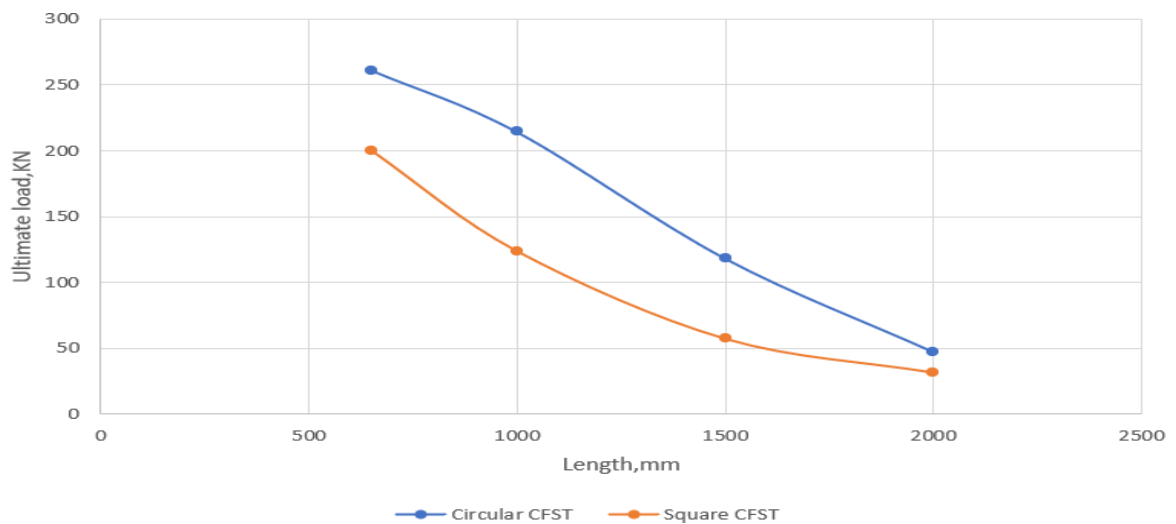


Fig.7.4 Comparison of circular and square CFST bridge pier specimens

In this comparison study , the length of square and circular CFST bridge pier ranging from 650mm to 2000mm. For CFST bridge pier of length 650mm, there is a difference of 23.55% of variation of ultimate load capacity between circular and square CFST bridge pier. CFST bridge pier of length 1000mm, there is an variation of ultimate load carrying capacity of 42.3% between circular and square CFSTs . CFST bridge pier of length 1500mm, there is an variation of ultimate load carrying capacity of 51.32% and for length 2000mm is 32.42% variation of ultimate load carrying capacity between circular and square CFSTs . From this study, it is found that circular CFST bridge pier specimens, when decreasing the length from 2000mm to 650mm,found that ultimate load increases by 81.9% and for square CFST bridge pier specimens, when decreasing the length from 2000mm to 650mm,found that ultimate load increases by 84%. From this we can conclude that circular section having better ultimate load carrying capacity ,this is because circular section takes more confining effect better than square section.

CHAPTER 8 CONCLUSIONS

8.1 GENERAL

Since there are many parameters that can affect the performance of the CFST bridge pier numerical analysis is justified. In this study also made a comparison between the effect of shape on the performance of the CFST bridge pier by varying length and made diameter and thickness constant.

8.2 MAJOR FINDINGS

In the initial phase, conducted a parametric study on the CFST bridge pier by considering parameters such as concrete grade, slenderness ratio and Diameter to thickness ratio. From that parametric study, conclusions found that:

- When the D/t ratio is decreased from 83 to 50, the ultimate cyclic lateral load of the column is found to be increase by 26.16%. From the results concluding that the cyclic lateral load capacity of a CFST column can be significantly increased by smaller D/t ratio.
- While increasing the concrete compressive strength from 30MPa to 50MPa increases the ultimate load by 9.75%. From the analysis, the cyclic lateral load capacity of a CFST bridge pier can be significantly increased by larger concrete grade.
- When slenderness ratio decreased from 18 to 10, ultimate load increases by 58.12%. From the analysis, the cyclic lateral load capacity of a CFST column can be significantly increased by smaller slenderness ratio.

Next conducted a comparative study between the square CFST bridge pier and circular CFST bridge pier by varying the length of the bridge pier and keeping constant diameter and thickness. From that comparative study, we had found results that:

- In this comparison study ,it is found that circular CFST bridge pier specimens, when decreasing the length from 2000mm to 650mm,found that ultimate load increases by 81.9% and for square CFST bridge pier specimens, when decreasing the length from 2000mm to 650mm,found that ultimate load increases by 84%.

8.3 FUTURE SCOPE

The proposed study has its own limitations which should be taken into consideration in future works. Future study should be focus on the following:

- More parameters can be taken into consideration like steel grade, ductility etc
- Fibre reinforced polymer (FRP) sheets also considered to analyze the composite behaviors of CFST bridge pier.
- Out of plane horizontal loading also considered to analyze CFST bridge pier

CHAPTER 9

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